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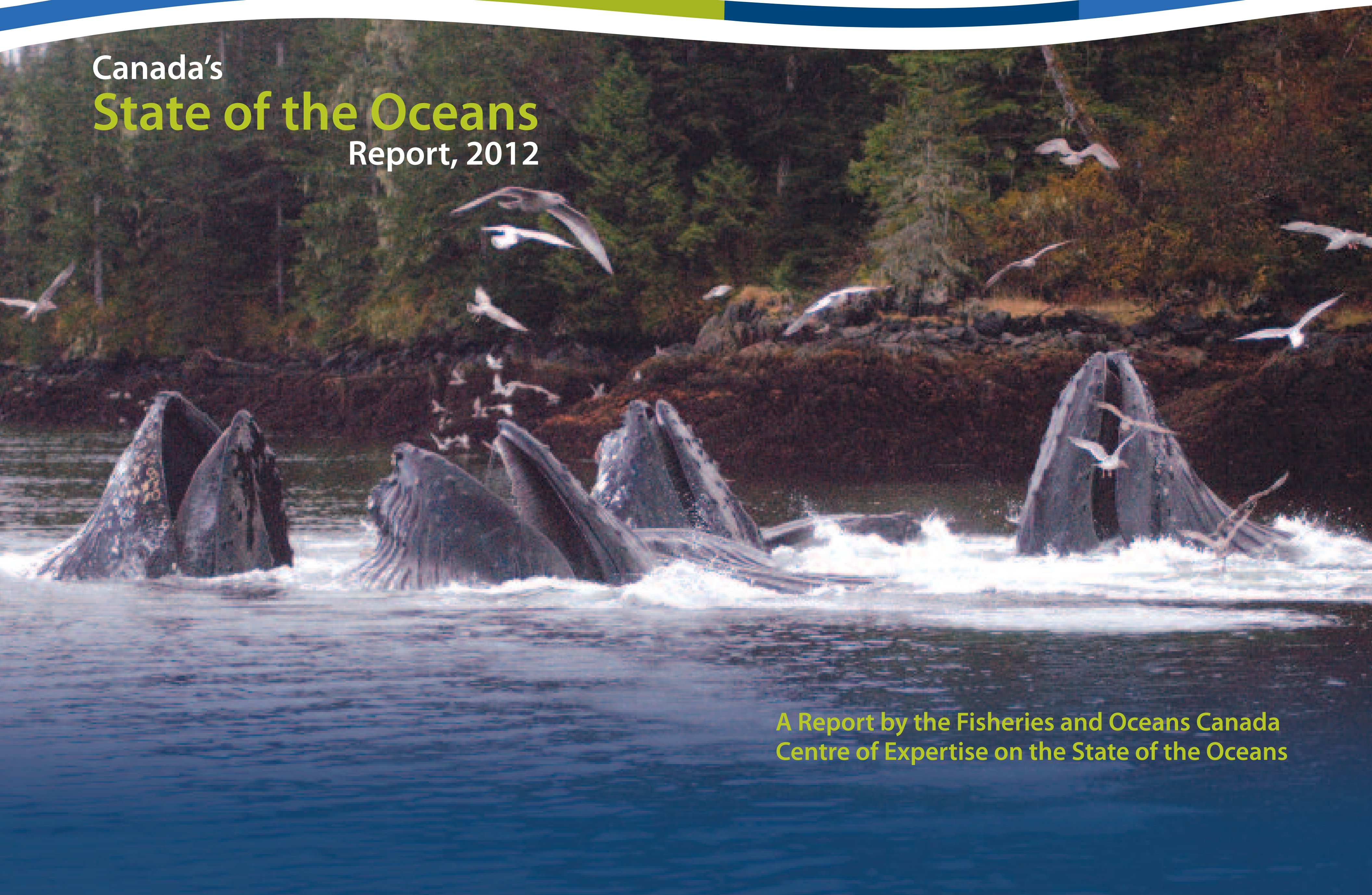
Sciences des écosystèmes et des océans

Canada's State of the Oceans Report, 2012



A Report by the Fisheries and Oceans Canada Centre of Expertise on the State of the Oceans

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On the Cover:
In Work Channel (just outside Prince Rupert, British Columbia), North Pacific humpback whales are seen "bubblenet feeding" on schools of herring. In this form of feeding, used mainly off northern British Columbia and in Alaskan waters, groups of whales co-operate to capture large schools of herring. One whale blows bubbles around the herring school to keep the fish from escaping; one vocalizes to scare or confuse the fish and help bring them to the surface, and others herd the fish together and upwards. Once the fish are at the surface, all the whales lunge upwards with their mouths wide open and capture as many fish as they can. The picture was taken during a photo-identification survey. Biologists working with Fisheries and Oceans Canada photograph the unique markings on the underside of the whales' tails to identify each individual animal. The photos are used to match them with catalogues from the main humpback breeding grounds, thus deciphering which population they belong to and which migration routes they are using. Photo: Miriam O, DFO.

Note from Dr. Bill Crawford, Chair of the Centre of Expertise on the State of the Oceans: The Centre of Expertise in State of the Ocean Reporting (SOTO) is a group of oceanographers at Fisheries and Oceans Canada with specialties in chemical, physical and biological marine sciences. From analysis of marine data, we create reports about changes and trends in Canada's oceans. In 2011, for the final stage of the Health of the Oceans Initiative (HOTO) initiative under which the Centre of Expertise was first funded, the Centre created this synthesis SOTO National Report consisting of highlights from our series of regional reports. I would like to thank the many people who contributed to the regional reports and especially the regional team leaders, who include: Jim Irvine who worked with me on the Pacific North Coast report; Andrea Niemi, for the Beaufort Sea; Hugues Benoit and Jacques Gagné, for the Gulf of St. Lawrence; Nancy Shackell and Melanie Maclean for the Scotian Shelf and Nadine Templeman, Vanessa Sutton-Pande and Atef Mansour for Placentia Bay/Grand Banks. I would also like to acknowledge the work of our science knowledge translation specialists: Karen Twitchell and Patricia Hunter.

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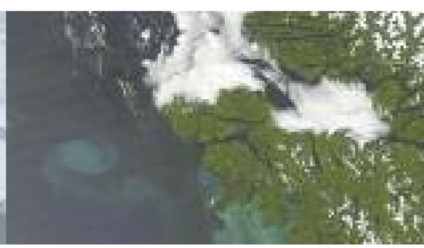
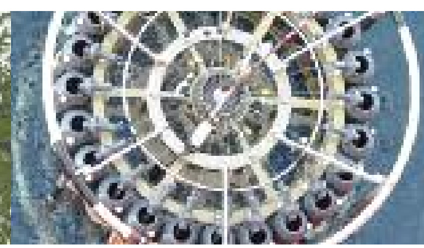
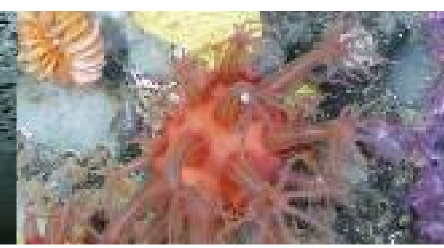





Introduction

The Centre of Expertise on State of the Oceans Reporting created this national report for the final stage of the **Health of the Oceans Initiative** (HOTO) under which it was first funded. It consists of highlights from the regional reports on **Large Ocean Management Areas** (LOMAs), created under the five-year (2007-2012) initiative. The initiative focused on: establishing **new marine protected areas**, enhancing our pollution prevention and response measures through improved surveillance, enforcement and containment, and collaboration with partners on matters in ocean and trans-boundary waters, including the Arctic and the Gulf of Maine.

Scope of the National Report

Canada's State of the Oceans Report 2012 presents highlights from regional reports on the five **Large Ocean Management Areas** established under the HOTO initiative, organized around themes. The availability of long term data sets and analysis varied, and in a few cases, there is either no information or very little information reported on certain themes from some of the Large Ocean Management Areas in this report (e.g., Beaufort Sea). Alternatively, there are also much more extensive theme-based reports published on the state of the Scotian Shelf area, which is particularly well studied.

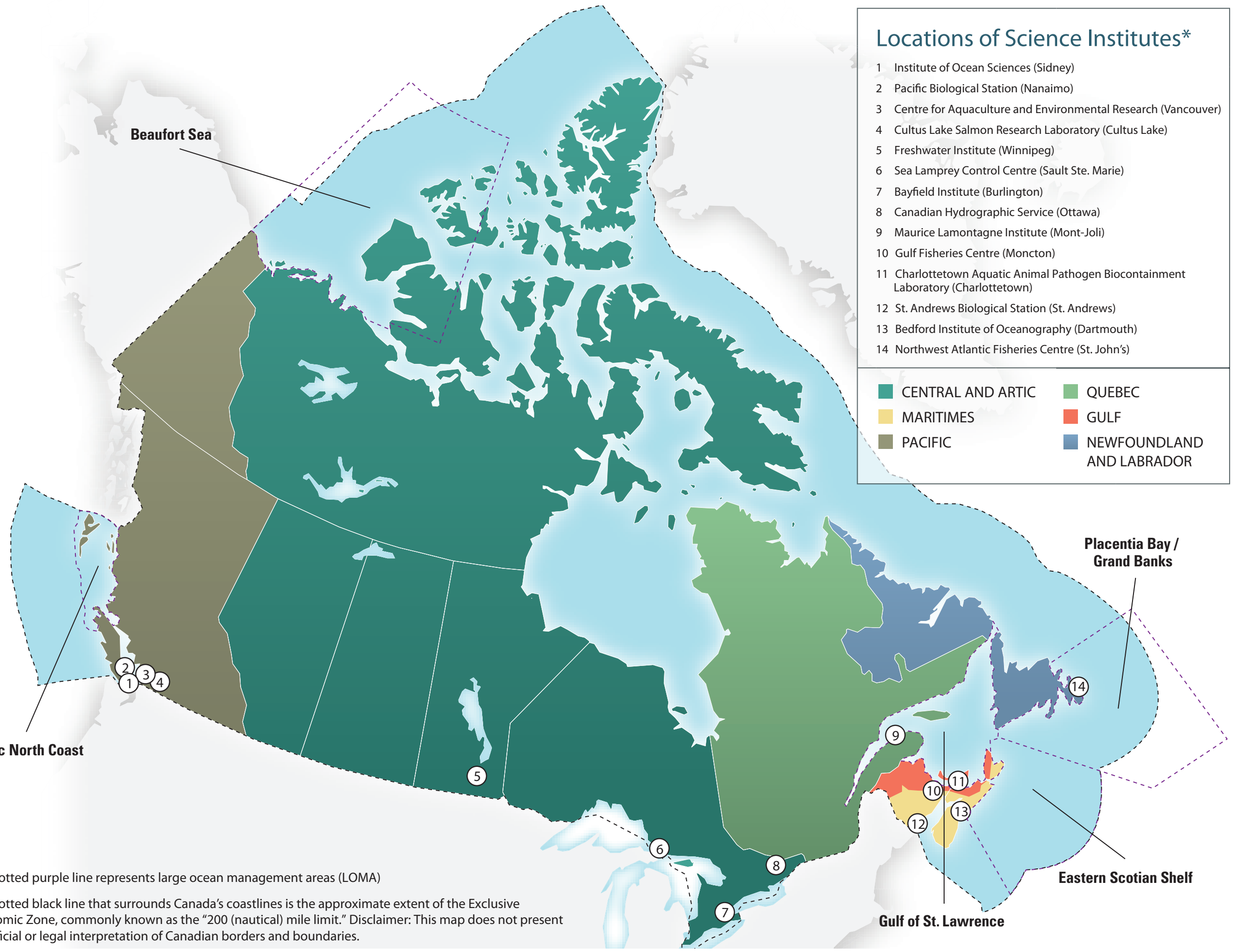
Scope of Regional Reports on Large Ocean Management Areas

Regional reports are based on the analysis of data collected from five **Large Ocean Management Areas** designated under the initiative: the Pacific North Coast; the Beaufort Sea in the Arctic Ocean; the Gulf of St. Lawrence; the Eastern Scotian Shelf and the Placentia Bay/Grand Banks regions of the Atlantic. Regional reports vary in approach and complexity due to variations in the amount of ocean data available, and the varied fisheries and socio-economic conditions. The Centre of Expertise members who led the development and preparation of the reports were: Pacific North Coast (Bill Crawford, Jim Irvine); Beaufort Sea (Andrea Niemi); Gulf of St. Lawrence (Hugues Benoit, Jacques Gagné); Scotian Shelf (Nancy Shackell, Melanie MacLean); and Placentia Bay-Grand Banks (Nadine Templeman, Vanessa Sutton-Pande, Atef Mansour).

