Canadian biodiversity: ecosystem status and trends 2010

Prepared by federal, provincial and territorial governments

Library and Archives Canada Cataloguing in Publication

Canadian biodiversity : ecosystem status and trends 2010. [electronic resource]

Issued also in French under title:
Biodiversité canadienne, état et tendances des écosystèmes en 2010.
Electronic monograph in PDF format.
Issued also in printed form.
ISBN 978-1-100-17033-6
Cat. no.: En14-26/2010E-PDF

1. Biotic Communities--Environmental aspects--Canada.
2. Biodiversity--Monitoring--Canada. 3. Environmental impact
analysis--Canada. 4. Human ecology--Canada. 5. Nature--Effect of human
beings on--Canada. 6. Climatic changes--Environmental aspects--Canada.
I. Canada. Environment Canada II. Title: Ecosystem status and trends 2010.

GE160 C3 C33 2010 363.7'0630971 C2010-980233-0

Photo credits are on photos. Further details for stock photography are on page 114.

Also available on the Internet:
www.biodivcanada.ca/ecosystems

This report should be cited as:
Federal, Provincial and Territorial Governments of Canada. 2010.
Canadian Biodiversity: Ecosystem Status and Trends 2010.
Canadian Councils of Resource Ministers. Ottawa, ON. vi + 142 p.

Aussi disponible en français

Canadian biodiversity: ecosystem status and trends 2010

Prepared by federal, provincial and territorial governments
www.biodivcanada.ca/ecosystems

acknowledgements

Canadian Biodiversity: Ecosystem Status and Trends 2010 is a collaborative effort of the federal, provincial, and territorial governments of Canada. It was prepared by Joan Eamer, Trish Hayes, and Risa Smith under the guidance of the Steering Committee and two secretariats. Information was drawn from technical reports prepared for each ecozone+ and for national cross-cutting themes. A list of these reports and their authors is provided on page 112 of this document.

Project Co-leads
Environment Canada: Risa Smith
Nova Scotia: Sherman Boates
British Columbia: Matt Austin

Steering Committee
Newfoundland and Labrador: Shelley Pardy Moores
Nova Scotia: Sherman Boates
Prince Edward Island: Dan McAskill, Rosemary Curley
New Brunswick: Steve Gordon, Vince Zelazny
Ontario: Bill Dalton
Manitoba: Veronika Kanya
Nunavut: Mathieu Dumond, Hillary Robison, Drikus Gissing
Northwest Territories: Suzanne Carrière
Saskatchewan: Ben Sawa, Randy Seguin, Doug Campbell, Sara James, Ann Riemer
Alberta: Ted Nason
British Columbia: Angeline Tillmanns, Rowena Rae, Matt Austin
Yukon: Tom Jung, Wendy Nixon, Michael White, Mike Connor
Fisheries and Oceans Canada: Henry Lear, Vanessa Sutton, Jake Rice
Environment Canada: Courtney Price, Julie Suzanne Pollock, Stephen Virc
Canadian Forest Service, Natural Resources Canada: John Hall, Mike Fullerton, Christian Malouin, Brenda McAfee
Agriculture and Agri-Food Canada: Melanie Dubois, Pat MacGregor, Sarah Kalff, Robin Mackay
Quebec (observer): Benoît Limoges

Secretariat (Environment Canada)
Trish Hayes (Chair), Joan Eamer, Risa Smith, Jodi Frisk, Isabelle Turcotte
Technical support: Kelly Badger, Cristina Spalvieri, Roxanne Koczwarski, Jennifer Elliot, Cynthia Johnston, Rob Rankin
Design support: Kelly Badger

Secretariat (Fisheries and Oceans Canada, marine ecozones+)
Andrea White, Patrice Simon, Robin Brown, Andrea Niemi, Réjean Dufour, Tana Worcester, Nadine Templeman

table of contents

Overview

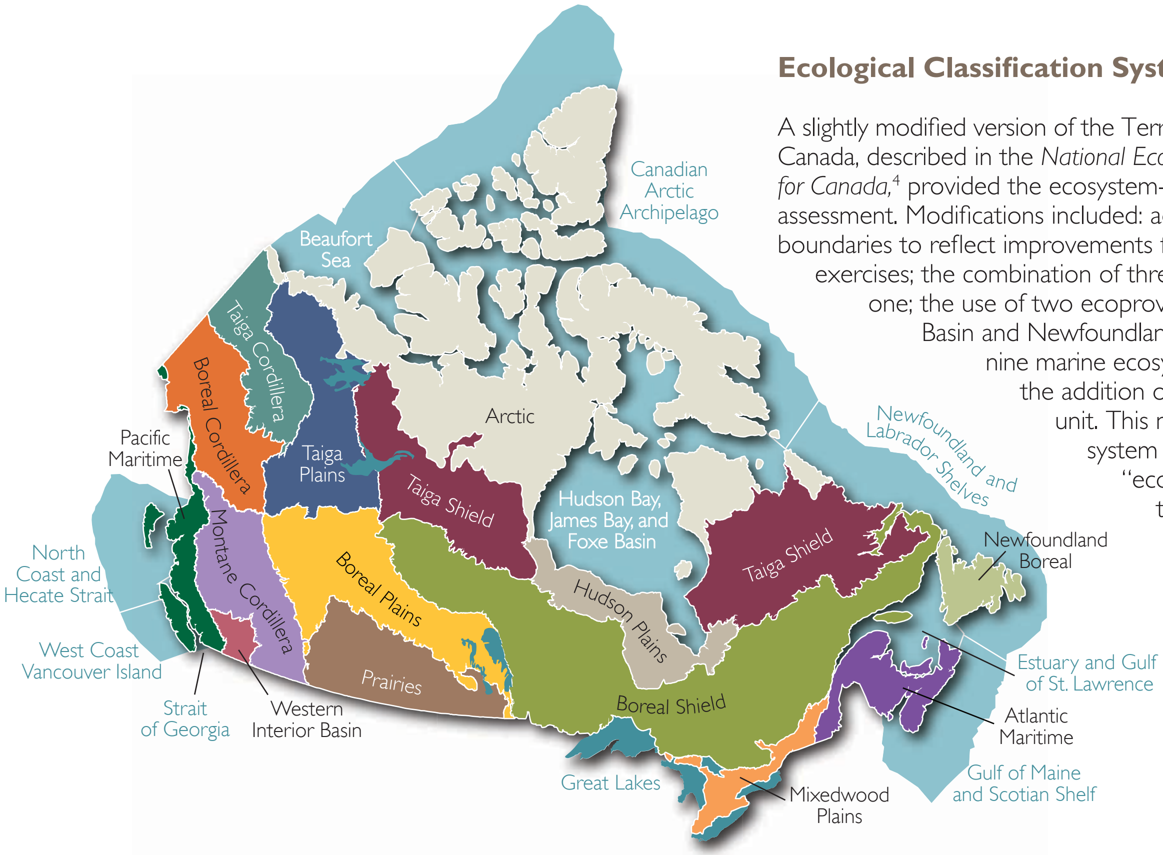
overview

ABOUT THIS ASSESSMENT

The Canadian Councils of Resource Ministers developed a Biodiversity Outcomes Framework in 2006[1] to focus conservation and restoration actions under the *Canadian Biodiversity Strategy*.[2] *Canadian Biodiversity: Ecosystem Status and Trends 2010* is a first report under this framework. It assesses progress towards the framework's goal of "Healthy and Diverse Ecosystems" and the two desired conservation outcomes, i) productive, resilient, diverse ecosystems with the capacity to recover and adapt, and ii) damaged ecosystems restored. The results of this assessment will be used to inform the national biodiversity agenda, complement the historical focus on species, and help set biodiversity priorities.

This report was prepared under the guidance of a steering committee of federal, provincial, and territorial government representatives. Over 500 experts participated in the preparation of foundation technical reports (see Contributors). Twenty-two recurring key findings emerged from the technical information and are presented here, organized under four interrelated themes: biomes; human/ecosystem interactions; habitat, wildlife, and ecosystem processes; and science/policy interface.

2010 is the International Year of Biodiversity. It is the intention of the Canadian Councils of Resource Ministers to use this report as a partial assessment of Canada's progress towards the United Nations biodiversity target *"to achieve by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national level as a contribution to poverty alleviation and to the benefit of all life on Earth."*[3]



Ecological Classification System – Ecozones+

A slightly modified version of the Terrestrial Ecozones of Canada, described in the *National Ecological Framework for Canada,*[4] provided the ecosystem-based units for this assessment. Modifications included: adjustments to terrestrial boundaries to reflect improvements from ground-truthing exercises; the combination of three Arctic ecozones into one; the use of two ecoprovinces – Western Interior Basin and Newfoundland Boreal; the addition of nine marine ecosystem-based units; and the addition of the Great Lakes as a unit. This modified classification system is referred to as "ecozones+" throughout the assessment to avoid confusion with the more familiar "ecozones" of the original framework.[5]

EXECUTIVE SUMMARY

Canadian Biodiversity: Ecosystem Status and Trends 2010 is the first assessment of Canada's biodiversity from an ecosystem perspective. It presents 22 key findings derived from technical background reports. Some findings reveal that much of Canada's natural endowment remains healthy, including large tracts of undisturbed wilderness, internationally significant wetlands, and thriving estuaries, particularly in sparsely populated or less accessible areas. Forest area is fairly stable. Over half of Canada's landscape remains intact and relatively free from human infrastructure. Although much is in the more remote North, this also includes large tracts of boreal forest and coastal temperate rainforest. Canada maintains commercial and recreational freshwater and marine fisheries of significant economic and cultural importance.

Several stressors that impaired ecosystems in the past have been either removed or reduced. Some marine mammal populations are recovering from past overharvesting. Concentrations of contaminants now phased out of use, such as DDT and PCBs, are declining in wildlife. In the past 15 years, federal, provincial, and territorial terrestrial protected areas have increased in number, area, and diversity of ecosystems represented. Canadians have demonstrated their commitment to biodiversity conservation through the growing number of individuals, groups, and businesses involved in stewardship initiatives.

Some key findings highlight areas of concern, where signals suggest that action is needed to maintain functioning ecosystems. These findings include loss of old forests, changes in river flows at critical times of the year, loss of wildlife habitat in agricultural landscapes, declines in certain bird populations, increases in wildfire, and significant shifts in marine, freshwater, and terrestrial food webs. Some contaminants recently detected in the environment are known to be increasing in wildlife. Plant communities and animal populations are responding to climate change. Temperature increases, shifting seasons, and changes in precipitation, ice cover, snowpack, and frozen ground are interacting to alter ecosystems, sometimes in unpredictable ways.

Some key findings identify ecosystems in which natural processes are compromised or increased stresses are reaching critical thresholds. Examples include: fish populations that have not recovered despite the removal of fishing pressure; declines in the area and condition of grasslands, where grassland bird populations are dropping sharply; and fragmented forests that place forest-dwelling caribou at risk. The dramatic loss of sea ice in the Arctic has many current ecosystem impacts and is expected to trigger declines in ice-associated species such as polar bears. Nutrient loading is on the rise in over 20% of the water bodies sampled, including some of the Great Lakes where, 20 years ago, regulations successfully reduced nutrient inputs. This time, causes are more complex and solutions will likely be more difficult. Lakes affected by acid deposition have been slow to recover, even when acidifying air emissions have been reduced. Invasive non-native species have reached critical levels in the Great Lakes and elsewhere.

