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REPORT

The Royal Society of Canada Expert Panel

Sustaining Canada's Marine Biodiversity: Responding to the Challenges Posed by Climate Change, Fisheries, and Aquaculture

February 2012

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SUSTAINING CANADIAN MARINE BIODIVERSITY

An Expert Panel Report on
Sustaining Canada's Marine Biodiversity:
Responding to the Challenges Posed by
Climate Change, Fisheries, and Aquaculture

Prepared by:

The Royal Society of Canada:
The Academies of Arts, Humanities and Sciences of Canada

February 2012

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Chapter One: Executive Summary

> "Nothing is so boundless as the sea, nothing so patient. It is not true that the sea is faithless, for it has never promised anything; without claim, without obligation, free, pure, and genuine beats the mighty heart, the last sound one in an ailing world. Many understand it scarce at all, but never two understand it in the same manner, for the sea has a distinct word for each one that sets himself face to face with it." (Kielland. 1880. *Garman and Worse*)

1. The Case for Sustaining Biodiversity

Canada's oceans constitute a vital biological, geochemical, and physical milieu that supports human health, societal well-being, and creation of wealth. Canada has the benefit of, and responsibility for, three marine coastlines that contribute to our society in numerous ways. For thousands of years, the oceans have provided habitat for species of traditional and cultural significance to aboriginal people. Today, sustainably exploited fish populations and environmentally responsible aquaculture operations should provide secure local and national access to the protein and oils contained in seafood, and Canada's oceans provide space for numerous recreational and commercial activities. On three sides of Canada, the physical integrity of natural coastlines reduces erosion and buffers the land from oceanic storms. Globally, marine life provides more than half the oxygen humans breathe and serves as a potentially rich source for modern pharmaceuticals.

The Millennium Ecosystem Assessment (an international scientific effort modelled after the Intergovernmental Panel on Climate Change) has unequivocally acknowledged the importance of aquatic and terrestrial biodiversity and ecosystems to human well-being and sustainable human development (www.maweb.odddrg/documents/document.354.aspx.pdf; accessed 12 December 2011). Indeed, there are compelling reasons to believe that reductions in Canadian and global marine biodiversity impair the ocean's capacity to provide a plethora of ecosystem services that contribute to the resilience of marine ecosystems and to the well-being of humankind. From a strictly financial perspective, the case for sustaining marine biodiversity and protecting marine ecosystems is based on the argument that the importance of species can be determined by their marketable value (e.g., food, potential sources of medicine, recreational harvesting) and for their ability to provide non-market goods and services (e.g., carbon sequestration, erosion control). Although the monetary worth of Canadian marine ecosystems has yet to be quantified, their combined value may well be substantial, based on estimates for other ecosystems. For example, for the year 2002, the non-market ecological services provided by Canada's boreal forests have been valued at $703 billion (including $582 billion for the storage of carbon in forests and wetlands), more than ten times the net market value associated with the commercial extraction of wood (Pembina Institute 2009). Of course, many sectors of society would also argue that there are other good reasons for conserving biodiversity, including: the potential for species to provide new drugs, foods, or genes; the role of biodiversity in contributing to people's enjoyment of the oceans, including educational, recreational, and inspirational experiences; and moral and ethical reasons for doing so (Kunin and Lawton 1996). Although these benefits can be difficult to quantify, they influence the ways in which society wishes to treat the marine environment.

Canada faces significant challenges in its efforts to conserve and sustain marine biodiversity in light of climate change, fisheries, and aquaculture. Among these three factors, human-induced climate change represents the greatest challenge primarily because its effects on marine biodiversity will not be readily reversed. Some might argue for complacency on the basis that little can be done to mitigate the effects of climate change. Based on the information presented in this Report, our Expert Panel asserts otherwise.

The simplest and best strategy to deal with climate change is to protect existing diversity and to rebuild depleted populations and species to restore natural diversity. The challenge then is to sustain them at levels at which Canada's marine biodiversity is able to optimize the ecosystem services that the oceans provide in support of Canadian society and in support of the welfare of the global community. By improving and protecting the health of Canada's oceans, such a strategy will restore the natural resilience of Canada's ocean ecosystems to adapt in response to the challenges posed by climate change and other anthropogenic activities.

2. The Report

This Expert Panel Report represents the only collation of information on marine life, oceanography, climate change, fisheries, and aquaculture in the context of Canada's national and international obligations to sustain marine biodiversity. The purposes of the Report are:

- to serve as an educational tool to increase awareness of Canada's oceans;
- to describe trends in Canada's oceans and marine biodiversity;
- to evaluate past, present, and forecasted changes in three stressors that affect marine biodiversity: climate change, fisheries, and aquaculture;
- to describe and forecast how these three stressors have affected, and are likely to affect, Canadian marine biodiversity;
- to determine whether Canada has fulfilled its commitments to sustain marine biodiversity;
- to provide broad, strategically based recommendations, each accompanied by key actions, to establish Canada as an international leader in oceans stewardship and marine conservation.

The Report's primary audience can be described as interested members of the Canadian public, including Members of Parliament, decision-makers within the political and bureaucratic hierarchies of government, non-governmental organizations, the natural and social scientific community, and industry. The Report's thirteen chapters can be envisaged as comprising five separate sections:

- Overview (Chapters 1-3);
- Trends in Biodiversity Stressors (Chapters 4-6);
- Effects of Stressors on Biodiversity (Chapters 7-9);
- Canada's Biodiversity Obligations (Chapters 10-12);
- Conclusions and Recommendations (Chapter 13).

The first three chapters are introductory in one form or another. Following the Executive Summary, Chapter Two (Introduction) provides information on: the Panel's mandate (including clarification of issues addressed and not addressed by the Panel); marine biodiversity (what is it? why is it important to sustain?); greenhouse gas emissions; Panel procedures; and acknowledgements. Chapter Three provides descriptions of Canada's physical and biological oceanography, including a 'biological audit' of Canada's marine species diversity. The next two sections focus on trends in three stressors and their consequences for biodiversity: climate change (Ch. 4, 7); fisheries (Ch. 5, 8); and aquaculture (Ch. 6, 9). Canada's obligations at the international (Ch. 10) and national levels (Ch. 11) are detailed in advance of the Panel's evaluation of the extent to which Canada is fulfilling its commitments to sustain marine biodiversity (Ch. 12) and the Panel's conclusions and recommendations (Ch. 13).

3. Topics and Key Findings

Canada's Oceans. Canada's coastline and ocean surface area are greater than those of most countries. More than 16,000 marine species have been recorded in Canada, although there may be at least 2-3 times as many species still to be found. The Pacific is particularly rich in seaweed species; the Arctic, in small crustaceans; and the Atlantic, in fishes; Canada hosts 40% of the world's marine mammal species.

Indicators of Climate Change in Canada's Oceans. Surface water temperatures are increasing and high-latitude waters are becoming less salty. This warming and freshening of the oceans can reduce the transport of nutrients from deep waters to surface waters. A nearly ice-free Arctic summer could occur as early as the late 2030s. Increasing sea levels are forecast to lead to increased flooding, coastal erosion, and saltwater intrusion into wetlands and ground water. Canada's oceans are also becoming increasingly acidic, and oxygen levels have been declining; in some areas, oxygen levels are so low (hypoxia) that the waters are now unsuitable for most aquatic life.

Trends in Canadian Marine Biodiversity. Any increase in the number of marine species assessed as being at risk in Canada (currently 116) is likely to be attributed to forthcoming assessments of Pacific salmon populations and population groups. Species assemblages of plankton are sensitive to changes in water temperature which, in turn, affect the quantity and quality of food available to invertebrates and fishes. Marine fishes in Canada's oceans are estimated to have declined in abundance by an average of 52% from 1970 to the mid-1990s and have remained stable thereafter; most commercially fished stocks remain well below conservation target levels. Most, but not all, marine mammals have increased following past over-exploitation. Trends in seabirds have been mixed, showing increases in some areas and declines in others.

Trends in Canadian Marine Fisheries and Aquaculture. In 2009, Canada's fishery catches were half those of the late 1980s; the landed value of all fisheries in 2009 was almost the lowest since 1977. Atlantic fisheries, once predominantly for bottom-dwelling fishes, are now dominated by lobster, shrimp, and crab; Pacific catches have experienced marked declines in salmon. Marine aquaculture, dominated by the farming of Atlantic salmon, experienced rapid growth from the early 1980s until 2002; production has since stabilized. British Columbia is the fourth largest producer of farmed salmon in the world and farms 67% of Canada's finfish aquaculture. Shellfish production, having grown considerably since the 1980s (valued at $736 million in 2009), is dominated by Atlantic Canada's culture of blue mussels.

Climate Change: Consequences for Canadian Marine Biodiversity. Climate change affects the physiology, development, reproduction, behaviour, food supply, and survival of marine species by influencing factors such as water temperature, salinity, oxygen, and acidity. Species are projected to shift their latitudinal and depth ranges, changing the community composition of native marine species and allowing for invasions of non-native species. Climate change is acting to decouple the timing of resource requirements and resource availability for some species, impairing their reproduction and development. The effects of ocean acidification on marine biodiversity, although not yet well understood, are likely to be far-reaching and complex.

Fisheries: Consequences for Canadian Marine Biodiversity. Fishing affects biodiversity primarily by reducing abundance, sometimes significantly, as a result of directed catches, bycatch, and the destruction of species or their habitat (e.g., corals and sponges). Over-fishing has depleted many fish stocks, potentially increasing their chance of extinction. By affecting abundance, fishing alters interactions among species, such as those between predator and prey, resulting in dramatic changes to marine ecosystems and food webs. Fishing mortality of marine fishes has declined since its peak in the late 1980s and early 1990s, although reductions in fishing pressure are not always sufficient to enable recovery.

Aquaculture: Consequences for Canadian Marine Biodiversity. Bottom-dwelling organisms and their habitat can be affected by organic wastes and chemical inputs, such as antibiotics, anti-foulants, and pesticides, in open-sea net pen facilities. Exchange of pathogens between farmed and wild species can seriously threaten wild species. Interbreeding between wild fish and escapees of the same species threatens the reproductive capability and recovery potential of wild populations of conservation concern. The primary biodiversity concern associated with shellfish aquaculture is the farming of non-native species.

Canada's Commitments to Sustain Marine Biodiversity. Canada has made numerous commitments to sustain marine biodiversity. Some key international targets agreed upon by Canada include commitments to: (i) implement an ecosystem-based management approach by 2010; (ii) restore depleted fish stocks to target levels that can produce maximum sustainable yield by 2015; (iii) minimize human pressures on vulnerable marine ecosystems affected by climate change to maintain their integrity and functions by 2015; and (iv) protect and conserve 10% of coastal and marine areas by establishing ecologically representative and well-connected systems of marine protected areas (MPAs) by 2020. Canada has embraced a long list of national commitments supportive of sustaining marine biodiversity through both legislation and numerous policy-related documents. Among other initiatives, Canada has committed to: promoting ecosystem and precautionary approaches; establishing a national network of MPAs; protecting and recovering marine species at risk; and implementing integrated ocean management plans.

Is Canada Fulfilling its Commitments to Sustain Marine Biodiversity? Canada has made little substantive progress in fulfilling national and international commitments to sustain marine biodiversity. Progress in meeting biodiversity obligations is impeded by regulatory conflict within Fisheries and Oceans Canada and by the absolute discretion afforded to the Minister of Fisheries and Oceans. Despite enabling legislation, the aspirational quality of integrated management planning initiatives has not been realized in practice, e.g., the promised national MPA network remains unfilled. Despite enabling policy, application of the precautionary approach, target and limit reference points, harvest control rules, and rebuilding/recovery plans are absent for most fisheries. The *Fisheries Act* is an insufficient statutory tool to enable Canada to fulfill many obligations to sustain marine biodiversity and requires extensive revision or replacement. The *Species at Risk Act* has yet to provide an effective legislative mechanism for the protection, conservation, and recovery of marine species at risk.

4. Recommendations

- That the Government of Canada identify international leadership in oceans stewardship and biodiversity conservation as a top government priority.
- That the Government of Canada resolve regulatory conflicts of interest affecting Canada's progress in fulfilling obligations to sustain marine biodiversity.
- That the Government of Canada reduce the discretionary power in fisheries management decisions exercised by the Minister of Fisheries and Oceans.
- That Fisheries and Oceans Canada (DFO) rapidly increase its rate of statutory and policy implementation.
- That Canada implement statutory renewal to fulfil national and international commitments to sustain marine biodiversity.
- That the Government of Canada establish national operational objectives, indicators, and targets for marine biodiversity.
- That Canada establish strategic research initiatives to strengthen scientific advice on sustaining marine biodiversity.

CHAPTER TWO: INTRODUCTION

1. The Expert Panel

The Report is submitted in response to a request by the Royal Society of Canada (RSC) that an independent Expert Panel be convened to advise on a series of questions related to the sustainability of Canada's marine biodiversity. The questions were specified in a provisional Terms of Reference communicated by the Royal Society of Canada Committee on Expert Panels (CEP) to the Society's President in 2009. Following consultations with the CEP, the President then selected a group of ten people from Canada, the United Kingdom, and the United States who represented a wide range of scientific and policy-related expertise relevant to the questions submitted. The Panel and its membership were announced by the Royal Society in November 2009. The provisional Terms of Reference were reviewed and interpreted at a meeting of the Expert Panel in June 2010.

2. Mandate and Terms of Reference for the Panel

a. Mandate

The mandate of the Expert Panel on Sustaining Canada's Marine Biodiversity: Responding to the Challenges Posed by Climate Change, Fisheries, and Aquaculture is to prepare expert assessments of: (i) the past and projected trends in Canada's ocean environments and marine biodiversity; (ii) the causes and projected consequences of these trends for biodiversity; and (iii) the extent to which Canada is fulfilling its national and international obligations to sustain marine biodiversity. Drawing upon the conclusions resulting from these assessments, the Panel is to identify new approaches, measures, and research initiatives to promote the sustainability of Canadian marine biodiversity. By combining these assessments and recommendations in a single document, the Panel Report represents a unique contribution to the state of knowledge of Canadian marine biodiversity and of Canada's commitments to sustain that biodiversity.

b. Terms of Reference

Canada's long coastline and vast oceans give it a stewardship responsibility to be an international leader in addressing anthropogenic stressors that threaten ocean health and marine biodiversity. Climate change, fishing, and aquaculture influence marine biodiversity (albeit at different spatial scales) and pose challenges for managers and society. The Arctic Ocean is being affected by reductions in the quality and quantity of sea ice caused by global warming and concomitant changes in ocean productivity, ecology, and human activity. The Atlantic Ocean has been especially impacted by overfishing and associated changes in marine food webs. Climate change, fishing, and aquaculture are also affecting biodiversity on Canada's Pacific coast.

Physical and biological changes in these oceans, along with direct human impacts, can modify marine biodiversity with implications for food security and the social and economic well-being of coastal communities. To assess the consequences of changes in biodiversity for Canada's oceans and society, it is necessary to understand the current state of marine biodiversity and how it might be affected by projected changes in climate and human uses. Canada already has a range of national and international obligations that addresses aspects of marine biodiversity, but a key question is: Have Canada's actions been sufficient to sustain healthy, safe, and prosperous oceans for the benefit of current and future generations of Canadians?

3. Questions for the Panel:

1. What are the past and current trends and associated uncertainties in (a) physical and chemical indicators of climate change in Canada's three oceans and (b) Canadian marine biodiversity?
2. What are the projected consequences to Canadian marine biodiversity (and associated uncertainties) of climate change, fisheries, and aquaculture?
3. What are Canada's national and international obligations to sustain marine biodiversity, and to what extent are these obligations being fulfilled?
4. What new approaches and measures are required to promote the sustainability of Canadian marine biodiversity?
5. What research initiatives are required to support scientific advice to sustain Canadian marine biodiversity?

4. What is Biodiversity?

The 1992 United Nations Conference on Environment and Development, Rio de Janeiro, dubbed the 'Earth Summit', led to the Convention on Biological Diversity (CBD) and significantly increased national and international awareness of the conservation and sustainable use of biodiversity. The Convention defines biodiversity as "the variability among living organisms from all sources including, *inter alia*, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, among species and of ecosystems" but it has been interpreted more broadly by society, policy makers, and scientists as the variety, quantity, and distribution of life (IEEP 2004). This is because quantity and distribution, like variety, influence the function of ecosystems and the services they provide. Ecosystem services are the benefits that people derive from ecosystems, ranging from climate regulation to food production and recreation (e.g., Fisher et al. 2009).

The variety, quantity, and spatial distribution of living things describe variation among biological populations, species, or communities. Variety can be measured with metrics such as species richness (the number of species present in a defined area). The quantity of life (i.e., the abundance of plants and animals) determines organismal functions in ecosystems, the services they provide, and their chance of extinction. The distribution of life describes where populations, species, or communities are found in the ocean. This depends on environmental factors, such as climate, depth, and productivity, but also on abundance, since more abundant species typically have wider geographical ranges (e.g., Fisher and Frank 2004). The greater the variety, quantity, and distribution of life, the greater the biodiversity.

Biodiversity can be expressed at multiple levels. Unseen to the naked eye, there is variability within and among the genes of living organisms. Even though individuals of the same species – even within the same population – can look similar to one another, that similarity in 'phenotype' (i.e., the visible characteristics of an organism) can mask variability at the genetic level. Genetic variability, thus, comprises one level of biodiversity. At another level, variability in phenotype (such as body colour, shape, behaviour, morphology, life history) can be considerable when one compares individuals from different populations. Population variability, then, comprises a second level of biodiversity. And there is, of course, tremendous variability at higher levels of biological organization, as reflected by the classification of organisms into various hierarchically arranged categories of taxonomy, such as species, genera, families, orders, and phyla.

Among the biodiversity indicators identified by the CBD are those that examine "trends in the abundance and distribution of selected species" and "trends in genetic diversity…of fish species of major socio-economic importance". However, at its core, the persistence of any species depends on the resistance and resilience of its component populations to anthropogenic and natural environmental perturbations (e.g., Schindler et al. 2010). This is the primary reason why the Panel focused on population trends in the Report (although species-level trends are presented where data exist). Secondary reasons include a lack of data on temporal trends in genetic diversity and the fact that an examination of trends in species numbers in Canada's oceans would not be particularly informative because few species have become extinct in our waters in recent millennia. Furthermore, there is ample precedent for using population trend data to describe temporal changes in marine biodiversity. For example, the population-level approach underpins the only marine index formally under consideration by the CBD – the Marine Living Planet Index (WWF 2010). Multi-species population indices have also been recently used to describe global trends in the biodiversity of marine fishes (e.g., Worm et al. 2009; Hutchings et al. 2010).

5. Why is Biodiversity Important to Sustain?

International efforts to protect biodiversity are embodied by the objectives of the CBD to: (i) conserve biological diversity; (ii) use biological diversity in a sustainable fashion; and (iii) share the benefits of biological diversity fairly and equitably (www.cbd.int; accessed 14-11-11 [day-month-year and hereafter]). Reasons for the conservation and sustainable use of biodiversity range from its role in providing valuable or essential ecosystem services to a view that humans have moral and ethical responsibilities to 'care' for life on earth (e.g., Kunin and Lawton 1996). Policy often focuses on service-related justifications, but sections of society are strongly influenced by moral and ethical concerns. Thus, where one person may see sustainability of resource extraction, another sees devastation of a fragile marine environment.

Diversity is directly related to persistence. The more variable things are, the more likely they will persist over time. Stock market portfolios typically reflect breadth to reduce the overall risk to one's investment capital. Farmers typically grow a variety of crops to reduce the chance of failure of any one particular crop. From a biological perspective, high genetic diversity increases the likelihood of having or producing genes that will allow adaptation to environmental change, including alterations to habitat or biological community brought about by natural variation and human actions. As well, the greater the genetic and phenotypic differentiation among populations, the greater the likelihood that some populations will be better able to respond favourably to environmental change than others.

The question often arises as to why biodiversity is important to sustain and conserve. Surely, one might ask, "Won't the biological functions of the oceans and their ability to provide renewable food resources be unaffected by the extinction of any one species or by the loss of any particular population of a species?" One response to this question is to draw an analogy between biodiversity and, say, the number of rivets that hold an airplane together. The loss of one, two or possibly ten rivets might not cause an airplane to fall apart. But if rivets continue to be lost, there will come a point when the plane will not be able to function and catastrophic failure will ensue. The same is likely to be true for the functioning of marine ecosystems. The loss of one, two or ten species/populations might not be unduly problematic, but at some (unknown) cumulative biodiversity loss, catastrophic ecosystem change will ensue. Of course, one flaw with this analogy is the premise that all airplane rivets, and all biological species and populations, are equal in terms of their importance to the structural integrity of the plane or to the functioning of ecosystems. Our lack of knowledge of the functional importance of different species and populations, and of what their loss would mean to the functional integrity of marine ecosystems, has led to the adoption of a precautionary approach to the assessment, conservation, and protection of Canadian biodiversity as articulated, for example, by the *Species at Risk Act*.

6. Canada's Stewardship Responsibilities to Marine Biodiversity

A compelling argument can be made that Canada is an ocean nation. The country's motto, *A Mari Usque Ad Mare*, means 'From Sea to Sea'. The borders of eight provinces and three territories, comprising 86% of the Canadian population, are adjacent to salt water. At more than 200,000 km, it has been estimated that Canada has the longest coastline in the world and that its oceans encompass an area (approximately seven million km^2; www.dfo-mpo.gc.ca; accessed 14-11-11) roughly equivalent to 70% of Canada's landmass and more than twice the size of India, the seventh largest country in the world. From a purely geographical perspective, the ocean stewardship responsibilities borne by Canada are arguably greater than those of any other country. Furthermore, given that most of Canada's coastline is located in Nunavut, the argument can be made that ocean issues in Canada are *de facto* Arctic issues, a region with which Canadians strongly identify.

The degree to which the health of Canada's oceans is a current priority for the federal government is unclear. The *Speech From the Throne* (3 June 2011) that opened Canada's 41st Parliament (http://www.speech.gc.ca/local_grfx/docs/sft-ddt-2011_e.pdf; accessed 4-6-11) made no reference to climate change, species recovery, fisheries rebuilding, or marine biodiversity. Neither the word 'ocean' nor 'Arctic' was mentioned in the throne speech. The 'sea' is mentioned in the context of a government commitment to complete the Dempster Highway to connect Canada "by road from sea to sea to sea". And 'fishing' is mentioned in the context of a government pledge to support it and other industries "as they innovate and grow". Asserting that the government has "expanded protected...marine areas to an unprecedented extent", the throne speech states that "the Government will engage a broad range of stakeholders on the development of a National Conservation Plan", although details of this Plan, and the degree to which it will pertain to life in the oceans, are not indicated. For comparison, the preceding throne speech (2008; http://www.discours.gc.ca/eng/media.asp?id=1364; accessed 9-6-11) did make reference to "tackling climate change and preserving Canada's environment", although oceans were not mentioned.

The near-absence of oceans issues in the throne speech could be interpreted as reflecting a lack of interest by the Government of Canada. It might also, however, be interpreted as reflecting a lack of interest on the part of Canadians. Perhaps the oceans are simply too distant – physically and experientially – for most people to feel strongly, one way or another, about the health of the marine environment.

However, rather than reflecting a real disinterest, any perceived disengagement of Canadians from the oceans might instead be attributable to the ways in which the oceans, and their relationship to Canadians, are communicated to society. It is not unusual, for example, for the oceans to be described primarily as a venue for human recreation, such as a 'playground' for tourists (e.g., www.explorenovascotia.com; accessed 4-6-11) or an 'adventure centre' for sport-fishing enthusiasts (www.oceanadventurecenter.com; accessed 4-6-11), rather than the primary global source of protein from wild animals. Fish and other commercially exploited marine organisms tend to be portrayed as commodities, rather than as integral biological components of ecosystems that comprise more than 70% of the planet's surface. Potentially confounding matters further, Fisheries and Oceans Canada (formerly Department of Fisheries and Oceans, and still widely known as DFO, which is the acronym that will be used in this report), the federal government department with primary jurisdictional responsibility for Canada's oceans, tends to identify its 'clients', 'partners', and 'stakeholders' as members of the fishing industry (e.g., DFO 2008), rather than the Canadian public.

Yet, the oceans belong to no government and to no industry. While all States enjoy various freedoms of the high seas, those freedoms are subject to numerous marine conservation responsibilities. Canada's oceans belong to the people of Canada, as the Supreme Court of Canada has affirmed (Supreme Court 1997). In some countries, affirmation of societal ownership of the oceans is enshrined in legislation. Norway's *Marine Resources Act* (2008), for example, establishes the principle that the rights to wild marine resources belong to Norwegians, and it sets out clearly the state's responsibility to manage marine resources for the common good, acknowledging that "wild living marine resources belong to Norwegian society as a whole" (section 2; *Marine Resources Act*). By contrast, the preamble to Canada's *Oceans Act* is more circumspect, acknowledging that the oceans "are the common heritage of all Canadians" and that "the oceans and their resources offer significant economic opportunities for economic diversification and the generation of wealth for the benefit of all Canadians, and in particular for coastal communities".

Given this recognition of public interests, stewardship of Canada's oceans is a national responsibility of all Canadians. From a governmental perspective, the DFO's clients, stakeholders, and partners comprise all of the people of Canada, not simply those who obtain direct financial benefits from the extraction of marine resources. This stewardship carries with it the burden and responsibility of international leadership in the protection, conservation, and sustainable exploitation of marine biodiversity.

It is intended that this Expert Panel Report will assist decision-makers and Canadian society in their joint assessment of the degree to which Canada has embraced its national and international ocean stewardship responsibilities to protect, conserve, and sustainably exploit marine biodiversity. Furthermore, we hope that this Report's recommendations will serve to strengthen efforts to meet those responsibilities and allow Canada to be *the* world leader in ocean stewardship.

7. Scientific and Extra-Scientific Issues

a. Drivers of Change in Marine Biodiversity

Climate change, fisheries, and aquaculture are among the anthropogenic activities known or hypothesized to negatively affect organisms in Canada's oceans. Thus, these drivers of biodiversity change merit attention. An additional consideration is that the biodiversity impacts of these drivers are manifest at a range of spatial scales. The effects of climate change on biodiversity have been, and are forecast to be, significant in all three of Canada's oceans. The predominant factor affecting recent past and present trends in the abundance of most marine species has been fishing; this driver of change has been (to date) of greater importance in the Atlantic and Pacific, rather than the Canadian Arctic. The biodiversity impacts of aquaculture, because of potential transfer of disease from farmed to wild species, might be manifest across broader spatial scales than the relatively small areal extent of farms in Canada's marine environment. Although other variables are likely to affect marine biodiversity, their spatial scales of influence are either small relative to those associated with climate change and fisheries (e.g., coastal pollution and shipping, although the latter is likely to be of increasing importance in the Arctic with the loss of sea ice) or little studied in Canadian waters (e.g., invasive marine species). A previous RSC Expert Panel report addressed issues related to oil and gas exploration activities in coastal British Columbia (RSC 2004).

b. Clarification of Issues Addressed and Not Addressed by the Panel

The breadth of the Panel's Terms of Reference necessitated the imposition of limits on what the Panel could address in this Report. The Panel acknowledges, for example, that societal discussions, evaluations, and debates concerning the potential effects of climate change, fisheries, and aquaculture on biodiversity are not entirely scientific. Here, the Panel echoes observations made by another RSC Expert Panel, one that examined the potential risks to human health, animal health, and the environment associated with the development, production, and use of foods derived from biotechnology (RSC 2001).

Specifically, the Panel accepts that debates pertaining to conservation, climate change, fisheries, and aquaculture often fall into the following three kinds of discord. The first are *scientific* disagreements about what constitutes sustainability from a biodiversity or exploitation perspective. Among other issues, these debates can centre on questions related to: target levels of population abundance and harvesting pressure; merits of alternative forecasting methods; and scientific uncertainty. The second form of disagreement can be described as *political* disagreements about the social and economic impacts of biodiversity loss, climate change, fisheries, and aquaculture. (Here, the term 'political' refers to opinions relating to, affecting, or acting in accordance with the interests of status or authority within an organization rather than matters of principle.) Finally, there can also be *religious, ethical and philosophical* disagreements about topics encompassed by the Panel's Terms of Reference, such as the question of whether *any* level of biodiversity loss or anthropogenic modification of the marine environment is acceptable.

Despite the existence and merits of these alternative forms of disagreement, debate, and discussion, this Report will focus primarily on the scientific elements of the questions posed in the Terms of Reference. More so, it will do so from a natural-sciences perspective rather than from a social-sciences perspective. One justification for doing so lies in the Panel's conclusion that the social and economic impacts of biodiversity loss, climate change, fisheries, and aquaculture are sufficiently broad and multi-faceted to warrant a separate comprehensive assessment. A second reason for restricting the Panel's efforts in this way lies in the contention that social, economic, political, and ethical discussions of the matters at hand are best preceded, and informed by, empirical documentation and scientific assessment of the potential biological consequences of climate change, fisheries, and aquaculture on Canada's ability to sustain marine biodiversity.

As additional points of clarification, the substantive chapters of this Report do not explicitly address issues that were outside of either the Panel's mandate or its Terms of Reference. Excluded topics include: Canada's role in international climate change negotiations and greenhouse-gas emission targets; government policies and legislation pertaining to the mitigation of greenhouse-gas emissions; potential biodiversity impacts of oil and gas development, pollution, coastal development, and shipping; aboriginal governance; or the adequacy or appropriateness of particular fisheries and aquaculture management tools, such as individual transferable quotas, effort- vs catch-based controls on fishing effort, and fishery-license buy-outs.

From a terminological perspective, the Panel uses the term 'fisheries' to refer to all past and present forms of extraction of marine organisms, such as fishes, mammals, invertebrates, and plants, and including those species that are caught incidentally by fishing gear, i.e., by-catch. When considering fishes, the Panel considers both 'marine' and 'diadromous' fishes. The former spend their entire lives within the ocean (e.g., Atlantic cod, *Gadus morhua*), whereas the latter typically spend part of their lives in freshwater rivers or lakes and part of their lives at sea (e.g., Atlantic salmon, *Salmo salar*; white sturgeon, *Acipenser transmontanus*; striped bass, *Morone saxatilis*; eulachon, *Thaleichthys pacificus*). (In accordance with the practice of most biological publications, the Latin binomial associated with the common name of a species is identified only when the common name is initially mentioned. That is the practice adopted in the Panel's Report.)

c. Recovery of Marine Biodiversity: Societal Influences

The degree to which the marine biodiversity losses documented in the Report are reversible will depend a very great deal on the wishes of society. Some reduction in fish abundance, for example, is unavoidable if society wishes to harvest fish for food. There are, and always will be, trade-offs associated with human use of the oceans and human protection of the oceans. But it is not the purview of a scientific panel to judge the relative importance of the societal benefits and costs associated with various marine-related activities.

Science can, however, provide advice on the degree to which biodiversity losses are reversible, if society asserts that such recovery is desirable. Many of the biodiversity consequences of aquaculture, for example, are likely to be readily reversible. The farming of fish in closed-containment facilities in water or on land would considerably reduce the environmental footprint of aquaculture. Affected marine ecosystems would likely recover within years, rather than decades, of such changes to fish-farming practices. The reversibility of some aquaculture-related biodiversity concerns, however, such as disease transfer and interbreeding with members of the same species, might be more problematic (Chapter Nine). As for fisheries, many over-exploited populations and species are likely to increase in abundance if fishing pressure is reduced. However, the magnitude of recovery likely depends on multiple factors (e.g., fishing-induced changes to species life histories and marine ecosystems). And, even if fisheries are closed, the recovery of depleted fish populations – which is not guaranteed -- is likely to require decades (Chapter Eight).

Climate change, on the other hand, is likely to be associated with a far greater degree of 'permanence' in its effects on biodiversity and lower probabilities of biodiversity recovery than either fisheries or aquaculture. Unlike fisheries and aquaculture, both of which are regulated by Canadian jurisdictions, the magnitude and rate of climate change are outside of Canada's direct control, insofar as Canada is responsible for a relatively small proportion of the global greenhouse gas emissions. But this lack of direct control over the magnitude of global emissions does not absolve Canada of its responsibilities to protect marine (and terrestrial) ecosystems from the effects of climate change. In this regard, a brief description of Canadian and global emission targets is appropriate, given the contributions of these emissions to climate change.

Canada, the United States (US), and 190 other countries are parties to the United Nations Framework Convention on Climate Change (UNFCCC; 1992), whose objective is the:

> "… stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

While the UNFCCC does not define what 'dangerous' means, it does provide some guidance insofar as the treaty states that steps should be taken to ensure that: (i) ecosystems can adapt naturally; (ii) food production is not threatened; and (iii) economic development can proceed in a sustainable manner.

The Kyoto Protocol to the UNFCCC, signed by both Canada and the US, was adopted in 1997. Annex B (developed) countries agreed to reduce greenhouse gas emissions to 5% below 1990 levels on average by 2008-2012. Canadian and American targets were 6% and 7%, respectively, below 1990 levels. Canada ratified the Protocol on 17 December 2002; it was never ratified by the US. By 2008, Canada's emissions were 24% above 1990 levels; US emissions had increased by 14%. By comparison, emissions in the United Kingdom had decreased by 18% and in Germany by 22%. The Canadian Government eventually announced that it would not try to meet its Kyoto target. Instead, in 2007, a 'Made-in-Canada' solution was proposed: Canada would reduce its emissions to 3% below 1990 levels by 2020. Canada officially withdrew from the

Kyoto Protocol on 12 December 2011.

At the December 2009 15th Conference of Parties (COP) to the UNFCCC, the non-binding Copenhagen Accord was put together as a potential follow-up to the Kyoto Protocol. A total of 114 countries have 'taken note' of the Copenhagen Accord which states that: "deep cuts in global emissions are required … with a view to reduce global emissions so as to hold the increase in global temperature below two degrees Celsius."

In essence, the Copenhagen Accord revealed a broad international consensus, defining the use of *dangerous* under the UNFCCC: Global warming should be kept to less than a 2.0°C increase from pre-industrial times (this constitutes a further warming of 1.3°C when compared to present-day temperature).

Shortly thereafter, Canada changed its position again, announcing that it was going to match the US number proposed by President Obama as part of the Copenhagen Accord. Obama promised that, by 2020, the US would reduce emissions by 17% relative to 2005 levels. This is equivalent to saying that, by 2020, US emissions would decline 3.6% relative to the 1990 level. In Canada's case, emissions would actually rise 2.5% from 1990 levels by 2020.

In the last few years, there have been significant advances in our understanding of the carbon cycle. It is now widely recognized that the lifetime of anthropogenic atmospheric CO_2 is very long (Eby et al. 2009; Solomon et al. 2009). Montenegro et al. (2007), for example, showed that if existing fossil fuel reserves were burnt, about 75% of the resulting CO_2 would remain in the atmosphere for 1800 years; 25% would remain for more than 5000 years.

An unfortunate corollary of this increased understanding is the recognition that stabilization of atmospheric CO_2 at any level requires anthropogenic CO_2 emissions to eventually decline to zero. However, the actual level of stabilization is independent of the emissions pathway. Rather, stabilization is determined by the cumulative emissions of anthropogenic CO_2 (Allen et al. 2009; Matthews et al. 2009; Meinshausen et al. 2009; Zickfeld et al. 2009). From a policy perspective, these realities have certain advantages. If a future level of atmospheric CO_2 stabilization or, equivalently, a future maximum allowable temperature increase is targeted, allowable future cumulative emissions can then be calculated.

Two recent analyses have estimated allowable cumulative emissions for limiting global warming to less than 2°C from pre-industrial values. In the first analysis (Zickfeld et al. 2009), it was assumed that any increase in human-produced, non-carbon dioxide greenhouse gases would be balanced by an increase in sulfate aerosols (or some other negative radiative forcing). While fairly accurate at present, this assumption should be viewed as extremely conservative, given that most future emission scenarios incorporate decreasing sulfate emissions and increasing emissions of non-carbon dioxide greenhouse gases. Zickfeld et al.'s (2009) best estimate of allowable cumulative emissions post 2000 (with a 66% probability of keeping warming below 2°C) was 590 gigatonnes of carbon (GtC). In the second study (Meinshausen et al. 2009), a reduction in the allowable emissions budget was computed, using various scenarios for aerosols and non-CO_2 greenhouse gases (Nakicenovic et al. 2000). The researchers found that limiting CO_2 emissions to 390 GtC from 2000 to 2050 led to a 50% chance of exceeding 2°C by 2100.

Considering that about 92 GtC have been emitted since 2000, and that about 10 GtC (and rising) are emitted annually, it is unlikely that temperatures will be kept below 2°C without rather dramatic emissions reductions in the near future.

The disconnect between scientific estimates of allowable emissions and the voluntary targets communicated by nations to the secretariat of the UNFCCC is rather profound. Recent analysis (Rogelj et al. 2010) has shown that even if countries meet their commitments under the Copenhagen Accord, the 2° warming threshold will almost certainly be crossed. This work further reveals a 50-50 chance that pre-industrial temperatures will be exceeded by 3°C during the 21st century. If emissions are not curtailed, the temperatures will increase by more than 4°C relative to pre-industrial levels.

Clearly, management actions to reduce the rate of climate change, and to control unsustainable but direct pressures on the marine environment, will affect the state of biodiversity on different time scales. Whereas actions to reduce CO_2 emissions and stabilize global climate will ultimately help to reduce rates of biodiversity change, these actions are not essential to meeting many existing objectives for the conservation and sustainable use of marine biodiversity. Importantly, by achieving existing objectives for biodiversity conservation and protection, Canada and other countries might help to mitigate further and unwanted ecological effects of climate change, thereby gaining additional time to reach the international agreement targets required to reduce global CO_2 emissions.

8. Panel Procedures

On 26 November 2009, the RSC issued a press release announcing the establishment of the Expert Panel, the appointment of the Panel members, and an outline of the provisional Terms of Reference. The Panel convened its first meeting in Ottawa on 9 and 10 June 2010. At this meeting, the Panel identified the major scientific and other issues that the Report would need to address in order to answer the questions put to it in the provisional Terms of Reference. A final Terms of Reference was drafted by the Panel and a draft structure for the Report was adopted. Research assignments were parsed out to the members of the Panel for reporting at subsequent meetings.

The Panel decided at its initial meeting to invite written submissions from any interested parties on issues relevant to its Terms of Reference. In September 2010, the Panel sent English and French texts of an Invitation to Submit Evidence (Appendix A) to various government departments, scientific societies, environmental non-governmental organizations, aboriginal groups, past and present government and academic scientists, and other interested individuals and organizations (Tables 2.1, 2.2).

By the end of November 2010, in addition to numerous verbal responses and informal email responses to the Invitation, the Panel had received formal written submissions from DFO and from several individuals or organizations. In response to a request by the Panel for additional information, DFO provided the Panel with a second submission, which was received in May 2011. Given its role as the government department primarily responsible for matters pertaining to Canada's marine biodiversity, the DFO's responses are included in the Report as Appendix B.

The Expert Panel convened a second meeting in 2010 (6 and 7 December) in Vancouver to consider the preliminary research carried out by the members and to discuss the submissions that the Panel had received from interested parties. Each submission was read by all members of the Panel. Issues raised in the submissions were considered as part of an extended discussion in which the members developed an inventory of the major issues to address and moved toward agreement on the positions they wished to take with respect to them, given the research findings to that date. Members left this meeting with a revised Report outline and with research and writing assignments for a preliminary Report to be considered at the subsequent meeting.

The final meeting of the Expert Panel took place in Ottawa on 8-10 June 2011. In the interim, the Panel members were asked to prepare drafts of chapters and chapter sections in advance of the final meeting for critique and evaluation. The Panel members reached agreement on most of the final revisions necessary for the Report at this meeting. The remaining revisions were agreed upon by electronic mail. The draft Report was sent to an anonymous group of seven Peer Reviewers selected by the RSC's Committee on Expert Panels. Two of the Peer Reviewers identified themselves to the Panel: Prof. Daniel Pauly (University of British Columbia) and Prof. Ray Hilborn (University of Washington). An evaluation by an eighth reviewer was gratefully received from Dr. Susanna Fuller (Ecology Action Centre, Halifax). The Panel acknowledges the comments and criticisms that these reviewers provided on the draft version of the Report. The Peer Reviewers were extremely helpful to the Panel and contributed significantly to the quality of the Report.

9. Acknowledgements

The Panel wishes to acknowledge the extremely helpful contributions it received during the preparation of this Report. First and foremost, the Panel wishes to acknowledge Dr. William Leiss who led the RSC's efforts in the 1990s and 2000s in fulfilling one of Canada's national academy's key roles to advise governments, non-governmental organizations, and Canadians generally, and who served as the RSC's President from 1999 to 2001 and as Chair of the RSC Committee on Expert Panels (CEP) from 2008 until May 2011. Since then, the Panel has been very ably assisted by CEP through the efforts of Dr. Geoffrey Flynn (School of Medicine, Queen's University), who served as Chair of the CEP from May 2011 through the Report's release in 2012, and by Dr. Chris Garrett (School of Earth and Ocean Sciences, University of Victoria), who served as the CEP's Peer Review Monitor for the Report. The Report's chapters that pertain to Canada's national and international obligations to sustain marine biodiversity benefitted tremendously from the outstanding research and writing efforts provided by Maria Cecilia Engler-Palma (Marine & Environmental Law Institute, Dalhousie University). Daniel Ricard (Department of Biology, Dalhousie University) provided invaluable assistance in the preparation of key figures on temporal trends in marine fish abundance and exploitation rates. Contributions by Dalhousie postgraduate students Emilie Reuchlin-Hugenholtz and David Keith were very much appreciated. The Report could not have been completed without the professional and exemplary administrative assistance provided by the RSC, notably Darren Gilmour (Executive Director), Anna Buczek (former Manager, External Relations), Louise Joly (Manager, Services and Administration), Erika Kujawski (Senior Officer, Communications), and Russel MacDonald (Assistant, External Relations). Joyce Yates is gratefully acknowledged for copy editing the Report. The Panel also wishes to thank Dr. Patricia Gallaugher (Director) and Laurie

Wood (Coordinator) of the Centre for Coastal Studies, Simon Fraser University (SFU), for their logistical assistance in support of the Panel's meeting in Vancouver. The Panel gratefully acknowledges the contributions it received from the many individuals and organizations who responded to its Invitation to Submit Evidence, including those who agreed to be publicly acknowledged (in alphabetical order): Kate Barley (Graduate Student, Memorial University of Newfoundland); James Boutillier (Marine Ecosystem Research Coordinator, DFO, Nanaimo, BC); Coastal Alliance For Aquaculture Reform (Vancouver); Claire Dansereau (Deputy Minister, DFO, Ottawa); Dr. Nicholas Dulvy (Canada Research Chair [CRC] in Marine Biodiversity and Conservation, SFU, and Co-Chair, IUCN Shark Specialist Group); Dr. Heike Lotze (CRC in Marine Renewable Resources, Dalhousie University); Dr. Howard Powles (Telfer School of Management, University of Ottawa; formerly with DFO, Ottawa); and Dr. Bettina Saier (Director, Oceans Program, WWF-Canada, Halifax).

Table 2.1. *List of individuals who were invited to submit evidence to the Expert Panel (the Invitation to Submit Evidence, including the questions asked, is given in Appendix A).*

Mr. Pardeep Ahluwalia	Dr. Scott Hinch	Ms. Susan Pinkus
Dr. Mark Angelo	Mr. Hugh Hunt	Ms. Rachel Plotkin
Dr. Bradley Anholt	Ms. Beth Hunter	Dr. Howard Powles
Dr. David Barber	Mr. Timothy Jackson	Dr. Robert Rangeley
Dr. Spencer Barrett	Dr. Kim Juniper	Dr. Justina Ray
Dr. Julia Baum	Dr. Rees Kassen	Dr. John Reynolds
Dr. Karen Beazley	Dr. Ellen Kenchington	Dr. Jake Rice
Dr. Graham Bell	Ms. Sarah King	Dr. George Rose
Dr. Tillmann Benfey	Dr. Martin Krkosek	Dr. Rick Routledge
Dr. Paul Bentzen	Dr. Marty Leonard	Dr. Daniel Ruzzante
Dr. Louis Bernatchez	Dr. John Loder	Dr. Bettina Saier
Mr. Jim Boutillier	Dr. Heike Lotze	Ms. Ruth Salmon
Dr. John Cullen	Dr. Connie Lovejoy	Dr. Robert Scheibling
Ms. Alexandra Curtis	Ms. Shauna MacKinnon	Dr. David Schneider
Dr. Ken Denman	M. Jean-Jacques Maguire	Mr. Alan Sinclair
Dr. Don Deibel	Ms. Denise McDonald	Dr. Michael Sinclair
Dr. Larry Dill	Mr. Patrick McGuinness	Dr. Paul Snelgrove
Dr. Nicholas Dulvy	Mr. Joshua McNeely	Mr. Bob Stevenson
Ms. Shelley Dwyer	Dr. Anna Metaxas	Mr. Iain Stewart
Dr. Stewart Elgie	Dr. Louise Milligan	Dr. Chris Taggart
Mr. David Ellis	Dr. Bill Montevecchi	Dr. Keith Thompson
Dr. Pete Ewins	Dr. Arne Mooers	Dr. Verena Tunnicliffe
Mr. Keith Ferguson	Dr. Faisal Moola	Dr. Warwick Vincent
Dr. Louis Fortier	Dr. Chris Moore	Mr. Joy Wade
Dr. Susanna Fuller	Ms. Alexandra Morton	Mr. Scott Wallace
Dr. Patricia Gallaugher	Dr. Barbara Neis	Dr. Carl Walters
Mr. David Vic Gillman	Mr. Aran O'Carroll	Dr. Reg Watson
Dr. Greg Goss	Dr. Craig Orr	Mr. Ken Wilson
M. Nicole Gougeon	Dr. Sally Otto	Dr. Stephen Woodley
Dr. Mart Gross	Mr. Devon Page	Dr. Boris Worm
Dr. Glen Harrison	Dr. Daniel Pauly	Mr. Howie Wright
Dr. Michael Healey	M. Jacques Perron	Dr. Dirk Zeller
Dr. Ray Hilborn	Ms. Merrell-Ann Phare	

Table 2.2. *Institutional and organizational affiliations of the individuals invited to submit evidence to the Expert Panel.*

Aquaculture Association of Canada	Memorial University of Newfoundland
Assembly of First Nations	Mohawk Council of Akwesasne
British Columbia Environmental Network	National Aboriginal Council on Species at Risk
British Columbia Institute of Technology	Nature Canada
Canadian Aquaculture Industry Alliance	Nisga'a Wildlife Committee & Joint Fisheries Management Committee
Canadian Healthy Oceans Network	Nunavut Wildlife Management Board
Canadian Parks and Wilderness Society	Ocean Management Research Network
Canadian Society For Ecology and Evolution	Okanagan Nation Alliance
Canadian Society of Zoology	Pacific Fisheries Resource Conservation Council
Canadian Wildlife Directors Committee	Parks Canada
Canadian Wildlife Federation	SeaChoice Atlantic
Centre For Indigenous Environmental Resources	Sierra Club Canada
Committee on the Status of Endangered Wildlife in Canada	Sierra Club of Canada BC Chapter
Dalhousie University	Simon Fraser University
David Suzuki Foundation	Torngat Joint Fisheries Board
Ecojustice	Université Laval
Ecology Action Centre	University of Alberta
Environment Canada	University of British Columbia
Fish For Life Foundation	University of Manitoba
Fish, Food and Allied Workers	University of New Brunswick
Fisheries and Oceans Canada	University of Ottawa
Fisheries Council of Canada	University of Toronto
Fisheries Joint Management Committee	University of Victoria
Fisheries Resource Conservation Council	University of Washington
Greenpeace Canada	University of Western Ontario
Hunting, Fishing and Trapping Coordinating Committee	Watershed Watch Salmon Society
Ikanawtiket, Maritime Aboriginal Peoples Council	Wildlife Conservation Society
Joint Secretariat Inuvialuit Settlement Region	Wildlife Management Advisory Council
Living Oceans Society	WWF-Canada
McGill University	Yukon Fish and Wildlife Management Board

Chapter Three: Canada's Oceans

1. Introduction

Canada's marine waters encompass an estimated 7.1 million km^2 (http://www.dfo-mpo.gc.ca/oceans/canadasoceans-oceansducanada/marinezones-zonesmarines-eng.htm#area). This oceanic area can be partitioned into different sections of sea, based on distances extending from the country's 'baseline'. As reported by DFO, the normal baseline is the low-water line along the coast, islands, rocks, including low-tide elevations, as marked on large-scale charts officially recognized by Canada. The length of highly irregular coastlines, such as that of Canada's, can be estimated by drawing straight baselines joining "appropriate points on the coast" (http://www.dfo-mpo.gc.ca/oceans/canadasoceans-oceansducanada/marinezones-zonesmarines-eng.htm#area). Based on such a procedure, Canada's coastline has been estimated at approximately 240,000 km, the world's longest.

Of the 7.1 million km^2 of ocean, the largest portion (2.9 million km^2) is that contained within Canada's Exclusive Economic Zone, or EEZ (extending 12 nautical miles from the coastal baseline to 200 nautical miles). Canada's internal waters (all waters landward of a coastal state's jurisdictional coastline) comprise 2.5 million km^2, and an additional 0.2 million km^2 make up Canada's territorial sea (0 to 12 nautical miles from the baseline). The waters overlying Canada's continental shelf beyond the EEZ (comprising the seabed and subsoil of the submarine areas that extend beyond the territorial sea throughout the natural extension of Canada's land territory to the outer edge of the continental margin) is currently estimated to be 1.5 million km^2. Canada has until 2013 to support this estimate with scientific and legal information as part of its eventual submission to the Commission on the Limits of the Continental Shelf, a UN body. Canada's extended continental shelves are situated on the Atlantic and Arctic coasts. The Commission's decision regarding Canada's submission will have implications for biodiversity, given that species in the benthos (sea bottom) on the extended continental shelves that are considered 'sedentary' will be under the jurisdictional control of the adjacent coastal state.

Canadian marine biodiversity is ultimately a function of the physical and biological oceanography. The primary objectives of this chapter are three-fold. The first is to present basic information on the geography, currents, circulation patterns, and water masses of those parts of the Atlantic, Arctic, and Pacific Oceans that are adjacent to Canada's coast. The second objective is to provide basic information on the biological oceanography of Canada's waters, focusing on energy transfer and a depth-based delineation of biological ecosystems, leading to a description of the Canada's marine ecoregions. Thirdly, the chapter presents an overview of Canadian marine biodiversity from a species-level perspective. Additional information on Canada's physical and biological oceanography, including descriptions of regional systems, sea-level pressure indices (e.g., North Atlantic Oscillation), food webs, and marine ecosystems is provided in Appendices C and D of the Report.

2. The Northwest Atlantic Ocean

a. Geography

The Atlantic Ocean, the world's second largest (approx. 82 million km^2), is connected to the Arctic Ocean via Fram Strait (situated between northeast Greenland and Svalbard) and the Barents Sea. Its average depth (3900 m) is approximately double the deepest average depth in Canadian waters (1900 m in the Labrador Sea) (Figure 3.1).

The Greenland-Scotland Ridge, with maximum depths between 600 and 800 m, separates the Greenland, Iceland, and Norwegian Seas from the rest of the North Atlantic. Deep waters originating in these Nordic Seas flow into the North Atlantic primarily via two deep-water pathways:

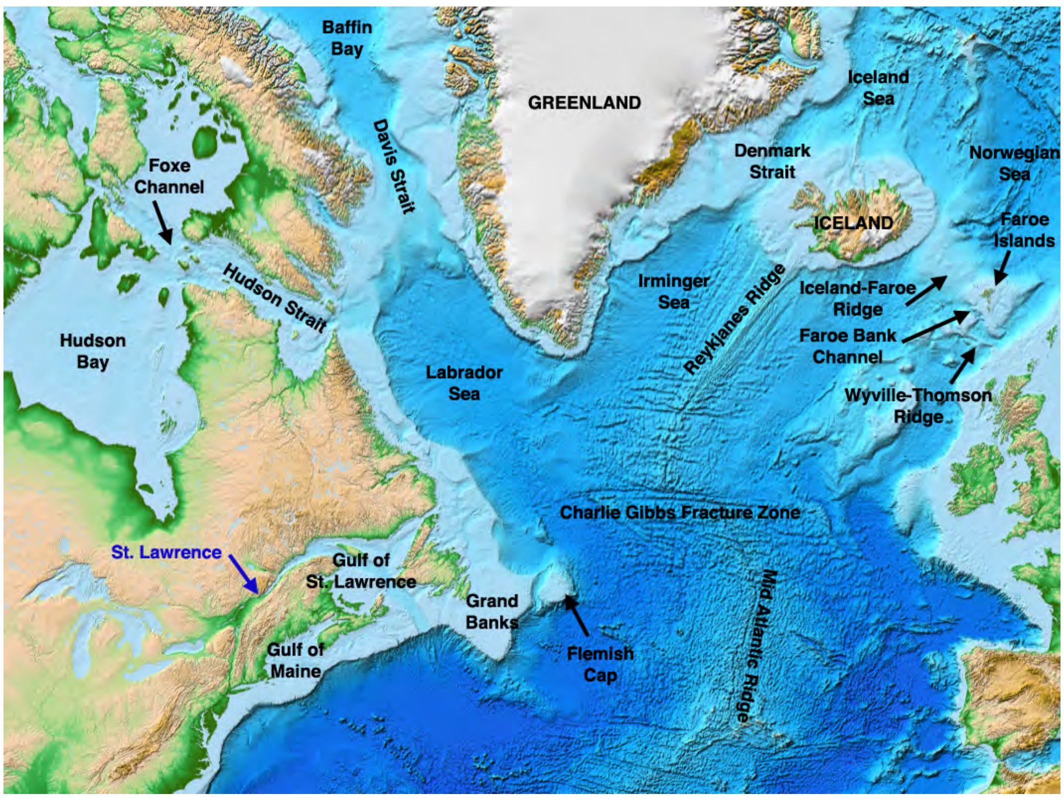


Figure 3.1. *Topographic map of the North Atlantic Ocean. Source: http://maps.ngdc.noaa.gov/viewers/bathymetry/. The Mid-Atlantic Ridge running along the bottom of the North Atlantic is associated with plate tectonics and seafloor spreading. Near 52°N, the Charlie Gibbs Fracture Zone traverses the Mid Atlantic-Ridge, breaking it into northern and southern components. The northern extension that connects to Iceland is known as Reykjanes Ridge.*

Denmark Strait (620 m deep sill; a sill is a submerged ridge at relatively shallow depth separating the basins of two bodies of water) and Faroe Bank Channel (840 m deep). Periodically, water also overflows the shallow Iceland-Faroe and Wyville-Thomson Ridges.

In Canada, Hudson Bay is an inland sea with a surface area of 819,000 km^2 and an average depth of ~100 m. It is the ultimate sink for 30% of Canada's freshwater runoff. Water leaving Hudson Bay joins the northwest Atlantic Ocean via Hudson Strait with an average depth of 275 m. To the north, Foxe Channel connects Hudson Bay to the shallow Foxe Basin (Figure 3.1). Within Canada, the other major freshwater source to the northwest Atlantic is the St. Lawrence River (mean annual flow rate of 12,300 $m^3 s^{-1}$ at Québec City).

The continental shelves along the east coast of Canada are typically very wide. Off Nova Scotia, the Scotian Shelf extends offshore up to 230 km with an average depth of 90 m. To the north, the Grand Banks comprise Canada's widest continental shelf, extending nearly 480 km. Most of the shelf is less than 150 m deep; some areas are as shallow as 25 m. Along the coast of Newfoundland and Labrador, the continental shelf has an average extent of about 150 km. The provinces of Nova Scotia, Newfoundland and Labrador, New Brunswick, and Prince Edward Island have a combined estimated total coastline length of approximately 40,000 km.

b. Circulation and Water Masses

Deep-water formation in the North Atlantic occurs in the Greenland Sea. The renewal of the deep North Atlantic is actually fed by an overflow of intermediate-depth water from the Nordic Seas (Aagaard et al. 1985). About 1Sv (1Sv $=10^6 m^3 s^{-1}$) of northern source water passes between Iceland and the Faroe Islands and ~2 Sv passes between the Faroe Islands and Scotland (Østerhus et al. 2008). As these overflow waters flow south-westward into a deep western boundary current, they entrain surrounding waters, yielding ~3.2 Sv of transport southeast of Iceland (Saunders 1996; Hansen and Østerhus 2000). While some of the resulting overflow waters recirculate around the deep Iceland basin, ~2.4 Sv passes through the Charlie Gibbs Fracture Zone (Saunders 1994), eventually heading northward into the Irminger Sea (Figure 3.2).

In addition, a nearly equal volume (~4 Sv; Dickson et al. 2008) of slightly colder northern source water passes over the shallow sill in the Denmark Strait, rapidly entraining surrounding water (Price and Baringer 1994) and yielding about 5.2 Sv 320 km downstream from the sill (Dickson and Brown 1994). At 480 km downstream from the sill, Dickson et al. (1990) and Dickson & Brown (1994) report 10.7 Sv of deep transport. Dickson and Brown (1994), in reference to McCartney (1992), provide compelling arguments suggesting that the difference between the observed transport (10.7 Sv) and the overflow transport, in concert with the Charlie Gibbs Fracture Zone transport (5.1 Sv + 2.4 Sv = 7.5 Sv), is largely caused by entrainment of recirculating cold, relatively fresh water from the Labrador Sea. Still farther downstream, off the tip of Greenland, Clarke (1984) estimated 13.3 Sv of deep transport, an increase from that upstream by means of additional recirculating components and water mass entrainment. The deep western boundary undercurrent is thought to be 200 to 300 km wide and to transport 13 to 14 Sv of newly formed North Atlantic Deep Water (NADW) (Warren 1981; McCartney and Talley 1984; Schmitz and McCartney 1993; Schmitz 1995) southward. These waters eventually encounter northward flowing Antarctic Bottom Water (AABW). Despite the high salinity of the NADW at such great pressures (further enhanced by mixing with Mediterranean water at mid-latitudes), the colder AABW has higher density and passes below the NADW.

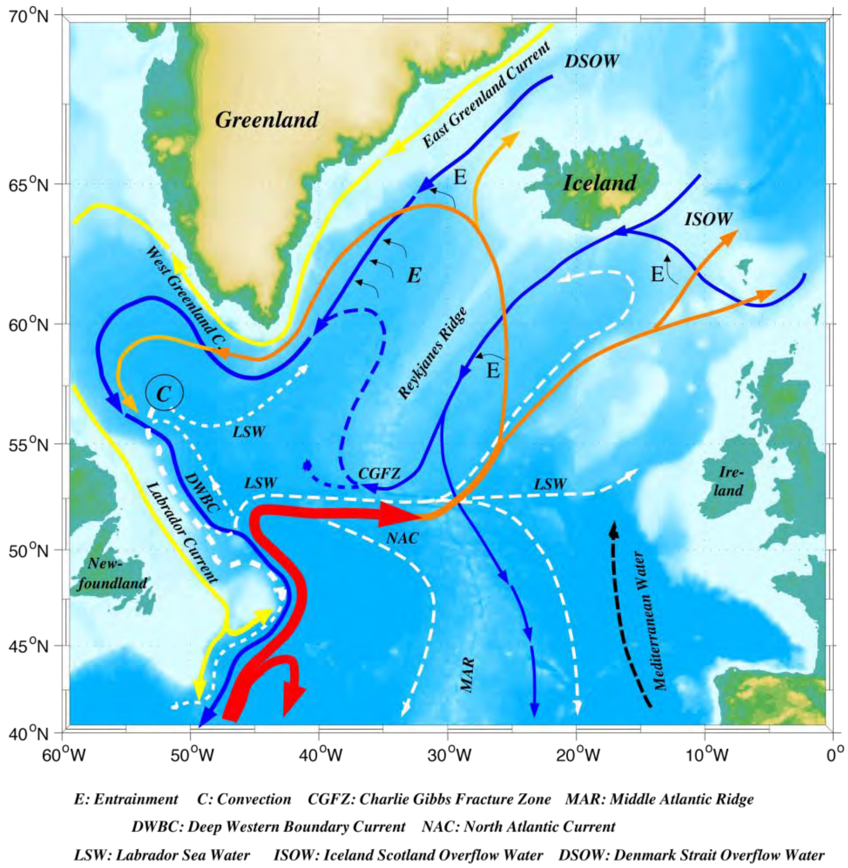


Figure 3.2. *The ocean circulation in the northern North Atlantic. Red, orange, and yellow lines show surface currents. Blue curves portray deep currents, while the dashed white line tracks water associated with the formation of the Labrador Sea Water mass. Source: www.ifm-geomar.de/index.php?id=19&L=1.*

Deep water also forms in the Labrador Sea; the depth at which it occurs in any given year is highly variable. Aside from two notable exceptions, convection depths in 1995 to 2005 were generally between 1000 and 1400 m. In 1995, convection extended downward to 2300 m, whereas in 2004 it was confined to 700 m (Avsic et al. 2006). Between 1987 and 1995, Yashayaev and Loder (2008) also noted a sequence of deep (~2300 m) convection years. Labrador Sea Water overrides North Atlantic Deep Water formed in the Nordic Seas and is sometimes known as Upper North Atlantic Deep Water.

The surface circulation of the North Atlantic is characterized by the warm, saline northward-flowing Gulf Stream which, as it traverses the North Atlantic Ocean, becomes the North Atlantic Current. To the east of Reykjanes Ridge, the North Atlantic Current bifurcates into the northwestward flowing Irminger Current as well as the North Atlantic Drift that continues onward towards the northeast (Figure 3.2). Cold, fresh Arctic waters are exported to the North Atlantic via the East Greenland Current. These are further fed by warmer, more saline Atlantic waters from the Irminger Current. Once it passes the southern tip of Greenland, the East Greenland Current becomes known as the West Greenland Current. A branch of the West Greenland Current flows northward into, around, and subsequently out of Baffin Bay (as the Baffin Current). Here, it meets with the southward flowing Labrador Current (Figure 3.2). The other branch of the West Greenland Current follows the topographic contours to the south of Davis Strait, eventually joining the Labrador Current. Cold, fresh, surface water flowing out of Hudson Strait also feeds the current.

3. The Arctic Ocean

a. Geography

The Arctic Ocean is a semi-enclosed basin comprising 11.5 million km^2. It is bordered by six nations (Canada, US, Denmark [via Greenland], Iceland, Norway, Russia). The Lomonosov Ridge, rising to a minimum depth of ~950 m, separates the Arctic Ocean into the Amerasian and Eurasian Basins. The Alpha-Mendeleev Ridge breaks the Amerasian Basin into the Canada and Makarov Basins, while the Nansen-Gakkel Ridge partitions the Eurasian Basin into the Nansen and Fram Basins (Figure 3.3). The Arctic Ocean is connected to the Pacific Ocean by the shallow (~50 m deep), 85 km wide Bering Strait. There are both deep (Fram Strait) and shallow (Barents Sea) connections between the Arctic and North Atlantic Oceans. The Arctic Ocean is also connected to the North Atlantic Ocean via narrow channels through the Canadian Arctic Archipelago. The most significant of these are Lancaster Sound, north of Baffin Island, Cardigan Straight to the south of Ellesmere Island, and Nares Strait between Ellesmere Island and Greenland.

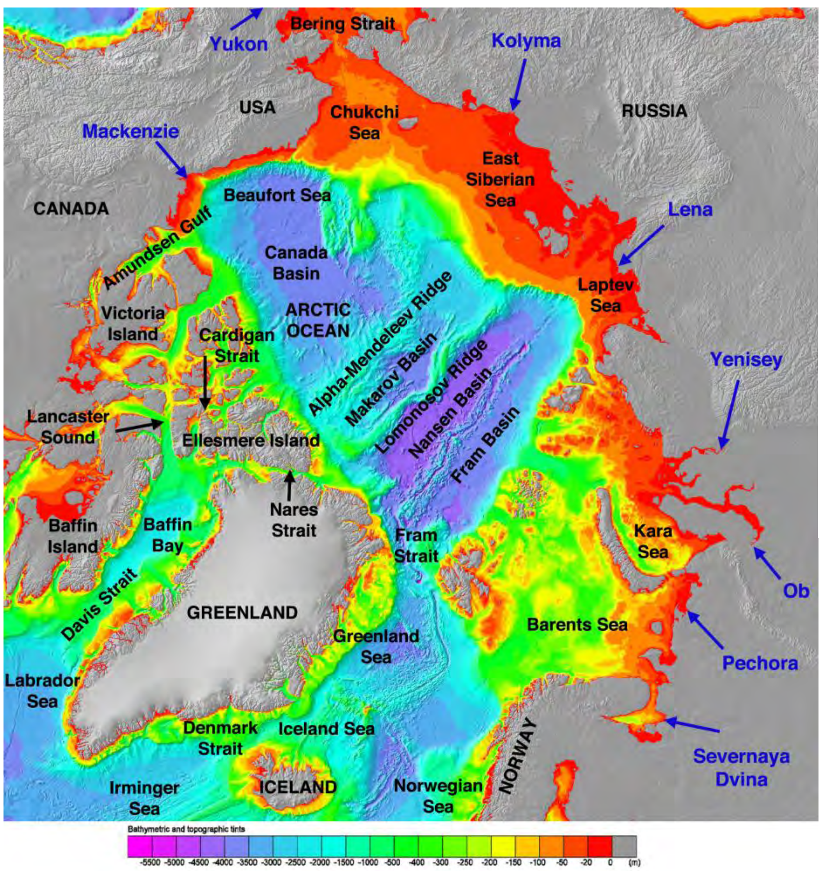


Figure 3.3. Topographic map of the Arctic Ocean (International Bathymetric Chart of the Arctic Ocean). Source: www.ngdc.noaa.gov/mgg/bathymetry/arctic/currentmap.html [Jakobsson et al. 2008]).

Two-thirds of Canada's coastline borders the Arctic Ocean, with the majority of this being associated with the islands of the Canadian Arctic Archipelago. Among these, Baffin Island (507,451 km^2), Victoria Island (217,291 km^2), and Ellesmere Island (196,236 km^2) are the fifth, eighth, and tenth largest islands in the world, respectively. Fresh water from land entering the Arctic Ocean is dominated by seven drainage systems. The Mackenzie River dominates runoff into the Arctic from the North American continent with a discharge rate of 281 km^3 yr^{-1} (ACIA 2005). Eurasian runoff is largely attributable to six river systems (Kolyma, Lena, Yenisey, Ob, Pechora, Severnaya Dvina); the Yenisey has more than twice the annual discharge of the Mackenzie River (580 km^3 yr^{-1}; ACIA 2005). The Kolyma, Lena, Ob, Pechora, and Severnaya Dvina discharge 103, 528, 402, 108, and 105 km^3 yr^{-1}, respectively (ACIA 2005).

The annual cycle of Arctic sea ice extent is characterized by an end-of-summer minimum in September and an end-of-winter maximum in March. On 19 September 2010, the minimum sea ice extent was the third lowest recorded since the satellite era (which began in 1979) (Figure 3.4), dropping to 4.60 million km^2, or 2.11 million km^2 below the 1979-to-2000 median. On 7 March 2011, the maximum Arctic sea ice extent matched the lowest recorded level since the satellite era (Figure 3.4), reaching 14.64 million km^2, which was 1.2 million km^2 below the 1979-to-2000 median.

b. Circulation and Water Masses

A cold, fresh, surface layer overlying a warm, saline layer of Atlantic origin characterizes the water mass structure of the Arctic Ocean. The transition between these layers is marked by a distinct halocline and temperature inversion (the halocline occurs at the depth at which the rate of change in salinity with increasing depth is greatest). Arctic bottom waters are both cold and saline, with the boundary between the overlying Atlantic waters involving a weak thermocline (the thermocline occurs at the depth at which the rate of decline in temperature with increasing depth is greatest). The salinity characteristics of the upper layer vary across Arctic waters, depending on whether or not surface waters from the Pacific are present (McLaughlin et al. 2002). Driven by differences in temperature and salinity between the North Pacific and North Atlantic, which affect the density, volume, and height (steric height) of the oceans, ~0.8 Sv (1 Sv = 10^6 m^3s^{-1}) flows into the Arctic Ocean via Bering Strait. This brings about 0.08 Sv of fresh water from the Pacific into the Arctic. Freshwater export to the Atlantic occurs through the Canadian Arctic Archipelago and Fram Strait (Melling et al. 2008).

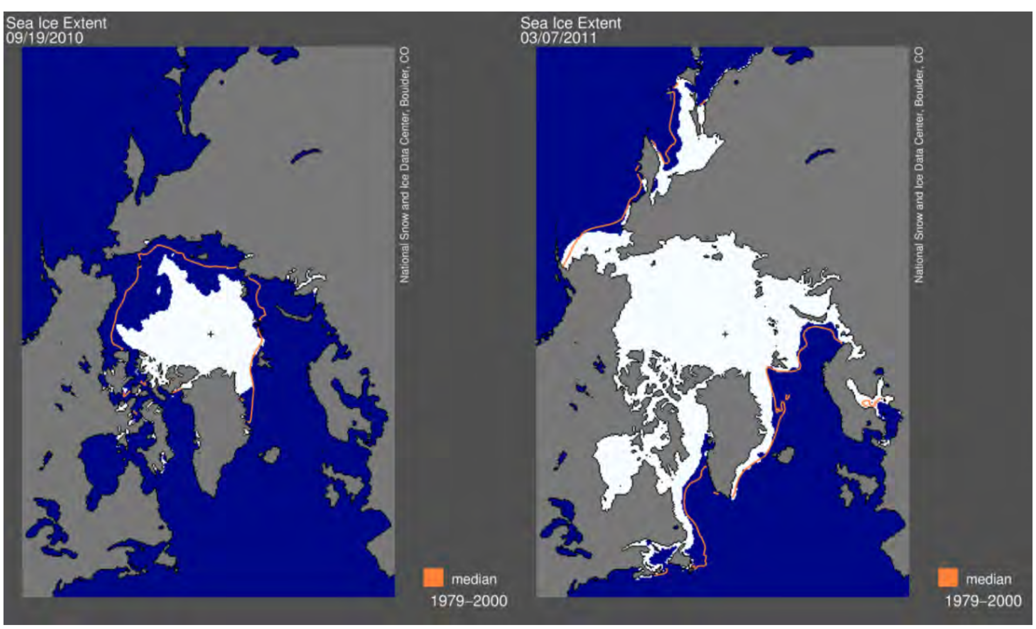


Figure 3.4. *Arctic Sea ice extent at its 2010 minimum on 19 September and at its 2011 maximum on 7 March. The orange line shows the median sea ice extent over the period 1979–2000. Source: www.nsidc.org*

Warm, subsurface Atlantic waters enter the Arctic via two distinct branches: Fram Strait and Barents Sea (Figure 3.3; Jones 2001). These flow along continental slopes around the Arctic and its deep ocean basins in a counter-clockwise fashion (Rudels et al. 1994). The surface circulation of the Arctic Ocean is generally clockwise (Figure 3.5), albeit highly variable. The Beaufort Gyre in the Beaufort Sea and the Transpolar Drift from the Siberian Shelves to the Atlantic Ocean are the dominant features of this circulation. The Beaufort Gyre is particularly important to the climate system because it contains a vast reservoir of fresh water (Proshutinsky et al. 2002, 2009). Proshutinsky and Johnson (1997) demonstrate that the wind-driven surface circulation of the Arctic Ocean is characterised by two differing regimes. Fresh water is generally exported from the Beaufort Gyre to the North Atlantic in the cyclonic (counter-clockwise) regime (Proshutinsky et al. 2005; left panel in Figure 3.5) and accumulates in the Beaufort Gyre in the anticyclonic (clockwise) regime (Proshutinsky et al. 2005; right panel in Figure 3.5).

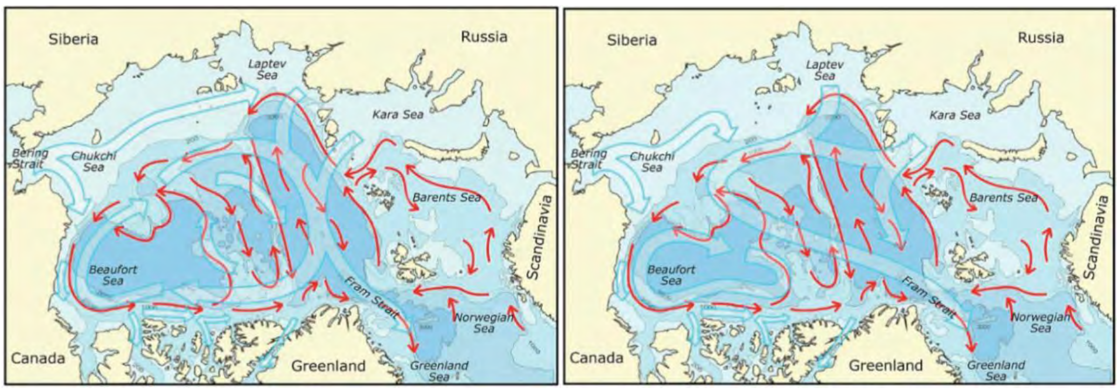


Figure 3.5. *Schematic diagram of the major surface (open blue arrows) and deep (red arrows) currents of the Arctic Ocean. Left: the anticyclonic regime. Right: the cyclonic regime. Source: Proshutinsky et al. (2005).*

In 2009, winds over the Arctic drove annual-mean cyclonic surface flow that greatly weakened the Beaufort Gyre and the transpolar drift (Proshutinsky et al. 2010). In addition, the seasonal cycle of the wind-driven circulation reversed relative to climatology, becoming anticyclonic in summer rather than cyclonic, and cyclonic instead of anticyclonic in winter.

4. The Northeast Pacific Ocean

a. Geography

The northeast Pacific Ocean off British Columbia (BC) is bounded to the east by a rugged coastline with steep and complex topography. Vancouver Island and the mainland's Coast Mountain Range, the somewhat less rugged but still complex topography in Haida Gwaii, and numerous smaller islands closer to the mainland are the predominant topographical features (Figure 3.6). The mainland coast is dissected by a complex network of inlets, straits, passes, sounds, and narrows. From the border of Washington State to the Alaska panhandle, the coastline, inclusive of islands, is almost 27,300 km long (Thomson 1981).

The continental shelf bordering the coast and islands is relatively broad in Queen Charlotte Sound and Dixon Entrance, but is especially narrow on the west coast of Haida Gwaii. On the west coast of Vancouver Island, the shelf is relatively narrow in the north but relatively broad near the exit of the Strait of Juan de Fuca. Three major areas of deep bathymetry on the continental shelf are located at Dixon Entrance, Queen Charlotte Sound, and the Strait of Juan de Fuca.

Figure 3.6. *Topographic and bathymetric map of the northeast Pacific Ocean.*
Source: http://maps.ngdc.noaa.gov/viewers/bathymetry/

The slope connecting the continental shelf with deeper offshore waters is relatively steep and narrow compared with the slope fringing the continental shelves in the Arctic and northwest Atlantic Oceans. There are about 30 steep-walled canyons cutting across the slope between Cape Flattery to the south and Cape St. James to the north (Thomson 1981).

Moving offshore, depths gradually increase, with the exception of numerous inactive subfloor volcanoes called seamounts and some broad underwater ridges, which are characterized by peaks and valleys. Bowie, Union, and Cobb seamounts are among the most prominent undersea seamounts off BC and are part of a cluster of approximately 100 that extend from the Gulf of Alaska to the Oregon coast (Thomson 1981). Parts of these seamounts rise to within the sunlit portion of the upper ocean waters and are considered 'hotspots' for sea life.

b. Circulation and Water Masses

The large-scale current systems of the North Pacific are associated with oceanic gyres in the Bering Sea, the western Subarctic, the Gulf of Alaska, and sub-tropical Central Pacific areas (Figure 3.7). The North Pacific Current is a broad, slow-moving eastward extension of the Kuroshio Current that lies to the south of the Subarctic Boundary. The Subarctic Boundary is an oceanic front that separates the relatively warm, high-salinity, and low-productivity waters of the subtropics from the cooler, fresher, nutrient-rich, and more productive waters of the subarctic North Pacific. The West Wind Drift is part of the Subarctic Current system, which bifurcates into the north-eastward flowing Alaska Current and the south-eastward flowing California Current as it nears the Gulf of Alaska. The area of divergence between the Alaska and California Currents typically has variable currents that include many eddies and meanders that range in size from tens to hundreds of kilometres.

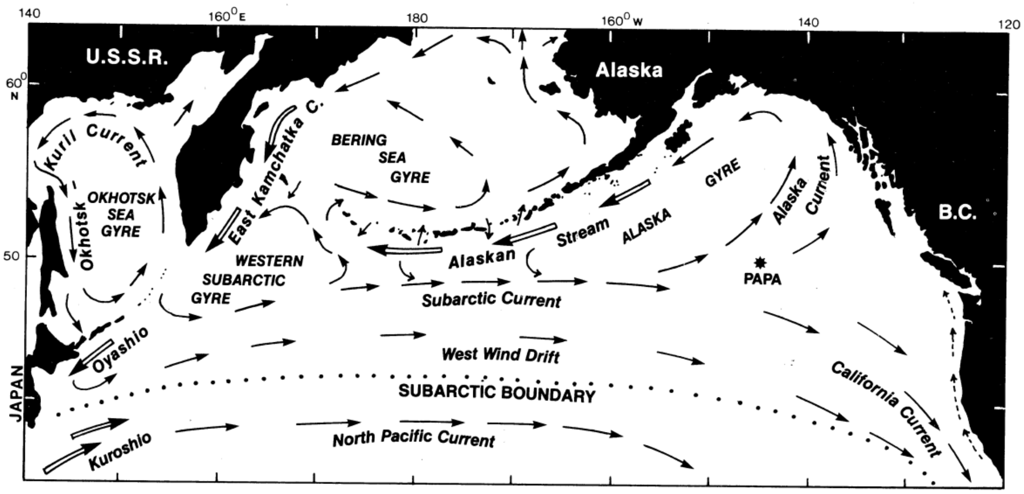


Figure 3.7. *Prevailing surface currents in the North Pacific Ocean. Double arrows are intense boundary currents with speeds typically 1-2 m s^{-1}; over most of the region speeds are less than 0.25 m s^{-1}. Broken arrows correspond to the winter Davidson Current off the Oregon-Washington coast. The asterisk off the coast of BC is the location of Ocean Station PAPA, a weather ship, from 1957 to 1980. Source: Thomson (1981).*

5. Biological Oceanography: The Basics

Marine ecosystems, like terrestrial ones, are composed of a variety of living organisms and physical attributes that interact through a sequence of processes involving the production and transfer of energy (Kaisir et al. 2005; Nybakken and Bertness 2005; Castro and Huber 2007). Energy from the sun is captured by autotrophs (e.g., plants, bacteria, and algae) and is stored in the chemical bonds of organic compounds. Heterotrophic organisms obtain energy by eating autotrophs (herbivores), by eating other organisms that have eaten autotrophs (carnivores), or by absorbing dissolved organic matter from the environment. This arrangement of autotrophs and succeeding levels of heterotrophs defines a trophic structure (often illustrated as a food web), a characteristic feature of all ecosystems. The final component of the trophic structure consists of the detritivores and decomposers. Detritivores are multi-cellular organisms that consume fragments of dead organisms. Decomposers, typically bacteria and fungi, break down the complex organic compounds of dead organisms. Simple molecules are thus released in the form of dissolved organic carbon which is again exploited within the food web. This is a unique feature of aquatic food webs. In addition to an energy source (generally, but not exclusively, sunlight), marine ecosystems require nutrients, of which nitrogen, phosphorus, iron, and silicate are the most important.

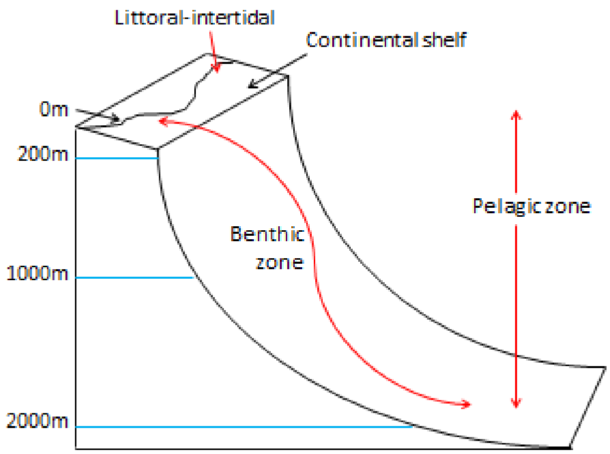


Figure 3.8. *Three marine ecosystem zones (littoral-intertidal, pelagic, benthic) in relation to depth.*

The marine realm may be viewed as a hierarchical arrangement of such ecosystems (Figure 3.8). Five major categories of ecosystems are recognized in marine waters: pelagic, benthic, littoral-intertidal, estuarine-brackish, and deep sea. The pelagic realm encompasses the water column away from the bottom and the shore. The upper pelagic (or epipelagic) ecosystem, comprising the first 200 m of the water column, is the warmest and receives the most sunlight of the pelagic realm. It thus includes the photic zone where light is sufficient to permit photosynthesis. The benthic realm includes organisms associated with the seabed that are collectively known as benthos. The shallowest part of the benthic realm is the littoral-intertidal zone, the narrow fringe along the shoreline found between the highest high tide and the lowest low tide. Although accounting for the smallest area of the world's oceans, they are the best known of marine ecosystems because they are so readily accessible for study. The intertidal zone is unique among marine ecosystems because it is regularly exposed to air and experiences the greatest variation in environmental factors. The estuarine-brackish realm comprises an ecosystem created when fresh waters flowing from rivers first meet and mix with salt water from the sea. These systems are among the most productive environments on the planet, ranking alongside tropical rain forests and coral reefs. The deep sea ranges from the edge of the continental shelf at about 200 m depth down to the abyssal plain 5 km below the surface, with some deep trenches continuing down to a depth of 10,000 m. Of the 70% of the planet's surface covered with water, about 85% of the area constitutes the deep sea. Although inhospitable to most forms of life because of massive pressure, near-freezing waters, and a total lack of sunlight, the deep sea is believed to harbour a huge yet largely unexplored biodiversity (Webb et al. 2010).

Each of these realms (pelagic, benthic, littoral-intertidal, estuarine-brackish, deep sea) can be subdivided into more discrete functional units characterised by specific physical conditions, including light and available nutrients which vary in concert with, among other attributes, depth, water clarity, salinity, and temperature (Appendix D). In addition, there are geographical differences in the communities of living organisms composing these functional units, reflecting in part the evolutionary history of different parts of the marine realm. The resulting geographical patterns of this biodiversity and their associated food webs contribute to the identification of marine ecoregions.

6. Canadian Marine Ecoregions

Marine ecoregions are biogeographic classifications of patterns of biodiversity. A major objective of biogeography is to identify and characterize geographic groupings of species and the biogeochemical conditions that make them different (Longhurst et al. 1998). Thus, marine ecoregions are defined at the scale of the continental shelf according to a combination of geological, physical oceanographic, and biological properties. Ecoregions may be grouped within larger marine areas known as ecoprovinces. Here, we adopt the scheme proposed by Powles et al. (2004) and adopted by DFO (2009) in the national framework for Canada's proposed network of marine protected areas. Canadian marine waters encompass three marine ecoprovinces and 12 ecoregions: three in the Cold Temperate Northwest Atlantic; four in the Cold Temperate Northern Pacific; and five in the vast Arctic realm. Coastal and shelf waters, combining benthic and shelf epipelagic biotas, represent the areas in which most marine biodiversity is found.

At times, ecoregion boundaries coincide with major biogeographical discontinuities. For example, in the Pacific Ocean, the *Southern Shelf* ecoregion (ecoregion 2; Figure 3.9) is bordered in the north by the Brooks Peninsula which divides the continental shelf at this point. The Brooks Peninsula represents the northern distribution of many marine species. To the north of the Brooks Peninsula is the *Northern Shelf* ecoregion (ecoregion 4; Figure 3.9). A distinctive feature of this ecoregion is the shallow-water area located between Haida Gwaii and the mainland. Many species and populations in this ecoregion do not extend to the south of the Brooks Peninsula. For example, all major bird colonies in British Columbia occur north of the Brooks Peninsula.

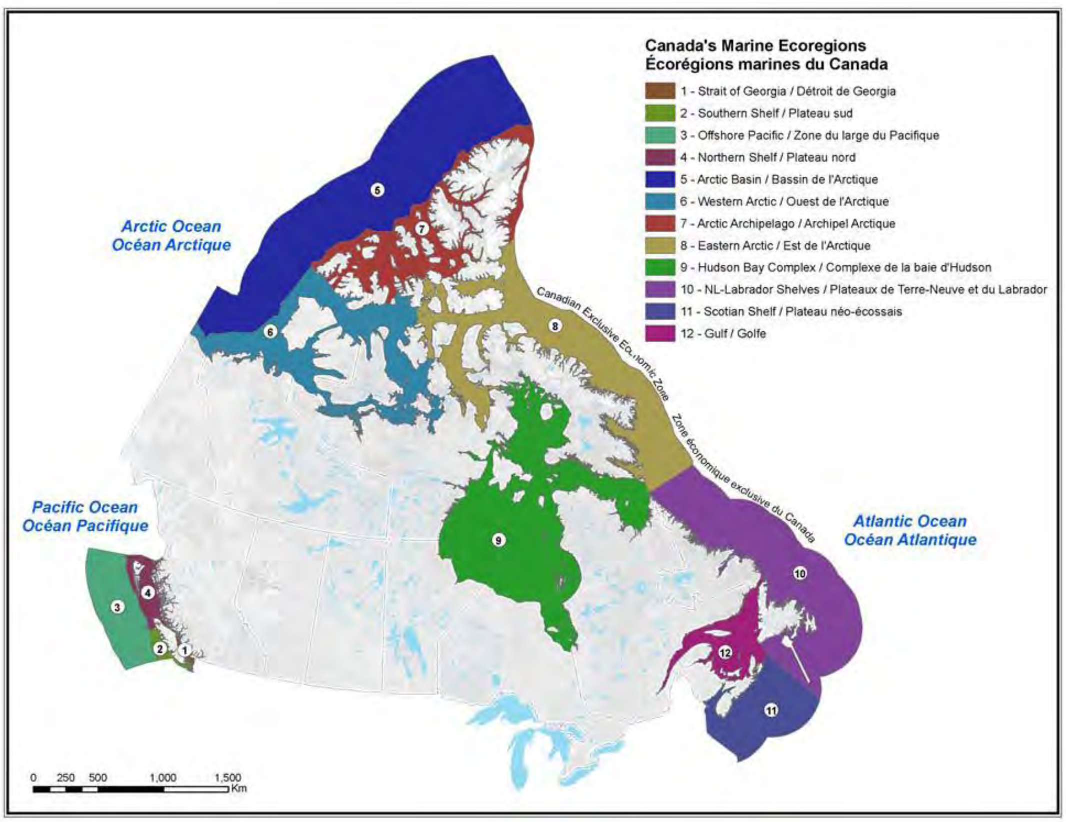


Figure 3.9. *Canadian marine ecoregions. Source: DFO (2009).*

Some ecoregions are clearly defined by depth and their position on or off the continental shelf. In the Arctic Ocean, the *Arctic Basin* ecoregion (ecoregion 5; Figure 3.9) is located off the continental shelf and is characterised by depths greater than 1000 m. Primary production is considered low in this ecoregion due to permanent ice cover. In contrast, the *Western Arctic* (ecoregion 6; Figure 3.9) is a relatively shallow region, encompassing the Beaufort Sea to the west, Amundsen Gulf, Queen Maude Gulf to the southeast of Victoria Island, and Viscount Melville Sound to the north of Victoria Island (Figure 3.3). The ecoregion is characterised by pack ice in the north and seasonal ice in the south, although these patterns are rapidly changing as the Arctic Ocean warms. The region is also relatively shallow (less than 200 m), and has two particularly shallow areas, one being the Queen Maude Gulf and the other located between Viscount Melville and Lancaster Sound to the east. This latter shallow-water boundary is an important biological boundary between eastern and western populations for many species.

Enclosed marine areas also represent unique ecoregions because of the dominance of tidal mixing and freshwater outflow from adjacent rivers. The *Hudson Bay Complex* ecoregion (ecoregion 9; Figure 3.9) is characterised by its degree of closure and relatively shallow depth. Tides are an important oceanographic feature here as is the large input of fresh water from Québec rivers. Ice cover is seasonal and primary production is generally low, although higher productivity is evident in Hudson Strait and Foxe Basin, as result of strong tidal mixing. In the Atlantic ecoprovince, the primary feature of the *Gulf of St. Lawrence* ecoregion (ecoregion 12; Figure 3.9) is water flow, which is essentially continuous from the Strait of Belle Isle in the north, through the Gulf, and onto the eastern Scotian Shelf. Freshwater influence is important, with the St. Lawrence River flowing eastward across the southern Gulf and onto the Scotian Shelf. The southern Gulf has warmer water temperatures due to its shallowness and has greater stratification than adjacent waters. The St. Lawrence estuary has colder water, but strong mixing does result in high primary productivity at the mouth of the river.

These 12 marine ecoregions define Canada's marine landscape. They demonstrate spatial patterns in ecosystem processes as well as geographical differences in the communities of living organisms comprising Canadian marine ecosystems. Mapping biogeographic patterns in this way is an essential step in understanding the richness, functionality, and distribution of Canadian marine biodiversity and in planning an integrated management approach that will take into consideration the regional impacts arising from climate change and differing sectors of human activity, including fisheries and aquaculture.

However, important as these ecoregions are for biogeographic purposes, they belie an absence of data at finer spatial scales on the biological use of marine habitats for most Canadian species. Although efforts have been made to document these habitats (e.g., Stewart et al. 2001), and to increase the spatial resolution of benthic habitat mapping (e.g., using multi-beam acoustic mapping of the seafloor; Smith et al. 2009), temporal data on the physical and biological characteristics of Canada's marine habitats are lacking. For example, according to one of the submissions received by the Expert Panel, Canada lacks time series data of the areal extent of marine macrophytes, a deficiency that might be explained by the assertion (from the same submission) that there is only one individual in DFO responsible for undertaking near-shore habitat mapping on bay-wide scales. It is to be hoped that Stephenson and Hartwig's (2010) recent mapping efforts to identify areas of high biological importance in the Arctic will be repeated elsewhere.

7. Species Richness of Canada's Oceans

Canada's geography has mixed effects on the biodiversity of marine species. On one hand, Canada is disadvantaged because it is a northern country. With few exceptions, species richness (the number of species in a given area) becomes poorer as latitude increases. This trend is particularly marked in the northern hemisphere because of the relatively young age of the Arctic, which has afforded comparatively little time for speciation and endemism (Dayton 1994). On the other hand, the areal extent of Canada's oceans is vast (~7.1 million km^2); more species are typically found in larger areas. The species richness of Canada's oceans is also likely to be enhanced by the heterogeneity of the country's marine realm, given the country's location at the junction of three oceans, each of which contributes its own fauna and flora to national marine biodiversity.