State of the Oceans Reporting and Ocean Science Data at DFO

During the five year time span of the initiative, the Department also collected marine data in the Arctic, as part of projects funded under the Climate Change stream of Canada's two-year International Polar Year program, notably the ***Canadian Archipelago Through-Flow Study*** and ***Canada's Three Oceans Project***, as well as via the Department's two-year Climate Change Science Initiative. Ongoing marine data collection and analysis is also facilitated through the **Atlantic Zone Monitoring Program**; **the Argo program** and other **Ocean Sciences** programs at DFO.

In November 2011, the **five-year Aquatic Climate Change Adaptation Services Program** was launched at Fisheries and Oceans Canada (DFO). This program is intended to advance knowledge and understanding of climate change risks, impacts and opportunities in Canada's marine territories and the development of adaptation tools, relative to DFO's areas of responsibility. The Aquatic Climate Change Adaptation Services Program is focused at a large scale – Canada's marine estate in each of the Pacific, Arctic, and Atlantic marine regions, plus the Great Lakes freshwater basin.



* The dotted purple line represents large ocean management areas (LOMA)

* The dotted black line that surrounds Canada's coastlines is the approximate extent of the Exclusive Economic Zone, commonly known as the "200 (nautical) mile limit." Disclaimer: This map does not present an official or legal interpretation of Canadian borders and boundaries.

Ecosystem Shifts

The rapid reorganization of an ecosystem from one relatively stable state to another contrasting, persistent state is called an ecosystem shift. This rapid change in ocean conditions may involve changes in species abundance, community composition and trophic (food web) reorganization. Not all organisms in an ecosystem will necessarily be involved in or influenced by a shift, which may range in scale from a few kilometres to more widespread, such as on the Scotian Shelf or even basin-wide.

The Beaufort Sea, July 2010, seen from the CCGS *Louis S. St-Laurent*. Photo: DFO

There are two key causes of ecosystem shifts:

- climate factors including climate change; and
- anthropogenic factors such as fishing, introduced species and changes in habitat.

Ecosystem Shifts and Impacts in Canada's Oceans

A variety of natural and anthropogenic factors have led to ecosystem shifts in Canada's oceans, which have been characterized by important changes in marine food webs and the abundance of some species.

It is important to note that, to date, some shifts have been reported for only a portion of the areas under discussion.

Beaufort Sea:

Since 2002, the international Joint Ocean Ice Studies (JOIS), which involved scientists from Fisheries and Oceans Canada, has carried out an annual expedition to the Canada Basin. The expedition studies the oceanographic condition of the area, specifically the Beaufort Gyre, which is a portion of the ocean basin that circulates in a clockwise direction.

Observed changes include a dramatic reduction in the extent and age of multi-year sea ice in the Canada Basin since the mid-1990s. The decline of this thicker ice has increased the amount of fresh water in the surface layer of the Beaufort Gyre since 2003, resulting in impacts on the marine food web.

More fresh water combined with changing winds and ocean circulation has caused the water column to become more stratified (layered) because fresh water is less dense and doesn't mix well with saltier, deeper ocean water, forming a "cap" over the surface of the ocean. This stratification impedes mixing of the ocean layers, which is the main mechanism that transports nutrients upward into the sunlit surface layer or euphotic zone where phytoplankton grows. So as stratification increases, there is also a decline in nutrients available to nourish phytoplankton, the very foundation of the marine food web.

According to **research by Fisheries and Oceans Canada**, these changes have led to an increase in the smallest algae (picoplankton) in the Canada Basin, both in total amount and as a percentage of the total phytoplankton, and a decrease in larger nanoplankton during the five years in which data were collected (2004-2009). Samples taken in the late summer and early autumn of 2009 revealed a continued increase in the bacterial component of picoplankton.

Gulf of St. Lawrence:

There have been dramatic shifts to both the northern and southern Gulf of St. Lawrence ecosystems, particularly in response to fishing and to a lesser extent changes in environmental conditions. These shifts include changes in species abundance and/or biomass and food web structure and functioning.

In the 1980s, these ecosystems were dominated by large groundfish predators including Atlantic Cod (*Gadus morhua*), Redfish (*Sebastes spp.*) and White Hake (*Urophycis tenuis*), and small-bodied forage species such as Capelin (*Mallotus villosus*), Mackerel (*Scomber scombrus*), Herring (*Clupea harengus*) and Northern Shrimp (*Pandalus borealis*). Today, small-bodied forage species dominate the northern and southern Gulf.

Fishing of large groundfish increased during the 1980s, and continued to escalate in the early 1990s. This led to the collapse of a number of stocks, including northern and southern Gulf cod.

With the exception of northern Gulf cod, there has been very little or no fishing for large groundfish in this area since the mid-1990s. Despite this, the stocks have not recovered, leading scientists to conclude that factors other than fishing must be responsible for the lack of recovery and ongoing declines in many groundfish populations.

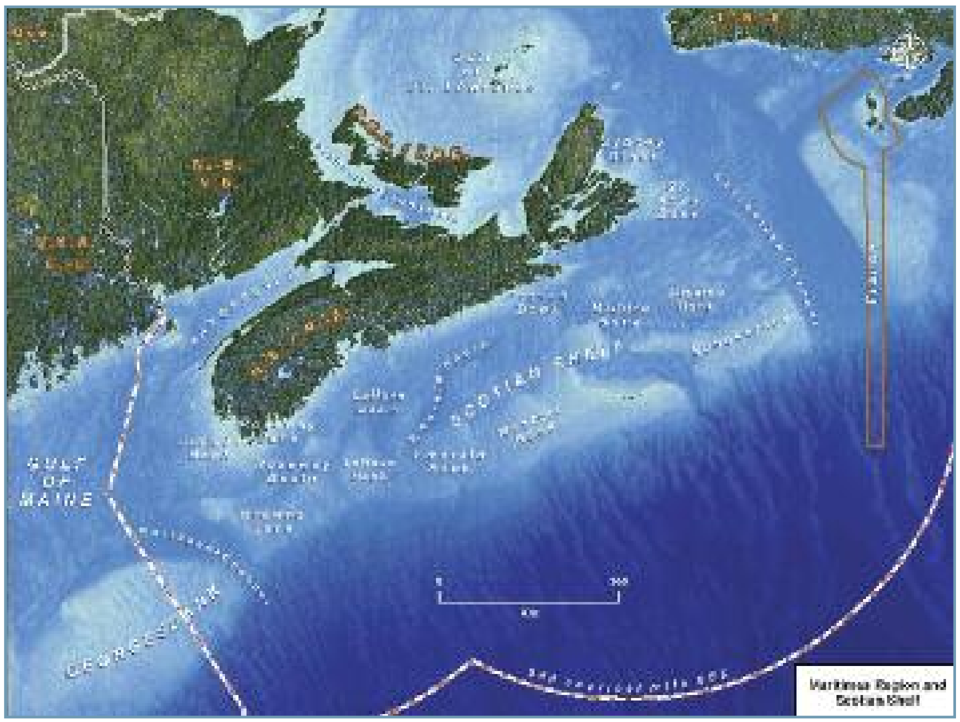
Decadal-scale changes in the cold intermediate layer and the deeper waters of the Gulf are thought to be a dominant climatic influence on groundfish and other bottom-dwelling marine life. At the population level, the most prominent effect has been on cod, mainly in the northern Gulf.

During periods of cold water in the northern Gulf, the physical condition of the cod declined, as indicated by a very low average ratio of body weight to length. Scientists have concluded that the poor condition of the fish caused the mortality of many cod at sea during the early to mid-1990s, precipitating fishery-induced declines and slowing the stock's recovery even after the fishing moratorium was introduced in 1994. As temperatures increased in the northern Gulf, the physical condition of the fish improved and temperature-related mortality declined.

The case of the southern Gulf cod is a study in contrast. If they did suffer from poor physical condition, the contribution of this factor to their decline is believed to be considerably less. Despite the absence of fishing and improvements in September condition since the mid-1980s, the natural mortality of southern Gulf cod remained high, causing a decline in their abundance. There is mounting evidence that predation is the cause of this mortality.

Collapsed groundfish populations throughout the Northwest Atlantic have failed to recover and predation by seals has been proposed as an important contributor. Unusually high natural mortality is particularly common among not only cod, but also other large groundfish in the southern Gulf. Evidence strongly indicates that predation by Grey Seals may be a large factor. The evidence includes:

- generally coincident trends in the mortality rates of groundfish and increases in the seal population;
- similar downward trends in the abundance of most species that Grey Seals prey on;
- shifts in fish distribution away from areas frequented by seals; and



Scotian Shelf - Fisheries and Oceans Canada, Maritimes Region

- calculations confirming there is sufficient feeding demand by seals and an overlap with prey, both spatially and temporally, to explain elevated natural mortality in at least Atlantic Cod, White Hake and Winter Skate in the southern Gulf of St. Lawrence.

Scotian Shelf:

Due to the combined effects of human activities and changing environmental conditions, the Scotian Shelf ecosystem has undergone a major structural shift in recent decades that has affected all levels of the food web and altered the structure of marine communities. This shift involved concurrent increases in seals, small pelagic fish, bottom-dwelling macroinvertebrates and phytoplankton, and decreases in groundfish and zooplankton.

These findings are the result of Fisheries and Oceans Canada research on the Scotian Shelf, which has revealed that the removal of top predators due to intensive fishing can cause large and possibly permanent changes to ocean ecosystems, completely restructuring the food web. Research published in the early 2000s to 2005 indicated that the food web was restructured on the Scotian Shelf when overfishing of top predators such as large groundfishes led to population collapses of the these large benthic predators. Planktivorous, pelagic forage fish species and macroinvertebrates became dominant, and reached biomass levels 900% greater than those prevalent before large groundfish populations collapsed. Despite management measures, including fishing moratoriums, which were put in force in the early 1990s, the Scotian Shelf ecosystem has not reverted back to its former structure.

The prolonged duration of the altered food web, and its current recovery, was and continues to be dominated by all-consuming forage fish. The forage species that quickly escalated into dominance shortly after the large groundfish populations collapsed are now themselves in decline because they have outstripped their zooplankton food supply. However, researchers within the Department have recently found there is some evidence at the broad, system dynamics scale to indicate that this large, altered ecosystem is transient and that it is possible that it may be on a path to return to a food web dominated again by the larger groundfish. However, new cod-specific research undertaken by the Department (cod recovery potential assessment) is not completely consistent with the hypothesis that the ecosystem is currently reverting to its former structure, at least with respect to large groundfish. The spawning stock biomass of cod on the Eastern Scotian Shelf reached the lowest level observed in the 53-year record in 2003 at about 7,500 tonnes. While the stock is not considered to be recovered, it has grown rapidly to 64,000 tonnes in 2011. Despite the increase, long term projections suggest that the stock will remain below the level that would allow fishing to resume. Moreover, with respect to forage fish biomass, the 2004 cod cohort that fueled the rapid improvement in abundance of Eastern Scotian Shelf cod was produced in a year during which pelagic fish biomass appears to have been high. The divergence of views illustrates the complexity of ocean ecosystem research, and points to the need for ongoing research into these processes.