A strategy of detecting ecosystem change and acting before thresholds are crossed has the greatest likelihood of preventing biodiversity loss. Examples throughout the assessment demonstrate the excellent return on investment from early response and prevention. Restoration, although more costly than prevention, has also had successes.

Lessons have been learned from preparing this assessment. Canada's long-term climate and hydrological monitoring programs ensure the reliability and relevance of climate and water trends in areas where station coverage is good. Equivalent monitoring of biodiversity and ecosystems is rare. Local and regional trends are helpful but usually cannot be extrapolated to a wider scale. Information collected for other purposes is often not useful for understanding changes in biodiversity and ecosystems. Relevant ecosystem-level information is less available than decision-makers may realize. Finally, this assessment would not have been possible without the combined efforts of federal, provincial, and territorial governments in sharing data, knowledge, and perspectives.

KEY FINDINGS AT A GLANCE

THEME: BIOMES

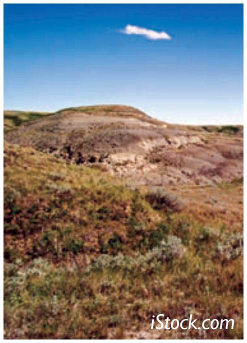
A biome is a large community of plants and animals that occupies a distinct type of environment. This section reports on six biomes and a seventh category of particular importance to Canadian ecosystems – ice across biomes.

iStock.com

1. FORESTS

At a national level, the extent of forests has changed little since 1990; at a regional level, loss of forest extent is significant in some places. The structure of some Canadian forests, including species composition, age classes, and size of intact patches of forest, has changed over longer time frames.

Forests cover 3.5 million km^2 (60%) of Canada's landscape. Of this, about 70% is boreal forest. The northern boreal forest has relatively little human imprint, but the southern boreal forest is fragmented by human disturbance. Only 0.01 to 0.02% of Canada's forest is lost annually to other types of land cover. Although old forests have shifted to young forests in some areas, old forests still make up 40% of both Newfoundland and Labrador's boreal forest and British Columbia's coastal rainforest. Ecosystems near northern and mountain treelines are changing. For example, trees are expanding northward along the Labrador coast and tree growth and density are increasing near treelines in the Yukon and northern Quebec.

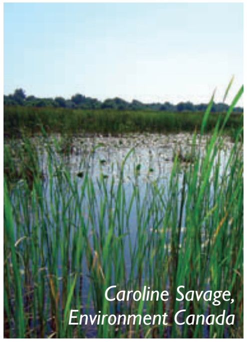


iStock.com

2. GRASSLANDS

Native grasslands have been reduced to a fraction of their original extent. Although at a slower pace, declines continue in some areas. The health of many existing grasslands has also been compromised by a variety of stressors.

Grassland losses exceed those of other major biomes in North America. Most loss in Canada occurred before the 1930s as the result of conversion for cropland. Estimates of total loss prior to the 1990s include 97% of tallgrass/savannah in southern Ontario, 70% of prairie grasslands (by far the largest of Canada's grasslands), and 19% of bunchgrass/sagebrush in British Columbia. Losses continue in some areas, particularly small, remnant patches. Grassland health has also suffered. Over the long term, changes in natural disturbance regimes due to factors like fire suppression and confined cattle grazing have had negative impacts on grasslands. Sound stewardship practices in some areas are helping to address the problem. Other stressors include invasive non-native species, forest encroachment, fragmentation, and intensification of agriculture.



Caroline Savage, Environment Canada

3. WETLANDS

High loss of wetlands has occurred in southern Canada; loss and degradation continue due to a wide range of stressors. Some wetlands have been or are being restored.

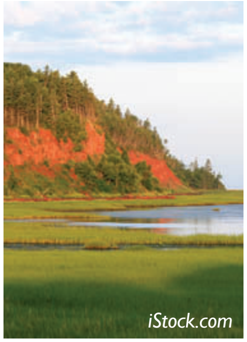
Approximately 16% of Canada's land area is covered by freshwater wetlands, making the country steward to about a quarter of the world's remaining wetlands. Wetland conversion was rapid in southern Canada post-settlement, with an estimated 200,000 km^2 lost prior to 1990. Despite significant efforts to conserve and restore wetlands in some areas, overall loss and degradation continue. Wetlands near urban areas are particularly threatened, with 80 to 98% of original wetlands converted to other uses in or near Canada's large urban centres. Current threats include conversion to other land uses, water regulation, pollution, and invasive non-native species. Climate change poses a significant threat to wetlands. In the North, wetland changes due to permafrost thaw and greater evaporation during warmer summers are already apparent.


Environment Canada

4. LAKES AND RIVERS

Trends over the past 40 years influencing biodiversity in lakes and rivers include seasonal changes in magnitude of stream flows, increases in river and lake temperatures, decreases in lake levels, and habitat loss and fragmentation.

Annual low flows in natural streams decreased at many sites in southern Canada and increased at sites in the west and northwest. Annual peak flows decreased at many sites across Canada, but increased in the Atlantic Maritime. Other trends, such as changes in seasonal average flows, were also specific to regions and types of streams. Changes in stream flow affect aquatic life. For example, decreased low flows can cause problems for late-spawning fish and increase heat stress and predation for all fish. Trends in lakes include decreases in seasonal and year-to-year water-level fluctuations in some of the Great Lakes. In Lake Ontario, since 1960, water-level regulation has reduced plant diversity and altered habitat for animals living along the shoreline.


iStock.com

5. COASTAL

Coastal ecosystems, such as estuaries, salt marshes, and mud flats, are believed to be healthy in less-developed coastal areas, although there are exceptions. In developed areas, extent and quality of coastal ecosystems are declining as a result of habitat modification, erosion, and sea-level rise.

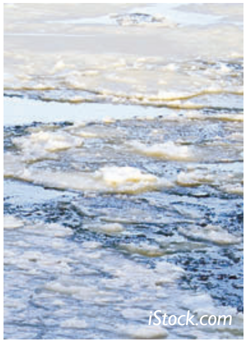
On the Atlantic coast, wetlands, dunes, and beaches are at risk from coastal development and increased erosion – and are known to be declining in some areas. The erosion results from several interacting factors: changes from development make the shoreline more vulnerable, and rising sea level combines with more intense storm surges. On the Pacific coast, development in the early 20th century resulted in loss of intertidal wetlands, mudflats, and estuarine habitat. Losses continue today, with increasing human populations. Eelgrass meadows are internationally recognized as productive, at-risk coastal ecosystems. There is evidence of recent rapid declines in eelgrass in areas of James Bay, the Atlantic Coast, and the Gulf of St. Lawrence.


iStock.com

6. MARINE

Observed changes in marine biodiversity over the past 50 years have been driven by a combination of physical factors and human activities, such as oceanographic and climate variability, and overexploitation. While certain marine mammals have recovered from past overharvesting, many commercial fisheries have not.

Management efforts to reverse long-term fisheries declines have been largely unsuccessful, hampered by shifts in ocean regimes and loss of habitat for spawning and rearing fish. Food webs in waters off all three of Canada's coasts are changing. The most dramatic example is the increase in invertebrates, such as shrimp, following the collapse of Atlantic ground fish. Ocean changes include shifts to warmer, less salty seawater over the past few decades, a result of natural climate oscillations and, possibly, climate change. Ocean acidification, caused by the oceans absorbing the increased atmospheric carbon dioxide, is already occurring in Canada's oceans, with severe consequences for marine biodiversity predicted by the end of this century.


iStock.com

7. ICE ACROSS BIOMES

Declining extent and thickness of sea ice, warming and thawing of permafrost, accelerating loss of glacier mass, and shortening of lake-ice seasons are detected across Canada's biomes. Impacts, apparent now in some areas and likely to spread, include effects on species and food webs.

Ice is a defining feature of much of the Canadian landscape and many plants and animals are adapted to seasonally or permanently frozen environments. Loss of ice alters entire biomes – thawing permafrost is already changing frozen peatland ecosystems to wetlands in some areas. Over the long term, thawing permafrost will lead to shifts in plant and animal communities across the current permafrost zone. Sea ice has undergone the most dramatic, large-scale decline, especially in the last few years. There are direct impacts on species, including seals, polar bears, Arctic cod and Arctic foxes. Indirect effects include changes in coastal climate and impacts on Arctic food webs, including the range expansion of killer whales into ice-free areas.

KEY FINDINGS AT A GLANCE

THEME: HUMAN/ECOSYSTEM INTERACTIONS

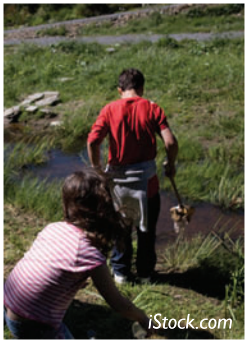
Humans now dominate most ecosystems on Earth. In Canada, with more wilderness than most countries, this dominance is not always obvious – but even in remote areas, human influence is increasingly apparent. This section examines the status and trends of some of the actions Canadians are taking to conserve ecosystems, some ecosystem stressors that are by-products of human activity, and trends in services provided by healthy and diverse ecosystems.

Parks Canada

8. PROTECTED AREAS

Both the extent and representativeness of the protected areas network have increased in recent years. In many places, the area protected is well above the United Nations 10% target. It is below the target in highly developed areas and the oceans.

As of May 2009, 9.4% of Canada's land area and 0.64% of its ocean area had provincial, territorial, or federal protected-area designation. Large and small protected areas have a role to play in biodiversity conservation. Thirty-six protected areas in Canada are larger than 5,000 km^2, making up 59% of the total area protected. In several places, adjacent protected areas create large protected-area complexes. At the other end of the scale, 3,464 protected areas smaller than 10 km^2, which make up less than 1% of the total area protected, play an important role in protecting rare species and habitats. Progress has been made in identifying potential sites for marine protected areas, although designation of marine areas has been slow.



iStock.com

9. STEWARDSHIP

Stewardship activity in Canada is increasing, both in number and types of initiatives and in participation rates. The overall effectiveness of these activities in conserving and improving biodiversity and ecosystem health has not been fully assessed.

Over a million people and a thousand stewardship groups participate in stewardship activities in Canada – everything from community projects to government initiatives. Tax incentives, conservation easements, and the growth of land trusts have helped facilitate stewardship on private land. Also important are large, landscape-level initiatives. For example, the North American Waterfowl Management Plan has influenced the stewardship of over 70,000 km^2 of wetland, grassland, and agricultural habitat across Canada in the 2000s alone. Standards and codes of practice, such as forest and marine certification, are important tools in the stewardship of public and private lands and waters. Participation in all forms of stewardship has increased substantially since the 1980s.