Species richness is often the most practical means of considering biodiversity, given that it describes well the variety of life that people encounter. However, it is, of course, only one facet of biodiversity (Chapter Two). One important consideration, from the perspective of this Report, is that species richness is generally not as sensitive to direct human impacts as are other aspects of biodiversity, such as abundance and distribution. For example, even though Atlantic cod has been severely depleted (Chapter Seven) and its core distribution much reduced (Hutchings 1996), it still contributes to the richness of the Atlantic fish community, as do species that have never declined to historically low levels of abundance.

The question of how many species occur in any relatively large area cannot be answered with great certainty. No comprehensive inventory of marine species exists for any part of the world. Even in regions such as Europe, which has a relatively extensive marine species list, it is estimated that up to 33% of species remain to be described (Costello and Wilson 2011). This means that for every ten European marine species known, at least three more are not. Globally, the proportion of described marine species is likely much lower. Mora et al. (2011), for example, estimated that 91% of their estimated 2.2 million marine species have yet to be described. The overall proportion of species remaining to be discovered is undoubtedly higher for places such as Canada, where the national marine inventory is much less complete. Nevertheless, species richness is relatively well established for some marine taxa in Canadian waters. The aim here is thus to give an appreciation, rather than a complete accounting, of the natural biological wealth of Canadian coastal waters. This is achieved by: (i) presenting information on the better-known groups to illustrate the patterns of richness of Canada's three oceans; (ii) comparing them to patterns found in Canadian terrestrial fauna and flora; and (iii) estimating the numbers of species yet to be discovered.

8. How Many Species are in Canada's Oceans?

The recent global Census of Marine Life programme prompted an attempt at cataloguing the biodiversity of the world's oceans, including Canada's (Archambault et al. 2010). The total number of species in Canadian waters enumerated by 2010 reached a minimum of 15,988 (Table 3.1). This increases to almost 16,500 species by adding: (i) an estimated 38 (known to breed in

Canada; Cheung et al. 2011) to 64 species of seabirds (Dr. Ian Jones, Memorial University of Newfoundland, and Dr. Richard Cannings, Okanagan Valley, BC, personal communications), which are considered here because of their near-exclusive reliance on marine foraging resources; (ii) 265 species of sponges (Austin et al. 2010; Fuller 2011; Dr. Susanna Fuller, Ecology Action Centre, Halifax, personal communication); (iii) 104 species of cold-water corals (Campbell and Simms 2009); and (iv) 66 species of invertebrates and fishes recorded to date in exclusive association with deep-sea hydrothermal vents off BC (Bachraty et al. 2009).

Table 3.1. *Marine species richness for select taxonomic groups and habitats in Canada.*

Taxonomic group or habitat	Estimated number of species		Source
	Canada	Global	
Microbes (Arctic only)	9,500 – 54,000	Unknown	Archambault et al. (2010)
Phytoplankton	1,657	~ 5,000 (25,000)	Archambault et al. (2010)
Macroalgae	860 – 979	~ 9,300	Archambault et al. (2010); Mike Guiry (www.algaebase.org)
Cold-water corals	104	700	Campbell and Simms (2009)
Sponges	265	5,000 – 10,000	Susanna Fuller (pers. comm.); Austin et al. (2010); Fuller (2011)
Zooplankton	900	Unknown	Archambault et al. (2010)
Benthic infauna	2,127	Unknown	Archambault et al. (2010)
Fishes			
Cartilaginous	61	~ 1,100	Nick Dulvy (pers. comm.)
Bony	831 – 971	14,200	Archambault et al. (2010)
Seabirds	38 – 64	383 – 475	I. Jones and R. Cannings (pers. comm.); www.cornell.edu; Clementschecklist; Cheung et al. (2011)
Mammals	52	125	Archambault et al. (2010)
Hydrothermal vents	66	592	Bachraty el al. (2009)

This overview is, by necessity, incomplete. It focuses on a few taxonomic groups for which information is both sufficient and accessible. Thus, marine fishes, birds, and mammals are relatively well enumerated, but significant gaps remain for other taxa and habitats that are known, or suspected to be, species-rich. Marine microbes, for example, have to date only been enumerated in the Canadian Arctic, where only a fraction of the expected full species diversity has been described. Although an old adage holds that at least half of the species in the world are parasites, there are currently no parasites or other symbionts on the Canadian marine list. The list of invertebrates associated with the sea floor includes only those organisms that live buried in sediment (i.e., infaunal invertebrates), but not those attached to the bottom. Moreover, the spatial extent of sampling for infaunal invertebrates has been minuscule, amounting to only 248 m^2 of the sea floor (much less than one millionth of 1% of Canada's continental shelf) surveyed to date (Archambault et al. 2010). Many species of animals and algae associated with rocky intertidal habitats are missing from the tally, as are those that depend on cold-water coral and sponge reefs, because information pertaining to these habitats is either sparse or non-existent.

Even for groups for which there is a Canadian total, their numbers may, to various degrees, be underestimated. For example, Shackell and Frank (2003) estimated that, since the mid-1970s, one to six new species are added annually to the list of fishes caught in DFO bottom-trawl surveys on the Scotian Shelf. The degree of error for macroalgae is even more extreme. Recently, genetic studies have uncovered 150-200 new species of macroalgae in Canada with most hailing from the Pacific coast (Dr. Gary Saunders, University of New Brunswick, personal communication). These recent discoveries are estimated to boost the current species richness of Canadian macroalgae by 15-23% (Table 3.1).

9. Patterns of Species Diversity

The current assessment of Canadian marine biodiversity, however incomplete, still allows a glimpse of the relative distribution of species on the country's three coasts. Some of the patterns can almost certainly be attributed to regionally uneven research effort. For example, it might seem surprising that the overall number of species in the Arctic is similar to that of the other two coasts (Figure 3.10). However, this is in large part due to the abundance of Arctic phytoplankton species (especially diatoms in the subkingdom Chromista; Figure 3.10A) that have been the subject of compilations for the polar region, but not for the other two coasts.

Other patterns may reflect true differences in species richness. For example, crustaceans, notably harpacticoid copepods and infaunal amphipods, appear to be more numerous in Arctic waters than elsewhere, despite lower sampling efforts in the north. The Pacific coast is likely to be a true national hotspot of macroalgae diversity (Figure 3.10B), with at least 650 species enumerated to date (not including recent discoveries; see above). In addition, the enumeration of species of vertebrates is considered to be relatively complete. Thus, fish species richness peaks on the Atlantic coast (Figure 3.10C), a pattern which might be influenced in part by the relatively limited extent of Canada's Pacific coastline. The pattern of seabird diversity mirrors that for marine mammals, with both being low in the Arctic and similarly high on the east and west coasts. It is also notable that Canadian oceans are home to more than 40% of the world's marine mammal species.

10. Canadian Species Diversity in a Terrestrial Context

How does Canadian marine species diversity compare to its terrestrial counterpart? At nearly ten million km^2, the surface area of Canada is almost 1.5 times greater than that of Canadian marine waters. To date, scientists have enumerated ~71,000 Canadian species (Mosquin et al. 1995), ranging from freshwater micro-organisms to the giant, western red cedars (*Thuja plicata*) of Pacific coastal rainforests. This represents approximately 4.4 times more species than are currently identified within Canada's oceans. This unevenness varies across taxonomic groups. For example, terrestrial birds outnumber seabirds by approximately eight to one (land vs sea: 398 vs ~50), yet there are only about three times as many Canadian terrestrial mammal species as there are marine species (148 vs 52). Among fishes, the pattern is reversed, with some four marine species for every freshwater species (~900 vs ~204).

The overall higher richness of Canadian terrestrial and freshwater taxa may be real. After all, the most species-rich group – insects – is only found on land. In Canada, as elsewhere, insects dominate species tallies, typically contributing more than 40% of species. However, at least some of the apparent inequality might be attributed to poorer sampling effort and capacity to describe marine biodiversity. It is widely acknowledged, for example, that diversity in the

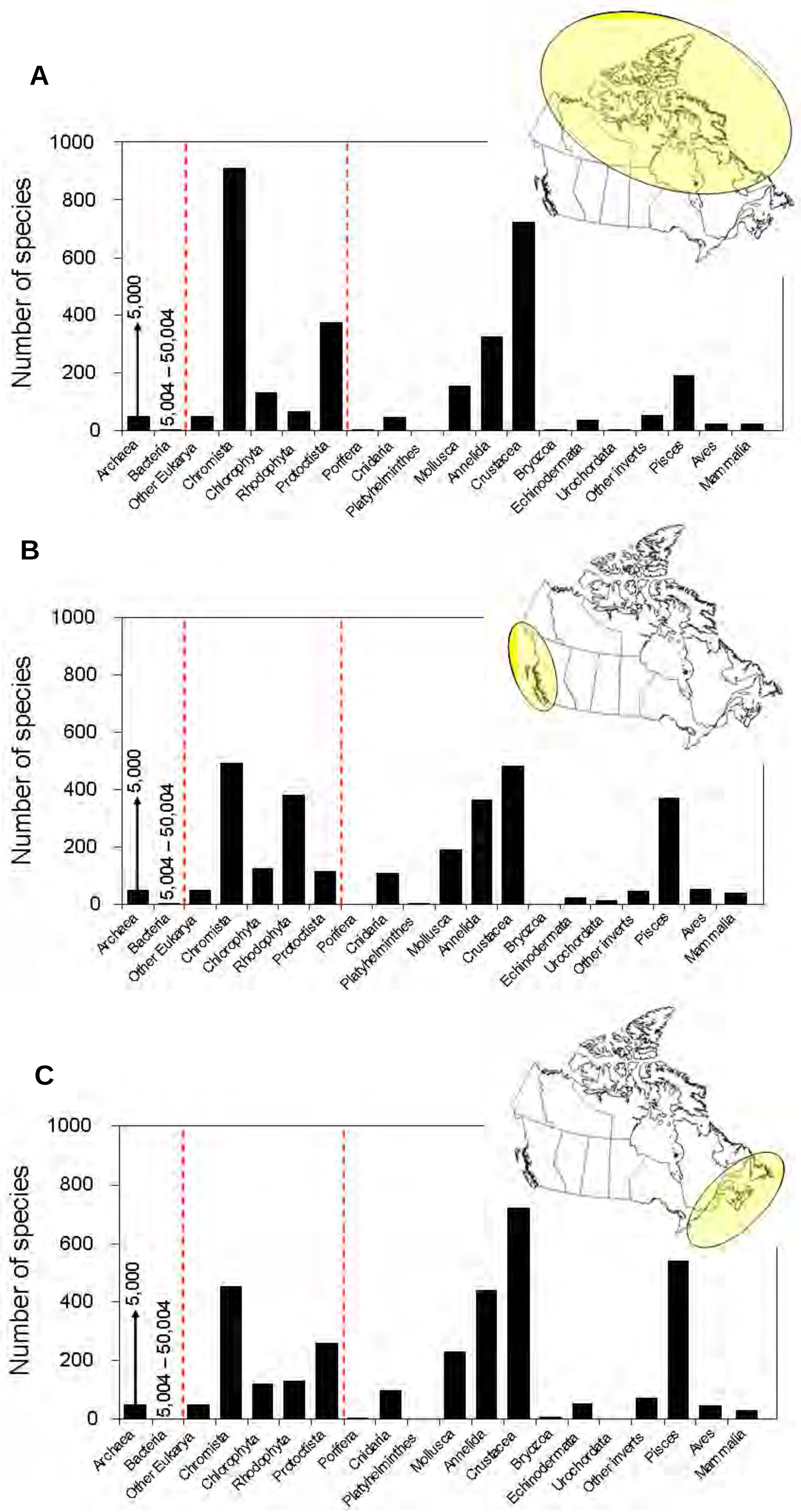


Figure 3.10. *Species richness of marine microbes, plants, and animals in the Canadian Arctic (A), Pacific (B), and Atlantic (C). Data compiled from Archambault et al. (2010) with additions from Campbell and Sims (2009) (Cnidaria) and from personal communications with I. Jones and R. Cannings (seabirds, Aves). 'Pisces' includes cartilaginous and bony fishes.*

midwater and deeper parts of the oceans is generally poorly known (Webb et al. 2010) and that it is likely to be very high. It is also telling that only 16% of Canadian researchers with taxonomic expertise surveyed by the Council of Canadian Academies' Expert Panel on Biodiversity Science (2010) reported marine habitats as the main habitat for their primary taxa of expertise. In contrast, 61% reported focusing on aspects of terrestrial biodiversity and 23% on freshwater taxa, and more than a quarter of taxonomic experts in Canada work on insects.

The current inequality in species diversity between land and sea is reversed, however, if one considers higher taxonomic levels. For example, at the phylum level, Canadian oceans are far more diverse than land; two-thirds of the 63 major phyla found in Canada are predominantly marine, reflecting the much longer evolutionary history of marine versus terrestrial organisms.

11. How Many More Species?

Canada's three oceans are very diverse. However, our understanding of this diversity is uneven. More is known about vertebrates than invertebrates, about large than small organisms, and about swimming than burrowing creatures. It is very likely that the most serious gaps in our knowledge of species diversity in Canadian waters pertain to the most species-rich groups (e.g., the smaller infaunal invertebrates). A more complete understanding of the species richness of Canada's oceans will require significant shifts in research focus and societal interest.

The number of species in Canada's oceans that have yet to be discovered can be estimated by various means. One is to consult taxonomic experts who can provide educated estimates of the number of species that remain to be recorded or described in their taxa of interest. This was done by Mosquin et al. (1995), who estimated that only 48% of marine species in Canada had, to that date, been named and classified.

Another method is to extrapolate from a taxonomic group, or a region, that has been relatively well surveyed. Marine fishes within European seas are good examples. There are currently 27,929 recorded species of multicellular plants and animals in the European Register of Marine Species (Costello and Wilson 2011). This list includes a much more comprehensive coverage of habitats and area than its Canadian counterparts. Of this total, 1,349 species are fishes. If fish species comprise the same proportion of species in Canada as they do in Europe, the ~900 Canadian marine fishes should be associated with ~18,600 plant and animal species in Canada's oceans (2.7 times as many as have been identified to date). Of course, this extrapolation will be biased if the ratio of fish to total richness varies geographically (which it probably does) or if the reference inventory is incomplete (which it certainly is).

A third approach is to consider the rate at which new species are added to an inventory as sampling effort increases or time elapses. The premise of this method is that new species should initially be added quickly, given that there are many unrecorded species available. However, the rate of addition of new species should decrease as samples accumulate and as time elapses, as scientists continue to search for elusive, unrecorded, or undescribed species. The relationship between the cumulative number of species in an area and effort or time should theoretically plateau to reveal the total number of species present. For example, when applied to the marine invertebrates of Haida Gwaii (Pacific Northern Shelf ecoregion), arguably the best inventoried marine subregion of the west coast (Sloan and Bartier 2010), the predicted number of species for this relatively small area exceeds 2,250 (Figure 3.11), nearly twice as many as that shown in Figure 3.10B for the entire Canadian Pacific region (Archambault et al. 2010).

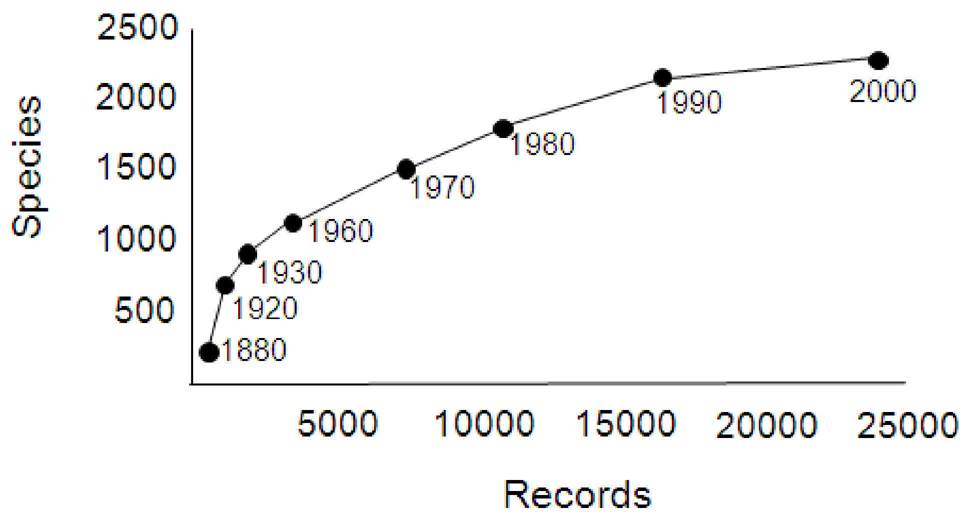


Figure 3.11. *Accumulation of marine invertebrate species around Haida Gwaii, BC, in relation to the number of literature- or collection-based records obtained between 1878 and 2000. Redrawn from Sloan and Bartier (2009).*

12. Main Findings

- Canada's coastline (two-thirds of which is in the Arctic) and ocean surface area exceed those of most countries.
- Twelve marine ecoregions delineate Canada's coastal waters: four in the Pacific; five in the Arctic; three in the Atlantic.
- More than 16,000 marine species have been recorded in Canada, although there may be at least two to three times as many species still to be found; a complete species inventory is lacking.
- The Pacific coast is particularly rich in seaweed species; the Arctic, in small crustaceans; and the Atlantic, in fish species.
- Canada hosts 40% of the world's marine mammal species.

Chapter Four: Physical and Chemical Indicators of Climate Change in Canada's Oceans

1. Introduction

The primary purpose of this chapter is address the question in the Panel's Terms of Reference that asked, "What are the past and current trends and associated uncertainties in physical and chemical indicators of climate change in Canada's three oceans?" The chapter begins with an examination of past and projected trends in several surface properties of the oceans (and, on occasion, comparative analyses of the terrestrial environment), including temperature, precipitation, salinity, and sea ice. This is followed by an examination of temporal trends in regional wind systems. Thereafter, the chapter focuses on trends in indices that reflect ocean climate variability. To take one of these indices as an example, when the Pacific Decadal Oscillation is positive, the west Pacific cools and parts of the eastern Pacific warm. The chapter concludes with treatments of temporal patterns in coastal sea levels, water chemistry (including ocean acidification), and ocean stratification. Although the primary focus is on Canadian waters, some of the trends are presented at a global scale either for comparative purposes or because of the difficulty in extrapolating projections derived from global models to the much smaller spatial scale of Canada's marine environment. The potential consequences of these past, current, and projected trends in these physical and chemical indicators of climate change are examined in Chapter Seven.

2. Surface Properties

a. Observed 20th Century Changes

Both globally and annually, averaged ocean surface temperatures have increased at a rate of 0.07°C/decade over the past century, but by 0.17°C/decade during the last thirty years (NOAA 2010). The spatial pattern of this annually-averaged warming trend reveals several characteristic features (Figure 4.1). First, there have been greater rates of warming over land than over oceans. (In the northern hemisphere, terrestrial warming rates have generally been greatest in winter for North America and Europe, and in spring for Asia; Figure 4.2.) Second, there is more warming in the northern hemisphere than in the southern hemisphere. Third, the warming rates are typically stronger in the middle of the continents or on their leeward coasts than on their windward coasts. Fourth, the warming rates at high latitudes are greater than those at low latitudes. Fifth, there have been some localized regions of cooling.

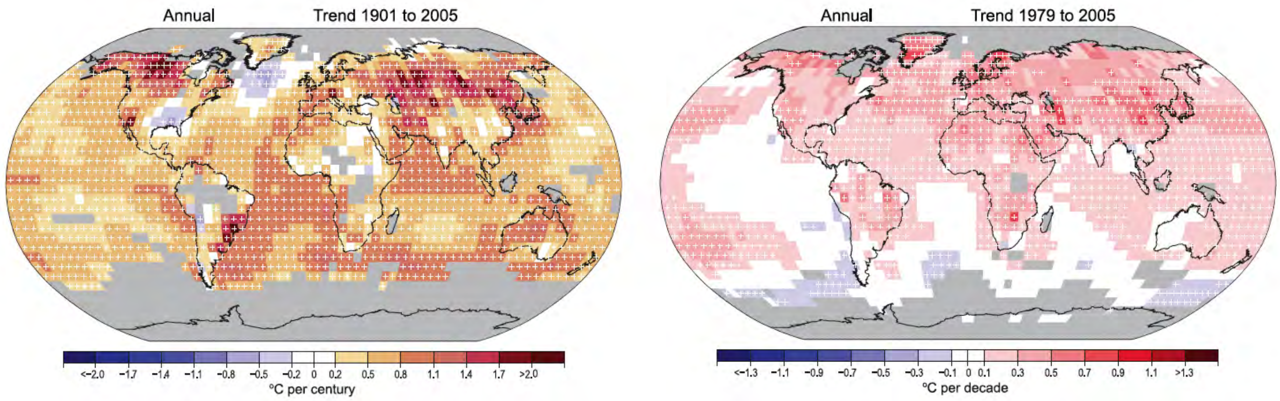


Figure 4.1. *Observed trends in annual mean temperatures over the period 1901 to 2005 (left) in °C per century and 1979 to 2005 (right) in °C per decade. Red regions indicate warming trends; blue regions indicate a cooling trend; grey regions indicate insufficient data to determine a trend reliably. Source: Trenberth et al. (2007).*

The northwest Atlantic annual mean surface air temperature trend over the last century (left panel of Figure 4.1) is also discernible from localized station temperature data in the Gulf of St. Lawrence and on the Newfoundland Shelf (Figures 4.3, 4.4). As noted by Galbraith et al. (2010), the warming trend inferred from Charlottetown surface air temperature data is 0.78–0.90°C per century, whereas it is 2.0°C per century for equivalent data from Pointe-au-Père (Figure 4.3). Although data from Station 27 on the Newfoundland Shelf show very little warming since 1950 (Figure 4.4), the rate of warming since the mid-1980s is significant, both within the Gulf of St. Lawrence and at Station 27.

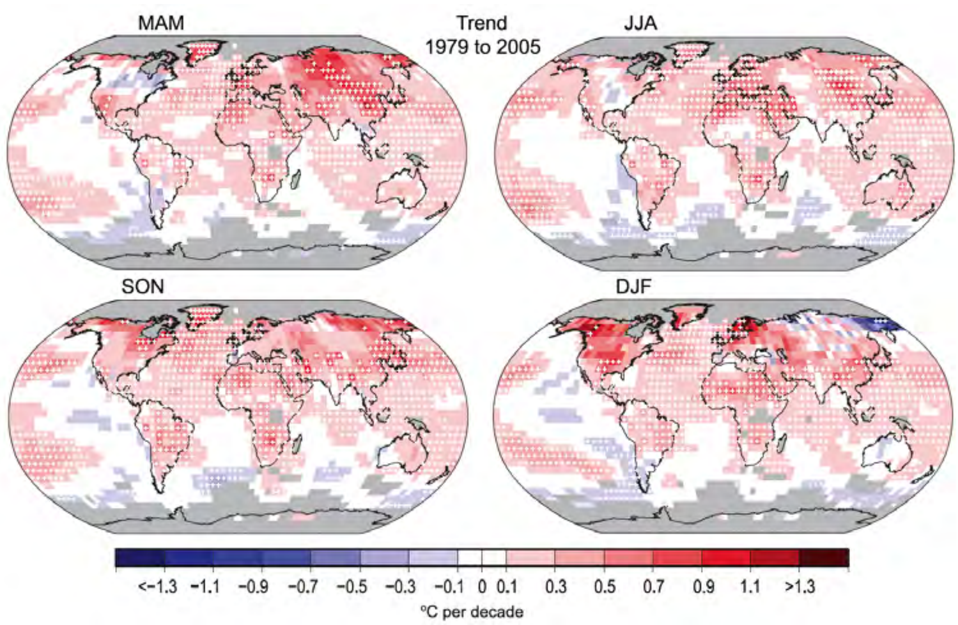


Figure 4.2. *Trends in seasonal mean temperatures over the period 1979 to 2005 in °C per decade. Red regions indicate warming trends; blue regions indicate a cooling trend; grey regions indicate insufficient data to determine a trend reliably. Results are shown for the seasons spring (March, April, May: MAM), summer (June, July, August: JJA), autumn (September, October, November: SON), and winter (December, January, February: DJF). Source: Trenberth et al. (2007).*

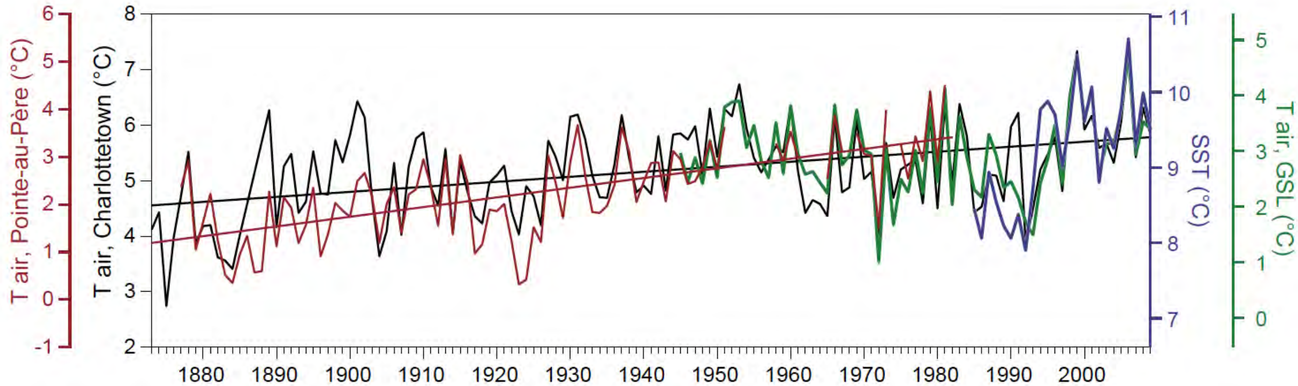


Figure 4.3. *Blue line: Average sea surface temperature (SST) over the Gulf of St. Lawrence from May to November. Green line: Annual mean average surface air temperature averaged over nine Environment Canada stations around the Gulf of St. Lawrence (Sept-Îles, Natasquan, Blanc-Sablon, Mont-Joli, Gaspé, Daniel's Harbour, Charlottetown, Îles de-la-Madeleine, and Port aux Basques). Black line: Annual mean average surface air temperature from Charlottetown together with the linear trend. Red line: Annual mean average surface air temperature from Pointe-au-Père (near Rimouski) together with the linear trend. Galbraith et al. (2010) used the surface air temperature records as a proxy for Gulf of St. Lawrence SST based on a very high correlation between these time series during modern times. Source: Galbraith et al. (2010).*

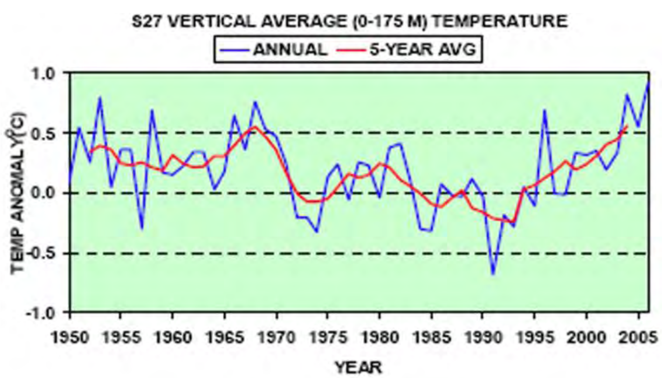


Figure 4.4. *Time series (1950-2005) of vertically-averaged temperature (0-175 m) from Station 27 located on the Newfoundland Shelf off St. John's Harbour (47°32.8'N, 52°35.2'W). Source: Templeman (2010).*

Adequate data are not available to allow for the reliable calculation of precipitation trends over many parts of the world (Figure 4.5). However, those features of the climate system that integrate precipitation falling over wide surface areas, and for which long-term records exist (such as sea surface salinity [SSS] and river discharge), provide valuable indicators of changes in the hydrological cycle and, in particular, its intensification. For example, Petersen et al. (2002) reported that discharge into the Arctic Ocean from the six largest Eurasian rivers (see Figure 3.3) had increased by 7% from 1936 to 1999. In addition, Durack and Wijffels (2010) examined trends in global ocean surface salinity changes from 1950 to 2008 (Figure 4.6). Their analysis revealed strong trends in SSS over much of the global ocean. The researchers noted that the pattern of these spatially coherent trends bore a striking resemblance to the climatological SSS field (Figure 4.6B; cf. Figure 4.6A). Those high SSS subtropical regions dominated by net evaporation are typically becoming more saline; lower SSS regions at high latitudes are typically becoming fresher (Figure 4.6B; cf. Figure 4.6C). In the North Atlantic, the northward transport of saline, subtropical waters by the Atlantic meridional and subsequent overturning circulation complicates this scenario slightly.

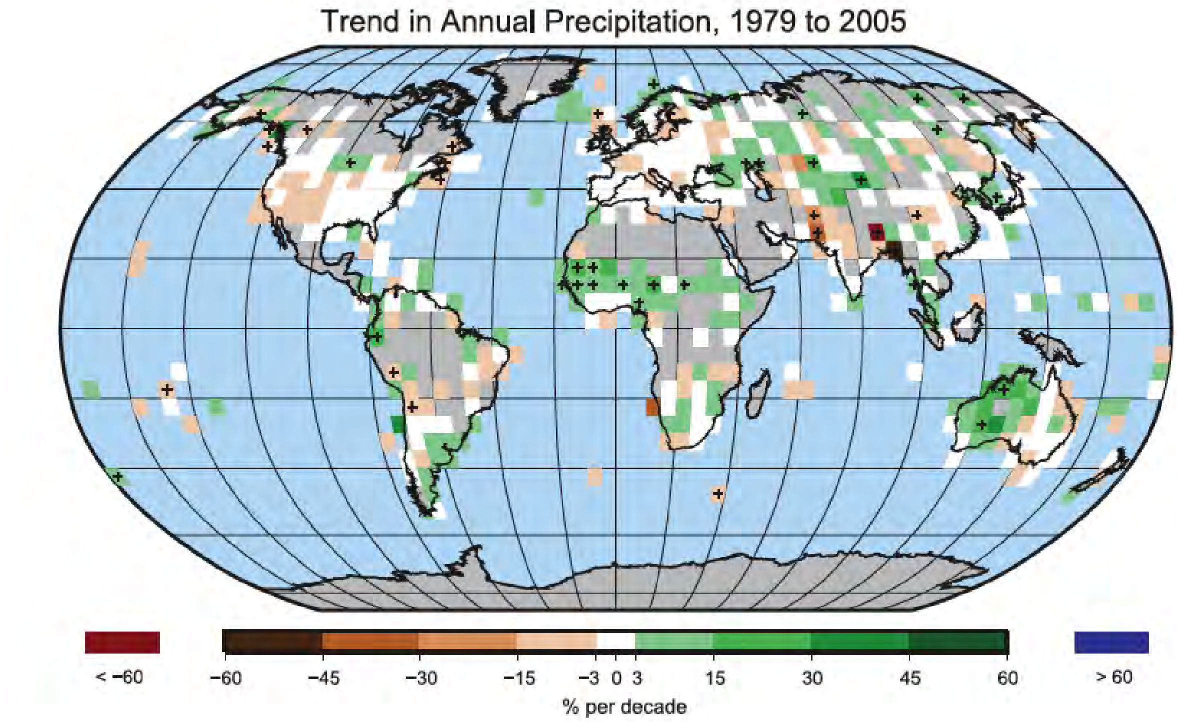


Figure 4.5. *Observed trends in annual precipitation (1979-2005) in % per decade (the % is relative to the 1961-1990 mean). Green: increasing precipitation trends; brown: decreasing precipitation; grey: insufficient dat a available to determine a trend reliably. Source: Trenberth et al. (2007).*

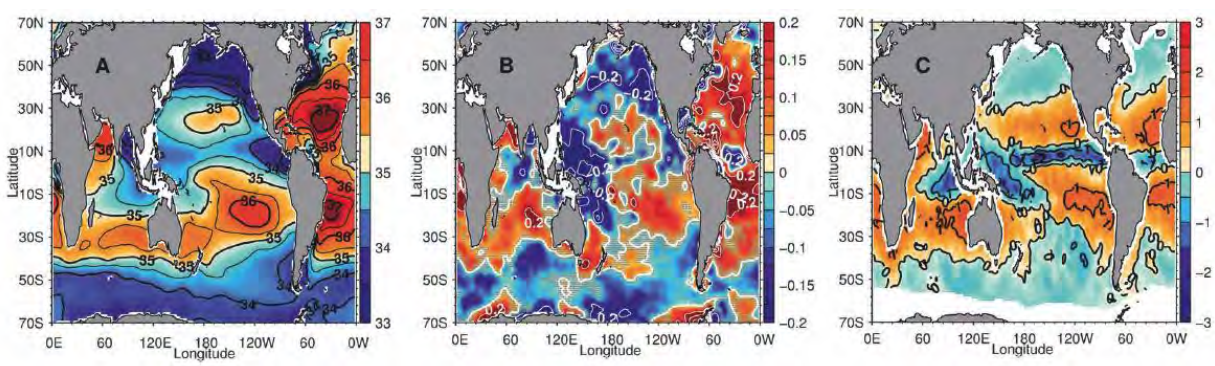


Figure 4.6. *(A) Climatological annual mean surface salinity (in parts per thousand, on the right axis) from 1950-2000. (B) The linear trend in salinity over-calculated the period 1950-2008 (units: pss [practical salinity scale] per 50 years). (C) Freshwater flux (m^3 yr^{-1}) at the ocean atmosphere interface averaged over the period 1980-1993. Source: Durack and Wijffels (2010).*

Since the 1979 advent of satellite measurement, Arctic sea ice cover in both summer and winter has been in steady decline (Figure 4.7). Minimum September sea ice extent has decreased at a rate of 12.04% per decade, whereas March sea ice extent has been decreasing at a rate of 2.74% per decade. Given this scenario, the extrapolated extension of the linear trend points to an ice-free Arctic in September 2071 (but see the chapter section below entitled "Projected Changes During the 21st Century").

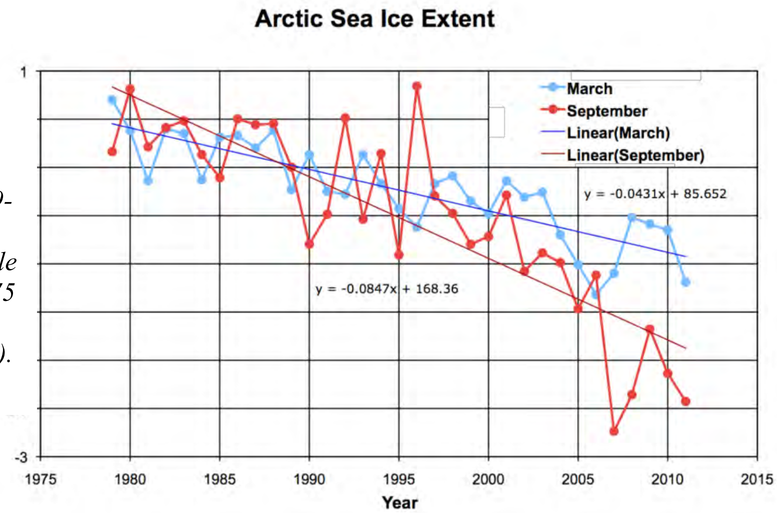


Figure 4.7. *Arctic sea ice extent from 1979 to the present for March and September. Area is expressed as an anomaly in million km*^{2} *from the 1979-2000 average. The September 1979-2000 average is 6.04 million km*^{2} *while the March 1979-2000 average is 15.75 million km*^{2}*. Source: National Snow and Ice Data Centre (http://nsidc.org).*

In recent years, Arctic sea ice thickness has also been decreasing. Kwok and Rothrock (2009) found that the average winter sea ice thickness declined 48% from 3.60 m in 1980 to 1.89 m in 2008. Using a coupled ice-ocean model, Lindsay et al. (2009) further estimated that the September sea ice thickness has, since 1987, been decreasing at a rate of 57 cm per decade. Given that older ice tends to be thicker than younger ice, this decline in thickness can be readily seen in the observed reduction of Arctic sea ice age during the last 30 years (Figure 4.8). Average ice age in the Arctic continued to decline in 2009 (Figure 4.8C) before recovering slightly in 2010 (Figure 4.8D; Figure 4.9). While there was a slight aging of ice in 2011, less than 30% of the Arctic ice is more than a year old, a drop of nearly 50% since 1979 (Figure 4.9).

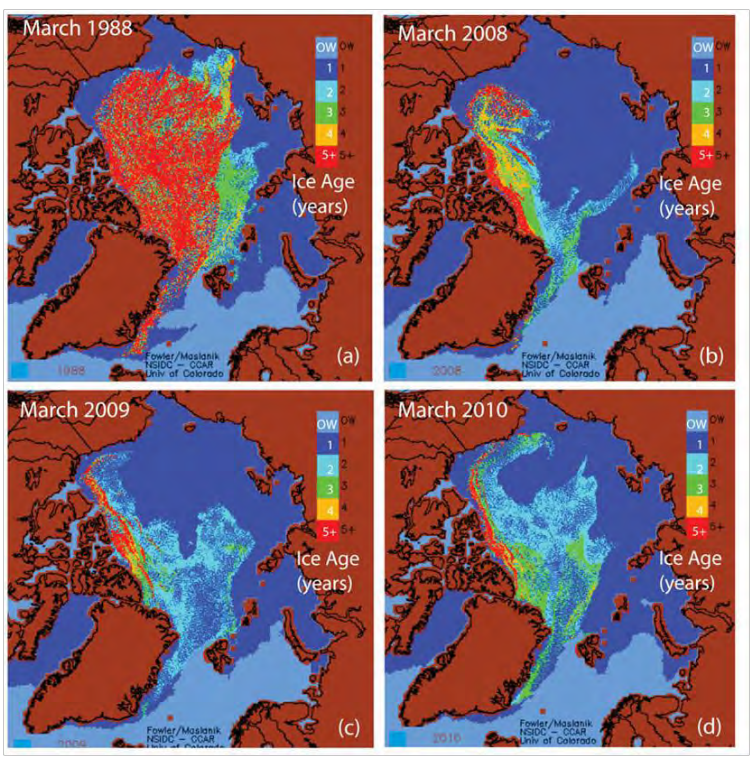


Figure 4.8. *Age of Arctic sea ice in March (a) 1988; (b) 2008; (c) 2009; (d) 2010. Red indicates ice of an age of five or more years. Source: Perovich et al. (2010).*

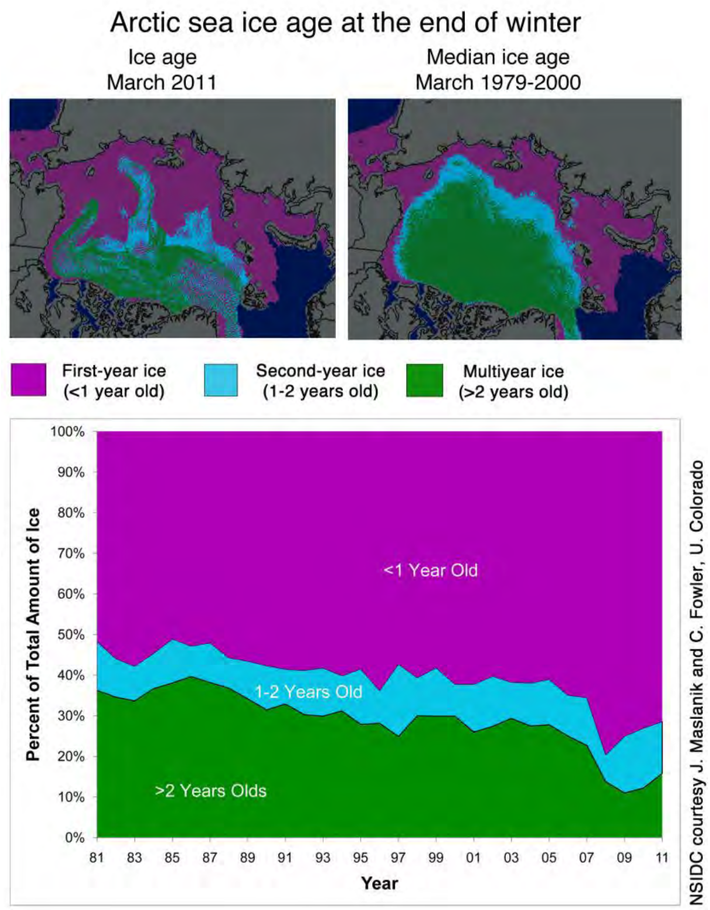


Figure 4.9. *Top: Age of Arctic sea ice in March 2011 and the median ice age for March over the period 1979-2000. Bottom: Percentage of March ice with a particular age from 1981-2011. Source: National Snow and Ice Data Centre (http://nsidc.org).*

Significant trends towards declining sea ice extent and thickness are also evident on Canada's east coast. For example, the linear trend of sea ice coverage from 1979-2011 is -3.9% (± 2.2%) per decade for the Gulf of St. Lawrence region (Figure 4.10 top) and -3.1% (± 1.5%) per decade for the Labrador Sea region (Figure 4.10 bottom). Sea ice extent was at, or below, record minimum levels during the winters of both 2009/2010 and 2010/2011. During 2010/2011, sea ice coverage (5.2%) was 72% below its 1979-2011 winter average in the Gulf of St. Lawrence. In the same year, the ice cover in the Labrador Sea region was at a record low of only 4.0% coverage, 71% below the 1979-2011 average.

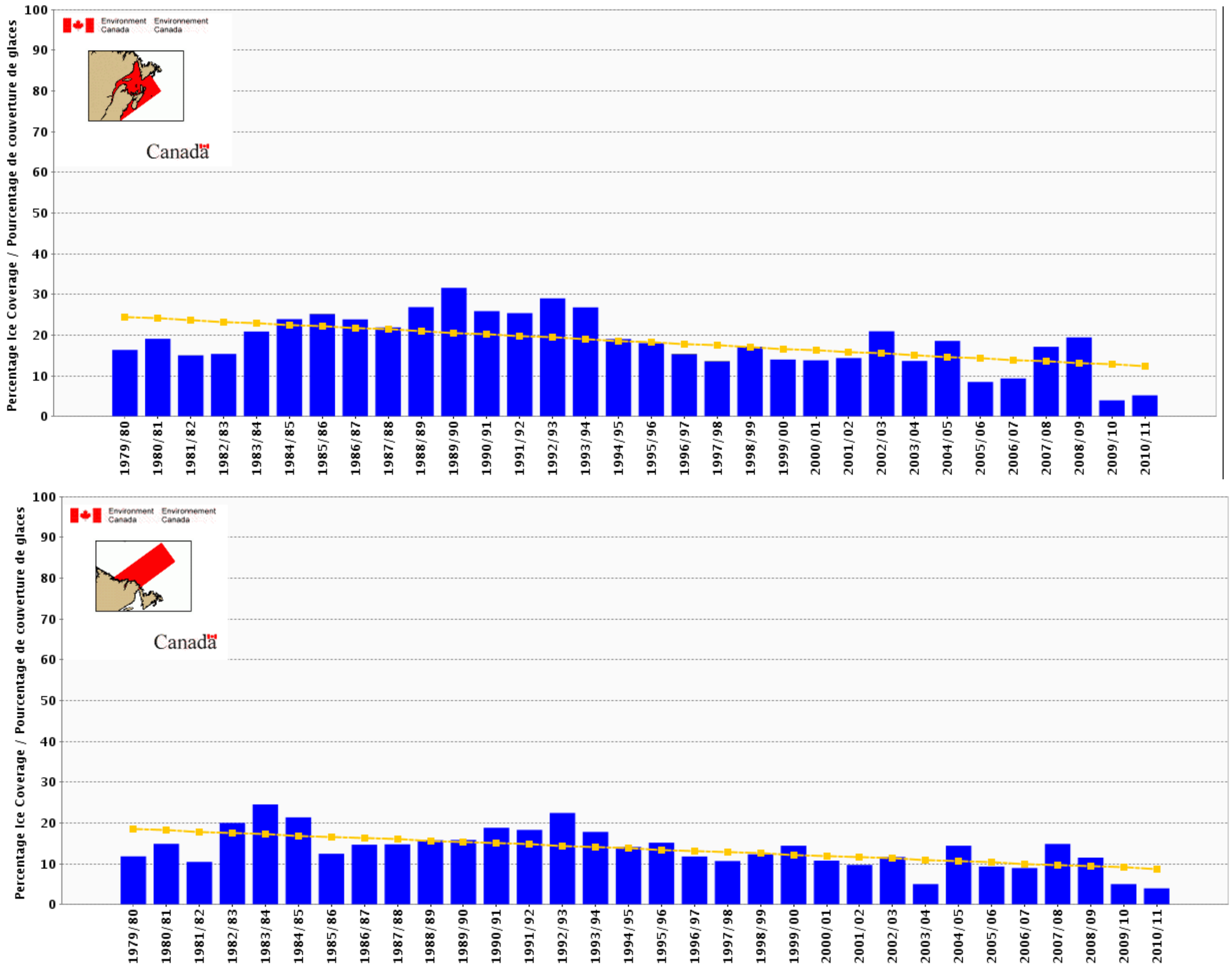


Figure 4.10. *Top: Percentage winter (November 26 through March 5) sea ice coverage in the Gulf of St. Lawrence (red area in top left corner of panel) for the period 1979–2011. Bottom: Percentage winter (November 26 through March 5) sea ice coverage over the Labrador Sea region (red area in top left corner of panel) for the period 1979–2011. The linear trend is indicated in yellow. Source: Canadian Ice Service (http://dynaweb.cis.ec.gc.ca/IceGraph20/).*

b. Projected Changes During the 21st Century

The retreat of September Arctic sea ice over the last several decades was much faster than that simulated by any of the climate models assessed in the IPCC 4th Assessment Report (Stroeve et al. 2007). This is likely due to a combination of several model deficiencies: (i) incomplete representation of ice albedo (reflecting power) physics, including the treatment of melt ponds (e.g., Pedersen et al. 2009); (ii) omission of surface warming associated with the deposition of black carbon (soot) (e.g., Flanner et al. 2007; Ramanathan and Carmichael 2008); and (iii) incomplete representation of the physics of vertical and horizontal mixing in the ocean (e.g., Arzel et al. 2006).

Climate models assessed by the IPCC Fourth Assessment Report, or AR4, revealed a linear relationship between annual mean Arctic sea ice extent and global mean surface air temperature

(NRC 2011; Winton 2011). In particular, annually-averaged Arctic sea ice extent is predicted to decrease by about 15% per degree of global warming (NRC 2011). However, Winton (2011) showed that the observational record exhibits a greater decline per degree of warming than the AR4 models. Several recent studies (Boé et al. 2009; Wang and Overland 2009; Zhang 2010) have used observational constraints on subsets of the AR4 climate model simulations to estimate when, during summer, the Arctic might first become ice free. Both Wang and Overland (2009) and Zhang (2010) suggest a nearly ice-free summer could occur in the Arctic as early as the late 2030s, with a few remaining ice covered areas existing around the northern edge of the Canadian Arctic Archipelago (cf. Figure 4.2).

The fifth phase of the Coupled Model Intercomparison Project (CMIP5) involves contributions from twenty modelling groups worldwide. Environment Canada's Canadian Centre for Climate Modelling and Analysis provides the Canadian contribution. Future climate projections, coordinated through CMIP5, are also being used in the fifth Assessment Report of the Intergovernmental Panel on Climate Change (AR5). As part of CMIP5/AR5, four new Representative Concentration Pathways (RCPs) were developed to provide models with estimates of future radiative forcing associated with anthropogenic emissions of greenhouse gases and aerosols. Each of the four components is named after the radiative forcing (in W[watts] m^{-2}) it produces at year 2100. By definition, RCP4.5 yields a net radiative forcing of 4.5 W m^{-2} in year 2100.

Projected warming of globally-averaged sea surface temperature (Figure 4.11) over the next two decades (~0.24°C per decade in the Canadian CGCM4/CanCM4 model) is relatively insensitive to the emissions trajectory. However, projected outcomes diverge as the 21st century progresses. By year 2100, RCP4.5 yields 1.6°C additional warming above the 1995-2005 average. The corresponding results for RCP8.5 and RCP 2.6 are 2.6°C and 0.9°C, respectively.

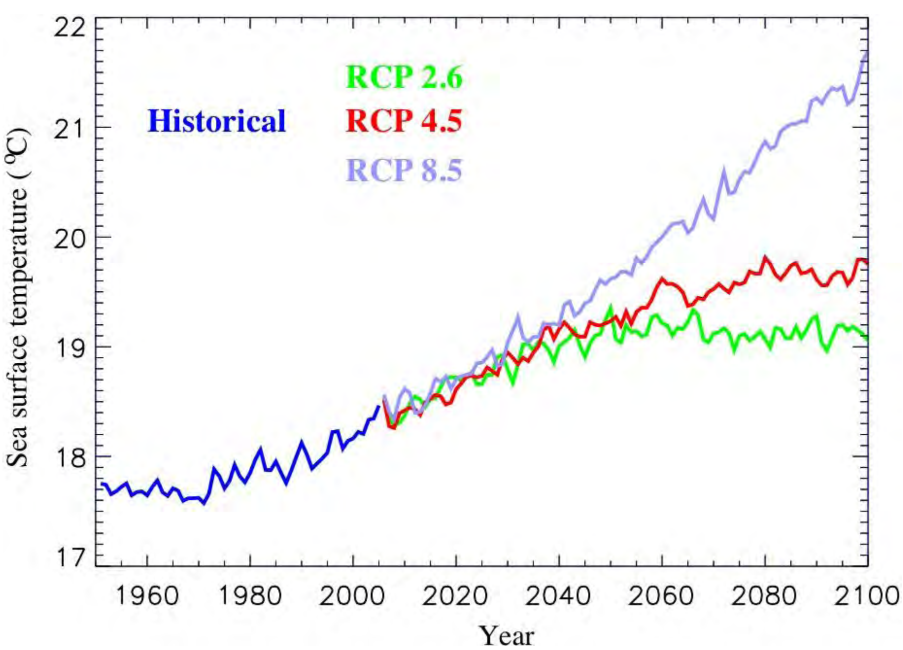


Figure 4.11. *Projected ensemble average of the RCP 2.6, 4.5, 6, and 8.5 globally-averaged, annual mean sea surface temperature from 1955 through to 2100. The output shown is from the Canadian CGCM4/CanCM4 contribution to CMIP5 (see Arora et al. 2011).*

The warming of the upper ocean is further illustrated in the zonally-averaged potential temperature fields shown in Figure 4.12. Sub-surface warming is most pronounced where North Atlantic deep water forms in the northern hemisphere and where Antarctic Intermediate Water forms in the southern hemisphere. Projected regional warming patterns for the new RCP emissions trajectories are not yet available from the various modelling groups. Given this, and as an illustration of the projected regional change in surface temperature, we include Figure 4.13 taken from Christensen et al. (2007). Several features are notable and are consistent with a continuation of existing trends. First, projected warming is amplified over land, relative to the oceans, because of the high heat capacity of water. Second, due to the downstream influence of the ocean, the warming is typically stronger in the middle of the continents, or on their leeward coasts, than on their windward coasts. Third, warming is greater at higher latitudes than at lower latitudes, due to local feedbacks, particularly ice/snow-albedo and ice-insulating feedbacks. Moreover, at these same higher latitudes, warming is much greater in winter than in summer because this is when the feedbacks are strongest. The opposite is true over southern continental areas where reduced summer precipitation and soil moisture leads to an increased Bowen ratio (ratio of sensible to latent surface heat flux).

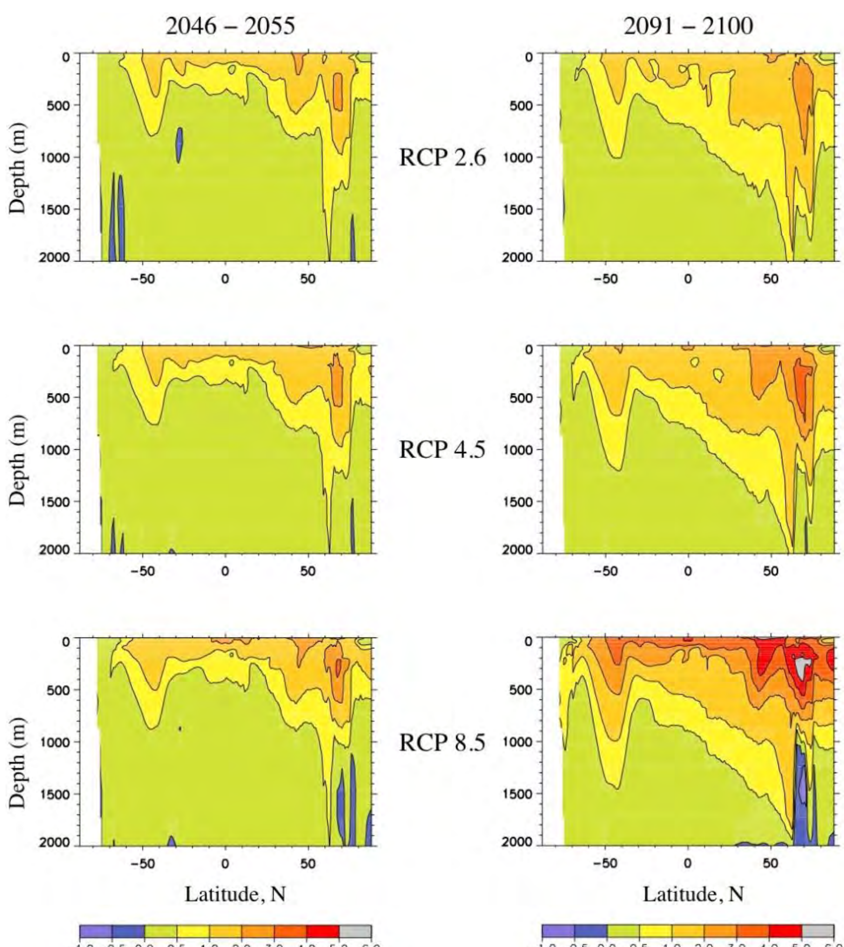


Figure 4.12. *Projected ensemble average of the RCP 2.6, 4.5, 6, and 8.5 zonal mean potential temperature change from pre-industrial times averaged over 2040-2060 and 2080-2100. Model results are shown from the CGCM4/CanCM4 contribution to CMIP5.*

Over the middle to high latitudes of North America, including all of Canada, precipitation is expected to increase (Figure 4.13). The opposite is true for the subtropical latitudes of the United States. In middle to high latitudes, the increase is greater in winter, with an increasing likelihood of rain instead of snow. At the same time, there is a greater likelihood of summer drought. Precipitation intensity and the interval between precipitation events are also projected to increase. That is, it will rain less often, but when it does rain, there will be more of it. As the difference between high latitude and subtropical temperatures shrinks, due to amplification of global warming at high latitudes, the overall number of mid-latitude storms is projected to decrease. Concurrently, the paths these storms take (storm tracks) will shift poleward and the likelihood of storms with intense wind speeds will increase. Therefore, there will be fewer overall storms, but when they do occur, there is a greater chance of their bringing stronger winds. The consequences for wave height and for coastal erosion are potentially profound.

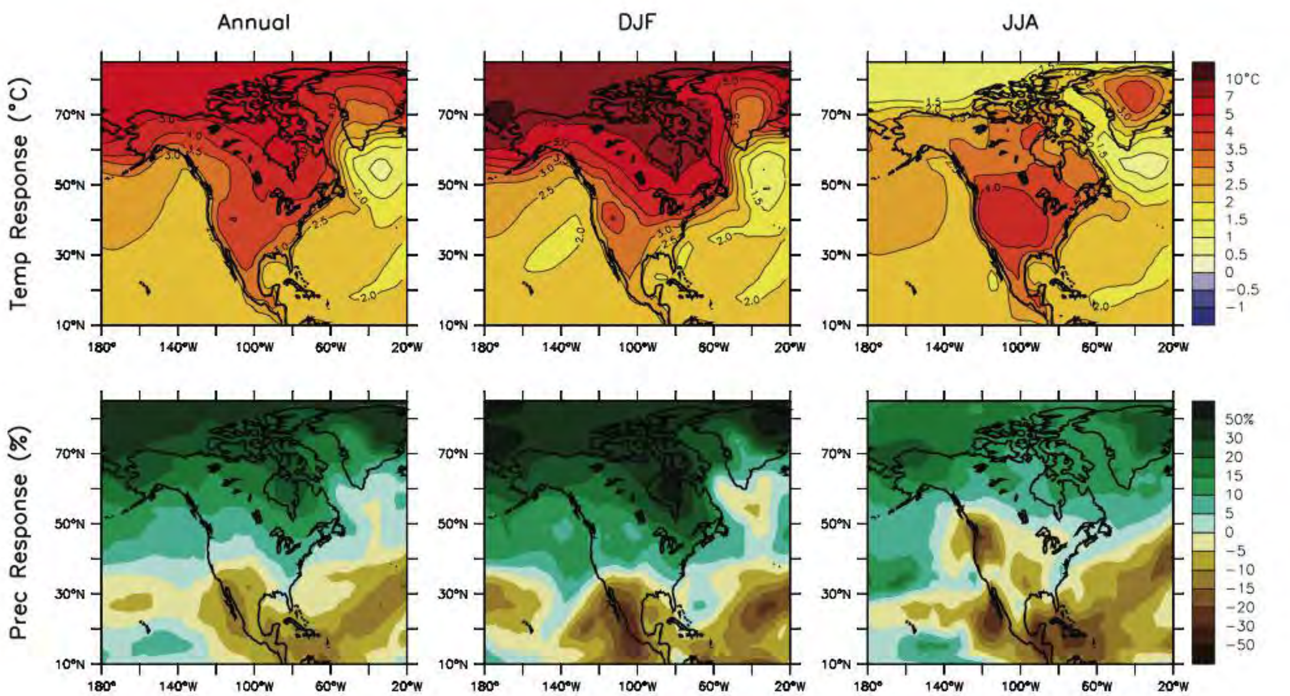


Figure 4.13. *Projected multi-model ensemble temperature (top) and precipitation (bottom) changes over North America from the 1980-1999 average to the average over 2080-2099. The mid-range A1B emissions scenario was used. The first column shows the annual mean response whereas the second and third columns provide the average winter (December–February) and summer (June-August) responses, respectively. Source: Christensen et al. (2007).*

The projected increase in both high-latitude temperature and precipitation tends to make the high-latitude surface waters of the North Atlantic lighter and hence heightens their stability. As illustrated in Figure 4.14 for the CGCM4/CanCM4 models, a slight weakening of the Atlantic meridional overturning circulation (AMOC) is predicted to occur during the 21st century. This is associated with a cessation of deep-water formation in the Labrador Sea and, hence, reduced vertical mixing of cold surface waters with underlying warmer subsurface waters. The net result is a reduction of the surface warming trend there (Figure 4.13). Once the radiative forcing is stabilized, the AMOC recovers to its preindustrial level (Figure 4.14). Gregory et al. (2005) found that for all eleven models analysed, the AMOC reduction was caused more by changes in surface heat flux than by alterations in surface freshwater flux.

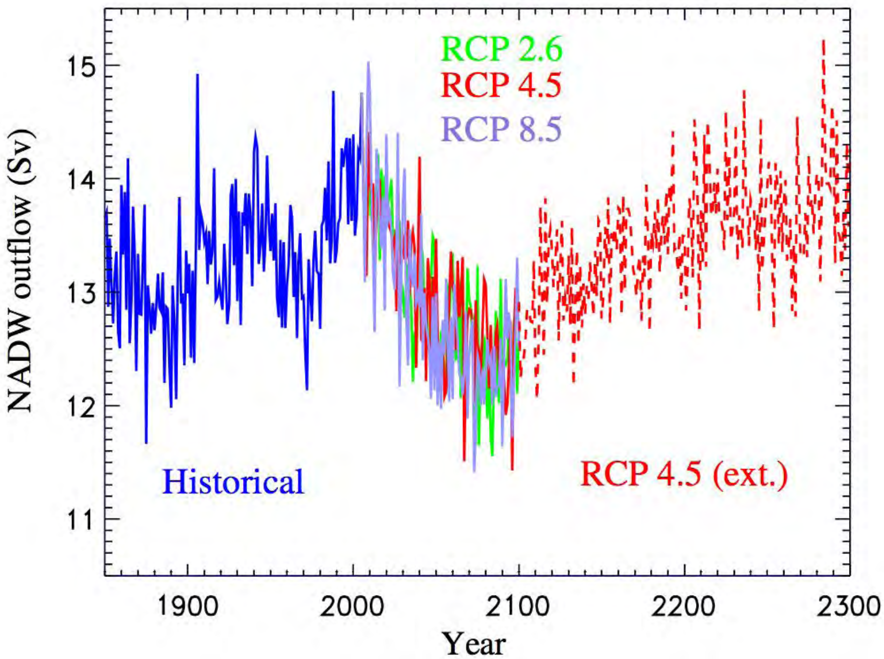


Figure 4.14. *Ensemble average outflow of the Atlantic Meridional Overturning Circulation (AMOC) at 25-30°S from 1850-2100. The RCP 4.5 extension to 2300 with radiative forcing held fixed at 4.5 W/m^2 after 2100 is also presented. Model results are shown from the CGCM4/CanCM4 contribution to CMIP5.*

As noted in Meehl et al. (2007), it is very unlikely that the AMOC will undergo an abrupt transition or collapse in the 21st century. As noted by Delworth et al. (2008), for such a phenomenon to occur, the sensitivity of the AMOC to forcing would have to be far greater than that seen in current models, or significant ablation of the Greenland ice sheet would be required, far exceeding even the most aggressive of current projections. Whereas neither possibility can be eliminated entirely, it is unlikely that the AMOC will collapse during the 21st century because of global warming.

3. Observed and Projected Trends in Regional Wind Systems

At the largest spatial scales, analyses of historical sea level pressure (SLP) and surface wind data have revealed that the intensity of both the Icelandic and Aleutian Low pressure cells, along with the strength of associated west-to-east blowing surface winds over the North Pacific and North Atlantic Oceans, increased between 1970 and 2005. Aspects of these increases are captured by indices tracking the state of atmospheric modes of variability over the North Pacific, North Atlantic, and Arctic Oceans.

a. Aleutian Low

Major changes in the intensity of the Aleutian Low over the North Pacific were associated with the 1976-77 climate shift, which saw a persistently more intense Aleutian Low, and a stronger counter-clockwise surface wind circulation in the decade after 1976, when compared with the previous decade (Trenberth 1990; Trenberth and Hurrell 1994). In the period between 1989 and 2011, the intensity of the Aleutian Low and the associated counter-clockwise winds over the

North Pacific have, on average, been weaker than in the 1980s, given the substantial year-to-year variability in the 1990-2011 period (Figure 4.15).

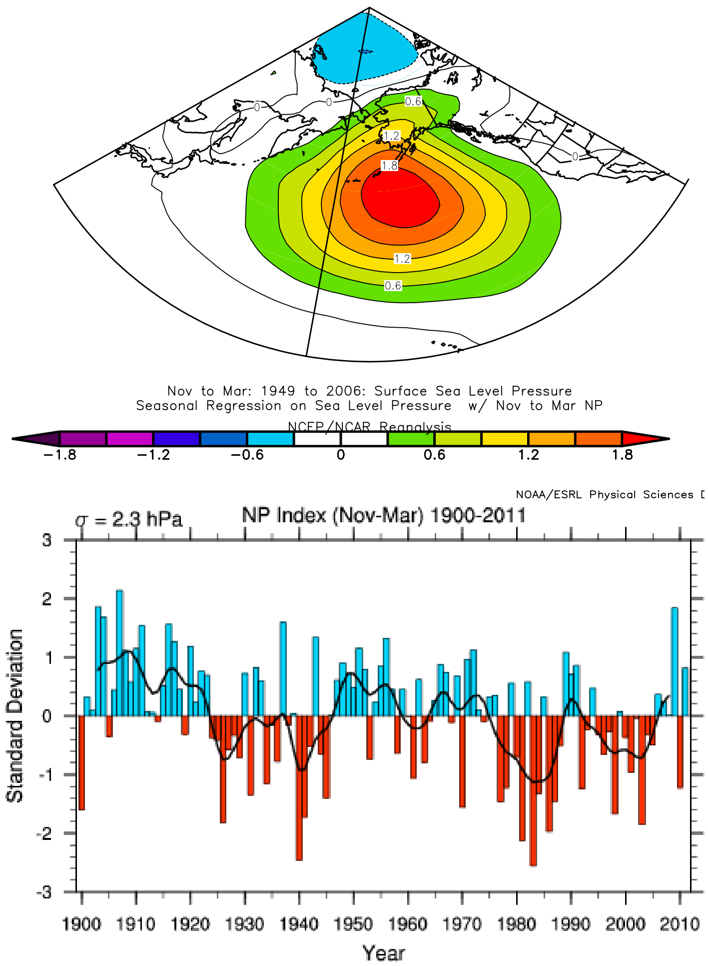


Figure 4.15. *(Top) Spatial pattern of Aleutian Low sea level pressure variations tracked by the "North Pacific" (NP) index of Trenberth and Hurrell (1994) (image created using NOAA's online plotting tool at http://www.esrl.noaa.gov/psd/data/correlation/.*
(Bottom) Time series of the Nov-Mar NP index from 1900-2011. Figure obtained from http://www.cgd.ucar.edu/cas/jhurrell/indices.info.html#np.

Most models of climatic change project a northward displacement and strengthening of the mid-latitude west-to-east flow of winds and that this will be most pronounced in autumn and winter. These climate projections take into account a tendency for the centre of the Aleutian Low to move north of its historical climatological location. The reductions in surface pressure in the north are projected to be strongest in winter. The subtropical North Pacific High is also projected to intensify in summer, particularly off the coast of California and its Baja coast (Meehl et al. 2007).

b. Arctic Oscillation and Arctic Dipole

Interannual variability in sea level pressure over the northern hemisphere is dominated by changes in the Arctic Oscillation (AO) (Appendix C). When the AO index is positive, westerly winds that form a polar vortex are intensified, with the core of the western winds displaced poleward. In the 20th century, the winter-averaged AO index exhibited persistent periods during which it remained in the same phase (i.e., either positive or negative; Appendix C). During the 1990s, the winter AO remained in the positive phase, whereas prior to 1970 the opposite prevailed. In the period between 1995 and 2010, the AO exhibited substantial year-to-year variability. In the summer of 2007, an unprecedented shift in atmospheric conditions occurred over the Arctic (Zhang et al. 2008). The typical tri-pole structure of the AO was replaced by what is now known as the Arctic Dipole (Figure C.6 in Appendix C) which was also present in the late spring of 2009 and 2010 (Overland and Wang 2010). Many scenarios project decreases in Arctic surface pressure in the 21st century, as demonstrated by the average of scenarios from 13 different climate models (Figure 4.16) (Meehl et al. 2007). This contributes to an increase in indices of the AO and the North Atlantic Oscillation (NAO). However, the multi-model average from a larger number (n=21) of models indicates that, because different climate model scenarios show alternative trends, the future behaviour of the AO (and NAO) index is highly uncertain.

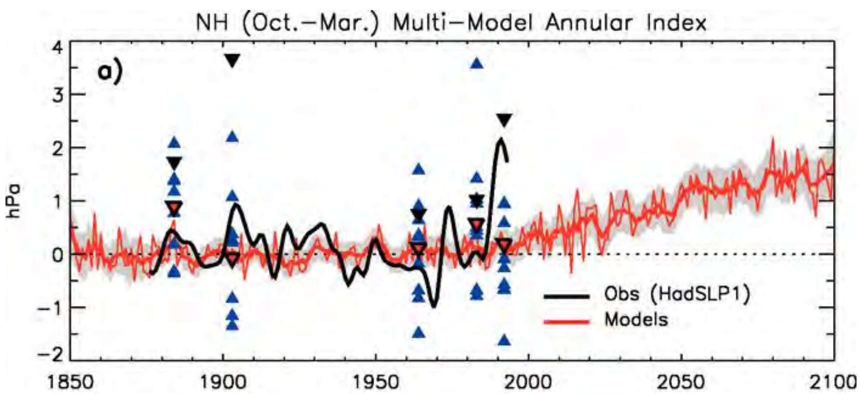


Figure 4.16. *Multi-model mean of the regression of the leading (EOF) empirical orthogonal function of ensemble mean Northern Hemisphere SLP (sea level pressure) (thin red line) relative to a 1900-1970 reference period with zero mean from 13 different climate models. The thick red line is a 10-year low-pass filtered version of the mean. The grey shading represents the inter-model spread at the 95% confidence level and is filtered. A filtered version of the observed sea level pressure from the Hadley Centre (HadSLP1) is shown in black. The regression coefficient for the winter following a major tropical eruption is marked by red, blue, and black triangles for the multi-model mean, the individual model mean, and observations, respectively. Source: Meehl et al. (2007).*

c. Coastal Upwelling and Downwelling Winds on Canada's West Coast

In winter, Canada's west coast typically experiences intense wind-driven coastal downwelling, while in summer, winds are typically weaker and more variable. Off the west coast of Vancouver Island, there are frequent periods of wind-driven coastal upwelling in summer. Coastal wind observations collected along this coast over the past 40 years do not indicate any clear trends in either summer upwelling or winter downwelling (Ianson and Flostrand 2010). Similarly, from 1948 to 2006, there are no definitive trends in local, wind-driven upwelling or winter downwelling for Queen Charlotte Sound and Hecate Strait. There are, however, especially large winter downwelling variations between years and decades (Cummins and Haigh 2010).

Merryfield et al. (2009) evaluated future trends in wind scenarios for locations off the west coast of Canada. Using 18 climate models, the researchers reported that upwelling winds will increase in speed by 5-10% and rotate clockwise ~5°, a combination that leads to increased summertime upwelling, whereas ensemble mean changes in winter downwelling winds are not statistically significant.

4. Observed and Projected Trends in ENSO, PDO, and NPGO

a. El Niño Southern Oscillation (ENSO)

The behaviour of ENSO varied considerably from the late 19th to early 21st century, with especially active periods in the early 1900s and again since the 1950s. The period from 1925 to 1950 was relatively quiet. ENSO behaviour changed following the previously mentioned 1976-77 climate shift; since then it has been characterized by a tendency for longer-lasting and more intense ENSO events (Meehl et al. 2007). For example, the 1982-83 and 1997-98 El Niño events are the strongest on record. During the 1990s and through the early 2000s, a new type of El Niño was prominent, with maximal warming located near the International Dateline rather than the eastern equatorial Pacific (Yeh et al. 2009). This phenomenon has been recently named by various researchers as the central Pacific warming (CPW), dateline El Niño, the El Niño Modoki, and the warm pool El Niño. Among the climate model scenarios summarized in the IPCC's Fourth Assessment Report, most projections indicate weak trends towards El Niño-like changes in the climate of the tropical Pacific, while only a few show weak trends toward La Niña-like conditions (Meehl et al. 2007). The models are more evenly split in projections for trends in the ratio of future variability of ENSO compared with that of past variability (Figure 4.17).

Collins et al. (2010) use several metrics to screen future scenarios based on each climate model's ability to reproduce key characteristics of observed ENSO behaviour. The authors find that half the scenarios from the subset of 'best'-performing models show increased ENSO variability, while the other half show decreased ENSO variability. Moreover, this same split between increased and decreased ENSO variability is present for the subset of 'worst'-performing models. Recent analyses show that model projections of anthropogenic climate change are associated with an increased frequency of CPW El Niño events, when compared to the canonical eastern Pacific El Niño events that characterized most of the 20th Century (Yeh et al. 2009).

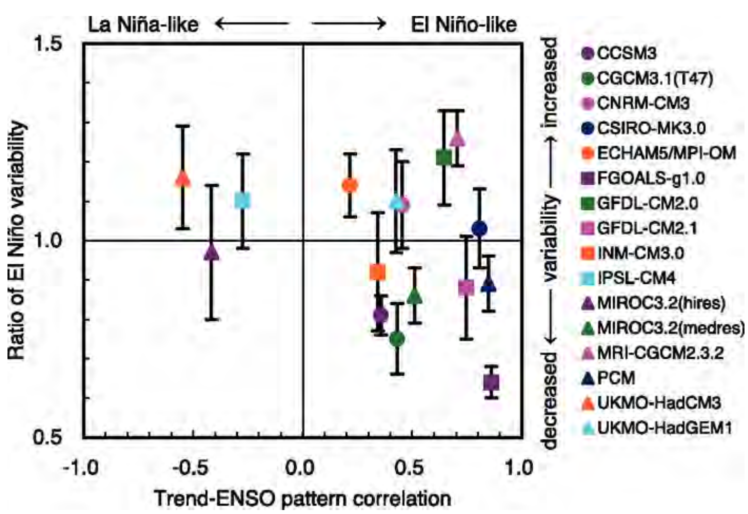


Figure 4.17. *Base state change in average tropical Pacific sea surface temperatures and change in El Niño variability simulated by climate models contributing to the IPCC's Fourth Assessment Report. Source: Meehl et al. (2007).*

b. Pacific Decadal Oscillation (PDO)

In records from 1900-2010, the PDO pattern varied across periods ranging from interannual to interdecadal, with a tendency for elevated variance at periods of 15-to-25 and 50-to-70 years, but with no distinct periodicities (Minobe 1999). Paleoclimate reconstructions for PDO behaviour over the past few centuries find sustained interannual to interdecadal variability across a range of timescales, with no predominant fixed bands of periodicities.

Overland and Wang (2007) evaluated several dozen 21st century scenarios produced by 18 climate models to better understand the behaviour of the PDO and North Pacific SST (sea surface temperature) changes in a warming climate. The authors found that ten of the climate models reproduce the spatial patterns and characteristic variability associated with the PDO in both 20th century 'control' experiments as well as 21st century future scenarios. Nonetheless, the near-uniform warming trends become the most prominent pattern in the 21st century. By comparing multimodel average trends with individual model scenarios for SST in the central North Pacific, the authors demonstrate that, probably until some point in the 2030s to the 2050s, the anthropogenic climate change signal is likely to be swamped by natural-origin SST variations (some of which are associated with the PDO) (Figure 4.18).

c. *North Pacific Gyre Oscillation (NPGO)*

Di Lorenzo et al. (2010) showed that decadal fluctuations in the NPGO are characterized by a pattern of SST anomalies that resemble the central Pacific warming (CPW) pattern of recent El Niño events, and that the tropical SST anomalies are responsible for an atmospheric teleconnection that forces the NPGO pattern in the North Pacific. If the 21st century climate scenarios indicating an increased frequency of the CPW El Niño events are realized, the NPGO is likely to play an increasingly predominant role in future North Pacific climate and oceanographic variability.

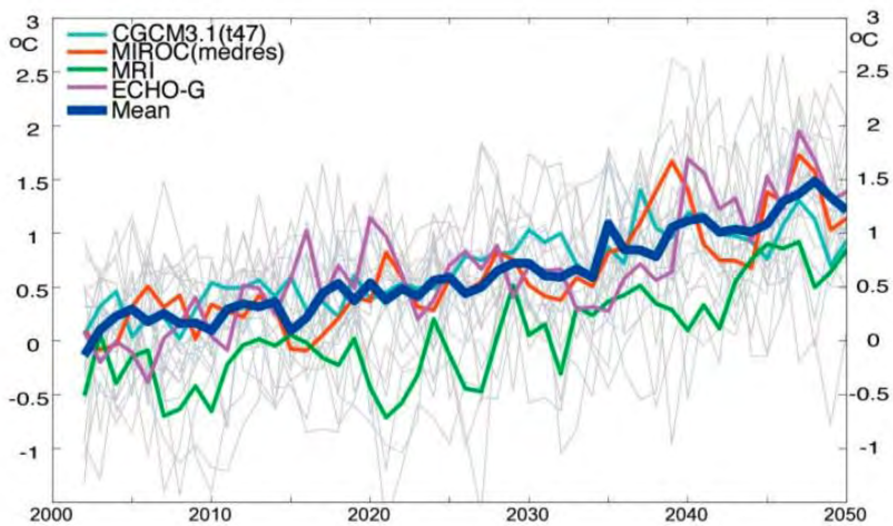


Figure 4.18. *Projected winter SST anomalies (°C) relative to a 1980-1999 base period for the central North Pacific Ocean (in the centre of the PDO SST pattern). Thin grey lines indicate individual ensemble member projections from ten different climate models under the A1B greenhouse gas emissions scenario, while coloured curves are the ensemble means from four of the individual models. The bold blue curve indicates the trend of the all-model ensemble mean. Source: Overland and Wang (2007).*

5. Coastal Sea Level

a. Present Rate of Change and Coastal Erosion

At the last glacial maximum, approximately 21,000 years ago, most of Canada was covered by the extensive Laurentide Ice Sheet. Whereas this ice sheet has long since melted, its effects are still evident on Canada's coastlines. When the Laurentide ice sheet grew, it depressed the surface of the earth below it. When the ice sheet melted, the crust began to return to its normal elevation. Today, the land is still rising in large parts of Canada, as a result of a process known as post-glacial or isostatic rebound (Figure 4.19). Peltier (2004) estimated peak rates of isostatic uplift to be about 1.5 cm year^{-1} and occurring in the middle of Hudson Bay; isostatic uplift for the town of Churchill, Manitoba, is about 1.2 cm year^{-1}. Similarly, Lake Superior's northern shores are rising by 3 to 4 mm year^{-1}, thereby affecting its shorelines. Conversely, at the same time, the southern shore of Lake Michigan is sinking by about 1 mm year^{-1}. So, too, glacial isostatic adjustment along the coasts of BC and the Maritimes is causing the land to subside, which compounds the sea level rise associated with global warming. Halifax, St. John's, Victoria, and Richmond all have coastlines that are sinking by about 1 mm year^{-1}, solely as a consequence of the past melting of the Laurentide ice sheet. Tectonic compression coupled with subsequent uplift in the Cascadia Subduction Zone is causing the sea level to fall in parts of coastal BC.

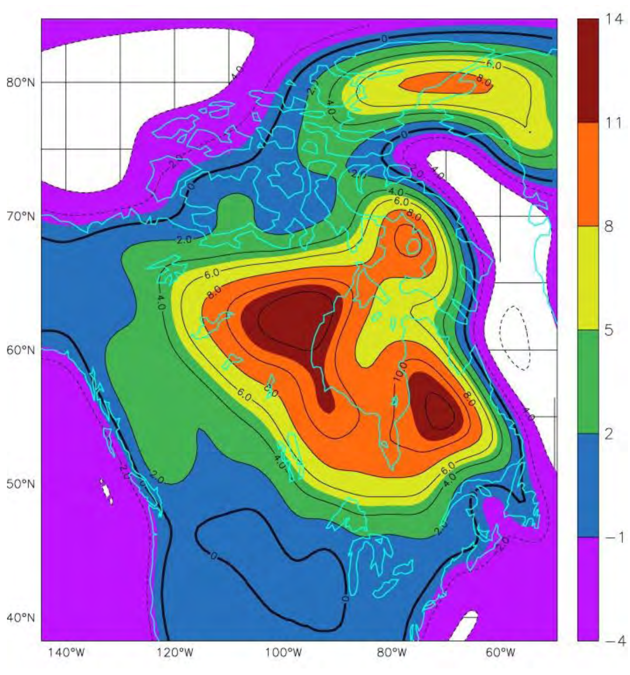


Figure 4.19. *Present-day vertical uplift in mm year^{-1} of the Earth's crust in North America, as projected by the ICE-5G model of Peltier (2004).*

Sea level rise also occurs through thermal expansion when water temperatures increase. Another major component of sea level rise comes from the melting of glaciers and ice sheets on land. Observations reveal that, from 1993 to 2007, global sea levels rose by about 3.3 mm year^{-1} (Cazenave and Llovel 2010), with about 40% of this increase stemming from thermal expansion, and approximately 60% originating from terrestrial ice melting. In recent years, the contribution from land ice melting has increased to 80% of the total sea level rise (Cazenave et al. 2009). As noted by Rignot et al. (2011), the combined loss of mass from the Greenland and Antarctic ice sheets has accelerated by 21.9 Gt/yr^2 (1Gt = one billion tonnes) over the last 18 years.

The regional manifestation of global sea level rise is highly variable (Figure 4.20), with patterns closely reflecting upper ocean temperature trends over the same period. From 1992 to 2009, sea level rise was great over much of the Atlantic, western Pacific, and Indian Oceans, as well as in parts of the Arctic. In the eastern equatorial and North Pacific, sea level rise was small or even negative.

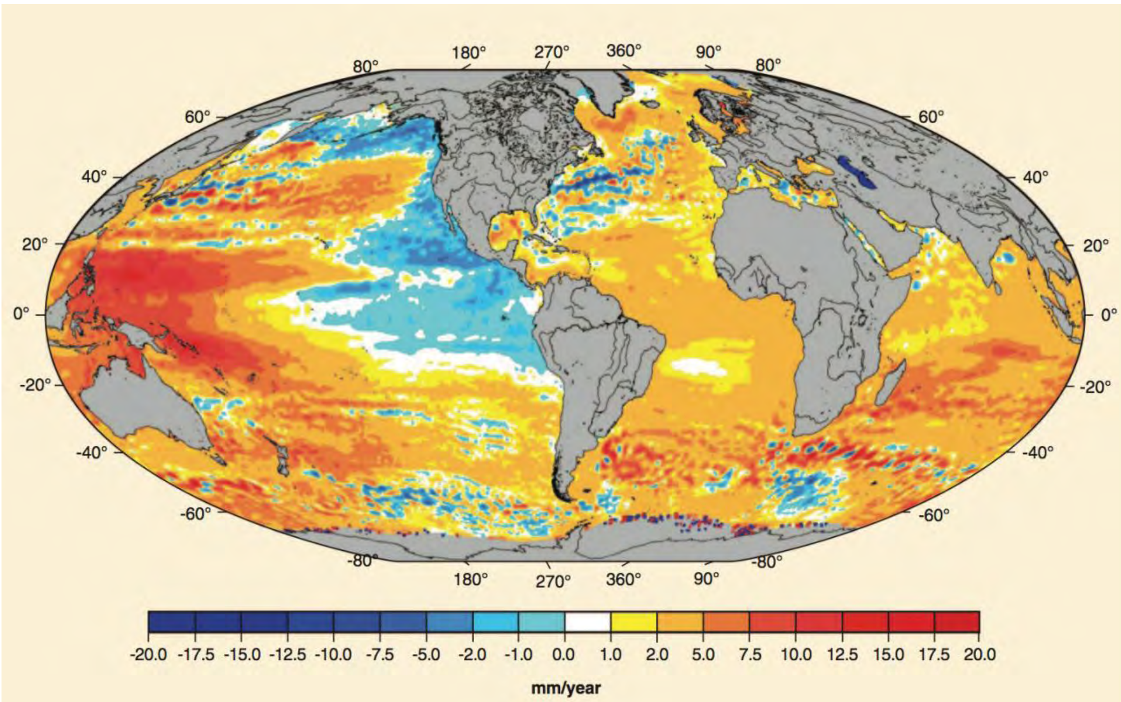


Figure 4.20. *Regional trends in sea level rise over the period October 1992 to July 2009, as derived from satellite altimetry. Source: Nicholls and Cazenave (2010).*

Enhanced inland flooding associated with storm surges and coastal erosion are potential impacts of sea level rise on Canadian coasts. Rising water tables, coupled with potential saltwater intrusion into wetlands and ground water, are also a concern for many coastal areas. Parts of Arctic Canada are particularly susceptible to coastal erosion, which is compounded by reduced ice cover (and hence enhanced coastal wave activity) and melting permafrost resulting from increasing temperatures (Figure 4.21).

Figure 4.21. *Photograph taken in 2004 showing coastal erosion of exposed permafrost at Drew Point in Alaska. Source: http://energy.usgs.gov/alaska/ak_coastalerosion_images.html*

b. Projected Changes During the 21st Century

There have been substantial advances in scientific understanding of 21st century projected sea level rise since the release of the 4th Assessment Report of the Intergovernmental Panel on Climate Change (see Meehl et al. 2007). The IPCC report estimated 21st century global sea level rise of between 18 and 59 cm (relative to 1980-1999 average), depending on the magnitude of future anthropogenic greenhouse gas emissions. The report further noted that the upper limit is uncertain, given that model-based estimates of sea level rise do not account for ice-sheet dynamics. More recent analyses have estimated a projected sea level increase from 1990 to 2100 of 75–190 cm (Vermeer and Rahmstorf 2009) or 80-200 cm (Pfeffer et al. 2008), with a central estimate of ~120 cm provided by Rahmstorf (2010).

Using ten of the IPCC climate models, Yin et al. (2009) examined the regional response of projected sea level rise over the 20th century. They concluded that the projected change in sea level was amplified in the Arctic and the northwest Atlantic, relative to the global mean. The amplification in the northwest Atlantic was a consequence of a weakening of the North Atlantic overturning. Shaw et al. (1998) undertook a comprehensive assessment of the vulnerability of the Canadian coast to sea level rise. Through a careful analysis of the contributions to regional sea level from tectonic and anthropogenic factors, they classified the Canadian coastline as being either at low, moderate, or high risk to sea level rise (Figure 4.22).

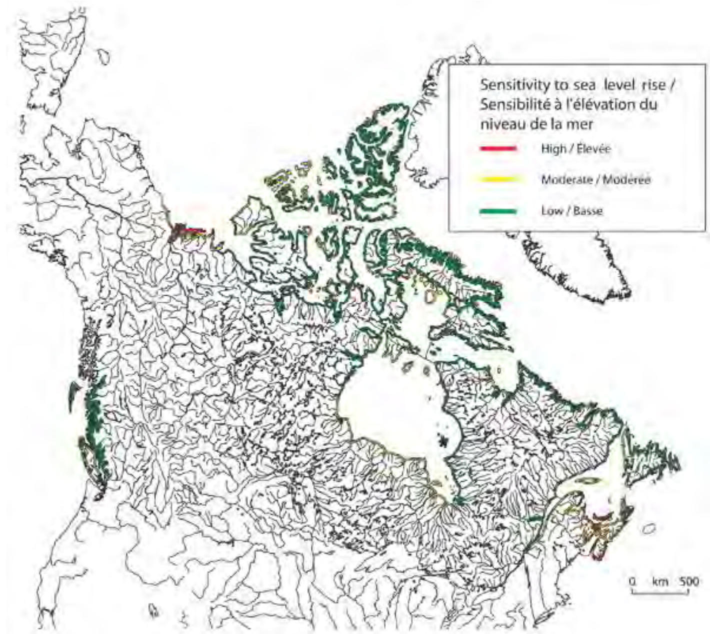


Figure 4.22. *Sensitivity of Canada's marine coastline to sea level rise as assessed by Shaw et al. (1998). Available from (http://adaptation.nrcan.gc.ca/perspective/coastal_1_e.php)*

The most at-risk regions are the coasts of Nova Scotia, New Brunswick, and Prince Edward Island, the entire Beaufort Sea coastline bordering Yukon and Northwest Territories, and the Fraser River Delta in BC. Much of the remaining BC coast was found to be at low risk to the effects of 21^{st} century sea level rise, due to the nature of its high, rocky topography.

6. Water Chemistry and Stratification

Future climate change scenarios include both increased temperature and reduced salinity in the upper ocean at high latitudes. The combination of warmer and fresher surface waters leads to reduced density in the surface layer and increased stratification of the water column. By itself, increased vertical stratification is likely to reduce the flux of nutrients from deeper, denser waters below the pycnocline upward to the surface layer, and to reduce the ventilation of the thermocline. A reduced nutrient supply is likely to reduce phytoplankton production in Canada's nutrient-limited shelf ecosystems, but to increase plankton productivity where nutrients are abundant and the availability of sunlight is limiting. Reduced ventilation of the thermocline is also expected to reduce the dissolved oxygen concentration at depth. This combination has already been observed in recent decades in the North Pacific Ocean (see below). Increased uptake of atmospheric CO_2 into the upper ocean has also led to increased ocean acidification. These trends are expected to continue beyond the 21^{st} century (see below).

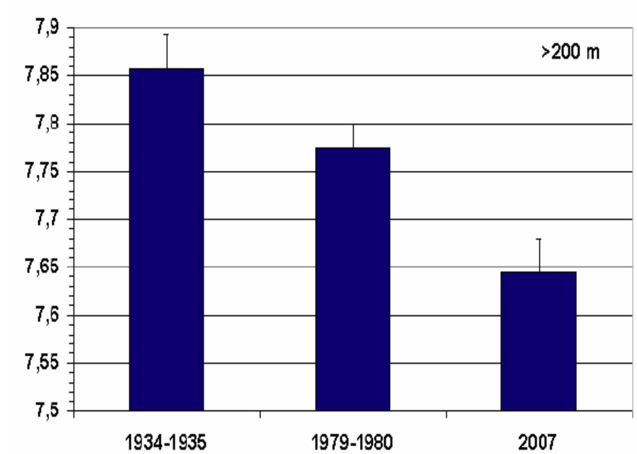
a. Observed Trends in Carbonate Chemistry and pH

Rapid increases in the atmospheric concentration of CO_2 increase the ocean's uptake of CO_2, causing the oceans to become more acidic. Recent calculations estimate that approximately 26% of anthropogenic CO_2 emissions between 2000 and 2009 entered the global oceans (Friedlingstein et al. 2010). Between 1750 and 1994, the estimated uptake of anthropogenic carbon was calculated to have reduced the pH of the global surface ocean from 8.2 to 8.1, corresponding to a 30% increase in the H^+ concentration (Sabine et al. 2004). At the same time, the carbonate ion concentration in seawater has decreased dramatically, reducing the availability of calcium carbonates used by marine organisms to build hard shells and carbonate skeletal structures. Aragonite is one of the most soluble calcium carbonate minerals and is frequently incorporated into the hard parts of calcifying organisms. Shoaling of the aragonite saturation depth (the depth at which carbonate minerals dissolve more readily than they can form) has been observed in all of the world's ocean basins. Future declines in carbonate saturation states are expected to have consequences for high-latitude marine ecosystems, primarily because baseline carbonate saturation states are relatively low in sub-Arctic and Arctic seas, including the North Pacific, Arctic, and North Atlantic Oceans. Already, in 2008, surface waters in the Canada Basin of the Arctic Ocean were observed to be undersaturated with respect to aragonite. Recent trends towards undersaturated surface waters in the Canadian Arctic are linked to melting sea ice and increased upwelling of carbon-rich waters onto the continental shelf (Yamamoto-Kawai et al. 2009).