The broader, system dynamics scale perspective favours the view that the existing food web on the Scotian Shelf is being affected by a series of factors combined with a limited food supply for forage fishes. This view sees a reduction in predation accompanied by slowed increases in species abundances at both lower and higher trophic levels. This was first observed in zooplankton and subsequently in large-bodied predators, all considered consistent with a return towards the earlier ecosystem structure. In the longer term, the broader system view supposes that the current trend could lead to the inverted food web reversing, with the possibility that the collapsed fisheries could recover.

Placentia Bay-Grand Banks:

In the early 1990s, a major shift in community structure occurred along the entire shelf, which involved:

- a decrease in the abundance of commercial and other fish species (e.g., Atlantic Cod, American Plaice, Thorny Skate, wolffishes);
- a dramatic increase in the biomass of invertebrates (e.g., Snow Crab and Northern Shrimp);
- the reduction in availability of Capelin and changes in their biology; and
- a continued increase in the Harp Seal population.

The reasons for these changes are still under debate. However, potential factors include overfishing, climate change and changes in interactions among species. In contrast to observations on the Scotian Shelf, these changes did not coincide with a decrease in zooplankton or an increase in small forage species.

Stocks of many historically dominant groundfish have declined to a small percentage of their previous levels. Fishing is thought to be a major driver of these changes; however, environmental conditions in the Northwest Atlantic may also be a factor. Despite fisheries closures and other management measures, populations remain low and individuals are often smaller at maturity.

Since the collapse of groundfish stocks in the early 1990s, invertebrates have dominated fisheries catches. The increase in abundance of Northern Shrimp and Snow Crab could be due to a combination of water temperatures, which affect the early stages of life, and reduced predation from groundfish.

The population of Capelin, a key forage species with a dominant role in the Newfoundland Shelf food web, was high in the 1980s, decreased dramatically in the early 1990s and has remained low ever since. This decline was accompanied by significant changes in the species biology. For example, individual capelin continue to be smaller and changes in behaviour include later spawning times and a decrease in the extent of diurnal migrations.

In 2010, Capelin numbers were estimated to be at less than one percent of historical levels.

Among marine mammals, Harp Seals are the single most abundant species in the Newfoundland Shelf system. The Harp Seal population declined during the 1960s, reaching a minimum of less than two million in the early 1970s. By the mid-1990s, the population had tripled to about 5.5 million. Since then, the Harp Seal population has slowly increased to an estimated 8.61- 9.55 million animals in 2010.

Pacific North Coast:

Shifts in the prevalence of upwelling and downwelling winds correspond with ecosystem shifts within the Pacific North Coast Integrated Management Area (PNCIMA). Winds blow mainly from the south in winter and from the north in mid-summer, with much stronger winds in winter. Upwelling winds from the north push surface coastal waters away from shore, which are replaced by nutrient-rich deep water, providing nutrients that feed the entire food chain. In contrast, years with strong downwelling winds from the south may have delayed spring phytoplankton blooms, resulting in reduced survivals for various marine species. In general, downwelling winds have been stronger than average since an ecosystem shift in the late 1970s, except from 1988 to 1996. These southerly winds have been associated with generally increasing water temperatures and decreasing salinities.

Increases or decreases in the abundance for some aquatic populations over time are associated with oceanic ecosystem shifts. Other populations exhibit more pronounced interannual variability, perhaps related to changes occurring during a critical life history stage. For instance, Chum and especially Pink Salmon abundances generally increased after the late 1970s, while abundances of Coho Salmon decreased. The Sockeye Salmon in Smith inlet supported a valuable fishery until severe stock declines in the early to mid-1990s. Herring abundances, except those in the Prince Rupert district, have generally decreased since the late 1970s. Sardines returned to southern Vancouver Island waters in 1992 after a 45 year absence, and expanded their distribution northward into PNCIMA by 1998. The northward extent of sardine migration varies from year to year and is strongly affected by temperature. In 2009, Humboldt Squid were much more widespread and abundant in B.C. waters, including PNCIMA, than in previous years. However, in 2010 squid were virtually absent from B.C. waters.

Fisheries and Oceans Canada scientists are finding new ways to increase our understanding of marine ecosystems. For example, research on the west coast is using satellite oceanographic observations to explore the interconnections between ocean ecosystems and particular marine species: **Satellites and Seabirds: What They Are Telling Us About the Marine Ecosystem**

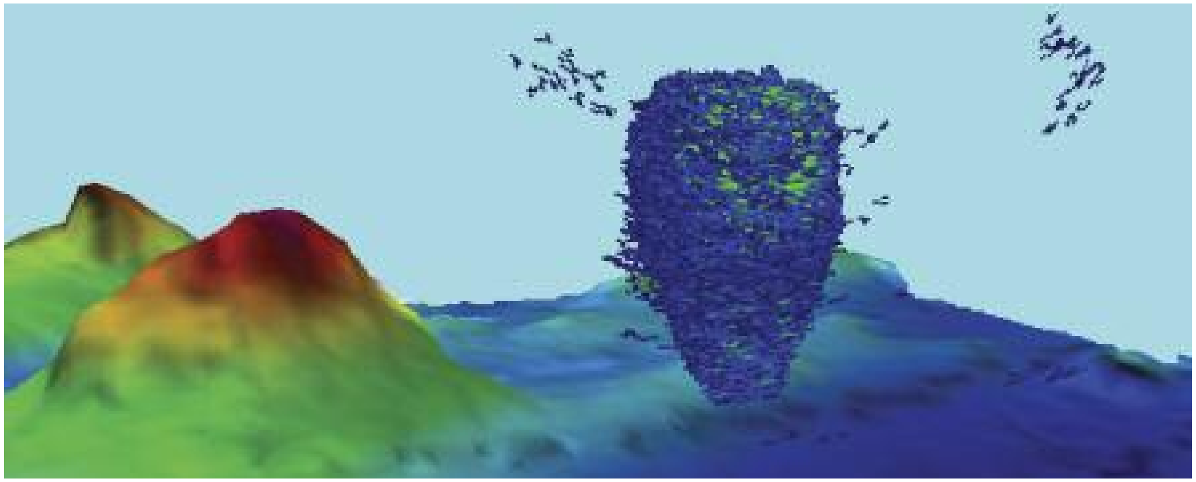
Addressing Ecosystem Shifts

It is essential that ocean activities be managed in a way that preserves the health of marine ecosystems while allowing for sustainable use.

Given the complexity of ecosystem interactions, natural science and socio-economic experts must join forces with managers to follow major ecosystem changes and assess their causes. This will help inform the development of an ecosystem approach to marine resource management in the face of climate change and aid in the development of management measures to mitigate anticipated detrimental impacts.

A variety of management actions have been implemented to protect the offshore habitats and communities in the various ecosystems including a variety of legislation and policies, and scientific research and monitoring programs.

A crew making a helicopter ice survey of the Gulf of St. Lawrence in early March 2012 took this photo of part of the Gulf seal population. Photo: DFO



Scientists are observing seabirds to understand aquatic ecosystem changes. In Newfoundland, scientists caught this common murre making a meal of a small capelin, and generated this computer image of a school of capelin using sonar data with CARIS software. Capelin was once a dominant forage species of the Newfoundland Shelf foodweb but the population declined in the 1990s and remains low. Photo: © Joel Heath, CG Image: DFO/CHS

What is Ocean Acidification?

Ocean acidification is a global threat with potential impacts on marine food webs, ecosystem productivity, commercial fisheries and global food security. This threat has prompted the international scientific community, including Fisheries and Oceans Canada, to investigate the implications of this significant international governance issue.

Each year, about one third of the carbon dioxide (CO_2) in fossil fuel emissions dissolves in ocean surface waters, forming carbonic acid and increasing ocean acidity. Over the next century or so, acidification will be intensified near the surface where much of the marine life that humans depend upon live.

The ocean surface is becoming more acidic with increasing atmospheric CO_2, and acidity has increased by about 30% since the beginning of the industrial revolution. Estimates of future carbon dioxide levels, based on "business as usual" CO_2 emission scenarios, indicate that by the end of this century, the surface waters of the ocean could be nearly 150% more acidic, resulting in a pH (a measure of acidity) that the oceans haven't experienced for more than 20-million years and raising serious concerns about the ability of marine organisms to adapt. This scenario is based on information provided by the **U.S. National Oceanic and Atmospheric Administration** (NOAA).

Monitoring ocean acidification and assessing its potential impacts are essential to the development of an ecosystem approach to managing the marine resources that are likely to be affected by this global threat.

Canada's cold coastal waters may be particularly prone to acidification due to the natural occurrence of undersaturated waters at shallow depths (Pacific coast), or large freshwater input (Arctic coast). Freshwater input from runoff and ice melt reduces the ocean's capacity to buffer against changes in pH. Runoff may also contain organic matter from land which can also increase acidification.

Acidification and the Saturation State of Calcium Carbonate

Acidification hampers the ability of marine organisms to form shells and skeletons of calcium carbonate ($CaCO_3$). The degree to which seawater is saturated with $CaCO_3$ is known as the "saturation state" (denoted by the Greek symbol omega, Ω). Saturated water has a saturation state (Ω) of greater than or equal to ($\geq$) 1.0. Water with a $\Omega > 1$ is oversaturated and the mineral will tend to precipitate (form a solid). Water with a Ω of less than ($<$) 1 is undersaturated and the mineral will tend to dissolve.

Increasing acidification reduces the saturation state of calcite and aragonite, the two most common forms of $CaCO_3$. When undersaturation occurs, it is impossible for organisms to maintain or grow $CaCO_3$ shells and skeletons. The saturation state of $CaCO_3$ is determined primarily by the concentration of carbonate ions (CO_3^{2-}) and pressure (i.e., depth), with temperature and salinity playing smaller roles. It is also affected by ocean processes, including inputs of CO_2 from the decay of organic matter or the uptake of anthropogenic CO_2 from the atmosphere, surface temperature change, freshwater runoff, stratification and mixing of the water column.

Acidification in Canada's Oceans

Pacific North Coast:

In summer along the west coast of Canada, acidic water from depths of 100 to 200 metres upwells onto the continental shelf and into the ocean surface layer. This upwelling water is acidic due to a high concentration of dissolved inorganic carbon. However, the exposure of the continental shelf to this water is expected to be intermittent since the uptake of CO_2 by phytoplankton and outgassing of CO_2 to the atmosphere remove the excess dissolved inorganic carbon. Nonetheless the combination of undersaturated water at relatively shallow depths and winds that favour upwelling make the British Columbia shelf particularly vulnerable.

Over the last century, the depth below which the aragonitic shells of shellfish, corals and some plankton dissolve — known as the aragonite saturation depth or horizon (Ω_a) — has become shallower by, typically, 30-50 metres. In the Northeast Pacific Ocean, the saturation horizon is naturally shallow – as little as 100 metres below the surface. Scientists expect the saturation depth to become shallower as global atmospheric CO_2 concentrations increase over the coming century, putting organisms close to the surface at risk from ocean acidification.

Beaufort Sea:

Ocean acidification in this Large Ocean Management Area has been observed in the Canada Basin of the Beaufort Sea. However, increasing ice melt and runoff in summer, combined with higher atmospheric CO_2, may increase the frequency and/or area affected by acidified waters on the Canadian Beaufort shelf, a broad estuarine region of the southeastern Beaufort Sea.

From space, the satellite carrying NASA's Moderate Resolution Imaging Spectroradiometer or MODIS, captured this image of the waters around Vancouver Island and spied a 'bloom' of the tiny plant (about 10 microns in diameter) known as the coccolithophorid Emiliania huxleyi. Similar plants, with a calcium carbonate structure, are at risk from acidification due to increased carbon dioxide in the oceans from the burning of fossil fuels. Photo: courtesy Dr. Ken Denman and NASA.