10. INVASIVE NON-NATIVE SPECIES

Jim Moyes, Environment Canada

Invasive non-native species are a significant stressor on ecosystem functions, processes, and structure in terrestrial, freshwater, and marine environments. This impact is increasing as numbers of invasive non-native species continue to rise and their distributions continue to expand.

Invasive non-native species are considered the second greatest threat to biodiversity worldwide, after habitat destruction. Ecosystems that are already altered or degraded are more vulnerable to colonization by aggressive non-native species. Non-native species are destroying valuable wetland and grassland habitat, are invading marine intertidal areas, and dominate the Great Lakes. Economic and ecological losses caused by invasive non-native species have been estimated at $5.7 billion annually in the Great Lakes alone. Wildlife diseases caused by non-native pathogens, such as West Nile virus, have killed thousands of birds and potentially threaten many different wildlife species.

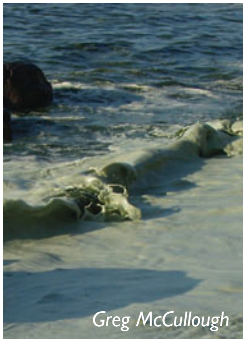
11. CONTAMINANTS

iStock.com

Concentrations of legacy contaminants in terrestrial, freshwater, and marine systems have generally declined over the past 10 to 40 years. Concentrations of many emerging contaminants are increasing in wildlife; mercury is increasing in some wildlife in some areas.

Levels of legacy contaminants – banned or restricted chemicals, such as PCBs – have declined in wildlife in the Strait of Georgia, St. Lawrence Estuary, Great Lakes, Bay of Fundy, and the Arctic since the 1970s, although rates of decline in some areas have slowed in recent years. The recovery of peregrine falcons after the banning of DDT demonstrates that some species can rebound after the contaminant stress has been lifted. Flame retardants (PBDEs) are examples of emerging contaminants, which have more recently been found to spread through and accumulate in ecosystems. PBDE levels have increased since the 1980s in fish, birds, whales, and polar bears. Contaminants can directly affect wildlife health and reproduction and increase vulnerability to other stressors.

12. NUTRIENT LOADING AND ALGAL BLOOMS

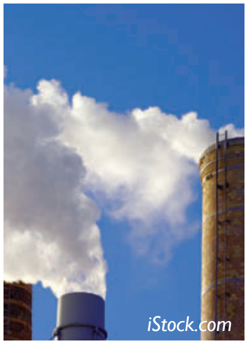


Greg McCullough

Inputs of nutrients to both freshwater and marine systems, particularly in urban and agriculture-dominated landscapes, have led to algal blooms that may be a nuisance and/or may be harmful. Nutrient inputs have been increasing in some places and decreasing in others.

Fertilizers from agriculture, phosphates from detergents and industry, and sewage from towns and cities add nutrients to aquatic systems, sometimes causing algal blooms. In recent years, algal blooms have been reported in lakes, reservoirs, ponds, rivers, swamps, and estuaries across the southern half of the country. Some past successes in nutrient reductions, particularly in the Great Lakes, are now being reversed. Over the past 16 years, nitrogen has increased in 28% of water bodies sampled and decreased in 12%, while phosphorus has increased in 21% and decreased in 29%. Although harmful marine algal blooms occur naturally, they may be increasing in some coastal areas.

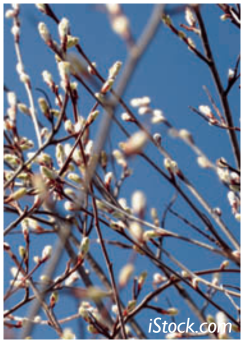
KEY FINDINGS AT A GLANCE



13. ACID DEPOSITION

Thresholds related to ecological impact of acid deposition, including acid rain, are exceeded in some areas, acidifying emissions are increasing in some areas, and biological recovery has not kept pace with emission reductions in other areas.

Acid deposition occurs when sulphur and nitrogen-based air pollutants react with water and settle to Earth. In aquatic systems, the survival of many species is threatened by the acidification of their habitat. Emissions have declined since 1980, but improvements in lake acidity have been slow to follow. Some areas, such as parts of the Boreal Shield, have acid deposition levels beyond the ability of the ecosystem to cope. The Atlantic Maritime has some of the most acidic waters and heavily affected fish habitat in North America. Although acidification is often considered an eastern issue, it is an increasing concern in parts of the West. In northwest Saskatchewan, for example, many lakes downwind of oil and gas development emissions are sensitive to acid deposition.



14. CLIMATE CHANGE

Rising temperatures across Canada, along with changes in other climatic variables over the past 50 years, have had both direct and indirect impacts on biodiversity in terrestrial, freshwater, and marine systems.

Canada's climate has changed significantly since the 1950s. Temperatures have increased across the country, especially in winter and spring. Spring now arrives earlier, meaning snow melts earlier and growing seasons are longer. Precipitation has generally increased, especially in the North. The average annual temperature has increased by 1.4°C. No significant cooling trend has occurred at any location in any season. Changes in climate have led to widespread environmental changes, such as loss of sea ice. Some currently localized changes are likely to increase and become more widespread with continued warming. These include rising sea levels, higher seawater temperatures, and increases in wildfires. Ecosystems and species are affected by all of these changes, often in complex and unexpected ways that interact with other stressors, such as habitat fragmentation.

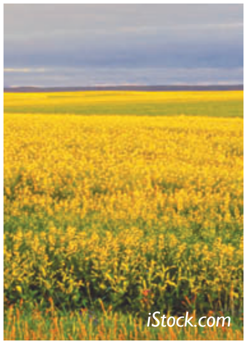
15. ECOSYSTEM SERVICES

Canada is well endowed with a natural environment that provides ecosystem services upon which our quality of life depends. In some areas where stressors have impaired ecosystem function, the cost of maintaining ecosystem services is high and deterioration in quantity, quality, and access to ecosystem services is evident.

Many of Canada's vast wetlands, coastal ecosystems, and forests are healthy and provide billions of dollars in ecosystem services annually. Services include commercial, recreational, and subsistence food gathering, flood and drought control, sediment filtering, nutrient cycling, erosion control, and climate regulation. There are also signs of loss of ecosystem services. Increased erosion, spread of wildlife diseases, and less predictable river flows have been documented. Several commercial fisheries are declining. Subsistence opportunities are hampered by wildlife population declines, contaminants in culturally important species, and, in the North, by altered access to harvesting due to changes in ice and permafrost. Recreational opportunities are affected by closed beaches, fouled fishing equipment, and invasive non-native species.

THEME: HABITAT, WILDLIFE, AND ECOSYSTEM PROCESSES

The key findings in this section are related to aspects of abundance and diversity of wildlife. First, the capacity of agricultural lands to support wildlife is considered. Trends are then assessed for selected species groups of high economic, cultural, or ecological significance. Three aspects of ecosystem processes are examined: primary productivity, relations of predators and prey through food webs and population cycles, and the role of natural disturbance in forested ecosystems.



16. AGRICULTURAL LANDSCAPES AS HABITAT

The potential capacity of agricultural landscapes to support wildlife in Canada has declined over the past 20 years, largely due to the intensification of agriculture and the loss of natural and semi-natural land cover.

Agricultural landscapes cover 7% of Canada's land area and provide important habitat for over 550 species of terrestrial vertebrates, including about half of the species assessed as at risk nationally. Natural areas, including wetlands, woodlands, and unimproved pasture, provide the highest biodiversity values, while croplands provide the lowest. Between 1986 and 2006 the capacity of agricultural landscapes to provide habitat for wildlife declined significantly across Canada. The main causes are the conversion of natural areas to cropland and more intensive use of agricultural land. The proportion of agricultural land classified as cropland increased from 46 to 53% over this period.

17. SPECIES OF SPECIAL INTEREST: ECONOMIC, CULTURAL, OR ECOLOGICAL

Many species of amphibians, fish, birds, and large mammals are of special economic, cultural, or ecological interest to Canadians. Some of these are declining in number and distribution, some are stable, and others are healthy or recovering.

Amphibians Twenty percent of native amphibians – frogs, toads and salamanders – are considered at risk of extinction in Canada. Declines of several amphibian populations since the mid-1990s have been documented in the Great Lakes Basin and the St. Lawrence River corridor. Trends for western Canada are not well documented. Habitat degradation and loss are the main causes of amphibian declines in Canada.

Fishes using freshwater habitat Freshwater species are at a high risk of extinction worldwide. In Canada 18% of freshwater and diadromous fish are Endangered or Threatened in all parts of their ranges. The number of Endangered or Threatened fishes has been increasing since the 1980s. The causes of declines vary across the country and include invasive non-native species, habitat loss, degradation, and fragmentation, overharvesting, pollution, and climate change.

Birds Since the 1970s, overall population declines have affected all landbird groups except forest birds. Birds of grassland and other open habitats exhibited the most marked declines, losing over 40% of their populations. Some common landbird species are also showing declines. Half of the 35 shorebird species assessed in 2000 showed a decline somewhere in their ranges. Trends for seabirds are mixed, but the number of populations in decline has increased since the 1980s. Waterfowl are generally healthy, although some species are in decline.

Caribou The range of caribou has contracted. Most northern herds are declining, some precipitously. Causes are not well understood and might include natural population cycles, climate change, increased impacts from human activity, changes in predation, and over-harvesting. Forest-dwelling woodland caribou are Threatened in the boreal forest, with many herds declining. The status of most herds in the northern mountain population is not well understood, while most herds in the southern mountain population are in decline. Woodland caribou are declining primarily because of loss and fragmentation of habitat.

KEY FINDINGS AT A GLANCE

18. PRIMARY PRODUCTIVITY

Primary productivity has increased on more than 20% of the vegetated land area of Canada over the past 20 years, as well as in some freshwater systems. The magnitude and timing of primary productivity are changing throughout the marine system.

The North, where temperature rise is highest, has experienced the largest increases in production of green vegetation. Productivity increases in southern Canada are likely related more to changes in land use than to changes in climate. Vegetation changes that correspond with northern Canada's greening trend include a shift to shrubs and grasses where lichens and mosses once dominated. In Arctic lakes and ponds, a longer growing season for algae, due to earlier melting of lake ice in spring, is considered the strongest factor driving the observed increase in productivity. Marine primary productivity, however, shows long-term declines in most of the world's ocean regions, including the Arctic, North Pacific and North Atlantic oceans.

19. NATURAL DISTURBANCES

The dynamics of natural disturbance regimes, such as fire and native insect outbreaks, are changing and this is reshaping the landscape. The direction and degree of change vary.

Natural disturbance regimes, such as fire and native insect outbreaks, are important drivers of biodiversity in forest and grassland ecosystems. Large fires, greater than 2 km^2, account for over 95% of the area burned, and over 90% of them occur in the boreal forest. Although highly variable, the annual area burned has increased since the 1960s. At the same time, fire is no longer a significant disturbance agent in parts of the country such as southern Ontario and the Prairies. No overall trend in native insect outbreaks is evident, although some insects, such as the mountain pine beetle, show significant change. The infestation of mountain pine beetle over the last decade was of unprecedented intensity, damaging over 163,000 km^2 of forest. Fire and insects affect each other and both are influenced by climate and management practices.