In the coastal waters of northern BC, saturation depths for aragonite are now approximately 300 m from the surface (Cummins and Haigh 2010). Due to the ocean's uptake of anthropogenic CO_2, and consequent increases in acidification, this saturation depth is estimated to have shoaled by 50-200 m over the past century (Feely et al. 2008). The nearshore waters off the west coast of Vancouver Island are, in summer, frequently further undersaturated during those periods when coastal upwelling brings deep carbon-rich waters onto the shelf. Corrosive waters were actually observed at the surface near parts of the Oregon and California coast during a 2007 summer research cruise (Feely et al. 2008).

In the Gulf of St. Lawrence, recent findings reveal a significant pH decrease in hypoxic waters. In the 1930s, the in situ pH at >200 m depth in the lower St. Lawrence Estuary was about 7.90 (Figure 4.23). Today, in situ pH levels are down to about 7.65, with some observations as low as 7.60. This change represents a 60-90% increase in H^+ ions. In addition, the pH levels in the Lower St. Lawrence Estuary hypoxic waters have already reached levels expected for the surface ocean's global average for the end of the 21st century. These findings suggest that an increased flux of organic matter to bottom waters in the St. Lawrence may have increased respiration and resulted in the region's lower pH conditions (Dufour et al. 2010).

Figure 4.23. *Observed pH between 200 and 320 m depth in the Lower St. Lawrence Estuary. Source: Dufour et al. (2010).*



Climate system models predict extremely rapid declines in ocean pH (i.e., increases in ocean acidity) in the next century under a wide range of future greenhouse gas emissions scenarios (Orr et al. 2005). Multi-model projections based on scenarios considered in the IPCC's AR4 give reductions in pH of between 0.14 and 0.35 units in the 21st century, adding to the already documented decrease of 0.10 units from pre-industrial times (Bindoff et al. 2007).

Cooley et al. (2011) use simulations with a climate system model to identify the 'transition decade' wherein future aragonite saturation states become distinctly different from those simulated for 2010. For Ocean Station PAPA (located in the Gulf of Alaska; Figure 3.7), this transition is predicted to occur in the 2030s (Figure 4.24). In fact, this modeling study suggests that most of Canada's coastal waters will experience a transition to a new envelope of aragonite saturation states during the 2030s (Figure 4.25).

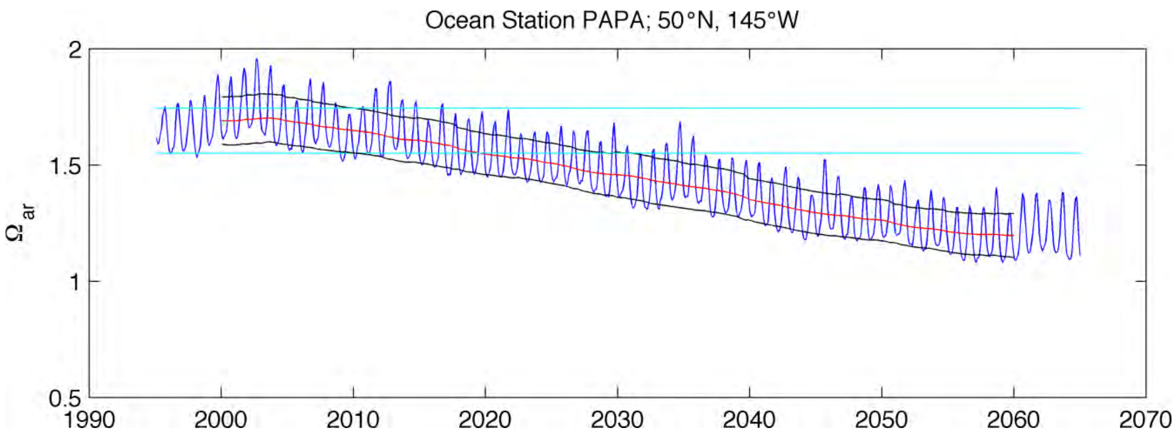


Figure 4.24. *Time series of monthly mean CCSM3-modelled surface aragonite saturation state for Ocean Station PAPA (50°N, 145°W), with the 10-year running average (red) shown for reference. At Station PAPA, the normal range of annual variability (area between the black lines), or 'envelope', will no longer overlap that of 2010 (area between the light blue lines) in approximately 2031. Source: Cooley et al. (2011).*

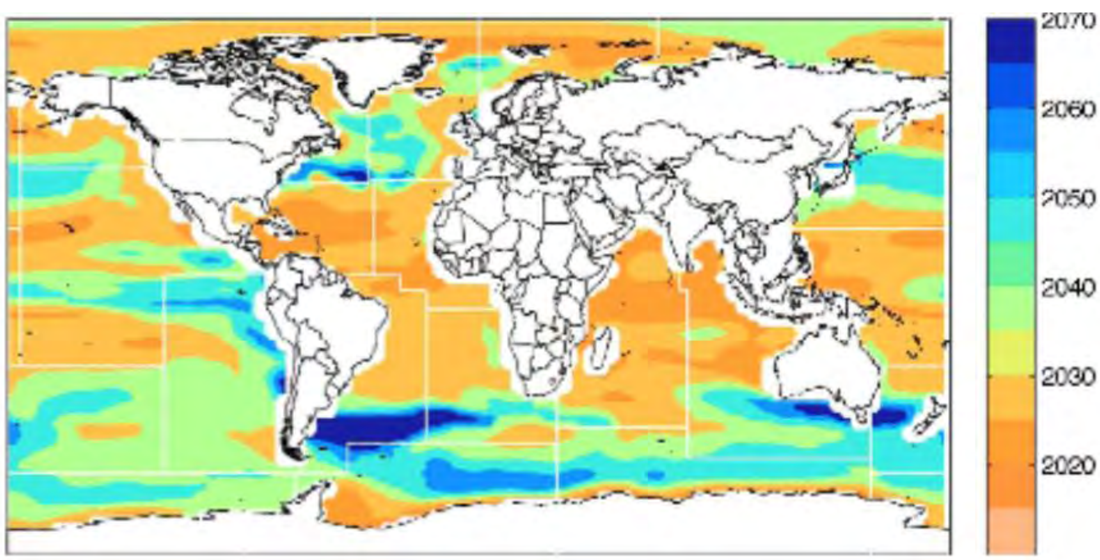


Figure 4.25. *Transition decades when future surface aragonite saturation states will no longer overlap those of 2010. Source: Cooley et al. (2011).*

b. Dissolved Oxygen

Over the past 50 years, trends and variations in dissolved oxygen have been documented for many parts of the world's upper oceans. The available data are insufficient to indicate if the changes in O_2 are caused by natural variability or are trends that are likely to persist in the future. However, the data indicate that large-scale changes in ocean physics do influence natural biogeochemical cycles, and thus the cycles of O_2 and CO_2 are likely to undergo changes if ocean circulation changes persist (Bindoff et al. 2007).

Differences in dissolved oxygen concentrations between the late 1990s and mid-1980s on two transects across the North Pacific Ocean reveal a pattern of increase in the upper 100 m and of decline at depths between 100 and 400 m (Figure 4.26). A time series of observations from Ocean Station PAPA also shows declining oxygen concentrations from depths of 100 and 400 m between 1956 and 2006 (Whitney et al. 2007). Figure 4.27 presents trends in oxygen concentration for waters below 100 m depth along the North American coast from South California to Haida Gwaii (Crawford and Irvine 2009). These trends are based on time series data of at least 25 years duration. Declines in dissolved oxygen are seen at all depths below the mixed layer and along the entire coast. The greatest declines are found within the 200-300 m depth range. Within this range, the rate of decline represents about 1% of the dissolved oxygen per year in BC coastal waters. The decline is attributed to the weakening of the ventilation of surface waters off the coast of Asia, a trend linked to freshening and warming that increases the water's stratification (Whitney et al. 2007).

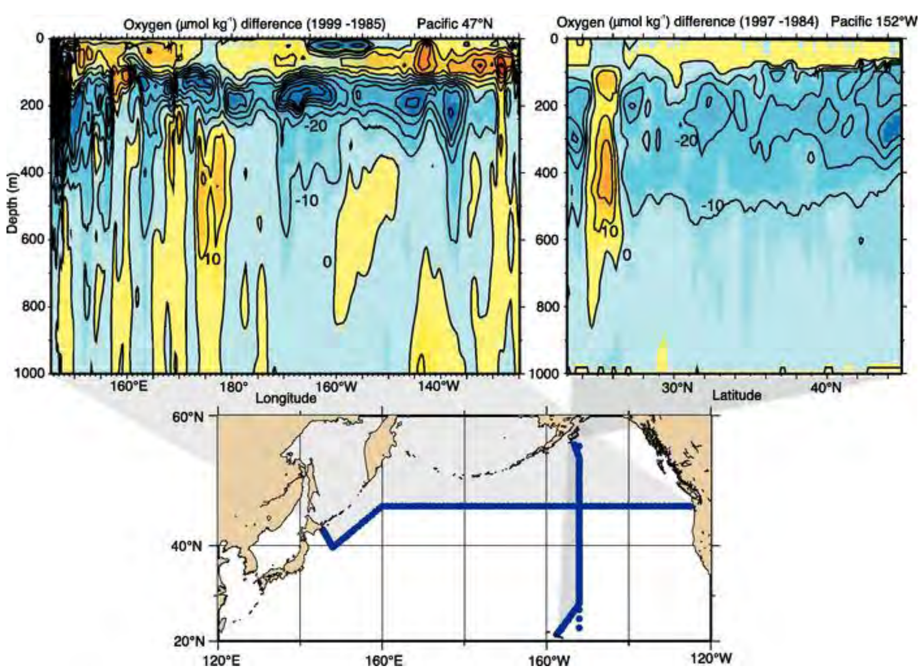
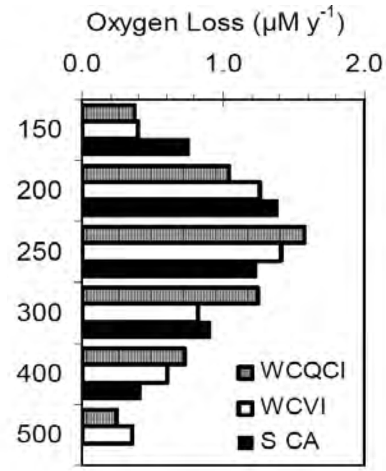


Figure 4.26. *Changes in oxygen concentration (μmol kg^{-1}) along two sections in the North Pacific (see map, bottom panel). Top left panel: Difference (1999 minus 1985) along 47°N. Top right panel: Difference (1997 minus 1984) at 152°W. Blue colours indicate a decrease and yellow colours indicate an increase in oxygen over time. The differences were calculated using density as the vertical coordinate. Source: Bindoff et al. (2007).*

In the 1930s and early 1970s, oxygen levels in deep waters of the Gulf of St. Lawrence estuary were above the hypoxic threshold of 30% saturation. The deep waters of the estuary were briefly hypoxic in the early 1960s and have consistently been hypoxic at about 19-21% saturation since 1984. One half to two thirds of this decrease is associated with changes in source water masses at the continental shelf (Gilbert et al. 2005).

Figure 4.27. *Trends in oxygen concentration for waters below 100 m depth along the North American coast from Southern California (SCA) to Haida Gwaii (WCQCI) (DFO 2009). These trends are based on time series data of at least 25 years duration. Source: Crawford and Irvine (2009).*



In offshore areas of the Newfoundland and Labrador coasts, there is significant mixing of highly oxygenated cold water, and therefore hypoxia is generally not a major consideration. However, there have been reports of low oxygen levels along northeastern Newfoundland, where levels in the 1990s were the lowest in a 70-year time series (Kiceniuk and Colbourne 1997). While hypoxia is not currently reported to be a significant issue within this region, occurring mainly in small fjords with restricted circulation and soft organic bottoms, it is likely that many Newfoundland and Labrador harbours could experience hypoxic conditions at some times of the year, due to organic loading from nearby fish plants or other forms of development (e.g., mines, lumber mills, sewage, and agricultural run-off) (Templeman 2010).

c. Nutrient Pools

Essential plant nutrients in the ocean's surface layer are typically consumed rapidly in the process of photosynthesis by marine algae. In high-latitude systems, a spring phytoplankton bloom is typically initiated when daylight is sufficient to both warm the upper ocean enough to stratify the surface layer and supply light needed for photosynthesis. In the absence of a nutrient supply, photosynthesis by phytoplankton quickly depletes nutrients in the sunlit upper ocean. Below the sunlit portion of the upper ocean, nutrients are typically abundant year-round. Thus, the concentration of surface nutrients can be influenced by surface mixing, given that a reduction in mixing leads to a decreased supply and concentration of surface nutrients. In most of the Pacific Ocean, the observed surface warming and freshening trends between 1950 and 2005 act in the same direction and contribute to reduced mixing (Bindoff et al. 2007). This is consistent with regional observations in the northeast Pacific Ocean (e.g., Freeland et al. 1997).

Time series data combining surface nitrate and silicate concentrations in shelf and slope waters off Southern Vancouver Island from 1988 to 2008 indicate substantial seasonal, interannual, and decadal variability (Figure 4.28). Petrie and Yeats (2000) documented interannual variations in nitrate, silicate, and phosphate at a depth of 150 m in the Gulf of Maine and on the central Scotian Shelf that were only weakly correlated between these two regions in the 1960s through 1990s period. They suggested that these variations were related to changes in water mass structure. As in most marine ecosystems, nitrogen availability is the limiting factor to primary production in Gulf of Maine and Scotian Shelf waters. Although there is significant seasonal variation in nitrate concentrations in surface and deep waters of the Gulf of Maine and Scotian

Shelf, no long-term trends have been observed at coastal and offshore sampling stations in the last ten years (Worcester and Parker 2010).

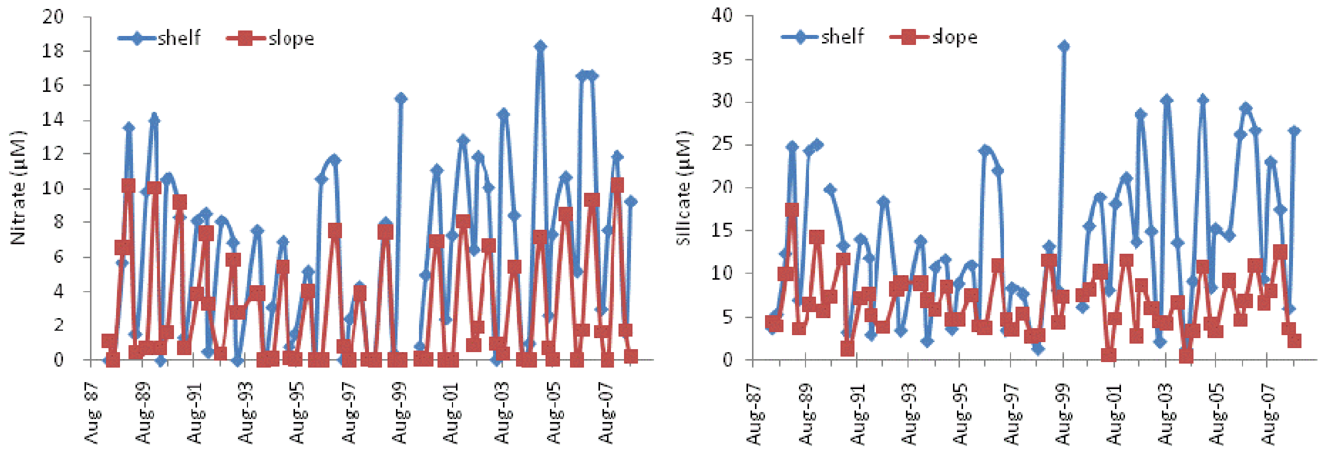


Figure 4.28. *Surface nitrate and silicate concentrations in shelf (here defined as the continental shelf and just beyond the shelf break) and slope waters (here defined as the region beyond the 1000 m depth contour between the slope and Alaskan Gyre) off southern Vancouver Island from May 1988 to August 2008. Source: Ianson and Flostrand (2010).*

Time series data on the primary marine nutrients do not appear to be available for the northern coastal waters of BC or the Canadian Arctic (Cummins and Haigh 2010; Niemi et al. 2010).

d. Stratification

Whitney and Freeland (1999) argue that, over the latter portion of the 20th century, increased stratification in the northeast Pacific (due mainly to basin freshening) reduced the flux of nutrients across the pycnocline and into the surface layer. In contrast, for most of the Atlantic, temperature and salinity trends in the 1950-2005 period generally acted in opposite directions and had mixed effects on upper ocean stratification (Bindoff et al. 2007).

On the Scotian Shelf, the average 0 to 50 m stratification index increased between 1960 and 2008, but most significantly in the 1990s. From the mid to late 1990s, the index was at or near its maximum over the 59-year record (Figure 4.29) (Petrie et al. 2009). Important changes in stratification are also noted in the eastern Gulf of Maine and Georges Bank, coupled with increasing temperature and changes in salinity. Stratification increased steadily from the mid-1980s on Georges Bank and in the eastern Gulf of Maine (Figure 4.30) (Worcester and Parker 2010).

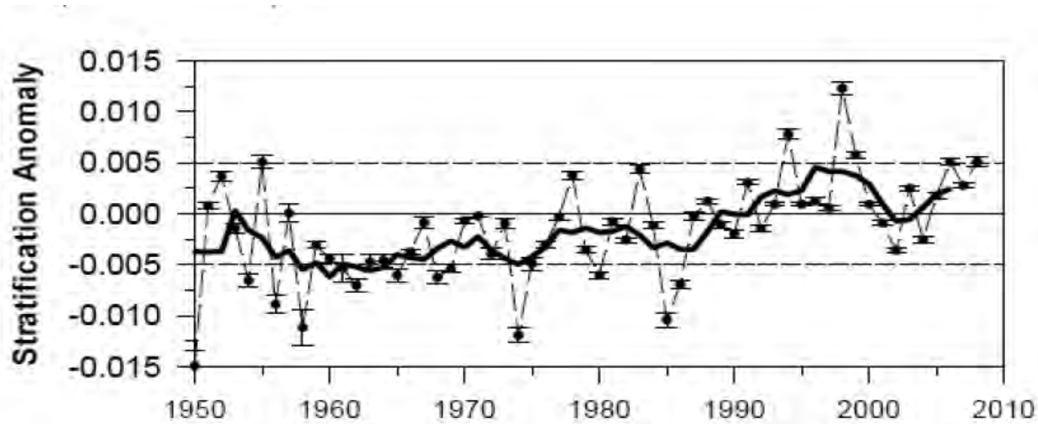


Figure 4.29. *The mean annual (dashed line) and 5-year running mean (solid line) of the stratification index over the Scotian Shelf. Standard error estimates for each annual value are shown. Source: Petrie et al. 2009).*

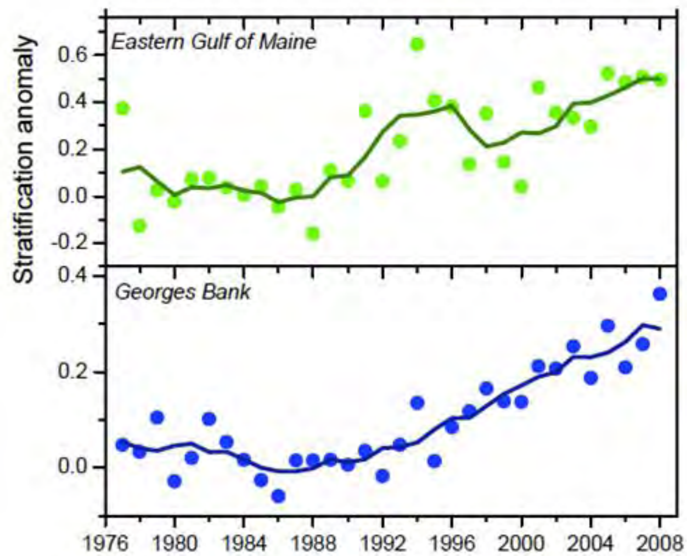


Figure 4.30. *Trends in stratification for the eastern Gulf of Maine and Georges Bank. Source: Worcester and Parker (2010).*

7. Main Findings

- Global surface temperatures are increasing: 0.07°C per decade (past century); 0.17°C per decade (past 30 years); ~0.24°C per decade (projected, next 20 years). (Based on Copenhagen Accord's voluntary emission reduction targets, global warming will increase more than 2°C above pre-industrial levels.)
- Discharge into the Arctic Ocean from the six largest Eurasian rivers increased 7% from 1936 to 1999; high-latitude waters, such as those in Canada, are becoming fresher (less saline).
- A nearly ice-free Arctic summer could occur as early as the late 2030s. Since 1979, sea ice has decreased every decade by 11.6% in the Arctic (September), 3.9% in the Gulf of St. Lawrence (winter), and 3.1% in Labrador Sea (winter). Arctic winter sea ice has thinned by 48% (1980-2008).
- It is unlikely that the Atlantic Meridional Overturning Circulation (which carries warm upper waters to far-northern latitudes, returning cold deep waters southward across the Equator) will undergo an abrupt transition or collapse in the 21st century.

- Increased sea levels are likely to lead to increased flooding, coastal erosion, and saltwater intrusion into wetlands and ground water; areas at greatest risk include coastal regions of Nova Scotia, New Brunswick, Prince Edward Island, Yukon, Northwest Territories, and Fraser River Delta in BC.
- Canada's oceans will be affected by rapid increases in acidification projected for the 21st century.
- Oxygen levels have been declining along parts of Canada's Atlantic and Pacific coasts; in some areas, waters are now hypoxic, rendering the waters unsuitable for most aquatic life.
- The increasing trend in upper-ocean stratification (caused by warming or freshening of surface waters) reduces the transport of nutrients from deep waters to surface waters.

CHAPTER FIVE: TRENDS IN CANADIAN MARINE BIODIVERSITY

1. Introduction

Trends in biodiversity are driven by human and environmental pressures. The primary purpose of this chapter is to address the question in the Terms of Reference, “What are the past and current trends and associated uncertainties in Canadian marine biodiversity?”, focussing on trends affected by fishing and climate change. As clarified in Chapter Two, the chapter deals primarily with population trends (species data are presented where they exist) because of the lack of trend data for most species (Chapter Three). An additional consideration is that many, but not all, species for which estimates of abundance can be obtained are, or were, of commercial importance. Among those for which trend data exist, the time periods often extend several decades. This is true for many fishes. Data are available for phytoplankton and zooplankton for periods of time extending, in some areas, to fifty years, although shorter periods are much more common. Abundance data are available for some marine mammals, although not always on an annual basis, with the exception of some intensively monitored species, such as Pacific killer whales (*Orcinus orca*) and Atlantic pinnipeds (e.g., harp seals, *Pagophilus groenlandicus*). For seabirds, long-term data exist for colonies on all three coasts, rendering this one of the few taxonomic groups (in addition to marine mammals) for which trend data have been collected in the Arctic. Data are limited for macro-invertebrates.

2. Marine Species at Risk

In the absence of yearly abundance data for many (indeed most) species, one means of evaluating the directional change in marine biodiversity over the past half century is to examine the numbers of marine species assessed as being at risk in Canada by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). A legislatively recognized body, independent from government, COSEWIC is responsible for assessing the status of species believed to be at heightened chance of extinction, for communicating its assessments to society and to various levels of jurisdictional authority, and for advising the federal government of those species that warrant inclusion on the national legal list of species at risk and, thus, some form of protection under the *Species at Risk Act* (SARA). The list of species assessed by COSEWIC to be at risk differs from the national SARA legal list of species at risk. The former is based solely on the best available information pertaining to a species’ risk of extinction, whereas the decision to include a species on the SARA list is influenced by non-scientific influences, such as the perceived political and socio-economic consequences of a listing decision. In addition to making assessments at the species level, the Act provides for the assessment of populations, or groups of populations, below the species level, acknowledging implicitly that such Designatable Units, or DUs, represent irreplaceable units of biodiversity critical to the persistence of biological species. COSEWIC identifies discreteness and evolutionary significance as the primary criteria for recognizing DUs (http://www.cosewic.gc.ca/eng/sct2/sct2_5_e.cfm; accessed 19-6-11). Given its definition in SARA, the legislatively defined ‘wildlife species’ can be considered functionally equivalent to a DU.

As of January 2012, COSEWIC had assessed 120 marine wildlife species (including diadromous fishes) as being either Extinct (n=4) or a Species at Risk (i.e., wildlife species assessed as

Extirpated [no longer in existence in the wild in Canada], Endangered, Threatened, or Special Concern) (Table 5.1). The extinct species include sea mink (*Neovision macrodon*; a mammal), great auk (*Pinguinus impennis*; a bird), and eelgrass limpet (*Lottia alveus*; a mollusc). Marine (n=41) and diadromous fishes (n=27) comprise slightly more than half of the wildlife species assessed as Extirpated, Endangered, Threatened, or Special Concern. Marine mammals (n=34) have the second highest representation in these four assessment categories. Seabirds (n=8), molluscs (n=3), and reptiles (n=3, all of which are sea turtles) comprise the remaining taxonomic categories. Of the total of 640 species assessed by COSEWIC as being at risk (as of January 2012), approximately 18% are marine.

Table 5.1. *Marine wildlife species assessments by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), as of January 2012. For each taxonomic species, the numbers of COSEWIC Designatable Units [DUs] is indicated in parentheses and separated by a semi-colon.*

Taxonomic Group	Extinct	Extirpated	Endangered	Threatened	Special Concern
Marine Mammals	Sea Mink (Pacific)	Grey Whale (Atlantic)	Beluga Whale (Eastern Hudson Bay; Ungava Bay)	Beluga Whale (St. Lawrence Estuary; Cumberland Sound)	Beluga Whale (Eastern High Arctic-Baffin Bay; Western Hudson Bay)
			Blue Whale (Atlantic; Pacific)	Northern Fur Seal (Pacific)	Narwhal (Arctic)
			Killer Whale (Pacific Southern Resident)	Killer Whale (Pacific: 3DUs)	Sea Otter (Pacific)
			North Atlantic Right Whale	Fin Whale (Pacific)	Harbour Porpoise (Atlantic; Pacific)
			North Pacific Right Whale		Steller Sea Lion (Pacific)
			Northern Bottlenose Whale (Scotian Shelf)		Atlantic Walrus
			Sei Whale Pacific)		Polar Bear (Arctic)
					Bowhead Whale (Beaufort Sea; Eastern Canada)
					Fin Whale (Atlantic)
					Grey Whale (NE

					Pacific)
					Killer Whale (NW Atlantic-Eastern Arctic)
					Humpback Whale (Pacific)
					Northern Bottlenose Whale (Davis Strait)
					Sowerby's Beaked whale (Atlantic)
Marine Fishes			Atlantic Cod (4 DUs)	Bocaccio (Pacific)	Atlantic Cod (Lakes on Baffin Island)
			Roundnose Grenadier (Atlantic)	Cusk (Atlantic)	Spiny Dogfish (Atlantic)
			Porbeagle (Atlantic)	Shortfin Mako (Atlantic)	Roughhead Grenadier (Atlantic)
			Deepwater Redfish (Gulf St. Lawrence-Laurentian Channel)	Deepwater Redfish (Northern Population)	Rougheye Rockfish (Pacific: Type I; Type II)
			Basking Shark (Pacific)	American Plaice (Newfoundland and Labrador;Maritimes)	Basking Shark (Atlantic)
			White Shark (Atlantic)	Acadian Redfish (Atlantic population)	Acadian Redfish (Bonne Bay population)
			Winter Skate (Southern Gulf of St. Lawrence)	Winter Skate (Eastern Scotian Shelf)	Darkblotched Rockfish (Pacific)
			Atlantic Bluefin Tuna	Quillback Rockfish (Pacific)	Yelloweye Rockfish (Pacific: inside waters; outside waters)
				Yellowmouth Rockfish (Pacific)	Blue Shark (Atlantic)
				Canary Rockfish (Pacific)	Bluntnose Sixgill Shark (Pacific)
				Northern Wolffish	Winter Skate

				(Atlantic)	(Western Scotian Shelf-Bay of Fundy)
				Spotted Wolffish (Atlantic)	Atlantic Wolffish
					Tope (Pacific)
					Longspine thornyhead (Pacific)
					Spotted Spiny Dogfish (Pacific)
Diadromous Fishes		Striped Bass (St. Lawrence Estuary)	Atlantic Salmon (5 DUs)	Atlantic Salmon (South Newfoundland)	Atlantic Salmon (4 DUs)
			Coho Salmon (Interior Fraser)	Striped Bass (Southern Gulf of St. Lawrence; Bay of Fundy)	Bering Cisco (Arctic)
			Sockeye Salmon (Cultus Lake; Sakinaw Lake)	Chinook Salmon (Okanagan)	American Eel (Atlantic)
			Eulachon (Central Pacific; Fraser R.)	Eulachon (Nass and Skeena Rivers)	Green Sturgeon (Pacific)
				Atlantic Sturgeon (Maritimes; St. Lawrence)	Shortnose Sturgeon (Atlantic)
					Dolly Varden (Western Arctic)
Seabirds	Great Auk (Atlantic)		Ivory Gull (Arctic)	Short-tailed Albatross (Pacific)	Black-footed Albatross (Pacific)
	Labrador Duck		Roseate Tern (Atlantic)	Ross' Gull (Arctic)	Ancient Murrelet (Pacific)
				Marbled Murrelet (Pacific)	
				Pink-footed Shearwater (Pacific)	
Molluscs	Eelgrass Limpet (Atlantic)		Northern Abalone (Pacific)	Atlantic Mud-piddock	Olympia Oyster (Pacific)
Reptiles			Leatherback		

			Sea Turtle (Atlantic; Pacific)		
			Loggerhead Sea Turtle (Atlantic)		

Based on quantitative and qualitative inspection of temporal trends in species status assessments (e.g., Hutchings and Festa-Bianchet 2009; COSEWIC Species Specialist Subcommittee Annual Reports), and accounting for the number of species that have been assessed relative to the numbers present in Canada (e.g., Table 3.1), the Panel draws the following conclusions on future trends in the assessment of marine species. The greatest increase in numbers of marine species at risk will almost certainly be experienced by diadromous fishes, primarily because of the anticipated increased focus by COSEWIC on Pacific salmon (COSEWIC Marine Fishes Species Specialist Subcommittee 2010-11 Annual Report). It is highly probable that the number of diadromous fishes at risk will increase from their current 27 to more than 50 (perhaps to as many as 70 or 80) in the coming decade because of the high number of Pacific salmon DUs forecasted to be at heightened risk of extinction. Primarily because of data limitations, the numbers of wholly marine fishes at risk might not exceed 50 or 60 in total (41 had been assessed as being at risk as of January 2012). It is also unlikely that the number of species at risk among marine mammals, seabirds, reptiles, and molluscs will increase appreciably, if at all, in the coming decade.

3. Metrics of Population Status

It is not uncommon to use rate or magnitude of decline in abundance as metrics of increased chance of harm to a population or species. For example, this is the basis for one of the extinction-risk criteria developed by the IUCN (and modified for use by COSEWIC), to assess the status of species believed to be at heightened chance of extinction. Globally, and based on abundance estimates available from fish stock assessments, marine fishes declined 38% from the period 1970-1974 to the period 2002-2006; the trend is similar for both pelagic and demersal species (Hutchings et al. 2010). From one perspective, this magnitude of reduction over a period of nearly 40 years would be viewed as extremely problematic. The IUCN, for example, uses a decline rate of 30% (experienced over the longer of ten years or three generations) as a threshold above which species are assessed as Vulnerable ('Threatened', using COSEWIC's terminology). However, based on fisheries production models, if a species or a population had declined by 30% *from a virgin or unfished state* (B_0, something that can be estimated from models, such as the relationship between stock size and recruitment), it would not be considered to be at heightened risk of extinction; rather, it would be predicted that the population would be approaching a level of abundance at which the maximum sustainable yield, or MSY, for the population would be obtained. Depending on the stock-recruitment model used, the stock biomass at which MSY is obtained (B_{MSY}) is estimated to range between 25% and 40% of B_0 (Hilborn and Stokes 2010). In other words, reductions of 60% to 75% would result in a population attaining B_{MSY}.

Thus, among species for which declines can be attributable solely to exploitation (and not, for example, habitat change), it might be appropriate to interpret reductions in abundance relative to some point of reference of species or population productivity, such as a 'target reference point' or a 'limit reference point'. A target reference point (TRP) identifies the long-term objective for a fishery in terms of population biomass (B), whereas a limit reference point (LRP) represents a low population biomass that should be avoided. These TRPs and LRPs are often expressed as a depletion measure, i.e., some fraction of B_{MSY} or B_0.

Although Canada has not established TRPs for most of its commercially exploited marine fishes, particularly those on the east coast (Chapters Eleven, Twelve), many jurisdictions, including the US, New Zealand, and parts of the European Union, have adopted B_{MSY} as their TRP in harvesting management plans (the TRP in Australia is higher at 1.2 B_{MSY}). The Pacific Fisheries Management Council in the US uses a default value of B_{MSY} of $0.4B_0$, which would correspond to a 60% decline from a population's unfished state (Hilborn and Stokes 2010). LRPs, which are also used extensively in the countries that have adopted TRPs, are commonly identified as $0.5B_{\mathrm{MSY}}$. DFO has established reference points for the harvesting of marine mammals (www.dfo-mpo.gc.ca/science/coe-cde/cemam/report-rapport/sect4-eng.htm; accessed 10-4-11), using $0.7N_0$ as a TRP and $0.3N_0$ as a LRP, where N_0 is the unfished abundance in numbers of individuals, rather than biomass, B_0.

4. Abundance Trends

This section describes trends known or likely to have been driven by human and/or environmental impacts, notably climate change and fishing. In order to detect trends in abundance, monitoring needs to be quite thorough, which is why our coverage of components and attributes of Canadian marine ecosystems is patchy. Full consideration of the observed and projected consequences to marine biodiversity driven by climate change and fisheries are addressed in Chapters Six and Seven, respectively.

a. Plankton

i. Pacific

Trend data are available for plankton at variable spatial and temporal scales in Canadian Pacific waters, although comparatively few pertain to phytoplankton. Based on data obtained in Barkley Sound, Vancouver Island, no trend in chlorophyll biomass is evident since data were first available in 2005 (Pawlowicz 2011). The longest time series of zooplankton data in Canadian Pacific waters extends from 1979 to the present and encompasses a transect extending from the BC continental margin to southern Vancouver Island (Figure 5.1). Patterns in these southern BC waters, where zooplankton abundance and biomass is routinely estimated for more than 50 species, appear to be correlated with water temperature (Mackas et al. 2011). Relatively cool years (1980s, 1999-2002, 2007-2009) tend to favour boreal shelf copepods (small crustaceans, such as *Calanus marshallae*, *Pseudocalanus mimus*, *Acartia longiremis*) and subarctic copepods (e.g., *Neocalanus plumchrus, N. cristatus, Eucalanus bungii*) and northern chaetognaths (transparent or translucent dart-shaped animals); relatively warm years (1983, 1993-1998, 2004-2005) tend to favour southern copepods (species whose ranges are centred 1000 km south of

Vancouver Island) and southern chaetognaths. There is evidence to suggest that an abundant cool-water zooplankton community is associated with good local survival and growth of juvenile salmon and planktivorous seabirds (Mackas et al. 2007). Since 2000, there has also been an increase in the abundance of some gelatinous zooplankton, such as salps and doliolids (herbivorous planktonic tunicates) and medusae of jellyfish and ctenophores (which prey on other zooplankton and occasionally larval fish), and the warm-water planktonic snail *Clio pyramidata* (Figure 5.2) (Mackas et al. 2011).

In the Gulf of Alaska, mesozooplankton (which range in length from 200 µm to a few mm) have been sampled annually since 2000 as part of the Continuous Plankton Recorder (CPR) surveys. No significant annual trend in mesozooplankton abundance is evident in the past decade (although interannual variability can be considerable) (Batten 2011). There appear to be strong links between the species composition of mesozooplankton and temperature (which is related to the Pacific Decadal Oscillation, or PDO (Chapter Four, Appendix C). The proportional representation of small copepods tends to be higher when temperatures are relatively warm, whereas cold temperatures appear to favour large copepods (Batten 2011).

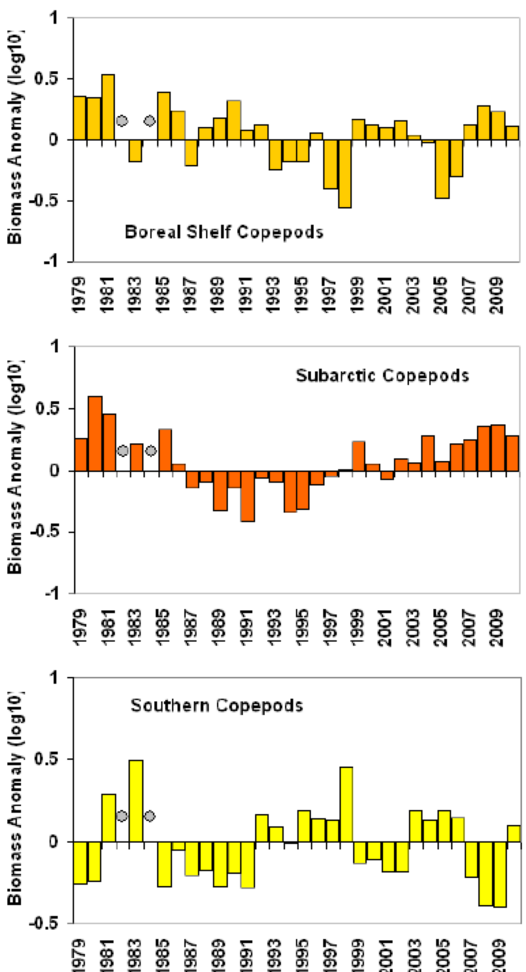
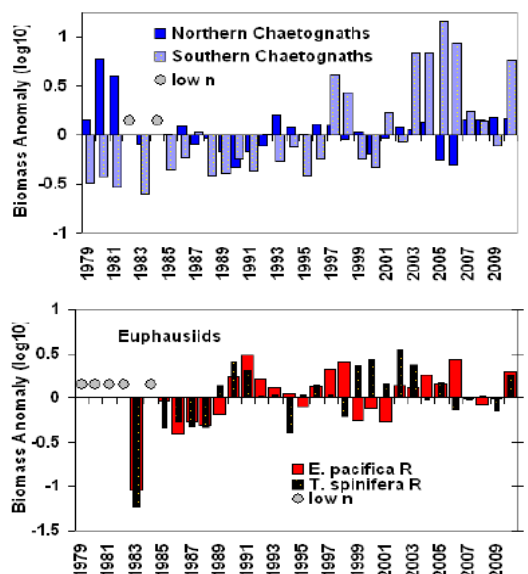


Figure 5.1. *Temporal trends in several groups of zooplankton species groups sampled from the BC continental margin to southern Vancouver Island. Data are presented as biomass anomalies, meaning that anomalies with positive values identify years with greater than the long-term average abundance. Circles indicate years with no or very few samples. The euphasiids (pelagic, shrimp-like crustaceans) in the final panel are* Euphausia pacifica *and* Thysanoessa spinifera. *Source: Mackas et al. (2011).*



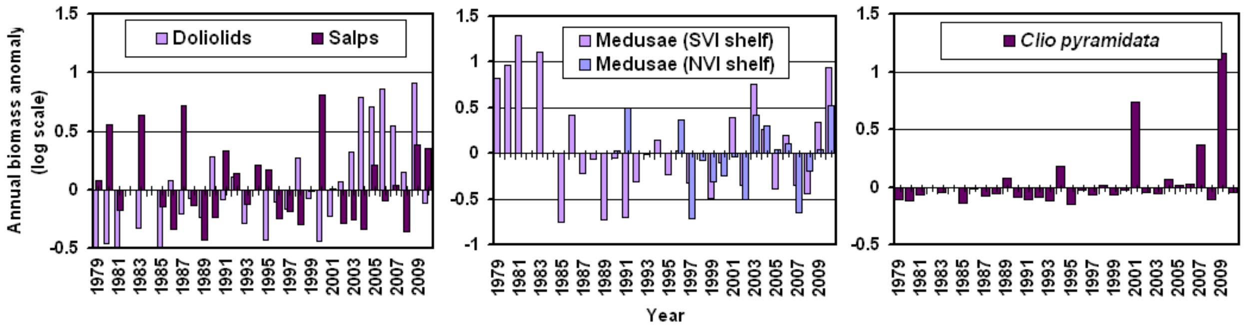


Figure 5.2. *Temporal trends in gelatinous zooplankton (doliolids, salps, jellyfish, and ctenophore medusae) and the warm-water planktonic snail* Clio pyramidata*) sampled from the BC continental margin to southern Vancouver Island. Data are presented as biomass anomalies, meaning that anomalies with positive values identify years with greater than the long-term average abundance. Source: Mackas et al. (2011).*

ii. Atlantic

Temporal data on plankton are available for areas of the Canadian Atlantic. The longest time series of zooplankton data is available from the CPR surveys, which generally extend back to the early 1960s; these trends have been summarized by Head and Pepin (2009). Since 1990, phytoplankton abundance has generally been higher than the long-term average (1960-2006), although declines have been evident in recent years on the Scotian Shelf. The abundance of *Calanus finmarchicus* on the continental shelf is currently high on the Scotian Shelf and somewhat so on the Newfoundland Shelf, having returned to levels evident in the 1960s and 1970s following levels of low abundance in the 1990s. On the continental shelf, two Arctic species of *Calanus* (*C. glacialis*, *C. hyperboreus*) were more abundant in the 1990s and 2000s than in previous decades, although their abundance is generally low and highly variable among years. For smaller copepods (e.g., *Paracalanus* spp., *Pseudocalanaus* spp.), abundance has generally declined since the 1960s on the Scotian Shelf whereas an increase is evident on the Newfoundland Shelf. At present, euphausiids are generally below their long-term average abundance, which peaked in the 1970s.

The patterns revealed by the CPR data are evident on smaller spatial scales. For example, based on samples obtained from Station 27 (7 km east of St. John's harbour), chlorophyll concentrations (a metric of phytoplankton abundance) off Newfoundland in 2009 were at their highest levels since 2000, albeit returning to near-normal levels in 2010 (Pepin et al. 2011). A somewhat similar pattern is evident if one excludes the chlorophyll present during its period of peak abundance (i.e., during the spring 'blooms') (Figure 5.3). In the same region, and based on the abundance of eight dominant species of copepods, zooplankton appeared to be more abundant in 2009 and 2010 than the long-term average, although the 2008 estimate was the lowest in the time series, again reflecting high inter-annual variability in zooplankton biomass (Figure 5.4).

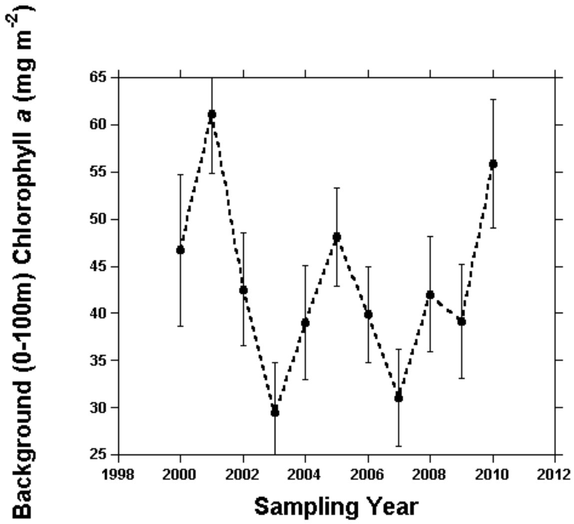
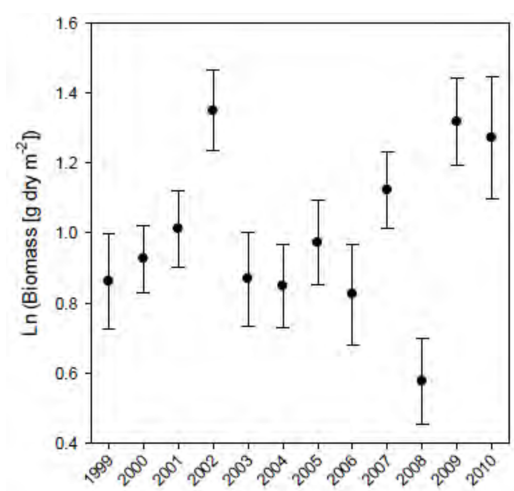


Figure 5.3. *Temporal trends in background chlorophyll a levels at Station 27 off St. John's, NL, during the time periods outside of the spring bloom periods (least squares annual averages ± 1 standard error). Source: Pepin et al. (2011).*

Specifically, the abundance of the small copepods (e.g., *Microcalanus* spp., *Oithona* spp., *Pseudocalanus* spp., *Oncaea* spp.) reached peak or near-peak levels while that of warm-water species such as *Acartia* spp., *Centropages* spp., and *Temora longicornis* were at low levels of abundance (Pepin et al. 2011). With the exception of *Calanus glacialis* and large copepod nauplii, most large copepods also increased significantly in 2009 and 2010. The temporal patterns of abundance observed at Station 27 are similar to those observed northeast of the Grand Banks (Flemish Cap) and on the southeast Grand Banks (Pepin et al. 2011). Interestingly, the duration of the spring phytoplankton bloom on the Scotian Shelf declined between 1999 and 2008 (based on data collected at the Halifax-2 fixed station, southeast of Halifax) concomitant with a general decline in 'background' (outside the spring bloom) chlorophyll levels over the past ten years (Figure 5.5) (Harrison et al. 2009).

Figure 5.4. *Temporal trends in seasonally adjusted estimates of the mean biomass of eight dominant copepod species from Station 27 off St. John's (error bars represent one standard error). Source: Pepin et al. (2011).*



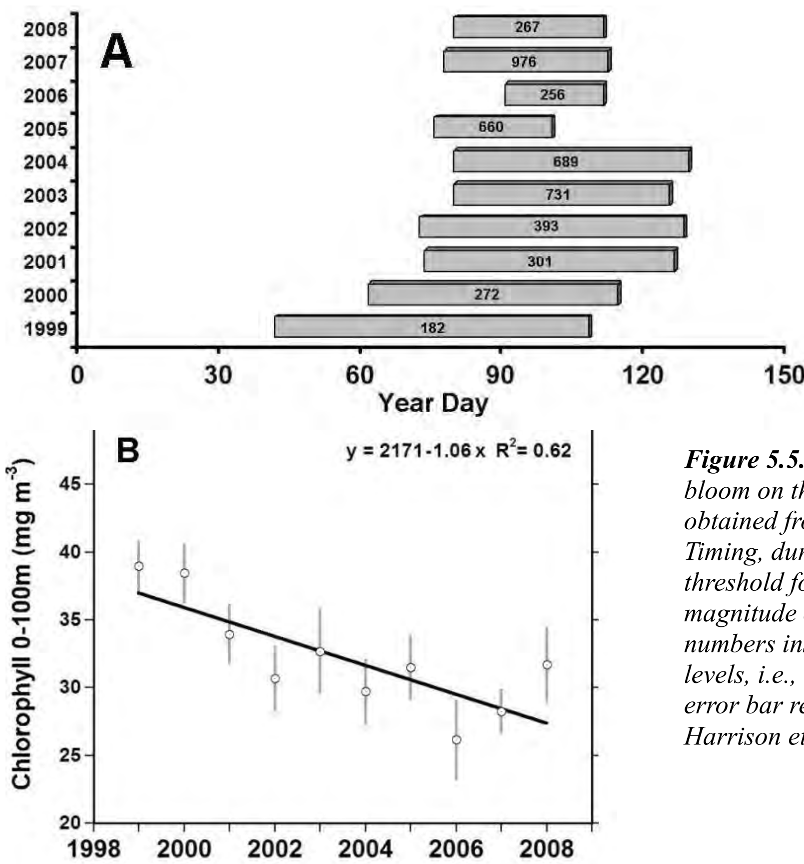


Figure 5.5. *Dynamics of the spring phytoplankton bloom on the Scotian Shelf (based on data obtained from sampling station Halifax-2). A: Timing, duration (based on 40 mg chlorophyll m^{-2} threshold for start and end of bloom), and magnitude of the bloom (as reflected by the numbers inside bars). B: Background chlorophyll levels, i.e., outside of spring bloom periods (each error bar represents 1 standard error). Source: Harrison et al. (2009).*

b. Marine Fishes

Trend data for marine fishes in Canadian waters can be obtained from two primary sources, both of which depend, to some extent, on DFO's fisheries-independent surveys. Population abundance or biomass data can be estimated from some form of sequential population analysis or statistical catch-at-age modelling (which incorporates catch-at-age data and assumptions concerning fish natural mortality; the model output is often then 'fitted' to the trend in survey catch rate), or they can be estimated directly from survey catch rates (such as numbers or weight of fish per unit of sampling effort, e.g., per tow of a bottom trawl net).

Restricting the analysis to marine fishes for which peer-reviewed stock assessments have been undertaken from 1970 to 2006, data are available for 40 populations of fishes that regularly inhabit Canadian waters (the full list of populations is given in Appendix E). Although the distribution of most of these fishes lies entirely in Canadian waters, the distribution of others (and the spatial breadth of threats that affect their sustainability) is considerably broader, e.g., Atlantic bluefin tuna, *Thunnus thynnus*. Multi-species abundance indices were constructed, following Hutchings et al. (2010). (Although the baseline year used here maximizes the number of populations for which data are available, it should be noted that many species, particularly on the Atlantic coast, had already experienced fishing-induced reductions by 1970.)

Overall, Canadian fish populations declined 52% between the first (1970-1974) and the last five years (2002-2006) in the time series (Figure 5.6). The index was relatively stable from 1970 until the mid-1980s, declined considerably until the mid-1990s, and remained relatively stable thereafter. The trend differed between pelagic (mid-water) and demersal (bottom-dwelling) fishes. Following a period of increase through the 1970s and 1980s, pelagic fishes (n=16) have declined to a level 40% lower than that of the early 1970s. By contrast, demersal fishes (n=24) have shown a steady increase since the mid-1990s, although their levels are 58% lower than they were in the early 1970s.

The reductions evident throughout Canadian waters are also evident at smaller spatial scales. In the Canadian Pacific, demersal (n=13) and pelagic fishes (n=6) have declined 51% and 18%, respectively, since the 1970s. In the Canadian Atlantic, current levels of abundance indicate declines of 69% and 51% by demersal (n=11) and pelagic (n=5) species, respectively. The five High Seas migratory species that are caught in Canadian waters have declined 61% since the early 1970s.

Although Canada has not identified Target Reference Points for most of its commercially exploited fishes, estimates of B_{MSY} for each stock, or population, can be made from surplus production models (Hilborn and Walters 1992). These estimates were reported by Worm et al. (2009) and by Hutchings et al. (2010). In addition, for fishes whose distribution encompasses Canadian waters, but for which fisheries assessment responsibilities are the purview of the US or an international body, estimates of B_{MSY} are available from stock assessments. Multi-species abundance indices were constructed for the period extending from 1970 to 2007.

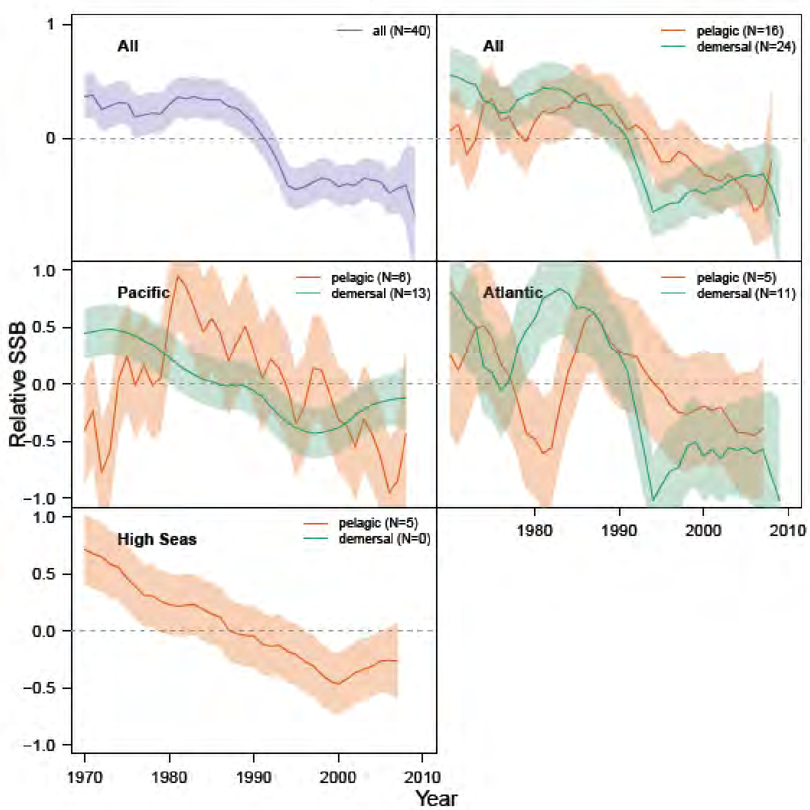


Figure 5.6. *Trends in multi-species abundance indices for Canadian marine fishes, as reflected by changes in spawning stock biomass (SSB). A multi-species index for all populations and regions combined is shown in upper left panel. Remaining panels illustrate multi-species indices for pelagic (red) and demersal (green) populations separately. The solid lines represent the fixed-effect mean yearly estimates, based on a mixed-effects model with population as a random effect. The shaded regions represent the 95% confidence intervals on the fixed-effect mean. The number of stocks in each trend line is identified by 'N'. Full details of methods are available in Hutchings et al. (2010).*

Restricting the multi-species indices to the 29 populations for which estimates of B/B_{MSY} are available for the time period under consideration, populations declined between 1970 and 2006 by an average 55% overall (from B/B_{MSY}=1.13 to 0.51), and by 42% and 61% for pelagic (0.80 to 0.47) and demersal (1.43 to 0.55) populations, respectively (Figure 5.7). The decline in B/B_{MSY} ratios for Canadian Atlantic fishes is consistent with temporal patterns evident in the Northeast Atlantic, which are also estimated to be well below B_{MSY} (Hutchings et al. 2010). Similarly, demersal fishes in the Canadian Pacific are estimated to be above B_{MSY}, a pattern consistent with fishes throughout the Northeast Pacific ocean that are managed by the US (Hutchings et al. 2010). With the exception of Pacific demersal fishes, Canadian marine fishes are currently below the B_{MSY}. This includes the broadly distributed High Seas pelagic species that are regularly caught in Canadian waters.

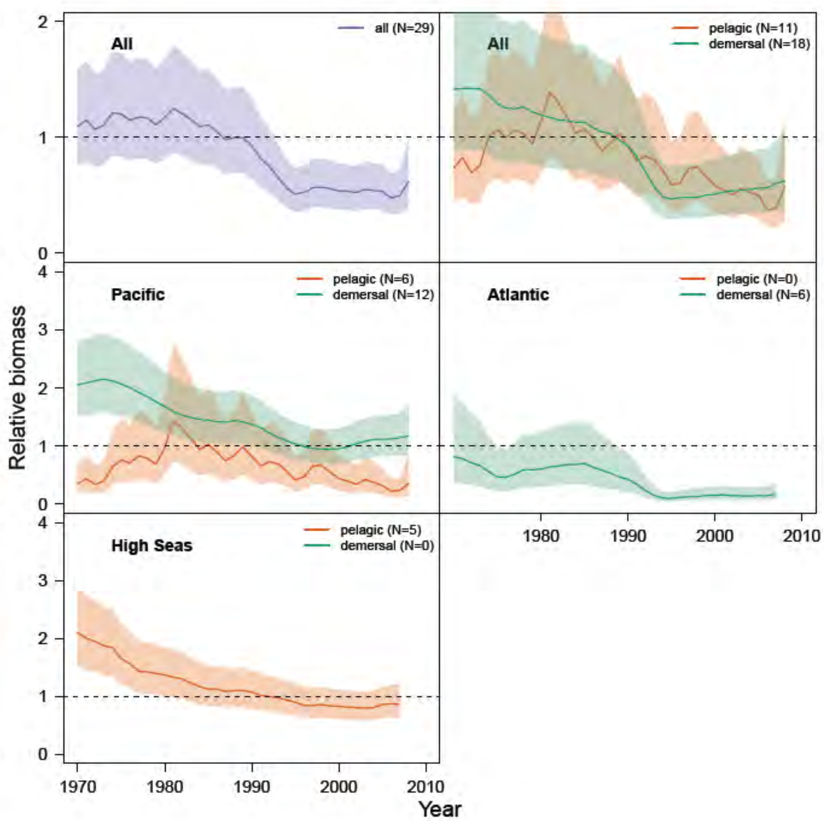


Figure 5.7. *Temporal trends in current biomass (*B*) relative to the estimated biomass at which the maximum sustainable yield should be obtained (*B_{MSY}*).* B_{MSY} *is set to one in each panel (broken lines). Multi-species index for all populations and regions combined is shown in upper left panel. Remaining panels illustrate multi-species indices for pelagic (red) and demersal (green) populations separately. The solid lines represent the fixed-effect mean yearly estimates, based on a mixed-effects model with population as a random effect. The shaded regions represent the 95% confidence intervals on the fixed-effect mean. Full details of methods are available in Hutchings et al. (2010).*

At the species level, the decline of Atlantic cod is estimated to have been the greatest of any Canadian terrestrial and aquatic vertebrate (Hutchings and Rangeley 2011). The breeding population size is estimated to have declined by ~2 billion breeding individuals between the early 1960s and the mid-1990s, corresponding to a reduction in spawning stock biomass of roughly two million tonnes (Figure 5.8). Notwithstanding recent, short-term positive trends in some areas (Frank et al. 2011; Hutchings and Rangeley 2011), meaningful recovery of the species has not been evident.

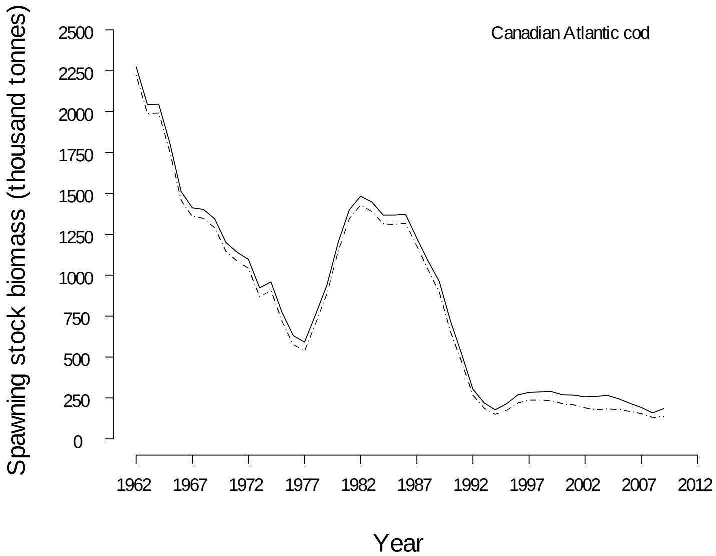


Figure 5.8. *Estimated spawning stock biomass of Canadian Atlantic cod from 1962 to 2009. The two lines reflect two different time series of spawning stock biomass considered equally plausible for one cod stock. Source: Hutchings and Rangeley (2011).*

c. *Diadromous Fishes*

i. *Pacific*

Within the marine and diadromous fishes in Canadian waters, Pacific salmon (*Oncorhynchus* spp.) are among the very few that can be termed 'iconic' (others being Atlantic salmon and Atlantic cod in the east, Arctic char [*Salvelinus alpinus*] in the north). Five primary species have supported substantial fisheries for aboriginal, commercial, and recreational harvesters for more than a century: pink (*O. gorbuscha*), chum (*O. keta*), coho (*O. kisutch*), sockeye (*O. nerka*), and Chinook (*O. tshawytscha*). Pacific salmon are key species in the ecological dynamics of their freshwater and coastal marine habitats and are perceived by the general public as reflecting the quality of their freshwater and marine ecosystems.

The status of Pacific salmon depends on the spatial scale being considered. The last 50 years have been marked by a dramatic increase in the North Pacific of the total number of wild (i.e., non-hatchery) adults 'returns' (i.e., catches plus spawners) of the three species for which the best long-term data are available: pink, chum, and sockeye (the North Pacific region includes populations from Korea, Japan, Russia, Alaska, Canada, and the conterminous US; Ruggerone et al. 2010a). On average, total annual abundances of wild pink and sockeye salmon populations increased by 60% and 56%, respectively, between the two decades 1952-1961 and 1996-2005, whereas total wild chum decreased by 20% (Figure 5.9; Ruggerone et al. 2010a,b).

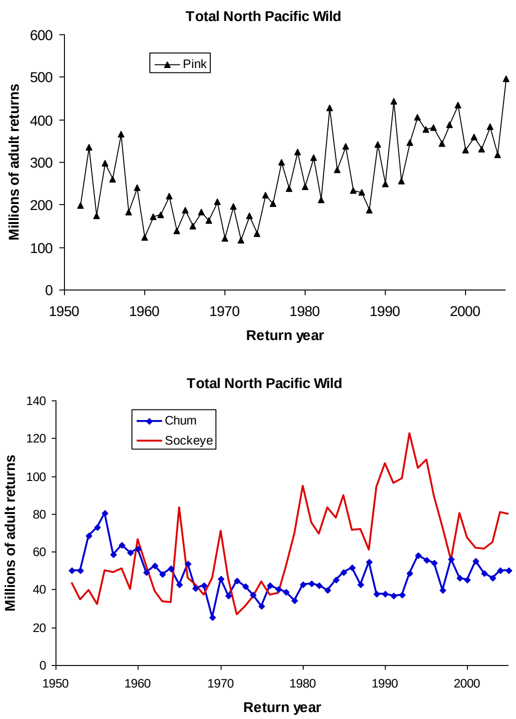
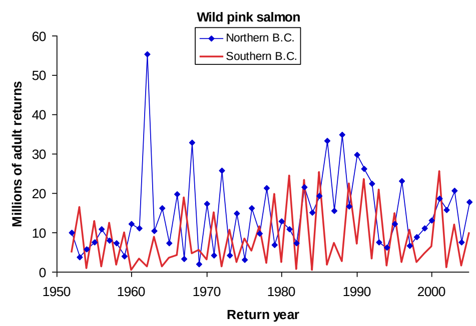
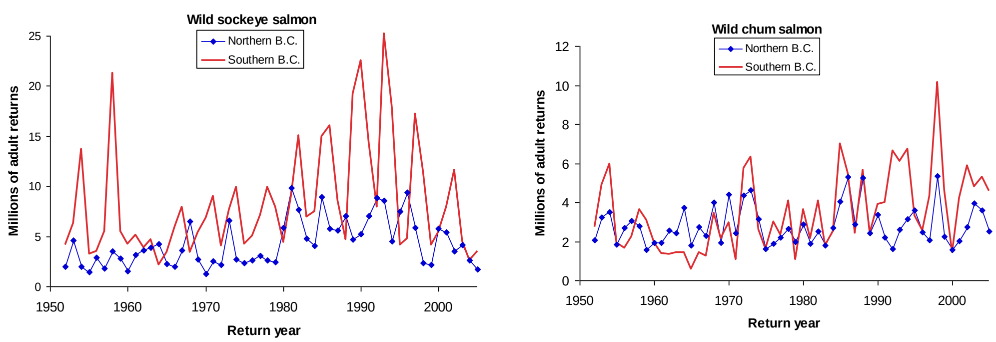


Figure 5.9. *Total annual abundance of adult returns (catch plus number of spawners, in millions) of wild pink, chum, and sockeye salmon for populations originating from the North Pacific Rim from 1952-2000. Note that vertical-axis scales differ on each graph.*

Figure 5.10. *Total annual abundance of adult returns (catch plus number of spawners, in millions) of wild pink, chum, and sockeye salmon for populations originating in northern and southern BC. Note that vertical-axis scales differ on each graph.*



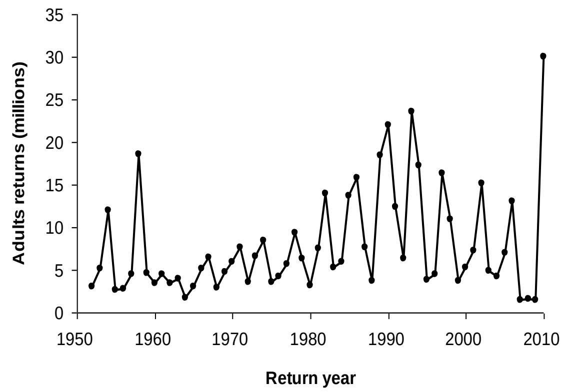


Canada's total wild populations of these species also tended to increase. Comparing the same two decades, pink, chum, and sockeye salmon in northern BC (the northern tip of Vancouver Island northward) have increased 78%, 16%, and 66%, respectively. This is considerably greater than two of those species in southern BC (19%, 61%, and 1%, respectively) (Figure 5.10).

However, against this broad backdrop of general increases in regional aggregate abundance, there are numerous individual populations that show widely differing temporal trends, some exhibiting stability, some increasing, and others decreasing, sometimes considerably. Fraser River sockeye provide an important example of a declining population (Box 5.1).

Box 5.1. The decline in Fraser River sockeye salmon.

Although abundance data since the 1950s for the total of 18 main Fraser River sockeye salmon populations show total adult returns increasing to highs in the late-1980s, they have generally since dropped by more than half. This occurred despite large increases in spawner abundances in most of those populations, as well as severely reduced harvest rates starting in 1995. The 2009 abundance of returns of sockeye to the Fraser River was the lowest since 1947. That event was the latest of many years of major fishery closures, and it led to the formation in 2009 of a federal Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River (Cohen Commission). Ironically, just after that near-record low abundance occurred, 30 million Fraser River sockeye adults returned in 2010 – a record high (see figure below).



Before 2010, however, 16 of the 18 major Fraser River sockeye populations had suffered reduced productivity (adult returns produced per spawner) during the previous two decades (Peterman et al. 2010). For the other two populations, the Late Shuswap population had experienced relatively constant productivity whereas the Harrison River population had dramatically increased in productivity and abundance. The eight Fraser sockeye populations that have additional abundance data on a juvenile life stage showed that reductions in productivity over the entire life cycle (spawners to adult returns) are most highly correlated with reductions in the juvenile-to-adult life stage (mostly marine life stage). This is in marked contrast to productivity in the freshwater stage. This result suggests either that the main sources of reduced survival in these eight Fraser sockeye populations occurred in the post-juvenile stage, or that these sources started to affect juveniles in fresh water but did not lead to mortality until later in life. In direct contrast, abundance of Fraser River pink salmon has increased substantially. The causes of the large increase in Fraser sockeye abundance in 2010 are not known, but it resulted from a productivity of 6.4 adults per spawner (near the average level experienced throughout the 1980s).

A key challenge for maintaining biological diversity among Pacific salmon stocks is that they are harvested in mixed-stock fisheries, in which adults from multiple populations of a given species return at the same time to fishing areas. These multiple populations are subjected to the same percentage harvest rate, yet some populations are more productive than others and can maintain relatively high spawner abundances despite high harvest rates. A good example of a mixed-stock fishery relates to the Cultus Lake sockeye population, which was assessed as Endangered by COSEWIC in 2003 because of very low and decreasing abundance.

However, the Cultus stock was not listed for any protection under SARA because the Minister of Fisheries and Oceans concluded that a SARA listing would restrict commercial fisheries too severely on other, more abundant and productive populations that move through fishing zones at the same time as the Cultus stock. Despite the lack of SARA listing, DFO's Integrated Fisheries Management Plans for BC salmon contain restrictions on fisheries to take into account 'stocks of concern', including Cultus sockeye, where target harvest rates are about 30%, which is much lower than the 70-80% rates in previous decades (DFO 2010a,b).

Large-scale salmon hatcheries exacerbate this mixed-stock fisheries problem by producing groups of fish that have higher productivity than their nearby wild counterparts and that can withstand higher harvest rates. Although DFO has not constructed new large-scale 'production' salmon hatcheries since 1985, the legacy of older hatcheries remains. For example, the percentage of hatchery-reared Strait of Georgia coho salmon that were caught in commercial and recreational fisheries increased from zero to almost 80% in the 1975-2000 period (Sweeting et al. 2003). Also, it is not clear the extent to which these hatchery coho have augmented, as opposed to supplanted, wild coho salmon in the Strait. However, research on a similar problem concerning hatchery and wild pink salmon in Prince William Sound, Alaska, concluded that there was at least some replacement of wild stocks (e.g., Hilborn and Eggers 2001; Wertheimer et al. 2004).

Southern Interior BC coho salmon provide another example of Pacific salmon that are under stress. Due to declining rates of return associated with increasing human land use (Bradford and Irvine 2000) and decreasing survival in the ocean, commercial harvesting of these fishes has largely ceased since 1998. Exacerbating the problem of rebuilding these coho salmon populations are changing ocean conditions, which are reflected in southern BC waters by long-term decreases in survival of both wild and hatchery-origin juvenile coho salmon during their time at sea (Figure 5.11).

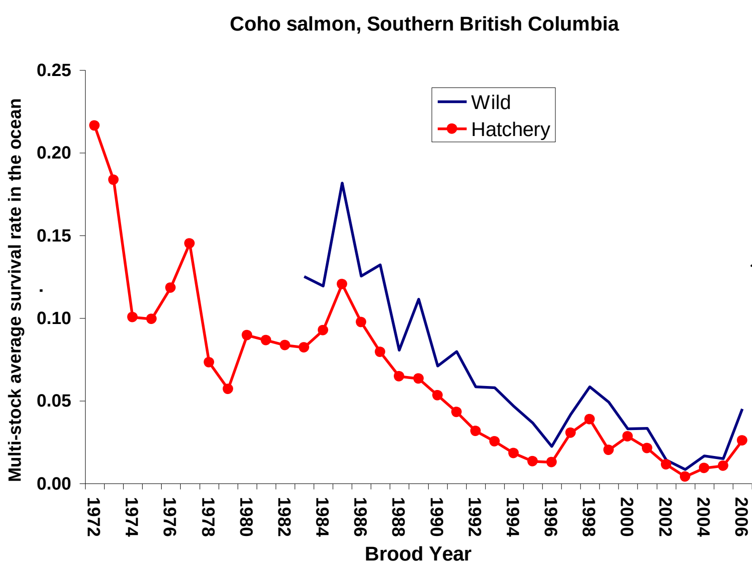


Figure 5.11. *Survival rate of wild and hatchery-origin juvenile coho salmon from southern BC populations during their residence in the ocean. 'Brood year' is the year in which those fish were spawned.*

The fifth major salmon species in BC is Chinook salmon, which has the largest body size of all Canadian salmon. Although population trends vary considerably, most major stocks in southern BC have decreased in abundance during the last decade (Figures 5.12, 5.13).

An important challenge for meeting conservation goals is that it is logistically and financially impossible to monitor all populations of Pacific salmon. There are literally thousands of spawning sites and distinguishing fishes from all those individual sites in mixed-stock catches is not possible. Although stock identification methods exist through use of genetics, scale-growth patterns, or the presence of unique parasites, they are generally associated with the most commercially important stocks. Given this situation, both Canada and the US use numerous intensively monitored 'indicator stocks' to indirectly represent the trends in survival rate and/or abundance of other nearby non-monitored stocks of the same species. Although survival rate and/or abundance levels tend to be, on average, positively correlated across such nearby populations, individual stocks can, and often do, move in different directions than do indicator stocks. This can lead to drastic reductions, or even complete loss, of particular stocks without any remedial action being taken.

Overall, Pacific salmon in BC show a mix of time trends in abundance and survival rates, but there are serious and growing concerns about the conservation status of many sockeye, coho, and Chinook salmon stocks, especially in southern BC. These downward trends for many coho and sockeye stocks have continued, even after fishing was severely reduced or even eliminated. Causes of these downward trends are not clear, but a recent Expert Panel Report on the decline of Fraser River sockeye concluded that the causes most likely arise in the ocean, rather than in fresh water, and that the primary candidates are marine food supply, marine predators, pathogens from fresh or marine waters, and competition with pink salmon in the high seas (Peterman et al. 2010). Another possible cause, termed delayed density dependence, appeared most relevant to only a subset of sockeye stocks (Peterman et al. 2010).

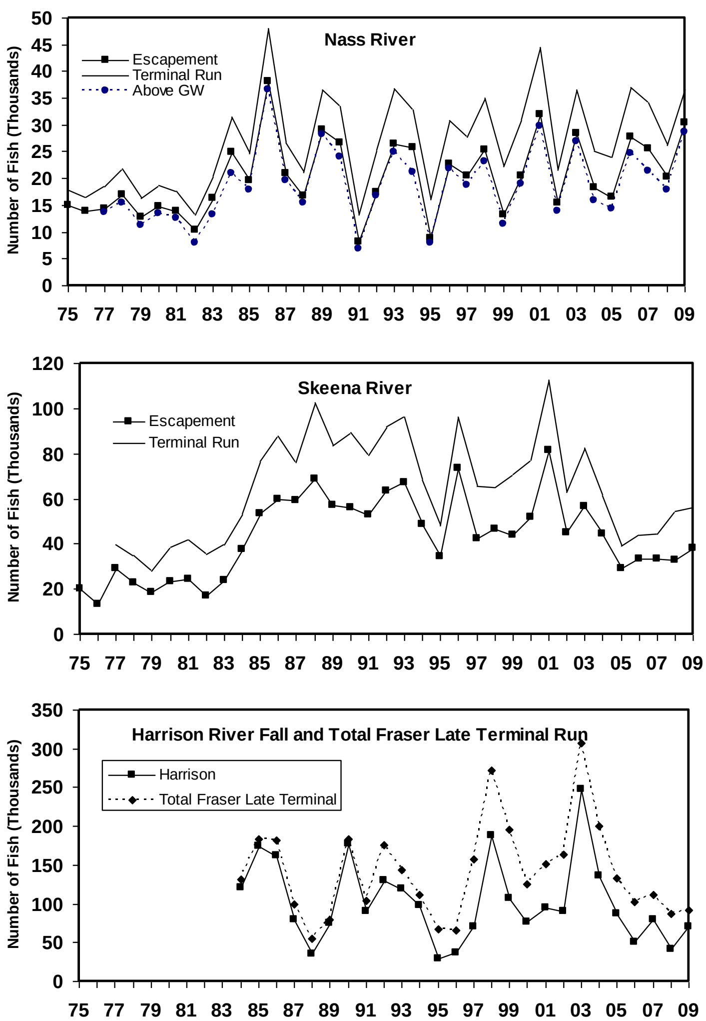


Figure 5.12. *Total annual abundance of spawners ('escapement') and adult returns ('terminal run', which is the catch plus number of spawners in thousands) for BC Chinook salmon in the Nass River, Skeena River, and Harrison River fall Chinook, as well as the total Fraser River late terminal run. In the upper panel, 'Above GW' refers to a specific location in the Nass River at Gitwinksihlkw. Note that vertical-axis scales differ on each graph.*

The Wild Salmon Policy (DFO 2005) outlines general objectives and strategies for maintaining a healthy and diverse set of wild salmon populations called Conservation Units (CUs). Work is still ongoing to identify appropriate ‘benchmarks’ (analogous to reference points; see above) for the five Pacific salmon species. Those benchmarks will be used to categorize CUs into red (critical), amber (cautious), or green (healthy) states. Depending on available data, benchmarks will be set in terms of spawner abundance, trends in its abundance, or occupancy of the spawning sites (Holt et al. 2009).

In addition to Pacific salmon, several other diadromous species inhabit coastal BC. Prominent among these are steelhead (*O. mykiss*), cutthroat trout (*O. clarki*), eulachon, green sturgeon (*Acipenser medirostris*), white sturgeon, and Dolly Varden (*Salvelinus malma*). Unfortunately, trend data are generally not available for BC’s diadromous fishes, other than Pacific salmon. The exceptions tend to be those species assessed by COSEWIC. With a generation time of 30-40 years, the long-lived white sturgeon is estimated to have declined more than 50% in the past century and was assessed as Endangered in 2003. Many populations of eulachon have experienced declines in excess of 90% in the past two decades, perhaps the most dramatic of these being the 98% reduction by the Fraser River population(s), resulting in COSEWIC status assessments in 2011 of Threatened and Endangered. The green sturgeon was assessed a status of Special Concern in 2004.

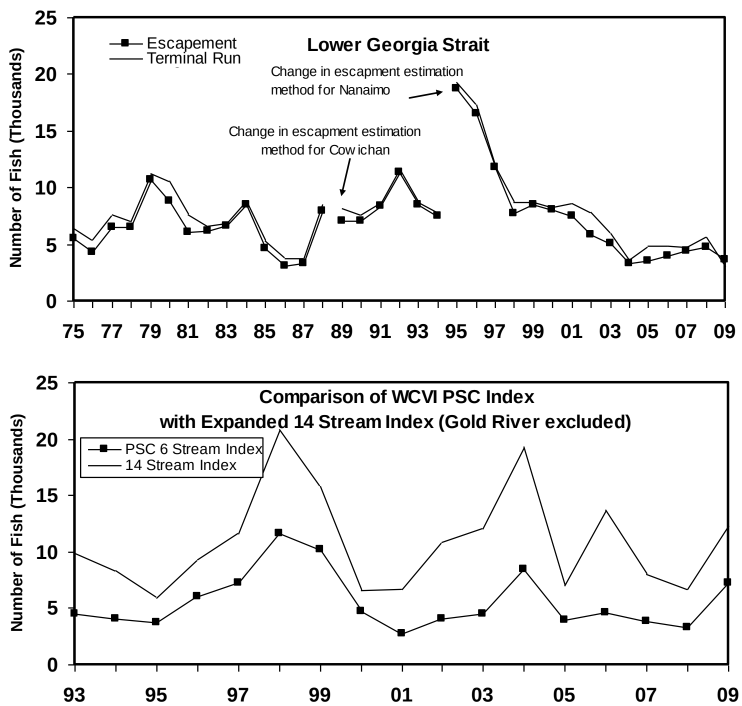


Figure 5.13. *Total annual abundance of spawners (‘escapement’) and adult returns (‘terminal run’, which is the catch plus number of spawners in thousands) for BC Chinook salmon in the Lower Strait of Georgia (upper panel). The lower panel shows abundance for two sets of index stocks for Chinook salmon, one based on 14 streams and another based on six streams that are used by the Pacific Salmon Commission (PSC) for the West Coast of Vancouver Island (WCVI).*

ii. Atlantic

Diadromy is characteristic of the life histories of several native species of fishes in the Atlantic, including sea lamprey (*Petromyzon marinus*), two species of sturgeon (*Acipenser* spp.), American eel (*Anguilla rostrata*), several clupeids (e.g., shad), rainbow smelt (*Osmerus mordax*), Atlantic salmon, Arctic char, brook trout (*Salvelinus fontinalis*), and striped bass.

The wild species with the broadest spatial distribution in Atlantic Canada is Atlantic salmon, existing from Ungava Bay south to the American border. Between the early 1970s and the early 1990s, these salmon experienced a 70-80% decline in the abundance of multi-sea-winter fish (i.e., salmon that spend more than one winter at sea prior to their return to their natal river) (Figure 5.14); their abundance has remained stable since the mid-1990s, as has that of one-sea-winter salmon.

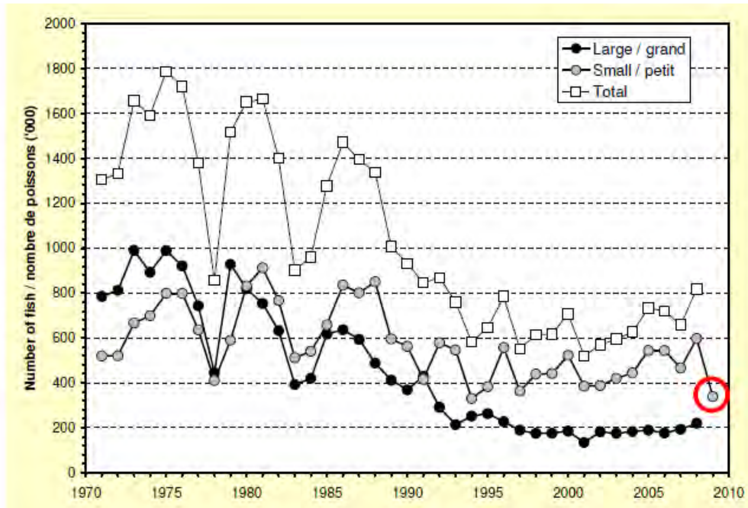


Figure 5.14. *Trends in the pre-fishery abundance of large (multi-sea-winter; black circles) and small (one-sea-winter; grey circles) Atlantic salmon to Canadian rivers. Source: COSEWIC (2011).*

It is important to note that these pan-Canadian trends in Atlantic salmon abundance mask significant spatial differences at smaller regional scales. For example, many (albeit not all) river populations of salmon in Newfoundland and Labrador have increased since the closure of commercial fisheries in that area in 1992 (Figure 5.15). Indeed, most were assessed as Not At Risk by COSEWIC in 2010. In contrast, many populations in Québec (Figure 5.16), and most in the Maritimes (Figure 5.17), have experienced significant declines. At the southern end of their Canadian range, in the Bay of Fundy and along the southeastern coast of Nova Scotia, most Atlantic salmon populations have either been Extirpated or are Endangered.

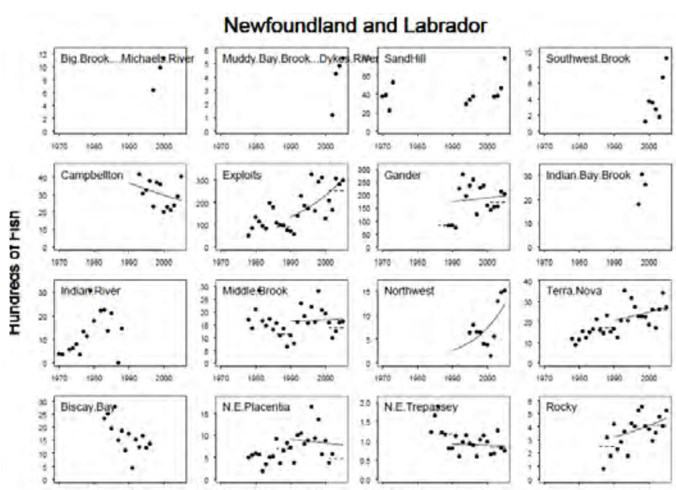


Figure 5.15. *Trends in the abundance of Atlantic salmon returning to selected rivers in Newfoundland and Labrador. Source: Gibson et al. (2006).*

Figure 5.16. Trends in the abundance of Atlantic salmon returning to selected rivers in Québec. Source: Gibson et al. (2006).

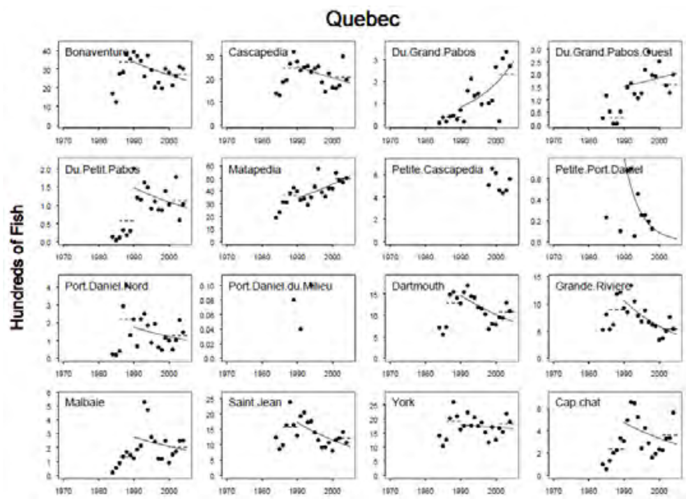
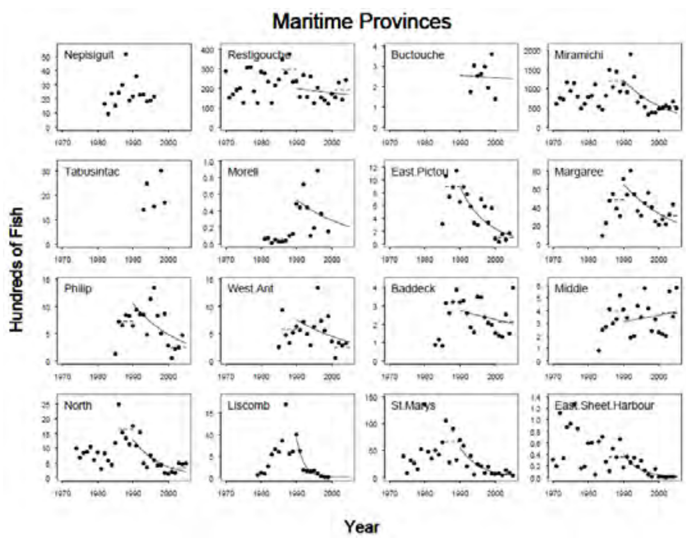


Figure 5.17. Trends in the abundance of Atlantic salmon returning to selected rivers in the Maritimes. Source: Gibson et al. (2006).



Although temporal abundance estimates are generally not available for most other diadromous species in Atlantic Canada, existing data generally reveal declines. The numbers of eels returning to Lake Ontario via the St. Lawrence River have declined more than 95% since the 1970s (Figure 5.18). Striped bass have been extirpated from the St. Lawrence Estuary (although recent introduction efforts may prove successful) and are deemed Threatened in the Southern Gulf of St. Lawrence and Bay of Fundy. As well, based on data available in COSEWIC species status reports (http://www.cosewic.gc.ca/), sturgeon have generally declined during the past half-century. Since 2005, both Atlantic Canadian species have been assessed as being at risk: Atlantic sturgeon (*A. oxyrinchus*) is Threatened (2011) and shortnose sturgeon (*A. brevirostrum*) is of Special Concern (2005).

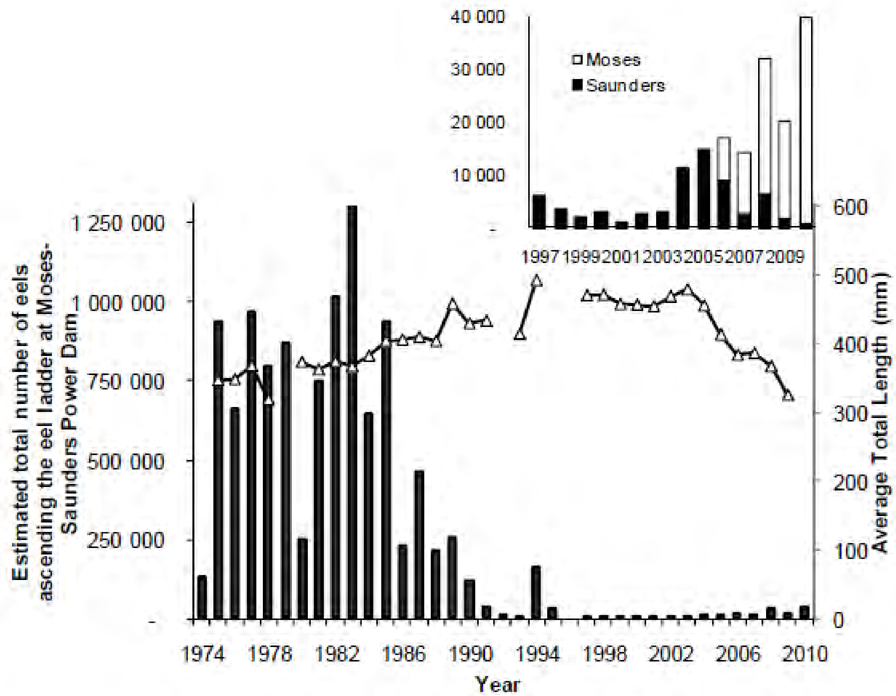


Figure 5.18. *Estimated number of American eels ascending the Moses-Saunders eel ladder in the Upper St. Lawrence River at Cornwall, ON, and NY Power Authority (Massena, NY) eel ladder (data are combined for both ladders). Source: COSEWIC (2012).*

d. Marine Mammals

In contrast to temporal trends in marine and some diadromous fishes, many marine mammals exhibit evidence of dramatic increases following lengthy periods of exploitation (DFO 2010c). This is particularly true of pinnipeds, such as harp seals and grey seals (*Halichoerus grypus*) off the east coast (Figure 5.19). Since the late 1960s, harp seals (which breed on ice flows from the Arctic south to the Gulf of St. Lawrence) increased from roughly two to eight million in 2008 (DFO 2011) and grey seals from ~10,000 in 1960 to as many as 430,000 today (DFO 2010d). Increases in abundance have also been evident among some cetaceans. The humpback whale (*Megaptera novaeangliae*), for example, on both Canada's east and west coasts has shown steady increases since the 1950s. Despite some impressive increases, other species have not fared as well. BC's killer whales were assessed as being at increased risk in recent years. Of the four Designatable Units of killer whales recognised by COSEWIC, three have been assessed as Threatened (Northeast Pacific Offshore, Northern Resident, West Coast Transient) and one Endangered (Southern Residents); these assessments are based primarily on small absolute numbers of reproductive maturely individuals. Populations of right whale (*Eubalaena glacialis*) and northern bottlenose whale (*Hyperoodon ampullatus*) in eastern Canada have both been assessed as Endangered. As of January 2012, 34 wildlife species of marine mammals had been assessed as species at risk by COSEWIC.

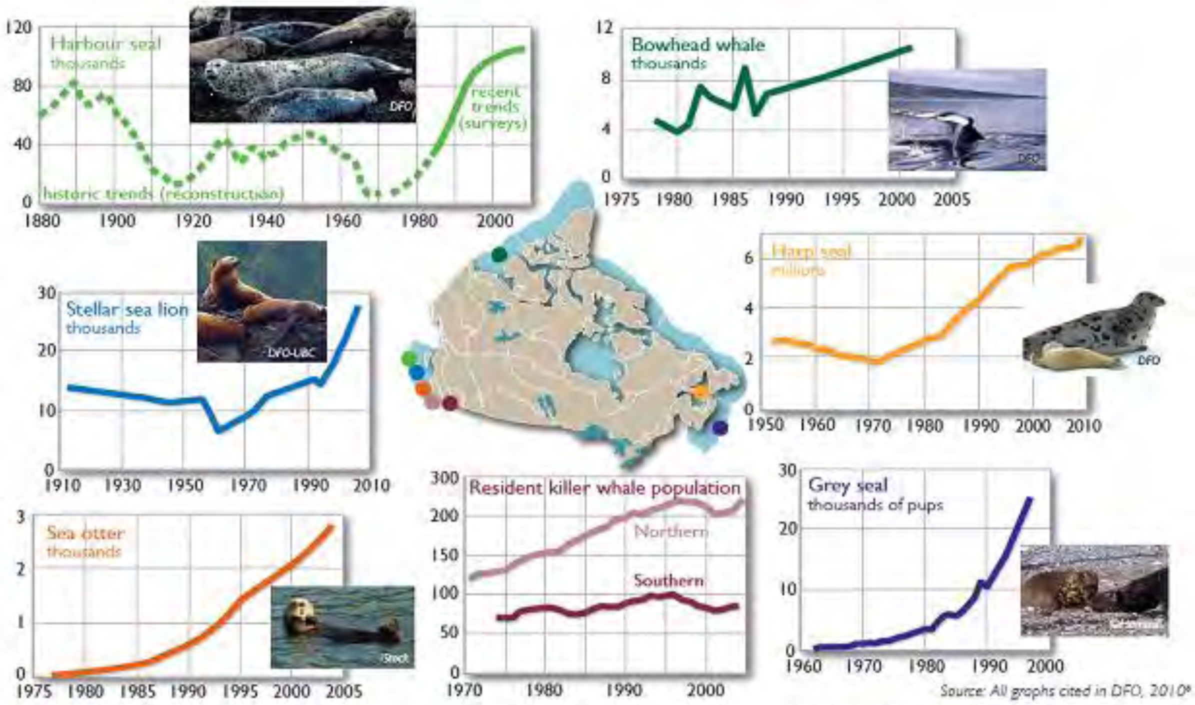


Figure 5.19. *Abundance trends for selected species of marine mammals. Source: DFO (2010c).*

e. Seabirds

Although the monitoring of some seabirds dates from the 1920s, abundance data were not systematically collected for many colonies until the 1980s (Gaston et al. 2009 provide an excellent overview of the population monitoring of Canadian seabirds). Trend data tend to originate from two sources. Ground-nesting birds, such as northern gannet (*Morus bassanus*), terns (*Sterna* spp.), and murres (*Uria* spp.), have been estimated either by counts made on the ground or from aerial photographs. Data on burrow-nesters, such as storm-petrels (Hydrobatidae) and various species of auks (Alcidae), have usually been obtained from transects and from randomly placed sampling plots.