Red sea urchins (*Strongylocentrotus franciscanus*) beside a painted sea star (*Orthasterias kochleri*), part of the vibrant habitat of Queen Charlotte Strait in British Columbia. Researchers are monitoring for ocean acidification in coastal Pacific ecosystems. Photo: Mike Wetklo

From 1997 to 2008, the saturation state of aragonite in the surface water of the Canada Basin decreased by 0.4 due to sea ice melt and increases in atmospheric CO_2. Surveys in 2008 revealed that aragonite was undersaturated in the surface layer, with the lowest values near the centre of the Beaufort Gyre (Ω_a about 0.8). Since saturation states are affected by water temperature, warming surface waters in the Canadian Basin counteracted some of the effects of ice melt and increasing atmospheric CO_2. Calcite was still marginally oversaturated (Ω_c of 1.1-2.0) in surface waters of the Canada Basin in 2008.

Although recent measurements of $CaCO_3$ saturation states are offshore in this LOMA, scientists anticipate that ocean acidification will affect the continental shelf waters due to factors such as the upwelling of nutrient rich, Pacific-origin water (which has a low aragonite saturation state) across the shelfbreak.

Scotian Shelf:

Data from the Scotian Shelf indicates that pH has declined by about 0.1 to 0.2 units since the early 1930s, indicating that ocean acidification is ongoing. There is concern that the outflow of more acidic water from the Arctic will affect Atlantic Canadian waters downstream.

Gulf of St. Lawrence:

There has been no significant change in the pH of surface waters in the St. Lawrence Estuary and Gulf since 1934. With the exception of transient acidified water in the shallow southern Gulf of St. Lawrence, acidified waters in this LOMA are generally deeper than 100 metres.

The pH of bottom waters at depths of 170 to 335 metres has decreased by 0.2 to 0.3 units over the 73 years from 1934 to 2007, which is similar to the change predicted for the open ocean over the next century. It is important to note that this decline in pH was not due to the uptake of anthropogenic CO_2 from the atmosphere. Rather, it was the result of an increase in CO_2 due to the decay of organic matter in the deeper waters of the estuary, which were isolated from the atmosphere during that time. Calcite is now only slightly supersaturated in the estuary while aragonite is highly undersaturated in the waters below 150 metres.

Impacts of Ocean Acidification

The most direct biological impact of acidification will be on marine "calcifiers" — organisms that form shells and skeletons containing $CaCO_3$. These organisms include phytoplankton, zooplankton and other invertebrates including molluscs, crustaceans, gastropods, sea urchins and other echinoderms, and corals. Several of these groups include species of commercial importance (e.g., bivalve molluscs, oysters, clams).

When there is too much CO_3 in seawater, the saturation state of $CaCO_3$ is low (see text box on "saturation state" page 10) and organisms have to use more energy to produce skeletons and shells.

In addition to decreases in calcification, or a softening of shells, studies reveal that a more acidic ocean environment also reduces growth rates and increases mortality in some marine species. A decline in the growth of marine calcifiers such as American Lobster, Ocean Quahog, and scallops means less shellfish meat to sell and to eat. Acidification is also expected to affect the reproduction and development of marine organisms to varying degrees.

Differences in the response of organisms to reduced pH could have a considerable impact on biodiversity, marine community structure, and ecosystem goods and services. Such goods and services pertain to the value and benefits that all living things derive from healthy ecosystems. Increasing acidity may also alter the chemistry of marine waters in other ways, potentially affecting nutrient availability and toxicity of some pollutants.

There is already evidence that acidification is having negative impacts on key marine species in the Arctic (i.e., the pelagic mollusc *Limacina helicina*). The undersaturation of aragonite in the Gulf of St. Lawrence suggests that acidification may already be affecting biota in that ecosystem, especially in deeper waters. Laboratory and microcosm experiments conducted throughout the world show that species such as crabs and shrimps may exhibit reduced rates of net calcification and even dissolution under conditions such as those currently encountered in the St. Lawrence hypoxic waters.

If atmospheric CO_2 doubles from preindustrial levels in the middle of the 21st century, it would reduce the $CaCO_3$ saturation state by 30%, which would affect plankton and favour non-calcifying species. The reorganization of the lower food chain would have impacts on the rest of the food web.

Addressing Ocean Acidification

Continued scientific research into ocean acidification is necessary to identify its impacts and drivers, which vary by location, with a view to developing a coherent response to the issue. Other studies are exploring the timing of seasonal acidification events and the potential impacts of a more acidic ocean environment on various organisms. Several international research programs are underway to examine possible impacts on pteropods, which are the most vulnerable organisms in the Gulf of Alaska because their shells are made of aragonite, the form of calcium carbonate that dissolves more readily. Plankton, which are at the bottom of the food chain and controlled by climate, should be intensely monitored as a sentinel of climate change impacts.

For more information, see: **Ocean Acidification**

Hypoxia

What is Hypoxia? Around the world, marine hypoxia — a shortage of dissolved oxygen — is a growing problem that can have dramatic impacts on marine life and ecosystems. A decline in oxygen in seawater is now recognized as one of the likely consequences of global warming, because warmer water does not hold as much oxygen. This condition may be naturally occurring or be exacerbated or directly caused by human influences. In either case, the processes involved and the resulting environmental stresses are essentially similar.

Scientists working on the CCGS *Louis S. St-Laurent* in the Beaufort Sea in July 2010 lowered a large instrument called a "CTD rosette" from the deck to sample the water. The CTD – which stands for conductivity, temperature and depth – is used to sample and record data about the ocean water's physical attributes including temperature, salinity, oxygen, nutrients, and alkalinity. Instruments such as this are vital to understanding processes such as hypoxia.

Surface waters are always rich in dissolved oxygen; however, waters below 100 to 150 metres in depth do not readily gain oxygen directly from the ocean surface. Hypoxia occurs in these deeper waters when oxygen is removed from the water much faster than it is replenished from the atmosphere or by photosynthesis. Microbial respiration due to the decay of organic material in deep water and in sediments can also contribute to hypoxia. This condition may be transient, seasonal or permanent depending on a variety of factors including local oceanographic conditions.

Sea Water and Oxygen Saturation

There is an upper limit to the amount of oxygen that can be dissolved in seawater, which depends on water temperature, salinity and atmospheric pressure. Oxygen saturation is a measure of how much oxygen is dissolved, as a percentage of the maximum oxygen concentration in seawater. For example, seawater at 10°C with a salinity of 35 and at normal atmospheric pressure is considered fully saturated (100%) when the dissolved oxygen concentration reaches 6.4 millilitres per litre (mL/L) of seawater, and 50% saturated when it reaches 3.2 mL/L.

The impact of hypoxia on living organisms depends on the concentration of dissolved oxygen as well as temperature, salinity and the tolerance of each particular species to low oxygen. Severely hypoxic waters have been referred to as "dead zones," where few macroscopic organisms can exist and commercial species are essentially absent.

Question: At what % saturation does seawater become hypoxic?

Answer: Hypoxia is generally considered to be less than 30% to 20% oxygen saturation. Each marine species responds differently to low oxygen concentration, and the term hypoxia differs depending on the species of interest. Mild hypoxia is in the range of 30-50%; severe hypoxia sets in below 10%.

Hypoxia in Canada's Oceans

In addition to the examples of hypoxia detailed below, climate change and future coastal development have the potential to cause localized hypoxia in other locations.

Pacific North Coast:

Along the Pacific Canadian coast, the greatest area of concern for stronger hypoxia is the continental shelf in late summer. Oxygen concentrations in sub-surface waters west of Vancouver Island have dropped in the past few decades; PNCIMA oxygen levels are somewhat higher, but there are too few observations in late summer to detect a trend.

Findings to date include:

- Hypoxia in these waters is most severe in fjord-type inlets, which exchange deep water very slowly with outside waters. Concentrations of dissolved oxygen in some fjords can be as low as zero, but because this condition has persisted for centuries it is not considered a problem.
- Oxygen levels in the waters of Queen Charlotte Sound, Hecate Strait and Dixon Entrance, which support diverse bottom life and rich fisheries, are low enough that future declines might alter the distribution of some or many species and lead to a loss of deep-water habitat. Some of these changes may have already occurred. On the bottom of Queen Charlotte Sound, dissolved oxygen saturation can be as low as 25%.
- In late summer of 2006 and 2009, oxygen saturation as low as 10% was observed at about 150 metres depth (mid-shelf) off southwest Vancouver Island. Although this was the lowest value recorded there since regular sampling began in 1979, previous levels were as low as 15% and there have been no reported changes to marine life. Since 2002, even lower oxygen levels have been found during summer off Washington and Oregon states, which have been related to major shellfish mortality.

There is concern that sub-surface oxygen concentrations might continue to decline along the west coast over the coming decades due to a potential impact of global climate warming; specifically, declining oxygen in subarctic waters caused by reduced ventilation (gas exchange between ocean and atmosphere) along the east Asian coast.

Gulf of St. Lawrence:

Recent and historical data reveal that hypoxia is progressively worsening in the deep waters of the Gulf of St. Lawrence, especially at the heads of the Laurentian, Anticosti and Esquiman channels. The lowest levels of dissolved oxygen were recorded in the Laurentian Channel, where measurements have routinely been in the range of 20% saturation since the mid-1980s. This hypoxia culminates a long decline in oxygen levels since 1932 (the earliest available data), when the bottom waters of the St. Lawrence Estuary averaged 38% saturation.

Up to two-thirds of the decline in oxygen saturation since 1932 is due to a higher influx of warm, oxygen-poor North Atlantic Central Water and a reduced input of oxygen-rich water from the Labrador Current. The remainder of the decline appears to be caused by increased oxygen demand in the deep water and sediments. Greater oxygen demand is possibly due to higher bacterial respiration associated with a nearly 2°C rise in the temperature of the deep water since the 1930s or with an increased supply of organic material from the ocean surface.

Scotian Shelf:

There is also evidence of a decrease in oxygen in the slope-derived deep waters in the Emerald Basin of the Scotian Shelf. However more data are necessary to identify the spatial and seasonal structure of the long-term trend.

Impacts of Hypoxia

Since oxygen is essential for aerobic metabolism, marine life can suffer a variety of impacts in hypoxic waters, including reduced growth rates, lower reproductive success and higher mortality. Some of these effects are evident even under mild hypoxia (30 to 50% oxygen saturation).

Hypoxia can also affect the distribution of species, since most species will leave an area well before the oxygen concentration falls to levels that might kill them. One concern in the Pacific North Coast LOMA is that even if oxygen levels in bottom water are not fatal to groundfish, these fish may still move to shallower waters where dissolved oxygen is greater, potentially depriving them of much of their preferred habitat.

The threshold at which impacts occur varies by species. Many species can thrive at oxygen levels that seriously impact others. In general, sediment-dwelling, longer-lived, immobile marine life is the most vulnerable. Larger, bottom dwelling (benthic) organisms such as lobster and sea cucumber need more oxygen and are also vulnerable in low oxygen environments, while annelid worms, molluscs and cnidarians are less sensitive. Preliminary research on Snow Crab suggests that they are quite tolerant of hypoxia; however, very little is known about its effects on crustaceans in the St. Lawrence Estuary and Gulf.

The most detailed studies into the effects of hypoxia on commercial species relevant to the current situation in the St. Lawrence Estuary have been on Atlantic Cod. Half of the fish die within 96 hours of exposure to 21% saturation, while 5% of the fish die within 96 hours when exposed to 28% saturation. Cod almost completely avoid areas of the Estuary and Gulf where near-bottom levels of dissolved oxygen are less than 30% saturation. There was also evidence of reduced feeding and growth rates (both for length and mass). Swimming performance also declines, which may reduce the ability of fish to capture prey, avoid predators and escape mobile fishing gear. Research also suggests that cod may deliberately avoid prolonged exposure to oxygen saturation levels of less than 70%.