20. FOOD WEBS

Fundamental changes in relationships among species have been observed in marine, freshwater, and terrestrial environments. The loss or reduction of important components of food webs has greatly altered some ecosystems.

An example of the impact from a major reduction in one food web component is the decline of *Diporeia*, a small relative of shrimp and historically the dominant invertebrate in most of the Great Lakes. This decline has had major consequences for Great Lakes fish populations and commercial fisheries. Reduction in predators also affects the whole food web. Most populations of large native carnivores have declined severely in southern and eastern Canada, affecting abundance and diversity of prey species and small predators. Population cycles are important features of boreal forest and tundra ecosystems. Herbivores – especially the snowshoe hare in forests and small rodents in tundra – are at the heart of these cycles. There is emerging evidence that these population cycles are weakening at several locations in northern Canada.

THEME: SCIENCE/POLICY INTERFACE

Although the interface between science and policy was not the focus of this assessment, themes and ideas recurred throughout the development and review process and have been grouped into two categories. The first deals with the nature and quality of information available for assessing ecosystem status and trends in Canada. The second deals with the policy implications resulting from rapid and unexpected change and the crossing of ecological thresholds, especially in the context of a changing climate.

Jim Leafloor

21. BIODIVERSITY MONITORING, RESEARCH, INFORMATION MANAGEMENT, AND REPORTING

Long-term, standardized, spatially complete, and readily accessible monitoring information, complemented by ecosystem research, provides the most useful findings for policy-relevant assessments of status and trends. The lack of this type of information in many areas has hindered development of this assessment.

Piecing together information from disparate sources is currently the only way to assess status and trends of Canada's ecosystems. In some cases, there are good data sets backed by long-term monitoring programs. Information is sometimes available for status but not trends, or trend information is limited to a small geographic area over a short time interval. Often, information critical to the assessment of ecosystem health is missing. Reporting on status and trends requires more than monitoring results. The context, cause-and-effect linkages, and knowledge of ecosystem functioning that will tell a coherent story is drawn from ecological research. Improved collaboration among Canada's ecological research, monitoring, and policy communities and institutions, focused on identifying and addressing policy-relevant questions, would enhance future assessments of status and trends.

iStock.com

22. RAPID CHANGES AND THRESHOLDS

Growing understanding of rapid and unexpected changes, interactions, and thresholds, especially in relation to climate change, points to a need for policy that responds and adapts quickly to signals of environmental change in order to avert major and irreversible biodiversity losses.

When thresholds have been crossed, ecosystems shift irrevocably from one state to another. Options for action are usually limited, expensive, and have a low probability of success. Taking earlier action, when ecosystem changes have been detected but thresholds have not yet been crossed, creates more options and a greater probability of reversing or stabilizing impacts. In some cases, early warning signals appear in a few locations or in a few individuals in a population. When it is possible to take preventative action in response to early warnings, the probability of success is greatest and the long-term costs are usually lower.

SYNTHESIS OF KEY FINDINGS

This diagram presents the status and trends of the key findings, as well as confidence in the conclusions drawn. The key findings are grouped in themes, each occupying a quarter of the diagram. They are presented as parts of a circle to highlight the holistic nature of ecosystems – these key findings are interrelated and their common, central focus is the health and diversity of ecosystems.

The topics in the left half of the circle are aspects of the ecosystems themselves – biomes, habitat, wildlife, and ecosystem processes.

The topics in the right half of the circle are human activities – alteration of ecosystems and actions taken to understand and conserve ecosystems.

By necessity, the time frames over which the ratings of status and trends are made vary – both because time frames that are meaningful for these diverse aspects of ecosystems vary and because the assessment is based on the best available information, which is over a range of time periods.

Beside each topic is a coloured circle indicating the status associated with the key finding. Within each circle is an arrow that shows both the direction and the rate of change. Beside some topics there are two circle/arrow combinations to represent a range or a dichotomy of status and trends.

The height of the stack of papers beside each key finding represents confidence in the finding, based on an evaluation of the adequacy of the supporting evidence. Confidence is lowered when the ecosystem aspect is not well understood or when data are inadequate in spatial or temporal coverage.

In the body of the report, at the beginning of each key finding section, these symbols are repeated, along with short phrases summarizing the basis for the ratings.

The red flags in some key finding sections are used to highlight aspects of the findings that may be early warning signs of significant ecological change.

LEGEND

STATUS

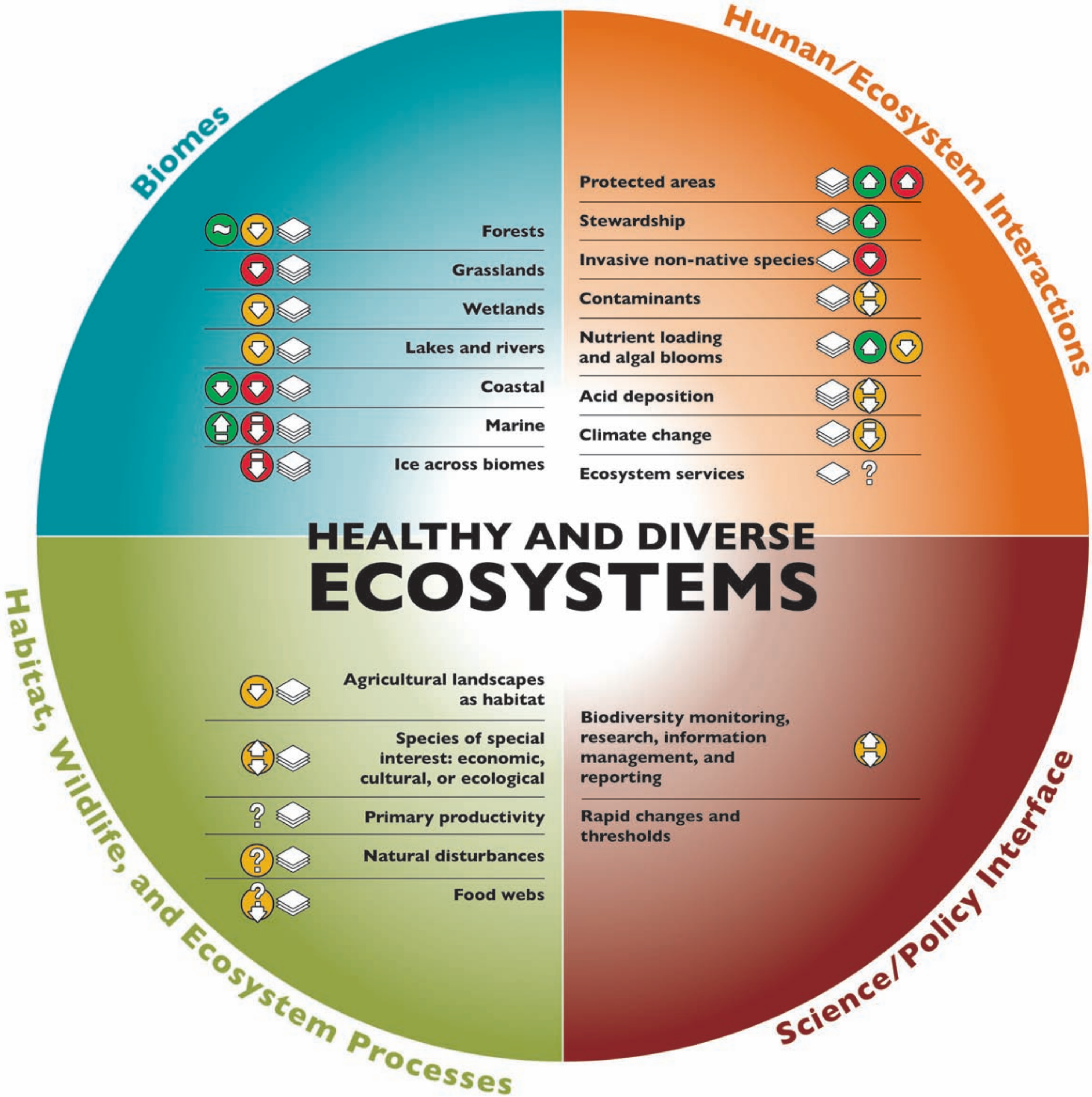
	ECOSYSTEM ASPECTS	HUMAN ACTIVITIES
HEALTHY	likely to persist and likely able to recover from disturbances	actions adequate for conservation or showing good progress, or stressor not causing major impacts
CONCERN	showing signs of stress	showing signs of insufficient actions, or signs of major impacts from stressor
IMPAIRED	outside of range of natural variation, unstable, or likely not recovering	poor progress or insufficient actions, or stressors causing major impacts

TREND

- IMPROVING AT A RAPID RATE
- IMPROVING AT A SLOW TO MODERATE RATE
- LITTLE CHANGE
- GETTING WORSE AT A SLOW TO MODERATE RATE
- GETTING WORSE AT A RAPID RATE
- UNKNOWN

CONFIDENCE IN FINDING

LOW	limits in temporal and/or spatial extent of data, or gaps in understanding of the topic, making interpretation difficult
MEDIUM	data coverage only fair and/or understanding of the topic poor
HIGH	sufficient evidence and adequate understanding of the topic


Biomes
Forests
Grasslands
Wetlands
Lakes and rivers
Coastal
Marine
Ice across biomes
Human/Ecosystem Interactions
Protected areas
Stewardship
Invasive non-native species
Contaminants
Nutrient loading and algal blooms
Acid deposition
Climate change
Ecosystem services
HEALTHY AND DIVERSE ECOSYSTEMS
Habitat, Wildlife, and Ecosystem Processes
Agricultural landscapes as habitat
Species of special interest: economic, cultural, or ecological
Primary productivity
Natural disturbances
Food webs
Science/Policy Interface
Biodiversity monitoring, research, information management, and reporting
Rapid changes and thresholds

biomes

KEY FINDINGS

1. Forests At a national level, the extent of forests has changed little since 1990; at a regional level, loss of forest extent is significant in some places. The structure of some Canadian forests, including species composition, age classes, and size of intact patches of forest, has changed over longer time frames.

2. Grasslands Native grasslands have been reduced to a fraction of their original extent. Although at a slower pace, declines continue in some areas. The health of many existing grasslands has also been compromised by a variety of stressors.

3. Wetlands High loss of wetlands has occurred in southern Canada; loss and degradation continue due to a wide range of stressors. Some wetlands have been or are being restored.

4. Lakes and rivers Trends over the past 40 years influencing biodiversity in lakes and rivers include seasonal changes in magnitude of stream flows, increases in river and lake temperatures, decreases in lake levels, and habitat loss and fragmentation.

5. Coastal Coastal ecosystems, such as estuaries, salt marshes, and mud flats, are believed to be healthy in less-developed coastal areas, although there are exceptions. In developed areas, extent and quality of coastal ecosystems are declining as a result of habitat modification, erosion, and sea-level rise.

6. Marine Observed changes in marine biodiversity over the past 50 years have been driven by a combination of physical factors and human activities, such as oceanographic and climate variability, and overexploitation. While certain marine mammals have recovered from past overharvesting, many commercial fisheries have not.