Gaston et al. (2009) recognized six zones for the purposes of estimating abundance of seabirds in Canadian waters: two in each of the Pacific, Arctic, and Atlantic. On the Pacific coast, south of Queen Charlotte Sound, the most important breeding colony is that located on Triangle Island, where censuses have generally indicated declines from 1984 to 2004, based on abundance data for three burrow-nesting auks: rhinoceros auklet (*Cerorhinca monocerata*; 4% decline), Cassin's auklet (*Ptychoramphus aleuticus*; 46% decline), and tufted puffin (*Fratercula cirrhata*; 34% decline). In contrast to southern BC waters, burrow-nesting auks breeding north of Queen Charlotte Sound on Haida Gwaii have increased in abundance, e.g., ancient murrelets (*Synthliboramphus antiquus*; 66% from 1985 to 1995), rhinoceros auklets (34 and 90% from the mid-1980s to 2006 in two separate colonies) (Gaston et al. 2009).

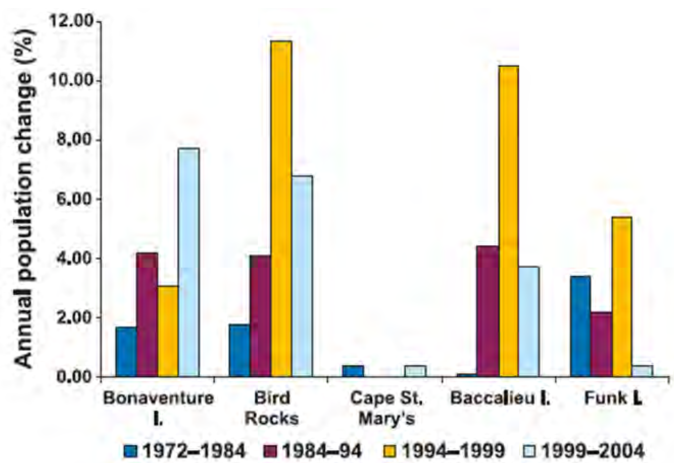
According to Gaston et al. (2009), long-term data on seabirds in the Arctic are available for two primary areas: the central Arctic Archipelago (principally Prince Leopold Island in Barrow Strait and the Hell Gate/Cape Vera region between Devon and Ellesmere Islands); and Digges and

Coats Islands at the mouth of Hudson Bay. At Prince Leopold Island, thick-billed murre (*Uria lomvia*) and black-legged kittiwake (*Rissa tridactyla*) have increased since the 1970s. Data of a more limited quality suggest that northern fulmars (*Fulmarus glacialis*) and glaucous gulls (*Larus hyperboreus*) might have declined during this period. Perhaps the most dramatic population reduction has been experienced by ivory gulls (*Pagophila eburnea*) breeding in northern Nunavut. Formerly numbering 4000 breeding individuals, this population is estimated to have declined more than 80% between the 1980s and 2005 (Gilchrist and Mallory 2005), a rate sufficiently high to have resulted in the species being assessed as Endangered by COSEWIC. Thick-billed murres have increased by approximately 33% on Coats and Digges Islands between 1985 and 2007. By contrast, glaucous gulls and Arctic terns (*Sterna paradisaea*) may have declined more than 50% between the 1980s and 1997 in Hudson Bay.

In the Atlantic, northern gannet (the species for which abundance data are most extensive) have increased since the 1950s (Figure 5.20). Most colonies of black-legged kittiwakes and common murres (*Uria aalge*) appear to have increased from 1970 to the early 1990s, and to have declined moderately thereafter.

As of January 2012, COSEWIC had assessed eight seabirds as being at risk. However, only five of these breed in Canada (ivory gull, roseate tern [*Sterna dougallii*], marbled murrelet, ancient murrelet, Ross' gull [*Rhodostethia rosea*]).

__Figure 5.20.__ Trends in northern gannet abundance at colonies in the Gulf of St. Lawrence and off eastern Newfoundland. Source: Gaston et al. (2009).



5. Main Findings

- Any increase in the number of marine species assessed as being at risk (currently 116) is likely to be attributed to forthcoming assessments of Pacific salmon.
- Marine fishes declined in abundance by an average of 52% from 1970 to the mid-1990s and have remained stable thereafter; most fished stocks are well below target reference levels.
- Since the 1950s, combined numbers of wild pink, chum, and sockeye salmon have increased; however, in the last few decades, despite drastically reduced harvest rates, the abundance and/or productivity of many individual populations, e.g., Fraser River sockeye, has declined.

- Among Atlantic diadromous fishes, Atlantic salmon has declined markedly in the south but remained relatively stable elsewhere; several other species (eel, sturgeon) are species at risk.
- Most, but not all, marine mammals have increased following past over-exploitation.
- Trends in seabirds have been mixed, showing increases in some areas (e.g., auks in northern BC waters; murres and kittiwakes in the Arctic; gannets in Atlantic Canada) and declines in others (e.g., auklets in southern BC waters; ivory gulls in the Arctic).

Chapter Six: Trends in Canadian Marine Fisheries and Aquaculture

1. Introduction

A key objective of this chapter is to lay groundwork for some of the chapters that follow. That is, before one can address the projected consequences to marine biodiversity of fisheries (Chapter Eight) and aquaculture (Chapter Nine), one requires descriptions of the past and present magnitude of these potential stressors. To provide perspective, the chapter begins by briefly examining global trends in capture fisheries and aquaculture before turning to the trends in Canada, including a consideration of their respective monetary value.

As of 2009, it is estimated that capture fisheries and aquaculture supplied the world with 145 million tonnes of fish and aquatic invertebrates (Figure 6.1), with Canada supplying ~1% of this amount. At present, Canada ranks 20th among nations in fisheries catches. However, in terms of monetary value, Canada ranks seventh globally, with the vast majority of its production used for human consumption. Approximately 117.8 million tonnes of the global catch in 2009 was for human consumption, resulting in an average food supply of 17.2 kg of fish and aquatic invertebrates per person (FAO 2010)

Capture fisheries supplied about 90 million tonnes of the global fish and aquatic invertebrate production in 2009, 89% of which derived from marine fisheries (Figure 6.1). Marine capture fisheries production has been relatively stable over the past decade. Increases in global fisheries production during that period have come from aquaculture, both marine and inland. In fact, aquaculture is the fastest growing animal-food-producing sector globally and, given the 55.1 million tonnes produced in 2009, it could overtake capture fisheries as the main source of food derived from fish (and invertebrates) as early as 2012, assuming that its annual rate of growth of 6.6% in 2008 (FAO 2010) is maintained and that capture fishery landings remain stable. Approximately 47% of the fish and aquatic invertebrates for human consumption in 2009 was derived from aquaculture (FAO 2010), with 35.0 million tonnes supplied by inland aquaculture and 20.1 million tonnes supplied by marine aquaculture (Figure 6.1). Similarly, in Canada, catches from capture fisheries have remained relatively stable or have declined somewhat over the past decades (Figure 6.2), whereas aquaculture production has increased (Figure 6.3). Aquaculture in Canada, however, still only contributes about 15% of the country's total fisheries production.

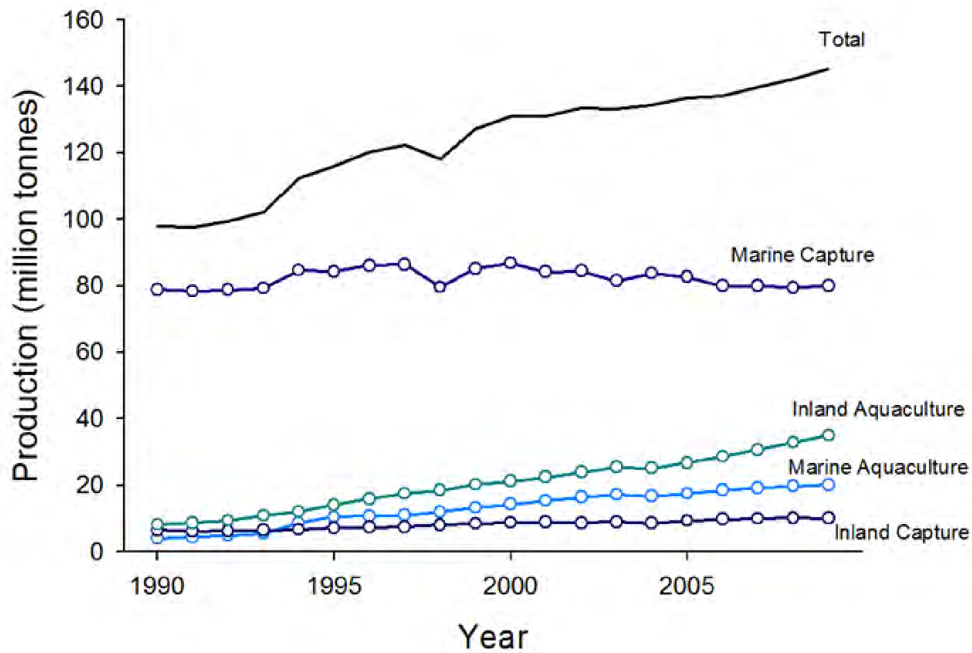


Figure 6.1. *Contribution of marine capture fisheries and marine aquaculture to world fisheries production during the last two decades. Data source: FAO (2010).*

2. Capture Fisheries

a. Landed Catches in Canada

Data on fisheries landings by Canadian enterprises are generally available for catches made in Canadian waters since the mid-1970s. Detailed data on tonnage caught on a species-by-species basis are available for 1990 through 2009. (Data of an instructive albeit more limited nature are available for earlier years, e.g., Figure 6.4.) These detailed data allow for catches to be apportioned to demersal (bottom-dwelling) fishes, pelagic (mid-water) fishes, diadromous fishes (e.g., Pacific salmon, alewife [*Alosa pseudoherangus*]), invertebrates (dominated by lobster [*Homarus americanus*] and snow crab [*Chionoecetes opilio*]), and other species (e.g., plants, sea cucumbers [Holothuriidae], sea urchins [e.g., *Strongylocentrotus droebachiensis]).* When evaluating the magnitudes of these catches, it is important to note that these landings data do not account for fish that were illegally captured or discarded.

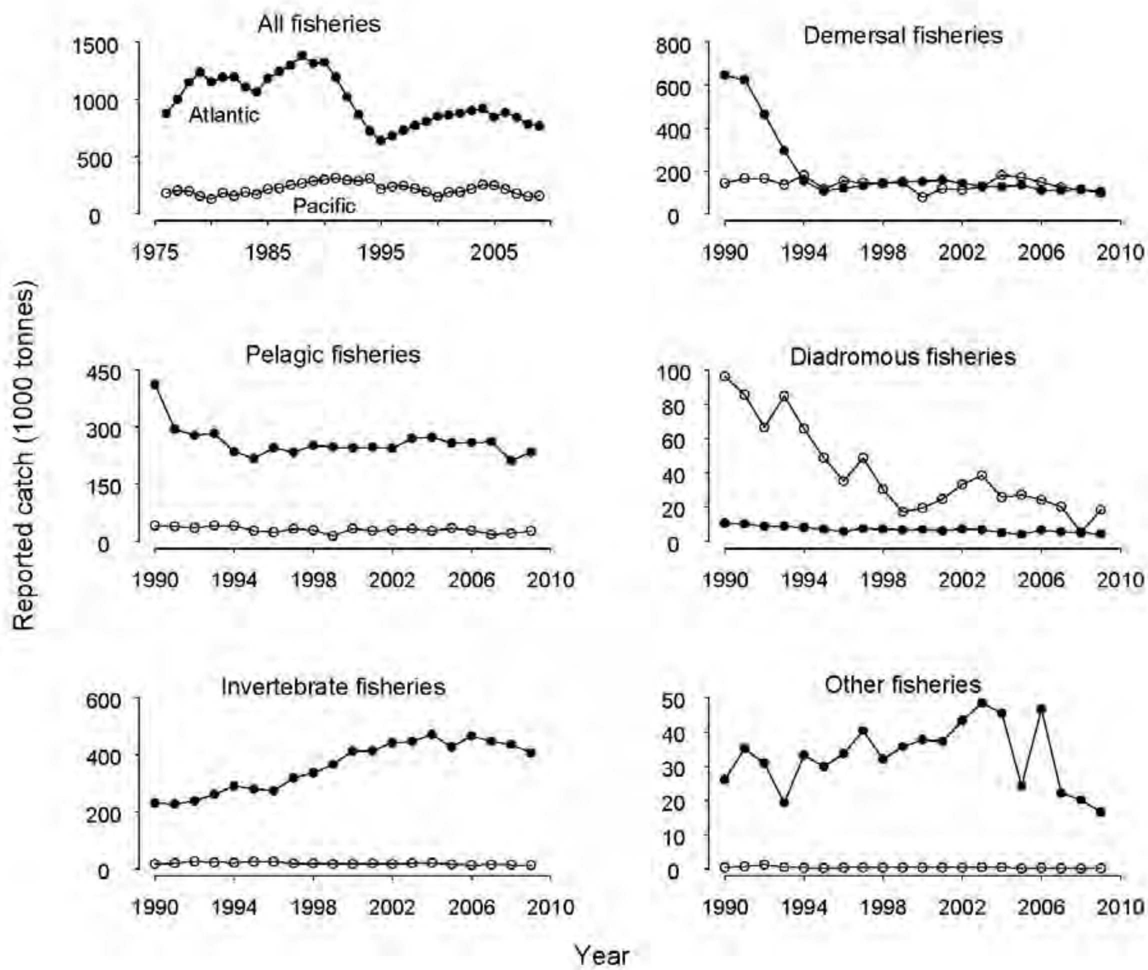


Figure 6.2. *Reported catches from various fisheries in the Atlantic (●) and Pacific (○) regions. Data source: (http://www.dfo-mpo.gc.ca/stats/stats-eng.htm).*

In 2009, Canadian fishing enterprises landed 924,757 tonnes, the third lowest catch in Canadian waters since 1976 and almost certainly in the past half-century. The only years since 1976 in which catches were lower were 1995 (857,310 tonnes) and 1996 (918,662 tonnes). Since Canada extended its fisheries jurisdiction to 200 nautical miles in 1977, the trends in catches from all sources have differed between Atlantic and Pacific fisheries. After reaching a peak in 1988 (1,385,137 tonnes), Atlantic catches declined by approximately half; the total Atlantic catch in 2009 was 767,573 tonnes (Figure 6.2). Between 1976 and 2009, catches in Pacific waters fluctuated about a mean of 217,324 tonnes. Following a near doubling during the 1980s, catches in Pacific waters declined from a peak of 312,104 tonnes in 1991 to 157,184 tonnes in 2009.

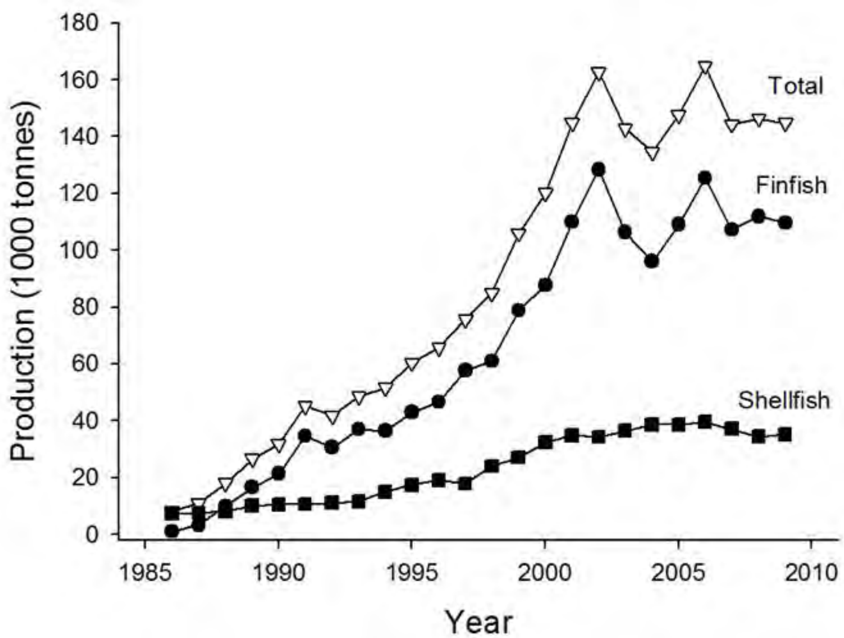


Figure 6.3. *Marine aquaculture production in Canada.*
Data source: dfo-mpo.gc.ca/stats/stats-eng.htm

Canada's fisheries differ considerably in terms of species composition. The Atlantic fishery, once dominated by demersal fishes such as cod (note the catches of demersal fishes prior to 1990; Figure 6.4), is now predominantly comprised of invertebrates. Since the 1994 minimum for Atlantic Canada, the annual tonnage of invertebrate catches increased to roughly 400,000 tonnes, while those for the pelagic and demersal fisheries remained comparatively stable at 300,000 tonnes and 200,000 tonnes, respectively. From 1990 to 2009, the landed catches of the Pacific fishery were dominated by demersal fishes, averaging 137,984 tonnes annually. Catches of Pacific diadromous fishes (being comprised entirely of Pacific salmon) declined markedly from almost 100,000 tonnes in 1990 to a low of 5,373 tonnes in 2009. In contrast to the Canadian Atlantic, Pacific landings of pelagic fishes and invertebrates have been comparatively low and have not experienced systematic trends over time.

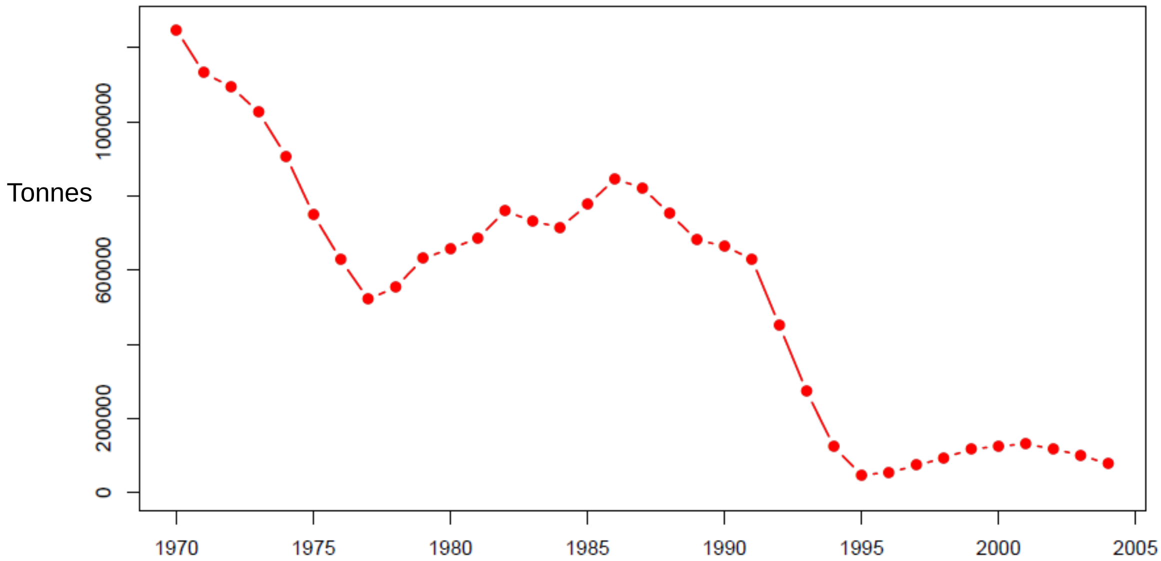


Figure 6.4. *Landings (tonnes) reported from Canadian Atlantic fisheries for demersal (bottom-dwelling) fishes from 1970 to 2004. Data are from DFO stock assessments for Atlantic Canadian demersal fishes listed in Appendix E of this report.*

b. Value of Landed Catches in Canada

The landed value of Canada's commercial fisheries in 2009 was among the lowest values since Canada's responsibility for fisheries management was extended from 12 to 200 nautical miles in 1977 (Figure 6.5). Corrected for inflation and reported in 2011 dollars, Canadian landings from the Atlantic and Pacific coasts combined were valued at $1.66 billion in 1977 and $1.72 billion in 2009. At its height, the landed value of Canadian fisheries was $2.78 billion in 1987 and $2.69 billion in 2000. Concomitant with these changes is an increase in the export of wild fisheries products, from ~30% of production in 1990 to ~46% in 2009. The value of the Atlantic fisheries has always exceeded that of the Pacific fisheries (Figure 6.5). The latter has been declining since the late 1970s, primarily because of a reduction in salmon. In contrast, the Atlantic fisheries increased steadily in value until the early 2000s (because of the increased value of the invertebrate fisheries), after which it declined.

3. Aquaculture

a. Marine Aquaculture Production in Canada

Marine aquaculture in Canada began to develop in earnest in the 1980s. Initially dominated by shellfish, it was rapidly surpassed by finfish production (Figure 6.3). (The word 'shellfish' is now widely used in the fisheries and aquaculture literature to refer to invertebrates, such as blue mussels, Mytilus edulis, and lobster, although none of these 'shellfish' is actually a fish, which are often identified as 'finfish'.) The expansion of aquaculture, driven largely by finfish production, was rapid until 2002 when production then stabilized (Figure 6.3), a 'stalled expansion' attributed to multiple factors, including disease, government-imposed moratoria in response to environmental concerns, and market considerations. Industry believes that opportunity for expansion remains, and that production could more than triple by 2015 (aquaculture.ca/files/opportunity-expansion.php; accessed 17-11-11).

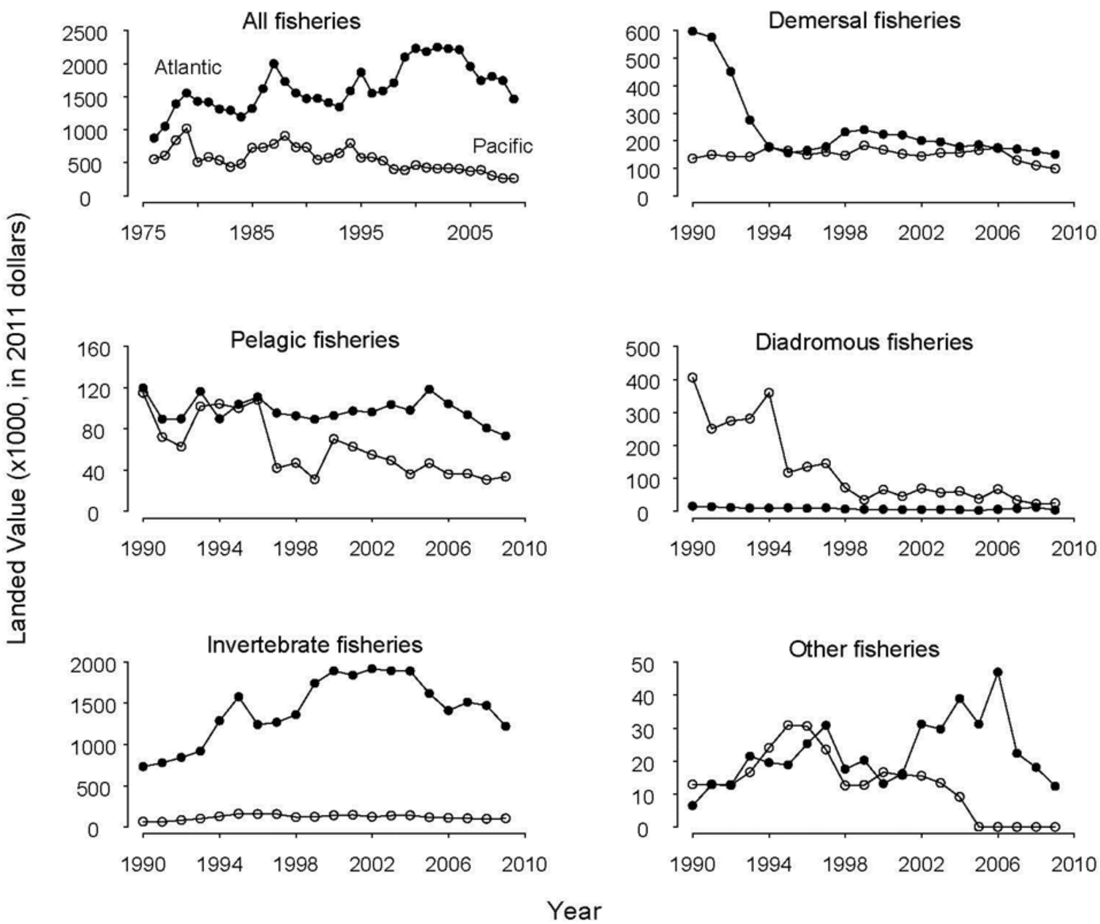


Figure 6.5. Landed value in thousands of 2011 dollars from various fisheries in the Atlantic (●) and Pacific (○) regions. Data source: http://www.dfo-mpo.gc.ca/stats/stats-eng.htm.

Marine finfish aquaculture in Canada has been dominated by the production of salmonid fishes (Atlantic salmon, Chinook salmon, coho salmon and steelhead trout), although more recently small-scale aquaculture of other marine species (Atlantic halibut, Atlantic cod, sablefish [*Anopoploma fimbria*], spotted wolfish [*Anarhichas minor*], and Atlantic wolfish [*A. lupus*]) has been initiated. The major finfish aquaculture region is BC, where more than two-thirds of the country's production is located (Figure 6.6). Finfish aquaculture on the Pacific coast has developed rapidly since the mid-1980s and now involves about 130 licensed tenures encompassing a total area of 4,575 hectares. Approximately 100 of the tenures are currently active, with typically 80% of these tenures operational in any one year.

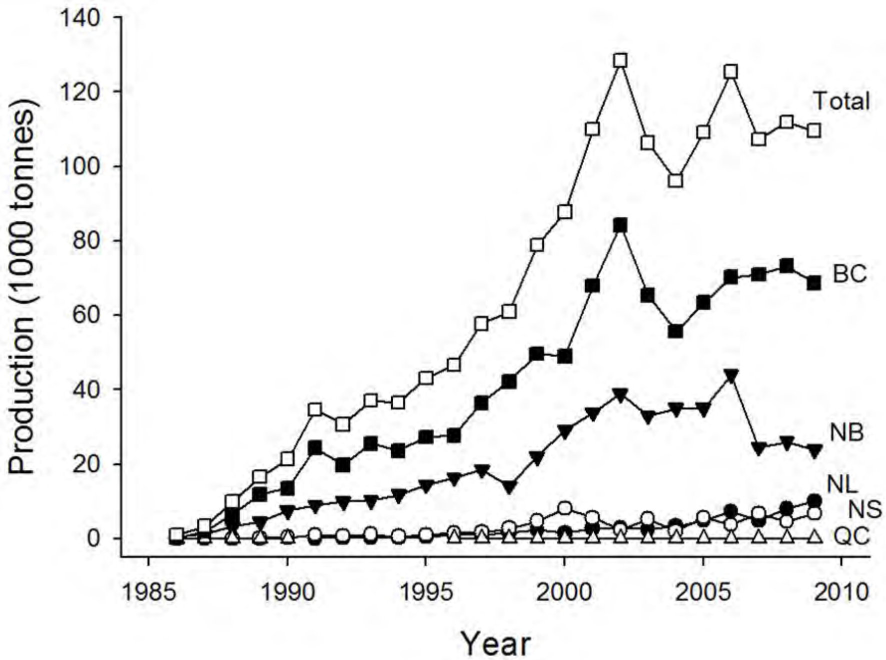


Figure 6.6. *Canadian aquaculture production of marine finfish. Production is dominated by salmonid fishes, particularly Atlantic salmon. Production of other marine finfish constitutes < 1% of the total marine finfish aquaculture production. Data source: (www.dfo-mpo.gc.ca/stats/stats-eng.htm; accessed 17-11-11).*

New Brunswick remains Canada's second largest finfish producer, though recent rapid expansion of operations in Newfoundland may soon challenge this ranking. Newfoundland has more than doubled its finfish aquaculture production in the last five years from 5,006 tonnes in 2005 to 12,899 tonnes in 2010 (http://www.fishaq.gov.nl.ca/stats/index.html; accessed 17-11-11).

The predominant finfish species in aquaculture on both coasts is Atlantic salmon (Figure 6.7). On the Atlantic, there is also a relatively small production of non-native steelhead trout (Figure 6.7A). While the non-native Atlantic salmon currently dominates production on the Pacific coast, this was not always the case. Initially, the Pacific finfish aquaculture focused solely on native coho, Chinook, and steelhead trout (Figure 6.7B). Atlantic salmon, however, was soon introduced into the Pacific aquaculture industry and, in 1987, the first harvest of Atlantic salmon occurred. Since then, the production of Atlantic salmon has expanded rapidly; today it constitutes about 95% of BC's salmon aquaculture. BC is the fourth largest producer of farmed salmon in the world after Norway, Chile, and the UK. Moreover, its aquaculture production of salmon well exceeds that of its capture fisheries for salmon (78,700 and 23,100 tonnes, respectively, in 2010; env.gov.bc.ca/omfd/fishstats/index.html; accessed 12-9-12). There are also two farms and one hatchery in BC that are rearing sablefish; the combined annual production of these facilities currently ranges between 2,000 and 3,000 tonnes.

Canadian aquaculture production of shellfish is about one-third, by weight, that of finfish (Figure 6.3). In contrast to finfish aquaculture, the Atlantic region dominates production (~79% of Canada's production; Figure 6.8). Both native and non-native species are cultured in Canadian waters. The main producer in the Atlantic is Prince Edward Island (PEI), being responsible for about 62% of Canada's farmed shellfish. Shellfish aquaculture in the Atlantic involves primarily mussels (native species: *Mytilus edulis* and *M. trossulus*) and secondarily oysters (mainly native *Crassostrea virginica* with some non-native *Ostrea edulis*) (Figure 6.9). There are also small harvests of clams (native species: *Mya arenaria*, *Mercenaria mercenaria*), scallops (native *Placopecten magellanicus* and non-native *Argopecten irradians* and *Chlamys islandica*), and abalone (non-native *Haliotis rufescens*). By contrast, BC is Canada's major producer of oysters (non-native species, primarily *Crassostrea gigas*, but also C. *virginica* and *O. edulis*), clams (non-native *Nuttallia obscurata* and *Tapes phillippinarum*, and to a lesser extent, the native *Protothaca staminea*), and scallops (non-native hybrid *Patinopecten caurinus* X *P. yessoensis*). BC also has a small production of mussels (non-native *Mytilus edulis* and *M. galloprovincialis*). In 2009, shellfish culture involved 460 site tenures and all but two tenures were in southern BC; production totalled 7,300 tonnes from a total area of 2,114 hectares (reported value of $16.3 million). Shellfish aquaculture on the west coast is expected to grow substantially, but at this time it is much smaller than the east coast industry. There are also some additional invertebrate species under aquaculture development, including sea urchins (native *Strongylocentrotus droebachiensis* and *S. franciscanus*), geoducks (native *Panope abrupta*), abalone (native *Hailiotis kamtschatkana*), sea cucumber (native *Parastichopus californianus*), and cockle (native *Clinodardium nuttalli*).

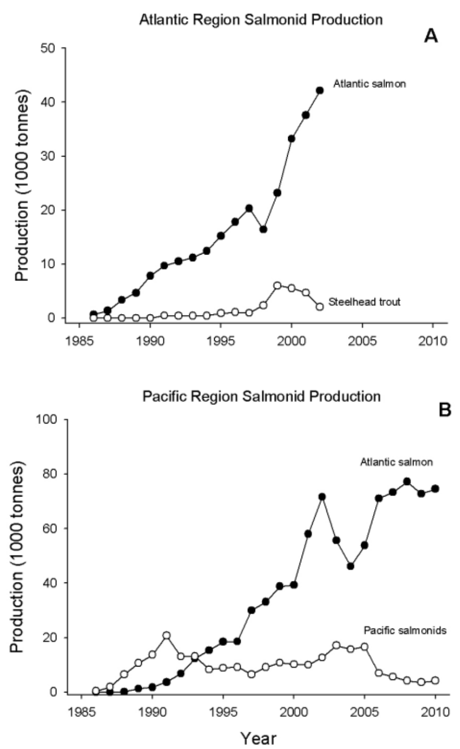


Figure 6.7. *Marine aquaculture production of salmonid fishes in (A) the Atlantic and (B) the Pacific regions of Canada. In 2003, species-specific production statistics for the Atlantic region were discontinued.*
Data sources: (http://www.dfo-mpo.gc.ca/stats/stats-eng.htm) and (http://www.env.gov.bc.ca/omfd/fishstats/aqua/salmon.html).

Canada also has a small seaweed aquaculture industry, focused on native species, including Irish moss (*Chondrus* crispus), kelps (*Macrocystis integrifolia* and *Nereocystis luetkeanna*), brown algae (*Laminaria saccharina* and *L. groenlandica*), and knotted wrack (*Ascophyllum nodosom*). The principal provinces involved are BC, Nova Scotia, and PEI.

b. Value of Aquaculture Production in Canada

In 2009, marine aquaculture production in Canada was valued at $736 million (Figure 6.10). Of this, 69% was derived from exports, 97% of which was destined to the US. The value of marine finfish aquaculture was ten times greater than that of shellfish; the value of aquaculture production in BC was ~26% greater than that in the Atlantic. In 2007, the total economic activity generated by aquaculture in Canada was estimated at $2.1 billion (DFO 2010); aquaculture was also estimated to account for 4,895 direct jobs 6,400 indirect jobs (DFO 2010).

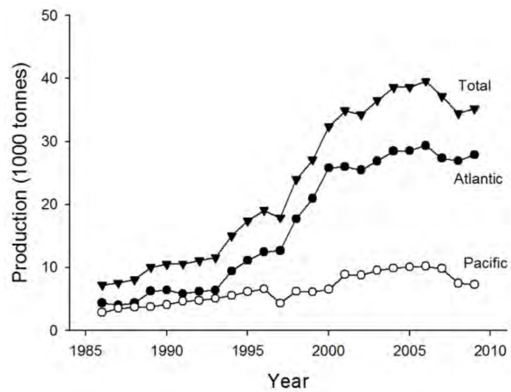


Figure 6.8. *Canadian aquaculture production of shellfish, by region. Source: (http://www.dfo-mpo.gc.ca/stats/stats-eng.htm).*

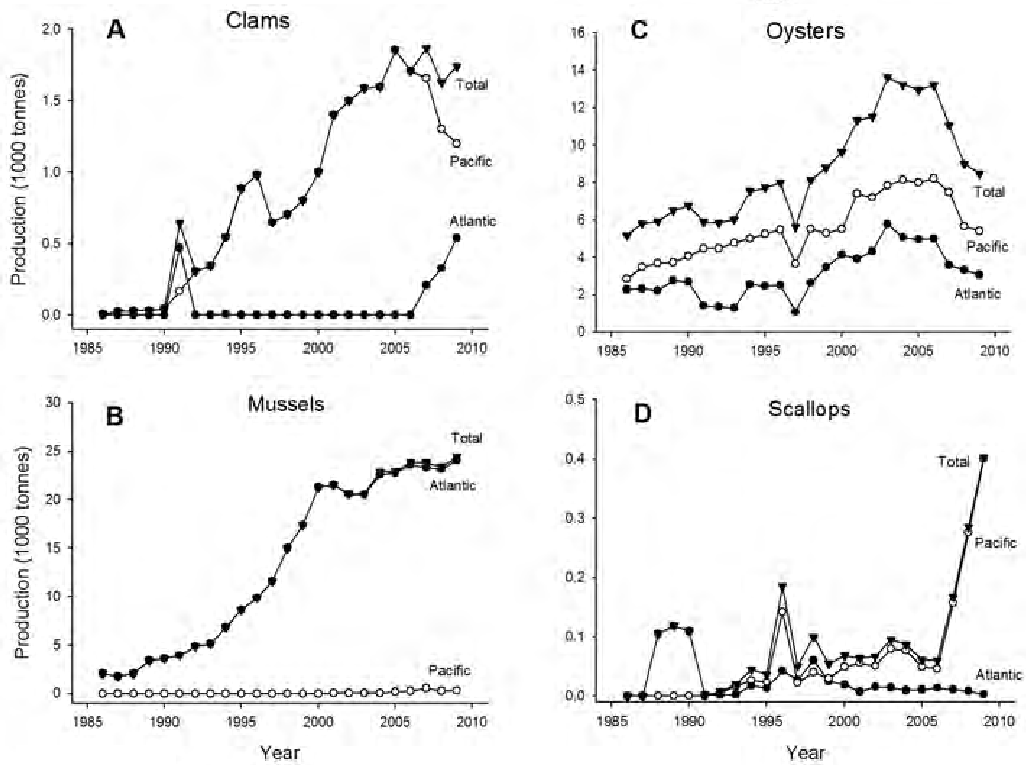


Figure 6.9. *Aquaculture production of (A) clams, (B) mussels, (C) oysters, and (D) scallops in Canada, by region. Data source: www.dfo-mpo.gc.ca/stats/stats-eng.htm.*

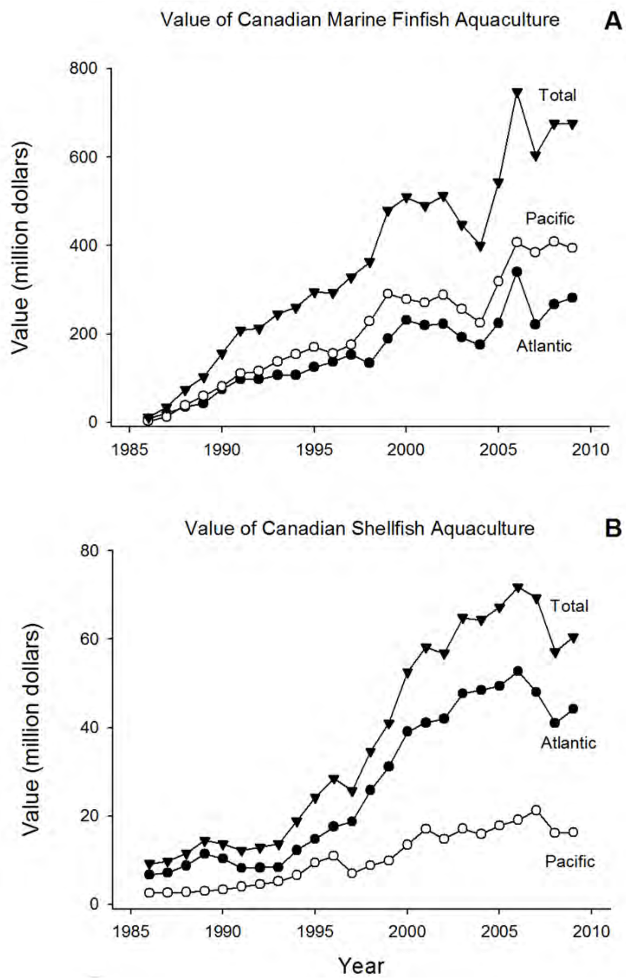


__Figure 6.10.__ Value of (A) marine finfish aquaculture and (B) shellfish aquaculture in Canada separated by region. Data Source: (http://www.dfo-mpo.gc.ca/stats/stats-eng.htm).

4. Fisheries Enhancement Activities

Hatchery fish – artificially reared offspring of captively bred adults – are used for fish enhancement activities in the marine environment and are directed almost solely towards salmon. In BC, these activities are aimed towards supporting targeted fishing opportunities on enhanced stocks and, more recently, rebuilding severely depressed stocks. There has been a decline in the scale of these activities from a peak in the early 1990s, yet there remain roughly 110 facilities associated with DFO's Salmonid Enhancement Programme in BC. As of 2010, these facilities produced ~124 million Pacific salmon juveniles for release (Figure 6.11A).

Canadian releases of hatchery salmon in the Atlantic are about two orders of magnitude less numerous than those in the Pacific (Figure 6.11). There was a major shift in emphasis in Atlantic Canada in the mid-1990s, from one of production of surplus fish for catch, to that of conservation of vulnerable stocks. As a consequence, there was a decrease in enhancement releases (Figure 6.11B). In 1997, DFO divested itself of eight of the nine hatcheries it had been operating in the Maritimes. The remaining hatchery subsequently became part of a 'Live Gene Bank' (LGB) programme, mandated to conserve endangered fish populations. Later, two of the other hatcheries were eventually returned to DFO control under the auspices of the LGB programme. There are also a number of small-scale hatcheries run by provincial governments or by non-governmental organizations. Accompanying the change in focus to conservation, hatchery releases in the Maritimes since 2000 have become dominated by fry (the earliest feeding stage of salmon development) rather than older juveniles (i.e., parr and smolts). While the data for Québec are less complete, the pattern is similar to what has been documented in the Maritimes (Figure 6.11B). It is noteworthy that there have never been large releases of hatchery salmon in Newfoundland and Labrador.

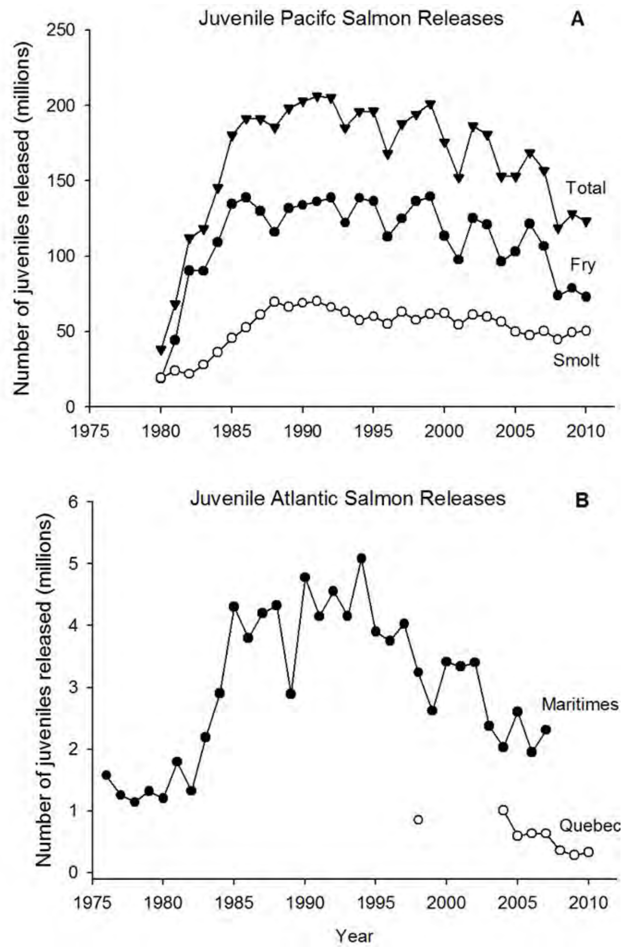


Figure 6.11. *Releases of juvenile anadromous salmonids from enchancement facilities in (A) the Pacific region of Canada and (B) the Maritimes and Québec. Pacific salmon releases are divided into fry (recently emerged juveniles that are ready to feed) and smolt (age one or older juveniles ready to migrate to sea) releases. Data for the Pacific region were provided by DFO's Salmon Enhancement Programme, and for the Maritimes by DFO's Maritimes Region Science Branch. Data for Québec were obtained from annual "Bilan l'exploitation du saumon au Québec" reports of the Ministère des Ressources naturelles et de la Faune du Québec (www.mrnf.gouv.qc.ca/guichet/publications/index.jsp).*

5. Main Findings

- In 2009, Canada's fishery catches (third lowest since 1976) were half those in the late 1980s; the landed value of all fisheries ($1.72 billion in 2011 dollars) was almost the lowest since 1977.
- The Atlantic fishery, once predominantly Atlantic cod, is now dominated by lobster, shrimp, and crab; Pacific catches, dominated by demersal fishes, have experienced marked declines in salmon.
- Since the early 1980s, marine aquaculture, predominantly the farming of Atlantic salmon, grew rapidly until 2002; production has stabilized since then.
- BC, 4th largest producer of farmed salmon globally, farms 67% of Canada's finfish aquaculture.

- Shellfish production, having grown considerably since the 1980s (valued at $736 million in 2009), is dominated by Atlantic Canada's culture of blue mussels.
- Hatchery fish releases in BC have declined, but remain considerable (~124 million annually).

Chapter Seven: Climate change: Observed and Projected Consequences for Canadian Marine Biodiversity

1. Introduction

Climate change directly impacts key physical attributes of the oceans that, in turn, regulate biodiversity and ecosystem functioning. The immediate consequences of an altered climate can include changes in temperature, precipitation and hydrography, acidification, and sea level rise (Chapter Four). Climate change will affect marine biodiversity. Direct effects are caused by the influence of physical and chemical factors, such as temperature, winds, vertical mixing, salinity, oxygen, and acidity that affect the physiology, development, reproduction, behaviour, and survival of organisms (Brander 2010). Indirect effects encompass those changes in communities that are mediated by food web interactions. Given the possibility that many such impacts may be more or less irreversible over long time scales (centuries), their effects will play a potentially critical role in managing marine biodiversity, especially with respect to ecosystem services (Chapter One), including Canada's fisheries.

These potential effects can be summarized in five principal categories: (i) patterns of net primary production and carbon export; (ii) biogeographical shifts that involve large-scale changes in the spatial distribution of organisms; (iii) phenology and environmental mismatch, whereby changes in the oceans cause a mismatch between habitat requirements and resource availability; (iv) regime shifts, involving relatively rapid re-organisations of ecosystem functioning; and (v) biological responses to ocean acidification. These impacts, some of which are not mutually exclusive, are occurring in virtually all marine ecosystems, including the epipelagic, intertidal, benthic, and estuarine ecosystems (Chapter Three), and are most evident at high latitudes. The chapter concludes with a consideration of how the effects of climate change might exacerbate the effects of fishing.

2. Net Primary Production and Carbon Export

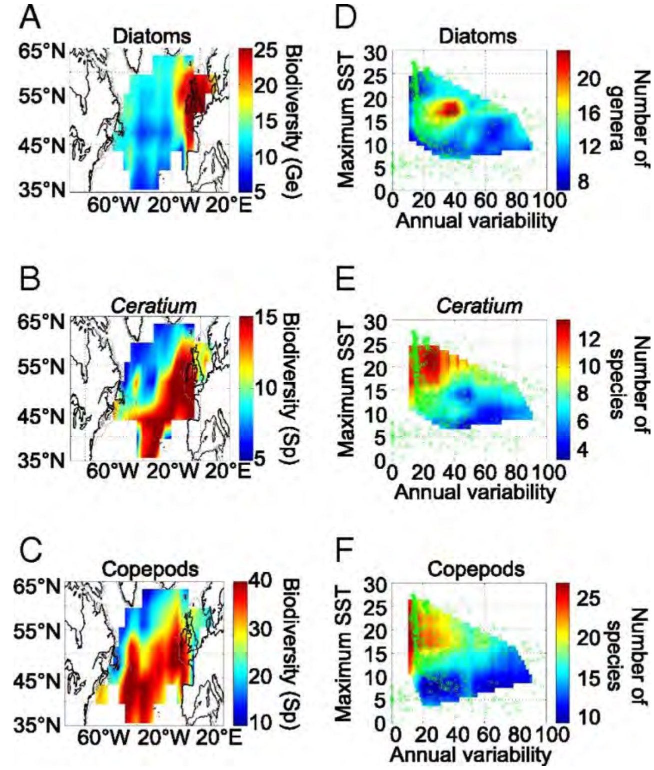
Over the past 40 years, approximately 84% of the increase in Earth's heat budget has been absorbed by the ocean's surface waters. The concomitant sea-surface warming will likely affect the pelagic ecosystem in several ways: directly through its effects on the rates of biological processes and light supply responses to changes in cloudiness and mixed-layer thickness, and indirectly through decreased surface layer mixing and, hence, reduced nutrient supply (Sarmiento et al. 2004). Climate model simulations project an overall reduction of the density of surface waters due to warmer sea surface temperatures and fresher surface waters at high latitudes. This phenomenon is expected to increase both vertical stratification (and thus reduce nutrient input; Chapter Four) and the length of growing seasons at high latitudes. However, a complex combination of factors leads to considerable geographical variation and considerable uncertainty in the predicted response of ocean productivity to climate warming. According to some estimates (Sarmiento et al. 2004), primary production is projected to: (i) increase globally between 0.7 and 8.1% by 2050; (ii) increase in the North Atlantic; and (iii) decrease in the North Pacific, due primarily to the retreat of the highly productive region of marginal sea ice. Other studies also predict a reduction in primary productivity. Steinacher et al. (2010), for example, project a decrease in global mean primary productivity of between two and 20% by 2100 relative to pre-industrial conditions, based on the outputs of four global-coupled carbon cycle-climate models.

The sensitivity of biological processes to temperature is described by the Q_{10} coefficient, namely, a measure of the rate of change of a biological process as a consequence of increasing the temperature by 10°C. While phytoplankton photosynthesis and growth show a moderate response to increasing temperature (a Q_{10} of between 1 and 2), bacterial heterotrophic activities show a stronger response (a Q_{10} of between 2 and 3). In addition, bacterial growth efficiency declines with increasing temperature, such that an increasing fraction of assimilated carbon is respired at higher temperatures. Based on such considerations, and taking into account experimental evidence, ocean warming may shift the balance between autotrophic production and heterotrophic consumption of organic matter toward enhanced recycling and respiration. Consequentially, the loss of carbon through sinking may be significantly reduced at higher temperatures. These changes have the potential to reduce the transfer of primary produced organic matter to higher trophic levels, and to weaken the biological carbon pump (Appendix D), thus providing a positive feedback to rising atmospheric CO_2 (Wholers et al. 2009).

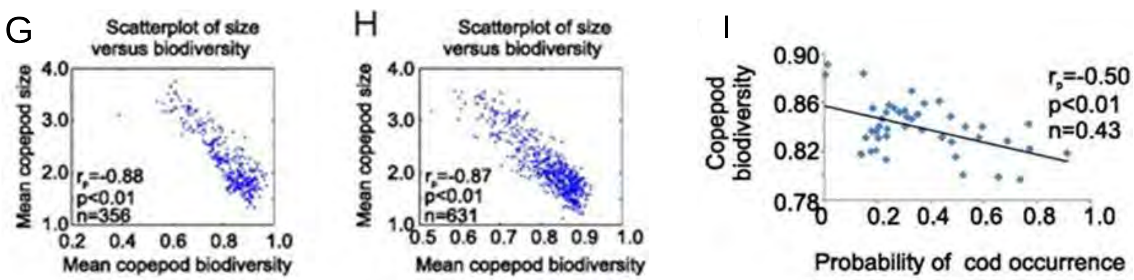
Consistent with these observations, pronounced latitudinal increases in phytoplankton biodiversity in parts of the North Atlantic Ocean are paralleled by a decrease in the mean size of phytoplankton (Beaugrand et al. 2010). In the Arctic Ocean, the smallest phytoplankton cells thrive as surface waters warm and freshen because of increased sea ice meltwater and episodic input of fresh water from large-river runoff. Predictably, small picophytoplankton cells proliferate in a regime of lower nitrate supply and greater hydrodynamic stability (Li et al. 2009). A reduction in community average body size, caused by an increase in the abundance of individuals belonging to small-sized species, might represent a common response to global warming (Daufresne et al. 2009).

Box 7.1. Potential fishery consequences of a temperature-induced shift in plankton biodiversity: one hypothesis.

There has been a pronounced latitudinal increase in phytoplankton and zooplankton biodiversity in the temperate and polar North Atlantic in recent decades. Focusing on three planktonic groups (diatoms at the genus level (A), the photosynthetic dinoflagellate genus Ceratium *(B) and the herbivorous copepods (C), Grégory Beaugrand and his colleagues have found that diatoms are characteristic of mixed waters and are most diverse in continental-shelf ecosystems, whereas* Ceratium *and copepods are most diverse in stable, warmer, stratified oceanic ecosystems (see adjacent figure). The number of species of* Ceratium *and the copepods (E, F) increases with maximum sea surface temperatures (SST) and an index of the annual variability in SST.*



These authors also noted a significant multi-decadal northward shift in biodiversity in copepods which co-occurred with warming in the North Atlantic and the Baltic and North Seas. Increasing biodiversity was associated with smaller mean community body size in both space (North Atlantic: G) and in time (multi-decadal scale: H). Such a general decrease in size of copepods co-occurred with temperature warming.



In the North Sea, the probability of cod occurrence and copepod biodiversity varied inversely (I). Cod have a high probability of occurrence only where more than 50% of copepods in the community are large. The decrease in the size of planktonic organisms associated with temperature-mediated increases in biodiversity has been hypothesized to reduce fishery yield in the Northeast Atlantic.

Source: Beaugrand et al. (2010)

3. Biogeographical Shifts

Environmental temperature plays a pivotal role in determining the spatial distribution of virtually all ocean plants and animals. By altering environmental temperature patterns, climate change affects marine biodiversity, and potential yields from fisheries, through changes in species distributions. One such example is the shift towards smaller organisms in North Atlantic plankton that has been thought to result in a reduced fisheries yield (Beaugrand et al. 2010; Box 7.1).

Empirical and theoretical studies suggest that marine fishes and invertebrates respond to ocean warming by shifting their latitudinal and depth ranges, with observed and projected rates of range shift of between 30-130 km decade^{-1} pole-wards and 3.5 m decade^{-1} to deeper waters (Mueter and Litzow 2008; Cheung et al. 2009, 2010). Such changes may result in the local extinction of some species, the invasion of others, and increased rates of species turnover resulting in ecological modifications.

A globally based projection of the distributional ranges of a sample of 1066 exploited marine fish and invertebrates for the year 2050 (Cheung et al. 2009) indicates that climate change may lead to an elevated level of local extinction in sub-polar regions, the tropics, and in semi-enclosed seas, resulting in species turnovers of more than 60% of the present biodiversity. In combination with projected patterns of primary production, the catch potential in global fisheries will in all likelihood undergo significant changes (Cheung et al. 2010; Figure 7.1). Globally, in the northern hemisphere, 10-year average changes in maximum catch potential (projected from 2005 to 2055) indicate a moderate decline in temperate regions (25^{o}N-50^{o}N), but increases at higher latitudes, particularly in the sub-Arctic (Figure 7.1, upper left panel). In the Pacific Ocean, the pattern of change in catch potential parallels the global trend, but with a much higher magnitude of change (Figure 7.1, upper right panel). In the Atlantic, the projected magnitudes of change in temperate regions are smaller than those in the Pacific (Figure 7.1, lower left panel). It is important to note, however, that these projections do not account for potentially strong ecological interactions among species (see below), nor do they account for physiological impacts on fish metabolism, such as reduced growth performance resulting from increased acidification and lower oxygen content (Cheung et al. 2011a).

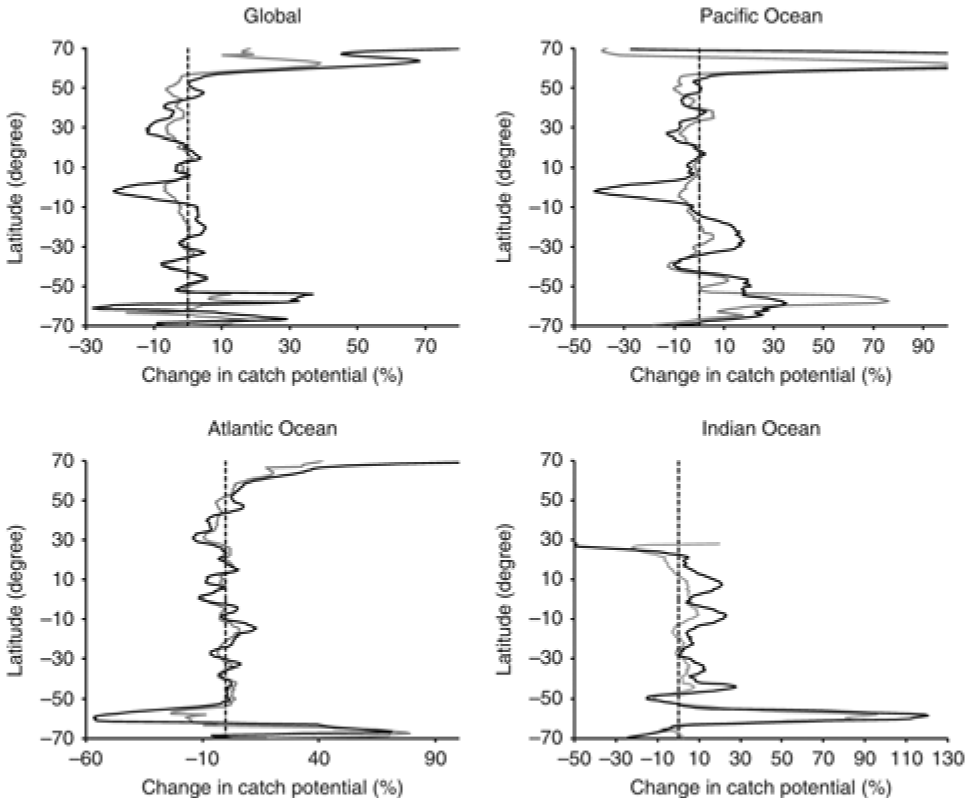


Figure 7.1. *Projected zonal (latitudinal) changes (globally and by region) in 10-year average maximum fishery catch potential from 2005 to 2055 under high-range (black line) and low-range (grey line) greenhouse-gas emission scenarios. The dotted line indicates no change in catch potential. Source: Cheung et al. (2010).*

In Canadian waters, warming ocean temperatures are predicted to result in the loss of some fish and invertebrate species but a gain in others (Figure 7.2; Cheung et al. 2011b). The greatest species losses (6-10 species) are predicted to occur at lower latitudes, including the Scotian Shelf, the Newfoundland-Labrador Shelf, and the marine ecoregions of the Pacific. Overall, however, the predicted pattern is one of species gain. Species turnover (species gains minus species losses) is predicted to be greatest at lower latitudes and throughout the Arctic; as a proportion of the current numbers of species, species turnover might be highest in the western Arctic (Figure 7.2).

A striking example of relatively rapid changes in the biogeography of the epipelagic ecosystem in response to climate warming is provided by the copepod communities of the Northeast Atlantic and European shelf seas (Beaugrand et al. 2002). Major biogeographical shifts for all species assemblages have occurred since the early 1980s, with a northward extension of more than ten degrees of latitude for warm-water species. In contrast, the diversity of colder-temperate, sub-Arctic, and Arctic species has declined. All the biological associations show consistent long-term changes, reflecting a shift in marine ecosystems towards a warmer state, with potential modifications in the abundance of exploited boreal species, such as Atlantic cod.

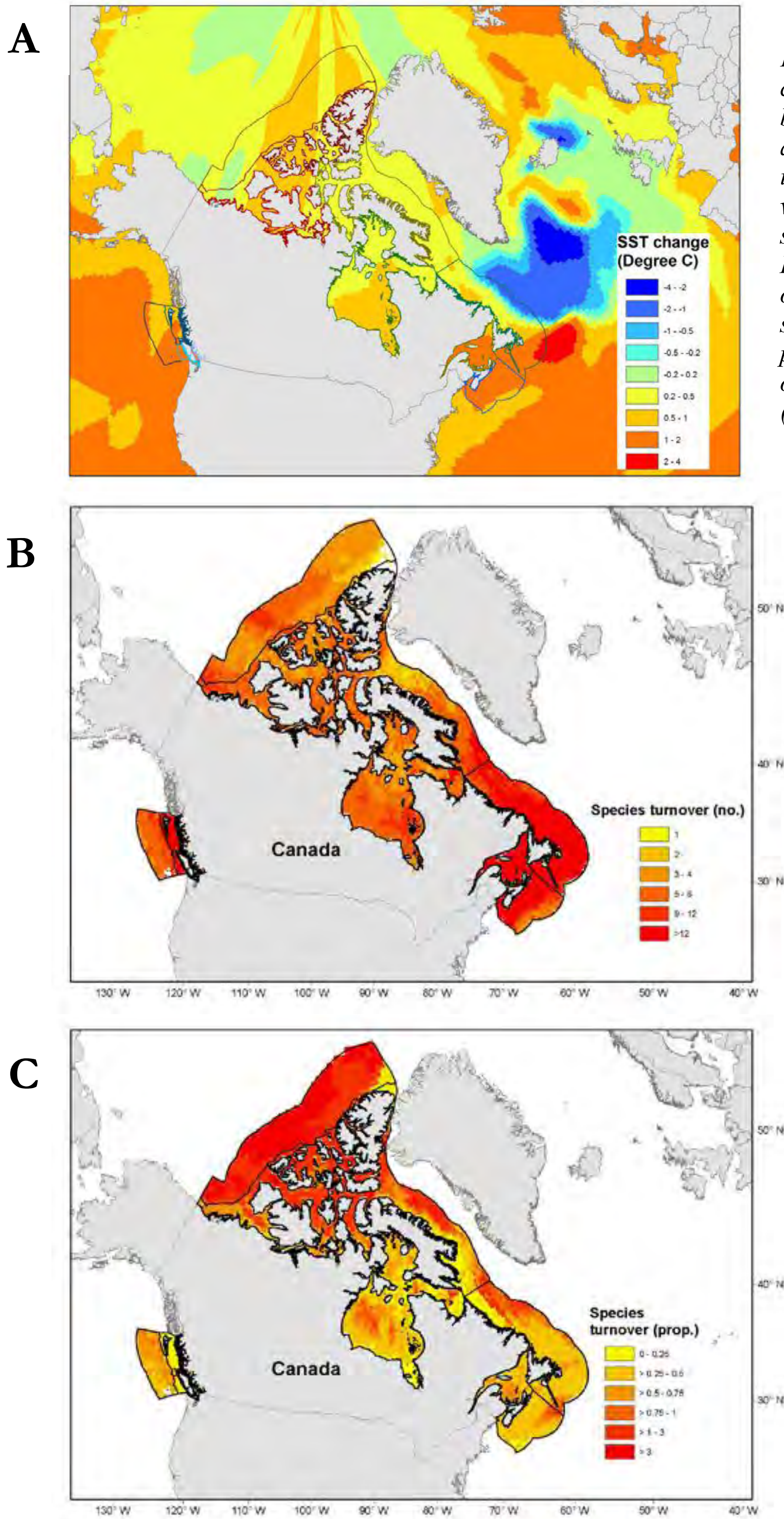


Figure 7.2. *One forecast of how changes in water temperature between 2005 and 2050 might affect the distribution of fish and invertebrate species in Canadian waters. A: Predicted changes in sea surface temperature (SST). B: Predicted turnover in number of species (species gains minus species losses). C: Predicted proportional change in numbers of species. Source: Cheung et al. (2011b).*

Biogeographical shifts in species distribution have already affected intertidal biodiversity and community structure. The locations of range edges of many rocky intertidal species found in the

North Atlantic, for example, have shifted by as much as 50 km decade^{-1}, much faster than most recorded shifts of terrestrial species. The rate and extent of contractions in the equatorial range limits are less than the changes observed at the pole-ward limits of distribution. These biogeographic shifts have been accompanied by increases in the abundance of many species close to their pole-ward range limits and by changes in the relative abundance of warm- and cold-water species (Helmuth et al. 2006).

One means by which a warmer ocean can produce indirect effects on biodiversity is through temperature-mediated ecological interactions. For example, the upper limits of zonation of many species of intertidal invertebrates and algae are correlated with maximum air temperatures. When these upper limits of an organism are compressed down to the upper limit of a predator or dominant competitor, the prey or subordinate species is eliminated from the intertidal zone (Helmuth et al. 2006). Such species interactions may have a greater impact on community structure than simply the replacement of cold-water species by warm-water species. A 3.5 ^{o}C rise in seawater temperature, induced by the thermal outfall of a power-generating station, over ten years along 2 km of rocky coastline in California resulted in significant, but largely unpredictable, community-wide changes in 150 species of algae and invertebrates (Schiel et al. 2004). Temperature-sensitive algae (particularly subtidal kelps and intertidal red algae) decreased in abundance while many invertebrate grazers increased in number. Community response was, thus, coupled to the direct effects of temperature on key species and the indirect effects operating through ecological interactions (Schiel et al. 2004).

The ecological consequences of species' range expansions, particularly those of exotic species invading new habitats, are of concern in the context of a warmer ocean. Although only a small fraction of the many marine species introduced outside of their native range are able to proliferate and invade new habitats, their effects can be profound.

An increase in the number of marine invasive species fostered by a warmer ocean may have a negative impact on marine biodiversity. One example from the Mediterranean Sea serves to illustrate this phenomenon. A large part of the eastern Mediterranean Sea is undergoing substantial warming which has modified the potential thermal habitat available for warm-water species, facilitating their establishment at an unexpectedly rapid rate (Raitsos et al. 2010). There has been a 150% increase in the annual mean rate of species entry since 1998. The speed of alien species spreading, a response to global warming, appears much faster than temperature increase itself, which could lead to a re-structuring of the pelagic ecosystem (Raitsos et al. 2010). Whether such changes are judged in the future as positive, negative, or neutral, remains to be seen.

Closer to home, and with unpredictable consequences, the warming of the Arctic Ocean is expected to facilitate the expansion of Pacific species into a warmer Arctic Ocean, and eventually into the North Atlantic Ocean. Trans-Arctic invasions began about 3.5 million years ago, having been periodically halted by sea-ice expansion in the coastal Arctic Ocean. Conditions are ripe, however, for invasions to resume, with at least 77 molluscan lineages having the potential to extend to the North Atlantic via the warmer Arctic Ocean without direct human intervention (Vermeij and Roopnarine 2008).

Recent evidence suggests that new invasions have begun, probably facilitated by modified current regimes (Chapter Four). In 1999, a long-term monitoring programme documented the presence of a Pacific diatom between Canada and Greenland. The species, known previously only from the North Pacific and Bering Sea, has subsequently spread south to Georges Bank and east to Iceland, providing one indication of the speed and scale of change that can take place in response to climate warming (Reid et al. 2008). The Capelin (*Mallotus villosus*), an important forage species in northern waters, has recently spread from the western Arctic eastwards to Cumberland Sound (Dodson et al. 2007), a distributional shift that might explain the proportional shift in diet in at least one species of seabird (thick-billed murre, *Uria lomvia*) in the eastern Arctic (Figure 7.3; Gaston et al. 2009).

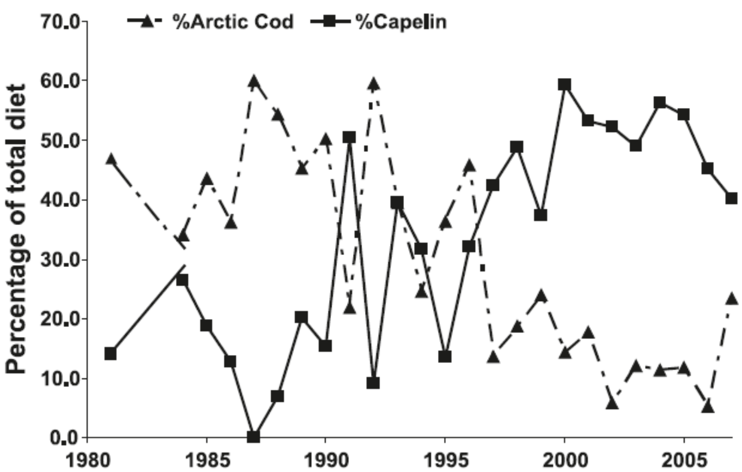


Figure 7.3. *Proportional representation of Arctic cod*, Boreogadus saida, *and capelin (% loads delivered) fed to nestling thick-billed murres at Coats Island (northern Hudson Bay) between 1981 and 2007 (no data for 1982 and 1983). Source: (Gaston et al. 2009).*

4. Phenology and Environmental Mismatch

Changes in temperature directly impact the timing of life-history events (phenology) that comprise the life-cycle of marine organisms. These events include, among others, reproduction, hatching, and metamorphosis. Climate plays a critical role in controlling the match between predator requirements and resource availability (Cushing 1969; Visser and Both 2005; Durant et al. 2007). Climate change affects the relative timing of food requirement and food availability for various organisms and, by doing so, influences their reproduction and survival. Differences in the temporal and spatial match between predator and prey thus generate variability in predator survival rates.

One striking example of a change in the timing of life-history events concomitant with temperature change is the pattern of increasingly earlier seasonal timing of the peak abundance ('bloom') of the dominant species of zooplankton in the Strait of Georgia, *Pseudocalanus plumchrus*. In the late 1960s, it has been estimated that the spring bloom occurred in mid-May (Figure 7.4).

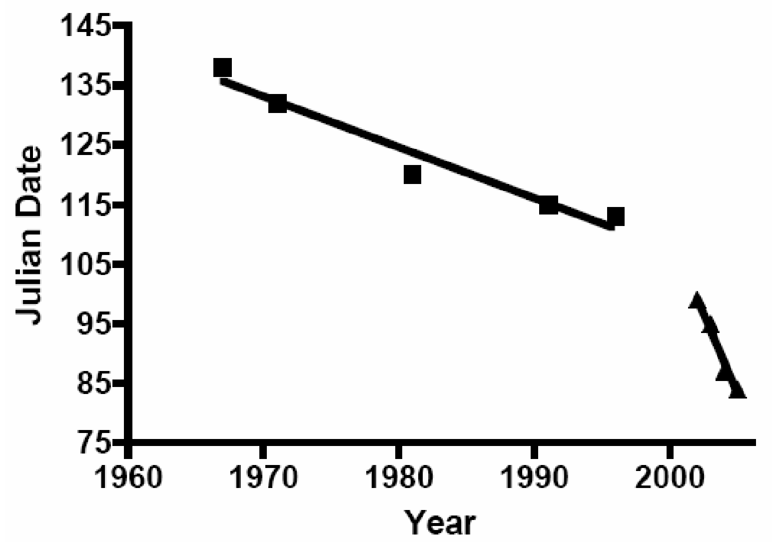


Figure 7.4. *Trend in the timing of peak biomass of the zooplankton,* Pseudocalanus neoplumchrus*, in the Strait of Georgia (Julian date=day of year). Source: DFO (2010).*

By 2004, the bloom was occurring in mid-March, a trend associated with warming sea surface temperatures in this area (Chapter Three). The progressively earlier timing of peak abundance will have some effect on the multitudes of species that utilize this zooplankton for food. It may, for example, partially explain the earlier hatch dates observed in some Pacific seabirds (Figure 7.5), for which the consequences to the persistence of these species are not known.

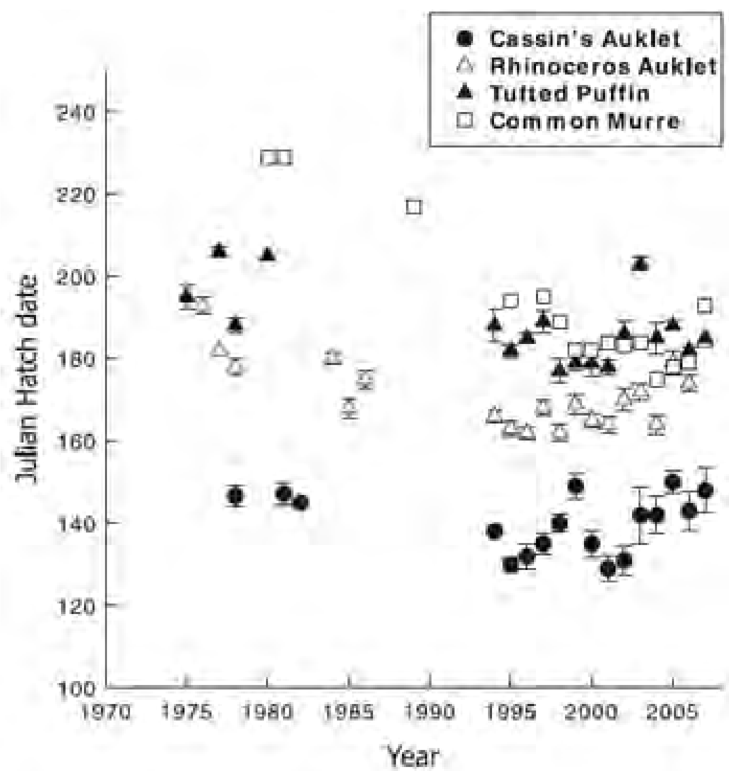


Figure 7.5. *Mean Julian dates (day of year) of hatching for four species of seabirds at Triangle Island, BC. Source: Gaston et al. (2009).*

In a survey of 25,532 rates of phenological change for 726 UK terrestrial, freshwater, and marine taxa, the majority of spring and summer events were found to be occurring earlier, and more rapidly, than previously documented (Thackery et al. 2010). Phenological events associated with predators advanced less rapidly than those for prey species. Such consistency is indicative of shared large-scale drivers across terrestrial, freshwater and marine environments.

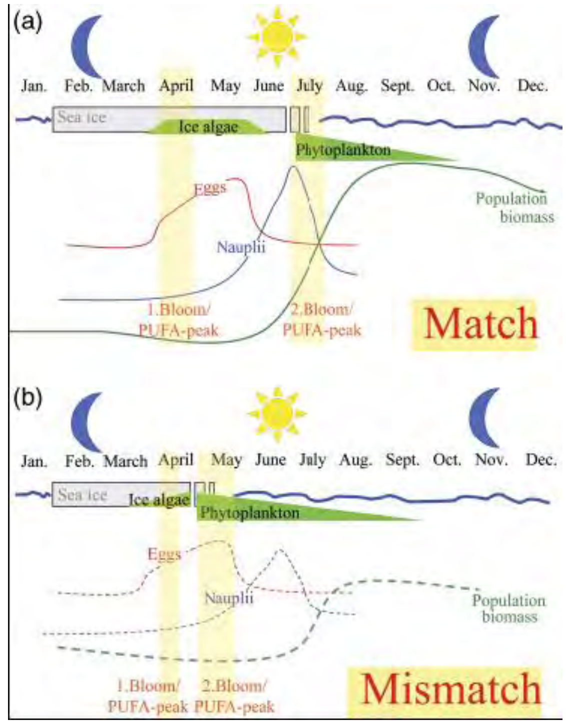
There is, thus, compelling evidence that climate-change driven phenological asynchronies can disrupt the stability and functioning of ecosystems and, as a consequence, the delivery of key ecosystem services.

Temperate and high-latitude epipelagic ecosystems might be particularly vulnerable to phenological changes caused by climatic warming (Rubao et al. 2010). Recruitment success at higher trophic levels is dependent on synchronization with seasonally pulsed primary production; the response to regional warming varies among functional groups. For example, changes in the North Sea planktonic assemblage and copepod phenology were correlated with warming over the last few decades. This has resulted in a poor food environment for cod larvae and a decline in overall recruitment success (Beaugrand et al. 2002). Similar evidence linking plankton phenology and higher trophic levels has been found elsewhere in the North Atlantic (phenology of shrimps and phytoplankton; Koeller et al. 2009) and in the North Pacific (seasonality of zooplankton abundance and energy propagation to fish and seabird predators (Mackas et al. 2007; Bertram et al. 2009). A potential mismatch between the primary production peaks of high-quality food and the reproductive cycle of key Arctic grazers may have negative consequences for the Arctic epipelagic marine ecosystem (Box 7.2).

Environmental mismatch can also occur between distinct life-history stages and the environmental conditions encountered during ontogeny. This ontogeny-climate interaction occurs when the physical tolerances and habitat requirements of individuals change through development and because individuals may migrate among habitat types. Species that undergo long-distance migrations are especially prone to this effect because their migrations take them to geographic regions with distinct climates. For example, the timing of the downstream migration of Atlantic salmon smolts in Gulf of St. Lawrence populations appears to be out of synchronization with ocean conditions in the post-smolt nursery areas; decreased smolt survival is associated with abnormally warmer sea surface temperatures (Friedland et al. 2003). Another example is provided by Chinook salmon. The stream-type Chinook salmon life history is, like many Pacific salmonids, characteristic of cooler water. The entire migration and spawning strategy is adapted to a snowfall-dominated hydrological regime typical of Pacific Northwest rivers. However, global warming is predicted to increase summer stream temperatures and to reduce summer/fall flow levels. Temperatures that are above optimal levels impede developmental processes (e.g., smoltification), predator-avoidance behaviour, and growth. Extremely low flows may decrease survival in small streams by reducing potential habitat availability, thereby increasing both competition for food and predator mortality. The mismatch created by climate impacts on juvenile habitat requirements is projected to reduce population abundance and significantly increase the probability of extinction for affected populations (Crozier et al. 2008).

Box 7.2. Mismatch between primary productivity and reproduction: consequences for Arctic ecosystems.

*A potential mismatch between the primary production peaks and the reproductive cycle of key Arctic grazers may have negative consequences for the Arctic epipelagic marine ecosystem. The Arctic bloom consists of two distinct types of primary producers, ice algae growing in sea ice, and phytoplankton growing in open waters. Long chain omega-3 fatty acids, a subgroup of polyunsaturated fatty acids (PUFAs) produced exclusively by these algae, are essential to all marine organisms for successful reproduction, growth, and development. A first PUFA-peak occurs in late April at the onset of the ice algal bloom. A second PUFA-peak occurs in early July at the onset of the phytoplankton bloom just after ice break-up. Females of the key Arctic copepod grazer (*Calanus glacialis*) utilize the high-quality ice algal bloom to fuel reproduction. The resulting offspring graze on the high-quality food during the phytoplankton bloom two months later. Reduction in sea ice thickness and coverage area will alter the current primary production regime due to earlier ice break-up and onset of the phytoplankton bloom. The time lag between the ice-associated and pelagic blooms is predicted to shorten, resulting in a potential mismatch between the phytoplankton bloom and the ontogenetic development of the copepod (see figure). The current dramatic reduction is sea ice thickness and coverage area may therefore have direct negative impacts on higher trophic levels, such as sea birds and large predators, given the importance of these lipid-rich grazers in the Arctic food web (Soreide et al. 2010).*



*Current primary production regime in Arctic shelf seas **(a)** has highest food quality during the ice algal and phytoplankton blooms. The copepod uses the high-quality ice algal food in early spring to fuel reproduction, which allows the offspring to exploit the high food quality in the phytoplankton bloom. This match ensures high population biomass of* C. glacialis*. Future primary production regime **(b)** with shorter growth season for ice algae due to earlier ice break up, will lead to shorter time between the two blooms. This decrease may lead to a mismatch between primary producers and the development of the offspring. Because* C. glacialis *requires roughly three weeks to attain the first feeding developmental stage, it may partially or totally miss the high-quality phytoplankton bloom during its most critical growth phase (reprinted from Soreide et al. 2010).*

Nowhere is the mismatch between the requirements of developmental stages and the availability of adequate habitat more striking than in the Arctic and subpolar regions of both the Pacific and Atlantic Oceans (e.g., Gulf of St. Lawrence region, Labrador Sea) (Chapter Four). Reductions in the extent of sea ice will be most harmful to species that rely on ice as a platform for breeding or foraging (Friedlaender et al. 2010). Ice-related declines in abundance have been reported in hooded seals (*Cystophora cristata*), harp seals, and ringed seals (*Pusa hispida*), and there is also evidence of impacts on the distribution and health status of Pacific walrus (*Odobenus rosmarus*) (Vincent et al. in press). Early ice breakup may result in premature separation of mothers and pups, leading to higher mortality rates among pups. In the southern Baltic Sea, from 1989 to 1995, a series of nearly ice-free winters led to very high pup mortality rates (Härkönen et al. 1998). Similarly, several nearly ice-free winters in the Gulf of St. Lawrence have led to high mortality rates among harp seal pups. Polar bears (*Ursus maritimus*) are especially prone to the negative consequences of changing sea-ice conditions and severe population declines have been projected for some areas of the Arctic (Regehr et al. 2010).

Although its effect may not strictly be a case of mismatching of ecological processes, changes in sea surface temperature (SST) are known to be associated with changes in productivity (i.e., adults produced per spawner) of Pacific salmon populations. The relationship is either positive or negative, depending on the location along North America's west coast. Specifically, increased SST in the location of early ocean residence of a given population's juveniles is associated with increased productivity in Alaska, but *decreased* productivity for Washington State and most BC pink and sockeye salmon (Mueter et al. 2002). The highest SST values are well below the lethal temperature limit for salmon, so it is thought from various sources of evidence that SST is simply an indirect indicator of the food supply for juvenile salmon and the abundance of their predators.

5. System Regime Shifts

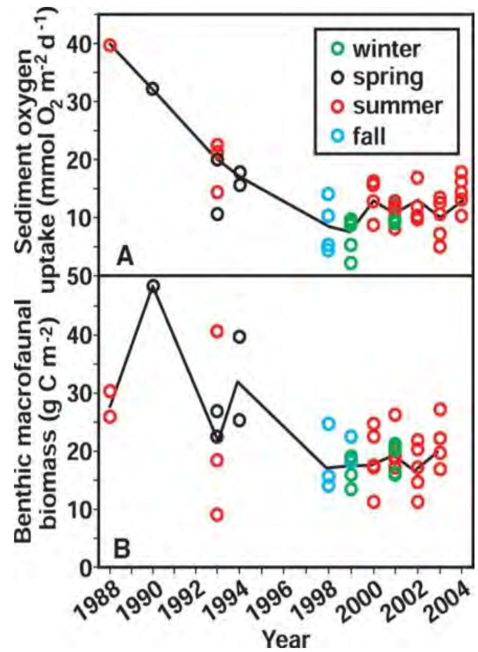
Perturbations in the marine realm can cause ecosystems to shift between contrasting, sometimes persistent states (deYoung et al. 2008), with major alterations to community composition and ecosystem services (Box 7.3). Such shifts can occur quite suddenly because ecological relationships such as predation and competition between key species are affected. The major drivers of ecosystem regime shifts include abiotic factors, such as changes in ocean stratification, storm events, and temperature, and biotic factors such as community changes resulting from overfishing or species invasions. Four examples below serve to illustrate how marine ecosystems can shift to drastically different forms and functions in response to changing climate.

In the North Pacific, there have been large and rapid changes in ocean productivity, with the greatest change occurring as a result of intensification of the Aleutian low-pressure atmospheric system over the winter of 1976/77 (Mantua et al. 1997). That atmospheric forcing changed wind and current patterns in such a way that the eastern North Pacific Ocean became more productive than in the past. Hare and Mantua (2000) found clear evidence of biological responses to these climatic changes in their analysis of 31 climatic and 69 biological time series, the latter of which included data series as diverse as zooplankton, shrimp, demersal fish, pelagic schooling fishes, and salmon. For instance, catches of sockeye salmon increased after 1977, especially in Alaska, a result that was consistent with data on a biological measure of productivity (adult returns per spawner) (Peterman et al. 1998). It is thought that increased spin-up of the Gulf of Alaska gyre, starting in 1976/77, brought more nutrients to the surface, leading to increased primary and secondary productivity. Hare and Mantua (2000) also found another regime shift in 1989, but that shift was less extensive and did not return to pre-1977 conditions. Mueter et al. (2007) confirmed that both pelagic productivity (mostly salmon) and demersal productivity increased in response to the 1976/77 climatic regime shift, whereas the 1988/89 regime shift produced inconsistent or short-lived responses.

Box 7.3. A major ecosystem shift in the northern Bering Sea.

The northern (Arctic) Bering Sea supports some of the highest benthic faunal biomasses in the world's oceans, despite extensive seasonal ice cover. Here, a large fraction of usable carbon produced in the epipelagic zone sinks and is consumed by the benthos. Benthic feeding seabirds and marine mammals have been the primary consumers in the Northern Bering Sea. This tight pelagic-benthic coupling is not characteristic of the southern (sub-Arctic) Bering Sea where pelagic fish are the principal consumers.

The northern Bering Sea has had lower ice concentrations in the past decade (although ice coverage was greater than average in 2010; Napp 2011) and bottom water temperatures are increasing. In the northern Bering Sea, sediment oxygen uptake – an indicator of carbon supply to the benthos – has declined from 1988 to 2004 (A) as have estimates of benthic standing stock (B).



This reduction in sea ice and increase in ocean temperatures have coincided with a reduction in the biomass of the benthos, an increase in pelagic fish and a weakening of pelagic-benthic coupling. As a consequence, the prey base for benthic-feeding gray whales, walrus, and sea ducks is declining in the northern Bering Sea. Source: Grebmeier et al. 2006.

On a smaller scale, in 1987, the benthic community on rocky reefs of Southern California underwent an abrupt shift from a community in which sea cucumbers were rare to one in which they dominated. The new community state persisted until 2002 when sea cucumber densities suddenly declined dramatically everywhere, remaining relatively low through 2008. It seems that a combination of an unusual period free of large storm events, and low abundance of seastar predators, allowed sea cucumber populations to increase dramatically. The shift back to few sea cucumbers coincided with an increase in the number of predatory seastars. The consequences for primary production of high sea cucumber numbers were profound. The abundance of macroalgae, which compete for space with sea cucumbers, plummeted as the sea cucumber population grew, with cascading effects reverberating through the entire food chain in the form of reductions in herbivorous micro-crustaceans and their associated fish predators (Rassweiler et al. 2010).

Additional examples from coastal waters serve to illustrate how multiple factors can interact to generate synergistic responses, which occur when the impact of combined factors is disproportionately amplified compared to that of those same factors operating individually. Kelp forests occur along the majority of the world's temperate coastlines (Appendix D). On many coasts where humans have altered chemical and biological conditions, however, kelp forests have been replaced by mats of turf-forming algae. While kelp canopies inhibit turfs, shifts from kelp to turf domination are fostered by reduced water quality, enabling the cover of turf to expand and persist beyond its seasonal limits. Controlled experiments have shown that at elevated levels of CO_2 and temperature, such as those expected by 2050, algal turfs grew very quickly – much more quickly than under each elevated condition separately or under present-day conditions. Moreover, turfs inhibited kelp recruitment, potentially locking the ecosystem into a turf-dominated state in the long-term (Connell and Russell 2010). Johannessen and MacDonald (2009) provide an excellent case study of the effects of climate change on a small spatial scale (Strait of Georgia) in Canadian waters.

6. Hypoxia

In Canadian waters, both the Pacific and Atlantic coasts are sites of growing hypoxic bottom waters (Chapter Four). A water mass is hypoxic when the concentration of dissolved oxygen is so low as to cause stress for aquatic organisms. In general, this occurs when the oxygen concentration is < 2 mg L^{-1} (although some fish larvae may suffer at < 3 mg L^{-1} and other organisms such as euphausiids can survive to 0.1 mg L^{-1}; Ekau et al. 2010). At this level, many fish species cannot survive, and the benthic community structure undergoes significant modifications. The dominant natural processes involved in the formation of hypoxic waters are photosynthetic carbon production and microbial respiration. The re-supply rate of oxygen is indirectly related to its isolation from the surface layer. Hypoxic water masses thus occur at depth, and are more likely to occur in systems where the water residence time is extended, water exchange and ventilation are minimal, stratification occurs, and where carbon production and export to the bottom layer are relatively high (Rabalais et al. 2010).

The formation of hypoxic areas is exacerbated by any process that increases primary production and the accumulation of organic carbon, leading to increased respiratory demand for oxygen below a pycnocline (see Chapter Four). Thus, nutrient loading and coastal eutrophication are particularly problematic. Climate change threatens to further complicate the situation. The likelihood of strengthened stratification, stemming from increased surface water temperature as the global climate warms, is sufficient to exacerbate hypoxia where it currently exists and to facilitate its formation elsewhere. Heavier precipitation that increases freshwater discharge and the flux of nutrients will contribute to increasing local primary production, thus promoting hypoxia (Rabalais et al. 2010). Along the Oregon coast, for example, low-oxygen events have caused fish and crab kills at the ocean bottom during the last several years, events that had not been observed in the previous century (DFO 2011).

7. Ocean Acidification

When the CO_2 concentration increases, more carbonic acid (H_2CO_3) is formed, which partially dissociates into bicarbonate (HCO_3) and hydrogen (H+) ions, resulting in increased acidity, as reflected by lower water pH. The pH is a measure of H+ activity, and is an important water quality indicator because fish and other organisms are highly sensitive to changes in pH. This ocean acidification (Chapter Four) decreases the availability of carbonate, making it more difficult for many marine organisms to construct their hard parts out of calcium carbonate minerals. The combination of increased acidity and decreased carbonate concentration also has implications for the physiological functions of numerous marine organisms. When seawater is under-saturated in calcium carbonate ($CaCO_3$), structures composed of carbonate tend to dissolve. In such cases, sea water is corrosive to $CaCO_3$ (Fabry et al. 2008, 2009). The pH of the oceans is declining rapidly. Models project that surface waters of the Arctic Ocean and parts of the sub-Arctic Pacific will become increasingly corrosive to $CaCO_3$ as early as the middle of the 21st century (Fabry et al. 2009). As noted in Chapter Four, because of the projected release of fresh water to the North Atlantic over the next century, waters as far south as Newfoundland may become under-saturated with respect to aragonite by 2100 (Denman et al. 2011).

Many marine organisms that use calcium carbonate to construct their shells or skeletons—including corals, coccolithophores (calcareous phytoplankton), lobsters, mussels, snails, and sea urchins—are potentially the most vulnerable to acidification. As carbonate becomes scarce, organisms should find it increasingly difficult to form their skeletal material. For example, decreased calcification rates will slow the growth of coral reefs and make them more fragile and vulnerable to erosion. By the middle of the 21st century, reef erosion may surpass reef-building. Many laboratory studies on a variety of coral species, indeed almost every study published to date (reviewed by Doney et al. 2009), confirm that coral calcification rates decrease in response to decreasing aragonite saturation state. Analyses of cores from coral colonies of the Great Barrier Reef show that calcification rates declined 21% between 1988 and 2003 (Cooper et al. 2008). (Canada's cold-water corals may respond similarly to those in south-temperate and tropical waters; research in this area, however, is lacking.)