Hypoxia also has ecosystem-level effects, including direct loss of habitat or habitat compression, altered trophic (food web) relationships, changes in migration patterns, and changes in biodiversity. Since the 1970s, there has been a substantial decline in the abundance of several groups of bottom-dwelling species in the Lower St. Lawrence Estuary (echinoderms, crustaceans), as well as the diversity and activity of benthic organisms. Whether these major changes in the ecosystem are due to hypoxia, acidification or both remains an open question.

Another concern is the interaction between acidification and hypoxia, which could make respiration more difficult for a number of organisms including fish such as cod.

Addressing Hypoxia

Research into the biological impacts of hypoxia is ongoing. For example, scientists are studying the impact of near-bottom dissolved oxygen levels on two other important species in the St. Lawrence Estuary and Gulf: the Greenland Halibut (*Reinhardtius hippoglosoides*) and the Northern Shrimp (*Pandalus borealis*). Both of these species inhabit deep waters and are therefore exposed to hypoxia.

Integrated, multidisciplinary research is necessary to assess the combined effects of warming, hypoxia and acidification on marine life and ecosystem structure and function in the St. Lawrence Estuary and Gulf. Continued monitoring of ecosystem variables — chemical and physical conditions, primary productivity and food web interactions — and potentially vulnerable commercial species will improve under-standing of the impacts of hypoxia before significant changes occur.

In the Pacific Region, the oxygen concentrations are monitored by DFO ocean and fisheries research surveys. Future distributions of groundfish will be monitored to determine impacts of changing oxygen concentrations. **NEPTUNE Canada** has recently added oxygen sensors to its array of ocean instruments off the southwest coast of British Columbia to monitor changes in the future.

For more information on the causes and drivers of hypoxia (i.e., inflow of waters plus local factors) please see the regional Gulf of St. Lawrence LOMA report.

Northern shrimp. Photo: DFO

Sea Ice Variability

A dynamic and ever changing component of ocean ecosystems, sea ice is one of the most important climatic variables and a key indicator of climate change. Along with other elements of polar ecosystems, sea ice is part of the global climate system and plays a crucial role in its regulation.

The area covered by sea ice grows in the winter and shrinks in the warmer months. Marine life is closely linked to this seasonal cycle. In addition, ice conditions are characterized by inter-annual variability in extent, duration, thickness, condition (i.e., fragility) and mobility, which are influenced by a range of factors or drivers. A decline in the extent of the ice-covered area will increase the amount of energy entering an ecosystem because sea ice reflects 80 percent of sunlight back into space while a dark ocean surface absorbs 90 percent of sunlight.

As global climate change alters this important component of marine ecosystems, there will be inevitable shifts in the marine food web, putting some species at risk while benefitting others. Changing sea ice can also have impacts on traditional subsistence cultures, coastal communities and other infrastructure, and human activities such as subsistence hunting and fishing, marine shipping, and oil and gas exploration and development. Understanding these changes and their potential impacts is critical toward the development of ecosystem approaches for marine resource management and mitigation and adaptation strategies for northern communities and various social and economic activities.

It is important to note that sea ice trends within a particular Large Ocean Management Area (LOMA) or other ocean region may differ from whole Arctic observations.

Sea Ice Variability in Canada's Oceans

Gulf of St. Lawrence:

Even though the Gulf of St. Lawrence has some of the warmest surface water in Atlantic Canada during the summer, the region also has the most southerly seasonal sea ice during winter.

Winter air temperatures over the Gulf are a key factor that drives the formation of sea ice cover, since cold air combined with strong winds extract heat from the ocean surface. The ice begins forming in early to late December and reaches its greatest extent and volume by early March. Since sea ice is more fragile during its early growth period, storms, thaws and other events can prevent the ice from reaching its full thickness and coverage potential for the season. Storm and thaws can also affect the timing of ice breakup in the spring.

In the winter of 2010, the Gulf of St. Lawrence had the least amount of ice coverage (virtually none) since the Canadian Ice Service began gathering data in 1969. The rare conditions were attributed to the warmest air temperatures on record in the Gulf since 1945. Ice-free winters are likely to occur more regularly due to climate change; however interannual variability will likely ensure there will be sea ice present during many winters over the next few decades.

Placentia Bay-Grand Banks:

Sea ice extent and duration on the Newfoundland and Labrador Shelf was below normal in 2010 for the 15th consecutive year, with the annual average reaching a 48-year record low. The International Ice Patrol of the U.S. Coast Guard reported that only one iceberg drifted south of 48° north latitude onto the Northern Grand Bank during 2010 compared with 1,204 in 2009.

Sea ice is influenced by the North Atlantic Oscillation (NAO), a large-scale variation in atmospheric pressure over the North Atlantic Ocean and a key indicator of climate conditions in the region. Variations in the NAO can directly or indirectly affect ice flow, ocean temperature, the strength of the Labrador Current, and the distribution and biology of marine species. A high NAO index generally indicates colder water temperatures, stronger northwest winds, cooler air temperatures, and heavy ice sea conditions, which was the pattern for the majority of the 1980s and 1990s.

In 2010, the NAO index hit a record low, weakening the outflow of Arctic air to the Northwest Atlantic. This led to broad-scale warming (relative to 2009) throughout the Northwest Atlantic from West Greenland to Baffin Island to Newfoundland.

Beaufort Sea:

Since the late 1990s, there has been a dramatic reduction in the extent and age of multi-year sea ice in the Arctic Ocean including the northwestern portion of the Beaufort Sea LOMA. A reduced expanse of multi-year ice implies a greater expanse of ice-free water in August and September. Summertime ice cover is the most important environmental control in the Beaufort marine ecosystem. Moreover, younger pack ice is thinner and weaker and may be more responsive to wind stress.

Understanding the role of ice in the marine ecosystem is a major challenge. In Franklin Bay, a large inlet of the Amundsen Gulf, in the southeastern Beaufort Sea (Northwest Territories), a diving specialist positions an ultra-sensitive light meter beneath two metres of Arctic sea ice to learn more about life on the under-side of the sea ice. Photo: Jeremy Stewart, DFO.

Humpback whales in the Gulf of St. Lawrence.
Photo: DFO

Therefore, a thinner arctic ice pack can influence ocean circulation and the distribution of surface salinity, with consequences for the marine food web. Although multi-year ice is clearly less common in the Arctic Ocean than two decades ago, observations reveal no trend in the thickness of first-year ice.

Other characteristics of sea ice conditions in the Beaufort LOMA during the last five years include:

- large inter-annual variations in the mean thickness of first-year ice;
- large inter-annual variations in summer ice concentration (the fraction of the sea surface covered by sea ice of any thickness);
- the duration of summertime ice clearance from the shelf varied by more than two months.

There are 30-year trends towards a reduced presence of sea ice over the Mackenzie Shelf, in Amundsen Gulf and in the Canadian sector of the Canada Basin. However, these trends are small relative to the magnitude of inter-annual variations.

Inter-annual variability makes it more challenging to identify the drivers of change in sea ice (i.e., natural variation versus climate change.)

Impacts of Sea Ice Variability

Gulf of St. Lawrence:

Variations in sea ice can have far-reaching impacts on marine ecosystems, including ocean characteristics (i.e., water layers and mixing), food webs, and the distribution, habitat and survival of marine life. For example, ice could have direct and indirect impacts on the survival of the 16 species of whales (cetaceans) and seven species of seals that inhabit the St. Lawrence Estuary and Gulf either seasonally or throughout the year. Changes in ice cover, freeze-up and melt patterns may affect the availability of zooplankton and other food resources for fish. Ice may limit access to the surface or reduce the available foraging habitat for some marine mammals while providing other species with a platform for breeding and resting. Ice movement could also lead to the entrapment of whales.

It is difficult to predict how marine mammals will respond to changing ice conditions. In the St. Lawrence Estuary and Gulf, a reduction in total ice cover and stability has the potential to:

- open up foraging areas that were previously not accessible;
- cause marine mammals to become more widely dispersed or alter their north-south distribution;
- cause seasonally resident cetaceans to spend more time in the Estuary and Gulf, increasing the potential for competition between Harp Seals, Beluga Whales and other cetaceans for zooplankton and fish species such as Capelin, Herring and cod;
- increase exposure to potential predation from Killer Whales, which generally try to avoid sea ice because it can entrap them or injure their large dorsal fin;
- likely cause the breeding population of Harp Seals to shift more towards the northern Gulf or even outside of the Gulf;
- favour an expansion in distribution and abundance of Grey Seals throughout the Gulf, and increase interactions with fisheries and the transmission of parasites to commercially important fish species;
- increase shipping opportunities or cause a shift in shipping patterns. Higher ship traffic would increase potential for vessels to strike marine mammals and increase ambient noise levels, which may have an impact on marine mammal communication, particularly among cetaceans.

Beaufort Sea:

Since 2002, the Joint Ocean Ice Studies (JOIS) has carried out an annual expedition to the Beaufort Gyre, a clockwise circulation (looking from above the North Pole) in the Beaufort Sea north of Alaska. This circulation is the result of a strong high-pressure system that creates winds over the region.

Since 2003, the surface waters of the Beaufort Gyre have been freshening (becoming less saline), a trend that has been linked to wind-induced convergence of low salinity water at the surface and to the melting of thick, multi-year ice. Reduced ice cover over the gyre means there is more open water. The darker open water surface absorbs more energy from the sun, causing the surface water to warm and reducing sea ice.

Since warmer water is less dense (lighter) than cold water, and fresher water is lighter than salty water, the ocean here is becoming increasingly stratified. Increased stratification reduces water column mixing and the movement of nutrients into the surface layer. It is in this sun-lit, near-surface zone that the foundation of the marine food web, phytoplankton, grows. Greater stratification has led to an increase in the smallest algae (picoplankton) in the Canada Basin, both in total amount and as a percentage of total phytoplankton and a decrease in larger nanoplankton, which has the potential to alter other parts of the food web. For more information see: **Freshening of Arctic Ocean Favours Smallest Algae, Potentially Altering Food Webs**.

Ocean Climate

Ocean climate is the average over a long time of marine features such as temperature, salinity, nutrients, waves, stratification and winds. Data on ocean climate conditions — such as the average July and January ocean temperature over a recent 30-year period — are often reported in climate information.

Interactions between the oceans, sea ice, snow pack and the atmosphere are a fundamental part of the Earth's global climate system. Understanding the role of oceans in global climate and the impacts of climate change on aquatic ecosystems is of critical importance to the international community and countries such as Canada, which borders three interconnected oceans.

What is the North Atlantic Oscillation?

The North Atlantic Oscillation (NAO) is a large-scale variation in atmospheric pressure over the North Atlantic Ocean and a key indicator of climate conditions in the region. Large-scale spatial variations in ocean temperature and salinity in the North Atlantic are related to the NAO index, which represents the relative strengths of atmospheric pressures over Iceland and the Azores.

Ocean Climate in Canada's Oceans

Gulf of St. Lawrence:

In addition to fishing, changes in ocean climate also directly and indirectly contribute to changes in marine populations and communities. Over the past four decades, changes in the North Atlantic Oscillation (NAO) and other changes in large scale weather patterns that persist for several years or more have led to profound changes in water temperatures in the Gulf of St. Lawrence.

During the summer, the Gulf typically has three temperature layers: a warm, relatively fresh (less salty) surface layer; a cold intermediate layer from about 50 to 150 metres; and, a deeper, warm salty layer covering channels and other areas that are deeper than 200 metres. Observed temperature variations in the Gulf include:

- Surface water temperatures during the ice-free months have warmed by 1.5°C between 1982 and 2010.
- Temperatures in the cold intermediate layer shifted from exceptionally warm during the later 1960s and early 1980s, to very cold from 1986 to 1998. Recent conditions have been closer to average.
- Exceptionally cold conditions occurred at depths of around 200 to 300 metres from 1991 to 1996. Although waters have since warmed and have recently been close to their long-term (1981 to 2010) average of 4.5°C at 200 metres and 5.5°C at 300 metres, conditions were colder than average again in 2009-2010 but returned to average in 2011.