7. Ice across biomes Declining extent and thickness of sea ice, warming and thawing of permafrost, accelerating loss of glacier mass, and shortening of lake-ice seasons are detected across Canada's biomes. Impacts, apparent now in some areas and likely to spread, include effects on species and food webs.

FORESTS

KEY FINDING 1. At a national level, the extent of forests has changed little since 1990; at a regional level, loss of forest extent is significant in some places. The structure of some Canadian forests, including species composition, age classes, and size of intact patches of forest, has changed over longer time frames.

Status and Trends

extent unchanged in most places

quality, such as intactness and age class distribution, declining

improved temporal coverage required

Forests are dynamic and diverse ecosystems, where complex interactions occur between species and ecological processes, from below ground to high in the canopy. **Forests are important** to biodiversity because they provide habitat for a wide array of plant and animal species from microorganisms to large mammals and because they are a pool of genetic diversity. It is estimated that approximately two-thirds of the species in Canada are associated with forests for at least part of their life cycle.[1, 2] Forests also provide ecosystem services, including the regulation of water flow across the landscape, erosion control, water purification, climate stabilization, and immense economic benefits.

Forest types

There are two forest bioclimatic zones in Canada – boreal and temperate. Each zone possesses a unique geography, vegetation, climate, soil, and wildlife. Canada has approximately 24 and 15% of the world's boreal and temperate forests,[3, 4, 5] and 9% of the world's total forest cover.[4] The boreal forest stretches across eight ecozones+ (see map). It is the largest contiguous forest ecosystem on Earth, and Canada's largest biome, covering 25% of its total land area and 72% of its total forest area.[1]

Spruce forests dominate all boreal forest ecozones+.[5] Black spruce forests are of particular ecological significance because of their nearly continuous ground cover of lichens, feather mosses, and sphagnum mosses. Lichens are critical forage for wintering migratory caribou herds and mosses provide habitat for a number of species. In northern Quebec, 9% of the dense black spruce forest has shifted to lichen-woodland systems over the past 50 years.[6] The proportion of the boreal forest that is dominated by spruce has decreased in the managed forest portion of Ontario's Boreal Shield,[7] and in the southern part of Manitoba's Boreal Shield.[8] Spruce is also declining outside the boreal forest.[9, 10]

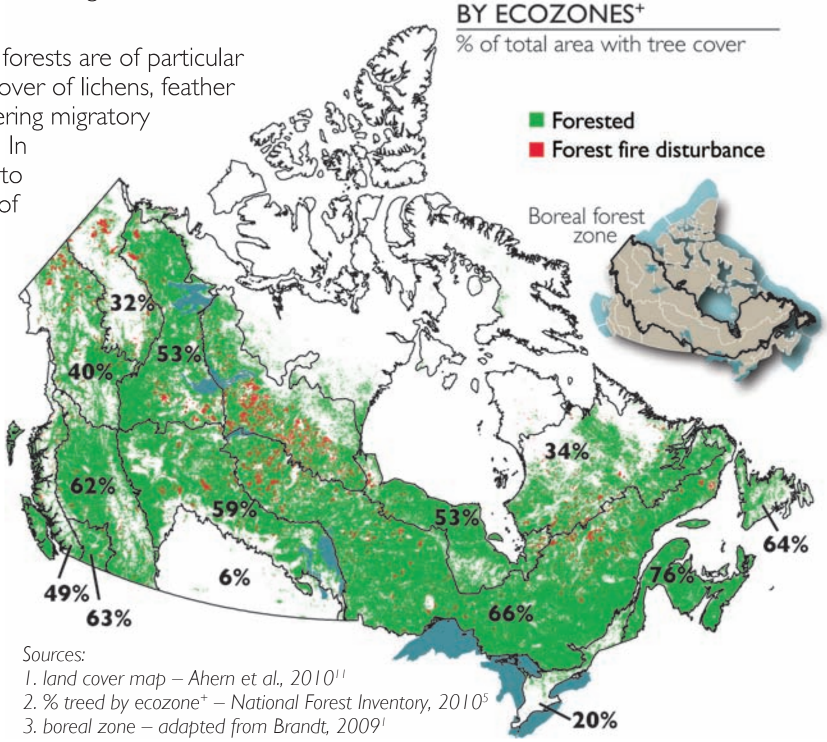
The temperate forest stretches across six ecozones+ and tree species are more variable. Dominant species include spruce and maple in the Atlantic Maritime, deciduous species in the Carolinian forest of the Mixedwood Plains, spruce and pine in the Montane Cordillera, and hemlock in the Pacific Maritime.[5]

Global Trends

About 130,000 km² of forest was lost each year in the last decade. This compares to 160,000 km² lost in the 1990s.[4] From 1990 to 2005, 3.1% of the world's forests were lost.[12]

PERCENT OF FOREST AREA BY ECOZONES+

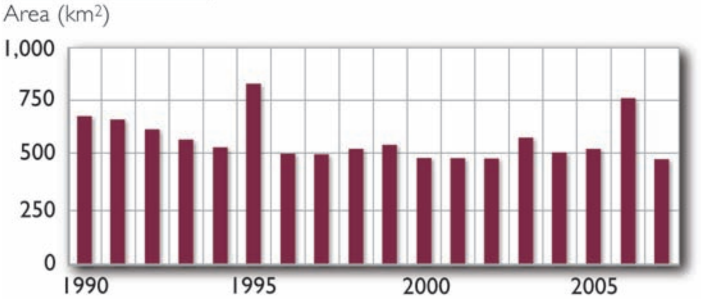
% of total area with tree cover



Sources:
1. land cover map – Ahern et al., 2010[11]
2. % treed by ecozone+ – National Forest Inventory, 2010[5]
3. boreal zone – adapted from Brandt, 2009[1]

Boreal forest

DEFORESTATION



Note: This graph depicts deforestation – the area of forest converted to other land cover types. As it does not include the area converted from other land types to forests, it is not a depiction of net change in forest area.
Source: adapted from Environment Canada, 2009[13] and Natural Resources Canada, 2008[14]

The total forest area in Canada is approximately 3.48 million km^2.[15] From 1990 to 2007, the annual area deforested – permanently converted from forests to other land cover – ranged from 482 to 760 km^2, an annual rate of deforestation of 0.01 to 0.02%. This is a very small loss when compared to the global rate of deforestation and the extent of Canada's forests.[12, 16] Trends in total forest area, including afforestation – the expansion of forests into other land cover types – cannot be calculated from available data.

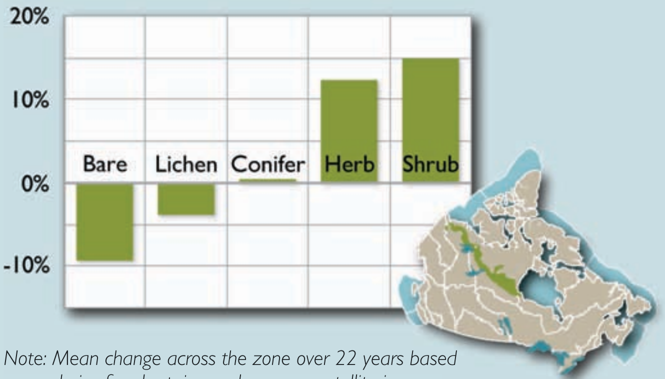
Conversion of forest land to cropland, resource roads, transmission lines, oil and gas development, urban development, and flooding for new hydro reservoirs, contributes to deforestation.[13] The rate of deforestation is small at a national level, but it can be significant in some regions. For example, 45% of the highly forested coastal Douglas fir zone in B.C. has been converted to other land cover types.[17] A small amount of afforestation is occurring in the Ontario portion of the Mixedwood Plains Ecozone+, where forest cover has rebounded from a low of 11% in the 1920s to an average of 22% today.[18]

CHANGES IN THE TREELINE ZONE

The term "treeline" is deceptive – there is not a sharp line where trees end, but rather a zone of transition from increasingly sparse trees to tundra. Treeline zones in Canada are both latitudinal, across the north of the country, and altitudinal, on the slopes of hills and mountains. The emerging picture is one of change, but not a uniform expansion of the treeline. In northern Quebec, trees in the forest-tundra zone have grown faster and taller since the 1970s[19] but distribution of trees has not changed greatly.[20] In Labrador, treelines have expanded northward and up slopes over the past 50 years along the coast, but not inland.[21] In the mountains of northwestern Canada, tree growth and density have changed more than the position of alpine treelines.[22]

VEGETATION CHANGES IN THE TREELINE ZONE OF WESTERN CANADA

1985 to 2006



Note: Mean change across the zone over 22 years based on analysis of early spring and summer satellite images.
Source: data from Olthof and Pouliot, 2010[23]

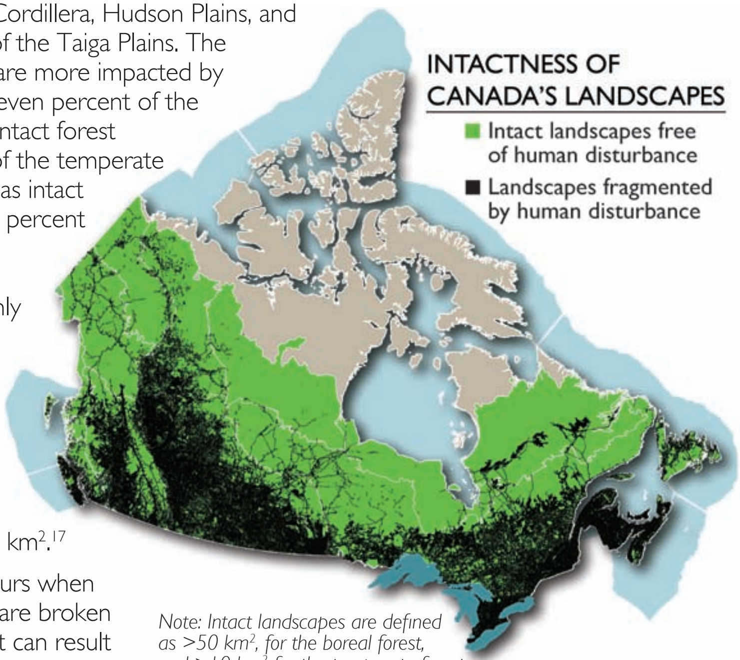
A study on the treeline in western Canada found only a small net increase in tree cover, but major changes in vegetation within the treeline zone. Tree cover increased in the northern half of the zone, but this was mainly offset by decreases in the southern half, especially west of the Mackenzie Delta – likely related to drier conditions due to higher temperatures.[24] The biggest changes were an increase in shrubs and, in the northwest of the treeline zone, a replacement of lichen cover and bare land with small, non-woody plants (herbs).