Responses of other groups of calcifying organisms to ocean acidification may be more variable (Ries et al. 2009). In the laboratory, blue mussels exhibit no response to variation in CO_2 levels, while the calcification rate of limpets, urchins, coralline red algae, and calcareous green algae increases at 2-3 times pre-industrial levels, before declining at higher levels. In three species of crustaceans (crabs, lobsters, shrimps), net calcification rate was greatest under a CO_2 level equivalent to ten times pre-industrial levels (Ries et al. 2009).

The potential impacts of ocean acidification appear to be far reaching and complex, even for non-calcifying species such as fishes. Fish larvae exposed to high CO_2 concentrations display odd behaviours, such as an attraction to the smell of predatory fish and a dangerous willingness to leave shelters, resulting in dramatic reductions in survival and recruitment (Munday et al. 2010). At the larval stage of development, fish might not have developed appropriate mechanisms for acid-base regulation. Increased levels of CO_2 have been shown to be associated with reduced growth and increased mortality in inland silversides (*Menidia beryllina*) (Baumann et al. 2011) and severe damage to internal organs in Atlantic cod (Frommel et al. 2011). On a somewhat positive note, ocean acidification can cause increases in carbon fixation rates in some photosynthetic organisms (both calcifying and non-calcifying), potentially contributing to the efficiency of the carbon pump (Appendix D). In general, however, the potential for marine organisms to adapt to increasing CO_2, and the broader implications of acidification for marine biodiversity and ecosystem functioning, are not well understood.

8. Interactions Between Climate Change and Fisheries

Climate is influencing populations and communities that are also affected by fishing. Both climate and exploitation contribute to observed trends and interact in their effects. Fishing, by altering the structure of populations and ecosystems, can modify their response to climate (Planque et al. 2010; Shackell et al. 2010). The demographic effects of fishing that lead to changes in age or size structure and distribution (Chapter Eight) can modify the capacity of populations to buffer climate effects. Similarly, changes in the relative abundance or loss of population sub-units may lead to a reduction in the capacity of the wider population to tolerate climate variability and change (Planque et al. 2010). Although detailed knowledge of the role of climate in influencing fisheries productivity, and our capacity to predict the effects of future climate change, is relatively limited, existing knowledge is sufficient to advise on many aspects of management in a changing climate. Broadly, the lower rates of fishing mortality associated with maintaining biomass at or above MSY will help provide populations with greater resilience to climate change, as will any management measure that preserves a broad age composition (e.g., Brander 2010). Given that climate change is occurring and will continue to occur, management systems will need to be appropriately responsive to this key stressor on marine biodiversity.

9. Main Findings

- Climate-change effects on ocean properties such as temperature, salinity, oxygen, and acidity affect the physiology, development, reproduction, behaviour, and survival of marine species.
- Warming temperatures are projected to increase primary production, potentially reduce the transfer of nutrients and organic matter, and negatively affect species' utilization of carbon.
- Species are projected to shift their latitudinal and depth ranges, changing the community composition of native marine species and allowing for invasions of non-native species.
- Climate change is acting to de-couple the timing of resource requirements and resource availability for some species, impairing their reproduction and development.
- The effects of ocean acidification on marine biodiversity, although not yet well understood, are likely to be far-reaching and complex.

Chapter Eight: Fisheries: Observed and Projected Consequences for Canadian Marine Biodiversity

1. Introduction

Fisheries can have multiple consequences for marine biodiversity. The most direct means is through reductions in the numbers of individuals directly targeted as catch by a fishery or caught incidentally, as bycatch. Such an effect need not, however, be problematic from a biodiversity perspective. It depends on the extent to which the population is reduced, relative to the levels at which it is predicted to be sustainable in the long term, both from a single-species and multi-species (or 'ecosystem') perspective. However, populations that decline further might experience reduced probabilities of persistence and contribute differently to ecosystem functionality. The deployment of fishing gear can reduce marine biodiversity through physical impacts on non-targeted individuals and the modification or destruction of their habitat. Also, by affecting the abundance of some species, fisheries have the potential to significantly influence interactions among others. Reduced abundance of a predator or group of predators, for example, can result in substantial increases in the abundance of their prey. Conversely, reductions of a fished species, concomitant with unchanged or even increased abundance of one of its predators, can significantly retard, or even prevent, the recovery of the depleted species.

The recovery of populations, and marine biodiversity, can also be influenced by fisheries-induced changes to the life-history traits (e.g., age and size at sexual maturity, growth rate) of the depleted population, i.e., characteristics that directly influence individual reproductive success and, thus, population growth rate. Some life-history trait changes might represent genetic or evolutionary responses to exploitation, meaning that, in the absence of fishing, they will not revert very rapidly to their former states. There is also evidence that fishing-induced reductions in the breadth or range of body sizes and ages in a population can also affect recovery potential.

2. Reductions in Abundance

Sustained exploitation generally reduces population abundance and always reduces population biomass (i.e., the total weight of all individuals). For many Canadian species, these reductions have been among the greatest recorded for fish worldwide, particularly in the Atlantic, where total biomass of species such as Atlantic cod, American plaice (*Hippoglossoides platessoides*), Acadian redfish (*Sebastes fasciatus*), roundnose grenadier (*Coryphaenoides rupestrus*), and winter skate (*Leucoraja ocellata*) have declined by more than 90% since the 1960s (www.cosewic.gc.ca; accessed 18-11-11). Most declines were experienced by species targeted by fishing, although some, such as winter skate, declined primarily because they were frequently caught as bycatch. Among marine and diadromous marine fishes assessed by COSEWIC as of January 2012, and for which fishing was the primary cause of decline, 18 are estimated to have declined more than 80% since the 1960s and to have exhibited little recovery (Table 8.1). The biodiversity of Canadian sharks has also been reduced by fishing. Notable examples, all of which have been assessed by COSEWIC as species at risk, include: basking shark (*Cetorhinus maximus*); porbeagle (*Lamna nasus*); white shark (*Carcharodon carcharias*); shortfin mako (*Isurus oxyrhinchus*); bluntnose sixgill shark (*Hexanchus griseus*); blue shark (*Prionace glauca*); and spiny dogfish (*Squalus acanthias*).

Past over-exploitation reduced the abundance of many marine mammals and led to the extirpation of at least one species from Canadian waters (grey whale). However, populations of many of these species have since grown following a cessation, or considerable reduction, in exploitation. For example, after being subjected to commercial whaling from 1500 until 1910, the Arctic's bowhead whale (*Balaena mysticetus*) has increased in abundance, having been subjected to only sporadic hunting by Inuit during the past century. Both grey and harp seals in Atlantic Canada have shown extraordinary population growth rates following reductions in hunting pressure in the 1960s and 1970s (DFO 2010a). By the 1900s, the sea otter (*Enhydra lutris*) had been extirpated from BC by the fur trade. The species was re-introduced from 1969 to 1972 and has since re-populated 25-33% of its historic range in Canadian Pacific waters.

Although quantitative historical data on marine bivalves are rare, it is clear that exploitation can, and has, resulted in significant depletions of some species in some areas. One example on Canada's east coast is the depletion of natural oyster beds in the southern Gulf of St. Lawrence (MacKenzie 1996; Milewski and Chapman 2002). On the west coast, harvesting has reduced northern abalone (*Haliotus kamtschatkana*) to such an extent that it has been assessed as Endangered by COSEWIC.

Table 8.1. *Marine fish populations estimated by COSEWIC to have declined more than 80% since the 1960s/1970s and for which over-fishing has been identified as a cause for the decline (data obtained from COSEWIC species status reports; www.cosewic.gc.ca).*

Ocean	Species	Population (estimated magnitude of decline)
Atlantic	Atlantic cod	Newfoundland & Labrador, incl. Grand Bank (97%), Northern Gulf and Newfoundland South Coast (89%), Southern Gulf & Eastern Scotian Shelf (90%)
	American plaice	Gulf of St. Lawrence (86%), Newfoundland & Labrador (96%)
	Northern wolffish	> 95%
	Spotted wolffish	> 90%
	Winter skate	Southern Gulf (98%), Eastern Scotian Shelf >90%)
	Roundnose grenadier	98%
	Porbeagle	89%
	Deepwater redfish	Gulf of St. Lawrence (98%), Newfoundland & Labrador (98%)
	Acadian redfish	99%
	White shark	80%
Pacific	Basking shark	> 90%
	Canary rockfish	78-96%
	Bocaccio	85-90%

3. Effects on Benthic Communities and Habitats

Fishing activity is patchily distributed. This reflects decisions by fishers, who are influenced by past catch rates, potential catching opportunities, the cost of fishing, interactions with other fishers, regulations or incentives in the management system, and competition for space with other users of the sea. Location and gear choice influences the frequency and intensity of disturbances that affect different habitat types. Almost any fishing gear will disturb marine habitat to some degree. The response of habitats to fishing depends on their sensitivity and the type and intensity of fishing effects. In general, towed fishing gears that directly impact the seabed, such as trawls and dredges, are responsible for most fishing-related alteration or destruction of habitat (Figure 8.1).

Meta-analyses of the recovery times of different habitats following fishing disturbance show that the impacts of scallop-dredging and other towed bottom-fishing gears on biogenic habitats (i.e., habitats produced or brought about by living organisms) are the most significant (Collie et al. 2000; Kaiser et al. 2006), while the biota of soft-sediment habitats, in particular muddy sands, can recover in a matter of years. Smaller free-living species with short lifespans tend to recover more quickly, especially in areas where they are already adapted to relatively high levels of natural disturbance.

Figure 8.1. *Trawl contents during the northern shrimp survey in Northwest Atlantic Fisheries Organization Division 0B (2006, 2008), showing catches of corals and sponges. Photo Credit: DFO.*

Glass sponge (family: Hexactinellidae) communities or reefs provide a noteworthy example of sensitive habitat. These are typically found in the deep sea (at more than 650 m depth), but are also found in shallow waters (in as little as 16 m) in the Queen Charlotte Basin, Howe Sound, Strait of Georgia, and fjords of BC (e.g., Leys et al. 2004; Conway et al. 2005; Marliave et al. 2009; Chu and Leys 2010). Following early reports of the presence of sponge colonies and reefs, high-resolution habitat mapping has better described their distribution on the western Canadian continental shelf (Conway et al. 2001, 2005). Glass sponge reefs provide habitat for species such as rockfishes, *Sebastes* spp. (Marliave et al. 2009; Chu et al. 2010), they 'process' significant quantities of water (a recent estimate suggested they could remove 0.96 g C m^{-2} day^{-1}; Chu et al. 2010), and they are sensitive to any impact from fishing gear (Conway et al. 2001; Cook et al. 2008). Other sensitive habitats in BC waters include 'gardens' of sea whips (order: Gorgonacea) that have been impacted by shrimp beam trawls (Troffe et al. 2005) and cold-water marine ecosystems dominated by sponges in the NAFO (Northwest Atlantic Fisheries Organization) convention area off the Atlantic coast.

Trawling and dredging for fish and shellfish are widespread and locally intense. Their impacts on a range of habitats have been described. In one of the first studies, Messieh et al. (1991) estimated that the length of track swept by trawlers and dredgers fishing off Canada's east coast was 4.3 million km^2 in 1985. Experimental studies of the effects of otter trawling on the hard-bottom habitats of Western Bank (Scotian Shelf) show that this fishing method leads to reductions in the abundance of sensitive taxa and an overall reduction in epifaunal biomass (Kenchington et al. 2006). A longer-term perspective, gained by comparing the diversity of larger species of benthic fauna on the scallop fishing grounds of the Bay of Fundy in 1966-67 and 1997 (Kenchington et al. 2007) showed that attached, fragile, epifaunal, filter-feeding taxa had been replaced by a combination of motile scavengers, motile filter-feeders, and robust, burrowing filter-feeders. The authors attributed the changes to the long-term effects of trawling.

Although trawling is known to affect diversity at local scales, there has been little systematic analysis of whether these effects are persistent. Clearly, any fishing with towed bottom gears will lead to collateral impact. On habitats subject to high rates of natural disturbance, where the impacts are smaller and recovery times are faster, society and management authorities have treated the collateral damage as acceptable. With respect to the most sensitive habitats, impacts are not reversible on management timescales, and society often considers that any impact is unacceptable. Societal pressure and responses of management agencies to policy drivers have, therefore, led to the protection of some of the more sensitive habitats from any fishing activity through area closure and/or a range of measures intended to reduce impacts.

The first pass of a fishing gear on a previously unfished habitat has a greater impact on biomass than subsequent passes (Kaiser et al. 2002). This has consequences for management since management policies that maintain a relatively constant 'footprint' of fishing through time will lead to a smaller impact on a given habitat than policies that lead to continuous movement and redistribution of effort. Further, management actions that lead to the concentration of a given level of effort in a smaller area type also lead to lower impacts. To minimise fishing impacts on habitats, managers need to minimize the size and variability of the spatial footprint of fishing, and ensure that management actions, taken for other reasons, do not lead to unintended extension and/or displacement of the spatial footprint of fishing. In addition, access to high-resolution habitat maps can allow fishers to operate close to sensitive habitat without unduly disturbing it (Kostylev et al. 2001).

Quantitative estimates of the areas of different habitat types impacted by fishing are not available for Canadian waters, but ongoing efforts to map habitats (e.g., Kostylev et al. 2001) and relatively fine-scale information on the distribution of fishing activities from Vessel Monitoring Systems does make this possible. The analysis could extend to an assessment of total impact, using estimates of the relative impacts of fishing on different habitats types. This would allow managers to assess the impacts and the sustainability of the impacts attributable to different fisheries. However, no benchmarks or reference points have yet been set for acceptable impacts of fishing, and impacts tend to be considered on a case-by-case basis. With, for example, increasingly large areas of glass sponge and cold-water coral reef being identified, the debate on appropriate targets for protection, and whether there is an option for any fishing in areas that harbour such habitats, has not yielded definitive conclusions. Nonetheless, DFO has assessed the potential impacts of fishing gear on benthic habitats, populations, and communities on at least two occasions (DFO 2006, 2010b). The 2006 advice identified the need to establish operational objectives for the conservation of benthic communities and recommended that these objectives should underpin criteria for the establishment of Large Ocean Management Areas (LOMAs; see Chapter Twelve). This process was based on the identification of habitats of particular ecological significance, according to DFO criteria for identifying ecologically or biologically significant areas (EBSAs) and for ensuring that habitat conservation efforts give priority to those areas.

4. Effects on Marine Fish Communities

The effects of fishing on the size and species composition of multispecies communities have been well described, especially in those areas of the continental shelf where annual trawl surveys are conducted. The community effects of fishing are often most profound in areas that are fished with relatively unselective gears, such as bottom trawls, which harvest a mixture of targeted and non-targeted species. Spatial comparisons between areas subject to different fishing intensities, and temporal comparison in areas where fishing effort is known, indicate broadly consistent community responses.

As fishing mortality rises, the mean size of individuals in the community falls, and species with larger body sizes form a smaller proportion of community biomass. These responses are largely a consequence of three processes: the extent to which higher mortality rates affect larger species, the higher sensitivity of larger species to a given rate of mortality, and the responses of prey species to reductions in their predators. Zwanenburg et al. (2000), for example, showed that the average individual weight of fishes caught in survey trawls on the Scotian Shelf since the 1970s decreased by 51% on the eastern shelf and by 41% on the western shelf. Declines in size were greatest for species targeted by commercial fisheries. The slope of the size spectrum (the relationship between the abundance of fishes in body mass classes and body mass) also became steeper, reflecting the relative losses of larger fish and increases in the proportional representation of smaller fishes. After the closure of the cod fishery on the eastern shelf in 1993, and the restrictions on landings on the western shelf, both average weights and community size structure stabilized. A subsequent analysis for the western Scotian Shelf by Shackell et al. (2010) showed that decreases in average body sizes had occurred in all functional groups (Figure 8.2). Reductions in average mass, relative to values during the 1970s, amounted to 59% for the large-sized benthivores, 48% for medium-sized benthivores, and 45% for piscivores.

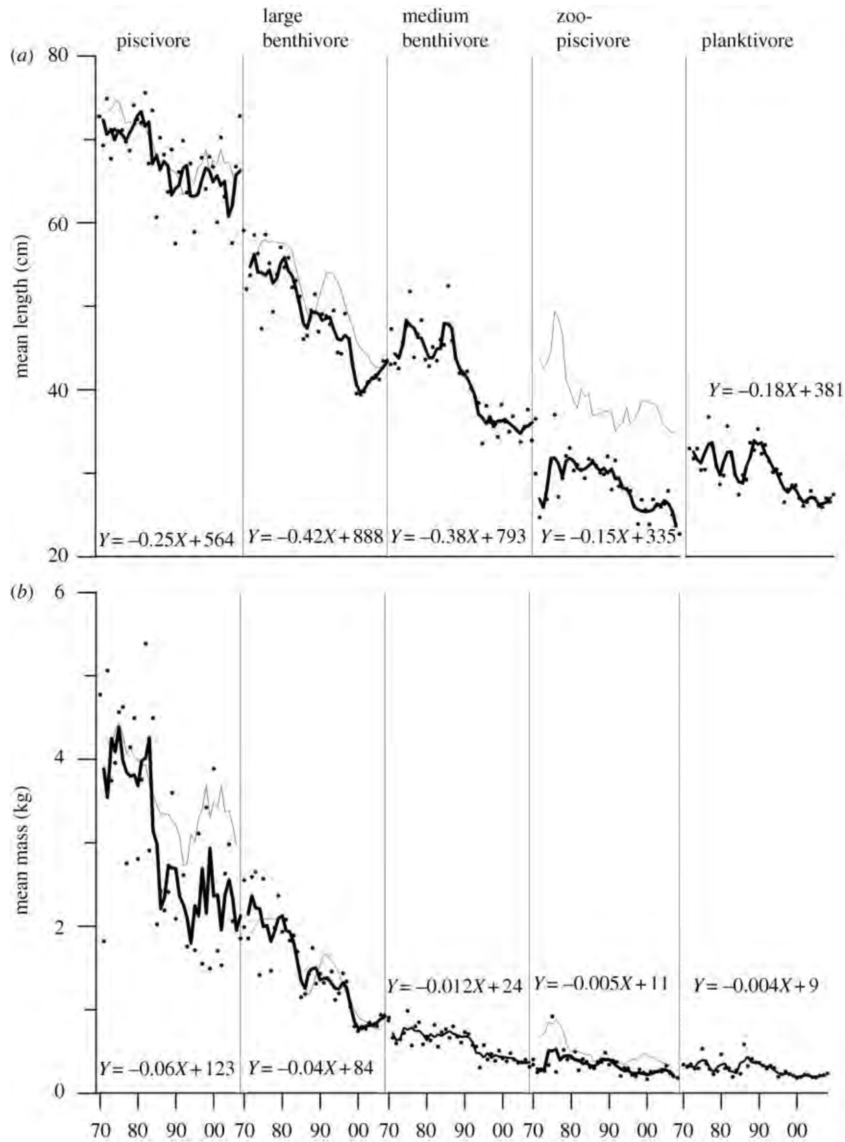


Figure 8.2. *Mean length (a) and mean mass (b) for five marine fish functional groups from 1970 to 2008 on the Scotian Shelf. Linear regression equations of body size through time are shown. Dots are annual values and lines show 3-year running averages. Grey lines denote the direct measure of growth (size at age 6 yr, as weighted by species biomass within each functional group). The x-axis represents time from 1970 to 2008 for each of the five functional groups. Source: Shackell et al. (2010).*

Planktivores and zoopiscivores declined by 34% and 18%, respectively. For prey species, biomass increased, despite the decline in average body size. The decline in average body size of aggregate top predators was the dominant factor accounting for the increase in prey species biomass. Reductions in abundance of species on the Scotian Shelf and Bay of Fundy led to decreases in the distributional ranges of about half the species studied, an effect likely mediated by changes in interactions within and among species (Fisher and Frank 2004).

The hypothesis that fishing-induced reductions in predator abundance allows for a 'release' (abundance increase) of their prey (e.g., Worm and Myers 2003) is further supported by research in the southern Gulf of St. Lawrence. Mean body length in the marine fish community decreased dramatically in the 1990s, a reflection of the removal of large-bodied fishes by fishing and sharp increases in the abundance of small fishes (Benoît and Swain 2008). Strong predator control of the abundance of small-bodied fishes is suggested by the observed inverse correlation between the biomass of small fish and an index of predation on those fish by larger fish (Figure 8.3).

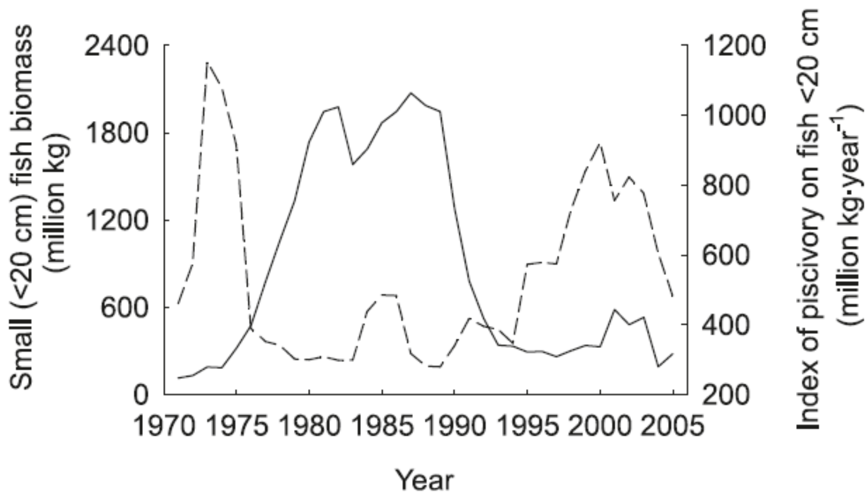


Figure 8.3. *Total annual biomass of small fish (dashed line, units on left vertical axis) and an index of potential predation by piscivorous fish on those small-bodied fish (solid line, units on right vertical axis) from 1971 to 2005. Source: Benoît and Swain (2008).*

5. Effects on Species Community Structure and Food Webs

Most fisheries are managed on the basis of single-species population dynamics models. This means that fisheries reference points (defined in Chapter Five, expanded upon in Chapter Twelve) are based on how harvesting is predicted to affect the population growth rate of the targeted species of interest, with no consideration as to how changes in the abundance of the targeted species might affect the abundance of interacting species. Reference points that account for these interactions will differ from single-species reference points (Worm et al. 2009).

Fisheries-induced changes to marine species assemblages have been best documented in Atlantic Canada (e.g., Lotze and Milewski 2004), where the overfishing of several species has contributed to an unprecedented change in Canadian marine biodiversity (Benoît and Swain 2008; DFO 2010b; Templeman 2010; Frank et al. 2011). Perhaps the most demonstrable consequence of these altered ecosystems is an increase in species that were once heavily preyed upon by Atlantic cod and other bottom-dwelling fish predators. One such example is the dramatic increase in shrimp (*Pandalus borealis*) and snow crab (*Chionoecetes opilio*) that followed the collapse of cod in the early 1990s (Worm and Myers 2003).

There are concerns that fishery-induced changes to predator-prey interactions may be responsible for significantly retarding, or even preventing, the recovery of depleted marine fishes. At least three species in the southern Gulf of St. Lawrence are experiencing unsustainably high levels of natural mortality, meaning that they will be extirpated from Canadian waters if mortality rates do not decline. White hake (*Urophycis tenuis*) in this area may be the most endangered marine fish in Canada. In the 1970s and 1980s, approximately 18% of hake (aged five to seven years) were dying annually; in the past decade, this annual level of natural mortality has increased to between 86 and 91% (DFO 2010c). At this level of mortality, white hake might disappear from the southern Gulf within the next decade. Unsustainably high mortality is predicted to prevent winter skate from increasing, following its 98% decline in the southern Gulf. Atlantic cod in the southern Gulf, once (in 1987) the largest spawning population of cod in the world (Hutchings and Rangeley 2011), are currently experiencing such high mortality that they are projected to be extirpated by 2050 (Swain and Chouinard 2008). One factor originally thought to be inhibiting their recovery is the increase in abundance of species, such as mackerel (*Scomber scombrus*) and Atlantic herring (*Clupea harengus*), that prey upon cod eggs and larvae (and potentially compete with larval and juvenile cod) (Swain and Sinclair 2000). In addition to this hypothesized negative influence on cod productivity is predation on small and large cod by grey seals (DFO 2010c; Swain 2011; Benoît et al. 2012).

Over-exploitation on Atlantic Canada's Scotian Shelf has also resulted in the restructuring of a food web. Formerly dominated by large-bodied demersal fishes such as cod and haddock (*Melanogrammus aeglefinus*), the species assemblage is now dominated by small pelagic fishes and macro-invertebrates. It has been posited that recovery of the former species community structure is possible, but that it has been severely delayed by the eruption of planktivorous species (formerly preyed upon by large-bodied predators) and by a subsequent outstripping of their zooplankton food supply (Frank et al. 2011).

6. Recovery From Overfishing

One common means of defining overfishing is to assess current fishing mortality (as defined by a parameter F) with the fishing mortality at which the maximum sustainable yield (MSY) is estimated to be obtained (i.e., F_{MSY}). When the ratio of F/F_{MSY} exceeds 1, overfishing (as defined by many jurisdictions) is occurring. Based on this metric, one can conclude that overfishing was a dominant characteristic of Canadian fisheries for marine fishes, most notably in the Atlantic, particularly from the 1960s through the early 1990s (Figure 8.3).

Reductions in abundance concomitant with overfishing are often associated with significant changes to fish life-history traits, i.e., characteristics that affect the ability of individuals to reproduce and the ability of populations to grow, or recover, following depletion (Hutchings and Baum 2005). Changes to life-history traits affect population growth (Cole 1954) and, thus, recovery potential (Hutchings et al. 2012). Prominent among fishing-induced changes to life history are reductions in age at maturity, i.e., first reproduction. In at least four populations of Atlantic cod, for example, age at maturity has declined by two and three years over the past five to six decades (Hutchings and Rangeley 2011). Within some populations, reductions in size at maturity have also been substantive. Length at maturity among Eastern Scotian Shelf cod, for example, declined from ~42 cm in the late 1970s to ~32 cm in the early 2000s (Hutchings 2005).

A second prominent feature of depleted populations is a narrowing of the breadth of ages and body sizes caused by the fishing-out of the largest and oldest individuals. There are theoretical and empirical reasons for believing that population productivity and recovery potential are affected by reductions in the breadth of the age and size classes of the spawning population (Venturelli et al. 2009; Hutchings and Rangeley 2011). All depleted Canadian cod populations have, to varying degrees, experienced significant truncations in their age and size distributions. Newfoundland's northern cod provide an illustrative example. The contribution of eggs by females ten years and older to the population is estimated to have declined from an annual average of 30% in the 1960s (46% in 1962, when the population had already been fished for almost 500 years) to 17% in the 1970s and to 12% in the 1980s (Hutchings and Myers 1994). Their current low incidence in fishery and survey catches (Brattey et al. 2009) suggests that cod ten years and older have contributed little to population growth since 1992.

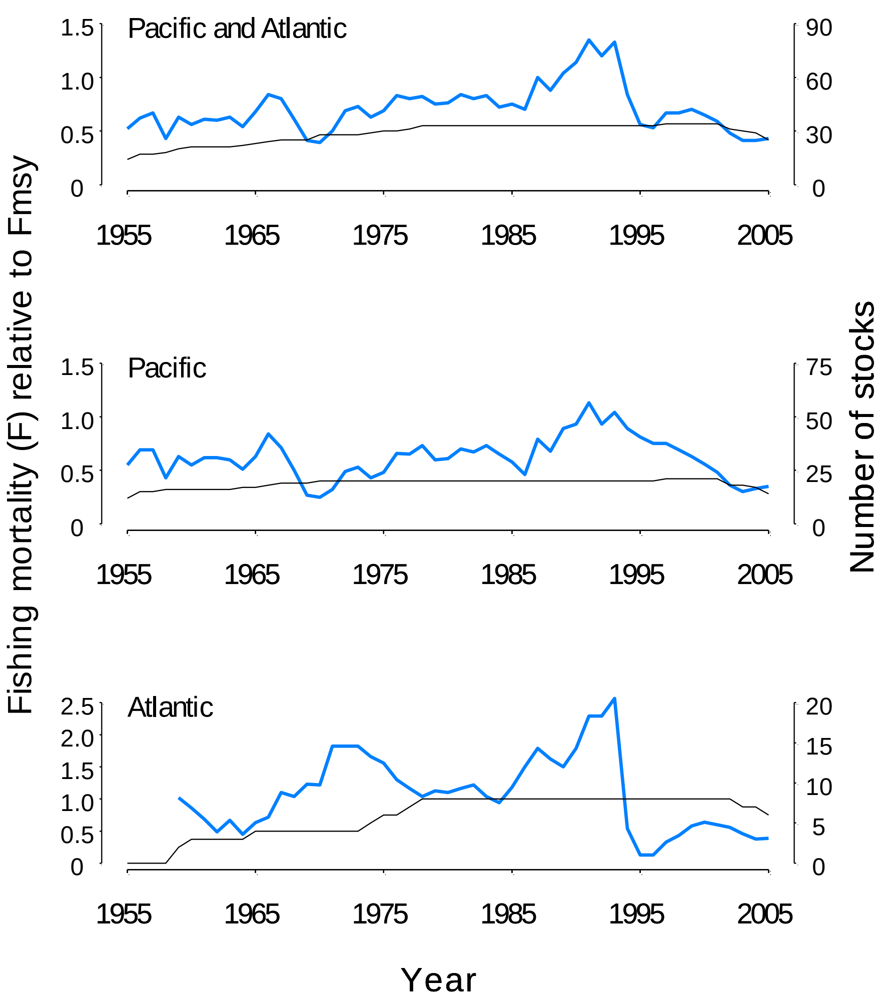


Figure 8.4. *Temporal trend in fishing mortality (*F*, the instantaneous mortality rate) relative to the fishing mortality estimated to achieve maximum sustainable yield (*F_{MSY}*) (blue line) for commercially exploited fish stocks in the Canadian Pacific and Atlantic. Number of fish stocks for which data are available in each year is shown by the black line. Note that when* F/F_{MSY} *exceeds 1, overfishing (as defined by many jurisdictions) is occurring. Sources: Appendix E and ramlegacy.marinebiodiversity.ca/srdb/updated-srdb*
http://ramlegacy.marinebiodiversity.ca/srdb/updated-srdb

A third feature hypothesized to be of importance to severely depleted populations is genetic change resulting from prolonged periods of over-fishing (Stokes et al. 1993; Kuparinen and Merilä 2007; Hutchings and Fraser 2008). The potential for fishing to cause evolutionary change is not appreciably different from other forms of predator-induced mortality, given the ability of fishing to effect differential mortality among genotypes. (The mortality wrought by humans on fishes often exceeds that of most natural predator-prey relationships.) Thus, changes to traits such as age and size at maturity might be explained, in part, as evolutionary responses to unsustainably high levels of fishing mortality. From a recovery perspective, if life-history change partly represents a genetic response to fisheries-induced selection, the reversibility of these life-history responses to exploitation may be slow. Changes to life-history traits and truncated distributions in age and size at maturity have the potential to negatively affect population growth rate and, thus, population recovery as a consequence of several factors. These include: higher post-reproductive mortality; reduced lifespan; lower fecundity; smaller egg size; and increased temporal variability in offspring survival (Hutchings 2005; Kuparinen et al. 2012).

The observation that many Canadian marine fishes (e.g., Atlantic cod, American plaice, winter skate, white hake) have shown little or no recovery following depletion, despite massive reductions in harvesting, indicates that reductions in fishing mortality, while being necessary for recovery, are not always sufficient to achieve it. However, given the necessity for fishing pressure to be reduced before recovery can take place, the declining trend in fishing mortality across all fish populations for which data are available in Canadian waters is encouraging (Figure 8.4).

7. Main Findings

- Fishing affects biodiversity primarily by reducing abundance, sometimes significantly, by directed catch, bycatch, and destruction of species or their habitat (e.g., corals and sponges).
- Over-fishing has depleted many Canadian fishes, potentially increasing their extinction risk.
- By affecting abundance, fishing alters interactions among species, such as those between predator and prey, resulting in biological changes to marine ecosystems and food webs.
- Fisheries can affect population and species reproductive capability and recovery potential by affecting life-history traits, age and body size distribution, and interactions among species.
- Fishing mortality of marine fishes has declined since its peak in the late 1980s/early 1990s, although reductions in fishing pressure are not always sufficient to enable recovery.

CHAPTER NINE: AQUACULTURE: OBSERVED AND PROJECTED CONSEQUENCES FOR CANADIAN MARINE BIODIVERSITY

1. Introduction

The growth and monetary value of Canadian aquaculture (Chapter Six) mask real and perceived environmental costs and a deeply rooted public controversy. Potential environmental impacts of aquaculture, which might have biodiversity consequences, are commonly grouped into four categories: ecological interactions; genetic consequences; disease and parasites; and habitat alteration (Figure 9.1). More specifically, these include concerns about: (i) benthic impacts and siting; (ii) chemical inputs, such as antibiotics, anti-foulants, and pesticides; (iii) nutrient loading and deterioration of the benthos; (iv) attraction of other organisms and predator exclusion; (v) feed sources; (vi) effects of escapees and use of exotic species; and (vii) exchange of pathogens, such as sea lice, between the local natural and culture environments (the term 'sea lice' refers to naturally occurring species of small, marine copepods in the family Caligidae; these parasitic organisms feed on the mucous, skin, and blood of their hosts). All of these interactions are known to occur in the open-net sea pens that are typical of Canadian aquaculture operations (it should be noted, however, that most or all of these interactions can be mitigated by the use of closed-containment facilities, particularly those deployed on land). The extent of their impact varies significantly depending on the species involved, spatial location of the culture activity (siting), magnitude or scale and type of activity, and local environment.

Unfortunately, background conditions are seldom considered to their full extent, a deficiency that becomes particularly important if we anticipate conditions changing in the future as a result of climate change. Annually varying environmental conditions can directly influence the assessment of potential impacts. For example, baseline monitoring (pre-development) and determination of reference farm sites are vital to the assessment of potential farming impacts; the susceptibility of juvenile Pacific salmon to pathogens from aquaculture farms could differ between years because of variability in the natural environment to which they were exposed prior to encountering farms. Much of the public controversy associated with aquaculture stems from the uncertainty of their impacts on natural systems (impacts can be localized, transient in time, and differ between sites), lack of an assessment framework for analysis (in the absence of a monitoring and assessment framework, how should impacts be assessed?), and reliance on statistical relationships and mathematical models to compensate for this uncertainty and lack of assessment framework. Although modelling is essential to most studies in natural biological systems, models can introduce concerns about understanding and trust in public debate of controversial topics.

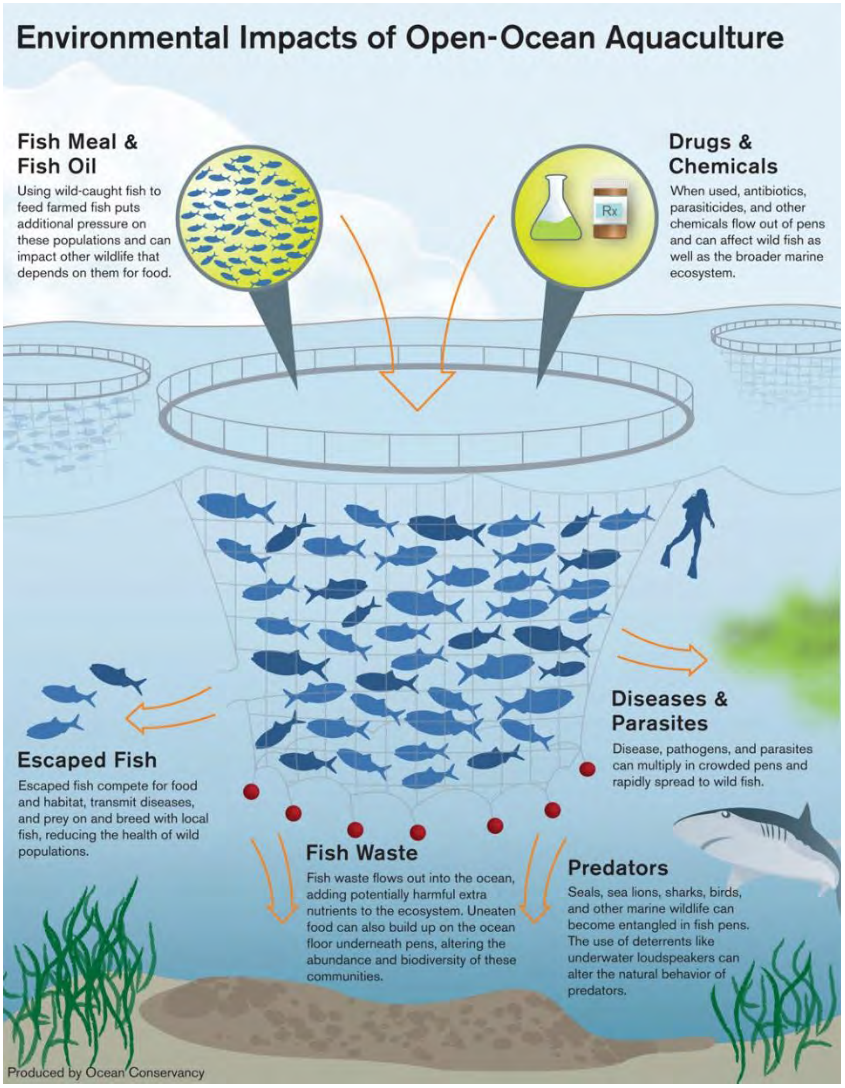


Figure 9.1. *Environmental impacts associated with open-net pen aquaculture. Impacts associated with other forms of open-ocean aquaculture will differ but commonly involve this same set of potential effects. Source: http://www.oceanconservancy.org/our-work/aquaculture/ .*

The issues outlined above become more complicated when considering biodiversity. Impacts associated with an aquaculture site on local habitats and in a limited area are difficult to extrapolate to biodiversity impacts on a broader scale, or on the production of local native species. Also, effects on biodiversity are more likely to be associated with cumulative effects of culture programmes, and not on any single issue or single culture site. Cumulative effects of culture activities, however, can be difficult to quantify and to isolate from other sources of variation in open natural ecosystems. In BC's Broughton Archipelago, for example, aboriginal people have practiced a form of shellfish culture for centuries (Williams 2006). Once natural shellfish beaches, these 'clam gardens' were modified to increase clam production. Recently, however, many of the gardens have become less productive and the clams inedible. Aboriginal people attribute this to salmon aquaculture; 28 farm sites have been developed in the archipelago since the mid-1980s. Questions persist about the role of aquaculture versus changes in how the gardens are used, or changes in local environmental conditions, and research on the issue is incomplete at present.

Globally, published comments on the effect of aquaculture on biodiversity are generally negative and have fueled public concern (e.g., Naylor et al. 2005, 2009; Alder et al. 2008; Ford and Myers 2008; Tacon and Metian 2008; Costello 2009; Burridge et al. 2010; but see Cubitt et al. 2009). (Although these reviews pertain primarily to finfish, Dumbauld et al.'s (2009) recent review of US shellfish aquaculture is relevant in the Canadian context.) The focus here will be on recent work related to biodiversity consequences. In this regard, DFO prepared a number of 'State of Knowledge' reports to provide a scientific review of potential environmental effects of aquaculture (DFO 2003-2006; www.dfo-mpo.gc.ca/science/enviro/aquaculture/index-eng.htm; accessed 17-12-11). Comprehensive as these reports are, their references have become increasingly dated (the most recent citations range typically between 2002 and 2004). The DFO (2003-2006) review includes marine (and freshwater) finfish and shellfish aquaculture and addresses concerns pertaining to impacts of: (i) waste deposition (including nutrient and organic matter); (ii) use of chemicals (e.g., pesticides, drugs, anti-fouling agents); and (iii) interactions/interbreeding between farmed and wild species (including disease transfer and genetic and ecological effects). Among recent DFO reports on aquaculture that have been published on DFO's Canadian Science Advisory Secretariat website (http://dfo-mpo.gc.ca/csas-sccs/index.htm; accessed 19-11-11) is a study of the degree to which aquaculture-related alterations to physical habitat acts as an ecosystem stressor (McKindsey 2010).

2. Finfish Aquaculture

a. Pacific

With the possible exceptions of pathogens, it is unlikely that the impacts of salmon net-pen aquaculture on marine biodiversity along BC's coast will be broad-ranging. Effects, however, are likely to be cumulative, particularly in areas of salmon farm concentration. Concerns about escaped Atlantic salmon, an exotic species in BC, were significant in the 1990s, but have decreased in recent years. Escapes of salmon certainly occur but are less frequent than they were in the developmental years of the aquaculture industry. DFO reports that between 1987 and 2002, 1.4 million Atlantic salmon escaped from BC salmon farms. In more recent years, escapes and catches of Atlantic salmon have been reported by the Aquatic Nuisance Species Project in Portland, Oregon (www.aquaticnuisance.org; accessed 19-11-11) (Table 9.1). Although escapes of salmon from BC farms must be reported to regulatory agencies, the number of escapees is clearly an estimate, and the recovery of Atlantic salmon depends on monitoring and sampling efforts, both of which vary considerably among years. (For example, DFO's Atlantic Salmon Watch programme has ceased.) Recoveries in Alaskan fisheries may be the best indicator of incidence of Atlantic salmon in Pacific coastal waters, due to the consistency of their fisheries and sampling programmes.

Table 9.1. *Reported escapes of Atlantic salmon from BC salmon farms and their recorded catches in Canadian and Alaskan fisheries. Values in brackets for Canadian catches of escapees are reported from freshwater sampling programmes (i.e., potential spawning fish).*

Year	Reported Losses	Canadian Catches of Escapees	Alaskan Fisheries
2000	31,855	7,834 (131)	81
2001	55,414	179 (116)	35
2002	11,257	562 (40)	6
2003	30	46 (36)	3
2004	43,969	148 (0)	1
2005	21	27 (2)	3
2006	17	225 (1)	1
2007	19,223	21 (5)	3
2008	111,679	no data	39
2009	48,857	no data	2
2010	0	Unreported	9

Although feral Atlantic salmon have been reported in coastal rivers (Volpe et al. 2000), there is no evidence, to the best of our knowledge, of self-reproducing populations of feral Atlantic salmon in BC. If a concern for escapees exists, it is more likely in Clayoquot Sound (west coast of Vancouver Island), where domesticated strains of Chinook salmon are reared in proximity to native Chinook populations (Kim et al. 2004; Withler et al. 2007). These native populations are also depressed in abundance and potentially vulnerable but, to our knowledge, monitoring programmes to assess the potential impacts of Chinook salmon aquaculture on native Chinook populations in Clayoquot Sound are not conducted.

The greatest concerns for biodiversity impacts are associated with the effects of sea lice from salmon farms on local populations of wild Pacific salmon, the potential for exchange of pathogens between farmed and wild salmonids, and the risk of introducing new pathogens to the wild. Although salmon farming in BC was initiated in the mid-1980s (Chapter Six), public and scientific focus on sea lice was not strong until the reporting of an epidemic in the Broughton Archipelago in June 2001 (Morton and Williams 2003). While essentially all adult salmonids returning from the Pacific Ocean carry sea lice naturally, juvenile salmonids in coastal waters do not. Observations of wild juvenile salmonids infected with lice in the vicinity of farms raised a series of questions: What is the source of the lice on juvenile salmonids? What is the effect of lice infections on individual juveniles entering coastal waters? Is there an effect on the productivity (the rate of adult return per adult spawner in the parental generation) of salmon populations in proximity to salmon farming?

After a decade of study, it is generally accepted that open-net pen salmon farms can cause infections of the salmon louse (a type of sea lice), *Lepeophtheirus salmonis,* and contribute to infections of *Caligus clemensi* in native salmonids, and that these infections can increase juvenile salmonid mortality rates (directly and probably indirectly through increased predation). Although it has also been hypothesized that increased juvenile mortality might reduce the productivity of salmon populations (e.g., Saksida et al. 2007a,b; Beamish et al. 2009; Marty et al. 2010; Krkosek and Hilborn 2011; Krkosek et al. 2011a,b; Price et al. 2010, 2011), definitive links between juvenile infections and adult salmon abundance have been difficult to establish. The number of adults returning to a specific region reflects variation in adult spawning numbers in the preceding parental generation, and conditions experienced subsequently by their progeny. This usually involves returns to multiple streams, variable environmental conditions in fresh water, and naturally variable conditions in the ocean between the juvenile and returning-adult stages. The natural mortality rate on all salmonids entering the ocean is known to be high (usually more than 90% die), so the ability to assess an incremental impact of sea lice during an early life stage will always be limited, particularly given the quality of data typically available for analysis.

Data obtained from the Broughton Archipelago demonstrate that sea lice infections on wild salmonids can be controlled through treatment of farmed salmon prior to the entrance of juvenile salmon into coastal waters (Saksida et al. 2010). Current treatment in BC involves the use of emamectin benzoate (SLICE®, Schering-Plough Animal Health) as a pre-mixed coating applied to fish food pellets and administered under veterinary supervision. For government-approved chemicals, recent research in Canada indicates limited impacts at the dosages currently applied (Waddy et al. 2007; Kuo et al. 2010) and that levels retained in flesh and skin are well below Health Canada guidelines (Whyte et al. 2011). (However, a law suit filed by Environment Canada against Cooke Aquaculture in autumn 2011 alleges that cypermethrin, an illegal pesticide, has been used to combat sea lice infestations in Atlantic salmon farms in the Bay of Fundy, leading to deaths of lobsters.) One emerging concern is the development of sea lice resistance to emamectin benzoate and reduced effectiveness in controlling lice infections. While variation in up-take of SLICE between animals has been documented (Berg and Horsberg 2009), the question of whether sea-lice resistance is developing in farmed fish remains unanswered and merits study. The control of sea lice is also important for the control of infectious diseases (Nese and Enger 1993; Nylund et al. 1994; Baker et al. 2009).

The introduction or exacerbation of infectious diseases and parasites probably constitutes the greatest potential threat to biodiversity posed by salmon aquaculture. Significant disease outbreaks in BC salmon farms have been documented. In one instance, the disease was an endemic one (infectious haematopoietic necrosis virus, IHNV) and it was likely spread within, and between, coastal areas as a result of farming practices (Saksida 2006). To date, diseases in BC salmon farms and in government salmon hatcheries have all been introduced by native bacteria or by viruses known to infect wild Pacific salmon. However, the recent outbreaks of infectious salmon anemia (ISA) in Chile (Vike et al. 2009), coupled with various disease transmission studies of ISA (e.g., Nylund et al. 2007), have greatly heightened awareness and concern in BC. Indeed, in 2011, there were conflicting reports that wild BC salmon had, for the first time, been infected with ISA. One set of analyses, undertaken by a World Animal Health Organization-endorsed lab at the University of Prince Edward Island, was reported to have found positive evidence of the virus, whereas a later set of analyses on different tissues (albeit apparently degraded) from the same fish by DFO were reported to be negative, according to the Canadian Food Inspection Agency (www.inspection.gc.ca/english/corpaffr/newcom/2011/20111109e.shtml; accessed 19-11-11). Prior to 2011, all records of disease incidence on BC salmon farms had been protected by the

Province of BC as being proprietary to the industry. Although the Cohen Commission into Fraser sockeye salmon is now in receipt of some portion of these records (www.cohencommission.ca; accessed 19-11-11), it is not yet known how accessible these records will be to the public. The introduction of a non-endemic disease, such as ISA, into BC's wild Pacific salmon would certainly constitute a major threat to the diversity of these species. Miller et al.'s (2011) functional genomics study has contributed strongly to these concerns; the researchers hypothesized that elevated mortality in Fraser sockeye salmon in recent years represents a response to an unknown viral infection (linkages cited with genes associated with leukemia). Clearly, this hypothesis warrants further study.

In summary, while adverse impacts of open-net pen salmon farming on the Pacific coast have been identified, the impact on marine biodiversity in these waters is likely to be localized and controllable, with the exception of potential impacts arising from the transfer of pathogens and disease to wild populations. There is reason to believe that the harm posed by pathogens might be greater than currently perceived. The lack of transparency in public reporting (cf. Principle 10 of the Rio Declaration in Chapter Ten) of diseases at aquaculture farms has hindered meaningful, constructive, and respectful debate. Public concern for salmon aquaculture in BC is frequently deflected to scientific arguments and burden of proof. But this type of 'objective' approach misses an essential subjective viewpoint:

> [Pacific salmon] are a symbol of place in the northwest, a marker of the community of individuals, enterprises and organizations committed to live in a way that strengthens local and regional economies, sustains the natural abundance of resources, and provides a nurturing for the spirit.
> (www.davidsuzuki.org/blogs/suzuki-elders/2010/05/salmon-farming-the-real-dispute/; accessed 19-11-11)

The sustainability of salmon farming in BC involves more than science and models, and will continue to be debated until there is a fuller understanding and more meaningful inclusion of public values and opinions within aquaculture management and government policy decisions. There are no other regions of the world where open-net pen salmon farming is practiced that have greater salmonid diversity, abundance, and dependent natural ecosystems that are potentially at risk than those in BC. The use of closed-containment technology has been proposed as a solution to mitigate some of the impacts of open-net pen salmon farming (www.farmedanddangerous.org/wp-content/uploads/2011/01/ClosedSystemAqua-FINAL.pdf; accessed 21-12-11) and land-based closed-containment fish farming may now be economically viable (e.g., www.saveoursalmon.ca/files/May_draft_05-04-10.pdf; accessed 21-12-11; www.sustainableblue.com; accessed 21-12-11). Ultimately, a higher standard of transparency and accountability by both industry and DFO should have been anticipated, but has yet to be achieved.

b. Atlantic

Given that the farming of salmon dominates finfish aquaculture on both coasts (Chapter Six), the projected consequences of the industry on marine biodiversity in the Atlantic are in many ways similar to those in the Pacific. Here, the Report focuses on aspects of escapes and disease issues that are somewhat more specific to the Atlantic region.

Unlike the Pacific, Atlantic salmon are native to Atlantic waters and the potential for negative impacts due to intraspecific competition and genetic introgression – the infusion of genes from escaped farmed fish into wild fish – are manifest (Fleming et al. 2000; McGinnity et al. 2003; Fraser et al. 2010). The scale of the industry, relative to the small size of wild salmon populations in the region, increases the likelihood of ecological and genetic impacts, even at relatively low escape rates (cf. Hindar et al. 2006). Concerns are further accentuated in the Atlantic because the industry is concentrated in areas where the abundance of wild salmon populations continues to be depressed (e.g., Bay of Fundy, south coast of Newfoundland; DFO and MRNF 2008, 2009). At a regional scale, the proportion of farmed salmon invading wild populations has increased through time (Figure 9.2), although this trend appears to be more of an effect of declines in wild populations than increases in the absolute number of farm escapees (Figure 9.3). Escaped farmed salmon have been reported in 54 rivers and bays, which constitute 87% of the watersheds that have been investigated since the inception of the salmon aquaculture industry (Morris et al. 2008).

There are important differences between farmed and wild salmon, such as growth rate, that affect behaviour, competitive ability, and breeding success (reviewed by Thorstad et al. 2008). These characteristics are caused partly by environmental differences and partly by genetic differences, and include responses to intentional and unintentional selection (domestication) in aquaculture facilities. While the outcomes of interactions between farmed and wild salmon depend on context, varying with a number of environmental and genetic factors, they will frequently be negative for wild salmon. Genetic introgression resulting from the interbreeding of farmed and wild salmon can disrupt adaptive traits (McGinnity et al. 2003; Fraser et al. 2010) and lead to genetic homogenization (i.e., a diminishment of between-population distinctiveness), which might further threaten the persistence of wild populations (Hindar et al. 2006).

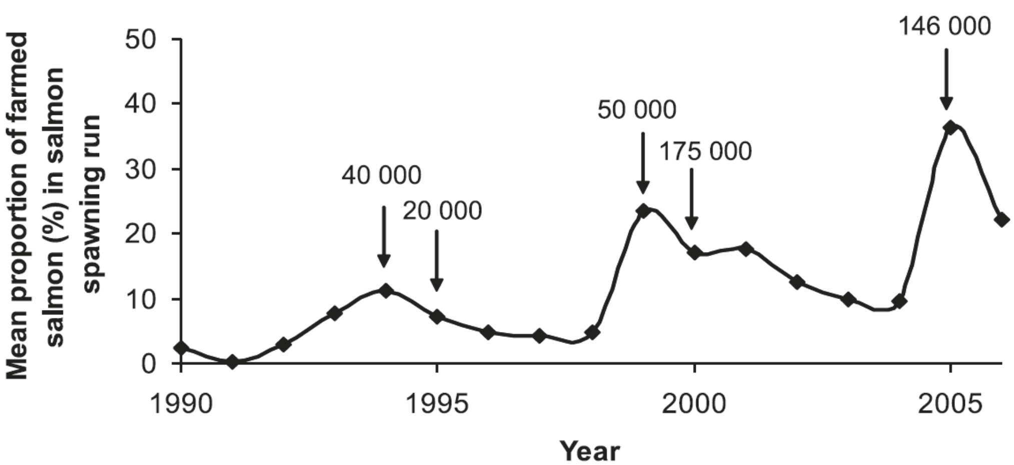


Figure 9.2. *Yearly mean proportions of escaped farmed Atlantic salmon within spawning runs, averaged over all eastern North American rivers investigated. Peaks appear to correspond with large episodic escape events, which are indicated by arrows with the estimated number of escapees noted. Source: Morris et al. (2008).*

Regarding pathogens of major concern in Atlantic Canada, the ISA virus has already caused enormous economic losses to salmon aquaculture and constitutes a threat to wild salmon populations because of the magnification of pathogen abundance within open-sea net cages. Surveillance of farms in the Bay of Fundy, subsequent to the first report of ISA in 1997, has identified 20 genetically distinct ISA virus isolates of differing levels of virulence (Leadbeater and Glebe 2010). Considerable efforts have since been expended to develop effective vaccines and to establish biosecurity plans to control the spread of disease when outbreaks occur. None of the current methods, however, provides a complete barrier to disease transfer between farmed and wild fish (Hammel et al. 2009); the risk of pathogens spreading to wild populations persists.

Many of the general environmental concerns associated with salmon aquaculture apply to the aquaculture of other marine fish raised in open-containment facilities, such as steelhead, Atlantic cod, Atlantic halibut (*Hippoglossoides hippoglossus*), spotted wolfish (*Anarhichas minor*), and Atlantic wolfish (*A. lupus*). An additional concern may manifest itself in regard to the containment of fishes, such as cod, capable of spawning within net cages and releasing viable embryos into the wild (Jørstad et al. 2008). However, the aquaculture of non-salmonid fish in the Atlantic is currently of a sufficiently small scale that the individual impacts of their operations are unlikely to be considerable. This could change with increased demand for seafood and subsequent industry growth. Moreover, as the aquaculture of different species of marine finfish share many of the same properties (e.g., net cages sited in the ocean), many of the concerns will be cumulative, regardless of the species of finfish being reared. It is also possible that warming temperatures associated with climate change will affect aquaculture production by increasing the number of potential sites, the growth rates of farmed species, and the numbers of species amenable to farming, but projections of this nature have not been undertaken.

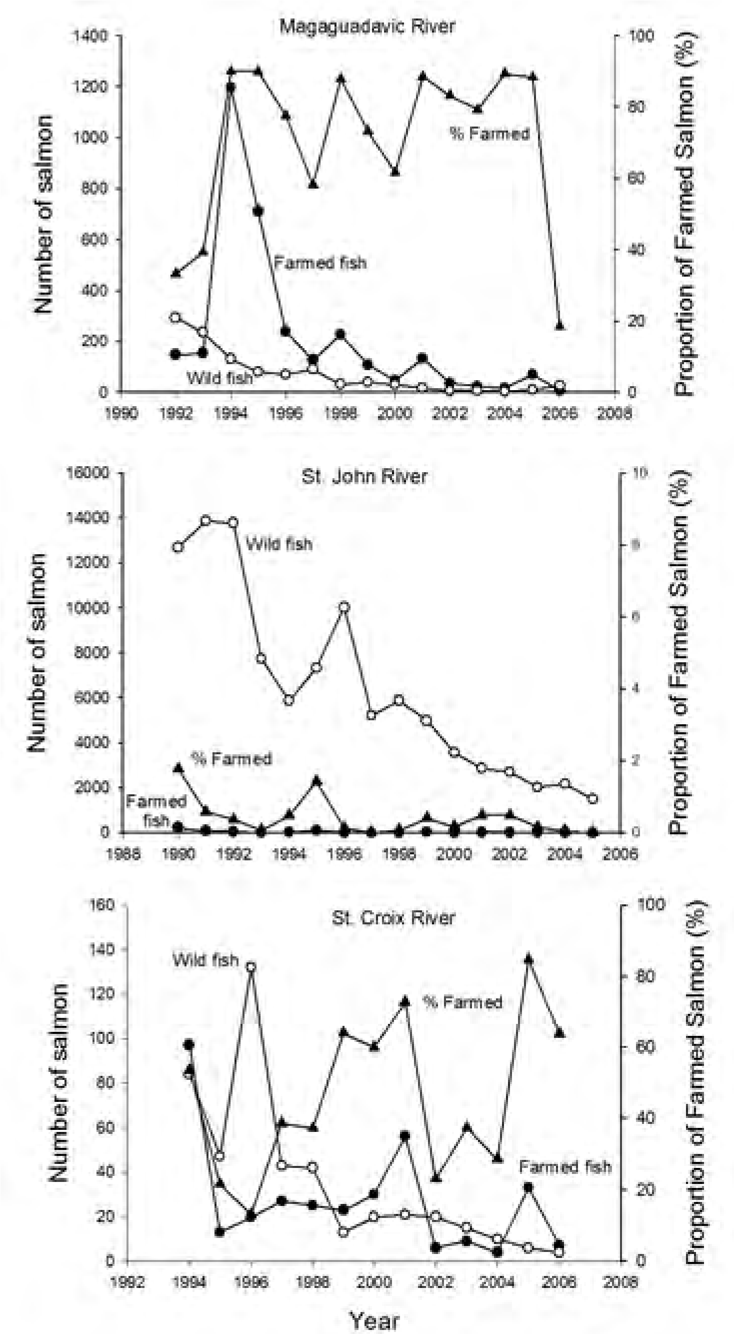


Figure 9.3. *Numbers of farmed and wild Atlantic salmon over time in three river systems in New Brunswick. Proportions of farmed salmon have varied temporally but have remained consistently high in some cases, despite declines in the numbers of farmed escapees present. This largely reflects declines in wild populations. Source: Morris et al. (2008)*

3. Shellfish Aquaculture

a. Pacific

Shellfish culture is the oldest sector of the aquaculture industry on the west coast of North America. Pacific oyster (*Crassostrea gigas*) was first introduced to BC from the Far East in 1912, although most seed was imported from Japan between 1930 and 1939. The species that dominates clam farming in BC (Manila clams, *Venerupis philippinarum*) was inadvertently introduced during importation of Pacific oyster seed. Manila clams were first observed in the natural environment in 1936 and are now distributed through central BC. Japanese scallop

(*Patinopecten yessoensis*) was also introduced and is now the most important cultured species both in production and value. Other species that are commercially produced include the European oyster (*Ostrea edulis*), the littleneck clam (*Protothaca staminea*), the Pacific scallop (a cultured hybrid; Bourne and Bunting 2009), blue mussel, Gallo mussel (*Mytilus galloprovincialis*), and the geoduck clam (*Panope abrupta*). Marine species being considered or under early development for culture include northern abalone, sea cucumber (*Parastichopus californicus*), green sea urchin (*Strongylocentrotus droebachiensis*), and cockles (*Clinocardium nattallii*). For successful commercial operations, hatchery culture and rearing of juveniles has been developed for most of these species. Additional information is available from an informative web site supported by the BC Shellfish Growers Association (www.bcsga.ca; accessed 19-11-11).

The potential environmental consequences of shellfish aquaculture are similar to those associated with finfish. Ecological concerns include: (i) changes to shellfish diversity within tenure areas caused by species removal for farming purposes; (ii) altered use of the tenure area by other species, including fishes (McKindsey et al. 2006, 2011; McKindsey 2010) and birds (Booth 2001); and (iii) cumulative effects, particularly in areas of dense utilization such as Baynes Sound, an area used by at least 12 species of seabirds of global and continental concern (Booth 2001) (although positive associations between the densities of surf scoters (*Melanitta perspicillata*) and white-winged scoters (*M. deglandi*) and farmed mussel densities have been reported; Zydelis et al. 2009). Eighty to 90% of the shoreline of Baynes Sound is under shellfish tenure, and Wan and Bendell-Young (2010) estimate that 56% of what they term ‘viable intertidal habitat’ is under culture.

Genetic-based concerns include those resulting from species interactions (three exotic species noted above) reported for mussels (Shields et al. 2008). The introduced Japanese oyster has also contributed to heightened conservation concern for the endemic Olympia oyster (Gillespie 2009) and its recovery (Trimble et al. 2009). Diseases and parasites, prevalent in any form of intensive animal culture, have been significant during industry development (Bower and McGladdery 2003) but are apparently under control, based on the observation that the BC Shellfish Growers Association does not identify them as a Research and Development priority. One known introduction of a parasite, previously unreported in BC, has been associated with shellfish aquaculture (Marty et al. 2006).

Habitat alterations are extensive within tenures, particularly in the benthos (Bendell-Young 2006; Whiteley and Bendell-Young 2007; but also see Munroe and McKinley 2007) and associated shorelines (Bendell-Young et al. 2010). Use of chemicals is apparently limited, but effects on aquatic primary production can be expected, considering the density of tenures in southern BC. However, these effects will be localized and temporary. Similar issues were previously addressed by Deal (2005) with respect to the development of a sustainable shellfish aquaculture industry in BC. Invasive species have only been noted when attributed to activities related to shellfish aquaculture, yet other species may become problematic for the industry or could affect the natural diversity of BC’s coastal waters. One such example is the purple varnish clam (or savory clam, *Nuttallia obscurata*), which entered the Strait of Georgia via ballast water in the later 1980s and is now widely distributed (Dudas and Dower 2006).

Dating back to the 1930s, and entailing the introduction of its major utilized species, BC's shellfish aquaculture industry has probably had limited effects on marine biodiversity, especially when considered on a coast-wide scale. Some individuals have even suggested that positive benefits accrue to natural ecosystems in the guise of improved water quality and the increased productivity of some native species. Nonetheless, the distribution and growth of the industry suggest that ecological impacts could be substantial in specific areas (Figure 9.4), although potential consequences to biodiversity have not yet been specifically assessed.

Figure 9.4. *Distribution of 458 shellfish tenures in southern British Columbia, identified by geographic clusters (two tenures exist in northern BC). Source: Vancouver Island University, Centre for Shellfish Research website.* *http://www.viu.ca/csr/industry/.*

b. Atlantic

In contrast to the Pacific, shellfish aquaculture in the Atlantic involves predominantly native species (blue mussel; horse mussel, *M. trossulus*; eastern oyster, *Crassostrea virginica*; sea scallop, *Placopecten magellanicus*; softshell clam, *Mya arenaria*; and the hard clam or quahaug *Mercenaria mercenaria*) (Chapter Six). Exceptions to this include small-scale cultivation of bay scallop (*Argopecten irradians*) from the US Atlantic coast, Iceland scallop (*Chlamys islandica*) and European oyster (*Ostrea edulis*) from the Northeast Atlantic, and red abalone (*Haliotis rufescens*) from the US Pacific coast. Thus, the potential exists for the establishment of non-native species in the wild and associated negative ecosystem effects resulting from such invasions (Ruesink et al. 2005; McKindsey et al. 2007; Forrest et al. 2009). The industry itself is threatened in parts of Atlantic Canada by non-cultured invasive species, including the vase tunicate (*Ciona intestinalis*) and green crab (*Carcinus maenas*) from the Northeast Atlantic; oyster drill (*Urosalpinx cinerea*) from the Northwest Atlantic; the Mediterranean golden star tunicate (*Botryllus scholesseri*); and clubbed tunicate (*Styela clava*), violate tunicate (*Botrylloides violaceus*), the alga *Codium fragile tomentosoides*, mitten crab (*Eriocheir sinensis*), and the tunicate (*Didemnum vexillum*) from the Western Pacific.

Many of the other concerns outlined in relation to shellfish culture in Pacific Canada apply to Atlantic Canada, including impacts on benthos, collection of wild spat/seed, transfer of diseases and other organisms associated with movement of shellfish and seed, predator attraction and exclusion, conflict with capture fisheries over access to coastal fishing grounds, chemical inputs, and local changes to primary productivity. An integrated multi-trophic aquaculture (IMTA; www.aquaculture.ca/files/species-multi-trophic.php; accessed 19-11-11) approach that combines finfish, shellfish and algae culture may ameliorate some impacts and reduce the ecological footprint.

4. Seaweed Aquaculture

At present, there are ten species of seaweed that constitute the primary aquaculture species grown in BC (Table 9.2). Each of these species is native to BC waters (Druehl 2000) and no invasive species have been recorded (Williams and Smith 2007). Beyond a simple species listing, there seems to be extremely little documentation on marine plant culture in Canadian Pacific waters.

The main seaweeds cultured in Atlantic Canada are the native Irish moss (*Chondrus crispus*) and knotted wrack (*Ascophyllum nodosom*). Irish moss has been harvested commercially in

Table 9.2. *Main species of seaweed grown in BC's aquaculture industry. Source: www.dfo-mpo.gc.ca/aquaculture/marine-eng.htm; accessed 19-11-11.*

Common Name	Scientific Name
Alaria	*Alaria marginata* – Winged Kelp
Brown Algae	*Costaria costata* – Five Rib Kelp
Green Algae	*Enteromorpha* spp. – Green String Lettuce
Red Algae	*Gelidium* – Gel Weed
Kombu	*Laminaria saccharina* – Tangle
Groenlandica	*Laminaria groenlandica* – Tangle
Giant Kelp	*Macrocystis intergrifolia*
Bull Kelp	*Nereocystis luetkeanna*
Nori	*Porphyra* spp. – Purple Laver
Sea Lettuce	*Ulva lactica*

Atlantic Canada since at least 1948, and is used as an industrial source of carrageenan, which serves as a thickener and stabilizer in milk products and processed foods. Knotted wrack is grown for the extraction of alginate, which is used for the production of gels, as a constituent of fertilizers, and as a gelling or thickening agent. Both species are harvested primarily by drag raking of designated seaweed beds in nearshore and intertidal areas. This technique disrupts near-shore environments and, although the impacts tend to be localized, the harvest does affect nursery areas for juvenile fish and the habitat of other nearshore organisms. As a result, management plans (including quotas, cutting height restrictions, gear restrictions, closed areas) have been implemented to help mitigate these impacts (Ugarte 2007).

5. Main Findings

- Aquaculture of finfish (e.g., salmon) and shellfish (e.g., mussels) typically affect marine biodiversity at localized scales (less than tens of kms), although farther-reaching impacts are possible.
- Wild bottom-dwelling organisms and their habitat can be affected by organic wastes and chemical inputs, such as antibiotics, anti-foulants, and pesticides.

- Exchange of pathogens between farmed and wild fish can seriously threaten the persistence of wild fish populations.
- Interbreeding between wild fish and escapees of the same species threatens the reproductive capability and recovery potential of wild populations of conservation concern.
- Open-sea net pens have far greater potential and realised negative consequences to marine biodiversity than closed-containment facilities.
- The primary biodiversity concern associated with shellfish aquaculture is the farming of non-native species in Canadian waters and the high density of culture in some regions.

Chapter Ten: Canada's International Commitments to Sustain Marine Biodiversity

1. Introduction

'Tangled currents' seems an apt descriptor of Canada's extensive international commitments to sustain marine biodiversity. A diverse array of international agreements and documents set out responsibilities for protection of marine biodiversity (Rayfuse 2007; Barnes 2010; Ong 2010; UN Secretary-General 2011). This chapter helps support the analysis in Chapter Twelve of the extent to which Canada has fulfilled its commitments to sustain marine biodiversity.

The chapter reviews four main categories of international instruments promoting marine biodiversity conservation. 'Mainstreams' are first described, that is, three conventions most central to sustaining marine biodiversity: the UN Convention on the Law of the Sea (1982); the UN Agreement on Straddling and Highly Migratory Fish Stocks (1995); and the Convention on Biological Diversity (1992). 'Sidestreams' are summarized next. Three global agreements with supportive relevance to marine biodiversity are reviewed: the Convention on Wetlands of International Importance (1971); the Convention on World Cultural and Natural Heritage (1972); and the Convention on International Trade in Endangered Species (1973). 'Soft cross-currents', various non-legally binding documents, are then surveyed. Those documents, not subject to the formal ratification process for international treaties and intended to be voluntary in nature, have emanated from various sources including UN Conferences, the Food and Agriculture Organization (FAO), and the UN General Assembly. An overview of 'regional eddies' rounds out the discussion on international commitments. Examples of Canada's commitments to marine biodiversity at the regional level are highlighted, specifically, through the North American Commission for Environmental Cooperation (CEC), the Asia-Pacific Economic Forum (APEC), and the Northwest Atlantic Fisheries Organization (NAFO).

This chapter does not cover the entire gamut of international agreements having some relevance to sustaining marine biodiversity. Since Canada is neither a Party to the International Whaling Convention (1946) nor the Convention on the Conservation of Migratory Species of Wild Animals (1979), those agreements are not discussed. Canada's participation in international agreements relating to marine pollution has been described elsewhere (e.g., VanderZwaag 1995; Mageau et al. 2009; VanderZwaag and Daniel 2009). Two international agreements important for ensuring compliance with, and enforcement of, international fisheries conservation measures are not reviewed, namely, the Agreement to Promote Compliance with International Conservation and Management Measures for Fishing Vessels on the High Seas (1993) and the Agreement on Port State Measures to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing (2009). Canada's poor record in meeting greenhouse gas reduction commitments under the Kyoto Protocol, which indirectly affects marine biodiversity, has been the subject of numerous publications (e.g., Bernstein et al. 2008; CESD 2011) and Canada's need to consider adopting stricter commitments is discussed briefly in Chapter Two. Given a recent publication that comprehensively analyzes the Canadian regional and bilateral arrangements for the conservation and sustainable use of living marine resources (Russell and VanderZwaag 2010), this chapter only includes a selective review of regional eddies to illustrate the challenges in transboundary resource management and regional cooperation. We defer until Chapter Twelve a description of the extent to which Canada has fulfilled or met the numerous obligations identified in these various agreements.

2. Mainstreams (Three Central Conventions)

a. UN Convention on the Law of the Sea

When Canada ratified the 1982 Law of the Sea Convention (LOSC) on 7 November 2003, it assumed a multitude of obligations relating to marine biodiversity. Although a central focus of the Convention is the conservation of commercial fish stocks and generally encouraging international cooperation in conserving transboundary fish stocks and discrete stocks on the high seas (Russell and VanderZwaag 2010), the LOSC does include various 'tangential' biodiversity provisions. Article 192 sets out perhaps the broadest and most powerful obligation, namely, States have a duty to "protect and preserve the marine environment." The LOSC also establishes a fundamental environmental assessment requirement. When proposed activities under the jurisdiction or control of a State may cause substantial pollution or significant and harmful changes to the marine environment, the State must assess the potential effects on the marine environment (Art. 206).

In managing fisheries, States are required to consider harvesting effects on biodiversity. In deciding on conservation and management measures for fisheries in the 200 nautical mile exclusive economic zone (EEZ), a coastal State must consider harvesting effects on associated or dependent species, with a view to maintaining or restoring such species above levels seriously threatening their reproduction (Art. 61(4)). Article 119(1)(b) bestows the same conservation obligation on States when determining allowable catches and conservation measures for living resources in the high seas.

The 1982 Convention contains a general obligation to protect important marine ecosystems. Article 194(5) requires States to take all necessary measures "to protect and preserve rare or fragile ecosystems as well as the habitat of depleted, threatened or endangered species and other forms of marine life." The LOSC also imposes a duty to control the introduction of alien species into the marine environment. Specifically, Article 196 requires States to take all necessary measures to prevent and control "the intentional or accidental introduction of species, alien or new, to a particular part of the marine environment, which may cause significant and harmful changes thereto".

b. UN Agreement on Straddling and Highly Migratory Fish Stocks

By ratifying the UN Agreement on Straddling and Highly Migratory Fish Stocks (UNFA) on 3 August 1999, Canada assumed numerous marine biodiversity related commitments for highly migratory fish species, such as tunas (*Thunnus* spp.), and stocks straddling the EEZ and high seas. Article 5 of the Agreement mandates the following of various general principles, including a specific obligation to "protect biodiversity in the marine environment" (Art. 5(g)). States must apply the precautionary approach (Art. 5(c)), assess the impacts of fishing on the marine ecosystem (Art. 5(d)), adopt conservation measures for species belonging to the same ecosystem as target stocks (Art. 5(e)), and minimize discards and the catch of non-target species, particularly through the use of selective and environmentally safe fishing gears and techniques (Art. 5(f)).

UNFA spells out in considerable detail responsibilities for applying the precautionary approach. Article 6 provides a long list of required measures to implement the same. States must develop research programmes to assess the impact of fishing on non-target species and their environment and must adopt plans to ensure conservation of such species and protection of habitats of special concern (Art. 6(3)(d)). States must determine precautionary reference points (cf. Chapters 5, 12) and restorative actions to be taken if the reference points are exceeded (Art. 6(3)(b)). States are also required to adopt, as soon as possible, cautious conservation and management measures for new or exploratory fisheries (Art. 6(6)).

Annex II of UNFA provides guidance for applying precautionary reference points. Conservation or limit reference points should be established to constrain harvesting within safe biological limits, and maximum sustainable yield should be regarded as the minimum standard for setting limit reference points. Target reference points are also urged to meet management objectives. To prevent a stock from falling below a limit reference point, recovery action should be initiated when abundance drops below some level above the limit reference point (for details, see Box 12.1 in Chapter Twelve). When information for determining fisheries reference points is poor or absent, provisional reference points are called for, along with enhanced monitoring of any fishery allowed in such circumstances.

UNFA also sets out extensive obligations relating to international cooperation in conserving straddling and highly migratory fish stocks. For example, States are urged to cooperate in strengthening existing regional fisheries management organizations and arrangements (Art. 13) and to establish new regional organizations or arrangements where needed (Art. 8(5)).

c. *Convention on Biological Diversity*

i. *Commitments*

When it ratified the Convention on Biological Diversity (CBD) on 4 December 1992, Canada adopted various biodiversity conservation and protection commitments. Key responsibilities assumed under the Convention itself and relevant to marine biodiversity include:

- Developing a national biodiversity conservation strategy or plan (Art. 6(a));
- Establishing a system of protected areas, including marine protected areas (Art. 8(a));
- Managing the risks to biological diversity arising from the use and release of living modified organisms resulting from biotechnology (Art. 8(g));
- Preventing alien species introductions from threatening ecosystems (Art. 8(h));
- Developing or strengthening legislation/regulations for the protection of threatened species (Art. 8(k));
- Requiring national environmental assessment processes to consider impacts of proposed projects on biological diversity (Art. 14(1)(a));

- Introducing strategic environmental assessment arrangements so that proposed programmes and policies are assessed for their potential to significantly impact biological diversity (Art. 14(1)(b)).

The Convention has been supplemented with numerous other 'soft commitments' (Harrop and Pritchard 2011). A complex array of obligations related to marine biodiversity has evolved through numerous decisions taken at Conferences of the Parties (COPs). These commitments can be substantially summarized under three headings: the Strategic Plan for Biodiversity 2011-2020; the programme of work on marine and coastal biodiversity; and issuance of technical guidelines.

ii. Strategic Plan for Biodiversity 2011-2020

Adopted at the 10th COP in Nagoya, Japan, in October 2010 through decision X/2, the Strategic Plan for Biodiversity 2011-2020 sets out 20 targets, called the Aichi Biodiversity Targets, which serve as aspirations for achievement at global, regional, and national levels. Four of the targets specifically refer to marine areas or ocean stressors:

- ***Target 6*** - By 2020, all fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally, and applying ecosystem based approaches, so that overfishing is avoided, recovery plans and measures are in place for all depleted species, fisheries have no significant adverse impacts on threatened species, and vulnerable ecosystems and the impacts of fisheries on stocks, species, and ecosystems are within safe ecological limits.
- ***Target 7*** - By 2020, areas under agriculture, aquaculture, and forestry are managed sustainably, ensuring conservation of biodiversity.
- ***Target 10*** - By 2015, the multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification, are minimized, so as to maintain their integrity and functioning.
- ***Target 11*** - By 2020, at least 17 per cent of terrestrial and inland water areas, and ten per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative, and well-connected systems of protected areas and other effective area-based conservation measures, and are integrated into the wider landscapes and seascapes.

Other targets are more general but still carry implications for sustaining marine biodiversity. For example, Target 3 urges the elimination or phasing out of incentives, including subsidies, harmful to biodiversity by 2020. Also, by 2020, Target 8 calls for reducing levels of pollution, including that from excess nutrients, to levels not detrimental to ecosystem function and biodiversity, while Target 12 encourages the prevention of extinction of human-threatened species and the improvement of their conservation status.

The Strategic Plan leaves Parties considerable flexibility in translating the Aichi targets at national and regional levels. Parties are urged to develop national and regional targets, using the Aichi Targets "as a flexible framework, in accordance with national priorities and capacities…" (Decision X/2, para. 3(b)). Parties are encouraged to review and, as appropriate, to update and revise their national biodiversity strategies and action plans in accordance with the Strategic Plan. Regional organizations are urged to consider the development or updating of regional biodiversity strategies, with regional targets contributing to the implementation of the Strategic Plan.

iii. Programme of Work on Marine and Coastal Biodiversity

With marine and coastal biodiversity becoming a CBD priority in 1995, as a result of the Jakarta Mandate on Marine and Coastal Diversity (Decision II/10), a programme of work on marine and coastal diversity was subsequently developed with major refinement occurring in 2004. Decision VII/5, which was taken at the 7th COP in 2004, extended the time period by an additional six years and provided an elaborated programme of work with Parties urged to undertake activities under five themes. For example, under theme 1 (implementation of integrated marine and coastal area management, or IMCAM), Parties were urged to promote the application of ecosystem-based management and to develop/implement strategies to overcome obstacles to IMCAM. Under theme 2 (marine and coastal living resources), Parties were encouraged to eliminate destructive fishing practices and restore fisheries stocks to sustainable levels by 2015. Pursuant to theme 3 (marine and coastal protected areas), the establishment by 2012 of integrated networks of marine and coastal protected areas was suggested at both national and regional levels. For mariculture, the 4th theme, Parties were urged to develop effective site selection methods in the framework of integrated marine and coastal area management and to use native species in mariculture. For invasive alien species, the 5th theme, Parties were encouraged to adopt measures to address invasive alien species in ballast water, including through the International Convention for the Control and Management of Ships' Ballast Water and Sediments, and to exchange information on effective prevention and control techniques.

Through Decision X/29 on marine and coastal biodiversity taken at the 10th COP in October 2010, Parties reaffirmed the programme of work, but the Decision suggested enhancements on many fronts. The need to highlight the role and potential of marine and coastal habitats, such as salt marshes, mangroves, and seagrasses, in mitigating and adapting to climate change was stressed. The need to address the potential adverse impacts of ocean acidification on marine and coastal biodiversity was emphasized. Targets of the programme of work were aligned with the Strategic Plan for Biodiversity 2011-2020 and the Aichi Biodiversity Targets. Parties were invited to increase efforts to apply marine spatial planning tools.

iv. Issuance of CBD Guidelines

CBD Parties have forged five key sets of guidelines especially important for sustaining marine biodiversity. The Addis Ababa Principles and Guidelines for the Sustainable Use of Biodiversity, adopted in 2004, through Decision VII/12, offer 14 practical principles along with operational guidelines for each principle. The need for governance frameworks to empower and support rights of local users to biodiversity components is highlighted (principle 2), as is the need to ensure equitable distribution of benefits to indigenous and local communities (principle 12). The avoidance or minimization of adverse impacts on ecosystem services is also advocated in the context of sustainable use of biodiversity resources (principle 5).

A second set of guidelines, also adopted in 2004 through Decision VII/16F (annex), is the Akwé:Kon Guidelines for the Conduct of Cultural, Environmental and Social Impact Assessment regarding Developments Proposed to Take Place on, or which are Likely to Impact on, Sacred Sites and on Lands and Waters Traditionally Occupied or Used by Indigenous and Local Communities (CBD Conference of the Parties 2004c). The Guidelines provide guidance to Parties on the incorporation of cultural, environmental, and social considerations of indigenous and local communities into impact assessment procedures. The taking into account of value systems of indigenous and local communities, and possible impacts of proposed developments on traditional systems of tenure and resource uses, is advocated (para. 47) and Parties are encouraged to provide appropriate legislative authority (para. 67).

A third set of guidelines to assist implementation of the ecosystem approach was embraced by CBD Parties in 2004 through Decision VII/11. The guidelines offer guidance on how to implement the 12 principles of the ecosystem approach adopted in Decision V/6 of the Conference of the Parties. Key principles include decentralizing management to the lowest appropriate level (principle 2), maintaining ecosystem services as a priority target of the ecosystem approach (principle 5), managing ecosystems within the limits of their functioning (principle 6), seeking an appropriate balance between conservation and use of biological diversity (principle 10), and considering all forms of relevant information, including scientific and indigenous and local knowledge (principle 11). Implementation guideline 6.2 urges application of the precautionary approach, given the uncertainty associated with defining the limits of ecosystem functioning under most circumstances.

Two other closely associated guidelines seek to strengthen the incorporation of biodiversity considerations into impact assessment procedures. The Voluntary Guidelines on Biodiversity-inclusive Environmental Impact Assessment, endorsed through Decision VIII/28 (2006), urge Parties to provide clear criteria for taking biodiversity into account in decision making and to apply the precautionary approach in cases of scientific uncertainty when there is a chance of significant harm to biodiversity. Draft Guidance on Biodiversity-inclusive Strategic Environmental Assessment, also endorsed through Decision VIII/28, encourages the application of strategic environmental assessment (SEA) procedures to proposed policies, plans, and programmes which may affect one or more important ecosystem services and highlights the need to fully involve all stakeholders in the SEA process.

3. Sidestreams

a. Convention on Wetlands of International Importance

The Convention on Wetlands of International Importance, often referred to as the Ramsar Convention because of the location in Iran where it was concluded in 1971, sets out five main commitments for Canada, which became a Contracting Party on 15 May 1981. First, the Convention requires Parties to designate suitable wetlands within their territories for inclusion in a List of Wetlands of International Importance (Art. 2(1)). At least one wetland must be included in the List at the time of signing or ratifying the Convention (Art. 2(4)). Listed wetlands may also incorporate adjacent coastal zones and islands or bodies of marine water lying within the wetlands (Art. 2(11)). Wetlands should be chosen for the List on account of their international

significance in terms of ecology, botany, zoology, limnology, or hydrology (Art. 2(2)).
A second commitment is a reporting obligation if the ecological character of a listed wetland changes because of human activities. If the ecological character of any listed wetland has changed, or is likely to change as a result of technological developments, pollution, or other human interference, a Contracting Party is required to report such changes to the IUCN, the organization responsible for bureau duties under the Convention (Art. 3(2)).

A third responsibility is to promote the conservation and wise use of wetlands through implementation of a planning approach. Article 3 provides: "The Contracting Parties should formulate and implement their planning so as to promote the conservation of wetlands included on the List, and as far as possible the wise use of wetlands in their territory."

Establishing nature reserves on wetlands is a fourth commitment. Article 4(1) requires each Party to promote the conservation of wetlands by establishing nature reserves on wetlands, whether they are included on the List or not. Adequate overseeing of nature reserves is also required.

A fifth commitment relates to international cooperation. Parties are required to consult with each other about implementing Convention obligations in instances where a wetland is transboundary in nature or where a water system is shared (Art. 5).

Over the years, at Conferences of the Parties, criteria for identifying wetlands of international importance were developed with eight criteria based upon the importance for conserving biological diversity (Ramsar Convention Secretariat 2009). For example, a wetland should be considered internationally important if it: supports vulnerable or endangered species or threatened ecological communities (criterion 2); regularly supports 20,000 or more waterbirds (criterion 5); or is an important source of food for fishing, or is an important spawning ground, nursery, and/or migration path on which fish stocks depend (criterion 7).

Ramsar strategic plans have sought to further flesh out priorities for action in implementing the Convention. For example, the Ramsar Strategic Plan 2003-2008 called on Parties to give priority to designating coastal and marine Ramsar sites as a contribution to the World Summit on Sustainable Development's target of establishing representative networks of marine protected areas by 2012 (para. 10.1.3). The Ramsar Strategic Plan 2009-2015 urges Parties by 2015 to initiate, or complete, national policies or guidelines enhancing the role of wetlands in mitigation and/or adaptation of climate change (para. 1.7.iii). Parties are encouraged to put in place, by 2015, national invasive species control and management policies/guidelines for wetlands (para. 1.9iii).

Parties to the Convention have especially emphasized the need to implement integrated coastal zone management (ICZM) at local, regional, and national levels to ensure the conservation and wise use of coastal wetlands, by adopting a set of principles and guidelines for incorporating wetland issues into ICZM (Annex to Resolution VIII.4; 8th COP meeting in Valencia, Spain).

b. Convention Concerning the Protection of the World Cultural and Natural Heritage

The World Heritage Convention, with Canada becoming a Party on 23 July 1976, contains minimal commitments. The Convention requires each Party to identify and delineate cultural and natural sites of outstanding universal value (Art. 3). Parties are required to take appropriate legal, scientific, administrative, and financial measures necessary for the protection and conservation of identified cultural and natural heritage areas (Art. 5(d)). Each Party must submit to the World Heritage Committee an inventory of cultural and natural heritage properties suitable for inclusion in the World Heritage List, however, inclusion of a property on the List requires the consent of the State concerned (Art. 11(3)).

The World Heritage Committee developed ten criteria for determining whether a property has outstanding universal value; only one criterion needs to be met for a property to be nominated for listing (UNESCO 2008). For example, a property would be considered to have outstanding universal value if it represents "an outstanding example of a traditional settlement, land use, or sea use which is representative of a culture (or cultures) or human interaction with the environment especially when it has become vulnerable under the impact of irreversible change" (criterion v). Containing "superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance" is an additional criterion (criterion vii), as is containing "the most important significant natural habitats for in-site conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation" (criterion x).

c. Convention on International Trade in Endangered Species (CITES)

CITES does not constitute a biodiversity-focused treaty. The Convention, to which Canada became a Party on 9 July 1975, does not contain an overall habitat conservation objective but has a rather narrow focus on trying to save listed endangered and threatened species from extinction by imposing strict international trade controls on any proposed shipments of listed flora and fauna or their parts. For species listed in the CITES Appendix I (those threatened with extinction), trade for primarily commercial purposes is not allowed and both export and import permit requirements apply. In the permitting process, both the Scientific Authority of the States of export and import must advise that the trade will not be detrimental to the survival of the species involved (Art. III).

For species listed in Appendix II (those not necessarily now threatened with extinction, but that may become so unless trade is subject to strict regulation), international trade may have a commercial purpose but is subject to an export permit. An export permit may only be granted if: the Scientific Authority of the State of export has advised that the export will not be detrimental to the survival of the species; a Management Authority of the State of export is satisfied the specimen was not obtained in contravention of the laws of that State for the protection of fauna and flora; and the Management Authority of the State of export is satisfied that any living specimen will be properly shipped to minimize the risk of injury or damage to health (Art. IV).

Appendix III species include those which any Party identifies as being within its jurisdiction and needing cooperation of other Parties to control trade. Any international trade of Appendix III

listed species would require an export permit which can only be granted if the Management Authority of the State of export is satisfied the specimen was legally obtained and the Authority is satisfied that any shipment of a living specimen will minimize the risk of injury or damage to health (Art. V).
Many marine species occurring within Canadian waters are listed under CITES. For example, numerous whale species are listed in Appendix I, including bowhead whale, North Atlantic right whale (*Eubalaena glacialis*), sei whale (*Balaenoptera borealis*), blue whale (*B. musculus*), and humpback whale (*Megaptera novaeangliae*). Examples of important northern species listed under Appendix II include the polar bear, beluga whale (*Delphinapterus leucas*), and narwhal (*Monodon monoceros*). Canada has chosen to list the walrus under Appendix III.

Listing of marine species with commercial interest has become exceedingly politicized and difficult. Some countries have taken the position that such species are more appropriately managed through existing regional fisheries management organizations or arrangements. At the 15th Conference of the Parties to CITES in Doha, Qatar, various proposals to list marine species were rejected, including a proposal by Monaco to list Atlantic bluefin tuna (*Thunnus thynnus*) in Appendix I. Rejected proposals for listing under Appendix II included: scalloped hammerhead shark (*Sphyrna lewini*) (along with look-alike species, great hammerhead, *S. mokarran*, and smooth hammerhead, *S. zygaena*); porbeagle shark; oceanic whitetip shark (*Carcharhinus longimanus*); spiny dogfish; and corals in the family Coralliidae (Blue Sky 2010; Clayton 2010).

4. Soft Cross-Currents

a. UN Conference Documents

Three main documents of special relevance to marine biodiversity have emerged over the past two decades from UN Conferences. Agenda 21 and the Rio Declaration on the Environment and Development were products of the 1992 Earth Summit held in Rio de Janeiro, Brazil (Johnson 1992), whereas the World Summit on Sustainable Development (WSSD) held in 2002 resulted in the Johannesburg Plan of Implementation, which set various ocean development and management goals.

i. Agenda 21

While Agenda 21 contains 40 chapters charting future directions for the global community in the quest for sustainable development, Agenda 21 has a specific chapter 17 addressing protection of the oceans and coastal areas where numerous national commitments relevant to marine biodiversity protection are set out under seven programme themes. Under the first programme area (integrated management and sustainable development of coastal and marine areas), coastal States are urged to establish or strengthen integrated coastal and marine management mechanisms at both the local and national levels. Under the second programme theme (marine environmental protection), States are encouraged to apply a precautionary and anticipatory rather than a reactive approach to prevent the degradation of the marine environment from multiple sources, including land-based and sea-based activities. Under the third programme theme (sustainable use and conservation of marine living resources of the high seas), a long list of sustainability objectives is spelled out for States, including the need to: promote the development and use of selective fishing gear and practices; protect and restore endangered marine species; and preserve habitats and other ecologically sensitive areas.