Scotian Shelf:

Temperature and salinity on the Scotian Shelf have a vertical structure that varies seasonally, similar to that in the Gulf of St. Lawrence, with lighter "shelf" water overlying saltier "slope" water that intrudes from offshore at depth. This results in a vertical gradient in water density that is referred to as "stratification". In the near-surface waters, this stratification is greatest in summer due to surface heating and the inflow of fresh water from the Gulf of St. Lawrence, and weakest in winter when cool winds increase vertical mixing that breaks down the stratification and brings important nutrients towards the surface.

Records of temperature and salinity dating back to about 1920 indicate that the largest changes that lasted several years on the Scotian Shelf occurred in the 1960s, when the intruding slope water was cooler and fresher. This arose from the enhanced flow of subpolar slope water around the Grand Bank during a period of negative NAO index (reduced wind forcing over the northern North Atlantic). The long-term trends in temperature and salinity on the Scotian Shelf vary with location and depth, and are generally weak, in part because of the strong natural (e.g., NAO) climate variability in the region. However, there is an indication of surface warming at most locations, and of increasing upper-ocean stratification across the Scotian Shelf and Gulf of Maine that is associated with a varying combination of surface warming and freshening. These changes are in the directions expected from anthropogenic climate change, and thus point to the possible emergence of a biologically important longer-term trend.

Beaufort Sea:

In the Beaufort Sea LOMA, some key changes in the ecosystem structure are episodic while others are more persistent. An example of a persistent change is the freshening of surface waters in the Canada Basin, observed since 2003. More fresh water in the LOMA has affected ocean structure (i.e., stratification of water layers) and the delivery of nutrients required for phytoplankton growth.

An episodic upwelling event of unprecedented intensity and duration occurred between November 2007 and February 2008 on the Mackenzie shelf. The salinity of water near the ocean bottom is generally around 33 units. During the upwelling event, bottom water salinity exceeded 34.5 units at the middle and outer shelf and was even higher (35-36.5 units) on the inner shelf. This high salinity water persisted for about two months. The changes in water salinity — caused by both the upwelling of deep salty water from the Canada Basin and the release of brine that occurs during sea ice growth — led to changes in ecosystem structure including increases in the growth of algae on the sea ice and phytoplankton in the water column. These changes in ecosystem structure highlight the importance of interactions and the cumulative effects of different factors.

Placentia Bay-Grand Banks:

Variations in the North Atlantic Oscillation (NAO) index can affect ice flow, ocean temperature and the strength of the Labrador Current. A high NAO index generally indicates colder water temperatures, stronger northwest winds, cooler air temperatures, and heavy ice sea conditions in the Northwest Atlantic, which was the pattern for most of the 1980s and 1990s. In winter 2010, the NAO index hit a record low, weakening the outflow of Arctic air to the Northwest Atlantic. This led to broad-scale warming (relative to 2009) throughout the Northwest Atlantic from West Greenland to Baffin Island to Newfoundland.

Water temperatures have a very important influence on the distribution and biology of marine animals. Changing water temperatures in this LOMA over the past four decades are thought to be responsible for some of the major changes in distribution and abundance of important commercial species.

Ocean temperature observations in the Placentia Bay-Grand Banks large ocean management area include:

- At Station 27, a monitoring site off Cape Spear, NL, the 2010 depth-averaged annual water temperature increased by 0.7°C, making it the second highest on record.
- Annual surface and bottom temperatures at Station 27 were also about 0.6°C above normal.
- The area of the cold-intermediate-layer that was less than 0°C declined on the eastern Newfoundland Shelf, which is indicative of warmer than normal water temperatures.
- Spring bottom temperatures in NAFO Divisions 3Ps and 3LNO during 2010 were above normal, resulting in a reduced area of the bottom habitat that was covered by water colder than 0°C.

Pacific North Coast:

In recent decades there have been increasingly frequent shifts between warm El Niño conditions (2010) and cool La Niña winters (2011). The El Niño/La Niña-Southern Oscillation, or ENSO, is a climatic pattern that occurs across the tropical Pacific Ocean about three to five years, although it can occur more frequently. It involves variations in the surface temperature of the equatorial Pacific Ocean that are set up by variations in tropical Pacific air pressure, known as the Southern Oscillation.

In the winter of 2010, El Niño — a warming of the ocean surface along the Pacific Equator — brought warm winds from the southwest along the west coast of the U.S. and Canada, pushing warm waters toward the British Columbia coast. In 2008, 2009 and 2011, La Niña (the cold phase of mid-Pacific equatorial waters) brought cool westerly winds and cool ocean surface waters to British Columbia.

What are Copepods?

Copepods are a diverse group of aquatic crustaceans and an important part of the zooplankton community. These tiny organisms form a critical part in the marine food web, linking microscopic phytoplankton to juvenile fish such as cod. Adult copepods are usually 1 to 2 millimetres (mm) in length, although the adults of some species may be as short as 0.2 mm or as long as 10 mm.

Biologists aboard the CCGS Louis S. St. Laurent sampled Arctic waters throughout the Canadian Arctic Archipelago during International Polar Year science expeditions. The tiny copepods in this sample were so abundant that the water wriggling with life in the white bucket took on their orange hue. Photo: © 2007, Paul Galipeau

Ocean waters in the region are generally becoming warmer and less saline:

- Daily sampling of ocean temperature at lighthouses on Kains Island and Langara Island in PNCIMA reveals warming by 0.5 to 0.6°C over the past 80 years.
- In 2010, an El Niño year, all stations reported an increase in temperature (compared to 2009, a La Niña year) ranging from 0.5 to 1°C.
- The largest decline in salinity was observed at Langara Island, along the coast of British Columbia, beginning in the late 1970s and accelerating through the 1990s and 2000s. This change may be due to the expansion of the Aleutian Low during winter in the late 1970s. Since then, this low pressure system has generally remained larger, which could affect salinity at Langara Island by altering winter winds and wind-driven ocean currents in the Gulf of Alaska.

Impacts of Changing Ocean Climate

Ocean temperatures can affect the growth and survival of marine life and the availability of the preferred and tolerated thermal habitats for various species. Changes in climate may also affect stock productivity and the sustainable harvest rates. Fishing could also exacerbate the impacts of temperature changes by decreasing stock resilience or increasing the variability in abundance and, therefore, the risks of a stock collapse.

Gulf of St. Lawrence:

Changes in ocean temperature in the St. Lawrence Estuary and Gulf are expected to affect the habitat, distribution and recruitment of marine species as well as community composition.

Observed and projected warming trends for surface waters in the Gulf will likely reduce the available habitat for certain temperature-sensitive species that now inhabit areas of the coastal zone. For example, temperatures over 23.5°C are lethal to Giant Scallop (*Placopecten magellanicus*) as are sudden increases to temperatures of 20°C. In contrast, the habitat of warmer water species such as lobster, which is currently limited to coastal waters in the Gulf, is likely to increase in area with projected warming.

Long-term changes in surface water temperature have also affected the timing, duration and intensity of plankton production, which impacts the recruitment (the annual rate at which new individuals increase the population) of key fisheries resources. For example, the recruitment success of Northern Shrimp in the northern Gulf is closely positively linked to spring oceanographic conditions such as the warming rate of the sea surface and the duration and productivity of the phytoplankton spring bloom. Similarly, the recruitment of Atlantic Mackerel is positively linked to the production of specific copepod species in the southern Gulf and, ultimately, to regional oceanographic conditions.

From 1986 to 1998, when the cold intermediate layer was exceptionally cold, there was an increase in species of Arctic and more northern origin in the southern Gulf including Polar Sculpin (*Cottunculus microps*), Arctic Sculpin (*Myoxocephalus scorpioides*) and Arctic Cod (*Boreogadus saida*). Their sudden appearance as waters cooled in the 1990s — and disappearance as they warmed — is consistent with a distributional shift.

Bottom temperatures also affect the distribution, and potentially the abundance, of several other species. Long-term changes in the thickness and core temperature of the cold intermediate layer affect the bottom temperature on the Magdalen Shallows of the southern Gulf. In some years, bottom waters colder than 0°C were non-existent by September, while in other years they covered as many as 25,000 square kilometres of the bottom. Snow Crab prefer cool waters in winter (-1 to 3°C). The cooling and expansion of the cold intermediate layer during the late 1980s to early 1990s may have led to the extended distribution of Snow Crab stock and contributed to high abundances during and following that period. However, a conclusive link has yet to be made due to the complex relationship between Snow Crab distribution, productivity and temperature.

The complexity of the many variables at play makes it very difficult to project with certainty how global warming will alter marine species and communities in Gulf. We can anticipate that warming will likely reduce habitat for some species that now inhabit the southern Gulf (e.g., Snow Crab, Capelin) and that it will likely create new habitat for more southerly species. Some species may shift to deeper waters or move northward. Global warming is also expected to bring increased variability in climate, leading to variations in the recruitment, growth and mortality of species and, as a result, their abundance. Some of the most profound changes to the marine communities may result from indirect effects of warming, such as hard-to-predict changes to the food web structure.

Scotian Shelf:

There have been no significant ecological impacts on the Scotian Shelf due to climate change but impacts may increase slowly over time (e.g., decades) or as an ecosystem shift (e.g. increased subtropical influences) at some future time. In the short term, changes in the timing of the strong seasonal cycle may have more impact than a slow increase in temperature. While a comprehensive and precise assessment is not yet possible, there is enough knowledge to broadly assess potential climate change impacts. Climate change affects species' physiology, timing of seasonal events and distribution. Those changes will in turn affect interactions between species, which impacts the species composition of an ecosystem.

Lower levels of the marine food web such as phytoplankton are greatly influenced by climate variability. Changing oceanographic conditions affect both the abundance and composition of phytoplankton communities. In general, if surface layers continue to warm, we should expect smaller-sized phytoplankton. If much higher temperatures lead to smaller organisms, energy flow through the ecosystem would be re-directed or less efficient, and might not support the productivity of historical fisheries. If increased stratification persists, there could also be significant changes in the seasonal cycle of phytoplankton growth, in part due to a reduced supply of nutrients into the surface layer where phytoplankton grow.

There is no question that climate plays a critical role in fish dynamics on the Scotian Shelf, but so does fishing. Internationally, over the past few decades, researchers have tried to separate the effects of climate and fishing on ecosystems. Increasingly, there is acknowledgement that the effects of climate and exploitation cannot be separated. Heavy fishing causes a reduction in diversity from the individual to the ecosystem level and diversity is the main buffer against climate variability. Intense fishing can lead to a loss of older, larger organisms, loss of sub-populations and a change in life-history traits, all of which render them much more susceptible to climate variability and chance events.

Beaufort Sea:

An increase in fresh water into the Canada Basin since 2003 has increased stratification and reduced water column mixing and the movement of nutrients from deeper layers into the sun-lit surface layer.

This has led to an increase in the smallest algae (picoplankton) in the Canada Basin, both in total amount and as a percentage of the total phytoplankton, and a decrease in larger nanoplankton. These early responses provide an indication of the potential to alter other parts of the marine food web. Some small plankton responded differently in 2009, highlighting the need for a long time series of data to assess ecosystem responses.

As a result of the 2007-2008 upwelling event on the Mackenzie shelf in this LOMA, the production of ice algae, phytoplankton, zooplankton and bottom-dwelling organisms increased by two- to six-fold. There was an overall increase in biological productivity, providing an opportunity to thrive for consumers such as zooplankton, which can adapt to the rapid change in ecosystem structure.

Pacific North Coast:

Increasingly frequent shifts between warm El Niño conditions and cool La Niña winters influence ocean life. For example, the abundance of certain copepod groups is strongly linked to annual changes in water temperature and circulation. Boreal and sub-arctic copepods, which tend to be more nutritious than southern copepods, were most abundant in cool years such as the early 1980s, 1999-2002, and 2007-2009. This benefited the survival and growth of young salmon, Sablefish and planktivorous seabirds.