Since 1900, treeline has advanced at 52% of the 166 sites examined around the world and has receded at only 1% of the sites.[25]

FORESTS

Canada is one of the few countries that still have large tracts of forests, relatively undisturbed by human activity, that are believed to contain most of their native biodiversity. Just how intact Canada's forests are depends on how they are measured and, as Long et al.[26] point out, measuring intactness, or its corollary, fragmentation, can be complex. Global Forest Watch measured intact landscapes as undisturbed areas, free from human impact, and at least 50 km^2 in size for the boreal and taiga forest ecozones, and 10 km^2 for temperate forest ecozones.[27] B.C. defined intact coastal rainforests as undisturbed landscapes greater than 500 km^2 .[17] The Alberta Biodiversity Monitoring Institute has taken a different approach, measuring intactness as a percentage of what would be expected in a pristine habitat.[28]

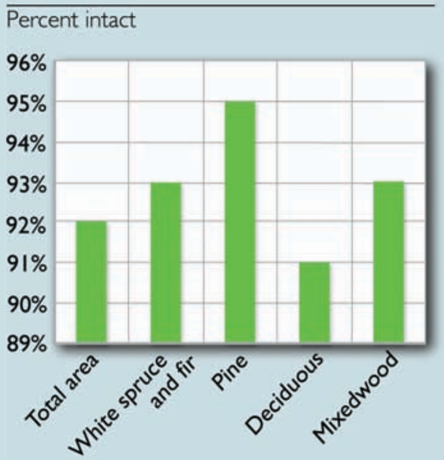
Global Forest Watch has published the only national perspective on intactness (see map) concluding that almost 50% of Canada's total land area, and more than 50% of the area of Canada's forested ecozones, consist of intact forest landscapes. This includes 94% of the northern boreal ecozones (using the Terrestrial Ecozones of Canada classification system[29]) – Taiga Cordillera, Boreal Cordillera, Hudson Plains, and Taiga Shield – and 73% of the Taiga Plains. The southern boreal regions are more impacted by human activities. Thirty-seven percent of the Boreal Plains remains as intact forest landscapes. About 42% of the temperate forest ecozones remains as intact forest landscapes. Ninety percent of this area is in B.C., the remainder is in Alberta.[27] In North America, the only remaining intact coastal temperate rainforest is in B.C. and Alaska. Approximately one-third of B.C.'s remaining coastal temperate rainforest is intact, in patches greater than 500 km^2.[17]



Note: Intact landscapes are defined as >50 km^2, for the boreal forest, and >10 km^2 for the temperate forest. Source: adapted from Lee et al., 2010[27]

Forest fragmentation occurs when large, continuous forests are broken up into smaller patches. It can result from human activities such as clearing for agriculture, urbanization, oil and gas exploration, and roads,[30] as well as from natural processes such as fire and insect infestations.[31, 32] Natural disturbance is discussed elsewhere in this report; the discussion here focuses only on fragmentation from human activities. The impact of forest fragmentation by human activities is dependant on the species and the spatial scale. Impacts can include: declines in neotropical migrant and resident birds requiring interior forest habitat;[33] declines in species with large area requirements, such as grizzly bear and caribou; increases in species that prefer to browse along forest edges, such as moose; increased exposure of interior forest species to predators and parasites; disruption of social structure of some species[34] and barriers to dispersal.[30] Sustainable forest practices can be designed to mitigate the effects of fragmentation.

INTACTNESS OF OLD FOREST HABITAT IN ALBERTA-PACIFIC FOREST MANAGEMENT AREA



Source: adapted from Alberta Biodiversity Monitoring Institute, 2009[28]

The Alberta Biodiversity Monitoring Institute measured habitat intactness and the human footprint of the Alberta-Pacific Forest Management Area (Al-Pac FMA). This area encompasses 57,331 km^2,[28] and makes up 9.5% of the Boreal Plains ecozone+.[5]

Old-forest habitat in the Al-Pac FMA is 92% intact. That is, it occupies 92% of the area that it would be expected to occupy if there were no human impacts. The human footprint index shows that human influence is evident in 7% of the Al-Pac FMA. Most of the human footprint is due to forestry, energy and transportation infrastructure. Half of the forestry footprint was created in the last 10 years.[28]

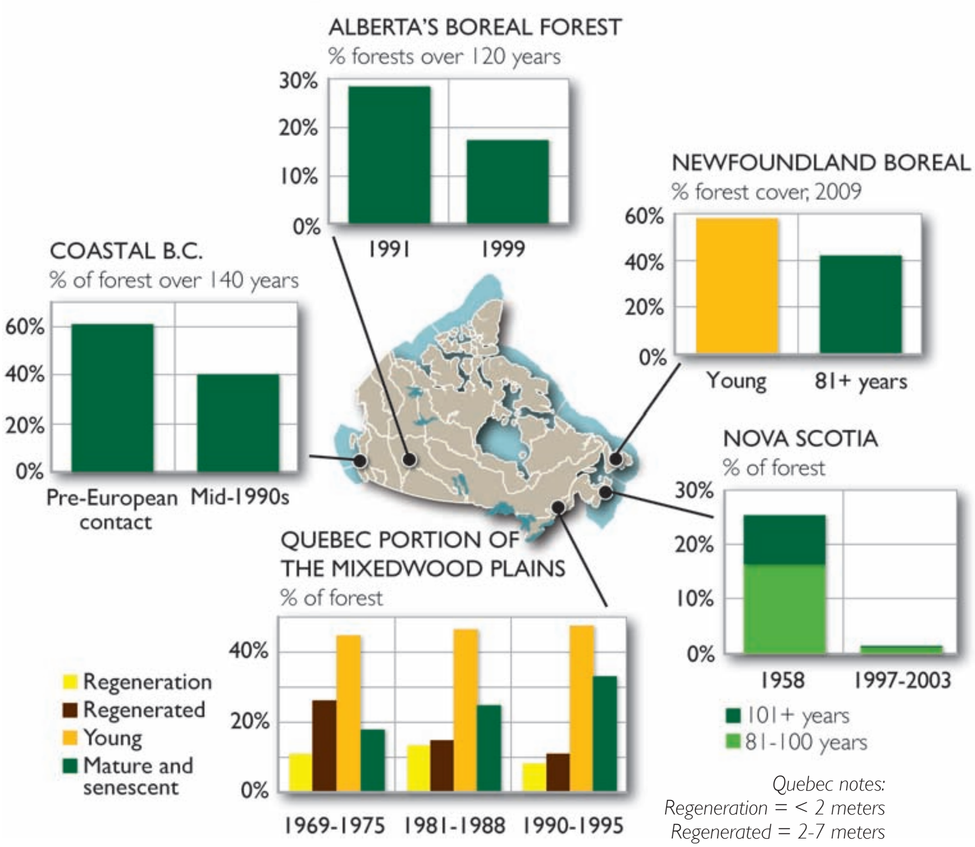
Gros Morne National Park, Newfoundland and Labrador

Shift from late-succession to early-succession forests

Much of the Canadian landscape was dominated by old forests when European settlement began, although natural disturbance from fires and insects ensured a range of age classes was found across the forested landscape. Old forests have greater structural diversity, complexity, and biodiversity than young forests, but the characteristics of old forests depend on the species and the site history.[17, 35] The age at onset of old-growth characteristics varies with disturbance regimes, forest types, and site characteristics.[35] For example, in the boreal forest, the age of old-growth stands ranges from about 80 to more than 300 years.[36] In Nova Scotia, the government defines old-growth forests as over 125 years of age.[35] In the B.C. interior, old-growth forests are defined as 120 to 140 years; on the coast, definitions vary from greater than 140 to greater than 250 years.[17, 37, 38] A shift from old to young forests has been observed in some managed forests across the country, such as in the Atlantic Maritime,[39] and Boreal Plains.[36]

In the Newfoundland Boreal[40] and Pacific Maritime[38] ecozones⁺, old forests still cover 40% of the forested area and it is assumed that old forests still dominate in the Hudson Plains, where human disturbance is minimal and natural disturbance regimes do not appear to have changed.

EXTENT OF OLD FORESTS



Quebec notes:
Regeneration = < 2 meters
Regenerated = 2-7 meters
Young = higher than 7 meters, increasing growth
Mature and senescent = higher than 7 meters, stable or decreasing growth

Note: age and size class distributions are affected by both natural and human disturbances. Sources (clockwise, starting with Alberta): Timoney, 2003,[36] Newfoundland and Labrador Department of Natural Resources, 2009,[40] Pannozza and Coleman, 2008,[39] Ministère des Ressources naturelles et Faune du Québec, 2010,[41] B.C. Ministry of Environment, 2006[38]

GRASSLANDS

KEY FINDING 2. Native grasslands have been reduced to a fraction of their original extent. Although at a slower pace, declines continue in some areas. The health of many existing grasslands has also been compromised by a variety of stressors.

Status and Trends

rate of loss slowed; extent impaired and health compromised in many areas

data not comprehensive, but trends are clear

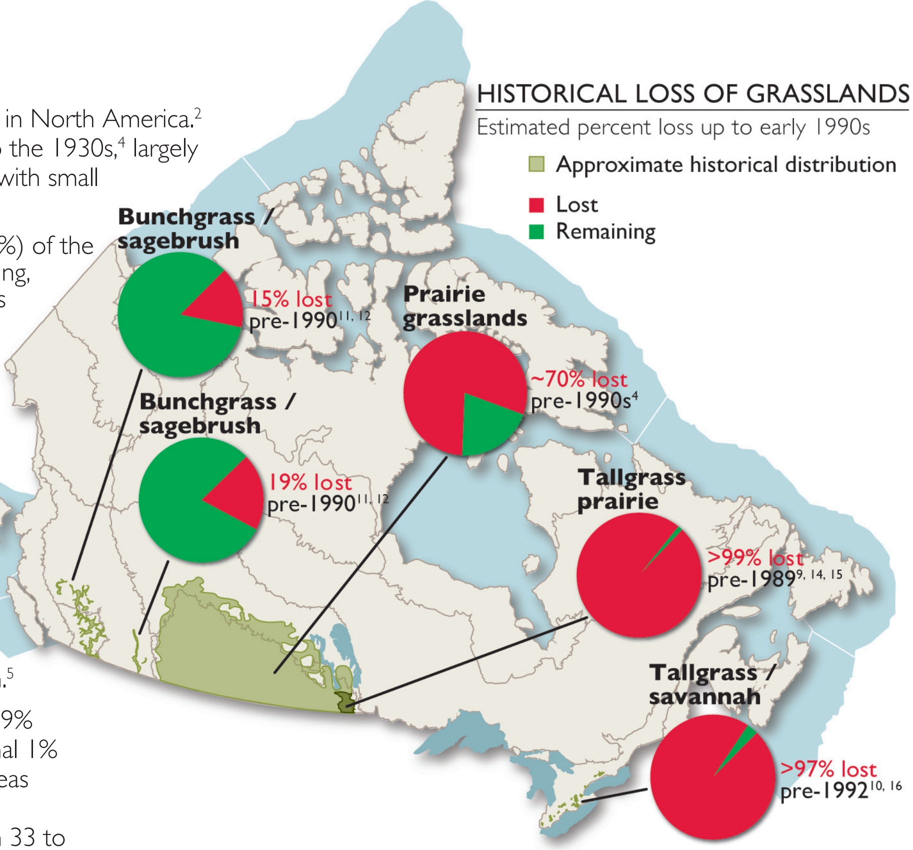
Grasslands are open ecosystems dominated by herbaceous (non-woody) vegetation. Typical temperate grasslands, like those in Canada, occur where there is low moisture, cold winters, and deep, fertile soils. Maintained historically by drought, fire, and grazing, temperate grasslands are the Earth's most altered, and one of the most threatened ecosystems, with the highest risk of biome-wide biodiversity loss.[1, 2] Although other ecosystem types, such as oak savannahs, alvars, and dunes support grasslands, this finding focuses on prairie and steppe.