Programme area four (sustainable use and conservation of marine living resources under national jurisdiction) advocates numerous management-related activities. States are urged to: strengthen legal and regulatory frameworks for managing marine living resources; promote the use of environmentally sound technology and the environmental assessment of major new fishery practices; and recognize the rights of small-scale fish-workers, indigenous people, and local communities. Priority for designation of protected areas is to be given to such areas as coral reefs, estuaries, sea grass beds, and spawning/nursery areas.

The final three programme areas have a more tangential relationship to marine biodiversity protection. Programme area five, which addresses critical uncertainties for the management of the marine environment and climate change, is largely devoted to encouraging increased scientific cooperation at the regional and global levels in studying the coastal and marine impacts of climate change. Programme area six calls for strengthening international and regional cooperation and coordination in addressing marine and coastal issues. Programme area seven urges capacity-building from the international community to promote the sustainable development of small islands.

ii. Rio Declaration of Environment and Development

While the Rio Declaration sets out 27 principles important for achieving sustainable development for the world's lands and seas (Van Dyke 1996), three principles are particularly critical for national implementation in the coastal/ocean governance context. Principle 15 urges application of the precautionary approach:

> In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.

Principle 10 calls for strengthening public participation in decision-making processes:

> Environmental issues are best handled with participation of all concerned citizens, at the relevant level. At the national level, each individual shall have appropriate access to information concerning the environment that is held by public authorities including information on hazardous materials and activities in their communities, and the opportunity to participate in decision-making processes. States shall facilitate and encourage public awareness and participation by making information widely available. Effective access to judicial and administrative proceedings, including redress and remedy, shall be provided.

Principle 22 charts a course towards enhancing community-based management by both local communities and indigenous people:

> Indigenous people and their communities and other local communities have a vital role in environmental management and development because of their knowledge and traditional practices. States should recognize and duly support their identity, culture and interests and enable their effective participation in the achievement of sustainable development.

iii. WSSD Plan of Implementation

The WSSD (World Summit on Sustainable Development) Plan of Implementation, besides further urging the implementation of chapter 17 of Agenda 21, establishes various general commitments in relation to sustainable ocean development and management. For example, the Plan encourages the application by 2010 of the ecosystem approach and the promotion of integrated coastal and ocean management at the national level (para. 32). The Plan also calls for the establishment of representative networks of marine protected areas, or MPAs, by 2012 (para. 32).

To achieve sustainable fisheries, various actions are suggested. They include: restoring depleted stocks to the maximum sustainable yield level not later than 2015; eliminating subsidies contributing to illegal, unreported and unregulated (IUU) fishing and to over-capacity; and supporting the sustainable development of aquaculture, including small-scale aquaculture (para. 31).

b. FAO Documents

i. FAO Code of Conduct

The FAO Code of Conduct for Responsible Fisheries, as adopted by the FAO Conference in 1995, is voluntary, but establishes principles and standards for the conservation, management, and development of all fisheries, many of which are relevant to the conservation of biodiversity. One of the main objectives of the Code of Conduct is to promote protection of living aquatic resources and their environments (Article 2(g)).

The general principles of the Code (Article 6) emphasize the need to minimize the impacts of fisheries on biodiversity and to protect critical habitats. States and users of living aquatic resources are urged to conserve aquatic ecosystems and are reminded that the right to fish carries with it the obligation to do so in a responsible manner, so as to ensure effective conservation and management of the living aquatic resources (Art. 6.1). Management measures should not only ensure the conservation of target species, but also of species belonging to the same ecosystem as, or associated with or dependent upon, the target species (Art. 6.2). Selective and environmentally safe fishing gear and practices should be further developed and applied, to the extent practicable, in order to maintain biodiversity and to conserve the population structure and aquatic ecosystems and protect fish quality (Art. 6.6). All critical fisheries habitats in marine and freshwater ecosystems, such as wetlands, mangroves, reefs, lagoons, and nursery and spawning areas should be protected and rehabilitated, as far as possible, and where necessary (Art. 6.8).

Article 7 of the Code urges management measures and a precautionary approach to support the protection of marine biodiversity. States and regional fisheries management organizations/arrangements (RFMO/As) are urged to ensure that fisheries management measures conserve the biodiversity of aquatic habitats and protect endangered species (Art. 7.2.2(d)). Key measures advocated are: allowing recovery of depleted stocks (Art. 7.2.2(e)); assessing the adverse environmental impacts on marine resources from human activities (Art. 7.2.2(f)); and minimizing waste discards, catch by lost or abandoned gear, and catch of non-target species (Art.

7.2.2(g)). Article 7.5 urges wide application of the precautionary approach. States and RFMO/As should determine stock-specific limit reference points and define the action to be taken if they are exceeded.

ii. International Plans of Action

The Code contributed to the subsequent development of four International Plans of Action to manage fishing impacts on biodiversity. The International Plans of Action (IPOAs) are also voluntary, with plans for sharks, seabirds, and fishing capacity introduced in 1999, and IUU fishing in 2001. The IPOAs are seen as elaborations of the Code of Conduct for Responsible Fisheries.

The International Plan of Action for Conservation and Management of Sharks (FAO 1999) recommends that States develop national plans for conservation and management of shark stocks, if their vessels conduct directed fisheries for sharks or catch sharks in non-directed fisheries. States are urged to ensure that shark catches are sustainable, to minimize unutilized incidental catches of sharks, to contribute to the protection of biodiversity and ecosystem structure and function, and to collect species-specific catch and landings data.

The International Plan of Action for Reducing Incidental Catch of Seabirds in Longline Fisheries (FAO 1999) urges development of national plans of action if an incidental catch problem exists and suggests approaches for reducing the incidental catch of seabirds in longline fisheries, in the EEZ of States where incidental catch occurs, and in other waters where the State has fishing interests. Mitigation approaches include: increasing the sink rate of baits, setting baited hooks underwater, using bird-scaring lines over areas where hooks are baited, resorting to artificial baits or modifying hooks, and relying on acoustic deterrents.

The International Plan of Action for the Management of Fishing Capacity (FAO 1999) requests that States take measures to prevent or eliminate excess fishing capacity and to ensure that levels of fishing effort are consistent with those required to achieve the sustainable use of fishery resources. Recommended actions to achieve this include assessments of capacity and improvement of the capability for monitoring fishing capacity, along with the development and implementation of national plans to manage capacity.

The International Plan of Action to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing (FAO 2001) recommends and identifies measures to prevent, deter, and eliminate IUU fishing. These include flag State responsibilities, coastal State measures, port State measures, and internationally agreed market-related measures.

iii. FAO Technical Guidelines

In further support of implementation of the Code of Conduct for Responsible Fisheries, FAO has developed over 20 technical guidelines, including the 2008 International Guidelines for the Management of Deep-sea Fisheries in the High Seas (FAO 2009), and the 2010 International Guidelines on Bycatch Management and Reduction of Discards (FAO 2011). Technical guidelines on implementing the precautionary and ecosystem approaches are especially central to managing fishing impacts on marine biodiversity.

The FAO Technical Guidelines on the Precautionary Approach to Capture Fisheries and Species Introductions (FAO 1996) introduces the precautionary approach and makes recommendations for implementation. These include: taking into account the best available scientific evidence when designing and adopting management and conservation measures; requiring information on status and impacts for any fishery to start or continue; ensuring that the lack of full scientific certainty shall be not used as a reason for postponing cost-effective measures to prevent fish-stock or environmental degradation; developing scientific information on multispecies and ecosystem processes as a foundation for identifying acceptable degrees of disturbance; identifying biological limit and target reference points for species, stocks, habitats, and ecosystems; and improving methods for quantification of direct and indirect impacts of fishing.

Technical Guidelines on the Ecosystems Approach to Fisheries (FAO 2003) emphasize the major changes accompanying an ecosystem approach to fisheries (EAF) and highlight key supportive principles that should be followed. While traditional fisheries management focused on maintaining sustainable yields from targeted species, the overall objective of EAF is to sustain the use of broader marine biodiversity (section 1.1). Annex 2 sets out various key principles including, among others: applying the precautionary approach; promoting sectoral integration; broadening stakeholder participation and decentralizing decision-making; and maintaining ecosystem integrity.

A key recommended avenue for putting the ecosystem approach into practice is through the development of EAF management plans (section 2.2). Such plans should: set environmental, social, and economic objectives for the fishery; consider potential ecosystem impacts, including on critical habitats, prey species, and endangered populations; address the extent fishery efforts would comply with international and national commitments to nature conservation; propose possible management measures to reduce adverse environmental impacts; and establish ways to evaluate management success, such as environmental indicators and reference points. Chapter Three of this EAF document encourages a broad range of possible management measures to protect ecosystem health and integrity from fisheries, including: gear modifications to improve selectivity; ‘sweeping’ campaigns to recover lost nets; spatial and temporal closures; prohibiting destructive fishing methods in ecologically sensitive habitats, such as coral reefs and seagrass areas; reducing fishing capacity; and establishing catch controls (such as quotas) for species vulnerable to by-catch.

The Guidelines also note the need to incorporate provisions of international instruments relevant to EAF into domestic law and practice (section 4.2.2). Annex I provides a review of the key international instruments many of which are discussed in this chapter, including the LOSC, CBD, and FAO Code of Conduct for Responsible Fisheries.

c. UN General Assembly Resolutions

Since 1993, the United Nations General Assembly has adopted an annual resolution on Oceans and the Law of the Sea, addressing *inter alia* the protection and sustainable use of marine environment, marine resources, and marine biodiversity. Additionally, a second UNGA resolution adopted every year addresses aspects of Sustainable Fisheries through the UN Fish Stocks Agreement, and related instruments.

These resolutions generally endorse and emphasize the commitments and obligations towards conservation and sustainable use of marine biodiversity and sustainable fisheries arising from other international instruments and global or regional fora, notably the Johannesburg Plan of Implementation. For example, both Resolutions (UNGA Resolutions 65/37A and 65/38, adopted by the UN General Assembly on 7 December 2010) call upon States to apply the ecosystem approach by 2010 and intensify efforts to assess and address impacts of climate change on sustainability of fish stocks and their habitats.

The Law of the Sea Resolution (UNGA Resolution 65/37A) further urges States to:

- establish a network of representative marine protected areas by 2012;
- increase reliance on scientific advice; and
- implement environmental impact assessment processes for planned activities under their jurisdiction or control that may cause significant and harmful changes to the marine environment.

The Resolution on Sustainable Fisheries (UNGA Resolution 65/38), in turn, requires States to:

- restore depleted stocks to levels that can produce maximum sustainable yield on an urgent basis and, where possible, not later than 2015;
- apply widely the precautionary approach and ecosystem approaches to the conservation, management and exploitation of fish stocks and conservation of their ecosystems;
- urgently adopt measures to fully implement the International Plan of Action for the Conservation and Management of Sharks, and to improve implementation of and compliance with existing measures that regulate shark fisheries and incidental catch fisheries, in particular prohibitions or restrictions to fisheries conducted solely for purpose of harvesting shark fins, and consider taking other measures such as requiring that all sharks be landed with each fin naturally attached; and
- take action to reduce or eliminate by-catch, catch by lost or abandoned gear, fish discards and post-harvest losses, and the incidence of catch of non-target species, and particularly the reduction of sea turtle mortality in fishing operations as well as the reduction of incidental catch of seabirds.

The Resolutions on Sustainable Fisheries have gone beyond this role by establishing new and specific non-binding commitments towards conservation and protection of marine biodiversity. An early example thereof was the global moratorium on the use of large-scale pelagic drift-net fishing in the high seas introduced in 1991 by UNGA Resolution 46/215. This moratorium was reaffirmed in subsequent resolutions and strengthened in the last Resolution 65/38. Recently, the annual resolutions have included specific and time-bound commitments for the sustainable management of deep-sea fisheries and the protection of vulnerable marine ecosystems (VMEs), including seamounts, hydrothermal vents, and cold-water corals, in the high seas. Resolution 61/105 requires RFMOs with competence to regulate bottom-fishing, States participating in the negotiation to establish such RFMO/As, and flag States to: adopt measures to identify vulnerable marine ecosystems; conduct assessments on the impacts of bottom fishing activities on VMEs; ensure that fishing activities having significant adverse impacts are managed to prevent such impacts (or they are not authorized to proceed); and to cease fishing where an encounter with VMEs occurs during fishing activities.

Considering progress towards implementation of these measures as insufficient, in 2009 the General Assembly further strengthened these obligations through paragraphs 119-130 of UNGA Resolution 64/72. These provisions require States to ensure that their vessels do not engage in bottom fishing until an assessment of the impacts of these activities on VMEs has been conducted consistent with the 2008 FAO International Guidelines for the Management of Deep-sea Fisheries in the High Seas.

In September 2007, the UN Declaration on the Rights of Indigenous Peoples was adopted through UN General Assembly Resolution 61/295 and the Declaration also has relevance to the protection of marine biodiversity. Art. 25 recognizes the right of indigenous peoples "to maintain and strengthen their distinctive spiritual relationship with their traditionally owned or otherwise occupied or used lands, territories, waters, and coastal seas and other resources and to uphold their responsibilities to future generations in this regard". Art. 29 recognizes the right of indigenous peoples "to the conservation and protection of the environment and the productive capacity of their lands or territories and resources". While Canada was initially one of only four States to oppose the Declaration, Canada subsequently endorsed it in November 2010 (Indian and Northern Affairs Canada 2010).

5. Regional Eddies

Canada has also made commitments to enhance marine biodiversity conservation in a transboundary context through a mix of bilateral and regional agreements and arrangements (Russell and VanderZwaag 2010) (Table 10.1). For example, under the auspices of the North American Commission for Environmental Cooperation (CEC), Canada joined Mexico and the United States in adopting a Strategic Plan for North American Cooperation in the Conservation of Biodiversity (CEC 2003). The Plan committed Parties to developing a North American Marine Protected Area Network (NAMPAN) and to cooperating in identifying and protecting marine species of common conservation concern. Four North American Conservation Action Plans (NACAPs) for marine species have been adopted to date for the humpback whale (CEC 2005a), Pacific leatherback turtle (*Dermochelys coriacea*) (CEC 2005b), pink-footed shearwater (*Puffinus creatopus*) (CEC 2005c), and vaquita porpoise (*Phocoena sinus*) (CEC 2008).

Through oceans-related ministerial meetings under the Asia Pacific Economic Cooperation (APEC) forum, Canada has endorsed various commitments relating to marine biodiversity. They include moving ecosystem-based management forward through the identification of ecologically and biologically significant areas and applying area-based management measures (APEC 2005; Bali Plan of Action 2005), and by promoting domestic marine spatial planning and the connectivity of MPA networks (APEC 2010; Paracas Action Agenda 2010).

An example of Canadian commitments towards sustaining marine biodiversity within a regional fisheries management organization may be seen in reforms to, and measures of, the Northwest Atlantic Fisheries Organization (NAFO). In 2005, the Organization started a reform process to bring the NAFO Convention in line with recent international instruments, including UNFA and the FAO Code of Conduct for Responsible Fisheries, and with modern principles for fisheries management. The new text, ratified to date by Norway, Canada, and the European Union, expressly incorporates an ecosystem approach to fisheries management (Russell 2010). It also explicitly considers the precautionary approach and the preservation of marine biological diversity among the general principles to be applied by the Contracting Parties in giving effect to the objective of the Convention (Amended Convention, Art. III). Although the amendment is not yet in force, the Contracting Parties adopted Resolution 01/08 through which they declare their willingness to implement these general principles immediately (NAFO 2008a).

In the wake of UNGA Sustainable Fisheries resolutions, NAFO has adopted various measures for the protection of marine biodiversity. A key area has been the protection of vulnerable marine ecosystems in the Regulatory Area beyond national jurisdiction. In 2007, it adopted the closure of four seamounts to all bottom fishing, and an additional two seamounts were closed in 2008. The closures, originally established until 2010, were prolonged for another four years. NAFO further established a coral protection zone in Division 3O (southwestern Grand Banks) and eleven closure zones for the protection of corals and sponges in the NAFO Regulatory Area, measures that are in force at least until 2014 (DFO 2011; NAFO 2011a). Contracting Parties are obliged to establish a coral and sponge monitoring programme into their governmental or industry research programmes (NAFO 2011b: Art. 16).

NAFO has also adopted an assessment framework for proposed bottom fishing activities. This framework includes provisions for identification of existing bottom fishing areas, (the 'footprint'); the assessment of the impacts of bottom fishing activities on known or likely vulnerable marine ecosystems; and the assessment of exploratory bottom fishing activities (fishing outside of the existing bottom fishing area or, if there are significant changes to the conduct or technology of existing bottom fishing activities, within the footprint) prior to their commencement (NAFO 2011b,: Arts. 3bis and 4bis). The assessment of the impacts of existing NAFO bottom fishing on known or likely vulnerable marine ecosystems was first required by 2008 (NAFO 2008b, art.4). However, no assessments were published, although several Contracting Parties reportedly submitted fishing plans (NAFO 2009, 205). As of the time of writing, no assessments for exploratory bottom fishing activities had been submitted. At its 2011 meeting, the Fisheries Commission agreed to conduct a re-assessment of the impact of NAFO bottom fishing by 2016 and every five years thereafter (NAFO 2011a, 62).

NAFO has also adopted an interim encounter provision. Fishing vessels encountering VME indicator species of live coral or sponge are required to report the encounter to the relevant flag State, cease fishing, and move at least 2 nautical miles from the endpoint of the tow/set in the direction least likely to result in further encounters (NAFO 2011b: Art. 5bis). The threshold of encounter (i.e., the amount of coral or sponges caught in a trawl that triggers a vessel to move away from an area) was set at 60 kg of live corals and 800 kg of sponges. In 2011, the sponge encounter threshold was lowered to 600 kg, and 400 kg in new fishing areas (NAFO 2011a, 61 art 6bis para.3; DFO 2011), a level still considered too high by some environmental organizations (DSCC 2011a; DSCC 2011b). As of April 2011, no reports of encounters had been made to the NAFO Secretariat (DSCC 2011b).

NAFO has further adopted measures for the conservation of sharks, specifically requiring the full utilization of the entire catch and the prohibition to retain onboard shark fins that total more than 5% of the weight of sharks onboard (NAFO 2011a: Art. 17). It has also adopted a non-binding resolution requiring Contracting Parties, individually and collectively, to implement the FAO Guidelines to Reduce Sea Turtle Mortality in Fishing Operations (NAFO 2006). Additionally, during their meeting in 2010, the Fisheries Commission agreed to keep on the Commissions' agenda, among other ecosystem considerations, the interactions of marine mammals and fish and the promotion of scientific research on climate change and its potential effects on NAFO fishery resources.

6. Main Findings

- Canada has made numerous commitments through international agreements to sustain marine biodiversity (Table 10.1)
- International commitments tend to be quite general in nature; precise governance implications of key principles, such as precaution and the ecosystem approach, are open to interpretation, leaving considerable room for discretion in implementation.
- While a core group of multilateral conventions has been forged to protect marine biodiversity, a plethora of soft law documents has emerged to provide more specific guidance to decision-makers and to progressively develop international law and policy.

Various marine biodiversity-related targets urge implementation at the national and, in some cases, the regional level. Key targets (fully described in this chapter) can be summarised as follows:

- By 2010, implement the ecosystem-based management approach.
- By 2012, establish representative networks of marine protected areas.
- By 2015, restore depleted fish stocks to levels that can produce maximum sustainable yield.
- By 2015, minimize human pressures on coral reefs and other vulnerable marine ecosystems affected by climate change or ocean acidification to maintain their integrity and functions.
- By 2020, harvest all species sustainably within an ecosystem-based management framework, to avoid overfishing, and develop recovery plans for depleted species.
- By 2020, conserve 10% of coastal and marine areas by establishing effectively and equitably managed, ecologically representative, and well-connected systems of protected areas.

Table 10.1. *A summary of selected Canada's international commitments to sustain marine biodiversity.*

Biodiversity Commitments	International Conventions and Decisions of International Organizations	Other International Instruments (non-binding)
General obligations		
Protect and preserve the marine environment	LOSC (1982)	UNGA Resolutions (various years)
Protect biodiversity in the marine environment	UNFA (1995)	UNGA Resolutions (annually since 1993); FAO Code of Conduct for Responsible Fisheries (1995)
Develop a national biodiversity conservation strategy or plan	CBD (1992)	
Precautionary approach		
Apply the precautionary approach	UNFA (1995); NAFO amended Convention (2007).	Agenda 21 (1992); Rio Declaration on Environment and Development (1992); FAO Code of Conduct for Responsible Fisheries (1995); UNGA Resolutions (various years)
Determine precautionary fisheries reference points and take restorative actions if reference points are exceeded	UNFA (1995)	FAO Code of Conduct for Responsible Fisheries (1995)
Adopt cautious conservation and management measures for new or exploratory fisheries	UNFA (1995)	FAO Code of Conduct for Responsible Fisheries (1995); Agenda 21 (1992)
Ecosystem approach		
(By 2010), adopt and apply ecosystem approach	UNFA (1995); CBD Decision VII/5 (Programme of Work on Marine and Coastal Biodiversity) (2004); CBD Decision X/2 (Strategic Plan for Biodiversity 2011-2020) (2010); NAFO amended Convention (2007).	FAO Code of Conduct for Responsible Fisheries (1995); UNGA Resolutions (various years); APEC Bali Plan of Action (2005); WSSD Plan of Implementation (2002); UNGA Resolutions (various years)
Study coastal and marine impacts of climate change, and the potential of marine and coastal habitats (such as salt marshes, mangroves and seagrasses) in mitigating and adapting to climate change	CBD Decision VII/5 (Programme of Work on Marine and Coastal Biodiversity) (2004)	Agenda 21 (1992); UNGA Resolutions (various years).

Address potential adverse impacts of ocean acidification on marine and coastal biodiversity	CBD Decision VII/5 (Programme of Work on Marine and Coastal Biodiversity) (2004)	
Integrated Management Plans for Coastal and Marine Waters		
Develop and implement integrated management plans for coastal and marine waters	LOSC (1982); CBD (1992); CBD Decision X/2 (Strategic Plan for Biodiversity 2011-2020) (2010); CBD Decision VII/5 (Programme of Work on Marine and Coastal Biodiversity) (2004)	Agenda 21 (1992); FAO Code of Conduct for Responsible Fisheries (1995); WSSD Plan of Implementation (2002); APEC Paracas Action Agenda (2010)
Protection of Marine Environment from Land-based Activities		
By 2020, bring down levels of pollution, including from excess nutrients, to levels not detrimental to ecosystem function and biodiversity	CBD Decision X/2 (Strategic Plan for Biodiversity 2011-2020) (2010)	
Environmental Assessment		
Establish a national environmental assessment process to consider impacts of proposed projects on biological diversity and the marine environment	LOSC (1982); CBD (1992)	UNGA Resolutions (various years)
Sustainable fisheries		
By 2015, eliminate destructive fishing practices and restore depleted fish stocks to maximum sustainable yield level.	CBD Decision VII/5 (Programme of Work on Marine and Coastal Biodiversity) (2004)	WSSD Plan of Implementation (2002); UNGA Resolutions (various years)
By 2020, all fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally and applying ecosystem based approaches.	CBD Decision X/2 (Strategic Plan for Biodiversity 2011-2020) (2010)	
Develop and implement national plans of action to prevent or eliminate excess fishing capacity and to ensure that levels of fishing effort are consistent with those required to achieve the sustainable use of fishery resources.		FAO IPOA Capacity (1999)
(By 2020), establish	UNFA (1995); CBD Decision	FAO Code of Conduct for

rebuilding or recovery plans for depleted populations or species.	X/2 (Strategic Plan for Biodiversity 2011-2020) (2010)	Responsible Fisheries (1995)
Assess and minimize the impacts of fishing on the marine environment	UNFA (1995)	FAO Code of Conduct for Responsible Fisheries (1995)
Consider harvesting effects on associated or dependent species and adopt conservation measures for species belonging to the same ecosystem (including use of selective fishing gear and practices, minimizing discards, catch by lost or abandoned gear, and catch of non-target species) with a view to maintaining or restoring such species above levels seriously threatening their reproduction	LOSC (1982); UNFA (1995)	Agenda 21 (1992); FAO Code of Conduct for Responsible Fisheries (1995); UNGA resolutions (various years)
Develop national plans for conservation and management of shark stocks; ensure that shark catches are sustainable; and minimize incidental catches of shark	NAFO Conservation and Management Measures (2011)	FAO IPOA Sharks (1999); UNGA Resolutions (various years)
Develop of national plans of actions for reducing incidental catch of seabirds in longline fisheries, if an incidental catch problem exists		FAO IPOA for Reducing Incidental Catch of Seabirds in Longline Fisheries (1999); UNGA Resolutions (various years)
Reduce sea turtle mortality		UNGA Resolutions (various years); NAFO Resolution (2006)
Protection of vulnerable, rare and fragile ecosystems		
Protect and preserve rare or fragile ecosystems (including deep-water vulnerable marine ecosystems, coral reefs, cold coral)	LOSC (1982); NAFO Conservation and Management Measures (2011).	FAO Code of Conduct for Responsible Fisheries (1995); Agenda 21 (1992); UNGA Resolutions (various years);
By 2015, anthropogenic pressures on vulnerable ecosystems (e.g., coral reefs) impacted by climate change are minimized, so as to	CBD Decision X/2 (Strategic Plan for Biodiversity 2011-2020) (2010)	

maintain their integrity and functioning		
Establish a system or network of marine protected areas	CBD (1992)	Agenda 21 (1992); UNGA Resolutions (various years); APEC Paracas Action Agenda (2010)
By 2012, establish representative networks of marine and coastal protected areas	CBD Decision VII/5 (Programme of Work on Marine and Coastal Biodiversity) (2004)	WSSD Plan of Implementation (2002); UNGA Resolutions (various years)
By 2020, 10% of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures	CBD Decision X/2 (Strategic Plan for Biodiversity 2011-2020) (2010)	
Develop a North American Marine Protected Area Network (NAMPAN)		Strategic Plan for North American Cooperation in the Conservation of Biodiversity (CEC 2003)
Designate wetlands of international importance (including coastal wetlands); and promote conservation and wise use of wetlands, including by establishing reserves within them	Ramsar Convention (1971)	
Complete national policies or guidelines enhancing the role of wetlands in mitigation and/or adaptation of climate change	Ramsar Resolution X.1 (Strategic Plan 2009-2015) (2008)	
By 2015, put in place national invasive species control and management policies/guidelines for wetlands.	Ramsar Resolution X.1 (Strategic Plan 2009-2015) (2008)	
Species at risk		
Develop or strengthen legislation / regulations for the	CBD (1992)	FAO Code of Conduct for Responsible Fisheries (1995)

protection of threatened species		
Prevent extinction of human threatened species and improve their conservation status	CBD Decision X/2 (Strategic Plan for Biodiversity 2011-2020) (2010)	Agenda 21 (1992)
Protect and preserve the habitats of depleted, threatened or endangered species	LOSC (1982); UNFA (1995)	Agenda 21 (1992); FAO Code of Conduct for Responsible Fisheries (1995)
By 2020, fisheries have no significant adverse impacts on threatened species and vulnerable ecosystems	CBD Decision X/2 (Strategic Plan for Biodiversity 2011-2020) (2010)	
Implement North American Conservation Action Plans for humpback whale, Pacific leatherback turtle, pink-footed shearwater, and vaquita porpoise.		North American Conservation Action Plans (CEC, 2005 and 2008)
Alien species		
Prevent and control the introduction of alien species into the marine environment (including through the International Convention for the Control and Management of Ships' Ballast Water and Sediments)	LOSC (1982); CBD (1992) CBD Decision VII/5 (Programme of Work on Marine and Coastal Biodiversity) (2004)	
Manage the risks to biological diversity arising from the use and release of living modified organisms resulting from biotechnology	CBD (1992)	
Sustainable aquaculture		
By 2020, areas affected by aquaculture are managed sustainably and ensuring conservation of biodiversity	Strategic Plan for Biodiversity 2011-2020 (2010)	
Develop effective site selection methods in the framework of integrated marine and coastal area management	CBD Decision VII/5: Programme of Work on Marine and Coastal Biodiversity	
Use native species in mariculture	CBD Decision VII/5: Programme of Work on	

	Marine and Coastal Biodiversity	
Governance		
Strengthen legal and regulatory frameworks for managing marine living resources, including by incorporating the UN Law of the Sea Convention (1982) and the UN Agreement on Straddling and Highly Migratory Fish Stocks (1995) in national legislation		Agenda 21 (1992)
Take appropriate legal, scientific, administrative and financial measures necessary for the protection and conservation of identified cultural and natural heritage areas	Convention concerning the Protection of the World Cultural and Natural Heritage (1972)	
By 2020, eliminate or phase out of incentives, including subsidies, harmful to biodiversity (including subsidies contributing to IUU fishing and to over-capacity).	CBD Decision X/2 (Strategic Plan for Biodiversity 2011-2020) (2010)	WSSD Plan of Implementation (2002)
Recognize the rights of small-scale fishworkers, indigenous people and local communities		Agenda 21 (1992); UNGA Resolution 61/295 (2007)
Enhance community-based management by both local communities and indigenous people		Rio Declaration on Environment and Development (1992); UNGA Resolution 61/295 (2007)
Strengthening public participation in decision-making processes		Rio Declaration on Environment and Development (1992)

Chapter Eleven: Canada's National Commitments to Sustain Marine Biodiversity

1. Introduction

While numerous provincial laws and policies may be relevant to sustaining coastal and marine biodiversity (DFO 2009a), this report focuses on Canada's federal legislative and other commitments (Table 11.1). Statutory commitments are first reviewed under a five-point format: *Oceans Act* pledges; marine conservation areas promises; fisheries management provisions; species at risk protections; and other sectoral legislative trickles. The voluminous aggregate of governmental documents pertaining to marine biodiversity sustainability is then summarized, including governmental strategies, plans, and policies. This chapter helps support the analysis in Chapter Twelve of the extent to which Canada has fulfilled its commitments to sustain marine biodiversity.

2. Statutory Commitments

a. *Oceans Act* Pledges

Canada's *Oceans Act*, which came into force on 31 January 1997, provides an overarching legal framework for strengthening ocean governance, with four main types of commitments. First, the Act articulates a Canadian commitment to follow key sustainability principles (Rothwell and VanderZwaag 2006). The Preamble of the Act recognizes an ecosystem approach as being of fundamental importance to maintaining marine biological diversity. It also promotes the wide application of the precautionary approach to the management of marine resources. The Preamble emphasizes the importance of taking an integrated management approach to oceans and marine resources. Article 29 requires the Minister of Fisheries and Oceans to lead the development and implementation of a national ocean strategy, which must be based on three key principles – sustainable development, integrated management, and the precautionary approach.

A second major commitment is to eventually develop and implement integrated management plans for all coastal and marine waters under Canadian jurisdiction. Article 31 of the Act requires the Minister of Fisheries and Oceans to lead the development and implementation of integrated management plans in a collaborative fashion, in concert with other federal departments/agencies, provincial and territorial governments, aboriginal organizations, and coastal communities.

A third commitment is to forge a national system of marine protected areas (MPAs). Article 35(2) of the Act requires the Minister of Fisheries and Oceans to lead and coordinate the development and implementation of a national MPA system, while Article 35(3) provides broad regulatory powers to prescribe zoning and control measures for any MPAs designated. The Act provides wide scope for establishing MPAs based on one or more reasons, namely, to conserve and protect: commercial and non-commercial fishing resources, including marine mammals and their habitats; endangered or threatened species and their habitats; marine areas of high biodiversity or biological productivity; and any other marine resource or habitat necessary to fulfill the mandate of the Minister (Art. 35(1)).

A fourth type of commitment is the promotion of marine sciences and marine services. The Minister of Fisheries and Oceans is responsible for providing coast guard and hydrographic services (Art. 40(2)). The Minister is also responsible for promoting national policies and programs regarding fisheries science, hydrology, oceanography, and other marine sciences (Art. 43).

b. Marine Conservation Area Promises

While Canada's *Oceans' Act* has become the central statutory route for establishing MPAs, three other pieces of federal legislation provide for establishing types of offshore conservation areas. The *Canada National Marine Conservation Areas Act*, enacted in 2002, sets out a Canadian commitment to establish a representative system of marine conservation areas for the Atlantic, Arctic, and Pacific Oceans and the Great Lakes. This Act also dictates that established marine conservation areas be managed in a sustainable manner that meets the needs of present and future generations, without compromising the structure and function of ecosystems (Art. 4(3)). The *Canada Wildlife Act* provides the legal authority for Environment Canada (Canadian Wildlife Service) to establish protected marine areas for the conservation of a range of wildlife (Art. 4.1(1)). The *Migratory Birds Convention Act, 1994*, aimed at protecting and conserving migratory birds, grants power to the Governor in Council (federal cabinet) to prescribe migratory bird sanctuaries through regulations (Art. 12(1)(i)).

c. Fisheries Management Provisions

Although Canada's *Fisheries Act*, dating back to 1868, is devoid of fisheries management objectives and principles relating to marine biodiversity and sustainability, the Act does include key legal provisions for protecting the marine environment. Section 36 prohibits persons from depositing or permitting the deposit of a deleterious substance into water frequented by fish unless authorized by regulations. Section 35 prohibits persons from carrying on any work or undertaking that results in the harmful alteration, disruption, or destruction of fish habitat, unless authorized by the Minister of Fisheries and Oceans or under regulations pursuant to the Act.

The *Coastal Fisheries Protection Act*, while itself is silent as to sustainability objectives and principles, incorporates into Canadian law the 1995 UN Fish Stocks Agreement (UNFA), described in Chapter Ten. In addition to generally prohibiting unauthorized foreign fishing in Canadian fisheries waters, the Act allows any conservation and enforcement measures of a regional fisheries management organization or any arrangement addressing a straddling or highly migratory fish stock to be given domestic effect through regulations.

d. Species at Risk Protections

Canada's *Species at Risk Act* (SARA), enacted in December 2002, might be described as a protective net aimed at preventing endangered or threatened species from becoming extinct. SARA provides a series of protective threads for listed marine species at risk, such as endangered inner Bay of Fundy Atlantic salmon and the Northeast Pacific southern resident population of killer whales. SARA prohibits any person from killing, harming, or harassing an endangered or threatened species (Art. 32(1)). SARA requires the development of recovery strategies and action plans for listed endangered or threatened species (Art. 37, 47). No person is allowed to destroy any part of the critical habitat of such species, if a recovery strategy or action plan has identified the critical habitat, and the required legal procedures for protecting such habitat have been followed (Art. 58).

e. Other Sectoral Legislative Trickles

A long list of federal statutes addressing specific sectors of human activity is also relevant to sustaining marine biodiversity. Some of the key statutes include:

- *Arctic Waters Pollution Prevention Act* (providing for the regulation of wastes, vessel-source pollution, and shipping activities in order to preserve the ecological balance of the Canadian Arctic);
- *Canadian Environmental Assessment Act* (requiring environmental assessment review of federal-related projects and activities);
- *Canadian Environmental Protection Act, 1999* (governing toxic chemicals management, ocean dumping, and introduction of living modified organisms);
- *Canada-Newfoundland Atlantic Accord Implementation Act* (instituting collaborative offshore petroleum resource management through the Canada-Newfoundland Offshore Petroleum Board);
- *Canada-Nova Scotia Offshore Petroleum Resources Accord Implementation Act* (formalizing collaborative offshore petroleum resource management through the Canada-Nova Scotia Offshore Petroleum Board);
- *Canada Oil and Gas Operations Act* (providing for licencing of oil and gas exploration and production activities by the National Energy Board in submarine areas not within a province, and not within the jurisdiction of offshore petroleum boards);
- *Canada Shipping Act, 2001* (regulating vessel-source pollution including oil, sewage, garbage, ballast water discharges, and air emissions);
- *Pest Control Products Act* (controlling the registration and labeling of pesticides).

3. Canadian Governmental Documents

Describing the abundance of federal governmental documents having relevance to marine biodiversity sustainability is no easy task, but the bulk of key commitments may be categorized under four headings. Canada's national biodiversity strategy is first highlighted with a focus on key strategic directions relevant to the marine environment. Second, policy and planning initiatives pursuant to the *Oceans Act* are described. Key documents supporting sustainable fisheries and aquaculture are then reviewed. Finally, efforts to encourage cooperation in establishing marine protected areas are set forth.

a. Canadian Biodiversity Strategy

Published in 1995 as Canada's response to the CBD, the Canadian Biodiversity Strategy (Government of Canada 1995) pledged the federal, provincial, and territorial governments to pursue over 150 fairly general strategic directions. The Strategy calls for:

- Ensuring the sustainable harvest of wild flora and fauna and minimizing adverse impacts on non-target species (Strategic Direction (S.D.) 1.4);
- Developing indicators to monitor trends and support the management of wild species, habitat, and ecosystems (S.D. 1.9);
- Accelerating the protection of areas that are representative of marine natural regions (S.D. 1.13);
- Considering multi-species/habitat recovery plans for areas containing a number of species at risk (S.D. 1.24);
- Establishing reserves to conserve aquatic biodiversity and contributing to networks of national and international protected areas (S.D. 1.56);
- Reducing to acceptable levels, or eliminating, adverse impacts of species introductions on aquatic biodiversity resulting from aquaculture projects, fisheries enhancement programmes, and interbasin transfers of water and organisms (S.D. 1.58);
- Improving ecological planning to assist in the conservation of biodiversity (S.D. 2.15);
- Developing and using biodiversity indicators that are meaningful, scientifically defensible, and practical (S.D. 2.28);
- Leading the development of community-based regimes designed to preserve traditional indigenous knowledge, innovations, and practices (S.D. 7.1.(c)).

The Strategy was an important catalyst for promoting various Canadian biodiversity conservation initiatives. For example, the Strategy's call for jurisdictions to review the adequacy of their species-at-risk legislation (S.D. 1.21) gave momentum to the drafting of SARA. The Strategy's urging of measures to prevent alien organisms from adversely affecting biodiversity and improving preventative mechanisms, such as risk assessment procedures (S.D. 1.81), supported the subsequent finalization of the National Code on Introductions and Transfers of Aquatic Organisms (DFO 2003) as well as an Invasive Alien Species Strategy for Canada (Government of Canada 2004).

b. Policy and Planning Initiatives Pursuant to the Oceans Act

Canada has followed up the overarching legislative enactment relating to oceans with five particularly important policy and planning initiatives, under the leadership of DFO. To guide MPA establishment under the *Oceans Act*, DFO adopted a Marine Protected Areas Policy in 1999 (DFO 1999). The policy, among other things: sets goals for a system of MPAs; urges identification and establishment of MPAs within the context of integrated management planning; calls for detailed management plans to be developed through participatory processes for individual MPAs; and encourages a flexible approach to MPA zoning from strictly no-take zones to sustainably managed zones.

In 2002, a second key document, the national strategy mandated by the *Oceans Act*, was released (Government of Canada 2002a). Canada's Oceans Strategy might be characterized as 'very general' with three overall policy directives set out:

- Better understanding and protecting of the marine environment;
- Supporting sustainable economic opportunities;

- Providing international leadership, supporting capacity-building in developing countries for sustainable resource management, and supporting consultative processes on oceans within the United Nations.

The Oceans Strategy further promised to improve existing legislation and guidelines on marine environmental protection. However, the document lacked substance and did not provide a timeline for making legislative and guideline reforms.

To further articulate how integrated management planning required under the *Oceans Act* would be carried out, a third document was developed: Policy and Operational Framework for Integrated Management of Estuarine, Coastal and Marine Environments in Canada (Government of Canada 2002b). The Framework is meant to guide integrated planning efforts in various ways by:

- Setting the ultimate objective of establishing integrated management plans for *all* Canadian marine waters;
- Establishing the short-term goal of initiating planning efforts where intensity of ocean uses are greatest and stakeholder capabilities and interests exist;
- Clarifying the six steps involved in the planning process (defining and assessing the management area; engaging affected interests; developing an integrated management plan; receiving embracement of the plan; implementing the plan; and monitoring and evaluating plan outcomes);
- Confirming the key principles guiding integrated management (ecosystem-based management; sustainable development; the precautionary approach; conservation; shared responsibility; flexibility);
- Proposing two main types of integrated planning (large ocean management areas (LOMAs) and coastal management areas (CMAs)).

A fourth major initiative was the development and implementation of Canada's Oceans Action Plan, published in 2005, which outlines priorities for action in four areas over a two-year period (2005-2007), utilizing $28 million in new funding (Government of Canada 2005a). Under the International Leadership, Sovereignty and Security theme, the Action Plan listed various priorities, including: enhancing North American maritime transportation and port security; supporting Canada-USA collaboration in the Gulf of Maine; co-leading under the Arctic Council publication of the Arctic Marine Shipping Assessment; addressing overfishing in the Northwest Atlantic Fisheries Organization's Regulatory Area through an increased governance presence and governance reforms; and pursuing the delimitation of Canada's outer continental shelf.

Under the Integrated Oceans Management for Sustainable Development theme, the Action Plan pledged to foster integrated management arrangements in five priority areas: Placentia Bay and the Grand Banks, the Scotian Shelf, the Gulf of St. Lawrence, the Beaufort Sea, and the Pacific North Coast. Ecosystem overview and assessment reports were also proposed for each priority area.

Under the Health of the Oceans theme, the Plan committed to promote the development of a MPA network by 2012; to develop binding regulations on ballast water dumping; to increase pollution surveillance patrols; and to pass regulations aimed at better protecting seabirds oiled at sea.

Under the Ocean Science and Technology theme, the Plan promised to foster an oceans technology network of ocean science researchers and technology innovators, and to launch a Placentia Bay technology demonstration project off the south coast of Newfoundland. The project promised to support ecosystem-based management through various technology developments, including meteorological buoys and water-quality samplers.

A fifth overall initiative was the governmental commitment in 2007 to provide funding of $61.5 million over five years to support a Health of the Oceans initiative as part of the National Water Strategy (DFO 2007a). Some 22 initiatives were listed for support, including: assessing Canadian Coast Guard response capacity in the Arctic and purchasing new emergency response equipment; developing a federal-provincial-territorial MPA network; formalizing a cold-water coral conservation strategy for Newfoundland and Labrador; and increasing aerial surveillance capacity/technology to detect ship-source pollution, including in the Arctic.

c. Documentary Support for Sustainable Fisheries and Aquaculture

i. Sustainable Fisheries

Four main documentary avenues have lent support to the goal of achieving sustainable fisheries in Canada. First, a Canadian Code of Conduct for Responsible Fishing Operations was adopted in 1998 in support of national implementation of the 1995 FAO Code of Conduct. The Canadian Code sets out nine fundamental principles, including a commitment to pursue the ecological sustainability of Canadian fisheries (principle 2) (DFO 1998a).

Second, the legislative commitment under the *Fisheries Act* to protect fish habitat has been further encouraged through a Policy for the Management of Fish Habitat adopted in 1986 (DFO 1986), as supplemented by various other guidelines. The Fish Habitat Policy establishes an overall objective of ensuring a net gain of habitat for Canadian fisheries resources and strives to conserve existing fish habitat, selectively restore fish habitats, and improve/create fish habitat. A key principle is no net loss of the productive capacity of habitats.

Eight implementation strategies are pledged, including commitments to: ensure effective compliance and enforcement of the *Fisheries Act* habitat provisions; encourage integrated resource planning; support fish habitat scientific research; and initiate fish habitat improvement projects. Supplementary guidance on policy application is provided through other documents, for example, Habitat Conservation and Protection Guidelines (DFO 1998b) and practitioner guides relating to risk management (DFO n.d.a.), fish passage (DFO 2007b), writing *Fisheries Act* authorizations (DFO 2010), and habitat compensation (DFO n.d.b.).

Third, Canada has made various general fisheries management commitments through National Plan of Action initiatives in its implementation response to FAO International Plans of Action. Canada's National Plan of Action to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing, issued in 2005, pledged to modernize fisheries management governance in light of precautionary and ecosystem approaches, and to improve monitoring, control, and surveillance operations (Government of Canada 2005b). Canada's National Plan of Action for Reducing the Incidental Catch of Seabirds in Longline Fisheries, published in March 2007, pledged to promote work with fishers in mitigating seabird bycatches and to undertake a reassessment of the bycatch of seabirds in the longline fishery (Government of Canada 2007a). The National Plan of Action for the Conservation and Management of Sharks, also published in March 2007, pledged to enhance research efforts on sharks, to reduce the bycatch of sharks, and to encourage Regional Fisheries Management Organizations to implement shark bycatch policies and management measures (Government of Canada 2007b).

Fourth, as part of a Fisheries Renewal programme, DFO has developed a Sustainable Fisheries Framework, which encompasses three main policy documents attempting to promote conservation and sustainable use in the fisheries sector, in addition to two wild salmon policies. A Fishery Decision-Making Framework Incorporating the Precautionary Approach calls for categorizing fish stocks into three status zones – healthy, cautious, and critical – and setting harvesting removal rates within each status zone. In the critical zone, management activities must ensure removals from all sources are kept to the lowest possible level and that a rebuilding plan is in place (DFO 2009b).

A Policy for Managing the Impacts of Fishing on Sensitive Benthic Areas seeks to avoid impacts of fishing likely to cause serious or irreversible harm to sensitive marine habitats and species and pledges to apply precautionary and ecosystem approaches in decision-making processes. For frontier areas not having a history of fishing in Canadian waters (specifically, waters deeper than 2000 m, or areas of the Arctic with little scientific information and no history of fishing), DFO will consider allowing small-scale exploratory fisheries. For historically fished areas, DFO is responsible for mapping the existence of benthic habitats and species, conducting a risk analysis of proposed fishing activities to any sensitive behthic ecosystem components, and determining whether mitigation measures are needed, such as gear restriction, area closures, and enhanced vessel monitoring (DFO 2009c).

A Policy on New Fisheries for Forage Species establishes a general policy that commercial fisheries for forage species, such as krill, will only be permitted when there is a reasonable expectation that five overall objectives will be met, including: the maintenance of ecological relationships among species directly, or indirectly, affected by the fishery within the bounds of natural fluctuations; and maintenance of the full reproductive potential of the forage species. Various management pre-requisites for overseeing forage fisheries are also set out. They include clearly identified reference points and associated harvest control rules for both forage species and some dependent marine predators, so as to be consistent with both the precautionary approach and adequate monitoring and enforcement arrangements (DFO 2009d).

Two policy documents have been developed to address the conservation of wild salmon. Canada's Policy for Conservation of Wild Pacific Salmon, published in 2005, sets out principles, objectives, strategies, and active measures in support of the overall goals to restore and maintain healthy and diverse salmon populations and their habitats for the benefit and enjoyment of Canadians in perpetuity (DFO 2005). A key principle here is conservation. Conservation of wild Pacific salmon and their habitats is recognized as the highest priority in resource management decision making related to these species. Three objectives are: to safeguard the genetic diversity of wild Pacific salmon; to maintain habitat and ecosystem integrity; and to manage fisheries for sustainable benefits. One of the key strategies is to develop long-term strategic plans for designated Conservation Units of wild salmon (Chapter Five), while also addressing the causes of any declines and identifying necessary resource management actions.

Canada's Policy for Conservation of Wild Atlantic Salmon, released in 2009, is quite closely modeled after the Pacific wild salmon policy and upholds similar goals and objectives and similar principles, strategies, and action steps (DFO 2009e). A key strategy commitment is to develop regional, integrated fisheries management plans (IFMPs) for Atlantic salmon for multi-year periods. Such IFMPs are to address the causes of any declines and identify necessary resource management actions.

ii. Sustainable Aquaculture

With no federal legislation specifically addressing aquaculture (VanderZwaag et al. 2006), the Canadian aquaculture policy framework has largely been forged through various policy documents. DFO's Aquaculture Policy Framework, issued in 2002, pledged various policy principles to guide aquaculture development in Canada, including a commitment in Principle 7 to "support aquaculture development in a manner consistent with its commitments to ecosystem-based and integrated management, as set out in departmental legislation, regulations and policies" (DFO 2002: 21).

An overarching document, the National Aquaculture Strategic Action Plan Initiative (NASAPI) 2011-2015 was developed under the auspices of, and endorsed by, the Canadian Council of Fisheries and Aquaculture Ministers in November 2010. NASAPI promotes a strategic vision to advance aquaculture development, based upon the three principles of sustainable development: environmental protection, social well-being, and economic priority (Government of Canada 2010a). The document highlights the need for governments to establish and enforce clear science-based standards and operating protocols to preserve healthy and productive aquatic environments and to protect sensitive habitats (Government of Canada 2010a: 7). Federal-provincial/territorial bilateral aquaculture Memorandum of Understanding (MOU) Management Committees are tasked with coordinating implementation efforts and preparing annual progress reports on actions taken to advance the objectives of NASAPI.

The overarching NASAPI document is supplemented by a set of five more detailed Strategic Action Plans covering east coast finfish (Government of Canada 2010b) and shellfish (Government of Canada 2010c), west coast finfish (Government of Canada 2010d) and shellfish (Government of Canada 2010e), and the freshwater sector (Government of Canada 2010f). The action plans, being quite similar in format, include a key section on governance commitments aimed at enhancing environmental management. For example, the East Coast Marine Finfish Strategic Action Plan pledges parties to develop a consolidated environmental management framework within a suggested three-year timeframe, and to prioritize research and development requirements for improved environmental management in aquaculture (Government of Canada 2010b: 2-3). The West Coast Marine Finfish Strategic Action Plan calls for the development of principles in support of ecosystem-based aquaculture management, as well as protocols to

incorporate the precautionary approach in aquaculture decisions (Government of Canada 2010d: 3). Both finfish plans propose investments in research and development to advance commercial closed-containment and
re-circulating aquaculture systems.

Following a 9 February 2009 BC Supreme Court decision, *Morton v. British Columbia (Minister of Aquaculture & Lands)*, which concluded that finfish aquaculture is a fishery under exclusive federal jurisdiction, and thus largely outside the constitutional jurisdiction of the Province, the Government of Canada developed *Pacific Aquaculture Regulations,* coming into force on 18 December 2010. The Regulations provide for federal licensing of aquaculture operations and the inclusion of license conditions to protect the marine environment. This includes, for example, measures to minimize escape of fish, to manage the impact of aquaculture on fish and fish habitat, and to monitor the environmental impacts of an aquaculture facility.

d. Cooperative MPA Encouragements

To promote federal interdepartmental cooperation among Fisheries and Oceans, Environment Canada, and the Parks Canada Agency in their development of a network of MPAs, Canada's Federal Marine Protected Areas Strategy was published in 2005 (Government of Canada 2005c). The Strategy sets out various activity commitments including: establishing or formalizing mechanisms for interdepartmental cooperation; collaboratively identifying and selecting new marine protected areas; and establishing a regional MPA action plan with the United States and Mexico.

In September 2011, Canada's federal, provincial and territorial members of the Canadian Council of Fisheries and Aquaculture Ministers reviewed and approved in principle the National Framework for Canada's Network of Marine Protected Areas (Government of Canada 2011) with the objective of achieving "[a]n ecologically comprehensive, resilient, and representative national network of marine protected areas that protects the biological diversity and health of the marine environment for present and future generations" (Government of Canada 2011, p. 6). The Framework encourages inter-jurisdictional cooperation in establishing a network of MPAs for 12 oceanic bioregions and the Great Lakes. Technical guidance and some initial action plans or bioregional network designs for Canada's network of marine protected areas are expected to be in place by 2012, while the development of the remaining action plans and establishment of new areas in the network will be incremental over time as resources allow (Government of Canada 2011, p. 19).

4. Main Findings

- Canada has embraced a long list of commitments supportive of sustaining national marine biodiversity through both legislation and numerous policy-related documents (Table 11.1).
- Many statutory commitments are consistent with Canada's international responsibilities and key legislative commitments.
- Canada has committed to developing and implementing integrated management plans for coastal and marine waters.

- Canada has committed to establishing a national network of MPAs.
- Canada has committed to promoting ecosystem and precautionary approaches.
- Canada has committed to protecting marine species at risk through prohibitions on harming or harassing them, developing recovery strategies, and identifying critical habitats.

Table 11.1. *A summary of selected national commitments by Canada to sustain marine biodiversity.*

Biodiversity Commitments	Canadian Statutes and Regulations	Canadian Policies, Strategies, or Action Plans
General obligations		
Protect and preserve the marine environment		Canada's Oceans Strategy (2002)
Protect biodiversity in the marine environment	*Oceans Act*	
Develop a national biodiversity conservation strategy or plan		Canadian Biodiversity Strategy (1995)
Promote marine sciences and services	*Oceans Act*	Canada's Oceans Action Plan (2005)
Precautionary approach		
Apply the precautionary approach	*Oceans Act*; *Species at Risk Act*	Sustainable Fisheries Framework (2009)
Determine precautionary fisheries reference points and take restorative actions if reference points are exceeded		Fishery Decision-Making Framework Incorporating the Precautionary Approach (Sustainable Fisheries Framework, 2009)
Ecosystem approach		
Apply ecosystem approach	*Oceans Act*	Canada's Oceans Action Plan (2005); Sustainable Fisheries Framework (2009)
Develop and use biodiversity indicators that are meaningful, scientifically defensible and practical		Canadian Biodiversity Strategy (1995)
Integrated Management Plans for Coastal and Marine Waters		
Develop and implement integrated management plans for coastal and marine waters	*Oceans Act*	Canadian Biodiversity Strategy (1995); Policy and Operational Framework for Integrated Management of Estuarine, Coastal and Marine Environments in Canada (2002); Canada's Oceans Action Plan (2005);

		Sustainable Fisheries Framework (2009)
Protection of Marine Environment from Land-based Activities		
Regulation of wastes in coastal and marine waters	*Fisheries Act; Arctic Waters Pollution Prevention Act*; *Canadian Environmental Protection Act*; *1999; Canada Shipping Act, 2001*; *Pest Control Products Act*	Canada's Oceans Action Plan (2005)
Prevent the harmful alteration, disruption or destruction of fish habitat	*Fisheries Act*	Policy for the Management of Fish Habitat (1986) and supplementary documents
Environmental Assessment		
Establish a national environmental assessment process to consider impacts of proposed projects on biological diversity and the marine environment	*Canadian Environmental Assessment Act*	
Sustainable fisheries		
Achieve ecological sustainability of Canadian fisheries		Canadian Biodiversity Strategy (1995); Canadian Code of Conduct for Responsible Fishing Operations (1998)
Assess and minimize the impacts of fishing on the marine environment		Canadian Biodiversity Strategy (1995)
Minimize adverse impacts of fishing on non-target species		Canadian Biodiversity Strategy (1995); Policy on New Fisheries for Forage Species (Sustainable Fisheries Framework, 2009); By-catch policy (in development)
Conserve Wild Salmon		Policy on Conservation of Wild Pacific Salmon (2005); Policy for Conservation of Wild Atlantic Salmon (2009)
Enhance shark research initiatives, reduce bycatch of sharks and encourage RFMOs to implement shark bycatch policies and management measures		Canada's National Plan of Action for the Conservation and Management of Sharks (2007)
Mitigate seabirds by-catches and undertake re-assessment		Canada's National Plan of Action for Reducing the

of bycatch of seabirds in longline fishery		Incidental Catch of Seabirds in Longline Fisheries (2007)
Protection of vulnerable, rare and fragile ecosystems		
Protect and preserve rare or fragile ecosystems (including deep-water vulnerable marine ecosystems, coral reefs, cold coral)		Policy for Managing the Impact of Fishing on Sensitive Benthic Areas (Sustainable Fisheries Framework, 2009); Health of the Oceans (2007)
Develop and implement a system of marine protected areas	*Oceans Act*; *Canada National Marine Conservation Areas Act*; *Canada Wildlife Act*; *Migratory Birds Convention Act, 1994*	Canadian Biodiversity Strategy (1995); Marine Protected Areas Policy (1999); Health of the Oceans (2007); Canada's Federal Marine Protected Areas Strategy (2005); National Framework for Canada's Network of Marine Protected Areas (2011)
By 2012, establish representative networks of marine and coastal protected areas		Canada's Oceans Action Plan (2005)
Designate wetlands of international importance (including coastal wetlands); and promote conservation and wise use of wetlands, including the establishment of wetland reserves.	*Canada Wildlife Act; Migratory Birds Convention Act, 1994*	Federal Policy on Wetland Conservation (1991)
Species at risk		
Prevent extinction of human threatened species and improve their conservation status	*Species at Risk Act*	
Protect and preserve the habitats of depleted, threatened or endangered species	*Oceans Act*; *Species at Risk Act*	
Develop and implement recovery strategies and action plans (including multi-species/habitat recovery plans)	*Species at Risk Act*	Canadian Biodiversity Strategy (1995)
Alien species		
Prevent and control the introduction of alien species into the marine environment		Canadian Biodiversity Strategy (1995); Canada's Oceans Action Plan (2005);

		National Code on Introductions and Transfers of Aquatic Organisms (2003); Invasive Alien Species Strategy for Canada (2004)
Prevent and control introduction of living modified organisms	*Canadian Environmental Protection Act*	
Sustainable aquaculture		
Support aquaculture development in a manner consistent with commitments to ecosystem-based and integrated management	*Pacific Aquaculture Regulations*	Canadian Biodiversity Strategy (1995); Aquaculture Policy Framework (2002); National Aquaculture Strategic Action Plan Initiative 2011-2015 (2010); East Coast Marine Finfish Sector Strategic Action Plan 2011–2015 (2010); East Coast Shellfish Sector Strategic Action Plan 2011–2015 (2010); West Coast Marine Finfish Sector Strategic Action Plan 2011–2015 (2010); West Coast Shellfish Sector Strategic Action Plan 2011–2015 (2010); Freshwater Sector Strategic Action Plan 2011–2015 (2010)
Governance		
Strengthen legal and regulatory frameworks for managing live marine resources, including incorporating the UN Law of the Sea Convention (1982) and the UN Agreement on Straddling and Highly Migratory Fish Stocks (1995) into national legislation	*Coastal Fisheries Protection Act*	Canadian Biodiversity Strategy (1995)
Develop community-based management regimes designed to preserve traditional indigenous knowledge, innovation and practices		Canadian Biodiversity Strategy (1995)

CHAPTER TWELVE: IS CANADA FULFILLING ITS COMMITMENTS TO SUSTAIN MARINE BIODIVERSITY? CHARTING FUTURE LAW AND POLICY COORDINATES

1. Introduction

The primary purpose of this chapter is to address the question posed in the Panel's Terms of Reference: To what extent is Canada fulfilling it national and international obligations to sustain marine biodiversity? Here, the Panel focuses on some of the most important of Canada's commitments (described in Chapters 10, 11), drawing considerably on approaches undertaken elsewhere as a means of evaluating what can and might be done; several of these approaches influenced the Panel's recommendations (Chapter Thirteen). The Panel concludes that Canada has made little substantive progress, when compared to most developed nations, in meeting its commitments to sustain marine biodiversity. Much of Canada's policy and rhetoric has not been operationalized, leaving many of the country's national and international obligations unfulfilled.

The Panel's evaluation is not based on a full audit of Canada's implementation of international and national law and policy commitments. Rather, it draws from available literature, including Canada's implementation reports under key conventions (Government of Canada 2008; Government of Canada n.d.a), interviews with governmental representatives, and comments received through the Panel's invitation for submissions of evidence.

Setting further law and policy coordinates to support the sustainability of Canadian marine biodiversity is complicated by the array of issues beckoning attention. They include, among others: the adequacy of climate change mitigation and adaptation measures (Government of Canada n.d.b; CESD 2010); lack of a national energy strategy (Council of Canadians n.d.); and the sufficiency of environmental assessment legislation for ensuring that project proposals fully assess their potential impacts on climate change (Hazell 2010).

Given the general and minimal nature of some international commitments, such as the basic requirement to list internationally important wetlands under the Ramsar Convention (Chapter Ten), Canada's compliance in certain areas might be viewed positively. For example, in its report to the 10th Meeting of the Conference of the Parties to the Convention on Wetlands of International Importance in 2008, Canada was able to substantiate progress in designating 37 wetlands of international importance, with sites having a total surface of more than 13 million hectares. As well, Canada has completed national wetland inventory mapping for approximately 10% of the country (Government of Canada 2008). Canada has also listed six cultural and nine natural properties on the World Heritage List. Although no specific marine sites have been listed, properties do include some coastal waters, specifically, Newfoundland's Gros Morne National Park and the transboundary Kluane/Wrangell-St. Ellias/Glacier Bay/Tautshenshini-Alsek region, which straddles the northwestern Canada-US border.

While an exhaustive charting of possible ways to bridge the gaps between rhetoric and reality is beyond the scope of the Panel's Report, key national and international coordinates do stand out for navigating towards the goal of effective protection of marine sustainability in Canada. National law and policy coordinates are first discussed, including the need to fully implement existing law and policy commitments articulated by the *Oceans Act*, existing fisheries management-related policies, and the *Species at Risk Act* (SARA). This is followed by arguments in favour of legislative and regulatory strengthenings, such as a modernized *Fisheries Act* and adoption of federal aquaculture legislation. Key international law and policy coordinates are described, including the need to strengthen bilateral and regional ocean governance arrangements, and the need for Canada to become a Party to key marine conservation conventions.

2. Charting National Law and Policy Coordinates

a. *Fully Implementing Existing Law and Policy Coordinates*

i. *Living Up to* Oceans Act *Commitments*

Two of the central legislative intentions of the *Oceans Act* have yet to be fully translated into practice, both of which could significantly enhance Canada's ability to sustain marine biodiversity. The development and implementation of integrated management plans for Canada's oceans and coastal areas are still in a nascent state. A national network of marine protected areas remains an unfinished initiative.

1. Advancing Integrated Management Planning

To date, integrated management planning (IMP) efforts and accomplishments have been limited (Jessen 2011; Ricketts and Hildebrand 2011). Federal IMP attention has largely focused on five Large Ocean Management Areas (LOMAs): Placentia Bay and the Grand Banks, the Eastern Scotian Shelf, the Gulf of St. Lawrence, the Beaufort Sea, and the Pacific North Coast. To date, IMPs have been completed for only 2 LOMAs: the Beaufort Sea IMP was endorsed by the Minister of Fisheries and Oceans in August 2010 (Beaufort Sea Planning Office 2009), while the Eastern Scotian Shelf Integrated Ocean Management Plan, published in 2007 (DFO 2007a), has yet to receive ministerial approval, reportedly because of a northeastern boundary overlap with the Newfoundland and Labrador region (Chircop and Hildebrand 2006; Jessen 2011). In the case of the North Pacific Coast LOMA, the Canadian government recently announced that it is withdrawing from an agreement which would ensure adequate funding to complete the integrated ocean management plan by December 2012 (wcel.org/resources/environmental-law-alert/why-harpers-shot-PNCIMA-also-hit-enbridge; accessed 16-12-11). The Government reported that the planning process under that agreement had become very detailed and too prescriptive, and that it is instead pursuing the elaboration of a document "at the appropriate level of planning" to be finished in the same timeline (House of Commons 2011). Completed plans stand out with respect to the very general nature of their mandates (and the setting of overall goals, objectives, and management strategies). Marine spatial planning (MSP) is still at a discussion stage, and there is a lack of clear national guidance on how best to advance MSP in Canada (Hall et al. 2011). Major offshore areas remain outside the integrated planning ambit, including the Bay of Fundy, the Gulf of Maine, and the central and eastern Arctic.

Extension of IMP to coastal areas might best be described as 'gradual'. DFO has participated in coastal management initiatives in various ways as a leader, an active participant, or as an observer. Claire Dansereau, Deputy Minister of DFO, in a submission to the Panel (Appendix B), provided a summary of current DFO participations which include:

> West Coast Vancouver Island (observer); Southwest New Brunswick – Bay of Fundy (co-chair and co-sponsor with Government of New Brunswick); the Collaborative Environmental Planning Initiative - Bras d'Or Lakes (member and co-sponsor with other federal departments and Government of Nova Scotia), and; five coastal management areas in Newfoundland and Labrador - Placentia Bay, Coast of Bays, Great Northern Peninsula, Bay of St. George/Port aux Port, and Bay of Islands (ex officio member). The Southwest New Brunswick Marine Resources Planning initiative has developed a series of priority actions for resource management in the planning area, and a steering committee with joint government-stakeholder participation is working together on these actions. The Bras d'Or Lakes initiative, which was established in 2003 to develop an environmental management plan for the Lakes and watershed, recently released a planning document *(The Spirit of the Lakes Speaks)*.

Formalizing cooperation with the provinces in *Oceans Act* implementation has been far from easy. The *Act* does not provide incentives to encourage provincial participation, such as financial support for provincial coastal planning initiatives (VanderZwaag and Rothwell 2006; Mageau et al. 2009). Provincial governments, including Newfoundland and Labrador, Nova Scotia, New Brunswick, and BC, have proceeded to develop their own strategies and policies relating to coastal and ocean management (Jessen 2011). While Canada and BC signed a MOU respecting Implementation of Canada's Oceans Strategy (DFO 2002a) on the Pacific Coast of Canada in 2004 (DFO 2004), and pledging the development of specific subsidiary agreements, including those for collaborating in coastal/ocean planning, these agreements were not subsequently adopted, largely because of federal-provincial disagreement over the future of offshore oil and gas development on the BC Coast (McCrimmon and Fanning 2010; Jessen 2011). In March 2010, Canada and Nova Scotia concluded a MOU on Coastal and Oceans Management, pledging increased collaboration on the development of subsidiary agreements/instruments and/or working groups in various areas of integrated coastal and oceans planning (Government of Nova Scotia 2011).

Ensuring adequate funding for IMP activities remains another challenge. The $61.5 million in funding over five years under the 2007 Health of the Oceans initiative did not specifically commit new funding for integrated management planning. This was despite the emergence of a coalition of national environmental organizations calling for the federal government to invest $600 million over five years to support MPAs and develop IMPs (Jessen 2011). Planned spending by DFO for 2010-11 showed a commitment given to support traditional priorities of fisheries and aquaculture management ($490.2 million), and safe and accessible waterways ($993.2 million). These allocations were markedly prioritized over oceans management, for which $15.9 million out of the $154.7 million envelope was projected to be spent on healthy and productive aquatic ecosystems (DFO 2010a). Cuts in funding to DFO of $57 million (to be achieved by 2014) announced by the Government of Canada in autumn 2011 raise additional concerns (http://www.cbc.ca/news/canada/newfoundland-labrador/story/2011/10/13/nl-dfo-shedding-services-1013.html; accessed 14-12-11).

Further advancing integrated management planning under the *Oceans Act* umbrella without substantive amendments might be fostered on various fronts. The March 2010 Canada-Nova Scotia MOU might provide a stimulus and model for other provinces to follow. Under the two completed LOMA plans, integrated management bodies might be formally recognized by the

Minister of Fisheries and Oceans pursuant to s. 32(c) of the *Oceans Act*. The 2002 Policy and Operational Framework for Integrated Management of Estuarine, Coastal and Marine Environments in Canada, might be substantially updated and strengthened, for example, by establishing an agenda for expanding the number of LOMAs and CMAs (Coastal Management Areas), highlighting the important role of integrated planning in addressing climate change mitigation and adaptation, clarifying the need for implementing action plans, and providing national guidance on marine spatial planning (MSP). Publication of a specific guide to MSP might also be considered, if only to promote political and public understanding of the concept and to suggest procedural steps to be followed.

2. Completing a Network of Marine Protected Areas

The establishment of protected areas has been far greater on land than the oceans (Figure 12.1). In contrast to Canada's terrestrial environment, 9.4% (941,418 km^2) of which was protected as of May 2009 (Environment Canada 2010), comparatively little (less than 1%) of Canada's marine environment is protected (Environment Canada 2010). In the past 50 years, terrestrial areas have been protected at a rate of approximately 14,000 km^2 per annum; this is 20 times the rate (approximately 700 km^2 per annum) at which marine areas have been afforded protection over the same period.

As highlighted in Chapter Ten, Canada lags in meeting its international commitments to establish a network of MPAs by 2012. Only eight site-specific MPAs exist to date under the *Oceans Act*: two in the Pacific (Bowie Seamount, Endeavour Hydrothermal Vents), five in Atlantic Canada (Musquash Estuary, Basin Head, The Gully, Eastport, Gilbert Bay), and one in the Arctic (Tarium Niryutait Marine Protected Area). No marine wildlife areas have been designated. Four national marine conservation areas have been established, namely, Fathom Five National Marine Park, Gwaii Haanas National Marine Conservation Area Reserve, Lake Superior National Marine Conservation Area, and Saguenay-St. Lawrence Marine Park (Parks Canada n.d.). With the inclusion of other protected areas, such as migratory bird sanctuaries and national wildlife areas with marine components, and the over 700 provincial or territorial MPAs, Canada's total number of MPAs was inventoried in 2010 at 797, accounting for less than 1% of Canada's oceans (DFO 2010b).

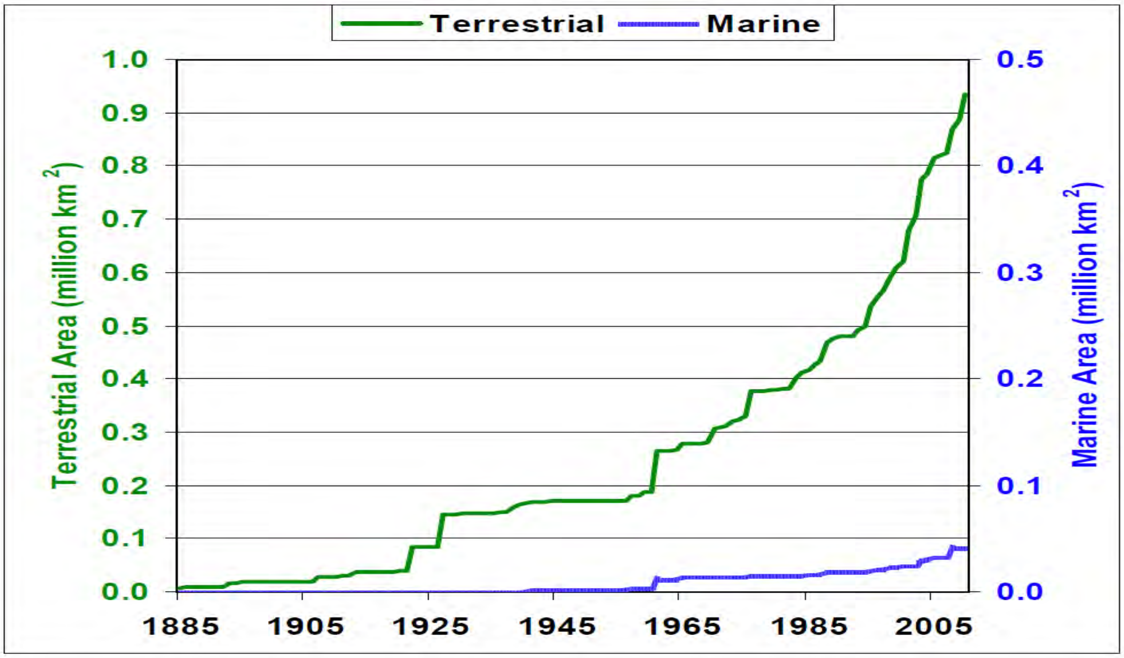


Figure 12.1. *Trends in the areal extent of terrestrial and marine protected areas in Canada. Note the different scales of the vertical axes. Source: Environment Canada (2010).*

Progress on the establishment of MPAs looms on the horizon. Pursuant to the Health of the Oceans initiative, the federal government has committed to designating six Areas of Interest as MPAs by March 2012. Three areas (St. Anns Bank, Shediac Valley, American Bank) were designated Areas of Interest on 8 June 2011. The Scott Islands archipelago in BC remains a proposed marine wildlife area site (Environment Canada n.d.). Parks Canada has committed to designating a national marine conservation area in Lancaster Sound (eastern Arctic). As highlighted in Chapter Eleven, the recent National Framework for Canada's Network of Marine Protected Areas promises to push forward federal-provincial-territorial cooperation in establishing a MPA network. This would be by means of the formation of bioregional network planning teams in 12 oceanic bioregions and the Great Lakes and the development of bioregional MPA network action plans (Government of Canada 2011).

Moving from MPA network rhetoric to reality remains a challenge, and timely and effective implementation of the National Framework will be crucial. The Aichi biodiversity target, adopted in 2010 under the Convention on Biological Diversity, calling for protection of 10% of coastal and marine areas by 2020, remains a long-term goal.

As steward of a high proportion of the world's coastlines and marine waters, Canada should consider adopting more ambitious targets for MPAs. Expanding fisheries closures in existing MPAs is identified as a major challenge, considering that 160 of 161 Pacific coast MPAs designated by federal, provincial, or municipal authorities are reportedly open to some commercial harvesting within their bounds (Robb et al. 2011). A recent report commissioned by the Canadian Parks and Wilderness Society has called for the establishment of 'no take' reserves, spanning no less than 30% of each bioregion of Canada, the intent being to protect critical marine wildlife habitat (Jessen et al. 2011). A 2009 Blue Carbon report, authored by some of the world's leading scientists and produced through inter-agency collaboration, including UNEP, FAO, and IOC-UNESCO, highlights the critical role coastal ecosystems play in sequestering carbon in the marine realm, and it calls for the immediate protection of at least 80% of remaining seagrass meadows, salt marshes, and mangrove forests by means of effective management (Nellemann et al. 2009).

ii. Putting Principled Governance into Fisheries Management Practice

1. Policy Context

Although overfishing has significantly affected Canadian marine biodiversity, appropriate fishing practices can be mitigated through judicious regulation and by attaining appropriately designed management objectives that will strengthen the resistance and resilience of aquatic systems to climate change. In Canada, aboriginal and recreational fisheries generally (but not always) have relatively small effects on marine populations and biodiversity, so instead, this Report focuses on the management of commercial fisheries that are regulated by DFO.

DFO has developed a two-part Sustainable Fisheries Framework (hereafter, the Framework; DFO 2009a). The first comprises five key policy documents (in addition to a forthcoming policy on bycatch) relating to conservation and sustainable use, as discussed in Chapter Eleven:

- A Fishery Decision-making Framework Incorporating the Precautionary Approach (DFO 2009b);
- Policy for Managing the Impact of Fishing on Sensitive Benthic Areas (DFO 2009c);
- Policy on New Fisheries for Forage Species (DFO 2009d);
- Canada's Policy for Conservation of Wild Pacific Salmon (DFO 2005a);
- Wild Atlantic Salmon Conservation Policy (DFO 2009e).

The second part of the Framework includes planning and monitoring tools, such as Fishery Checklists and Integrated Fisheries Management Plans (IFMPs). A wide variety of species groups across Canada have IFMPs, including invertebrates (such as lobster, shrimp, clams, and snow crab), groundfish, Pacific salmon, pelagic species, and Atlantic seals (http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/ifmp-gmp/index-eng.htm; accessed 20-11-11). IFMPs are termed 'integrated' because they aggregate information about a fishery's management objectives, management measures (regulations, such as quotas designed to achieve those objectives), an overview of the fishery (past and present), and a compliance plan. (IFMPs should not be confused with the IMPs mentioned in the previous section.)

Fishery Checklists are used within DFO to assess whether relevant issues have been addressed by scientists and managers; the checklists ask numerous questions similar to those asked during the Marine Stewardship Council's (www.msc.org; accessed 20-11-11) certification process (e.g., Are there objectives? Has bycatch been quantified? When was the stock last assessed?).

DFO describes the Framework as providing "... the foundation of an ecosystem-based and precautionary approach to fisheries management in Canada" and "... a key instrument in developing environmentally sustainable fisheries that also support economic prosperity in the industry and fishing communities" (DFO 2009a). The Framework essentially provides a new ecosystem-based context for traditional single-species management, as well as a framework for broader ecosystem-level considerations. (Effective single-species management is a pre-requisite for achieving an ecosystem-based approach and for ensuring effective conservation of Canadian marine biodiversity.)

Although a single-species focus has historically dominated both scientific advice and management decisions in large-scale commercial fisheries around the world (Mace 2001), the Framework provides a Canadian approach to various aspects of ecosystem-based fisheries management (EBFM). This framework reflects the growing recognition internationally that fisheries will only be sustainable in the long run if management agencies regulate them in an ecosystem context (Gislason et al. 2000; Sinclair et al. 2002). In general terms, an ecosystem approach to fisheries typically "strives to balance diverse societal objectives, by taking into account the knowledge and uncertainties about biotic, abiotic and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries" (Garcia et al. 2003). Furthermore, sustainable use of biodiversity is a pre-requisite for social and economic sustainability. As part of ecosystem-based fisheries management, decisions about management objectives and management measures need to account for the sustainability of ecosystem components and attributes, other than the main target species. In several jurisdictions, policies and management regulations have been modified to reflect this more comprehensive viewpoint (Murawski 2007; Smith et al. 2007).

Canadian practices and challenges in taking a more principled approach to fisheries management are reviewed through a five-part analysis that follows. Canadian efforts to apply a precautionary approach in single-species management are described first, followed by a more general evaluation of how Canada has fared in implementing the precautionary approach. The extent to which Canada has implemented ecosystem-based fisheries management is a third point of assessment. The role of eco-certification in promoting sustainable fisheries is then highlighted. Examples of how Canada has attempted to enhance public participation in fisheries management rounds out the discussion.

2. Precautionary Single-Species Management – A Contribution to EBFM

Implementation of the precautionary approach in single-species management in Canada, both in terms of defining biological targets and meeting them through the implementation of appropriate management measures, shows relatively weak implementation to date. Targets are not clear in many cases and still need to be defined for most fish stocks. Moves to define single-species targets and actions to meet them will represent key steps toward achieving sustainable use of Canadian marine biodiversity.

BC’s groundfish fishery represents an exception to Canada's relatively weak record for implementing fisheries management that better incorporates biodiversity considerations. In addition to having 100% dockside monitoring of off-loaded catch, it is highly advanced (nationally and internationally) at implementing two key features of responsible, modern-day fisheries management. The first is 100% at-sea monitoring of trawlers, which started in 1997 and was extended to a similar monitoring of all groundfish fishing vessels in 2006. The costs of these monitoring systems (e.g., on-board observers, electronic video monitoring and subsequent video auditing) are borne by vessel owners. The second feature, initiated in 2011, requires all groundfish vessels to be responsible for 100% of their multi-species catch, regardless of the catch portion retained (DFO 2011a). This 100% responsibility means that each vessel must either cease fishing after exceeding its quota for a particular species by some temporary 'overage' amount, or it must purchase quota from elsewhere (Adam Keizer, DFO, Vancouver, personal communication, 12 April 2011). Discards are recorded via observers or video and estimated losses from mortality are deducted from vessel quotas. This situation creates an incentive for harvesters to learn how to fish 'cleanly'.

To the Panel's knowledge, the electronic video monitoring systems that are standard on the Pacific coast are not used on the Atlantic coast, and on-board observer coverage is sparse. Some notable exceptions to the latter are evident in the lobster and northern shrimp fisheries, and for large (>65-foot) trawlers (Greg Workman, DFO, Nanaimo, personal communication, 4 April 2011; Susanna Fuller, Ecology Action Centre, Halifax, personal communication, 26 April 2011). From a national perspective, this clear inconsistency in catch monitoring practices between Canada's east and west coast groundfish fisheries is inconsistent with any national commitment to sustain marine biodiversity.

3. Precautionary Approach: Biological Reference Points

Within the context of Canada's national and international commitments to conserve marine biodiversity (Chapters Ten and Eleven), there is a need for Canada to develop fishery management plans that are quantitatively explicit and that formally acknowledge and utilize science-*determined* (as opposed to science-*based*) reference points. Science-determined reference points are those determined by scientists, using scientific models that are also applied elsewhere in the world to identify reference points; science-based reference points are the result of a consultation process with industry.

Those with a vested interest in the persistence of fish populations and the sustainability of fisheries (i.e., all Canadians) need to be confident that there exists a long-term plan to achieve both. Such a plan would also need to specify how to promote recovery if, for any reason, a population becomes seriously reduced. It seems self-evident that a fisheries management strategy should include a plan for how to manipulate harvest levels in such a way as to maximize the probability that a target level of abundance can be achieved in as expedient a time as is biologically feasible (albeit possibly subject to longer times as a result of social and economic considerations). Such a plan would articulate four key elements: (i) a science-determined target reference point (TRP) for spawning stock size; (ii) a timeline to achieve the target if spawning stock size is below the TRP; (iii) harvest control rules to govern changes in fishing mortality with changes in spawning stock size; and (iv) a science-determined limit reference point (LRP), also defined in terms of spawning stock size (cf. FAO 1995a).

The UN Fish Stocks Agreement makes explicit recommendations that Parties determine stock-specific TRPs and LRPs on the basis of the best scientific information available, and the actions that must be taken if the reference point thresholds are crossed. The FAO Guidelines on the Precautionary Approach (FAO 1995a) note that when a LRP is being approached, measures should be taken to ensure that the LRP is not crossed (Box 12.1). These reference points are often expressed as a depletion measure, e.g., some fraction of the biomass that generates the maximum sustainable yield, or MSY (B_{MSY}), or a fraction of the unfished equilibrium biomass (B_0) (cf. Chapter Five). The Sustainable Fisheries Framework developed by DFO articulates an Upper Stock Reference (USR) – the stock biomass that distinguishes a fish stock's 'healthy zone' from its 'cautious zone' (Figure 12.2). The harvest control rule is termed a 'removal reference' by DFO, which indicates the maximum harvest at a given estimated stock biomass.

Box 12.1. Biological reference points and the harvest guideline.

An important caution is necessary here regarding an apparently common misinterpretation of harvest control rules in Canada (e.g., DFO's 'removal reference' or, as referred to in other documents, 'maximum removal rates' and 'total allowable mortality'). The misinterpretation appears in figures in numerous DFO documents, including "A Fishery Decision-Making Framework Incorporating the Precautionary Approach" (DFO 2009b). In those documents, the relationship between removal rate and estimated stock biomass is usually shown with the lower inflection point (the point at which the removal rate goes to zero) occurring exactly *at the LRP, i.e., the boundary between the critical and cautious zones (Figure 12.2). However, according to the originating FAO (1995a) document and to practices advocated in most advanced fisheries management agencies outside of Canada, this point is not placed correctly. Instead, the harvest rate should drop to zero at some stock biomass (ideally to be determined by empirically based simulation analysis)* above *the LRP to reduce, to an acceptable level, the chance of falling into the critical zone (Figure 12.2). That uncertainty of moving into the critical zone results from the many sources of variation in outcomes in fisheries caused by natural variability, data uncertainties, and implementation uncertainty. Similarly, there is no inherent reason why the removal rate function should start to decrease from its maximum at exactly the stock biomass that separates the cautious zone from the healthy zone (DFO's Upper Stock Reference, Figure 12.2). Instead, the removal rate could be reduced at some other stock biomass, depending on the management objective.*

Although it might appear to some fisheries managers that specifying such a pre-agreed-upon, state-dependent harvest control rule is too inflexible and constraining, this approach has numerous precedents in environmental management, health, and other fields. For example, Canadian provincial and federal agencies have clear rules about actions that must be taken if water quality standards are not met. If coliform bacteria exceed some threshold, users are required to boil water and actions are taken to locate and eliminate the source of contamination. Similarly, if the concentration of some pollutant such as PCBs (polychlorinated biphenyls) in shellfish exceeds a certain value, the area is closed to harvesting of shellfish, and it stays that way until the concentration drops to an acceptable level. There are many instances of such closures in Canada. The advantage of having such pre-identified procedures is that action is taken quickly. Actions for managing fisheries should be treated the same way. When the indicator of status of a fish population (or other valued ecosystem component) reaches some level, a pre-agreed-upon action should be taken immediately, as described by the harvest control rule. Relevant parties should not spend time deliberating and negotiating as to what should be done. This latter point is an advantage in fisheries jurisdictions that have already implemented this type of harvest control rule, such as South Africa, New Zealand, Australia, Norway, parts of the European Union, and the US. Scientists and managers in these jurisdictions are better able to focus on developing and taking effective actions, rather than on time-consuming negotiations each year.

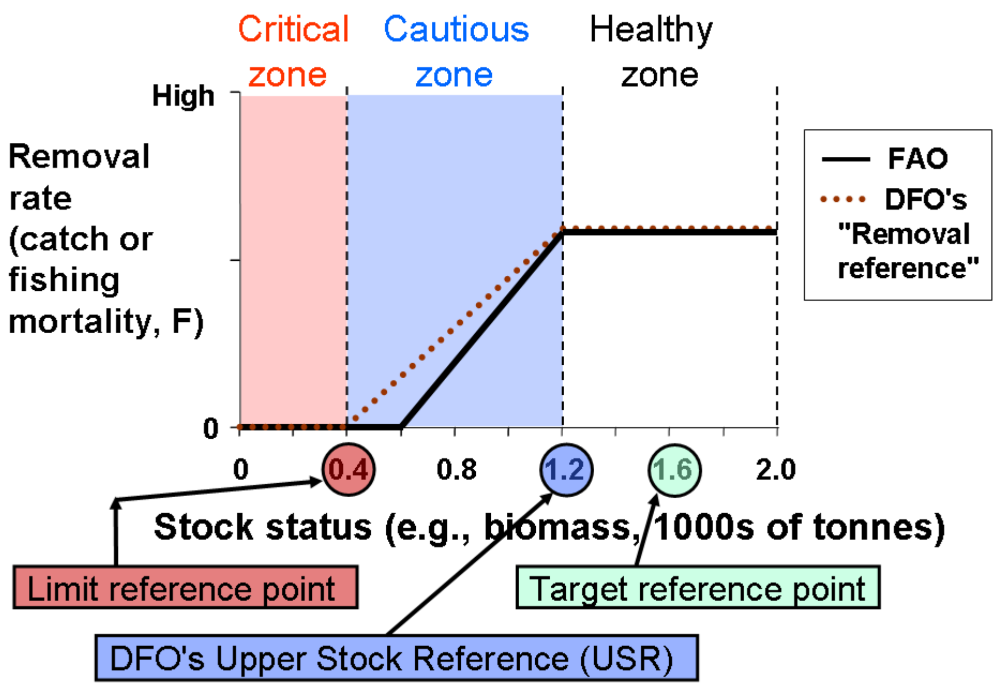


Figure 12.2. *Two generalized examples (dashed and solid lines) of a harvest control rule for a fish stock in which the harvest rate on the stock is a state-dependent function, meaning that it is related to estimates of the current stock size. See Box 12.1 for further information.*

In contrast to other developed fishing countries, Canada has not explicitly, or formally, adopted reference points in the management of most marine fisheries. For example, 20 years after the collapse of Newfoundland's northern cod (once one of the largest fish stocks in the world), DFO has yet to articulate a quantitative recovery target, yet alone a rebuilding timeline, for this stock. The Panel finds this unacceptable. One consequence of this lack of initiative is that, among industrialized fishing nations, the status of Canada's marine fish stocks is among the worst in the world. Using the stock biomass at which the MSY is estimated to be obtained as a TRP (estimates of B_{MSY} were obtained from stock assessments or surplus production models, as reported by Worm et al. [2009] and Hutchings et al. [2010]), the current biomass estimates for Canadian marine fishes are considerably lower than those of other key industrialized fishing nations and international fisheries management bodies (Figure 12.3).

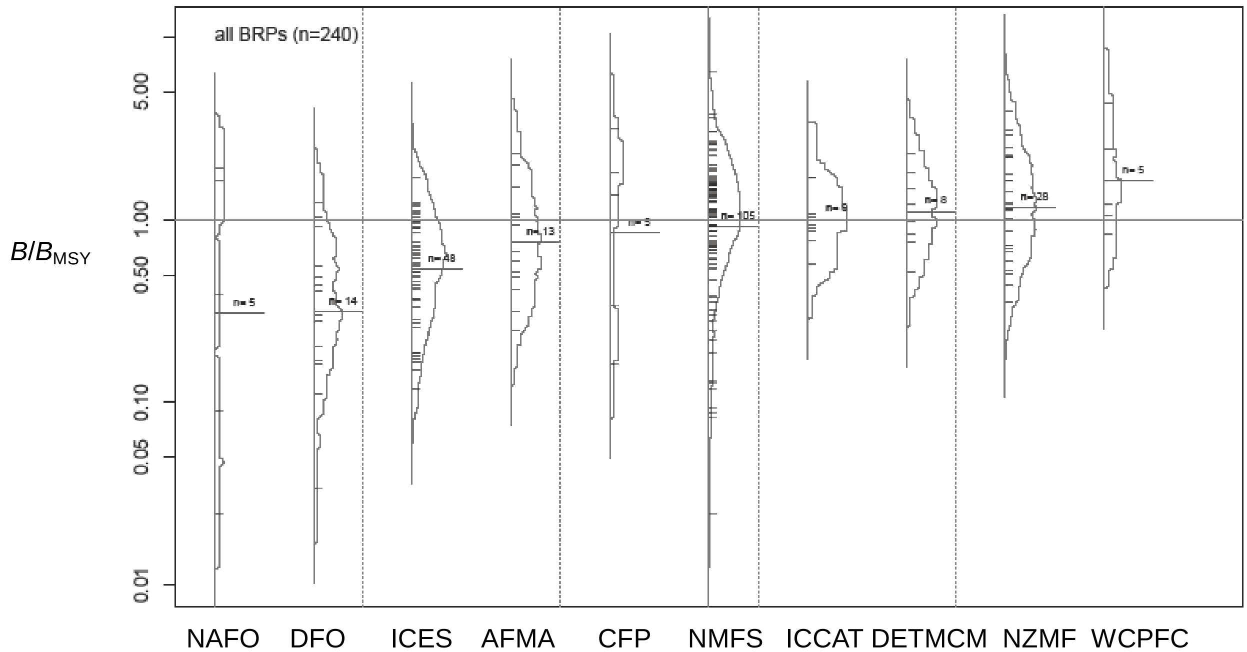


Figure 12.3. *Comparison of current spawning stock biomass (B), with the estimated spawning stock biomass at which the maximum sustainable yield would be obtained (B_{MSY}) for marine fish stocks assessed by various national and international agencies (NAFO: Northwest Atlantic Fisheries Organization; DFO; ICES: International Council for the Exploration of the Sea; AFMA: Australia Fisheries Management Authority; CFP: Argentina's Consejo Federal Pesquero: NMFS: U.S. National Marine Fisheries Service; ICCAT: International Commission for the Conservation of Atlantic Tunas; DETMCM: South African Department of Environment and Tourism, Marine and Coastal Management; NZMF: New Zealand Ministry of Fisheries; WCPFC: Western and Central Pacific Fisheries Commission). Medians are indicated by long horizontal lines; individual stocks are indicated by short horizontal lines. Note that the vertical axis is a logarithmic scale, with the horizontal line at $B/B_{MSY} = 1$.*

Despite a lack of progress in policy implementation, scientific efforts to estimate reference points have been ongoing for many years (Shelton and Rice 2002; DFO 2007a) and these efforts continue (e.g., DFO 2011b). DFO's Precautionary Approach document (DFO 2009b) suggests that scientists use a default limit reference point of $0.4B_{MSY}$ and an upper stock reference point of $0.8B_{MSY}$, if it is not possible to derive other values. Regrettably, few west-coast fisheries have biological reference points, and even fewer have quantitatively derived biological reference points that differ from the default values. Species for which reference points have been estimated include Pacific halibut (*Hippoglossus stenolepis*) and Pacific hake (*Merluccius productus*) (both of which are managed under international agreements with the US), sablefish, Pacific cod (*Gadus macrocephalus*), Pacific ocean perch (*Sebastes alutus*), and Pacific herring (*Clupea pallasii*). For Fraser River sockeye salmon, reference points were derived by applying a stochastic simulation modelling method (e.g., Holt et al. 2009); it represent the culmination of work conducted over many years through a collaborative process known as the Fraser River Sockeye Spawning Initiative (DFO 2010c). Biological reference points should preferably be set via quantitative analyses of data, because the default values of $0.4B_{MSY}$ and $0.8B_{MSY}$ contained in DFO's Precautionary Approach document (DFO 2009b) are not necessarily appropriate for any particular fishery. Furthermore, the default value of $0.4B_{MSY}$ is biologically more risk-prone than the analogous reference point for the US where a stock is defined as being overfished if its biomass is below $0.5B_{MSY}$ (Rosenberg et al. 2006).