Addressing Ocean Climate

Ongoing monitoring is essential to determine the ecological responses and interaction to persistent and year-to-year changes in ocean climate, including the impacts on commercial species. This knowledge will aid in the development of sustainable and flexible fisheries management plans in the face of changing ocean climate conditions. Phytoplankton, which forms the foundation of the marine food web, should be intensively monitored as "sentinels of climate change." Changes in species composition are currently under investigation.

From a global perspective, the sensitivity of Canadian fisheries to climate change is considered moderate and our nations' capacity to adapt is high relative to less developed countries that are more dependent on fisheries for sustenance. With a changing climate, some harvesting opportunities may be lost while others might be gained by northward movements of species into the LOMAs. This is likely to raise questions concerning the allocation of fishing opportunities among communities.

Establishing and implementing sustainable exploitation rates may be difficult depending on the rates of productivity change in the future. Strategies with more conservative objectives may therefore be required to keep pace with changes in productivity and to build resilience within the exploited population. A key to this resilience is the re-establishment of a diverse age structure among species that were formally much longer lived than they are today and a rebuilding of abundance. Both have known stabilizing effects on population abundance, which on one hand contributes to enhanced interannual predictability of yield and, on the other hand, reduces the risk of collapse or extinction resulting from sporadic mortality events or recruitment failures.

Aquatic Invasive Species

Sometimes described as "biological pollution", Aquatic Invasive Species (AIS) are plants, animals, aquatic life and micro-organisms that can out-compete native species when introduced outside of their natural environment. These invaders generally share common characteristics that can make them difficult to control and contain, including higher rates of reproduction, fewer natural predators and the ability to thrive in different environments.

An oyster cage retrieved from a Gulf of St. Lawrence oyster operation in 2011 is loaded down with the sea vase tunicate (*Ciona intestinalis*). The gelatinous 'sea squirts' threaten indigenous species and cause problems for growers of commercial species.

The impacts of invasive species usually worsen over time as they reproduce and disperse, posing a major, longterm threat to the health of aquatic ecosystems including native biodiversity, species at risk and the sustainability of aquaculture and fishing industries. While some are not considered harmful and may even have some commercial value, the vast majority of aquatic invasive species present an economic and social problem.

There are hundreds of invasive species in Canada, some of which come from other parts of the country and others that originate elsewhere in the world. Some better known examples of aquatic invasives are Zebra Mussels, Sea Lamprey and tunicates.

Aquatic Invasive Species in Canada's Oceans

Pacific North Coast:

Many invasive species have been reported on Canada's Pacific coast. Early introductions include Soft Shell Clams (*Mya arenaria*), which arrived in California from the east coast of North America in the 1880s and have since spread along the coast of British Columbia, including Haida Gwaii. Populations of Manila Clams (*Venerupis philippinarum*) also expanded from south to north and have been abundant enough since the early 1990s to support a commercial fishery near Bella Bella. The non-indigenous Japanese Wireweed (*Sargassum muticum*) is also now found throughout British Columbia, including Haida Gwaii.

Other aquatic invasive species on the west coast and in the Pacific North Coast Integrated Management Area (PNCIMA) include:

- Pacific Oysters, which were imported from Japan for aquaculture beginning in the 1910s. They are now common in southern British Columbia but their distribution within this LOMA is limited to Desolation and Quatsino sounds, and Klaskish and Klaskino inlets. There is also recent evidence that this species is reproducing in Skidegate Inlet, Haida Gwaii.
- the European Green Crab (*Carcinus maenas*), which is native to Europe and northern Africa, arrived in British Columbia as larvae in 1998-1999 and has spread throughout the west coast of Vancouver Island, including Klaskino Inlet and Quastsino Sound in southern PNCIMA.
- at least two non-indigenous sponges (in the LOMA): the boring sponges *Cliona* sp. and *Scypha* spp. Other subtidal invaders include three bryozoans, ascidians, and the caprellid amphipod *Caprella mutica*.
- the non-indigenous marine fish: the American Shad (*Alosa sapidissima*).

Other invasive species that inhabit waters just south of PNCIMA have the potential to spread north and become established within the LOMA if environmental conditions become favourable for them.

Gulf of St. Lawrence:

At least 25 aquatic invasive species (AIS) have become established in the Gulf of St. Lawrence, of which nine have arrived since 1994.

The mussel aquaculture industry in the Gulf has been severely affected by several invasive tunicates and has also played a pivotal role in their spread. Management strategies have been developed to reduce the transport of AIS when seed stock is moved from one body of water to another and when harvested product is transported to processing plants.

Since 1998, four new tunicate species have become established in the waters of Prince Edward Island: Clubbed Tunicate (*Styela clava*), Vase Tunicate (*Ciona intestinalis*), Violet Tunicate (Botrylloides violaceus) and Golden Star Tunicate (*Botryllus schlosseri*). A more recent invader, the European Green Crab, can severely impact all mollusc species in its range and damage valuable habitat.

Scotian Shelf:

There are at least 22 introduced or invasive species on the Scotian Shelf. Monitoring programs have focused on tunicates (Violet, Golden Star and Vase Tunicates) and the European Green Crab.

The earliest record of the Vase Tunicate in Atlantic Canada dates from 1852, but the species was not recorded in the scientific literature on the Scotian Shelf until population outbreaks occurred along the southeastern coast of Nova Scotia in the late 1990s. The species can be found in sheltered locations along the Atlantic coast of Nova Scotia, but has not been observed in the Bras d'Or Lakes. The Violet Tunicate and the Golden Star Tunicate are fouling species that attach to natural and artificial surfaces such as boat hulls and motors. The Golden Star Tunicate has been present on the Scotian Shelf and Bay of Fundy since the early 1980s, while the Violet Tunicate is a more recent arrival, with the first Atlantic Canada observation in Lunenburg and Mahone Bay in 2001.

Genetic evidence suggests that there have been two independent introductions of the European Green Crab to the Scotian Shelf. The crabs were first observed on the east coast of North America in Massachusetts in 1817. They most likely arrived from the coasts of Europe and North Africa in the ballast of ships. They then spread up the coast of New England, reaching Passamaquoddy Bay, New Brunswick, in 1951. The first reported sighting on the Scotian Shelf was in Wedgeport, Nova Scotia, in 1954. Further dispersal up the Atlantic coast of Nova Scotia appeared to stall south of Halifax from the mid-1960s to the mid-1970s, prompting speculation that Green Crabs had reached their northern temperature limit in North America. However, by the late 1970s the crabs were reported at Whitehead, south of Chedabucto Bay, 600 kilometres north of the nearest known population. These crabs likely represented a second, genetically distinct, introduction of Green Crabs to North America. By 1997, the crabs could be found all along the Scotian Shelf at least as far north as Ingonish and had also spread into the Gulf of St. Lawrence.

In 2001, scientists determined that the populations of Green Crabs in northern Nova Scotia and the Gulf of St. Lawrence were of genotypes found nowhere else in North America. However, the populations south of Halifax and into the Bay of Fundy included genotypes from both northern Nova Scotia and the original U.S. form. The northern Nova Scotia genotypes match those found in the northern part of the Green Crab's native range in Scandinavia and the North Sea, and appear to be more tolerant of cold temperatures. The prevalence of northern genotypes in southwestern Nova Scotia has increased over time. Crabs of the northern genotype, which are significantly more aggressive and more effective foragers, may be outcompeting the U.S. genotype, at least in the northern portion of the North American range.

In addition to the species discussed above, the marine algae known locally as Oyster Thief (*Codium fragile*) has substantially changed coastal ecosystems in Atlantic Canada. It was first observed in coastal waters of the Scotian Shelf in 1989 at Mahone Bay. By 2007, it had become established along 445 kilometres of coast. Codium may replace native marine algae, such as kelp, and thus affect the sea urchin-kelp bed dynamics of the Atlantic coast ecosystem. The replacement of kelp beds by Codium has been facilitated by another invasive species, the Coffin Box Bryozoan (*Membranipora membranacea*).

For more information, see the State of the Scotian Shelf Report, Invasive Species theme paper: **http://coinatlantic.ca/index.php/state-of-coast-and-ocean/state-of-the-scotian-shelf/218**.

Placentia Bay-Grand Banks:

To date, four Aquatic Invasive Species have been confirmed in these waters: the Violet and Golden Star Tunicates, the Coffin Box Bryozoan and the European Green Crab.

Control of Green Crab is a conservation priority in this area. Although reports of this species in the Maritimes date back to the 1950s, it was first reported in North Harbour, Placentia Bay, Newfoundland in 2007. Its arrival in the region is mostly likely due to vessel traffic.

There are now extremely large concentrations of Green Crabs in northern Placentia Bay and they are spreading rapidly throughout the bay. Populations have also been established in St. George's Bay on the western side of the island. Accurate population estimates are vital for establishing the levels of response measures, for determining the thresholds at which impacts may occur, and for measuring the success of control efforts. See: ***Ecological Assessment of the Invasive European Green Crab (Carcinus maenas) in Newfoundland 2007-2009***.

More information on the invasive species in Newfoundland waters and the Placentia Bay-Grand Banks area is available at: **http://www.nfl.dfo-mpo.gc.ca/AIS-EA**E.

Impact of Aquatic Invasive Species

In general, there are three broad categories of impacts from introduced marine species: ecosystem, economic and human health impacts.

Ecosystem impacts include effects on individuals, genetics, population/community dynamics and ecosystem processes. These impacts can range from localized to larger-scale regional impacts and may occur separately or in combination for any species or group of species. In coastal ecosystems, invasive species have the potential to disrupt food web relationships, reducing the productivity of oysters, eelgrass and other keystone species that play a critical role in maintaining the structure of ecological communities. Since invasive species disturb the ecosystem, an infestation can make it easier for new intruders to become established.

In general, economic impacts of non-native species may include costs associated with management, damages incurred due to fouling of equipment and vessels, aesthetic and/or recreation impacts, and losses related to impacts on fisheries or aquaculture resources. For example, the most commonly reported impacts of tunicates in the Gulf of St. Lawrence are that they dramatically increase the weight on growing mussel socks, farm structures and equipment used in mussel aquaculture, and can result in smothering and killing farmed mussels. In Atlantic Canada, the Vase Tunicate has caused fouling problems on mussel farms and losses to the shellfish industry in Nova Scotia.

Aquatic invasive species also have the potential to affect human health. In some places, disease-causing micro-organisms including harmful phytoplankton have been found in vessels' ballast water, which could potentially be discharged into local waters. Toxins in these species can become concentrated in shellfish and negatively affect human health.

Green Crabs are aggressive, fast, prolific breeders that can easily out-compete native crabs and have no natural predators in their adopted waters. Virtually all nearshore, bottom-dwelling organisms may be affected by predation or competition from this invader. They can also damage eelgrass beds and other ecologically and biologically significant habitat as they dig for prey or shelter, potentially reducing habitat for shellfish stocks and nurseries for juvenile fish.

In areas of Placentia Bay-Grand Banks where Green Crabs are in high abundance, there has been a substantial impact on the natural environment and commercial and non-commercial species of molluscs and crustaceans. As in other regions, the predominant prey of these crabs in Newfoundland waters is shellfish. They have also been known to prey on juvenile and trapped adult American Lobster (*Homarus americanus*).

Threats to fisheries from the European Green Crab include, but are not limited to, predation on bivalves, competition with other decapods, and damage to eel fisheries. The levels of impacts on the Scotian Shelf appear to be increasing in recent years based on anecdotal accounts. This increase is likely to continue due to a recent genetic shift in the Green Crab population structure. If populations of the more aggressive northern genotype continue to increase in southern Nova Scotia, it is likely that the impacts of Green Crabs in this area will also increase.