Grasslands are important as habitat for many species, including many species at risk. They also provide soil and water conservation, nutrient recycling, pollination, habitat for livestock grazing, genetic material for crops, recreation, climate regulation, and storage for about 34% of the terrestrial global carbon stock.[1, 3]

Changes in extent

Losses of grasslands exceed those of other major biomes in North America.[2] Although most grassland loss in Canada occurred prior to the 1930s,[4] largely the result of conversion for cropland,[2] it continues today with small remnants often suffering the most.[5, 6]

- **Mixed and fescue prairie** covers over 110,000 km^2 (25%) of the Prairie provinces. It is estimated, based on remote sensing, that 70% of original vegetation, including grasslands, was converted to other uses by the 1990s.[4] Conversion of native grasslands continues,[6, 7] but at a slower rate. Overall loss from 1971 to 1986 was estimated at 3%.[7] Losses vary among regions, for example a 10% loss was found from 1985 to 2001 in some areas.[6]
- **Tallgrass prairie,** North America's most threatened prairie,[8] now covers approximately 100 km^2 of its former 6,000 km^2 in Manitoba[9] and 820 km^2 in Ontario.[10] The small patches that remain are still threatened by conversion, with 23% of remnant patches in Manitoba converted between 1987 and 2006. Only a few of the larger patches secured for conservation increased in size, due to active restoration.[5]
- **Bunchgrass/sagebrush** in B.C. suffered losses of 15 to 19% prior to 1990.[11, 12] Between 1990 and 2005, an additional 1% of the original grasslands were lost.[12] Losses in some areas were higher, for example declines in South Okanagan grassland communities from 1800 to 2005 ranged from 33 to 75%.[13] Only small remnants of former expansive grasslands in northern B.C. remain.[12]



Source: B.C. map adapted from Grasslands Conservation Council of British Columbia, 2009;[17] prairie map adapted from Ostlie and Haferman, 1999 cited in White et al., 2000;[3] Manitoba map adapted from Joyce and Morgan, 1989;[9] Ontario map adapted from Natural Heritage Information Centre cited in Ontario Tallgrass Prairie and Savanna Association[18]

Parks Canada, M. Finkelstein, 2005

Mixed grass prairie, Grasslands National Park, Saskatchewan

Grassland health

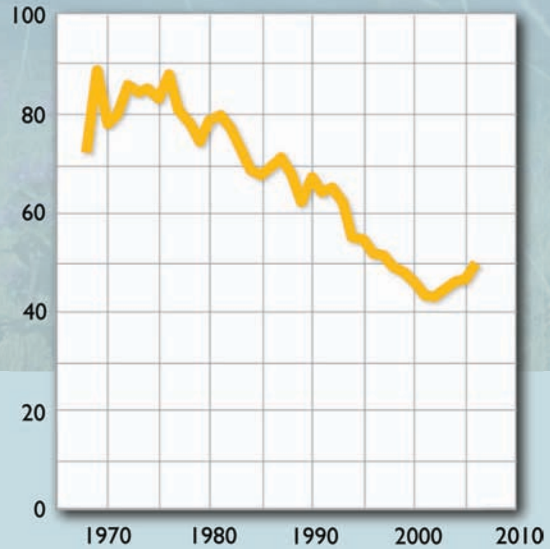
In addition to direct loss, the remaining grasslands in Canada are under stress. Natural disturbance regimes that historically maintained grasslands have been altered; in particular, the suppression of fire and replacement of free-ranging bison with confined cattle have modified the structure and composition of native grasslands. Also, many of the richest soils have been cultivated,[2, 19] leaving remaining grasslands on less productive soils. Other threats to grassland health include invasive non-native species, overgrazing, forest encroachment, continued fragmentation from development, and intensification of agriculture. Overall results from two studies investigating rangeland health in Alberta and Saskatchewan in 2008 showed that 49% were healthy, 8% unhealthy, and 43% healthy with problems.[20, 21] In the Okanagan Valley, between 19 and 69% of rangelands were in poor condition in the 1990s.[13] In Manitoba, 14% of remnant tallgrass prairie patches were so severely degraded by non-native species between 1987 and 2006 that patches could no longer be recognized as tallgrass prairie. Patch quality declined significantly over the time period and few are likely self-sustaining.[5]

Global Trends

Temperate grasslands, covering 8% of the Earth,[31] lost 70% of their native cover by 1950, with an additional 15% lost since.[32] In North America, over 97% of tallgrass prairie,[8, 33, 34] 71% of mixed prairie, and 48% of shortgrass prairie had been lost by 2003.[8]

CANADIAN GRASSLAND BIRDS

Breeding Bird Survey Abundance Index, 1967 to 2006



Source: adapted from Breeding Bird Survey[22] by Downes et al., 2010[23]

iStock.com

Grasshopper sparrow, declined by 78% since the 1970s[23]

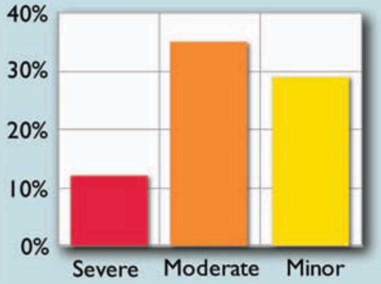
Grassland birds are showing steep and widespread declines throughout North America.[24, 25] In Canada, there has been an overall loss of 44% of the populations of grassland species since the 1970s, with individual species showing significant declines of up to 87%.[23]

GRAZING AND GRASSLAND HEALTH

Large areas of intact grasslands are used as rangelands for livestock grazing. The relationship between grazing and grassland health is complex. Most grasslands evolved with grazing by herbivores. Maintaining a range of grazing intensities is important for biodiversity as habitats with different grazing intensities support different species. Although improvements in land management practices have been made in some areas, for example community pastures and other stewardship initiatives in the Prairies,[4, 21, 26] livestock grazing can affect grassland health. Using data on species composition to indicate change, Thorpe[27] found almost 50% of plots in the Aspen Parkland and Mixed Grassland regions of Saskatchewan had, by 2007, been moderately or severely altered by livestock grazing. In B.C., about 90% of grasslands are now grazed by domestic livestock,[11] resulting in grasslands that are in early stages of succession, with many invasive species.[13, 28-30]

DEGREE OF ALTERATION OF SASKATCHEWAN GRASSLANDS DUE TO GRAZING

Percent, 2007



Source: Thorpe, 2009[27]

WETLANDS

KEY FINDING 3. High loss of wetlands has occurred in southern Canada; loss and degradation continue due to a wide range of stressors. Some wetlands have been or are being restored.

Status and Trends

status varies depending on wetland type and location; restoration in some areas

good data for some regions only; trends clear where data exist

ecosystem consequences of climate change on peatlands

Wetlands are land saturated with water all or most of the time, as indicated by poorly drained soils and vegetation and biological activity adapted to wet environments.[1, 2] They are of two types, organic (peatlands) and mineral, and are classified in five categories: bogs and fens, which are both peatlands; marshes and shallow water, which are both mineral; and swamps, which can be either.[1] Canada has approximately 1.5 million km^2 of wetlands.[1, 3] This represents about 16% of Canada's land mass and approximately one quarter of the world's remaining wetlands.[1] Thirty-seven of Canada's wetlands, an area covering almost 131,000 km^2, have been designated as wetlands of international importance.[4] This key finding discusses freshwater wetlands – estuaries, salt marshes, and other marine coastal wetlands are discussed in Coastal Biome.

Wetlands are important as one of Earth's most productive ecosystems, supporting a disproportionately high number of species,[5] including species at risk and significant numbers of migratory birds, fish, amphibians, a wide diversity of plants, and many other species. Wetlands provide essential services such as controlling floods, recharging groundwater and maintaining stream flows, filtering sediments and pollutants, cycling nutrients, stabilizing shorelines and reducing erosion, and sequestering carbon.

Status and trends

Despite the importance of wetlands, a comprehensive national inventory or monitoring program does not exist.[6] The most comprehensive data are for the Prairies and southern Ontario. Most studies examining wetland loss are small, localized, old, and vary in scale. Although results find high variability of loss and degradation across the landscape and across time, evidence shows that wetland conversion was rapid from settlement through the early 1900s in many parts of southern Canada, largely as a result of conversion for agriculture.[7] In 1991, it was estimated that the total wetland loss for Canada since the 1800s was 200,000 km^2.[8]

Recent studies indicate that although there is an increase of wetlands in some areas, loss continues in many parts of Canada from land conversion, water level control, including flooding from hydroelectric development, and climate change.[9-13] In addition to direct loss, wetlands continue to be degraded, fragmented, and to suffer a loss of function due to hydrological alteration, development, pollution, invasive species, recreation, grazing, management of adjacent land, and climate change.[5]

John Brazner

Subdivision development, Nova Scotia

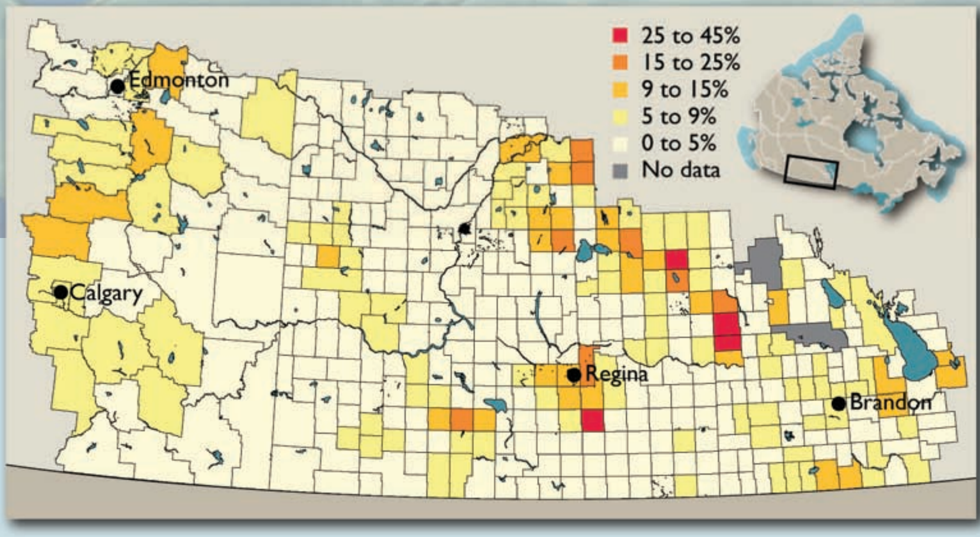
Wetlands near large urban centres are particularly at risk and have suffered severe losses. It has been estimated that less than 0.2% of Canada's wetlands fall within 40 km of urban centres,[14] and that 80 to 98% of wetlands in or adjacent to major urban centres have been lost.[8]

© Ducks Unlimited Canada

Prairie potholes

WETLAND LOSS IN THE PRAIRIES

Percent loss, 1985 to 2001



Source: Prairie Habitat Joint Venture, 2008[19] adapted from Watmough and Schmoll, 2007[12]

The millions of small wetlands of the Canadian and U.S. prairies are the most productive waterfowl habitat in the world, supporting 50 to 88% of the North American breeding populations of several species.[20-22] Availability and condition of wetlands are primary factors determining the number and diversity of these waterfowl. Although these factors are influenced greatly by climate variation,[22] land use change is also important.