The precautionary approach is also at the core of DFO's policies on wild Pacific salmon (DFO 2005a) and Atlantic salmon (DFO 2009e). Quantitative analyses have been done for Pacific salmon to identify which indicators and metrics are most reliable for setting appropriate ‘benchmarks’, i.e., states of salmon populations that DFO equates with biological reference points (Holt et al. 2009). However, although the methods have been identified, DFO has yet to conclusively determine benchmarks for most Pacific salmon populations. In contrast, Canadian Atlantic salmon populations have biological reference points that have changed negligibly over the past half-century. The spawning escapement required to meet the conservation target of a particular population is based on the number of eggs per unit area of fluvial rearing habitat (or lacustrine rearing habitat in Newfoundland) estimated to maximize the number of smolts produced by each population (Potter 2001; Chaput 2006).

One challenge for DFO in defining LRPs, USRs, and harvest functions is the large number of analyses required. For instance, there are 55 species-area combinations of managed groundfish units on the west coast alone, and most of these (e.g., numerous Pacific rockfishes and flatfishes) have not been assessed for many years. Although the intention is to develop reference points for Pacific groundfish stocks as they are re-assessed, the scientific personnel capacity of DFO's west-coast Science Branch is now limited to conducting only four to six groundfish stock assessments per year (Greg Workman, DFO, personal communication, 4 April 2011).

The Pacific sablefish fishery is the most marked exception to the slow progress in Canada at developing reference points and harvesting rules. In the sablefish fishery, catch quotas are now set by managers on the basis of biological reference points and a harvest control rule that were established through a rigorous, multi-year, collaborative simulation modelling process known as management strategy evaluation (MSE) (Box 12.2). That process involved the fishing industry, DFO scientists and managers, and academics (Cox and Kronlund 2008; Cox et al. 2011). It is particularly noteworthy that the west-coast Canadian sablefish fishery is one of only about 25 fisheries worldwide to have used the MSE method to generate accepted management procedures (Andre Punt, University of Washington, Seattle, personal communication, 8 April 2011).

Box 12.2. Management Strategy Evaluation (MSE).

The stimulus behind the development of Management Strategy Evaluation (MSE) was the realization that there are many uncertainties in fishery systems that make forecasts of fish abundance, distribution, and productivity quite error-prone. Estimates of vulnerability of fish to fishing gear and to the dynamics of fishing fleets are also subject to error (Hilborn 1979; Walters 1986; de la Mare 1998; Sainsbury 1998; Smith et al. 1999). To determine how best to meet management objectives in the presence of such uncertainties, MSE is based on Monte Carlo computer simulation models (i.e., ones that include random effects) that best represent those major stochastic processes, as well as data collection, stock assessment, and management decision making processes. The latter three elements are called the management procedure (MP) and the simulated decision process is a state-dependent decision rule, e.g., a specified maximum harvest rate that depends on the current estimate of fish stock abundance. The simulation model is run across thousands of Monte Carlo trials for each hypothesis about how the natural system dynamics work and all possible MPs to find the combination of the three MP elements that is most robust for meeting the initial management objectives across the widest range of assumptions about underlying system dynamics. Although the MSE method must be used carefully (Rochet and Rice 2009; Butterworth et al. 2010), it is now recognized internationally as the best approach for accounting for multiple sources of uncertainty and their resulting risks (Butterworth and Punt 1999; Sainsbury et al. 2000).

Uncertainties frequently lead to unacceptable outcomes. A key element of the precautionary approach is to estimate magnitudes of uncertainties and their associated risks, so as to improve the decision-making process. DFO's west-coast groundfish group is starting to apply a step-wise process known as Ecological Risk Assessment for the Effects of Fishing (ERAEF). This process, developed in Australia by the mid-2000s, has been applied to over 1800 species and 30 Australian fisheries (Smith et al. 2007; Hobday et al. 2011). The ERAEF framework is hierarchical and flexible enough to deal systematically with a range of data-poor to data-rich scenarios (Box 12.3).

Previous chapters highlight the range of fishing effects that pose risks to Canadian biodiversity, and also underscore the paucity of information with respect to effects upon various ecosystem components. To make the most effective use of existing knowledge, information, and data, and to adopt a precautionary approach to the management of fishing impacts on biodiversity, a systematic risk-assessment process needs to be applied to Canadian fisheries. Such a risk-assessment framework, based on the Australian ERAEF, is, as previously noted, currently being explored for Pacific groundfish. This framework, because of its hierarchical approach, which can deal with data-rich as well as data-poor situations, is particularly appropriate for dealing with biodiversity concerns. One important step, as in all risk assessments, is to clarify the management/conservation objectives at a level detailed enough to specify measurable indicators that can reflect how close a system is to reaching the objectives. In this respect, the ERAEF approach involves stakeholders as well as managers. Another key element of these risk assessments is a projection of how human activities, when combined with natural processes, might alter ecosystem dynamics and biodiversity. This is particularly challenging when data are limited, in which case expert opinions play an important role.

Box 12.3. Australia's Framework for "Ecological Risk Assessment for the Effects of Fishing" (ERAEF).

Implementation of an ecosystem approach to fisheries is widely seen as challenging, owing to the scale and range of issues that need to be addressed, and the paucity of data and understanding to provide an evidence base. Although several commentators suggest that waiting for more information should not be an impediment to implementation (Murawski 2007), there are few practical examples of the process.. One notable exception is the Australian approach to Ecological Risk Assessment for the Effects of Fishing (ERAEF), which seeks to define the probability that a given management objective relating to a given component of the ecosystem, will not be achieved (Hobday et al. 2011). The ERAEF is applied to target species, by-product and bycatch species, threatened, endangered and protected species, habitats and ecological communities, because the state of these components is broadly assumed to reflect the state of the ecosystem. The strength of the ERAEF is that it is based on a connected and hierarchical approach to risk assessment within a single framework. At the lowest level of analysis in the framework, the approach is qualitative and data demands are low, but at the highest level, quantitative analysis is required. Many activities that may pose a risk to meeting management objectives can be screened out at the qualitative level, leaving a subset of high-risk activities that may require management action. The approach is precautionary (see earlier section in this chapter), to the extent that fishing is assumed to pose a high risk to ecosystem components in the absence of logical argument or evidence to the contrary. ERAEF has been applied in Australian federally managed fisheries. The Australian Fisheries Management Authority (AFMA) then uses the results to develop management strategies for each fishery. They plan to apply the method to each sub-fishery (gear type within a managed fishery,) every 3-5 years. To date, 31 sub-fisheries have been assessed (Hobday et al. 2011). This approach makes good use of existing knowledge, information, and data, but focuses on risks associated with the ecosystem effects of fishing rather than the social and economic issues. Modifications of ERAEF are being developed and applied by the Marine Stewardship Council and US National Marine Fisheries Service.

4. Ecosystem-Based Fisheries Management

Biodiversity conservation benefits resulting from effective, single-species management contribute to ecosystem-based fishery management, but will need to be supplemented by management measures to meet specific biodiversity targets. In several jurisdictions, biodiversity targets are in place for habitats, species, food webs, and management measures over and above what is needed to meet single-species targets.

Canada's policies with respect to the Sustainable Fisheries Framework establish an appropriately broad strategic framework, incorporating both sustainability and ecosystem concepts. However, the record for implementing these policies varies widely across Canada's fisheries. Shelton and Sinclair (2008) concluded that "... with few exceptions, Canada has not implemented effective harvest strategies to convert policy on sustainability into action". Here, they were referring to single-species harvest rates, which contribute to EBFM, provided they are sufficiently low. Additional progress with respect to implementing EBFM harvest strategies has been made in some fisheries more than others, but implementation appears to have been hampered by both limited scientific information on ecosystem interactions and lack of clarity about how managers could use ecosystem-level information.

When compared to other major fishing nations such as Australia and New Zealand, Canada is progressing slowly with respect to incorporating ecosystem indicators into scientific guidance. This applies both to what is available for managers and what can be streamed into the decision-making framework. This lag exists, even though the major enabling legislation was implemented at about the same time in Canada, Australia, and New Zealand (1996 for Canada's *Oceans Act*, Australia's 1999 *Environmental Protection and Biodiversity Conservation Act* (EBFC), and New Zealand's 1996 *Fisheries Act*). One of Australia's leading fisheries scientists, A.D.M. Smith, stated that after the Australians EPBC Act was passed, he and his colleagues worked intensively to develop methods for producing scientific advice to assist managers in achieving a revolutionary ecosystem-based management system based on a precautionary approach (A.D.M. Smith, personal communication, 14 May 2010). This intense legislatively driven research activity is the main reason that Australian fisheries science and fisheries management are, from a global perspective, at the leading edge. Essentially, the Australian government created the legally binding requirements necessary to encourage proactive development of ecosystem-based, precautionary management methods and the science to go along with them (e.g., substantial new science staffing and research funding; clear accountability for meeting the terms of the legislation). The 2008 European Marine Strategy Framework Directive (MSFD) places a similar onus on European member States.

These conditions and legally binding requirements have not been matched in Canada, which might explain the relatively slow implementation of ecosystem-based, precautionary management methods. Although additional DFO science staff were assigned to the SARA Directorate and the Oceans Directorate, there still appears to be too little capacity in other facets of the DFO Science Branch to respond to additional requests for science advice. Moreover, unless managers of particular fisheries request such input, DFO scientists will not necessarily set high priority on producing the scientific advice needed for ecosystem-based, precautionary management (see in particular DFO 2011c).

Canada's policies for conservation of wild Pacific and Atlantic salmon recognize the need for consideration of ecosystem-level indicators (DFO 2005a, 2009e; Irvine et al. 2005 for Pacific salmon). However, specific, ecosystem-related sections have yet to be implemented within the policies. Ecosystem concerns are highlighted in DFO's Policy on New Fisheries on Forage Species, which explicitly recognizes the need to limit harvesting in order to provide some forage fish, such as herring, as food for other species. West coast scientists are currently evaluating the need to leave some portion of Chinook salmon populations as food for killer whales. As well, the Eastern Scotian Shelf Integrated Ocean Management Plan (ESSIM; DFO 2007b), a high-level strategic plan developed collaboratively by ocean stakeholders and government, sets out goals, objectives, and strategies for collaborative governance, integrated management, sustainable use, and healthy ecosystems. It is currently unclear how effective the ESSIM Plan is at maintaining ecosystem health.

From the standpoint of ecosystem management, sharks and rays are of interest because, in recent years, they have been recognized as amongst the most vulnerable and threatened marine fish species. According to one scientist, Dr. Nicholas Dulvy (Co-Chair, IUCN Shark Specialist Group), Canada was "...one of the first countries to develop and implement a fisheries management plan…for sharks (in 1994)". He further stated in his submission to the Panel that, "Canada has done more than most countries, by establishing quotas for a few shark and ray species, limiting the number of fishing licenses, imposing fishing gear restrictions and other restrictions such as fishing seasons, area limits, licensing, quota allocations, bycatch (landings) limits and a finning ban (Godin and Worm 2010)". As well, "There is no direct exploitation of pelagic sharks on the Pacific coast; the landing of sharks taken as bycatch is prohibited in other than trawl and hook and line fisheries (Godin and Worm 2010)". However, Dr. Dulvy states that "There is considerable room for improvement... shark bycatch is not restricted in swordfish and tuna longline fleets or in groundfish fixed gear fleets or [*sic*] Gulf region's mackerel fleet" and that "Canada ... does not specify actions to assess or mitigate threats to non-commercial or threatened shark species".

a. Evaluations of Effects on Biodiversity – Habitat Impacts

Trawling and dredging modify bottom habitats and can affect habitat structure, benthic productivity, and/or fish productivity (Chapter Eight; Sainsbury 1991; Asch and Collie et al. 2008). The effects on bottom habitats and biodiversity are currently being studied on the west coast by a group of scientists from DFO, the Canadian Groundfish Research and Conservation Society, and Simon Fraser University. For the most sensitive habitats, closure of areas to fishing is the only management measure that can effectively reduce fishing impacts. However, if impacts on habitats of low or intermediate sensitivity are managed by closures, displacement of fishing effort to more sensitive areas can occur, and the resulting risks will need to be estimated. Efforts to further protect marine habitat are ongoing, with research into less-damaging designs of trawl gear and the development of objectives and plans for additional protected areas (DFO 2007c, 2008). One positive example of collaboration in this regard is reflected by an agreement by the Pacific groundfish trawl fleet to close fishing in certain areas to protect glass sponge reefs (DFO 2011a).

b. Biodiversity Reference Points

Most biological reference points reflect the status of populations of harvested target species, but reference points for biodiversity indicators should also be developed to modify or determine harvest regulations. In Europe, for example, new policies and processes are starting to place an onus on fisheries managers to track biodiversity change and to identify and meet biodiversity targets for the marine environment. The European Marine Strategy Framework Directive (MSFD) of 2008 places a requirement on member States to achieve 'Good Environmental Status' (GES) for the marine environment, which requires that fishing impacts on aspects of biodiversity must be sustainable. Of 11 descriptors of GES that are identified in the MSFD, four relate to aspects of biodiversity that are known to be significantly affected by fishing ('biological diversity', 'commercially exploited fish and shellfish fish stocks', 'food webs', and 'sea-floor integrity'). The MSFD now defines a formal role for the Common Fisheries Policy (the EU instrument for fisheries management) in achieving GES for the marine environment. This role requires that fisheries managers should institute measures to ensure that fishing impacts on biodiversity are sustainable. At present, technical descriptions of indicators are being developed, at the same time as the debate on the selection of reference points to describe GES is underway. Within the existing Common Fisheries Policy, the EU has also requested that member States collect the data needed to report on the effects of fishing on the marine ecosystem as part of their required contribution to the Data Collection Framework. The indicators cover the conservation status of fishes, the proportion of large fish in the community, the life history composition of the fish community, and the size at maturation of exploited fishes; however, no targets have been agreed for them. To the Panel's knowledge, Canada does not have such biodiversity reference points.

5. Eco-certification

Non-governmental eco-labelling/eco-certification processes, such as those run by the Marine Stewardship Council (MSC), are putting pressure on fisheries management agencies worldwide, as well as the fishing industries, to make their practices more sustainable in the long term. The non-profit MSC, for example, sets its own standards for sustainable fishing, which are composed of principles and criteria based on the FAO Code of Conduct for Responsible Fisheries (1995b), as well as other internationally recognized documents (see Chapter Ten). MSC certification teams determine whether particular wild capture fisheries can use the MSC 'certified sustainable seafood' label in marketing initiatives, by evaluating the fisheries across three principles: (i) sustainability of fishing activities; (ii) maintenance of the relevant ecosystem's structure, productivity, function, and diversity; and (iii) effectiveness of the management system at meeting laws at all levels of jurisdiction.

As of 21 November 2011, the MSC had certified 134 fisheries worldwide (17 in Canada: six in the Pacific [all fishes]; 11 in the Atlantic [eight of which are invertebrates]) and 135 were undergoing assessment; these fisheries totaled annual catches of almost nine million tonnes, more than 10% of the global capture fisheries (www.msc.org/business-support/key-facts-about-msc; accessed 21-11-11). The MSC has thus created influential incentives for fisheries to maintain or increase their market share by meeting sustainability principles that are consistent with measures described in this Report.

6. Public Participation

While external participation in the science peer-review process has matured to a well-established procedure (DFO n.d.a.; Rice 2005, 2007), public participation in integrated management planning and in fisheries management has had a mixed record of success. One example of successful implementation of the public participation principle in integrated management planning is provided by the Eastern Scotian Shelf Integrated Ocean Management Plan (ESSIM Plan; DFO 2007b). The initiative began as a pilot study in 1998 and evolved to include a broad, multi-stakeholder dialogue in 2002. A Fishing Industry Framework Action Plan for Implementing Objectives has been prepared by an Industry-DFO Working Group aimed at ensuring that ESSIM Plan ecological and human-use objectives are incorporated into Integrated Fisheries Management Plans (DFO Maritimes Region 2009). Another good example of public participation is the lengthy consultation process that preceded the finalization of Canada's Policy for Conservation of Wild Pacific Salmon (DFO 2005a).

While acknowledging the progress that has been made, several aspects of the consultative process could be improved upon considerably. A comparative analysis undertaken by DFO in 2009 in support of a renewed stakeholder engagement for fisheries management (MacDonald 2010) noted a lack of consistency of the public participation structure and processes across the country, including differing regional approaches to membership on advisory committees, inconsistent and/or unclear roles of DFO and stakeholders in the different regional advisory process, and inconsistent financial and secretariat support. Meaningful participation of indigenous communities was highlighted as a significant challenge across Canada. In turn, some stakeholders (and in particular environmental NGOs) have raised concerns or expressed dissatisfaction with the limitations of consultation processes with which they have been involved. These criticisms relate mostly to accountability, transparency, and inclusiveness. Several stakeholders have identified a lack of DFO accountability with respect to some recommendations resulting from the consultations.

7. Fisheries Management and Biodiversity: Conclusions

Clearly, appropriate Canadian policies are in place and examples from other countries have been sufficiently well documented to enable implementation of the precautionary approach and ecosystem-based fisheries management in Canada. Slow progress at such implementation may be attributable to several factors, including a lack of the following:

- Legally binding requirements for establishing biological reference points and harvest control rules relating to them;
- Requirements (as stipulated by the US Magnuson-Stevens Reauthorization Act of 2006; see also Chapter Thirteen) to develop a recovery plan with specific corrective actions (within a given period) if a stock is being overfished (stock biomass is too low) or if overfishing is occurring (fishing-induced mortality is too high);
- Leadership/guidance from DFO to better support the fishing industry by putting in place management practices that help guide progress towards MSC certification, thereby giving all fisheries the option to achieve certification should they wish to apply;
- Acceptance by the fishing industry of the precautionary and ecosystem approaches.

The implementation of management measures to achieve sustainable use of target stocks will significantly reduce fishing mortality and the footprint of fisheries in Canadian marine ecosystems. Such implementation will also be a significant step towards reducing unwanted impacts on marine biodiversity. Effective implementation of existing policy is required while fisheries managers await agreement on targets set for wider conservation of biodiversity. In the longer term, single-species management measures will likely be further modified to meet these targets in the context of Integrated Fisheries Management Plans.

iii. Overcoming Slow SARA Implementation

The enactment of SARA in 2002 was a major step in Canada's commitment to the protection and preservation of Canadian biodiversity. The purposes of the Act are: to prevent wildlife species from being extirpated or becoming extinct; to provide for the recovery of wildlife species extirpated, endangered, or threatened as a result of human activities; and to manage species of special concern to prevent them from becoming endangered or threatened (SARA, s. 6). The tools through which SARA seeks to achieve those objectives include: an independent assessment of the status of the species based on best available scientific information; the protection of individuals, residences, and their critical habitats; a formal and on-going recovery planning process; environmental assessment for impacts of federal related projects to species at risk; substantial enforcement measures; and encouragement of financial support for recovery activities (see VanderZwaag et al. 2011).

Effective protection of Canadian wildlife at risk has been hindered by the slow implementation of SARA provisions. Implementation bottlenecks include: the federal listing process; adoption of recovery strategies, action plans, and management plans; and identification and protection of critical habitat (Mooers et al. 2007; SARAC 2009; David Suzuki Foundation et al. 2009; Findlay et al. 2009; Hutchings and Festa-Bianchet 2009; VanderZwaag et al. 2011).

The process for formally listing species under SARA that have been previously assessed by COSEWIC has been difficult. The main problems in listing include: the use of 'loopholes' (e.g., extended consultations of indeterminate time) to postpone federal listing decisions (VanderZwaag and Hutchings 2005); the consideration of socio-economic factors at the listing stage (Findlay et al. 2009); the discretionary authority of the Governor in Council (GIC, comprising federal cabinet ministers) to list species for SARA protection (VanderZwaag and Hutchings 2005; David Suzuki Foundation et al. 2009; Mooers et al. 2010); and a bias against listing marine aquatic species and northern species (Mooers et al. 2007; Findlay et al. 2009; Hutchings and Festa-Bianchet 2009).

As of 18 October 2011, 155 species assessed by COSEWIC as Extirpated, Endangered, Threatened, or of Special Concern had not been listed in Schedule 1 for protected actions (SARA Public Registry). In the case of 19 of these species, including 18 marine species, the GIC had decided not to list them, mostly on the basis of the socio-economic considerations. A further 59 species are included in the 2010 Report on Outstanding Species at Risk, which lists the species that have been subject to an extended process of consultation or have been referred back to COSEWIC for a new or revised assessment (SARA Public Registry 2010). Following the submission of COSEWIC's Annual Report to the Minister of the Environment, timeframes for the listing process have generally ranged between 19 and 40 months. However, the decision timeframe has been considerably longer in some cases (seven years in the case of the marine fish bocaccio, *Sebastes pinniger*).

The slow response from the government to adopt recovery strategies, even in violation of legal provisions, is a further target of criticism. A 2008 report of the Commissioner of Environment and Sustainable Development (CESD 2008) concluded that, as of June 2007, recovery strategies were required for 228 species, according to the statutory deadlines included in SARA. However, the federal government had adopted recovery strategies for only 55 species. As of February 2010, with 361 species listed as Extirpated, Endangered, or Threatened in Schedule 1, recovery strategies had been adopted for 144 species while, at the same time, work was ongoing for a further 190 species (Canadian Wildlife Service, in Statutory Review Process; 1 March 2011).

The second stage of recovery planning – the adoption of action plans – is virtually non-existent. The adoption of action plans required under SARA is not constrained by statutory time lines (VanderZwaag and Hutchings 2005; Mooers et al. 2010). As of December 2011, only four action plans hadbeen finalized (one freshwater mollusc: Banff Springs snail, *Physella johnsoni*; three terrestrial plants: Bolander's quillwort, *Isoetes bolanderi*, small whorled pogonia, *Isotria medeoloides*, and horsetail spike-rush, *Eleocharis equisetoides*) and three had been proposed. Action Plan Summary Statements pursuant to the requirements of SARA s. 50(4) had been issued for only four species.

SARA implementation has been further lacking in its identification of critical habitat. SARA only requires the identification of critical habitat in the recovery strategy or action plan stages, "to the extent possible", and lacks statutory time frames for the adoption of action plans, thereby leaving ample room for governmental discretion. In many cases, the federal government has not identified critical habitat in the finalized recovery strategies, and has justified the position because of the lack of sufficient scientific knowledge or certainty. As of February 2011, critical habitat had been partially or fully identified for 41 of 144 species with a finalized recovery strategy (Canadian Wildlife Service; House of Commons 2011). The federal government's weak interpretation of the SARA provisions with respect to critical habitat identification has been successfully challenged in the courts (*Alberta Wilderness Assn. v. Canada (Minister of Environment*) and *Environmental Defence Canada v. Canada (Minister of Fisheries and Oceans*)), and thus it is expected that forthcoming recovery strategies will be more proactive in identifying critical habitat. Indeed, many adopted recovery strategies have recently been modified to include critical habitat identification (SARA Public Registry).

Even in cases where critical habitat has been identified, its protection has been a further problem with respect to SARA implementation. The protection of identified marine (and freshwater) critical habitat does not operate automatically but is, instead, only implemented 180 days after its identification, and also upon an assessment of the effectiveness of the protection of critical habitat provided by other Acts of Parliament. In this respect, the federal government has explicitly stated, as a governmental policy, that "SARA's intent is to protect critical habitat as much as possible through voluntary actions and stewardship measures" (Government of Canada 2003), and that "an effort will be made to establish legal protection first using existing provisions in, or measures or authorities under, other Acts of Parliament" (Government of Canada 2009: 15). As a result, to date, there has been only one case where the federal government has triggered the protection of critical habitat through the specific protection of SARA s. 58, which prohibits the destruction of any part of the critical habitat of any listed endangered or threatened species. This critical habitat protection order was issued, probably due to a judicial action, rather than federal government's pro-activity (David Suzuki Foundation et al. 2009). For five species (including two marine species: northern bottlenose whale and North Atlantic right whale), the federal government concluded that critical habitat is protected by existing federal and provincial legislation, non-binding management instruments, and prospective legislation. This interpretation is currently under judicial review (*David Suzuki Foundation v. Canada (Minister of Fisheries and Oceans and Minister of the Environment)* under appeal). For other species, no statement has been issued on the effectiveness of the protection of other Acts of Parliament, nor have s. 58 prohibitions been triggered.

The management plans for species of Special Concern are also troublesome. From 119 species listed in SARA Schedule 1 as species of Special Concern, only 25 management plans have been adopted for 30 wildlife species (as of October 2011), and a further three management plans have been proposed but not yet finalized (SARA Public Registry). Management plans are adopted at a significantly lower proportion than recovery strategies, which suggests that the federal government has not put equal priority on preventing species from becoming threatened or endangered.

Further problems also exist in the implementation of the various tools that SARA considers for the protection of species at risk. They include the lack of conservation agreements and the limited policy guidance on key aspects of implementation, including the issuing of SARA permits and authorizations, harmful activities authorized in the recovery strategies, and enforcement and compliance (VanderZwaag and Hutchings 2005).

b. *Considering Legislative and Regulatory Strengthenings*

i. Re-Thinking the Oceans Act

While the *Oceans Act* has been subject to numerous criticisms (Chircop et al. 1995; Chircop and Hildebrand 2006; Mageau et al. 2009; McCrimmon and Fanning 2010; Jessen 2011), a key emerging issue is whether it provides an adequate legal foundation for marine spatial planning (MSP) and ocean zoning (Jessen 2011). Moving towards a MSP approach is being promoted, especially in the ESSIM context (Hall et al. 2011). DFO's Oceans and Coastal Management Division has undertaken policy research relating to MSP, including a study by a legislative auditor that examined the fit between marine spatial planning and federal legislation (Hall et al. 2011).

The *Oceans Act* certainly does not provide an 'ideal' legal umbrella for MSP. The Act imposes only 'bare bone' integrated management planning responsibilities, with no procedural or content details, and no mention of a marine spatial planning approach (the establishment of which has become a modern oceans governance trend; Schäfer 2009). While the Act provides specific authority to the GIC to make regulations, including zoning provisions for MPAs (s. 35(3)), no specific regulatory powers are granted for giving effect to integrated management plans. Under the present statutory framework, two options would exist for giving 'legal teeth' to a marine spatial plan. Existing statutory and regulatory authorities of federal and provincial governments may be used to control human uses in given marine areas. Regulations giving legal force to plans might also be issued, pursuant to the general power under the Act (s. 52.1) to pass regulations for carrying out the purposes and provisions of the Act (DFO 2002b).

Given the likely centrality of MSP, urged under the Convention on Biological Diversity as a tool for supporting sustainable marine biodiversity, re-thinking the adequacy of the *Oceans Act* should be a legislative priority. Key questions worthy of Parliamentary debate and guidance include: Should a MSP approach be mandated along with appropriate procedures to be followed for developing spatial plans? Might the role of provincial planning be legally enhanced, for example, through possible recognition of provincial coastal management plans and provision of financial support? Should there be a specific regulatory power for putting plans into practice or a specific approval requirement for proposed activities within planning areas?

ii. Modernizing the Fisheries Act

The need to modernize Canada's *Fisheries Act* (1868) in light of sustainability principles such as the ecosystem approach, precaution, and community-based management has been emphasized repeatedly (McRae and Pearse 2004; VanderZwaag and Hutchings 2005; VanderZwaag and Rothwell 2006) and was viewed as a priority in DFO's 2005-2010 Strategic Plan (DFO 2005b). Legislative attempts to reform the Act, however, have foundered. In October 1996, a major rewrite of the *Fisheries Act* was introduced in Parliament as Bill C-62, but the Bill died on the Order Paper when the 1997 general election was called (Côté and Kuruvila 2007). Further revisions of the Act were introduced in December 2006 (Bill C-45) and November 2007 (Bill C-32), but both of those bills died on the Order Paper when the parliamentary sessions were prorogued (Mageau et al. 2009). The future of legislative modernization remains uncertain. Following the aborted Bill C-32, no further proposed legislative revisions have been introduced in Parliament (as of January 2012).

If Canada is to attain an international leadership position in ocean governance, and if the nation takes its marine biodiversity commitments seriously, placing a high political priority on *Fisheries Act* modernization seems essential. The present lack of legislative guidance on fisheries management objectives, principles, and procedures, and the delegation of absolute discretion to the Minister of Fisheries and Oceans, is certainly out of step with international 'best practices', as judged by the sustainability-supportive fisheries legislation in countries such as the US (Territo 2000), Norway (*Marine Resources Act*; Chapter Two), and Australia (Gullett 2008).

In the US, explicit recognition of overfishing and the development of fishery management/rebuilding plans are addressed under the auspices of the *Magnuson-Stevens Fishery Conservation and Management Act* (www.nmfs.noaa.gov/sfa/magact/; accessed 20-11-11). Amendments in 1996 stipulated very clearly that any management plan prepared by the US Secretary of Commerce (analogous to the Minister of Fisheries and Oceans) shall contain measures necessary to prevent or end overfishing and to rebuild overfished stocks. This Act is an example of prescriptive, rather than discretionary, legislation, insofar as it specifies actions that the Secretary shall, or must, take if certain circumstances arise (in this case, if overfishing occurs).

The Act demands levels of transparency, clarity, and accountability that are absent from Canadian legislation. Sections 303 and 304 of the *Magnuson-Stevens Act*, for example, are very specific. A fisheries management plan shall specify objective and measurable criteria, i.e., reference points, for determining when a fishery has been overfished. Within two years of receiving advice that a fishery is overfished, the Secretary must establish a plan for rebuilding the overfished stocks such that rebuilding take place over a ten-year period. Although the 10-year time frame might not always be attainable, the key element to the legislation is that it requires that a re-building plan be put in place, and that limit reference points and rebuilding targets be fundamental components of such plans.

Given that it was under the auspices of Canada's *Fisheries Act* that the historically unprecedented depletions of Atlantic cod (and other marine fishes) took place, a logical argument could be made that it represents a sub-optimal legislative tool for fish population recovery and fishery rebuilding purposes. To explore this hypothesis, Hutchings and Rangeley (2011) searched for various keyword combinations that might reflect the degree to which various pieces of legislation are concerned with recovery or rebuilding. In the American *Magnuson-Stevens Act*, the words 'recovery', 'rebuild', 'overfishing', and 'target' appear 12, 27, 45, and 22 times, respectively. In the *Fisheries Act* (88 sections), the only one of the four words that appears is 'recovery', and it is there twice for the recovery of legal costs rather than for the recovery of a depleted fish stock.

Many possible legislative provisions to support sustainable fisheries and coastal communities may be gleaned from previously introduced fisheries bills. From a biodiversity perspective, key proposed modernizations include:

- Elevating sustainable development of Canada’s seacoast and inland fisheries as an overarching objective of the Act;
- Articulating key sustainability principles to be followed in fisheries management, such as the precautionary approach, public participation, and the ecosystem approach; and
- Establishing a Canada Fisheries Tribunal to decide sanctions for licence violations.

Further legislative measures should also be considered if marine biodiversity is to be adequately protected. Those measures include:

- Formally addressing the debilitating regulatory conflict within DFO to promote industry and economic activity on one hand, and the conservation of fish and fish habitat on the other;
- Requiring full ecological impact assessments for proposed fisheries;
- Encouraging the use of environmentally responsible fishing gears and fishing methods;
- Setting out clear and participatory procedures for integrated fisheries management planning;
- Mandating the following of scientific advice;
- Formalizing the explicit use of limit/target reference points and harvest control rules in fisheries conservation and management;
- Providing explicit and quantitative definitions of overfishing and recovery;
- Requiring recovery plans and rebuilding timelines for over-fished or depleted stocks; and
- Increasing political accountability and transparency in fisheries governance.

iii. Casting a Federal Legal Net for Sustainable Aquaculture

In the absence of federal legislation specifically addressing aquaculture, Canada continues to rely on a complex patchwork of federal and provincial laws to regulate the aquaculture industry (VanderZwaag et al. 2006). Following BC’s Supreme Court’s *Morton* decision in 2009, which ruled finfish aquaculture to be a fishery within exclusive federal jurisdiction, the federal government subsequently passed *Pacific Aquaculture Regulations* providing for the issuance of federal aquaculture licences with attached conditions. Similar regulations have not been issued for the Atlantic Provinces, where aquaculture licensing continues (with the exception of PEI) to be delegated to the provincial level, pursuant to federal-provincial MOUs (VanderZwaag et al. 2006). Provincial licensing in the Atlantic Provinces seems destined to persist, at least in the near term. In response to a question from the Panel as to whether consideration was being given to issuing federal aquaculture regulations applicable to the Atlantic region, DFO Deputy Minister Dansereu responded (Appendix 2):

> The British Columbia Supreme Court decision in the Morton case does not impact the regulatory authorities of other provincial jurisdictions. There are no changes to DFO's regulatory or legislative responsibility respecting aquaculture in these other jurisdictions. The Morton decision was made by a provincial court, and as such, its decision is limited to the province of British Columbia.

The existing legal patchwork of more than 70 pieces of federal and provincial legislation (CAIA n.d.) does not appear adequate for ensuring sustainable aquaculture and healthy marine biodiversity. The *Pacific Aquaculture Regulations,* being issued pursuant to the antiquated *Fisheries Act*, continue a wide discretionary approach to aquaculture licencing, without clear legislative guidance as to objectives, principles, and procedures. Existing aquaculture licences in Atlantic Canada may be open to legal challenge for being beyond the constitutional jurisdiction of the provinces.

The need for federal legislation specific to aquaculture has received considerable support. Various academic writers have emphasized potential benefits, including the assurance of a principled approach to aquaculture access and operations (VanderZwaag et al. 2006), clarification of property rights (Saunders and Finn 2006), and encouragement of an integrated regulatory approach (Wildsmith 1985). In a major critique of the federal role in aquaculture, the Standing Committee on Fisheries and Oceans has recommended enactment of a federal aquaculture act (House of Commons 2003). The Canadian Aquaculture Industry Alliance has been especially vocal about the need for Canada to join other major farmed seafood-producing countries in having dedicated aquaculture legislation. A poll conducted in April 2011 for the Industry Alliance found that eight in ten Canadians (81%) either strongly (40%) or somewhat (41%) supported a national aquaculture act (Abacus Data 2011).

In light of the anticipated growth of aquaculture in Canada, and the associated biodiversity issues discussed in Chapter Nine, the development and enactment of modern aquaculture legislation at the federal level should be a high political priority. Various practical questions will need to be considered. For example, should a stand-alone 'Sustainable Aquaculture Act' be pursued, or might aquaculture-related provisions be incorporated within a modernized *Fisheries Act*? And, are federal-provincial jurisdiction and roles best addressed through joint aquaculture licensing, some delegation of licensing and regulation to the provinces, or by some other means (VanderZwaag et al. 2006)?

iv. Considering SARA Legislative Amendments

The parliamentary review of SARA (initiated in 2009, ceased in 2011, and for which a public report is lacking), led by the House of Commons Standing Committee on Environment and Sustainable Development, generated some consensus that SARA's fundamental architecture represents a sound framework for the protection of species at risk. Some perceived deficiencies might be met through regulatory follow-through under SARA and more effective implementation efforts. Nevertheless, there are some key aspects for which legislative amendments are required.

One aspect is the species-oriented (or sub-unit of species) approach of the Act (House of Commons 2010a). Several sectors have advocated the strengthening of a multi-species and ecosystem approach to species at risk recovery and protection (Canadian Association of Petroleum Producers, in House of Commons 2009b; Congress of Aboriginal Peoples and Walpole Island First Nation, both in House of Commons 2010c; WWF Canada, in House of Commons 2010d). Specific amendments to different components of SARA have also been proposed, namely: listing of species at risk; the process and procedure for recovery strategy development and action planning; the use of incidental harm permits and authorizations under SARA; First Nations rights and role in the protection of species at risk; and the meanings of some key SARA concepts. Various amendments to the listing process have been proposed, including the establishment of precise timeframes for the 'extended-consultation' listing-decision process and a transparent evaluation and consultation process subsequent to a decision not to list a species at risk (Findlay, in House of Commons 2010e).

The need to streamline the procedure and process for developing recovery strategies and action plans has also motivated several amendment proposals. These include: establishing statutory timelines for the development and issuance of action plans (e.g., VanderZwaag et al. 2011; David Suzuki Foundation, in House of Commons 2010d; Findlay, in House of Commons 2010e); assigning the drafting of recovery strategies to recovery teams with participation of independent experts (David Suzuki Foundation, in House of Commons 2010d; Ontario Federation of Anglers and Hunters, in House of Commons 2010f); and establishing a peer-review body with the task of evaluating recovery strategies and action plans (SARAC 2009; Pearson, in House of Commons 2010e; Mooers, in House of Commons 2010e).

Amendments addressing the incidental harm permit and authorization provisions of SARA, and the authorized activities under recovery strategy statements, have also been advocated. Those amendments include:

- Revising the timeframes for incidental harm permits and authorizations currently issued under SARA (Canadian Association of Petroleum Producers, in House of Commons 2009b; Mining Association of Canada and Forest Products Association of Canada (FPAC), both in House of Commons 2010b);
- Ensuring appropriate monitoring and reporting, if timeframes for incidental harm permits and authorizations are extended (David Suzuki Foundation, in House of Commons 2010d);
- Including tolerance thresholds for disturbance in the recovery strategies, to clarify the impacts that may be allowed by a permit or authorization, particularly within critical habitat (David Suzuki Foundation in House of Commons 2010d);
- Providing exemptions from SARA's prohibitions for entities that enter, and comply with, conservation agreements (Canadian Electricity Association and Canadian Hydropower Association, both in House of Commons 2009b; FPAC, in House of Commons 2010b);
- Imposing procedural checks on issuance of incidental harm permits and authorizations (VanderZwaag and Hutchings 2005; VanderZwaag et al. 2011); and

- Restricting discretion to exempt activities from SARA's prohibitions and incidental harm permitting through recovery strategy statements (VanderZwaag and Hutchings 2005; VanderZwaag et al. 2011).

In addition, there is a need to clarify the meaning of several key concepts in SARA, including 'critical habitat', 'survival', 'recovery', 'damage', 'jeopardy', and 'destroy' (VanderZwaag and Hutchings 2005; David Suzuki Foundation, in House of Commons 2010d; SARAC, in House of Commons 2009a; Forest Products Association of Canada, in House of Commons 2010b).

v. Pondering Comprehensive Biodiversity Legislative Provisions

Both Australia and Norway have adopted comprehensive biodiversity legislation containing provisions that might be gleaned by Canada. Australia's *Environment Protection and Biodiversity Conservation Act 1999* (Cth.) has initiated a wide array of levers to ensure conservation of marine biodiversity, including the requirement of ministerial approvals for activities that will, or are likely to have, a significant impact on the marine environment (Art. 23); subjecting such approvals to principles of ecologically sustainable development (Art. 3A); requiring environmental assessments for Commonwealth-managed fisheries (Art. 147-154) (Haward and Vince 2008); providing a sound legal foundation for bioregional planning and requiring ministerial decisions to follow planning provisions (Art. 176); and establishing legal authority to issue regulations governing access to biological resources and their equitable sharing (Art. 301).

In June 2009, Norway adopted an *Act Relating to the Management of Biological, Geological and Landscape Diversity (Nature Diversity Act),* which includes various tenets worthy of emulation. For example, the Act sets overall management objectives for ecosystems (s. 4) and species (s. 5). The species conservation objective is "to maintain species and their genetic diversity for the long term, and to ensure that species occur in viable populations in their natural ranges" (s. 5). Decision-making practices in matters pertaining to biodiversity are to follow key sustainability principles (s. 7), such as the precautionary principle (s. 9), the ecosystem approach (s. 10), and user-pay systems (s. 11). Moreover, decisions taken must provide a statement on how the principles have been applied (s. 7).

vi. Enhancing Shark Conservation Measures

Various measures to enhance shark conservation have been proposed, including the mandatory live release of sharks of known conservation concern, specific gear modifications, and a catch-and-release policy for recreational shark fisheries (Godin and Worm 2010). Globally, a growing trend that Canada might follow is to more effectively address the practice of shark finning (Environment News Service 2011). The US recently passed the *Shark Conservation Act* (2010), which requires sharks to be landed with their fins naturally attached. Various jurisdictions, including Hawaii and Washington, have adopted prohibitions on the serving of shark fin soup; a recent article has suggested a parallel move at the provincial level in Canada (Jeffries 2011).

c. *Enhancing Transboundary and International Governance Arrangements*

A key focus of this Report is the status and changing nature of Canadian marine biodiversity in the wake of climate change, fisheries, and aquaculture, notably in the context of their associated management frameworks. However, many marine species are transboundary in nature and this raises additional governance challenges. To ensure a sustainable future for those shared populations, Canada should place a high priority on enhancing existing transboundary cooperative arrangements (Russell and VanderZwaag 2010). Priority transboundary cooperative initiatives include (Siron et al. 2009; Pudden and VanderZwaag 2010; Sanders and VanderZwaag 2010; Russell 2010; Russell and VanderZwaag 2010):

- Extending integrated management planning efforts across national maritime boundaries;
- Designating and managing bilateral and regional networks of MPAs;
- Expanding existing bilateral fisheries management arrangements with the US and with France (in relation to St. Pierre and Miquelon) beyond a focus largely on a few commercially important fish stocks to a broader ecosystem approach;
- Strengthening the implementation of sustainability principles, notably the ecosystem and precautionary approaches, within DFO and regional fisheries management organizations, e.g., NAFO and the International Commission for the Conservation of Atlantic Tunas.

Canada should aspire to take a leadership role in protecting marine biodiversity at the international level. The country could, for example, become a Party to the Convention on the Conservation of Migratory Species of Wild Animals (CMS). Among a long list of subsidiary agreements and memoranda of understanding aimed at protecting particular species, many of which are marine (CMS Secretariat 2011), the Memorandum of Understanding on the Conservation on Migratory Sharks (2010) is especially relevant for Canada. The MOU pledges signatories to cooperate on numerous fronts in conserving and managing the seven migratory sharks in the Northern Hemisphere listed in CMS Annex I. Signatories are urged to: apply ecosystem and precautionary approaches in managing directed and non-directed fisheries for sharks; improve research, monitoring, and information exchange on migratory populations; protect critical habitats, migratory corridors, and critical life stages of sharks; consider requiring sharks to be landed with each fin naturally attached; enhance national, regional, and international cooperation; and maintain species-specific national records of shark catches, landings, and discards.

In light of straddling leatherback and loggerhead turtle populations in both Atlantic and Pacific waters (DFO n.d.b.), Canada could also place priority on becoming a Party to the Inter-American Convention for the Protection and Conservation of Sea Turtles (IAC). The IAC, entering into force in May 2001, requires Parties to take various measures to protect sea turtles and their habitats. Canadian recovery strategies for leatherback turtles lend support for such Canadian participation. The Recovery Strategy for Leatherback Turtles in Pacific Waters (2006) sets an objective of supporting the efforts of other countries in promoting the recovery of the leatherback turtle population, and as a key strategy urges Canada to "ratify, respect and/or contribute to international instruments …. that promote leatherback protection and recovery (Pacific Leatherback Turtle Recovery Team 2006: 24).

Main Findings

- Compared to most developed nations, Canada has made little substantive progress in fulfilling national and international commitments to sustain marine biodiversity.
- Progress in meeting biodiversity obligations is impeded by the regulatory conflict within DFO to simultaneously promote industrial development and ocean conservation.
- Progress is also impeded by the absolute discretion afforded to, and absence of statutory prescriptive action demanded of, the federal Minister of Fisheries and Oceans.
- Despite enabling legislation, the aspirational quality of integrated planning initiatives has not been realized in practice, e.g., the promised national MPA network remains unfilled.
- Despite enabling policy, application of the precautionary approach, target and limit reference points, harvest control rules, and rebuilding plans are absent for most fisheries.
- The *Fisheries Act* is an insufficient statutory tool to enable Canada to fulfill many obligations to sustain marine biodiversity and requires extensive revision or replacement.
- Environmentally sustainable aquaculture concomitant with healthy marine biodiversity should comprise the overarching objective of a new federal aquaculture act.
- The *Species at Risk Act* has yet to provide an effective legislative mechanism for the protection, conservation, and recovery of marine species at risk.
- Canada's aspirations to be a leader in ocean stewardship requires the fulfilling of past commitments and the development of new initiatives, such as biodiversity reference points.

Chapter Thirteen: Conclusions and Recommendations

1. Canada's Approach to Sustaining Marine Biodiversity

a. Panel Conclusions

One of the Expert Panel's responsibilities under its Terms of Reference (Chapter Two) was to assess the degree to which Canada has fulfilled its national and international obligations to sustain marine biodiversity. Some progress has been made, but the Panel concludes that Canada has fallen well short of the progress made by most developed nations in fulfilling national and international commitments to sustain marine biodiversity. Many targets and obligations to conserve and to sustainably use biodiversity have not been met by Canada. The Panel attributes the lack of progress to an unduly slow pace of statutory and policy implementation. The Panel concludes that progress is impeded by conflicting regulatory responsibilities within DFO to promote industrial and economic activity while conserving marine life and ocean health. The Panel identifies the delegation of absolute discretion to the Minister of Fisheries and Oceans as an additional impediment to meaningful progress in operationalizing and thus fulfilling Canada's commitments to marine biodiversity. The Panel concludes further that Canada's lack of significant progress cannot be attributed to a lack of relevant policy on international fisheries or marine conservation issues, insufficient scientific knowledge, or inadequate scientific advice.

This chapter begins by identifying the most significant strengths of Canada's approach to date. The chapter closes with recommendations to identify approaches, measures, and research initiatives to promote the sustainability of Canadian marine biodiversity and to establish Canada as *the* international leader in oceans stewardship and marine conservation.

b. Some Strengths

Canada has contributed significantly to fisheries management reform in international waters. One example of this is the country's efforts to encourage the Northwest Atlantic Fisheries Organization (NAFO) to adopt harvest control rules and to implement reference points in NAFO's efforts to manage fish stocks in the shared waters of the Northwest Atlantic. As a member of the UN, Canada continues to urge countries to strengthen international efforts to prevent, deter, and eliminate Illegal, Unreported or Unregulated Fishing and to support efforts within the FAO to develop flag-state performance criteria (www.un.org/News/Press/docs/2010/ga11031.doc.htm; accessed 22-11-11).

Of national importance, but with global significance, the *Oceans Act* (1996) was, from an ecosystem-based management perspective, a landmark statute. In addition to providing a strong and clearly articulated legislative foundation for marine conservation (objectives absent from the preceding *Fisheries Act*), the Act appeared to signal an intent by Canada to afford a level of protection to its oceans similar to that afforded to its terrestrial environments. As well, passage of the *Species at Risk Act* (2002) met one of Canada's obligations under the Convention on Biological Diversity (1992) to develop legislation for the protection of threatened species. Canada has also developed potentially effective policies in support of its efforts to sustain marine biodiversity. In this regard, good examples include policies for the conservation of wild Pacific and Atlantic salmon, and policies developed under the Sustainable Fisheries Framework (Chapters Eleven, Twelve).

One additional strength underlying Canada's efforts to meet its commitments lies in the excellence and rigor associated with the advice provided by DFO scientists in support of management decisions and issues related to sustaining marine biodiversity. Since the 1990s, for example, DFO scientists have worked to develop methods for the identification of target and limit reference points for some fisheries, in support of Canada's commitments to apply the precautionary approach to fisheries management. In 2006, scientific advice to fisheries managers and to the Minister was crystal clear. DFO's Science Sector National Working Group on the Precautionary Approach concluded that, to be compliant with the precautionary approach, Canadian policy statements, and international fisheries agreements, Canadian fishery management plans must include harvest control rules that incorporate target and limit reference points (DFO 2006).

Concomitant with these efforts was a significant maturing of the means and the transparency by which scientific advice on the status of exploited marine species was communicated to fisheries managers. In addition to numerous publications in scientific journals, the high quality of the contributions by DFO scientists to research on both the state of ocean ecosystems and various facets of marine biodiversity is evident in the multiple publication series produced by the Canadian Science Advisory Secretariat (http://www.dfo-mpo.gc.ca/csas-sccs/index.htm; accessed 22-11-11).

However, as noted at the beginning of this chapter, and elsewhere in the Report (notably Chapter Twelve), counter-balancing these strengths is compelling evidence that, with some exceptions, Canada has not operationalized and fulfilled its national and international commitments to sustain marine biodiversity either in spirit or in practice. Canada's progress has been unduly slow in both an absolute sense (some commitments still having not been met almost two decades after they were agreed upon) and in a comparative sense, noting that substantive progress has been achieved by other western industrialized nations in meeting, and often exceeding, their national and international commitments to sustain marine biodiversity.

c. World Leader in Oceans and Marine Resources Management?

In the preamble to the *Oceans Act*, Parliament wished "to reaffirm Canada's role as a world leader in oceans and marine resources management", implying that Canada was, in 1996, a 'world leader' in this regard. This was a rather confident assertion, made only four years after the collapse of the northern cod fishery which resulted in the greatest single layoff in Canadian history (30-40,000 people; Bavington 2010), the expenditure of $2-3 billion in social and economic financial aid (CEC 2001), and one of the greatest numerical losses of a vertebrate in Canadian history (Hutchings and Rangeley 2011). Government's characterization of Canada as an international oceans leader persists today, as evidenced by statements that "Canada is among the world leaders in sustainable management of fisheries and aquaculture" (DFO 2009) (it is unclear what is meant by 'sustainable management').

In contrast to these self-identified ocean leadership aspirations, comparative analyses of Canada's marine conservation and management initiatives have been less than complimentary. One such analysis is represented by the efforts of researchers at Yale and Columbia Universities to construct an Environmental Performance Index and to use this to rank 163 countries on 25 performance indicators, tracked across ten policy categories encompassing environmental public health and ecosystem vitality (www.epi.yale.edu; accessed 12-12-11). In this analysis, Canada was ranked 125th of 127 countries in terms of fisheries conservation. In a recent separate analysis, Canada was ranked 70th of 228 countries in the establishment of marine protected areas, or MPAs (DFO 2010).

Although one can always identify interpretive limitations in ranking exercises such as these, they are consistent with the Panel's conclusion that Canada has yet to fulfill the most important of its marine biodiversity commitments. Among these commitments, two prominent shortcomings, from among those identified in Chapters Ten through Twelve, serve to illustrate the Panel's conclusion that Canada has failed to fulfil commitments associated with sustaining marine biodiversity. The two examples are the establishment of MPAs and the incorporation of the precautionary approach into fisheries management.

d. Marine Protected Areas

One of the key provisions of the *Oceans Act* was the commitment to develop and implement "a national system of marine protected areas on behalf of the Government of Canada". Yet, between 1996 and 2009, while the areal extent of *terrestrial* protected areas increased by 400,000 km^2 from ~540,000 km^2 to ~940,000 km^2, the areal extent of MPAs increased by just 24,000 km^2 from 22,000 km^2 to 46,000 km^2. It is also noteworthy that few, if any, of Canada's MPAs is entirely free of human activity. For example, fishing activity is reported to be permitted in 160 of 161 MPAs off Canada's Pacific coast (Robb et al. 2011).

Canada has not developed a network of MPAs, despite multiple commitments to do so, beginning twenty years ago when the country was signatory to the 1992 Convention of Biological Diversity (CBD). In 1995, the Canadian Biodiversity Strategy (Government of Canada 1995) pledged the federal, provincial, and territorial governments to accelerate the protection of areas that are representative of marine natural regions, to establish reserves to conserve aquatic biodiversity, and to contribute to a network of national and international protected areas. The Strategic Plan for North American Cooperation in the Conservation of Biodiversity (2003) articulated Canada's commitment to developing a North American marine protected area network. In 2005, a subsidiary body of the CBD set a global target (to which Canada agreed) of protecting 10% of all marine and coastal ecoregions by 2012. Canada's Oceans Action Plan (2005) committed Canada to promote the development of a network of MPAs by 2012. Canada voted in favour of The Law of the Sea Resolution (UNGA Resolution 65/37A) that urged States to establish a network of representative MPAs by 2012. In October 2010 at the 10th meeting of the Conference of the Parties of the CBD in Nagoya, Aichi Prefecture, Japan, Canada committed to the Aichi Biodiversity Target to conserve, by 2020, at least 10% of coastal and marine areas through the establishment of well-connected systems of protected areas. Interestingly, in October 2011, as part of its national submission to the Rio+20 UN Conference on Sustainable Development, Canada identified "networks of marine protected areas" as an outcome of its Integrated Oceans Management Programme (www.uncsd2012.org/rio20/index.php?page=view&type=510&nr=33&menu=20; accessed 22-11-11).

Although the 2020 target is consistent with past rhetoric, it is highly unlikely that Canada will meet it, given that Canada had protected only 0.8% of its oceans by 2011. To meet the 2020 target of protecting at least 10% of its waters as MPAs, Canada will have to increase its areal extent of MPAs from approximately 61,000 km^2 in 2011 (estimated from information available at http://www.dfo-mpo.gc.ca/oceans/marineareas-zonesmarines/mpa-zpm/spotlight-pleinsfeux/index-eng.htm#s2; accessed 11-12-2011) to approximately 710,000 km^2 in nine years. To place this in perspective, the average annual rate of MPA protection required to meet the 2020 target would have to be ~72,000 km^2 per year, an annual rate greater than the sum total of marine protected areas in Canada in 2011. Put another way, the rate of MPA production would have to be five times greater than the average annual rate of adding terrestrial protected areas in Canada between 1965 (285,000 km^2) and 2009 (941,418 km^2) (Environment Canada 2010).

e. Precautionary Approach

The second example of Canada's disappointing achievement related to biodiversity deals with implementation of the precautionary approach (PA). As a Party to the 1995 UN Agreement on Straddling and Highly Migratory Fish Stocks (UN Fish Stocks Agreement) and an endorser of the FAO Code of Conduct for Responsible Fisheries, Canada agreed to apply the PA to the management of its marine fisheries, a commitment entirely consistent with the objectives of the *Oceans Act*. The PA can be defined as an approach that recognizes that the absence of full scientific certainty shall not be used as a reason for postponing decisions where there is a chance of serious or irreversible harm. Thus, if one is to apply the PA, one needs to identify conditions under which serious or irreversible harm is likely to occur, and to have a clearly articulated strategy either for avoiding those conditions or for returning to conditions in which such harm is unlikely. In this regard, the UN Fish Stocks Agreement stipulated that, when implementing the PA, States shall determine stock-specific target and limit reference points for exploited fish stocks and shall identify the action to be taken if the reference points are exceeded (Chapter Ten). The FAO Guidelines accompanying the FAO Code of Conduct provide even more specific guidance, recommending that reference points for fishing mortality (a measure of exploitation pressure) and stock size (a measure of fish population abundance) be established to identify overfishing, to guide rebuilding plans, and to develop harvest control rules (Chapter Twelve).

The logical necessity of establishing target and limit reference points and associated harvest control rules cannot be over-stated. Put simply, if there are no recovery targets or timelines for recovery (there are neither for Canadian Atlantic cod), there is, in essence, no recovery plan. In the absence of targets or harvest control rules, neither society nor industry can inquire as to whether a proposed catch level for a particular stock is consistent with the objective of achieving a particular target within a pre-defined period. In the absence of reference points or control rules, there is no means of being able to audit the effectiveness, or to track the record, of fisheries management actions. But as the Supreme Court of Canada ruled, it is the Minister of Fisheries and Oceans' duty to manage, conserve, and develop the fisheries on behalf of Canadians and in the public interest (Supreme Court of Canada 1997). In effect, the Minister is responsible for investing (in biological reproductive capacity) and spending (exploiting) the marine biological capital held by *all* Canadians. A 'budget' for spending this capital, complete with quantitative objectives or targets, is as necessary for the Minister as it is of a financial manager responsible for managing an investment portfolio.

In the absence of reference points or control rules, there is no accountability and there is no transparency in the political and fisheries management decisions that ultimately determine the effectiveness with which Canada sustains its marine fish populations, which are part of Canada's marine biodiversity. The resultant *ad hoc* nature of many of Canada's fisheries management decisions is not, however, permitted in countries for which transparency and accountability are deemed to be integral to sustaining marine biodiversity. Reference points and harvest control rules are standard components of fisheries management plans in the US, Australia, New Zealand, increasingly so in Norway, and in international bodies such as the EU and NAFO. As noted in 2007, any harmonization of the criteria used by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) to assess the status of marine fishes with criteria used to assess the status of commercially exploited fishes is moot in the absence of reference points (DFO 2007).

The Panel agrees with recommendations made in a Canadian Science Advisory Secretariat (CSAS) document (DFO 2007) that DFO needs to identify target and limit reference points in accordance with the existing precautionary approach framework. DFO should also ensure that these reference points have a sound biological basis, and that target reference points are set at levels above which the best available scientific evidence suggests recovery would be both rapid and very likely in response to management actions. The CSAS document also recommends that DFO develop, adopt, test, and implement fisheries management strategies that respect these conservation reference points and that their effectiveness be evaluated on a regular basis (DFO 2007).

2. New Approaches, Measures, and Initiatives

The Panel was tasked with identifying new approaches and measures to promote the sustainability of Canadian marine biodiversity and new research initiatives to support scientific advice given to decision-makers. Although many of the Panel's recommendations focus on the management actions required to meet existing national and international commitments to biodiversity conservation, the Panel also considered how science can be used to strengthen the quality of Canada's strategies to sustain marine biodiversity, such as might be achieved by monitoring programmes, a national marine habitat mapping initiative, and research on the effects of climate change on Canada's marine biodiversity.

The Panel identifies seven overarching recommendations, the strategic basis for each recommendation, and some associated key actions required to fulfill these recommendations.

<u>Recommendation 1:</u> The Panel recommends that the Government of Canada identify international leadership in oceans stewardship and biodiversity conservation as a top government priority.

a. Strategic Basis

Canada has multiple international leadership and stewardship responsibilities generated by the geographical realities of the length of its coastline and the size of its seas. Canada has not kept pace with international efforts to sustain marine biodiversity when compared with the successful marine biodiversity initiatives and precautionary management approaches exercised by many other jurisdictions, such as Australia, New Zealand, US, and Norway. This can be explained by a lack of strong institutional leadership, societal ambivalence, and minimal incentives to move from well-intentioned rhetoric to meaningful action. The responsibility for fulfilling Recommendation 1 currently rests with the Prime Minister (who can lead this initiative), the Minister of Fisheries and Oceans (who can catalyse progress by implementing the Panel's recommendations), and all sectors of society, including industry (who can help fulfil the country's oceans leadership aspirations by increasing their awareness of the government's due diligence).

b. Key Actions

- The Government of Canada should fully implement existing statutory and policy commitments to sustain marine biodiversity.
- The Government of Canada should enhance transboundary and international governance arrangements by extending integrated management planning efforts across national maritime boundaries.
- The Government of Canada should increase Canada's formal membership to international agreements that pertain to the sustaining of marine biodiversity, such as the Convention on the Conservation of Migratory Species of Wild Animals.
- The Government of Canada should support research initiatives to strengthen scientific advice and ensure renewal of retiring scientific and managerial staff who have expertise in decision-making in the presence of complexity, trade-offs, uncertainties, and risks.
- The Government of Canada should fully support the provision and implementation of a management framework that maximizes opportunities for fisheries to achieve third-party certification of sustainability.
- The Auditor General of Canada could undertake a full financial, statutory, and policy audit of Canada's progress in meeting its international marine biodiversity obligations.

<u>Recommendation 2:</u> The Panel recommends that the Government of Canada resolve regulatory conflicts of interest affecting Canada's progress in fulfilling obligations to sustain marine biodiversity.

a. Strategic Basis

The Panel has identified regulatory conflict as an impediment to Canada's progress in fulfilling national and international commitments to sustain marine biodiversity. The Government of Canada has responsibilities to conserve and protect biodiversity as well as to promote the exploitation of biodiversity, either directly through commercial fisheries or indirectly through the deployment of aquaculture operations. As noted by the Auditor General of Canada (CESD 2011), the risk that fishing activity will endanger the long-term ecological sustainability of fish stocks can be reduced when there exists an effective framework of clear roles and responsibilities built on accountability and transparency. Without effective mechanisms to ensure that all parts of Government are accountable for supporting policies on the conservation of biodiversity during decision making, progress towards fulfilling Canada's national and international obligations to sustain biodiversity is impeded. Each stakeholder (the public, fishing industry, non-governmental organizations, coastal communities, aquaculture operators) is placed in the position of having to ask, with respect to each regulatory decision, whether its own interests have been unduly compromised by the interests of others.

The Panel's primary interest is from the point of view of how regulatory conflict can compromise the integrity of regulatory science and decision making, as well as public perception of that integrity. The more that DFO is, or is perceived to be, promoters of the exploitation of marine biodiversity and ocean life, the more they undermine public trust in their ability to regulate the conservation and protection of that biodiversity in the public interest.

b. Key Actions

- The Government of Canada should develop processes and, if necessary, amend institutional structures to limit or eliminate real and perceived regulatory conflicts of interest.
- The Government of Canada should develop processes and, if necessary, amend institutional structures to ensure that Ministers are fully and transparently accountable for policy commitments to the use and conservation of marine biodiversity.

Recommendation 3: **The Panel recommends that the Government of Canada reduce the discretionary power in fisheries management decisions exercised by the Minister of Fisheries and Oceans.**

a. Strategic Basis

Canada's progress in meeting its obligations to sustain marine biodiversity has been impeded by the absolute discretion afforded to the Minister of Fisheries and Oceans. The *Fisheries Act* (1868) reflects a period of time in Canadian history when Ministers were afforded 'czar-like' powers to approve, deny, or otherwise change proposals affecting activities coming under their aegis. In contrast, in the US, the *Magnuson-Stevens Fishery Conservation and Management Act* (MSFCMA) has facilitated a curtailment of discretionary decision-making authority, an increase in accountability, and a strengthening of links between policy and science in fisheries management. US regional fishery management councils are now required to adhere to binding scientific advice (from their scientific and statistical committees) on catch limits, overfishing prevention, and rebuilding of overfished stocks (Sale et al. 2008). The MSFCMA is prescriptive in that it does not provide the US Secretary of Commerce with absolute discretion in fisheries exploitation decisions. Unlike the *Fisheries Act* and the *Oceans Act*, neither of which is prescriptive, the MSFCMA specifies actions that the Secretary shall or must take if certain circumstances arise. The Auditor General of Canada (CESD 2011) has identified leadership and well-defined accountability as key elements to sustainable fisheries.

b. Key Actions

- The Government of Canada should enact prescriptive legislation containing primary objectives to: (i) prevent overfishing; (ii) rebuild depleted fish stocks; (iii) formalize the explicit use of reference points and harvest control rules; and (iv) ensure transparency and accountability in fisheries management plans, including those relating to aquaculture.
- The Government of Canada should consider the establishment of independent, arms-length advisory or decision-making bodies on matters pertaining to the use and conservation of marine biodiversity, including catch allocations, licensing, and environmental impact assessments.
- The Prime Minister (PM) should use a mandate letter (which outlines the PM's expectations and policy goals) to increase ministerial accountability within DFO; the letter could be used to provide the Minister of Fisheries and Oceans a mandate to respond to the Expert Panel's recommendations; the mandate letter should be publicly available.

Recommendation 4: The Panel recommends that Fisheries and Oceans Canada (DFO) rapidly increase its rate of statutory and policy implementation.

a. Strategic Basis

The current pace of statutory and policy implementation by DFO is impeding Canada's efforts to fulfil national and international obligations to sustain marine biodiversity, a deficiency increasingly magnified by the pressing need to adapt to and mitigate climate change. The slow pace of implementation has prevented Canada from incorporating the precautionary approach into the management of most of its commercial fisheries and from making good progress towards targets for the establishment of MPAs. As one example, quantitative recovery targets still do not exist for Canada's depleted cod stocks, twenty years after their demise (markedly longer than the five years required to complete the Canadian Pacific Railway in 1885), even though DFO has experience with establishing recovery targets for other fishes and some marine mammals. As concluded recently by the Auditor General of Canada (CESD 2011), "Canadians have the right to know how well fisheries are being managed", something that cannot be achieved in the absence of fishery reference points, recovery targets, and rebuilding timelines.

b. Key Actions

- DFO should fully implement the *Oceans Act* to: (i) identify biodiversity hotspots and vulnerable biological habitats; (ii) establish a comprehensive and biologically meaningful network of MPAs; and (iii) develop marine spatial planning with clear geographical priorities, explicit timelines, and transparent measures for public reporting.
- DFO should fully implement the *Species at Risk Act* for marine fishes by including endangered and threatened species on the national legal list and by affording them the full benefits of recovery strategies, including the identification of recovery targets, rebuilding timelines, and (when possible) limited directed harvests.
- DFO should fully implement existing policies on marine biodiversity use and conservation, such as those included within the Sustainable Fisheries Framework.

<u>Recommendation 5:</u> The Panel recommends that Canada implement statutory renewal to fulfill national and international commitments to sustain marine biodiversity.

a. Strategic Basis

Canada has not kept pace with international efforts to sustain marine biodiversity, as compared with the successful initiatives and precautionary management approaches exercised by many other countries. At a minimum, Canadian statutes and associated regulations require revision that will allow Canada to remove impediments to the timely implementation of policy and legislation pertaining to the sustainability of Canadian marine biodiversity. However, revising the *Fisheries Act*, promulgated in 1868 when Canada's post-Confederation concept of democracy was quite limited (neither women nor aboriginal peoples could vote), has proven to be complex and difficult. Thus, new legislation, such as that suggested under the aegis of Recommendation 3, might be necessary.

b. Key Actions

- Draft and enact a modernized *Fisheries Act*, or a new statute, that: (i) identifies full implementation of the precautionary approach as an over-arching objective; (ii) provides legislative requirements and guidance on fully implementing the Sustainable Fisheries Framework; and (iii) identifies conservation of biodiversity as a core consideration in the development of fisheries management plans.
- Draft and enact federal aquaculture legislation that specifies requirements and guidance on national objectives and procedures for all aquaculture operations and that requires a principled approach to aquaculture operations, to ensure the protection of biodiversity.
- Consider enacting comprehensive biodiversity legislation similar to that existing in Australia and Norway to set legally binding requirements for biodiversity protection.
- Consider amending the *Oceans Act* to clarify integrated management procedures and responsibilities and to provide a firm legal foundation for implementing completed management plans.
- Strengthen the *Species at Risk Act* through key amendments that would: (i) establish a transparent evaluation and consultation process for decisions not to list a species at risk, including external review of supporting listing-decision analyses; (ii) clarify the procedure and process for developing recovery strategies and action plans; and (iii) restrict discretion to exempt activities from SARA's prohibitions and incidental permitting requirements.

<u>Recommendation 6:</u> The Panel recommends that the Government of Canada establish national operational objectives, indicators, and targets for marine biodiversity.

a. Strategic Basis

Many of Canada's policy commitments to sustain marine biodiversity have yet to be translated into operational objectives that apply at the appropriate scales of impacts and management actions. Ideally, policies would establish a framework of required outcomes, specified as operational objectives, that are consistent with national and international biodiversity commitments. Indicators and targets would be used to track progress in relation to these objectives and to support reporting. One approach to prioritization of issues for which operational objectives need to be identified is Australia's Ecological Risk Assessment for the Effects of Fishing (Box 12.3). Biodiversity reporting would be strengthened by the issuance of annual reports that 'lay bare' performance in relation to operational objectives. Key actions associated with this recommendation should be initiated by the Government of Canada, but general reporting on biodiversity trends in relation to the targets and efforts to assess changes in biodiversity more widely should also be supported by one or more groups, including the Government of Canada, non-governmental organizations, and academic scientists.

b. Key Actions

- The Government of Canada should establish operational objectives that relate to existing commitments to biodiversity conservation and formally integrate them in oceans and fisheries management; highest priority should be assigned to objectives pertaining to those impacts most likely to compromise national and international commitments to sustain marine biodiversity.
- DFO should establish biodiversity indicators and targets to assess progress towards meeting operational objectives, and annually report the status and trends of marine biodiversity (using indicators), as well as national progress in attaining policy objectives.

<u>Recommendation 7:</u> The Panel recommends that Canada establish strategic research initiatives to strengthen scientific advice on sustaining marine biodiversity.

a. Strategic Basis

Canada's lack of significant progress in fulfilling marine biodiversity commitments cannot be attributed to inadequate scientific knowledge or advice. That said, there are research initiatives that will better support future scientific advice on the biodiversity consequences of climate change, fisheries, and aquaculture, thus contributing to the implementation of policy to sustain marine biodiversity. These initiatives will supplement current knowledge and allow managers and decision-makers to achieve their objectives more efficiently and effectively and across greater geographical scales than at present. New research is required to forecast the effects of climate change on appropriate regional spatial scales and to evaluate the degree to which changes to Canadian ecosystems are likely to be positive or negative. The only means of determining whether marine biodiversity is being sustained, and whether key stressors on biodiversity at broad and local scales are changing in intensity, is by monitoring spatio-temporal changes in those stressors as well as physical and biological properties of the oceans.

b. Key Actions

- Federal government departments (e.g., DFO, Natural Resources Canada, Environment Canada) should maintain, improve, and/or develop new long-term environmental monitoring programmes, especially for the Arctic, that would include the monitoring of key biodiversity sites ('hotspots') and functional changes at all levels of the marine food web.
- DFO should establish a nationally consistent programme for mapping ocean habitat and biological use of marine habitat (e.g., near-shore macrophytes, spawning grounds, migration corridors) to better inform decisions on integrated spatial management plans, identification of critical habitat (in the sense of the *Species At Risk Act*), location of MPAs, and environmental risk assessments of human activities, including aquaculture operations.
- The Government of Canada should promote and strengthen basic, discovery-oriented research on physical and biological oceanographic patterns, process, and function, as they affect or regulate marine ecosystems and biodiversity in Canada's Extended Economic Zone.
- The Government of Canada should develop a comprehensive research programme to forecast changes in Canadian marine biodiversity resulting from ongoing and projected climate-related changes to Canada's oceans.

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CHAPTER FIVE: TRENDS IN CANADIAN MARINE BIODIVERSITY

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CHAPTER EIGHT: FISHERIES: OBSERVED AND PROJECTED CONSEQUENCES FOR MARINE BIODIVERSITY

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Chapter Nine: aquaculture: Observed and Projected Consequences for Marine Biodiversity

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CHAPTER ELEVEN: CANADA'S NATIONAL COMMITMENTS TO SUSTAIN MARINE BIODIVERSITY

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Chapter Eleven: International Agreements, Statutes and Regulations, Cases

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Appendix A: Text of the Expert Panel's Invitation to Submit Evidence

As described in Chapter Two, in September 2010, the Panel sent both English and French texts of an Invitation to Submit Evidence to 162 government departments, scientific societies, environmental non-governmental organizations, aboriginal groups, past and present government and academic scientists, and other interested individuals and organizations (Tables 2.1, 2.2). The English version of the Invitation is presented here.

Text of the Expert Panel's *Invitation to Submit Evidence*

Introduction: Among the many public-service roles of national academies around the world, one of the most important is the preparation of expert reports on critical issues of public policy. The national academies in the United States and the United Kingdom are among the most active in this regard, but the senior academies in other nations, notably in Europe, also prepare expert reports. Such reports are designed to be balanced, thorough, independent, free from conflict of interest, and based on a deep knowledge of all of the published research that is pertinent to the questions that have been posed.

The Royal Society of Canada also has a long record of issuing definitive reports of this kind, either on its own initiative, or in response to specific requests from governments or other parties. The Society relies on the advice of one of its senior committees, The Committee on Expert Panels (CEP), in formulating the projects that develop new reports, and in responding to requests for projects from external parties. In addition, the members of the Society's CEP are responsible for selecting the members of panels that produce the reports, including the chair, overseeing the conduct of panel activities, managing the peer review of the draft final report, and assisting the panel members with any difficulties that arise during the conduct of their work.

The Royal Society of Canada's Expert Panel on "Sustaining Canada's Marine Biodiversity: Responding to the Challenges Posed by Climate Change, Fisheries, and Aquaculture" is one of a new series of reports that the Society has commissioned, at its own initiative, on issues of significant public interest and importance at the present time.

The members of the Panel are identified in Appendix A and the Panel's Terms of Reference are given in Appendix B below. [NOTE: These appendices have been excluded here because they appear elsewhere in the Panel Report.]

Invitation to submit evidence: This invitation identifies questions that the Expert Panel wishes to address as part of its procedure for fulfilling its Terms of Reference. These questions are not intended to limit the Panel's range of study, but rather to focus attention on areas where Panel members believe they would benefit from external input.

Given the breadth of topics encompassed by the Panel's Terms of Reference, responses to *each* of the issues articulated below will be restricted to a maximum of 1200 words (approximately the equivalent of two single-spaced pages, using Times New Roman font size 12). Thus, those wishing to contribute are encouraged to support their evidence with references.

Responses are requested by Monday, 1 November 2010. In submitting evidence, the Panel requests that contributors adhere to the following guidelines:

1. **Please note** that where information is provided, references to (preferably electronic) sources of relevant information accompanied by a brief summary of what these sources contain is, in general, **more helpful** to the Panel than reproducing the basic information in your response.
2. Opinions offered should be supported with arguments or evidence.
3. You do not need to address all the questions listed; indeed, you may feel that you can provide useful evidence on only a few.
4. Unless indicated otherwise when evidence is submitted, it will be assumed that the organisation or individual submitting it has no objection to its disclosure to other parties, should the Panel so decide.

This invitation letter has been sent to a wide range of interested parties, and has been posted on the Royal Society of Canada's website. If you think that we have missed any individual or organisation that might like to contribute, feel free either to contact the Chair of the Panel (Dr. Jeffrey Hutchings; jhutch@mathstat.dal.ca) or to pass a copy on to them directly.

Issues on which the Expert Panel would welcome evidence

A) The current situation and possible futures

- Trends in marine biodiversity can be reflected by various indicators, including changes in the abundance and distribution of marine populations and/or species. (Here, "marine" refers to both species that spend their entire lives in the ocean and to *diadromous* species that regularly move between salt and fresh water as a normal part of their life cycle, such as salmon and eels.) Is there firm evidence of substantial change (while accounting for scientific uncertainties) in marine biodiversity in Canada that is attributable to climate change, capture fisheries, or aquaculture?
- To what extent are effects on marine biodiversity attributable to climate change, fisheries, or aquaculture short-term or reversible?
- What are the most effective physical and chemical indicators of climate change in Canada's oceans, and what are the existing and projected trends in these indicators?
- How do the effects of climate change, fisheries, or aquaculture on marine biodiversity compare, in magnitude and nature, with the impacts on marine biodiversity of other anthropogenic activities, such as coastal development, oil and natural gas exploration, shipping, or tourism?

B) Regulatory or management practices or regimes

- What are the strengths and weaknesses of the Canadian approach to regulation of fisheries and of the aquaculture industry?

- Are there particular management or regulatory approaches, pertaining to climate change, fisheries, or aquaculture, used by other countries that the Panel should examine, as examples of models that either could be, or should not be, adopted?
- How should society ensure fair and effective public participation in the management of marine biodiversity and how can this be facilitated?

C) The institutional/legal framework

- Do Canadian policies and infrastructure provide a coherent and complete framework for managing marine biodiversity?
- Is Canada fulfilling its national and international obligations to protect marine biodiversity?
- How should responsibilities for sustaining marine biodiversity be divided between government, fishing and aquaculture industries, retailers, consumers, other ocean users, and conservation bodies? What could be their roles in efficient and effective marine stewardship and regulation?

APPENDIX B: SUBMISSIONS OF EVIDENCE TO THE EXPERT PANEL FROM FISHERIES AND OCEANS CANADA (DFO)

Invitations to submit evidence to the Expert Panel were solicited from three federal government agencies: Fisheries and Oceans Canada (DFO); Environment Canada; and Parks Canada. DFO was the only agency to respond to the Panel's invitation. DFO's initial submission (30 November 2010) was accompanied by an offer to provide additional information should the Panel request it. In response to a follow-up request by the Panel for greater specificity in DFO's original submission, the Department submitted a second submission on 4 May 2011. Both submissions are presented here.

Fisheries and Oceans Canada
Deputy Minister

Pêches et Océans Canada
Sous-ministre

NOV 3 0 2010

Your file Votre référence

Our file Notre référence

Dr. Jeffrey A. Hutchings
Professor and Canada Research Chair in Marine Conservation & Biodiversity
Department of Biology
Dalhousie University
1355 Oxford Street
Halifax, Nova Scotia
B3H 4J1

Dear Dr. Hutchings:

Thank you for inviting Fisheries and Oceans Canada to submit evidence to the Royal Society of Canada's Expert Panel on "Sustaining Canada's Marine Biodiversity: Responding to the Challenges Posed by Climate Change, Fisheries, and Aquaculture."

I would also like to thank you for granting us an extension from your original deadline for response; this has allowed us the time required to coordinate a departmental response, which you will find attached.

I wish you and the Panel all the best as you complete this important project, and I look forward to its findings. If you require further clarification or discussion on any of the points in the submission, please do not hesitate to contact us.

Yours sincerely,

Claire Dansereau

Claire Dansereau

Enclosure

Ottawa, Canada
K1A 0E6

Canada

Fisheries and Oceans Canada
Submission to Royal Society of Canada

A) The current situation and possible futures

Question A1:
Trends in marine biodiversity can be reflected by various indicators, including changes in the abundance and distribution of marine populations and/or species. (Here, "marine" refers to both species that spend their entire lives in the ocean and to diadromous species that regularly move between salt and fresh water as a normal part of their life cycle, such as salmon and eels.) Is there firm evidence of substantial change (while accounting for scientific uncertainties) in marine biodiversity in Canada that is attributable to climate change, capture fisheries, or aquaculture?

DFO Response A1:
DFO's 2010 Marine Ecosystem Status and Trends Report (ESTR) addresses this question. The literature cited at the end of the 2010 ESTR provides substantial background evidence for the findings in the science advisory report.
http://www.dfo-mpo.gc.ca/CSAS/Csas/Publications/SAR-AS/2010/2010_030_e.htm

It is true that trends in marine biodiversity can be reflected by various indicators, including abundance and distribution. Others, such as changes in phenology, population structure, body condition, community characteristics (e.g., size ratios of organisms at the lower trophic levels such as phyto- and zooplankton, seabird diets), can also be very useful indicators of change.

In the Canadian Arctic, it is still difficult to state unequivocally that changes are occurring to marine biodiversity caused by anthropogenic stressors. Further, except for a few local and/or limited situations, it is difficult to demonstrate that substantial (i.e., significant) changes are occurring to marine biodiversity in the Canadian Arctic. Scientists generally believe that changes are happening to Arctic marine biodiversity, and that human activities are at least partly responsible for these changes, but the necessary studies have not yet been conducted.

Compared to Canada's other two oceans, there is little data about biodiversity in the Canadian Arctic. This is partly due to the fact that the Arctic marine environment is ice-covered for much of the year (in some places, all year); that obtaining data—and in particular the ongoing year-upon-year monitoring data that is needed to detect changes and trends—is very expensive; and, due to the remoteness of the region, that relatively little scientific activity has taken place in the Arctic as compared to the south of the country.

Canada is participating in the Arctic Council effort to monitor Arctic marine biodiversity, due to start next year. This effort will—we hope—provide evidence regarding baselines of Arctic marine biodiversity, changes that are occurring, and whether/how these changes are attributable to anthropogenic stressors such as climate change, pollutants, shipping, development, harvesting, etc.

Additional References:

1. McRae, et al (2010): http://asti.is/images/stories/asti%20report%20april%2020_low%20res.pdf

2. Vongraven, et al (2009): http://www.docstoc.com/docs/50764180/CIRCUMPOLAR-MARINE-BIODIVERSITY-MONITORING-PLAN-BACKGROUND-PAPER

3. Arctic Marine Biodiversity Monitoring Plan (to be released in late 2010 - check http://cbmp.arcticportal.org/)

4. Archambault, et al (2010): http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0012182

5. Cusson, et al (2007): http://www.int-res.com/abstracts/meps/v331/p291-304/

6. Government of the Northwest Territories and NWT Biodiversity Team (2010): http://www.assembly.gov.nt.ca/_live/documents/content/10-05-20TD53-16%285%29.pdf

7. Federal, Provincial and Territorial Governments of Canada (2010: http://www.biodivcanada.ca/default.asp?lang=En&n=6F7EB059-1&wsdoc=A8E1EFFD-FCC0-4502-832A-359A50BAB5A3

8. CAFF International Secretariat (2010): http://arcticbiodiversity.is/images/stories/report/pdf/Arctic_Biodiversity_Trends_Report_2010.pdf

9. DFO (2010): http://www.dfo-mpo.gc.ca/CSAS/Csas/publications/sar-as/2010/2010_030_e.pdf

10. Niemi, et al (2010): http://www.dfo-mpo.gc.ca/CSAS/Csas/publications/resdocs-docrech/2010/2010_066_e.pdf

Question A2:
To what extent are effects on marine biodiversity attributable to climate change, fisheries, or aquaculture short-term or reversible?

DFO Response A2:
Although the question is interesting, owing to its complexity a formal peer-review science advisory process would be necessary to provide any kind of meaningful response. This question cannot be adequately addressed with the 2010 ESTR.

Question A3:
What are the most effective physical and chemical indicators of climate change in Canada's oceans, and what are the existing and projected trends in these indicators?

DFO Response A3:
Please see our response to question A2 above.

Question A4:
How do the effects of climate change, fisheries, or aquaculture on marine biodiversity compare, in magnitude and nature, with the impacts on marine biodiversity of other anthropogenic activities, such as coastal development, oil and natural gas exploration, shipping, or tourism?

DFO Response A4:
Please see our response to question A2 above.

While it is not yet possible to differentiate the relative impacts of various anthropogenic stressors on marine biodiversity in the Canadian Arctic, Canada is participating in an Arctic Council effort to monitor Arctic marine biodiversity, and implementation is due to start next year. This effort will—it is hoped—provide evidence regarding baselines of Arctic marine biodiversity, changes that are occurring, and whether/how these changes are attributable to anthropogenic stressors such as climate change, pollutants, shipping, development, harvesting, etc.

B) Regulatory or management practices or regimes

Question B1:
What are the strengths and weaknesses of the Canadian approach to regulation of fisheries and of the aquaculture industry?

DFO Response B1:
The strength of the Canadian approach to fisheries management is the legislation (the ***Fisheries Act***) and the sets of policies that implement the ecosystem approach, the precautionary approach, establishing limit reference points to determine stock status, and preparing tools like the Integrated Fisheries Management Plans as well as an annual Fishery Checklist to estimate the sustainability of the fisheries. While not every fishery has an Integrated Fisheries Management Plan and/or a Fishery Checklist yet, actions are being implemented to address this. See: http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/fish-ren-peche/sff-cpd/precaution-eng.htm

Management consists of the application of decision rules done in collaboration with industry and stakeholders. When effectively implemented, this approach facilitates the stable and predictable business environment in the fishery that participants need, while at the same time contributing to sustainability.

Powers under the ***Fisheries Act*** are guided by a modernized policy framework focused on conservation of marine biodiversity. The 2004 Atlantic Fisheries Policy Framework positions conservation as the highest priority for the management of fisheries, and defines conservation as “sustainable use that safeguards ecological processes and genetic diversity for present and future generations”. The ***Fisheries Act*** gives the Minister the authority to grant or rescind access to the fishery through licensing. If the Minister has reason to believe there is a conservation concern in regards to a particular fishing activity she can establish and enforce licence conditions to address the concern or, if necessary, she can cancel licences and/or close fisheries. See: http://www.dfo-mpo.gc.ca/fm-gp/policies-politiques/afpr-rppa/framework-cadre-eng.htm.

Canada has strong biological science advice to support the management of fisheries and aquaculture. However, the formal integration of sustainable economics into decision processes is not fully implemented. DFO is currently working on developing the analytical capacity for assessing the long-term biological and economic consequences of management actions, and incorporating these assessments into the decision-making process.

Question B2:
Are there particular management or regulatory approaches, pertaining to climate change, fisheries, or aquaculture, used by other countries that the Panel should examine, as examples of models that either could be, or should not be, adopted?

DFO Response B2:
The effects of climate change were analysed by Nicholas Stern for the UK government. A similar economic analysis could also be done for Canada.

As part of normal operations, DFO takes note of developments in fisheries management and regulatory approaches in other fishing nations (such as the European Union, Norway, Australia, and the United States) and takes these into consideration when developing domestic policies.

Question B3:
How should society ensure fair and effective public participation in the management of marine biodiversity and how can this be facilitated?

DFO Response B3:
Society or stakeholders should be actively involved in biodiversity assessment and management. Education and communication of issues relating to marine biodiversity management is paramount. Public and industry consultation should be undertaken prior to management program shifts, to ensure all relevant factors are considered when the management measures are designed, including the full economic implications (both costs and benefits). Failure to do so is likely to lead to an inefficient or unintended outcome which will not garner public support.

DFO already has regional advisory panels for resource management, so that interested stakeholders or public groups can seek engagement in the development of fishery management planning. An excellent Canadian example of public participation is the effort which went into the design and drafting of the Integrated Fisheries Management Plan for the Pacific Region Integrated Groundfish fishery. This document is available to the public at:
http://www-ops2.pac.dfo-mpo.gc.ca/xnet/content/MPLANS/MPlans.htm.

In Canada's north, there are a number of land claims agreements which describe how residents within the land claim areas are to be consulted and/or otherwise involved in managing the environment and wildlife.

Fisheries and Oceans Canada
Submission to Royal Society of Canada

C) The institutional/legal framework

Question C1:
Do Canadian policies and infrastructure provide a coherent and complete framework for managing marine biodiversity?

DFO Response C1:
Canada's ***Oceans Act***, complemented by other federal legislation, plays a key role in managing and protecting marine biodiversity. The Preamble to the ***Oceans Act*** establishes Canada's vision through the following aspirational statements:

> "WHEREAS Canada promotes the understanding of oceans, ocean processes, marine resources and marine ecosystems to foster the sustainable development of the oceans and their resources;" and
> "WHEREAS Canada holds that conservation, based on an ecosystem approach, is of fundamental importance to maintaining biological diversity and productivity in the marine environment;"

http://laws.justice.gc.ca/PDF/Statute/O/O-2.4.pdf

Under the ***Oceans Act***, the Minister of Fisheries and Oceans is called upon to lead and facilitate the development of a national ocean management strategy. Canada's Oceans Strategy responds to this requirement, providing for an integrated approach to ocean management, coordination of policies and programs across governments, and an ecosystem approach. The Strategy speaks to the importance of maintaining ecosystem health, especially in the face of uncertainty.
http://www.dfo-mpo.gc.ca/oceans/publications/cos-soc/pdf/cos-soc-eng.pdf

Integrated oceans management (IOM) is a modern approach to managing Canada's ocean resources. It is a collaborative way of making decisions on how Canada's marine resources can best be developed and protected. The intent of IOM, and its strength, is its capacity to facilitate sound decision making to address large-scale ecosystems, complex management environments characterized by multiple stakeholders and often competing interests and issues of marine quality and potential cumulative impacts.
For further information on the approach to Oceans Management see http://www.dfo-mpo.gc.ca/oceans/management-gestion/governmentsrole-roledesgouvernements/index-eng.htm#oceansact

The ***Oceans Act*** and Canada's Oceans Strategy are being implemented through integrated oceans management governance processes and management plans, as well as through authorities for regulatory tools such as Marine Protected Areas (MPA). MPA policies and operational procedures have been developed and they include ecosystem health in their design.

Program implementation has proceeded with the intent of providing policy coherence through national-level discussions and, where appropriate, scientific guidance. The following section provides links to some of the guidance that has been provided through the Canadian Science Advisory Secretariat (CSAS), which is the DFO body that coordinates the peer review of scientific issues.

Using state of the art knowledge nationally and internationally, a number of tools and concepts were developed to implement the requirements of ***Oceans Act*** and Canada's Oceans Strategy. Initial efforts have focussed on developing tools to identify key ecosystem attributes, processes and functions and defining geographic space in terms of ecoregions and management areas.

The Precautionary Approach to Fisheries Management (http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/fish-ren-peche/sff-cpd/precaution-eng.htm) provides a solid framework for the management of commercially-targeted species. The ***Species at Risk Act*** is not limited to commercially-targeted species, but does not come into play until a species is at a higher level of risk than is desirable from a sustainable management point of view.

Links to CSAS Guidance:

Ecologically and Biologically Significant Areas and Species:

- Identification of Ecologically and Biologically Significant Areas http://www.dfo-mpo.gc.ca/csas/Csas/status/2004/ESR2004_006_e.pdf
- National Science Workshop: Development of Criteria to Identify Ecologically and Biologically Significant Species (EBSS), September 6-8, 2006 http://www.dfo-mpo.gc.ca/csas/Csas/Proceedings/2006/PRO2006_028_B.pdf

Marine Ecoregions (2004) evolved to Biogeographic Marine Areas (2009):

- Proceedings of the Canadian Marine Ecoregions Workshop, March 23-25, 2004 http://www.dfo-mpo.gc.ca/csas/Csas/proceedings/2004/PRO2004_016_B.pdf
- Development of a Framework and Principles for the Biogeographic Classification of Canadian Marine Areas http://www.dfo-mpo.gc.ca/CSAS/Csas/Publications/SAR-AS/2009/2009_056_E.pdf

Conservation Objectives:

- Guidance Document on Identifying Conservation Priorities and Phrasing Conservation Objectives for Large Ocean Management Areas http://www.dfo-mpo.gc.ca/csas/csas/status/2007/SAR-AS2007_010_E.pdf
- Further Guidance on the Formulation, Prioritization, and Use of Conservation Objectives in an Ecosystem Approach to Integrated Management of Human Activities in Aquatic Ecosystems http://www.dfo-mpo.gc.ca/CSAS/Csas/Publications/SAR-AS/2008/SAR-AS2008_029_E.pdf

Fisheries and Oceans Canada
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Question C2:
Is Canada fulfilling its national and international obligations to protect marine biodiversity?