The European green crab (*Carcinus maenas*), native to several European coastal areas, recently arrived in Newfoundland waters. It is adapting and expanding rapidly in its new environment. There is concern that green crab may damage eelgrass habitat: when digging for prey in the sediment or making burrows, green crab cut the roots of the eelgrass, which destroys this ecological habitat. Photo: DFO

The recent invasion of Green Crabs in the marine protected area of Basin Head, Prince Edward Island, is being investigated as a possible cause of the decline of a unique type of Irish Moss that is not found anywhere else in the world.

Intense trapping can be an effective method of reducing the abundance of Green Crabs to limit their impact on the environment. However, threshold levels of population densities, timelines for action relative to impact, and measures of success will need to be well-defined for specific environments.

Adapting to Aquatic Invasive Species

The Government of Canada has strategies in place to reduce the risk of invasive species to the environment, economy and society, and to promote environmental values such as biodiversity and sustainability. For more information, see: **http://www.invasivespecies.gc.ca/**

Cold Water Corals and Sponges

In Canada, cold-water corals (also known as deep-sea corals) and sponges are known to inhabit the Pacific, Atlantic and eastern Arctic oceans. These organisms are increasingly being recognized as important components of benthic or bottom marine ecosystems. They provide the complex habitat structure that is important to invertebrates, fish and other deep sea life. High-complexity sponge reefs are associated with a greater abundance and diversity of species.

Their slow growth rates, longevity and limited habitat make corals and sponges particularly vulnerable to the adverse impacts of activities such as fishing, oil and gas exploration and development, and submarine cable and pipeline installation (see CSAS Advisory Report 2010/041: **Occurrence, susceptibility to fishing, and ecological function of corals, sponges, and hydrothermal vents in Canadian waters**.)

Increasing ocean acidification due to climate change is also a threat.

Due to their ecological importance and vulnerability, corals and sponges are the focus of international conservation and protection efforts and are examples of Vulnerable Marine Ecosystems (VMEs). Countries have a responsibility to implement conservation measures as defined in international conventions and agreements such as the Convention on Biological Diversity and United Nations General Assembly Resolution to protect VMEs.

For general information on corals and sponges, see the **website for the Centre of Expertise for Cold-Water Corals and Sponge Reefs**. The Department also produced three videos about exploring for cold water corals: **Oasis of the Deep: Cold Water Corals of Canada** and **Revealing a Hidden Realm** are online. The third video, Diving into the Deep - Coral and Sponge Conservation in Canada, will be online soon.

Placentia Bay-Grand Banks:

Since the early 2000s, scientists have been studying coral and sponges in the Newfoundland and Labrador region including specimens collected as trawl bycatch during multispecies surveys and the **At-Sea Observer Program**, for which private sector observers are placed aboard fishing vessels to report on activities. Other research projects have explored the biochemistry, habitat and geography of corals, and the importance of deep-sea corals to the structure and function of ecosystems, including their distribution, the relationship between corals and fish species, and trophic (food web) relationships. Results of these studies are available in: **The Ecology of Deep-Sea Corals of Newfoundland and Labrador Waters: Biogeography, Life History, Biogeochemistry and Relation to Fishes**.

In 2009, the research program was expanded to include ecological and taxonomic studies of deep-water sponges, which are now recognized as components of VMEs along with corals.

In 2007 and 2010, two dedicated deep-water research cruises were carried out to explore and document the biology and geology of the ocean bottom of the Southwest Grand Banks slope and areas adjacent to the Placentia Bay – Grand Banks LOMA (Flemish Cap and Orphan Knoll). Using the remote underwater vehicle, ROPOS (Remotely Operated Platform for Ocean Science), scientists carried out studies of deep-water ecosystems that support corals, including the first study of a seamount in the region.

Researchers analyzed concentrations of coral and sponge taxa (groups) for the Newfoundland-Labrador Shelves Bioregion, which encompasses the Placentia Bay-Grand Banks area, using an approach developed by the Northwest Atlantic Fisheries Organization. The coral database for this bioregion contains 38 coral taxa, of which:

- 61% were soft corals belonging to family *Nephtheidae*;
- 18% were sea pens;
- 9% were large gorgonians (species of *Paragorgia, Primnoa, Keratoisis* and *others*);
- 7.4% were small gorgonians (species of *Acanella* and *Anthothela*);
- 0.01% were black corals (antipatharians); and
- 0.04% were small cup corals (solitary scleractinians).

The largest catches of small gorgonian corals were on the Newfoundland and Labrador Shelf with two “significant” locations on the slope of the Grand Banks. Significant concentrations of large gorgonian corals also exist within the LOMA along the continental margins.

Although relationships between deep-sea corals and groundfish have not been extensively studied in the Northwest Atlantic, research indicates:

- there are correlations between coral biomass and fish biodiversity and the diversity of both corals and fish species; and
- soft corals, sea pens and small gorgonians are important to fish and invertebrates in this region.

Scotian Shelf:

In 1998, Fisheries and Oceans Canada began collaborating with university, non-governmental organizations and industry partners to collect information on corals in the Scotian Shelf region. The Department initiated a full coral research program in 2000, which included four research surveys on the Scotian Shelf to document the distribution, abundance, preferred habitats and condition of corals and the associated species. For more information see the Department’s web page on **Coral Research in the Maritimes**.

To date, five major orders of coral are known to inhabit the Scotian Shelf, including: soft corals (*Alcyonacea*), black/thorny corals (*Antipatharia*), branching corals (*Gorgonacea*), sea pens (*Pennatulacea*), stony corals and cup corals (*Scleractinia*). The Scotian Shelf is also home to sponges, but the overall biomass is relatively low. Sponge grounds here are typically composed of one or two large, structure-forming species and many smaller but abundant species. Unique populations of the large, barrel-shaped glass sponge *Vazella pourtalesi* (also known as “Russian Hats”) have been found in the vicinity of Emerald Basin and Sambro Bank as well as parts of the Northeast Channel.

Deep-sea corals and sponges form complex structures on the Scotian Shelf that:

- provide shelter for many species;
- support a greater diversity of fish and invertebrates compared to most other benthic (bottom) habitats;
- provide habitats at key life stages of many marine species; and
- serve as a food source for other invertebrates.

Pacific North Coast:

More than 80 species of cold-water corals and some 250 species of sponges inhabit the coastal waters of British Columbia. The Pacific North Coast Integrated Management Area (PNCIMA) is home to many of these, including the rare hexactinellid (glass) sponge reefs. Some of the coral colonies may be more than a century old, while some sponge reef communities may have developed over thousands of years. For example, in Hecate Strait and Queen Charlotte Sound (within the LOMA), sponge reefs that are approximately 9,000 years old live in channels carved by icebergs long ago.

Found in both shallow coastal and deep offshore waters, these organisms provide many ecosystem functions that are not yet fully understood. Cold-water corals and sponges host distinctive communities of fish and other species while sponge reefs provide important nursery habitat for young rockfish.

For more information about corals and sponges in this area, see the CSAS report: **Distribution of cold-water coral, sponges and sponge reefs in British Columbia with options for identifying significant encounters**.

Impacts Related to Cold Water Coral and Sponges

Corals and sponges are vulnerable to anthropogenic disturbance due to their slow growth and sensitivity to physical and chemical changes. Adequate protection is necessary to prevent the loss of these ecologically important species and the valuable habitat they provide for other marine life.

On the Scotian Shelf, for example, evidence of fishing impacts on corals includes broken live corals, tilted corals, scattered skeletons, tracks made by fishing gear where corals occur, and lost longlines entangled in corals. Other types of fishing gear can also disturb and damage bottom habitat and cause entanglement and breakage of bottom features such as corals.

Increasing ocean acidification is a threat to organisms that produce calcite and aragonite shells or structures, including corals, pteropods and shellfish.

Addressing Cold Water Coral and Sponge Conservation

In 2008, Fisheries and Oceans Canada established the **Centre of Expertise in Cold-Water Corals and Sponge Reefs**, located at Fisheries and Oceans Canada's Northwest Atlantic Fisheries Centre in St. John's, Newfoundland and Labrador. The Centre helps coordinate the Government of Canada's approach to coral and sponge conservation by:

- providing strategic advice to senior management;
- supporting regional, national, and international conservation efforts; and
- developing tools to improve coral and sponge conservation in Canada.

In order to deliver this mandate, the Centre has built a strong network within Fisheries and Oceans Canada, Parks Canada and Natural Resources Canada. For more information, see: **Status Report on Coral and Sponge Conservation in Canada**.

The Department carried out a national science advisory process which was convened in March 2010 to review the available information and provide science advice, concerning the occurrence, sensitivity to fishing, and ecological function of corals, sponges and hydrothermal vents in Canadian waters. Another national science advisory meeting held in March 2011 provided advice for the development of a protocol regarding encountering corals and sponges in Canadian waters. This advice is available through a Science Advisory Report, which is available on the **CSAS website**.

Placentia Bay-Grand Banks:

Corals and sponges are one of the four conservation priorities in the Placentia Bay-Grand Banks area. Priority research areas for deep-sea corals have been identified based on areas of high biodiversity and abundance in the Region. Management measures for their protection are ongoing. Work is also underway to increase regional expertise in the identification of sponges and to learn more about their biology and ecology.

To date, several dedicated areas in the proximity of the Region, including some in the Placentia Bay-Grand Banks area, have been closed to fishing due to the presence of corals and sponges. Closures include:

- an interim prohibition on trawling at depths of 800 to 2000 metres within the NAFO Division 3O until 2014;
- a restriction on all bottom fishing activities from January 1, 2010 until December 2014 for the NAFO closed areas in the Tail of the Grand Banks (NAFO Div. 3N), Flemish Pass/Eastern Canyon (NAFO Div. 3LN) and the Sackville Spur (NAFO Div. 3LM). A small part of the latter area is within the boundary of the LOMA. The boundaries of these closed areas have been determined by NAFO, and can be seen in the NAFO Conservation and Enforcement Measures (www.nafo.int).

The Newfoundland and Labrador/Eastern Arctic coral conservation strategy is currently being drafted. This strategy involves both the Newfoundland and Labrador Region and Central and Arctic Region.

Scotian Shelf:

Conservation measures on the Scotian Shelf include the establishment of Marine Protected Areas and coral conservation areas to protect habitat, ecologically significant species and species at risk. For example, bottom fishing is restricted year-round in the Northeast Channel Coral Conservation Area and the Lophelia Coral Conservation Area.

The Department has also developed a **Maritimes Region Coral Conservation Plan**, which summarizes the conservation efforts to date, identifies issues that require more work, and prioritizes activities to address coral conservation in the future.

Pacific North Coast:

To protect these rare and sensitive components of Canada's west coast marine ecosystem, the Department developed the **Pacific Region Cold-Water Coral and Sponge Conservation Strategy**, which:

- describes the state of knowledge of Pacific cold-water corals and sponges;
- describes the biology of cold-water corals and sponges;
- identifies conservation, management and research objectives, associated strategies and actions, and information gaps;
- discusses socio-economic and conservation implications with respect to cold-water coral and sponge conservation measures; and
- identifies management tools to aid in cold-water coral and sponge conservation.

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Coldwater corals of Atlantic Canada. Photos: 1. Many different species of coral are captured in this 'garden' of coral' found in the deep waters along the continental slopes below the **Stone Fence Lophelia Conservation Area**; 2. Seacorn (*Primnoa resedaeformis*) growing on a cliff face in the **Sable Gully Marine Protected Area**. This species has been aged to 800 years and is very slow growing. 3. A solitary cup coral (*Javania cailleti*), off the coast of Nova Scotia 4. A spectacular soft coral "sea pen" so-called for its resemblance to old-fashioned quill pens, (order Pennatulacea) was found in the Sable Gully Marine Protected Area.

DFO cetacean expert John Ford spends hours observing whales but the sight of a breaching Humpback Whale is always a thrill. This Humpback was photographed off our Pacific coast. Humpbacks also roam Canada's Atlantic coast and the Gulf of St. Lawrence. Photo: John Ford, DFO.