DFO Response C2:
Canada is making progress towards fulfilling its national and international obligations to protect marine biodiversity. For example, three federal authorities have mandated responsibilities under their respective legislation to establish and manage marine protected areas (MPAs) to protect marine biodiversity in Canada. Fisheries and Oceans Canada (DFO) can establish ***Oceans Act*** Marine Protected Areas; Environment Canada can establish National Wildlife Areas, Marine Wildlife Areas and Migratory Bird Sanctuaries; and Parks Canada can establish National Marine Conservation Areas (NMCAs) and National Parks.

On World Oceans Day, June 8, 2010, the ***Spotlight on Marine Protected Areas in Canada*** report was released. The report is based on a comprehensive national inventory of MPAs, with a tally of 797 including 83 federal, 705 provincial/territorial and nine non-government areas that protect the marine environment.

MPAs can be established under more than 40 different pieces of legislation by various federal, provincial and territorial agencies. This facilitates protection for different aspects of the marine environment, as well as more strategic planning of future MPAs. To further coordinate efforts and to guide the establishment of the national network of MPAs, federal authorities are working with provincial and territorial colleagues to draft a ***Framework for Canada's National Network of Marine Protected Areas***.

Progress is steadily being made by Canada to protect marine biodiversity and build its national network of MPAs. Recently, the Tarium Niryutait Marine Protected Area was announced, one of eight ***Oceans Act*** Marine Protected Areas established to date, and the first in the Arctic. Also recently announced were two new DFO Areas of Interest: the Hecate Strait/Queen Charlotte Sound glass sponge reefs within the Pacific North Coast Large Ocean Management Area, and an area of rich biodiversity within the Laurentian Channel off the coast of Newfoundland and Labrador. Progress has also been made on the identification of four additional DFO Areas of Interest, and decision on these sites is expected in the near future.

In addition, the Government of Canada has now formally protected the marine ecosystems of Gwaii Haanas by establishing the Gwaii Haanas National Marine Conservation Area Reserve and Haida Heritage Site, the fourth area within Parks Canada's NMCA system, based on a framework of 29 marine regions to be represented.

This brings the current total to 799 MPAs in Canada.

In addition to these advances in the domestic context, Canada participated in the development of the Arctic Council's Arctic Marine Biodiversity Monitoring Plan. Implementation of this Plan is scheduled to start in 2011.

Question C3:
How should responsibilities for sustaining marine biodiversity be divided between government, fishing and aquaculture industries, retailers, consumers, other ocean users, and conservation bodies? What could be their roles in efficient and effective marine stewardship and regulation?

DFO Response C3:
The long-term sustainability of marine biodiversity is ultimately shared across all of society and across the fish and seafood value chain, including harvesters/farmers, processors, distributors, retailers, food service participants (restaurants, caterers, chefs) and consumers. Along with governments, all of these actors play a part in and shape the global sustainable seafood movement. Value chain actors are demanding verifiable proof of sustainable wild capture and aquaculture practices as well as increased sustainability reporting on behalf of regulatory bodies as preconditions to market access and procurement. Non-governmental organizations, academic bodies and international organizations (e.g., the United Nations Food and Agriculture Organization and the Organisation for Economic Co-operation and Development) also have roles to play in advancing dialogue and cooperation within the sustainable seafood movement. In a dynamic, push-pull relationship these actors and regulatory bodies are, in some cases, developing stronger dialogue, areas of common understanding, synergies and advances in the sustainable management of marine biodiversity.

Aboriginal people and communities also have an important role to play. In Canada's North, for example, there are a number of land claims agreements which describe the responsibilities of the different parties with respect to the environment and wildlife. The best way to proceed in the North is to respect these constitutionally-protected land claim agreements.

Fisheries and Oceans Canada | Pêches et Océans Canada
Deputy Minister | Sous-ministre

MAY 0 4 2011

Your file Votre référence
Our file Notre référence

Dr. Jeffrey A. Hutchings
Professor and Canada Research Chair in Marine Conservation & Biodiversity
Department of Biology
Dalhousie University
1355 Oxford Street
Halifax, Nova Scotia
B3H 4J1

Dear Dr. Hutchings:

Thank you for your letter of February 1, 2011, in which you pose four questions regarding Fisheries and Oceans Canada's submission to the Royal Society of Canada's Expert Panel on "Sustaining Canada's Marine Biodiversity: Responding to the Challenges Posed by Climate Change, Fisheries, and Aquaculture."

I trust that the responses to your questions, which you will find attached, will be helpful to you and the Panel as you complete your investigation of this important issue.

Yours sincerely,

Claire Dansereau

Claire Dansereau

Enclosure

Fisheries and Oceans Canada
Submission to Royal Society of Canada
Supplemental Questions and Responses

Question 1:
What is the current status of plans to modernize the Fisheries Act as a possible follow-up to previous parliamentary attempts to amend the legislation?

DFO Response 1:
We are unable to provide a response at this time; legislative amendments, if any, will be directed by the new government once elected.

Question 2:
In light of the Morton case in British Columbia regarding the exclusive jurisdiction of the federal government over many aspects of aquaculture, has consideration been given to the potential need for federal aquaculture legislation? And, what are the implications of the Morton decision for aquaculture regulation in Atlantic Canada?

DFO Response 2:
The British Columbia Supreme Court decision in the Morton case does not impact the regulatory authorities of other provincial jurisdictions. There are no changes to DFO's regulatory or legislative responsibility respecting aquaculture in these other jurisdictions. The Morton decision was made by a provincial court and as such its decision is limited to the province of British Columbia.

Question 3:
As part of DFO's Integrated Oceans Management approach, what is the implementation status for all three coasts of Canada regarding the development of coastal management areas?

DFO Response 3:
DFO has been leading the development of integrated management plans for five pilot Large Oceans Management Areas covering approximately 30% of Canada's oceans space. Work has been completed in these five areas with regards to Ecosystem Overviews and Assessments, and extensive work has been undertaken to establish a baseline of socio-economic and cultural information. To date, the Eastern Scotian Shelf and Beaufort Sea Large Oceans Management Areas have Integrated Oceans Management Plans developed. Work is underway in the Placentia Bay/Grand Banks and the Pacific North Coast to develop management plans by 2012.

In support of our goals for Canada's oceans, DFO has also established a center of expertise focused on the development of coastal management tools. Funded under the Health of the Oceans initiative, the Centre of Expertise on Coastal Management has focused its efforts on decision-support tools for management, leveraging national and international practices and frameworks. Specifically, it has developed an ecosystem-based risk management framework and tools. These are aimed at supporting coastal planning and management initiatives in Canada, providing a sound ecosystem basis for management decision-making processes and policy analysis approaches.

In addition, DFO participates in smaller coastal management areas in a range of ways (e.g., as leader, active participant for a provincial or other federal lead, or observer) depending on the specific issues and departmental and federal interests being addressed. In these areas, DFO is engaged in a number of management actions, including the development of coastal management plans, with other federal agencies, provincial and territorial governments, Aboriginal groups and stakeholders. Current DFO participation includes: West Coast Vancouver Island (observer); Southwest New Brunswick - Bay of Fundy (co-chair and co-sponsor with Government of New Brunswick); the Collaborative Environmental Planning Initiative - Bras d'Or Lakes (member and co-sponsor with other federal departments and Government of Nova Scotia), and; five coastal management areas in Newfoundland and Labrador - Placentia Bay, Coast of Bays, Great Northern Peninsula, Bay of St. George/Port aux Port, and Bay of Islands (ex officio member). The Southwest New Brunswick Marine Resources Planning initiative has developed a series of priority actions for resource management in the planning area, and a steering committee with joint government-stakeholder participation is working together on these actions. The Bras d'Or Lakes initiative, which was established in 2003 to develop an environmental management plan for the Lakes and watershed, recently released a planning document (*The Spirit of the Lakes Speaks*).

Question 4:
Being one component of DFO's Sustainable Fisheries Framework, what is the current status of DFO's Bycatch Policy?

DFO Response 4:
Under its Sustainable Fisheries Framework initiative, DFO has begun a process to develop a national policy framework for the management of bycatch and discards that builds on existing measures to manage bycatch. Work on developing the policy framework will continue through 2011.

APPENDIX C: REGIONAL DESCRIPTIONS OF CANADA'S OCEANOGRAPHY

1. The Northwest Atlantic Ocean

a. Regional Systems

i. Scotian Shelf

Among several regional systems in the Northwest Atlantic (Figure C.1), the Scotian Shelf waters consist of three distinct water masses (Townsend et al. 2004). Warm, saline bottom waters originate from offshore of the continental shelf break. Above these bottom waters, and below the seasonal thermocline, lies a cold, less saline intermediate layer originating from the Labrador Current and from outflow of the Gulf of St. Lawrence. Heating in the summer and subsequent cooling in the winter modify the hydrographic characteristics of the surface waters that are above the seasonal thermocline.

While highly variable, mean flow along the Scotian Shelf consists of two elements: a branch of the Labrador Current, flowing along the shelf edge, and a southward flowing current, confined closer to the coast (Hannah et al. 2001). The varied topography of the region, consisting of a series of banks and channels, leads to local re-circulations, including gyres over Browns, Georges, and Sable Island Banks. These features prove to be critical for marine biodiversity (Hannah et al. 2001). Moreover, tidal mixing and tidal currents play a profound role on the regional circulation of the Scotian Shelf (Townsend et al. 2004; Ohashi et al. 2009a,b).

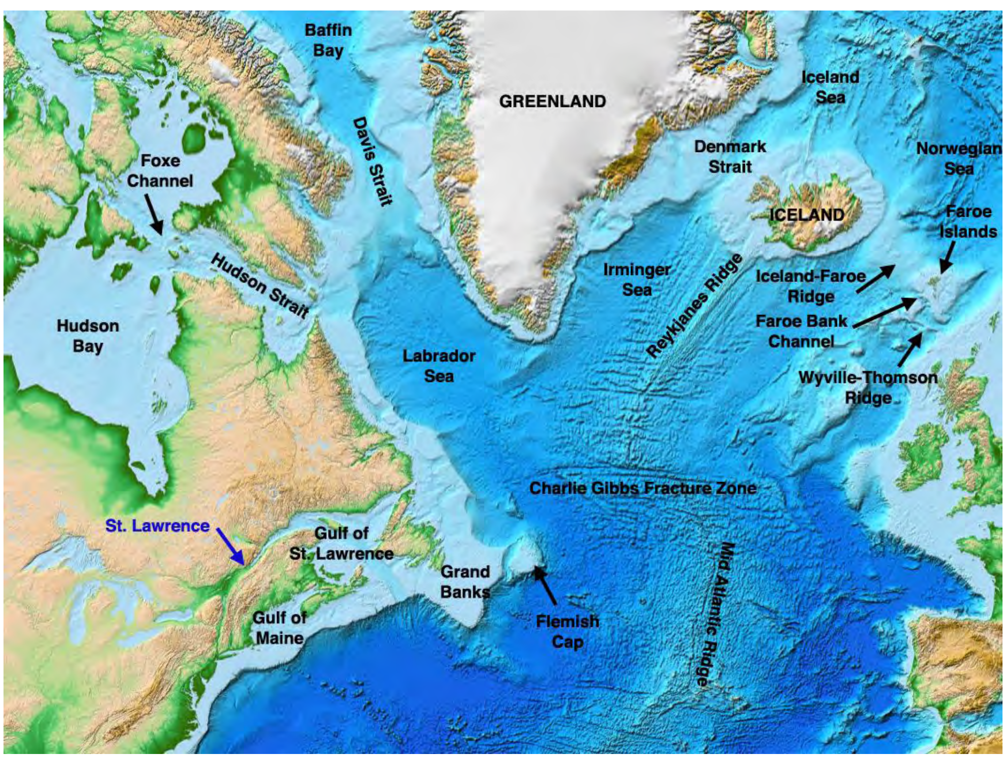


Figure C.1. *Topographic map of the North Atlantic Ocean. Source: http://maps.ngdc.noaa.gov/viewers/bathymetry/.*

ii. Hudson Bay

Hudson Bay is entirely covered by sea ice each winter. Brine rejection associated with winter sea ice formation causes penetrative convection to extend to depths as great as 90-100m (Prinsenberg 1987). In the summer, the sea ice melts, leaving in its wake a buoyant, fresh surface layer. Galbraith and Larouche (2011) demonstrate that, since 1971, Hudson Bay ice breakup has occurred earlier each summer, with a trend of 3.2 days earlier per decade. This trend was stronger in both Foxe Basin (4.9 days decade^{-1}) and Hudson Strait (5.6 days decade^{-1}). Gagnon and Gough (2005) noted similar trends towards later autumn freeze up, particularly in northern and northeastern Hudson Bay, where the trends varied from 3.2-5.5 days later freeze-up per decade. In 2010, freeze-up was particularly delayed. Over much of Hudson Bay, freeze-up occurred three to four weeks later than usual as a consequence of record warm regional temperatures.

The mean annual discharge rate into Hudson Bay (including James Bay to the south and Ungava Bay off northern Québec) is 30,900 $m^3 s^{-1}$ (NRCAN 1995). The Nelson River, having Canada's second largest drainage basin behind the Mackenzie basin, provides an annual mean discharge rate into Hudson Bay of 3,130 $m^3 s^{-1}$. Québec's La Grande River adds another 3,359 $m^3 s^{-1}$, as does the Moose River in Ontario, which contributes another 1,370 $m^3 s^{-1}$. Nine of the top 15 largest Canadian drainage basins also outflow into the Hudson/ James/Ungava Bay system. In addition to the Nelson, Moose, and La Grande rivers, such drainage basins include the Churchill, Thelon, Albany, Koksoak, Hayes, and Severn River systems. The distinct annual cycle of runoff into Hudson Bay consists of a minimum in April and a maximum in late May or early June (Ingram and Prinsenberg 1998). Runoff then typically decreases slowly as the year progresses, although hydroelectric projects have altered this annual cycle of runoff in a few locales.

Freshwater runoff into Hudson Bay sets up a buoyancy-driven coastal current that flows cyclonically (counter-clockwise) around the basin (Ingram and Prinsenberg 1998). While the current is present year round, it is deeper and weaker when sea ice is present in the winter and spring. James Bay, with an average depth of about 60 m, is located at the south end of Hudson Bay. It is more profoundly affected by river runoff and has fresher water than Hudson Bay. As such, it possesses its own distinct marine ecosystem (Stewart and Lockhart 2005).

b. Northern Annual Mode/North Atlantic Oscillation and North Atlantic Ocean Variability

The Northern Annular Mode is the leading empirical orthogonal function (EOF) or spatial pattern of northern hemisphere sea level pressure anomalies (Thompson and Wallace 1998, 2000). It is identical to the Arctic Oscillation of Thompson and Wallace (1998). The Northern Annular Mode embodies the North Atlantic Oscillation (NAO), often obtained as the leading EOF of sea level pressure variability over the North Atlantic (20°-80°N; 90°W-40°E). While not an "oscillation" in a traditional sense, the NAO has a dipole structure (Figure C.2 top) that yields the dominant pattern of sea level pressure variability throughout the year (Hurrell and Deser 2009). The NAO is strongest in the winter when it explains 41.9% of the year-to-year variance in sea level pressure (Figure C.2 top).

The NAO index is defined as the principal component of the first EOF defined above (Figure C.2 bottom). In the positive phase of the NAO (red bars in Figure C.2 bottom), the Icelandic low is deeper than normal and the subtropical high is stronger, while in the negative phase the opposite prevails. As shown by Feldstein (2000), the NAO has intrinsic variability on a timescale of ≤ 10 days. The spectral power on longer timescales only slightly increases with period (Hurrell and Deser 2009) and there are no dominant timescales of variability.

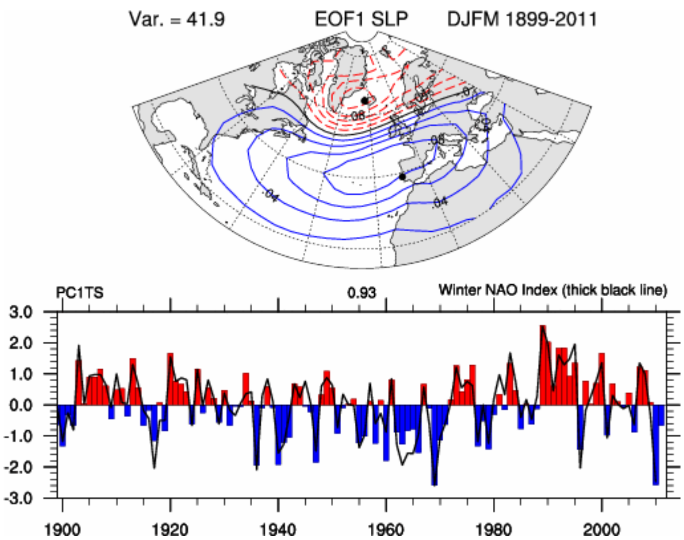


Figure C.2. *Top: Spatial pattern of the first EOF of December-March sea level pressure anomalies over 20°-80°N; 90°W-40°E. Bottom: Time series from 1899-2011 of the NAO Index defined as the principal component of the first EOF (see Hurrell et al. 2003; Hurrell and Deser 2009). Soucre: http://www.cgd.ucar.edu/cas/jhurrell/indices.html.*

Variability in the NAO has a profound effect on the climate of the northwestern North Atlantic. When the winter NAO is in a negative phase, such as that which occurred dramatically during the winter of 2009/2010, the eastern seaboard of the US is typically cold and snowy. Correspondingly, northeastern Canada is warm, with less sea ice in Baffin Bay, Hudson Bay, and the Labrador Sea (Figure C.3). In the positive phase, the Labrador Sea is colder and there is more extensive sea ice cover in the same regions.

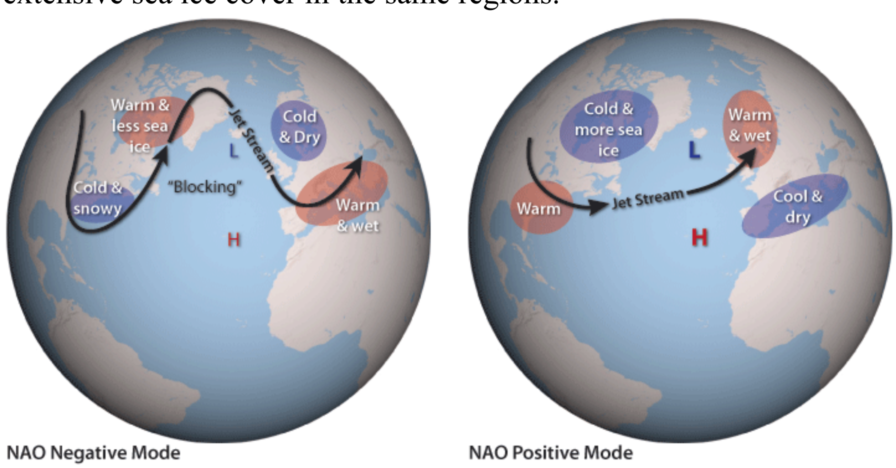


Figure C.3. *Schematic diagram showing the typical climatic impacts of negative (left) and positive (right) phases of the North Atlantic Oscillation. Source: http://www.climatewatch.noaa.gov/wp-content/uploads/2010/03/NAO_Schematic.png*

Visbeck et al. (2003) provide a comprehensive review of the ocean's response to variability of the NAO, while Drinkwater et al. (2003) review its concomitant effect on marine ecosystems. Visbeck et al. (2003) note that the sea surface temperature (SST) response to NAO variability exhibits a tripole structure. The positive phase of the NAO correlates with cold SSTs in the subpolar gyre including the Labrador Sea, warm SSTs in the western subtropical gyre, and cold SSTs in the northeastern Tropical Atlantic. They further point out that during the positive phase the separated Gulf Stream shifts northward slightly (Joyce et al. 2000) and that convection in the Labrador Sea deepens (Dickson et al. 1996).

The winter NAO index shown in Figure C.2 (bottom) indicates periods where the NAO remains in positive or negative phase for a number of successive years. Such persistent phases of the NAO, combined with the slow response time of the ocean, have been implicated as drivers of low frequency, decadal/interdecadal variability of the North Atlantic (Wohlleben and Weaver 1995; Dickson et al. 1996; McLaughlin et al. 2002; Visbeck et al. 2003; Sundby and Drinkwater 2007) and, in particular, the large scale salinity anomalies observed in the northern North Atlantic in the 1970s (Dickson et al. 1988), 1980s (Belkin et al. 1998) and 1990s (Belkin 2004).

2. The Arctic Ocean

a. Regional Systems

i. Baffin Bay

Baffin Bay is a semi-enclosed basin bounded by Baffin Island to the west and Greenland to the east. With a sill depth of ~250m, it is connected to the Arctic via the narrow 26-30 km wide Nares Strait between Ellesmere Island and Greenland. The western end of Lancaster Sound (between Baffin and Ellesmere Islands) also links Baffin Bay to the Arctic through the Canadian Arctic Archipelago (Figure C.4). Here, waters are constrained by a ~55 km channel with a ~125 m deep sill. Davis Strait, with a sill depth of ~650 m and a width of about 300 km, connects Baffin Bay to the Labrador Sea and the North Atlantic.

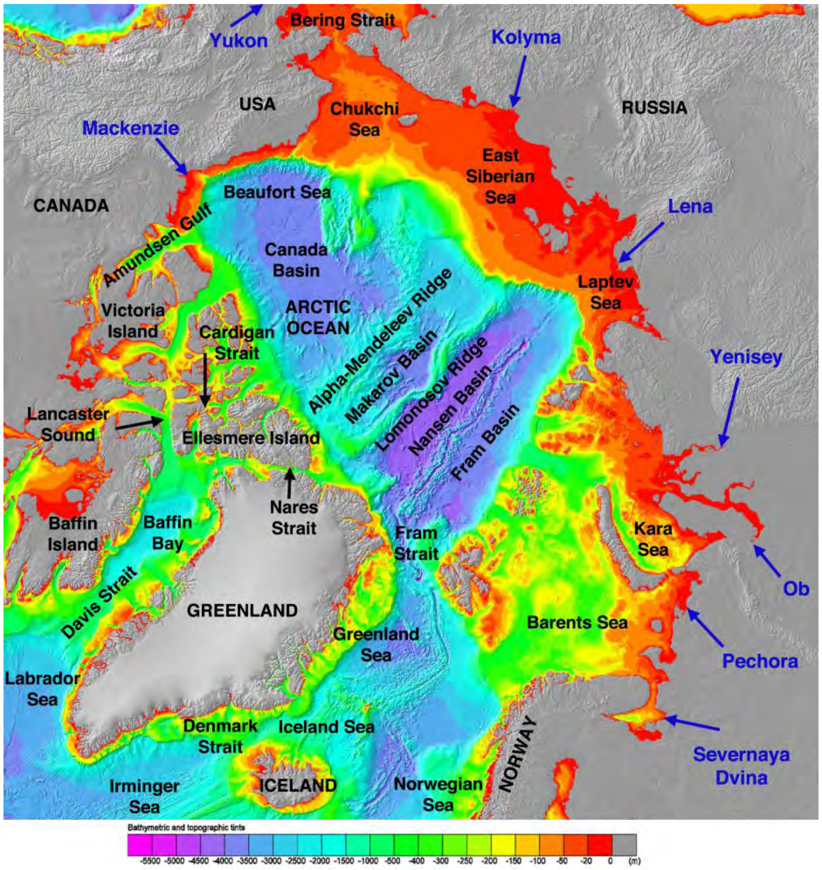


Figure C.4. *Topographic map of the Arctic Ocean (International Bathymetric Chart of the Arctic Ocean). Source: http://www.ngdc.noaa.gov/mgg/bathymetry/arctic/currentmap.html [Jakobsson et al. 2008]).*

Typically, winter freeze-up in the Nares Strait forms an ice bridge between Ellesmere Island and Greenland. However, in 2007, this ice bridge never formed, thereby allowing multi-year ice to be exported from the Arctic into Baffin Bay year round. Ice bridge formation has remained unusual in Nares Strait since 2007. Oceanographic conditions in Nares Strait were likely associated with the massive ice calving event from the Petermann Glacier on 15 July 2008.

Tang et al. (2004) provide a comprehensive review of the oceanography of Baffin Bay. They describe a three-layer system with a very cold, fresh upper layer of Arctic origin overlying a deeper (300-800 m) warmer, salty, layer, with both originating from the West Greenland Current. The bottom waters of Baffin Bay are colder but are still saline. They are likely formed through local mixing processes. Circulation in Baffin Bay is cyclonic, with waters entering Baffin Bay from the Atlantic via the West Greenland Current and leaving Baffin Bay by way of the Baffin Current along the western boundary. Where West Greenland Current water encounters Arctic water from Nares Strait, a frontal system with significant mixing occurs (Lobb et al. 2003). The North Water Polynya (region of open water bounded by sea ice) is a recurring winter feature of northern Baffin Bay (Melling et al. 2001; Yao and Tang 2003). Its occurrence is particularly important to marine biodiversity in Baffin Bay.

ii. Canadian Archipelago

In much of the Canadian Arctic Archipelago, pack ice is a persistent annual feature (Melling 2002). Summer melting may, however, open up all or part of the southern and eastern regions. Since 2007, the Northwest Passage has been opened for shipping, albeit briefly.

Freshwater export from the Arctic through the Canadian Arctic Archipelago occurs via both ocean currents and sea ice advection. Melling et al. (2008) estimate that 0.7 Sv flows from the Arctic to Baffin Bay through Lancaster Sound, 0.3 Sv through Cardigan Strait and 0.8 Sv through Nares Strait. These transports bring about 0.048, 0.010, and 0.033 Sv of freshwater into the North Atlantic, respectively. As noted by Jones et al. (2003), the Canadian Arctic Archipelago outflow contains a distinct signature of waters that have entered the Arctic from the North Pacific through Bering Strait. Freshwater export in the form of sea ice is an order of smaller magnitude, with 0.0015, 0.0003, 0.0042Sv being transported through the same three passages, respectively (Melling et al. 2008; see also Agnew et al. 2008).

b. Arctic Oscillation and Arctic Dipole

Interannual variability in the Arctic is dominated by changes in the Arctic Oscillation (AO or Northern Annular Mode). Accounting for 18.5% of the variance, the AO is defined as the leading Empirical Orthogonal Function (EOF) of northern hemisphere (20°N-90°N) sea level pressure (Figure C.5). When the AO is positive, surface air pressure over the Arctic is lower than normal and zonal winds are stronger. Cold Arctic air tends to be constrained to northern areas, so that much of eastern North America is warm. Storm tracks in the Atlantic tend to take a more northward path. In the negative phase of the AO, opposite conditions typically occur.

The winter-averaged AO Index exhibits persistent periods over which it remains in the same phase (Figure C.5). The 1990s marked a period when the wintertime AO remained in the positive phase, whereas prior to 1970, the opposite prevailed. In the summer of 2007, an unprecedented shift in atmospheric conditions occurred over the Arctic (Zhang et al. 2008). The typical tri-pole structure of the AO was replaced by what has become known as the Arctic Dipole (AD; Figure C.6). The AD was also present in the late spring of 2009 and 2010 (Overland and Wang 2010a; Figure C.6). The presence of the AD is associated with reductions in Arctic sea ice extent (Overland and Wang 2010b). The reduced summer sea ice has, in turn, affected the northern hemisphere atmospheric circulation in the subsequent autumn and winter (Francis et al. 2009). In particular, this led to anomalously cold late winters in Eurasia (Honda et al. 2009).

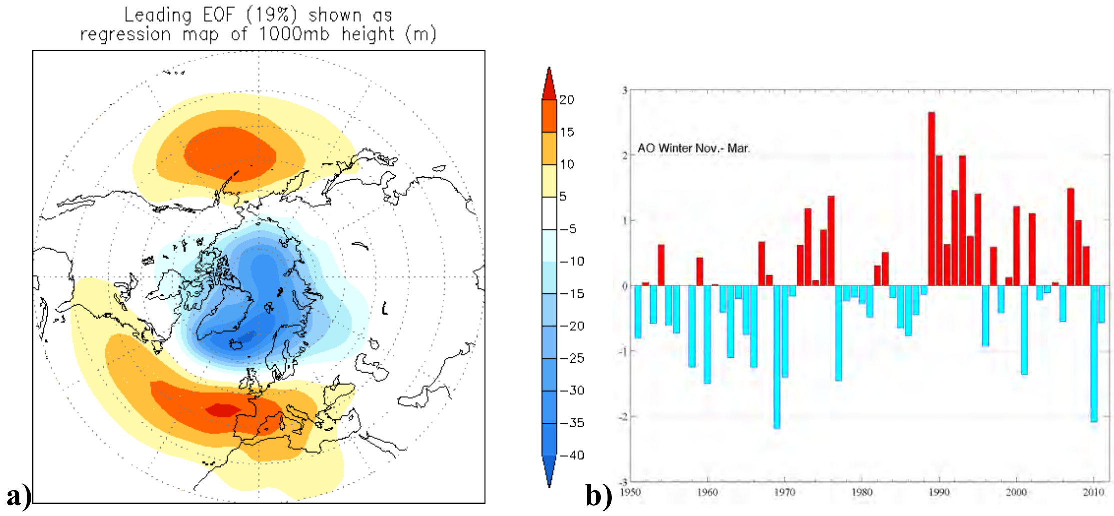


Figure C.5. *Spatial pattern of the Arctic Oscillation (1979–2000). Source:* [*http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/ao.loading.shtml*](http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/ao.loading.shtml) ***b:*** *Winter (November-March) Arctic Oscillation index from 1950-2011**.** Source:* [*http://www.arctic.noaa.gov/detect/climate-ao.shtml*](http://www.arctic.noaa.gov/detect/climate-ao.shtml)

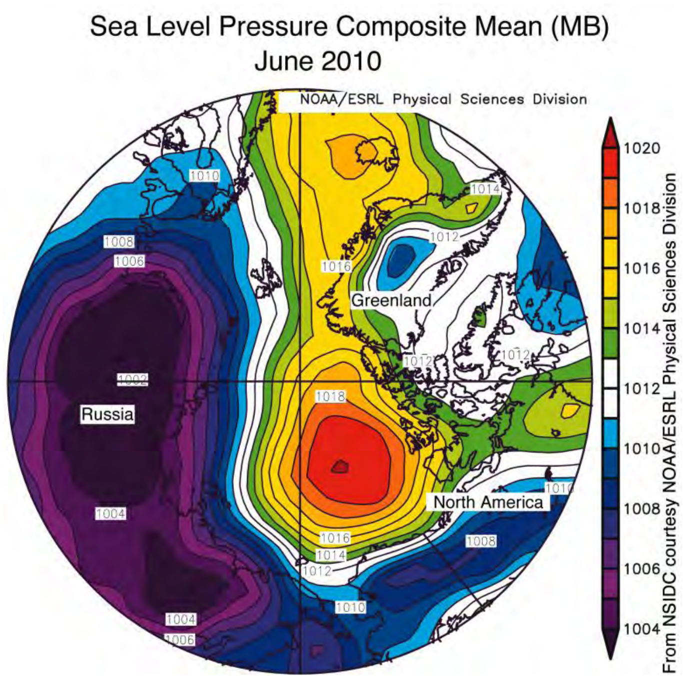


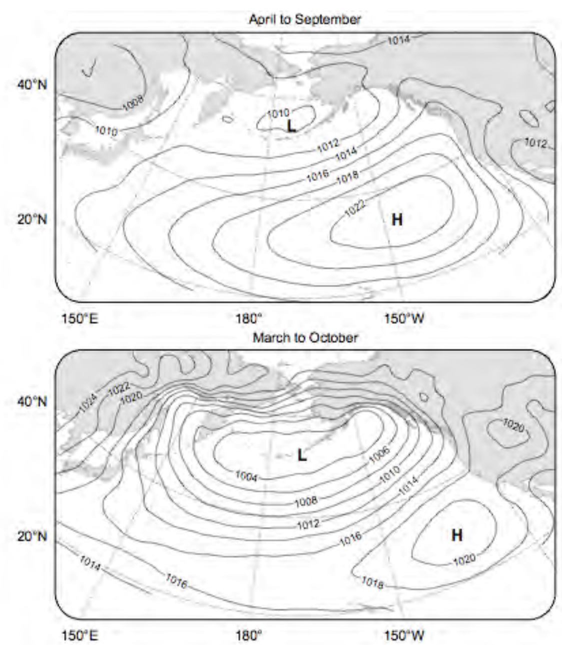
Figure C.6. *Sea Level Pressure Map of June 2010 showing the Arctic Dipole with high pressure centred over the Arctic Ocean and low pressure centred over Eurasia. Source:* [*http://nsidc.org/arcticseaicenews/2010/070610.html*](http://nsidc.org/arcticseaicenews/2010/070610.html)

3. The Northeast Pacific Ocean

a. Seasonal Winds and Coastal Currents

Beginning in approximately mid-October, a semi-permanent low-pressure cell, commonly called the Aleutian Low, intensifies and migrates southeastward over the Aleutian Islands and the Gulf of Alaska (Figure C.7). Surface winds blow in a counterclockwise circulation around the Aleutian Low. Further south, winds blow in a clockwise circulation around a semi-permanent center of high pressure typically located offshore of southern California. Typically, these high and low pressure cells together bring moist, mild, onshore flow into BC's coastal zone. As the moisture-laden air encounters the coastal mountains, it rises and cools, and the cooling causes water vapor to condense into cloud and rain or ice crystals and snowflakes. Because of seasonal shifts in these large-scale wind patterns, BC's wet season typically begins in the fall, peaks in mid-winter, and ends in the spring. During late spring, the Aleutian Low retreats to the northwest and becomes less intense, whereas the subtropical high pressure cell expands northward and intensifies (top panel of Figure C.7). The result is a tendency for weaker and more variable winds to occur along coastal BC in the summer and fall as opposed to the winter and spring.

Figure C.7. Seasonal changes in North Pacific atmospheric sea level pressure patterns. April-September averages are shown in the top panel, while October-March [the lower panel is mis-labeled 'March to October'] averages are shown in the bottom panel. Contours depict sea level pressure isobars in hPa (millibars). Data are from NCEP reanalysis fields (Kalnay et al. 1996), averaged for the 1949-1999 period.



An ecologically important consequence of the seasonal changes in BC's coastal winds is the switch from typically intense poleward and coastal downwelling winds prevailing from October through March, to more frequent periods of weak winds or intermittent equatorward and coastal upwelling winds occurring from April through September. Upwelling tends to supply scarce plant nutrients to phytoplankton dwelling in the upper ocean when summer sunlight is abundant. In turn, high phytoplankton production helps fuel high productivity throughout the entire marine food web. Coastal upwelling also brings carbon-rich, low-pH deep waters, characterized by low dissolved oxygen, onto the continental shelf, and in so doing, can dramatically impact benthic communities in instances where ecologically important thresholds are crossed (e.g., Feely et al. 2008; Chan et al. 2008; Connolly et al. 2010). In contrast, poleward winds move nutrient-poor, oxygen-rich, and relatively low-pH surface waters onshore. In such scenarios, convergence at the coastline causes coastal downwelling, driving surface waters to greater depths.

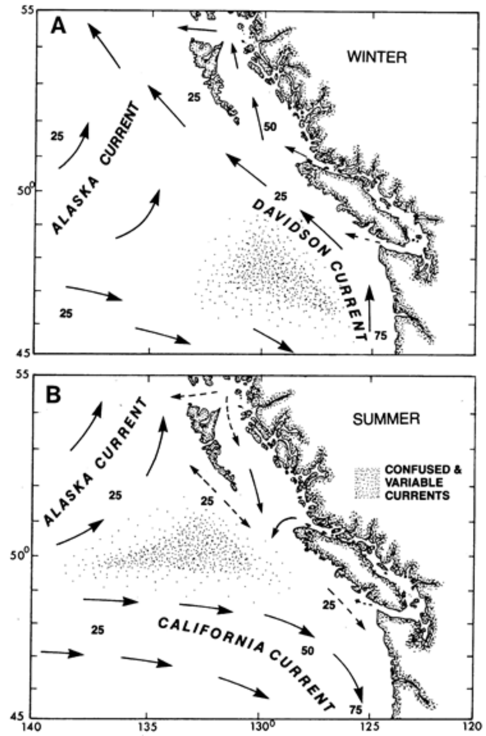
Upwelling and downwelling related variations in coastal water properties exert strong influences on the physical and chemical water properties in coastal basins and estuaries. In doing so, they represent an integral dynamical pathway for connecting offshore and nearshore marine systems (Hickey and Banas 2003).

Coastal currents typically undergo seasonal changes that are driven by the seasonal reversal of prevailing coastal winds. As the Aleutian Low intensifies in the autumn, so do the northward flowing coastal currents near the BC coast (Figure C.8). The Davidson Current is a seasonal, northward flowing feature of winter coastal circulation that shifts the California Current further offshore. The disappearance of the Davidson Current largely coincides with the seasonal reversal of prevailing coastal winds from southwesterly in winter, to northwesterly in spring and summer. Likewise, the Haida Current is a narrow, northward flowing surface current that flows over the continental slope of northwestern BC and southeast Alaska and is typically present between October and April (Thomson and Emery 1986). In summer, the Haida Current is absent due to a lack of strong southwesterly winds. Episodic periods wherein winds prevail from the northwest, can also reverse the nearshore portion of the Alaska Current and thereby lead to a system of eddies and irregular meanders along coastal margins. In all seasons, the divergence of the Alaska and California Currents is marked by a triangular-shaped region typified by confused currents featuring numerous eddies and meanders (Thomson 1981).

Another ecologically significant feature of the western coastal circulation is the California Undercurrent. This is a sometimes strongly northward sub-surface flow that hugs the continental slope at depths below 200 m. The California Undercurrent is strongest in fall and winter. It sometimes occurs as far north as Vancouver Island, and may provide a northward transport route for larval fish and invertebrates and, possibly, phytoplankton seed stock (Hickey and Banas 2003).

Buoyancy-driven coastal currents also influence the nearshore circulation of the BC coast. For instance, the Vancouver Island Coastal Current is a northward flowing, buoyancy-driven coastal current that is fed by the outflow of low-salinity surface waters originating in the Strait of Georgia. Year round, it exists from the BC coast to, at minimum, the middle of the continental shelf (Thomson et al. 1989).

__Figure C.8.__ Prevailing surface circulation off British Columbia-Washington coast in winter and summer. Broken arrows indication uncertain currents. Numbers give speeds (cm/s). Source: Thomson (1981).



b. Regional Systems

i. Strait of Georgia

The Strait of Georgia lies between Vancouver Island and the lower mainland of the BC coast (Figure C.9). On average, it is about 222 km long and 28 km wide; islands occupy roughly 7% of its total surface area of 68 km^2. The average depth within the Strait is around 155 m, with a maximum depth of 420 m (Thomson 1981).

The Strait of Georgia is linked to the Pacific Ocean via narrow, but long, channels. To the north are Discovery Passage and Johnstone Strait, which connect to the broader Queen Charlotte Strait. To the south are a few relatively wide channels between the San Juan and Gulf Islands and Juan de Fuca Strait. Freshwater discharge into the Strait of Georgia comes mostly from the Fraser River, with peak discharge contributed by snowmelt runoff in late spring and early summer. The freshwater discharge causes a strong estuarine circulation with low-density surface waters flowing towards the ocean, and in turn, a return flow of higher-density oceanic water at depth flowing into the Strait of Georgia through the Strait of Juan de Fuca.

Figure C.9. *Topographic and bathymetric map of the northeast Pacific Ocean. Taken from: http://maps.ngdc.noaa.gov/viewers/bathymetry/.*

Surface temperatures in the Strait of Georgia are renowned for significant seasonal variations. Surface temperatures in winter are typically as low as 5-6°C, but in late summer, it is not unusual to find within protected coves and bays, and even within the middle of the Strait, surface temperatures as high as 20°C (Thomson 1981).

In summer, both temperature and salinity in the Strait of Georgia are marked by a two-layer structure, with relatively warm and fresh water within a surface layer, overlying relatively cool and salty water at depth. These stratified waters are modified by turbulence caused by strong tidal exchanges across narrow passages and by sills found in locations such as the Haro and Rosario Straits located near the San Juan Islands.

ii. Strait of Juan de Fuca

The Strait of Juan de Fuca is a long, narrow submarine valley between Vancouver Island and the Washington State's Olympic Peninsula which was carved out by continental ice sheets over the course of 1-2 million years. The Strait of Juan de Fuca is ~100 km long and typically ~22-28 km wide, with a depth that decreases inland, gradually from around 250 m at mid-channel near its entrance, to only 55 m in depth over the sill south of Victoria. The coastline of the Strait of Juan de Fuca is relatively uniform, with a low rocky shoreline abutting cliffs that tower up to 20 m high. Centuries of wave action have turned much of the shore into rocky intertidal platforms, often covered by kelp in summer. A large terminal moraine forms a shallow, narrow sill in the eastern part of the Strait of Juan de Fuca and is a location of intense tidal mixing that strongly modifies the properties of water masses moving past it (Thomson 1981).

Water properties in the Strait of Juan de Fuca are influenced by the ocean to the west, to the east by river discharge into Puget Sound and the Strait of Georgia, and by the overlying atmosphere. Because of intense wind and tidal mixing and the direct connection with the Pacific Ocean, water temperatures in the Strait of Juan de Fuca remain cold year round. In summer, surface temperatures typically reach 12-14°C, while in winter they typically range from 8-10°C near the western end of the Strait to 6-8°C near the eastern end. A wedge of relatively salty oceanic water penetrates up-channel into the Strait in subsurface waters, with an estuarine outflow of lower salinity waters near the water's surface. Because of the Coriolis deflection and curvature of the Strait, the upper-layer outflows hug the Canadian side, while the oceanic inflows at depth favour the American side (Thomson 1981).

iii. Queen Charlotte Strait, Johnstone Strait, and Discovery Passage

Queen Charlotte Strait, Johnstone Strait, and Discovery Passage make up a major part of the navigable inside passage that separates Vancouver Island from the mainland coast of BC. Depending on the year, Johnstone Strait is a key part of the migration routes for approximately ten to 70% of the sockeye salmon that annually return to the Fraser River. Likewise, the protected nature of these channels attracts a substantial amount of marine ship traffic, including tug boats, bulk carriers, freighters, cruise ships and other pleasure craft.

Johnstone Strait and Discovery Passage are the narrowest of the major channels in the inside passage, ranging from about 2.5 to 4.5 km wide over much of their length. The depth in these channels is highly varied, ranging from 70 m to 500 m. In these waterways, one finds rapid tidal streams and intense turbulent mixing. Temperatures increase only slightly toward the Strait of Georgia, and remain relatively cold throughout the year (typically less than 10°C even in mid-summer). Because of the intense turbulent mixing, salinity is also nearly uniform along these narrow channels, though it increases slightly going from the Strait of Georgia to Queen Charlotte Strait. Year round, intense turbulent mixing also favours an abundance of dissolved oxygen throughout the water column. Strong bottom currents constantly supply well-oxygenated waters over the sea floor and support productive benthic communities (Thomson 1981).

Queen Charlotte Strait is the 90 km long, relatively shallow and island-strewn basin located at the seaward end of Johnstone Strait. Here, the width of the main basin ranges from about 13 to 26 km. Surface temperatures can exceed 15°C on calm, sunny days in late summer. Given these conditions, a relatively thin, brackish layer forms to stratify the water column and efficiently concentrate solar heating. Dissolved oxygen concentrations within Queen Charlotte Strait tend to be higher at the surface but lower near the bottom than in Johnstone Strait. However, values typically remain above 3 ml L^{-1}, enough to support most marine animals (Thomson 1981).

iv. Queen Charlotte Sound, Hecate Strait, and Dixon Entrance

Queen Charlotte Sound, Hecate Strait and Dixon Entrance comprise an oceanographically hybrid region on the northern BC coast. It is similar to offshore waters, but is modified substantially by estuarine processes typical of more protected inland waterways. Deep-sea currents, tides, winds, and river discharge are all important factors in the oceanography of this region.

Dixon Entrance is an east-west depression in the continental shelf bounded by Dall and Prince of Wales Island to the north and by Graham Island to the south. Hecate Strait is a relatively protected basin with Graham Island to the west and the mainland to the east. The axis of Hecate Strait is a narrow, submarine valley close to the mainland side, with depths that diminish from 300 m in the south to 50 m in the north. The bathymetry of Queen Charlotte Sound is more complex than either Dixon Entrance or Hecate Strait, because of shallow banks and three broad troughs that cut inland across the continental shelf. The continental slope of Queen Charlotte Sound is relatively gentle due to seaward transport of land-derived sediments originating from the coastal mountains (Thomson 1981).

Temperature and salinity of the surface waters in this region vary in response to the seasonal changes in solar radiation and freshwater discharge. The combined flows of the Nass and Skeena Rivers contribute around 5700 m^3 s^{-1} during early June, an amount that is comparable to that of the Fraser River. Freshwater runoff is relatively low in mid-winter, and this combination leads to maximal winter salinity and minimal salinity in summer. Average surface temperatures vary from about 6°C in April to approximately 14°C in August, with the waters in Dixon Entrance being consistently colder than those in Hecate Strait and Queen Charlotte Sound. The influence of freshwater discharge is greatest in Dixon Entrance in late spring and summer when snowmelt runoff peaks and the consequent outflows tend to follow the channel's north side. At this time, cooler, saltier, oceanic water tends to prevail over the southern half of the channel (Thomson 1981).

c. Prominent Patterns of Seasonal, Interannual and Decadal Variability: El Nino-Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), and North Pacific Gyre Oscillation (NPGO)

Substantial fractions of the interannual to interdecadal variability in western Canada's climate and the oceanography of the BC coast have been related to three large-scale patterns of climate variability: El Nino-Southern Oscillation (ENSO), the Pacific (inter)Decadal Oscillation (PDO), and the North Pacific Gyre Oscillation (NPGO).

ENSO is Earth's dominant source of year-to-year climate variations (Rasmussen and Wallace 1983). This phenomenon is understood to be a natural part of climate which spontaneously arises from interactions between tropical trade winds and ocean surface temperatures and currents near the Pacific equator. While the essential physics of ENSO are thought to be contained within the tropical Pacific sector, ENSO variations exert especially strong impacts on the northeast Pacific Ocean through atmospheric teleconnections. These influence the strength and location of the Aleutian Low, primarily from October through March (Alexander et al. 2002), and through oceanic teleconnections that involve coastally- trapped internal waves that, at times, influence the depth of the pycnocline, nearshore currents and the coastal sea levels (Parres Sierra and O'Brien 1989). During warm phases of ENSO, coastal SSTs in the northeast Pacific Ocean and along the BC coast tend to be warmer than average, but the cool ENSO phase is associated with cooler SSTs. ENSO variations are most prominent at periods of two to seven years (Figure C.10).

The PDO is defined as the leading pattern of monthly North Pacific sea surface temperature (SST) variations over the 20th century, wherein periods with cooler-than-average SSTs in the central and western North Pacific Ocean tend to occur with warmer-than-average SSTs in the northeast Pacific Ocean, and vice-versa (Figure C.10) (Mantua et al. 1997). This pattern is closely associated with the leading pattern of variability in monthly sea surface height in the northeast Pacific Ocean (Cummins et al. 2005). The PDO has been characterized as an ENSO-like pattern of Pacific climate variability that tends to vary over multiple years and decades. Its variability is closely associated with the interannual and interdecadal variability of the Aleutian Low (Zhang et al. 1997). There appears to be no timescale for PDO variations that predominates, but most of its variability occurs at decadal to interdecadal time scales. PDO variations are thought to be a consequence of atmospheric forcing on the North Pacific Ocean caused by the random and intrinsic variability of the Aleutian Low in combination with more systematic atmospheric and oceanic teleconnections relating to ENSO (Newman et al. 2003; Schneider and Cornuelle 2005). During warm phases of the PDO, SSTs near Canada's west coast tend to be warmer than average, whereas cool PDO phases have cooler SSTs (Figure C.10).

The NPGO is defined as the second-most dominant pattern of sea-surface height and SST variations in the northeast Pacific Ocean. It is well correlated with variations in salinity, nutrients, and chlorophyll-a measured in long-term observations in the California Current System and Gulf of Alaska along Line-P (DiLorenzo et al. 2008). Variability in the NPGO pattern exhibits a near decadal time scale and has been related to intrinsic variability in atmospheric forcing over the North Pacific (Chhak et al. 2009). Recent research suggests that so-called "central pacific" El Niño events are linked with atmospheric teleconnections to the NPGO (Di Lorenzo et al. 2010). During positive phases of the NPGO, SSTs near Canada's west coast tend to be cooler than average, and negative phases are warmer (Figure C.10).

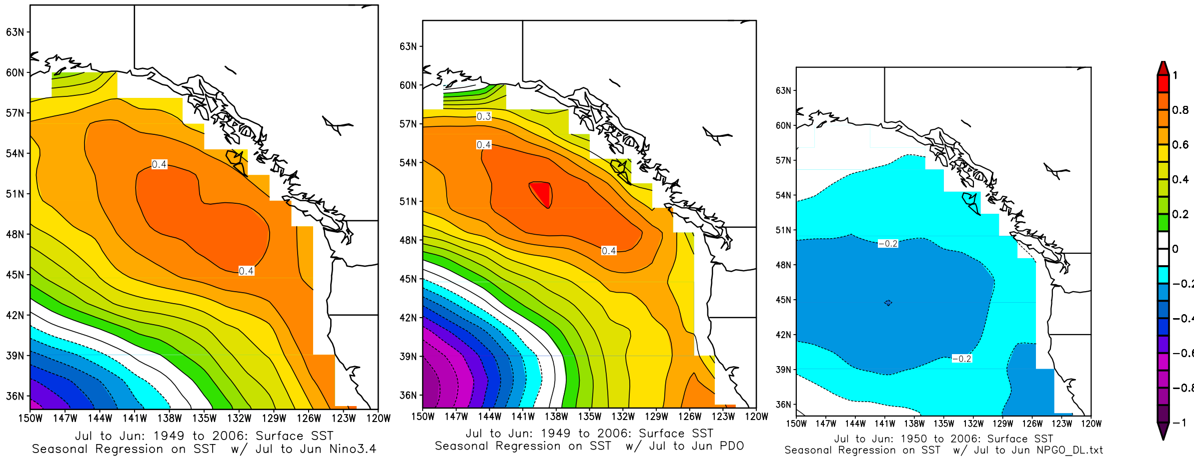
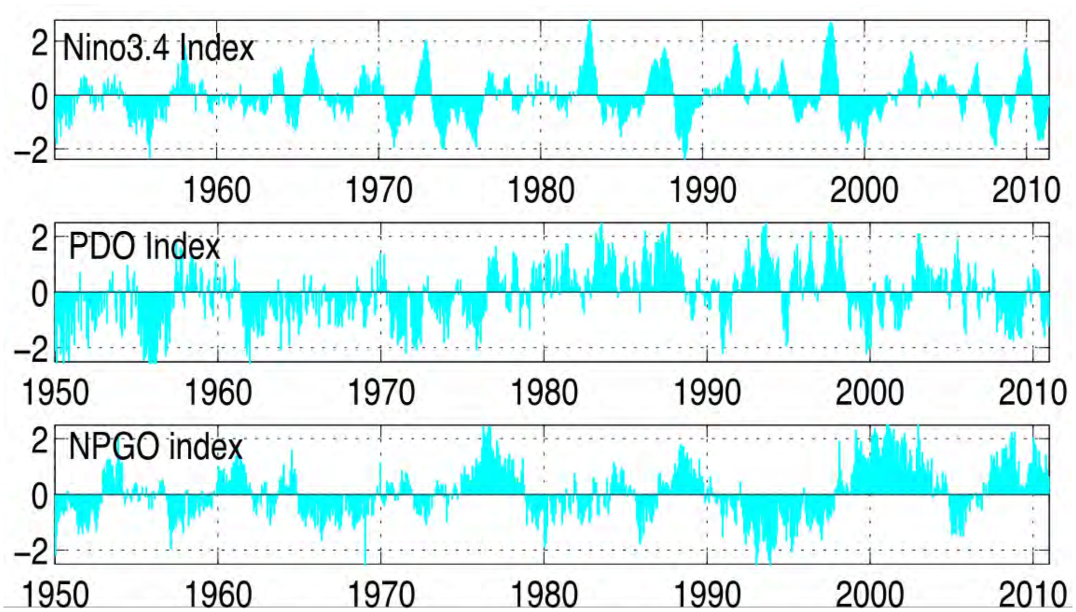


Figure C.10. *Patterns of SST variability associated with positive phases of the ENSO (upper left), PDO (upper middle), and NPGO (upper right) created by regressing July-June averages of gridded SST fields onto each of the three climate indices, respectively. Shading depicts the pattern of temperature change in °C for a +1 standard deviation value of the indicated climate index. Time series plotted in the lower panels show the standardized monthly index values for each of the large-scale climate patterns over the 1950-2010 period. Maps were generated with NOAA's Earth System Library Research tool at www.esrl.noaa.gov/psd/data/correlation/*



APPENDIX D: SOME BASIC BIOLOGICAL ELEMENTS OF MARINE ECOSYSTEMS

1. Plankton and Marine Food Webs

a. The Grazing Food Web

The classical view of how energy is transferred in the world's oceans is pictured as a grazing food web starting with large phytoplankton (mainly diatoms and larger dinoflagellates), progressing through to large herbivorous zooplankton, various nekton of intermediate size and ending with the large marine predators (the following represent good basic references on marine biology: Kaisir et al. 2005; Nybakken and Bertness 2005; Castro and Huber 2007). Primary production (i.e., the creation of organic carbon by photosynthesis) is largely controlled by the availability of light and nutrients, and by hydrography, those forces (wind and tides, for example) that act to mix the water column and move water masses around the ocean basins. The rate of photosynthesis varies with light intensity (irradiance) and thus decreases with depth as irradiance diminishes. In contrast, the rate of respiration (i.e., the consumption of organic carbon) of phytoplankton cells does not vary much with depth. Thus, as phytoplankton go deeper into the water column, photosynthetic rate declines in concert with the diminishing irradiance. At a specific depth (known as the compensation depth) the rates of photosynthesis and respiration are equal. This depth, where there is no net production of organic material, marks the lower limit of the euphotic zone. It varies geographically, being relatively shallow in turbid, coastal waters and as deep as 150 m or so in clear oceanic waters. It also varies seasonally according to the position of the sun and seasonal changes in turbidity, largely due to fluctuations in freshwater outflow into the near shore.

The major inorganic nutrients (nitrogen, phosphorus, iron and silicate) occur in small amounts in seawater and are thus the limiting factors for phytoplankton productivity under most conditions encountered in the oceans. Several mechanisms also act to reduce the reservoir of nutrients in the water column that is available to phytoplankton. For example, as the phytoplankton population grows in the euphotic zone, they absorb more and more light. Less light penetrates to deeper levels and the compensation depth becomes shallower. Consequently, more and more of the water column and hence its nutrient supply becomes inaccessible to the phytoplankton.

Inorganic nutrients are used up in the photic zone and are remineralised at depth where they accumulate to form a huge nutrient reservoir. Mixing of the water column permits the injection of deep-water nutrients into the photic zone, but density differences caused by differences in temperature and salinity create stable layers of surface and deeper waters that resist the forces of mixing. The surface mixed layer is a layer in which turbulence generated by winds or cooling has homogenized part of the water column. In temperate waters, this surface mixed layer in summer is warm and less dense than deeper waters and the two water masses tend not to mix. In the winter, density differences are reduced and the mixing layer deepens as strong winds blow across the ocean's surface. There are, however, special hydrographic conditions that inject nutrient-rich deep waters into the photic zone where they become available to support primary production. Of greatest importance is the phenomenon of coastal upwelling which occurs when surface coastal currents flow offshore and coastal water masses are replaced by deeper, nutrient-rich waters. Such upwelling along the western coast of North America is responsible for the region's high productivity and historically high fishery yields.

Vertical mixing, which results in deepening of the surface mixed layer caused by turbulence in the water column, not only injects nutrients into the photic zone, it also mixes phytoplankton into deeper waters and, in some cases, below the compensation depth. If phytoplankton cells spend most of their time below the compensation depth, photosynthesis will not be sufficient to fix the organic matter needed for respiration by cells that are below the compensation depth. In such a situation, there can be no net production. The depth at which total gross production of the autotrophs equals total respiration is referred to as the critical depth. Whenever the depth of the mixed surface layer is less than the critical depth, net production occurs. This mechanism has classically been considered to explain the spring phytoplankton bloom in the North Atlantic Ocean, one of the largest mass greenings observed on the Earth's surface, extending over more than 2000 km.

b. The Microbial Loop

With the realisation that microbes (bacteria, viruses and protists) play a predominant role in the trophic dynamics of the oceans, the foregoing classical description of the marine plankton system has undergone considerable modification. Every litre of sea water is teeming with a billion microbes, far exceeding all metazoa in abundance and biomass (Pomeroy et al. 2007). Their trophic interactions are manifest as a web of microbial life, often referred to as the microbial loop, which is functionally intertwined with the more familiar grazing food web. The dominant primary producers are the smallest phytoplankton in the pico- (0.2 to 2 micrometre) and nano- (2 to 20 micrometre) size range. Most ocean-dwelling bacteria are free living as bacterioplankton, are heterotrophic and are tiny, measuring about two tenths of a micrometer in diameter. Given their high numbers and their high assimilation efficiency, bacterioplankton convert large amounts of dissolved organic matter into particulate organic carbon in the form of bacterial cells. Heterotrophic bacterioplankton recover dissolved organic matter resulting from decomposition and lost due to phytoplankton leakage and recycle it back into the food web. This matter is in turn consumed by microzooplankton, mainly small protists, which are fed upon by larger zooplankton.

In weakly stratified or mixed waters, water masses are dominated by the classical grazing food web in which large phytoplankton, the dominant producers of the grazing food web, are consumed by herbivores such as copepods. The herbivores are then consumed by carnivores, including fishes and invertebrates, which are in turn consumed by the top predators (large fishes, squids, birds, mammals and, ultimately, humans). In strongly stratified, nutrient-poor waters, microzooplankton is responsible for the regeneration of nutrients in the photic zone. This permits the continued productivity of the prokaryotic phytoplankton in the absence of an influx of nutrient-rich waters. Such water masses are thus dominated by the microbial loop. Although microbes are highly efficient at recycling organic matter and nutrients, less energy in the form of food may be available for metazoans, ultimately the nekton, due to high respiratory losses at each trophic step within the microbial food web. The small cell size of the microbial plankton also means that they sink down to the sediments very slowly, and therefore provide less food for bottom-dwelling animals relative to fast-sinking, larger and heavier phytoplankton such as diatoms.

c. *The Carbon Pump*

The oceans provide an enormously important ecosystem service by regulating the planet's climate through carbon storage. The world's oceans store 50 times more carbon dioxide than does the atmosphere and 20 times more than the terrestrial biosphere and soils. Storage of carbon in the ocean depends on both physical and biological processes. Carbon dioxide dissolves in cold ocean water at high latitudes as a function of its concentration in the atmosphere and is carried to the deep ocean by sinking currents, where it stays for hundreds of years. The transfer of carbon to deep ocean currents is known as the physical carbon pump (or the solubility pump). The processes of fixation of inorganic carbon in organic matter during photosynthesis, its transformation by the dynamics of trophic structure and the transport of carbon to the deep ocean are collectively referred to as the biological carbon pump (Ducklow et al. 2001; Figure D.1). Inorganic nutrients and carbon dioxide are fixed during photosynthesis by the phytoplankton, releasing dissolved organic matter (DOM) which is consumed by herbivorous zooplankton. Larger zooplankton produce fecal pellets which can sink as aggregates with other organic detritus. DOM is consumed by bacteria and respired. DOM that is more resistant to bacterial consumption is mixed into the deep sea. DOM and aggregates exported into deep water are ingested and respired, thus returning organic carbon to the deep ocean reservoir of dissolved inorganic carbon. About 1% of the particles leaving the surface ocean reaches the seabed and are respired or buried in the sediments where they remain stored for millions of years. The biological pump also includes the sinking of various organisms that form calcium carbonate skeletal coverings. When these organisms die, some fraction of this calcium carbonate is eventually remineralized back to calcium and carbonate ions within the deeper parts of the water column and in sediments (the carbonate pump). The net effect of these processes is to remove carbon from the surface and to store it in the deep ocean.

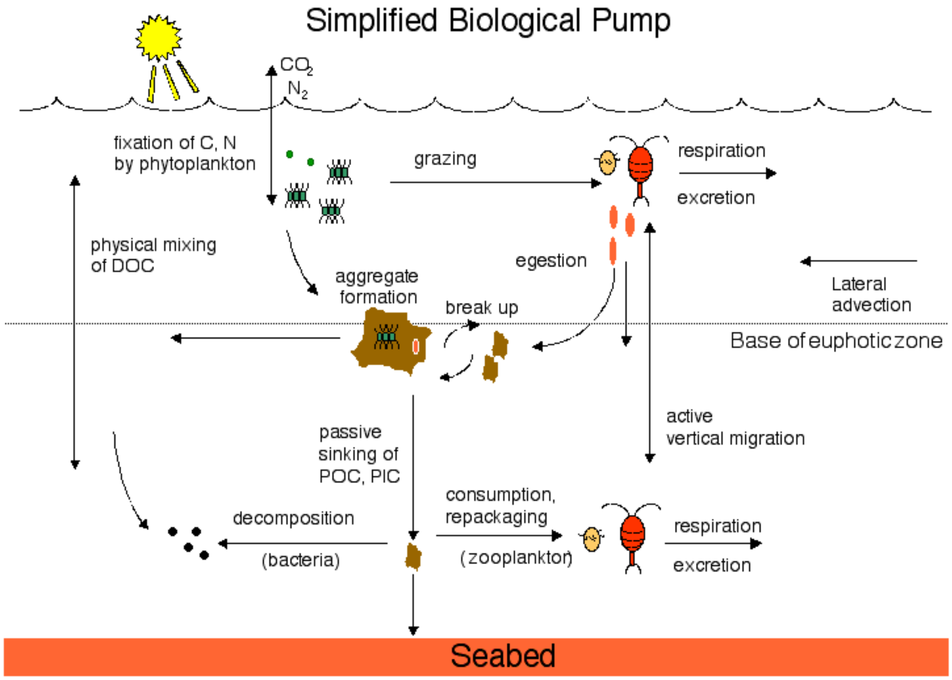


Figure D.1. *The biological carbon pump. Atmospheric CO_2 (or N_2 gas) fixed by autotrophs in the upper ocean is transported to deep waters by various processes. Phytoplankton die and sink as aggregates, or are consumed by herbivores that produce sinking fecal pellets (egestion). Aggregates may then be decomposed by bacteria or consumed by animals. Active vertical migration is a mechanism by which zooplankton (or nekton) feeding in the surface waters at night actively transport dissolved or particulate material to depth by metabolizing the ingested food at their daytime residence depths. Vertical migration of some phytoplankton species may bring nutrients from deeper waters into the euphotic zone. Dissolved organic carbon (DOC) produced by phytoplankton or by animal excretion in surface waters can be transported downward during deep mixing events. The biological pump also includes the sinking of particulate inorganic carbon (PIC) of biological origin (the 'carbonate pump'). Source: http://www.msrc.sunysb.edu/octet/biological_pump.html.*

The strength of the biological pump is determined by trophic processes. This may be evaluated by calculating the so-called f-ratio, the fraction of total primary production fuelled by nitrate as opposed to that fuelled by other nitrogen compounds like ammonium. When nitrogenous organic molecules are metabolized by organisms, they are returned to the water column as ammonium. The ammonium may be taken up by phytoplankton and re-enter the food web. Primary production fuelled by ammonium is referred to as regenerated production, as opposed to new production which is fuelled by nitrate. The production of nitrate (nitrification) was believed to occur in the aphotic zone in the absence of light, such that any nitrate in the water column must have originated from sinking organic material and been injected into the photic zone from below. Ideally, the export flux of organic material sinking into the aphotic zone is balanced by the upward flux of nitrate. In fact, about a half of surface nitrate is supplied by surface nitrification rather than upwelling (Yool et al. 2007). Nevertheless, high f-ratio values are associated with productive ecosystems dominated by large eukaryotic phytoplankton (particularly diatoms) that are consumed within the grazing food web, leading eventually to large predators. In contrast, low f-ratio values are associated with low-biomass, oligotrophic food webs consisting of the tiny picophytoplankton which are grazed by microzooplankton.

The precipitation of organic material from the euphotic zone comprises mainly carbon which has already been consumed (e.g., fecal pellets). The sinking flux comprises around 5% of total primary production in nutrient-poor oligotrophic waters, 10-15% in productive oceanic waters and 25-30% in coastal waters (Longhurst 1998). In productive oceanic waters, diatoms sink at about one meter per day; in oligotrophic waters small cells hardly sink at all. The critical observation from these basic principles is that systems based on larger-celled phytoplankton tend to support large exports of biogenic carbon that is then available for extraction (e.g., via fisheries) or for sequestration (via the biological carbon pump) (Beaugrand et al. 2010). A shift towards smaller organisms in the North Atlantic plankton has been thought to result in a reduced fisheries yield (Beaugrand et al. 2010), and the observed change in Arctic Ocean phytoplankton towards small-cell species has similarly raised concerns about reduced food web transfers to higher trophic levels (Li et al. 2009).

2. A Brief Survey of Canadian Marine Ecosystems

a. The Epipelagic Ecosystem

The pelagic realm encompasses the water column away from the bottom and the shore. The upper pelagic (or epipelagic) ecosystem, comprising the first 200 m of the water column, is the warmest and receives the most sunlight of the pelagic realm. It thus includes the photic zone where light is sufficient to permit photosynthesis. The epipelagic ecosystem is divided into two main components, the neritic (epipelagic waters that lie over the continental shelf) and the oceanic (epipelagic waters beyond the continental shelf). The two compartments are quite different, due in part to their varying proximity to land and the associated differences in nutrient and sediment supply. The neritic component is only a small part of the epipelagic, but is of great importance to humans because it supports most of the world's marine fisheries production and is most affected by human activities. The neritic component is tightly coupled to the underlying seabed ecosystem (see below).

Epipelagic food webs are complex, but primary production by phytoplankton, be they the pico-, nano- or larger plankton, forms the base. Much of the information presented in the preceding sections about plankton and food webs pertains to the epipelagic ecosystem. Some parts of the epipelagic are among the most productive ecosystems on the planet, whereas others are among the least productive, and comprise the oceanic equivalent of deserts. The diversity and abundance of epipelagic organisms, from plankton to whales, generally follows the pattern of primary production. In Canada, the cold temperate North-west Atlantic and the cold temperate North Pacific are influenced by the westerly winds (referring to the prevailing winds between 35 and 65 degrees latitude, blowing towards the north pole, from the west to the east), and the mixed depth layer is forced mainly by local winds and irradiance. In contrast, the depth of the mixed surface layer in the Arctic Ocean is constrained by a surface brackish layer which forms each spring when sea ice melts (Longhurst 1998). These most fundamental physical attributes largely control production within the epipelagic ecosystem.

b. Estuarine and Brackish Water Ecosystems

A unique ecosystem is created when fresh waters flowing from rivers first meet and mix with salt water from the sea. These systems are among the most productive environments on the planet, ranking alongside tropical rain forests and coral reefs. They also rank among the most impacted by human activities. Several distinct habitats are found in estuaries. These include open-water habitat, mudflats and salt marshes. Seagrass beds also occur in estuaries, although they are generally widespread in coastal waters and not restricted to estuaries. Estuarine communities consist of relatively few species. These species, however, are often highly abundant. Many species of commercially important fishes and shrimps use estuaries as nursery areas, exploiting the abundant food resources and relative absence of predators. Seagrass beds and salt marshes provide important ecosystem services in the form of carbon sequestration and shoreline stabilization (see below).

Estuaries are generally classified into four categories. The first type was formed when sea level rose because of the melting of the continental ice sheets at the end of the last ice age, approximately 12,000 years ago. The mouth of the St. Lawrence River is one such example. A second type of estuary was created when retreating glaciers cut deep valleys along those coasts that were subsequently flooded as sea levels rose and rivers flowed into them. Such estuaries, known as fjords, are common along the coast of British Columbia. Bar-built estuaries are created when the accumulation of sediments along the coast creates both sand bars and barrier islands that act as a wall between the ocean and fresh water from rivers. Such estuaries occur at various sites along the east coast of North America. Finally, tectonic estuaries were created when land subsided as a result of the movements of the planet's crust. Large-scale geomorphological features also influence the formation of estuaries. Broad, well-developed estuaries are common in regions with relatively flat coastal plains and wide continental shelves, features typical of the Atlantic coast. In contrast, the steep coasts and narrow continental shelves of the Pacific coast have generally restricted the formation of estuaries to narrow river mouths and fjords.

Estuaries exhibit steep environmental gradients related to the mixing of water masses of different salinities, temperatures and geochemical compositions. Salinity fluctuates dramatically along the longitudinal and vertical axes of an estuary. Generally speaking, fresh water of continental origin mixes with saline water such that salinity increases downstream. In well-mixed estuaries, salinity is evenly distributed from top to bottom with no vertical stratification. In deeper estuaries, partial stratification of the water column occurs when low-salinity, less dense, water flows along the surface whereas the more saline, denser, waters tend to flow upstream along the bottom. Density differences are amplified by differences in temperature, as saline waters are generally colder than fresh waters. This two-layer circulation pattern is referred to as estuarine circulation. These physical gradients move up and downstream with the daily rhythm of the tides; the amplitude of these horizontal displacements is controlled by freshwater discharge coming from the river.

Through the process of hydrodynamic trapping, estuarine circulation has an important impact on the distribution of both abiotic and biotic variables. In many large estuaries, an area of high turbidity forms where inorganic and organic particles sink into the landward bottom current and are transported upstream until they are again vertically mixed at the upstream end of the estuary and flow downstream in the surface flow. This maximum turbidity zone is the critical interface for biogeochemical interactions between river water and the sea. Such hydrodynamic trapping has also been observed at higher trophic levels; many zooplankton species accumulate passively along with suspended particulate matter. More actively swimming species, such as the nekton, may migrate vertically to exploit the vertical pattern of current speed and direction, so as to position themselves along the longitudinal gradient. On the other hand, benthic species, which live on the bottom, are exposed to considerable environmental variation as the gradients move upstream and downstream in concert with the tidal cycle.

Huge amounts of detritus are brought into estuaries by rivers and tides. Estuarine circulation contributes to the retention of much of this detritus within the estuary. The bottoms of estuaries that are exposed at low tides may thus form extensive mudflats with their own unique biological community. Stretching inland from the mudflats are extensive grassy areas that are known as salt, or tidal, marshes. Salt marshes can also develop along sheltered open coastlines. Salt marshes are particularly extensive along the Atlantic coast of Canada. Cordgrasses (*Spartina*) and bulrush (*Scirpus* or *Schoenoplectus*) are the most common grasses, growing principally at the junction of the marsh and the adjacent mud flat. Microbial communities in the mud decompose dead plants and contribute to the detritus in the estuary. Marsh plants also provide habitat for a variety of organisms, including seabirds and terrestrial mammals.

Biotic and abiotic processes occurring in open-water habitat, in mudflats and in tidal marshes are intimately linked through the dynamics of sedimentation and seasonal erosion. In the St. Lawrence estuary, for example, the maximum turbidity zone supports important populations of phyto- and zooplankton and acts as a major summer nursery area for the larvae and juveniles of rainbow smelt (*Osmerus mordax*) and Atlantic tomcod (*Microgadus tomcod*), the two numerically dominant fish species of the St. Lawrence estuary (Winkler et al. 2003). The seasonal persistence of the maximum turbidity zone is controlled by sediment exchanges between tidal marshes and the open waters of the estuary. This, in turn, is heavily influenced by the tidal marsh foraging activity of the Greater Snow Goose (*Chen caerulescens*). During the fall migration of geese, tidal marsh grasses are uprooted, causing rapid erosion of the marsh sediments. Grasses regenerate during the spring and summer and sediments once again accumulate in the salt marsh (Lucotte and D'Anglejan 1986).

c. *The Continental Shelf Seabed Ecosystem*

The subtidal or sublittoral zone extends from the low-tide level on shore to the outer edge of the continental shelf at a depth of about 150 m. The width of the shelf varies from 1 km to over 750 km. The organisms associated with the seabed are collectively known as the benthos. Because the bottom is in shallow water, it is far more affected by waves and currents than in the deep sea. The resultant turbulence generally impedes stratification and nutrients thereby remain available to primary producers throughout the water column. Rivers are also an important source of nutrients such that continental shelf waters are more productive and plankton-rich than the open ocean. Indeed, the vast majority of global fisheries are conducted in the productive continental shelf ecosystems and upwelling areas.

The continental shelf seabed ecosystem comprises four major habitats: (1) unvegetated, soft bottoms composed of sandy and muddy substrates, (2) hard, rocky bottoms, (3) kelp beds and forests, and (4) seagrass beds. Soft-bottom substrates are the most abundant of the four major habitats. Their defining feature is the almost complete absence of large seaweeds and plants. As a consequence, primary production by benthic primary producers is usually very low and nearly all primary production comes from phytoplankton that is part of the overlying neritic epipelagic ecosystem. As such, detritus that rains down from above is a very important food source for benthic communities. This detritus usually originates from the plankton and nekton in the water column, but is also brought in by currents from estuaries and other coastal communities. In turn, these benthic communities, dominated by infaunal bivalves and worms, are exploited by epipelagic organisms, including demersal fishes and marine mammals that feed on the bottom. In addition, the larval stages of benthic organisms are pelagic and thus are dispersed by the dominant currents of the epipelagic zone to eventually settle and re-colonize benthic communities. This close relationship between water-column and benthic processes is known as pelagic-benthic coupling and represents a key process regulating the continental shelf ecosystem and its associated ecosystem services (e.g., global fisheries). This function plays a particularly important role at high latitudes because of the extreme seasonality in primary production and phytoplankton biomass.

Hard bottoms occur wherever water motion and gravity prevents the accumulation of sediments, thereby exposing bedrock or aggregated cobbles or boulders. Although this habitat makes up a relatively small portion of the shelf ecosystem, its associated communities are rich and productive, being dominated by a huge diversity of invertebrates and seaweeds. Invertebrate animals include sessile, encrusting taxa (including sponges, sea anemones, soft corals, barnacles, mussels and sea squirts) as well as mobile species, such as sea urchins and snails. Whereas the sessile species are typically filter-feeders, exploiting the phytoplankton and detritus found in the water column, the mobile species are either grazers of the abundant sea weeds or carnivores (e.g., seastars, crabs, whelks and lobsters) that prey on both sessile and mobile invertebrates.

Rocky bottoms can be dominated by giant brown seaweeds, collectively referred to as kelp. The communities associated with them are known as kelp forests or beds, depending on whether or not, respectively, they form a floating surface canopy. Kelp is limited by high temperatures and low nutrients. They flourish in cold, nutrient-rich waters and thus form an important part of the Canadian continental shelf ecosystem, distributed along both the east and west coasts and in the Arctic.

Kelp plays a key role in nearshore marine ecosystems by forming complex three-dimensional structures that provide a great diversity of ecological niches. These support many species of algae, invertebrates, fish, and at times, marine mammals. Sea urchins are by far the most important grazers in kelp communities. Population explosions of sea urchins may at times completely eliminate kelp, producing areas known as ‘urchin barrens’. This phenomenon is related to the strong species interactions that characterize the kelp community. On the west coast of North America, sea urchins are often kept in check by sea otter predation. Prior to the 1970s, sea otters were depleted by human hunting. Recently however, sea otter populations were reduced because of predation by killer whales. Killer whales normally prefer seals and sea lions, but these key prey species have declined since the 1980s in some parts of the North Pacific (e.g., western Aleutian Islands), possibly because overfishing has reduced their food supply. The decimation of sea otter populations has released sea urchins from predatory control, promoting urchin population explosions and overgrazing by urchins on kelp. Local restoration of sea otter populations is reversing this trend. A similar cycle is evident along the coast of Nova Scotia, but here the dynamic appears to be controlled by the outbreak of disease in sea urchins. Such trophic 'cascades' are exacerbated by strong storm events and warm currents that physically damage kelp, illustrating the dramatic, and at times unexpected, role that overfishing and climate can play in regulating species interactions within aquatic food webs.

In shallow, near-shore environments, soft bottoms along the coast are often covered with a luxuriant growth of aquatic vascular plants collectively referred to as seagrasses. In Canadian waters, dense beds of eelgrass (*Zostera* spp.) may extend downward by approximately 50 m, although they are most abundant below the low tide level. As with kelp beds, seagrass beds provide habitat for a wide variety of organisms and a nursery ground for many fish species of commercial importance. Although sea grasses are rarely grazed directly, their decomposing leaves contribute greatly to the local pool of detritus, which is then exploited by a myriad of invertebrates. Seagrass beds also dampen wave action and their dense root systems penetrate the soft substrate and stabilize bottom sediments. Seagrass beds thus provide a natural form of coastal protection against erosion. Seagrasses, as well as salt marsh grasses, capture and store immense amounts of carbon, and they do so far more efficiently than terrestrial forests. Carbon uptake rates of these marine gardens are up to 90 times than those of equivalent areas of terrestrial forest. This 'Blue Carbon' is stored in sediments where it is stable for thousands of years. In BC, roughly 400 km^2 of salt marsh and seagrass beds sequester as much carbon as the province's portion of the boreal forest (Campbell et al. 2011).

d. The Littoral-Intertidal Ecosystem

The intertidal zone is the narrow fringe along the shoreline found between the highest high tide and the lowest low tide. Although accounting for the smallest area of the world's oceans, they are the most renowned of marine ecosystems because they are so readily accessible for study. The intertidal zone is unique among marine ecosystems because it is regularly exposed to air and experiences the greatest variation in environmental factors. As intertidal organisms are primarily marine in origin, they must be capable of resisting desiccation during low tide, maintaining their internal heat balance when exposed to temperature extremes associated with the cycle of emergence and submergence, and must resist the destructive effects of waves and the osmotic stresses associated with wide fluctuations in salinity.

Although both soft- and hard-bottom habitats can be found in the intertidal zone, the rocky intertidal habitats are the most densely inhabited and exhibit the greatest biodiversity in Canadian intertidal ecosystems. There are, however, major differences in the geographical, physical and biological characteristics of rocky shores along the Canadian coastline. Whereas intertidal communities along the Atlantic coast of Canada can be exposed to frigid winter temperatures and ice scouring as well as high summer temperatures, those of the Pacific coast are rarely exposed to sub-zero temperatures or ice during winter. In addition, cloud and fog cover protect Pacific rocky intertidal communities from high summer temperatures. Thus, stress and mortality are relatively higher in Atlantic rocky intertidal communities. As a result of the above factors intertidal species assemblages in the Pacific are more diverse than those in the Atlantic. In the case of gastropod molluscs, many of which occupy the intertidal zones, the number of species living along North America's west coast (from the Bering Strait to Puget Sound) exceeds those along the corresponding east coast (from Southern Labrador to Cape Cod) by approximately three-fold (Vermeij 1991).

One of the most striking characteristics of rocky intertidal shores is the vertical zonation of the resident community into prominent horizontal bands of different species assemblages. Any given species is generally not found throughout the intertidal. As a general rule, the upper limit of vertical zonation is determined by physical factors such as temperature or desiccation, whereas the lower limit is set by biological factors such as predation and competition. The upper intertidal zone is seldom submerged but is kept wet by splashing waves. Lichen and cyanobacteria are the dominant primary producers in that zone and the small gastropods, periwinkles (*Littorina* spp.), are the most prominent animals. The middle intertidal is submerged and exposed by the tides on a regular, cyclical basis. There is further zonation within the middle intertidal. Its upper boundary is almost always characterized by a band of acorn barnacles (*Balanus* spp.). The lower limit of this band is often determined by either predation from whelks (e.g., *Buccinum* spp.) or competition for space with mussels (*Mytilus* spp.). Mussels are the dominant competitors for space on rocky shores. Their upper limit is set by time for feeding, while submerged, and the risk of desiccation. Their lower limit is set by voracious predation from sea stars. The lower intertidal is mostly immersed and is dominated by seaweeds which form a thick turf on the rocks. This in turn provides a mosaic of habitats that is exploited by a variety of species.

Sandy beaches, because of their recreational importance, constitute one of our most valuable intertidal ecosystems for humans. Exposed sand beaches face the open sea with a pronounced slope whereas sand flats generally face a bay with little or no slope. The dominant environmental factor acting on open beaches is wave action, resulting in an unstable, constantly shifting substrate. To tolerate this instability, organisms such as clams may burrow deeply into the sand below the effects of waves, whereas other organisms such as sand crabs burrow quickly as soon as a passing wave has dislodged them from their shallow refuge within the sand. Although far less obvious than on rocky shores, there also exists a degree of vertical zonation of organisms composing the sandy shore community.

e. Deep-Sea Ecosystems

The deep-sea floor represents the largest habitat on the planet, yet it remains the least known. It ranges from the edge of the continental shelf at about 150 m depth down to the abyssal plain 5 km below the surface, with some deep trenches continuing down to 10 km depth. Of the 70% of the planet's surface covered with water, about 85% of the area constitutes the deep sea. Although inhospitable to most forms of life because of massive pressure, near-freezing waters and a total lack of sunlight, the deep sea is believed to harbour a huge yet largely unexplored biodiversity (Webb et al. 2010).

The deep-sea floor is not featureless. Apart from deep trenches, there are at least 30000 seamounts in the world's ocean. These are typically extinct volcanoes that rise at least 1000 m above the surrounding seafloor, forming archipelagos of underwater islands. Although very few have been studied, they are known to support stocks of commercially important fishes and invertebrates. Apart from seamount habitats, there are two special habitats that are considered as hot-spots for biodiversity associated with the deep sea: cold-water corals and hydrothermal vents.

i. Cold-Water Corals

Canadians rarely think of coral reefs as a significant component of Canadian marine ecosystems, inevitably relating them to warmer, tropical climates. However, deep-water corals occur around the world at depths between 200 and 1500 m. They are restricted to oceanic waters and temperatures between 4 and 12 ^{o}C. At least 19 species of deep-water coral occur off Atlantic Canada, most of them occurring below 200 m in submarine canyons along the shelf edge or in deep channels between fishing banks. The corals off Nova Scotia do not build reefs, but instead form forest-like stands. Deep-sea corals also occur off the coast of British Columbia and are considered important enough to be protected from deep-sea bottom trawling fishing gear. Cold-water corals lack the symbiotic photosynthetic dinoflagellates that are typical of tropical, shallow-water reefs. Instead, they are fuelled by primary production in surface waters that is transported to the sea floor. The structural complexity of these corals provides ecological niches for many species and their biodiversity may be comparable to that found on tropical coral reefs. Although research into the ecology of deep-water corals is relatively recent, bottom trawling for fish and invertebrates, hydrocarbon drilling and seabed mining and ocean acidification represent clear threats to the persistence of these vulnerable ecosystems and their associated biodiversity (Roberts et al. 2006).

ii. Hydrothermal Vents

Hydrothermal vents are fissures in the earth's crust through which geothermally heated water gushes forth. In the deep ocean, they typically form along the East Pacific Rise and the Mid-Atlantic Ridge where tectonic plates are diverging and new crust is being formed. Water emerges from these vents at temperatures ranging from 60°C up to as high as 450°C. Exploration in the 1970s of such vents, at depths of 2,700 m in the Galapagos rift zone, revealed an abundance of previously unknown marine organisms living in and around the hot-water geysers. Water temperature in the vent areas is 8 to 16°C, far greater than the ambient 2°C typical at these depths. This warm water is rich in reduced sulphur compounds, mainly hydrogen sulfide, which is used as an inorganic energy source by chemosynthetic bacteria and archaea at the bottom of the food web. These communities thus do not depend on sunlight to make organic matter, or on importation of detritus from the photic zone. Some hydrothermal vents form cylindrical chimney structures from minerals that precipitate when in contact with cold water. When emissions are high in sulfides, they appear black and the vents are referred to as black smokers. White smokers refer to vents that emit lighter-colored minerals and lower-temperature plumes. Vent communities have been found around the world at depths ranging from 1,500 to 3,200 m in depth (Tunnicliffe et al. 1998). Similar communities of organisms have been found that are not associated with the edges of tectonic plates. These communities are called cold-seep communities. They constitute areas where hydrogen sulfide, methane and other hydrocarbon-rich fluid seep from the sea floor. They are often associated with cold, hypersaline brines. All of these vent areas and cold seeps harbour a spectacular array of large animals that form truly unique oases of life in an otherwise relatively barren expanse of the deep-sea floor.

APPENDIX E: ATLANTIC AND PACIFIC CANADIAN MARINE FISH STOCKS

This Appendix lists the marine fish stocks used in compiling: (i) the multi-species indices in Figures 5.6 and 5.7; (ii) catch data in Figure 6.4; and the multi-species indices of fishing mortality in Figure 8.4. Assessment body abbreviations: DFO (Department of fisheries and Oceans); NAFO (Northwest Atlantic Fisheries Organization): ICCAT (International Commission for the Conservation of Atlantic Tunas); NMFS (U.S. National Marine Fisheries Service).

Ocean	Species	Management Unit	Years	Assessment Body
Atlantic	Atlantic Herring (*Clupea harengus*)	Scotian Shelf and Bay of Fundy	1965-2006	DFO
		4R Fall Spawners (Northern Gulf)	1971-2003	DFO
		4R Spring Spawners (Northern Gulf)	1963-2004	DFO
		4T Fall Spawners (Southern Gulf)	1974-2007	DFO
		4T Spring Spawners (Southern Gulf)	1974-2007	DFO
	Atlantic Cod (*Gadus morhua*)	2J3KL (Northern Cod)	1962-1992	DFO
		3NO (Southern Grand Bank)	1953-2007	NAFO
		3Ps (St. Pierre Bank)	1959-2004	DFO
		3Pn4RS (Northern Gulf)	1964-2007	DFO
		4TVn (Southern Gulf, Sydney Bight)	1965-2009	DFO
		4VsW (Eastern Scotian Shelf)	1958-2002	DFO
		5Zjm (Georges Bank)	1978-2003	DFO
	Haddock (*Melanogrammus aeglefinus*)	4X5Y (Bay of Fundy, Gulf of Maine)	1960-2003	DFO
		5Zejm (Georges Bank)	1968-2003	DFO
	Pollock (*Pollachias virens*)	4VWX5Zc (Scotian Shelf to Georges Bank)	1974-2007	DFO
	Cusk (*Brosme brosme*)	4X (Western Scotian Shelf, Bay of Fundy)	1970-2007	DFO
	White Hake (*Urophycis tenuis*)	Scotian Shelf, Bay of Fundy, Georges Bank	1964-2005	Catch data only
	American Plaice (*Hippoglossoides platessoides*)	23K (Newfoundland and Labrador)	1960-2004	DFO
		3LNO (Grand Bank)	1955-2007	NAFO
		3Ps (St. Pierre Bank)	1960-2005	Catch data only
	Monkfish (*Lophius americanus*)	Labrador, Grand Bank, St. Pierre Bank	1977-2000	DFO
	Redfish (*Sebastes* sp.)	23K (Newfoundland and Labrador)	1959-2001	Catch only

		3LN (Grand Bank)	1959-2008	NAFO
		3Pn4RSTVn (Gulf of St. Lawrence)	1953-2000	Catch data only
	Greenland Halibut (*Reinhardtius hippoglossoides*)	01ABCDEF (Baffin Bay, Davis Strait)	1987-2006	Catch data only
		23KLMNO (Newfoundland and Labrador)	1975-2006	NAFO
		4RST (Gulf of St. Lawrence)	1970-2002	Catch data only
	Yellowtail Flounder (*Limanda ferruginea*)	3LNO (Grand Bank)	1965-2009	NAFO
	Albacore Tuna (*Thunnus alalunga*)	North Atlantic	1929-2005	ICCAT
	Yellowfin Tuna (*T. albacares*)	Atlantic	1970-2006	ICCAT
	Bigeye Tuna (*T. obesus*)	Atlantic	1950-2005	ICCAT
	Bluefin Tuna (*T. thynnus*)	Western Atlantic	1969-2007	ICCAT
	Swordfish (*Xiphias gladius*)	North Atlantic	1978-2007	ICCAT
	Spiny Dogfish (*Squalus acanthias*)	Atlantic Coast	1990-2006	NMFS
	Ocean Pout (*Zoarces americanus*)	Northeast Atlantic Coast		NMFS
Pacific	Sablefish (*Aonoplopoma fimbria*)	Pacific Coast	1979-2004	DFO
	Pacific Herring (*Clupea pallasii*)	Central Coast	1951-2007	DFO
		Prince Rupert District	1951-2007	DFO
		Queen Charlotte Islands	1951-2007	DFO
		Strait of Georgia	1951-2007	DFO
		West Coast of Vancouver Island	1951-2007	DFO
	Pacific Cod (*Gadus macrocephalus*)	Hecate Strait	1956-2005	DFO
		West Coast of Vancouver Island	1945-2001	DFO
	Rock Sole (*Lepidopsetta bilineata*)	Hecate Strait	1945-2001	DFO
	English Sole (*Parophrys vetulus*)	Hecate Strait	1944-2001	DFO

	Petrale Sole (*Eopsetta jordani*)	Northern Pacific Coast	1910-2005	NMFS
	Pacific Hake (*Merluccius productus*)	Pacific Cast	1966-2008	NMFS
	Longnose Skate (*Raja rhina*)	Pacific Coast	1915-2007	NMFS
	Pacific Ocean Perch (*Sebastes alutus*)	Pacific Coast	1953-2007	NMFS
	Darkblotched Rockfish (*S. crameri*)	Pacific Coast	1928-2007	NMFS
	Widow Rockfish (*S. entomelas*)	Pacific Coast	1955-2006	NMFS
	Yellowtail Rockfish (*S. flavidus*)	Pacific Coast	1967-2005	NMFS
	Canary Rockfish (*S. pinnegar*)	Pacific coast	1916-2009	NMFS
	Yelloweye Rockfish (*S. ruberrimus*)	Pacific Coast	1923-2006	NMFS
	Shortspine Thornyhead (*Sebastolobus alascanus*)	Pacific Coast	1901-2005	NMFS
	Longspine Thornyhead (*S. altivelis*)	Pacific Coast	1962-2005	NMFS
	Lingcod (*Ophiodon elongates*)	Northern Pacific Coast	1956-2005	NMFS
	Starry Flounder (*Platichthys stellatus*)	Northern Pacific Coast	1970-2005	NMFS
	Pacific Sardine (*Sardinops sagax*)	Pacific Coast	1981-2005	NMFS
	Pacific Chub Mackerel (*Scomber japonicas*)	Pacific Coast	1929-2008	NMFS