As land was settled and converted to agriculture, extensive areas of wetlands were drained. No comprehensive data on historical loss exist, however analysis of localized studies in the Canadian Prairies shows high variability[12, 23-25] with loss estimates between settlement and the 1990s of 40 to 71%.[12, 24, 26, 27] Despite conservation efforts over the past several decades, wetland loss and degradation continue, largely as a result of intensification of agriculture.[25, 28] Between 1985 and 2001, 6% of wetland basins were lost, representing 5% of the total estimated wetland area. In addition, estimates of wetland area suffering a loss of function due to factors such as partial drainage were about 6% annually.[12] An analysis of agricultural impact and recovery of wetlands between 1985 and 2005 found the edges of wetlands were impacted more than wetland basins. Although the rate of impact for edges declined over the period, the rate of recovery was slower, indicating an increasing overall impact. The percent of edges impacted ranged between 82 and 97% in 1985, depending upon location, and stabilized in the early 1990s at between 90 and 95%.[28]

Up to 90% of prairie wetlands are estimated to be smaller than 1 ha.[12] Research indicates that, overall, smaller wetlands support a greater number of waterfowl than larger ones.[29] These small wetlands are also suffering the greatest losses. From 1985 to 2001, the average size of wetland basins lost was 0.2 ha, with 77% smaller than 2.6 ha.[12] Between 1985 and 2005, shallow seasonal wetlands in agricultural fields had the highest rate of impact and slowest recovery rates relative to other wetland types.[28]

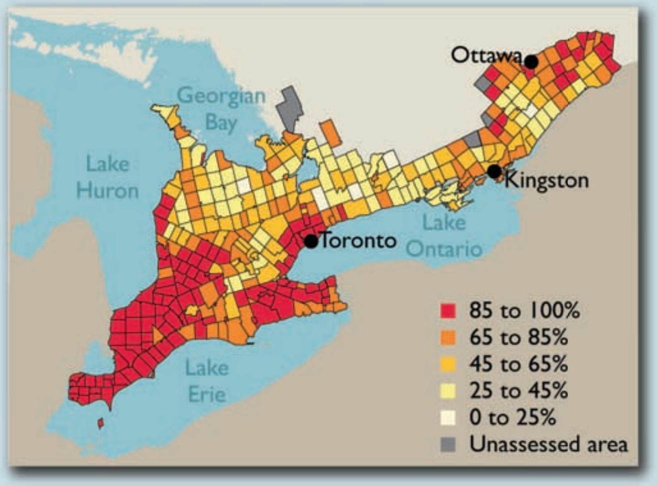
Global Trends

Wetlands currently cover between 5 to 10% of the Earth's land area.[15-17] It is estimated that more than half of the world's original wetlands have disappeared,[5, 15, 17, 18] and they are being lost and degraded more quickly than any other ecosystem type.[15, 17]

WETLANDS

WETLAND LOSS IN SOUTHERN ONTARIO

Percent loss by township, 1800 to 2002



Note: only wetlands larger than 10 ha are included.
Source: Ducks Unlimited Canada, 2010[11]

Prior to European settlement, southern Ontario had approximately 20,266 km^2 of wetlands. By 2002, 72% had been converted to other uses. This represents a decrease in the proportion of wetland cover on the landscape from 25 to 7%.[11] Historically, the highest concentrations of wetlands were found in southwestern and eastern Ontario. These areas are also where the most severe losses have occurred. For example, prior to settlement, 83% of Essex County, at the tip of southwestern Ontario, was wetland but by 2002 this was reduced to less than 2%.[11, 30] From 1967 to 1982, conversion of wetlands for agriculture accounted for 85% of the losses.[30] Urban development and associated transportation infrastructure were significant factors in the areas surrounding southeastern Lake Ontario.[11]

Most wetland conversion happened in the 19th and early 20th centuries (68% of wetlands were converted prior to 1967).[30] Nevertheless, despite wetland gains in some areas, overall net loss continues. While the estimated extent of wetlands larger than 10 ha remained relatively stable between 1967 and 1982, from 1982 to 2002 an additional 3.5% of pre-settlement wetlands were lost – an average of 3.5 km^2 per year. These estimates are conservative since Great Lakes coastal wetlands and wetlands smaller than 10 ha were not included in the analyses.[11]

WETLANDS OF THE GREAT LAKES

Covering over 700 km^2, wetlands along the shores of the Great Lakes, their connecting channels, and tributaries provide critical habitat for wildlife, including birds, mammals, fish, amphibians, reptiles, and a diversity of plants. They have suffered extensive loss and degradation over the past 200 years[30, 31] and many have been greatly affected by pollution.[32, 33] It is estimated that, by 1984, 35% of wetlands along the Canadian shores of lakes Erie, Ontario, and St. Clair had been lost,[34] with greatest losses, 73 to 100% by 1979, occurring between Toronto and the Niagara River.[35] Most conversion occurred from the late 19th to early 20th centuries when large wetlands were dredged for shipping and filled for industrial and urban development.[36] Loss and degradation continue due to shoreline alteration, water level control, nutrient and sediment loading, invasive non-native species, dredging, and industrial, agricultural, and residential development.[36-41] Upstream land practices also have an impact, particularly through run-off from agricultural lands and impervious surfaces.[42-44]

Recent surveys show that the health of wetlands is variable across the basin.[40] Water Quality Index scores, one method of monitoring wetland health, indicate that for Canada, the lower Great Lakes, especially the western end of lakes Ontario and Erie, which are most heavily impacted by urbanization and agriculture, suffer the most degradation. Comparatively few sites in Canada in Georgian Bay, Lake Huron, and Lake Superior are degraded.[45-48]

GREAT LAKES WATER QUALITY INDEX SCORES IN CANADA

Lakes Ontario and Erie and Georgian Bay, sampled 2006 to 2009
Lakes Superior and Huron, sampled 1998 to 2005

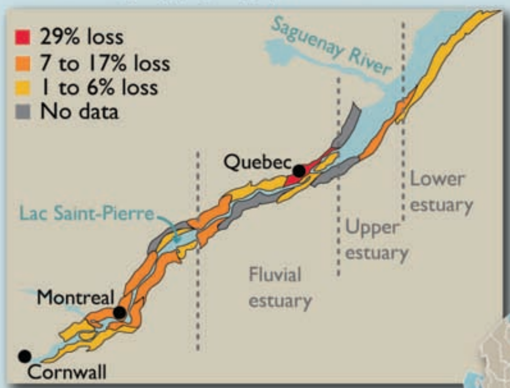
Source: updated from Chow-Fraser, 2006[45] *with 2008 unpublished data collected primarily in eastern Georgian Bay and the North Channel by the author, and with unpublished 2009 data collected in lakes Erie and Ontario by Canadian Wildlife Service, Environment Canada, Ontario Region*[48]

Caroline Savage, Environment Canada

St. Lawrence River wetland

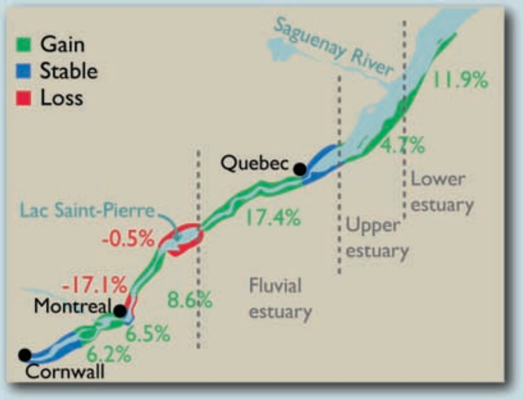
CHANGE IN EXTENT OF WETLANDS ALONG THE ST. LAWRENCE RIVER

Percent change by physiographic unit between 1945 and 1978



Source: adapted from Lehoux and Chamard, 2002[49]

Percent change between 1970-1978 and 2001-2002



Source: adapted from Jean and Létourneau, 2007[50]

Over 60 km^2 of riparian habitat along the St. Lawrence River was modified from 1945 to 1984.[51] Most changes occurred prior to the mid-1970s and were a result of draining and filling of open waters and wetlands for housing, roads, and agriculture. Losses near major urban centres were the greatest,[49, 51] for example, 83% of Montreal's wetlands were lost by 1976.[52] Construction of water control structures, including dams and the St. Lawrence Seaway (1954-1958), was also responsible for change in the late 1950s,[49] while urbanization was more important after that time.[52]

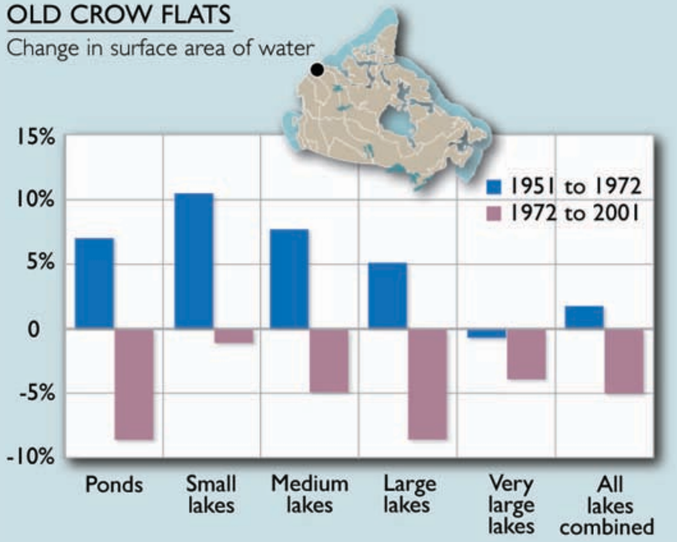
Since the 1970s, the overall extent of wetlands has increased, although there is variability depending upon the type and location of the wetland.[51] While wetland loss continues due to urbanization, particularly in the Montreal and Lac Saint-Pierre areas, restoration efforts and reduced water levels have resulted in a 2.7% net gain of marshes and swamps between 1990 and 2002.[51] Gains were mainly in the fluvial, upper, and lower estuaries and occurred mainly at the expense of open water. Declining water levels in the 1990s may have accelerated the drying trend in some areas,[51, 53] transforming low marshes to high marshes and swamps that are dominated by invasive plant species. Water levels are influenced by a number of factors, including water control structures, flow from the Great Lakes and the Ottawa River, and climate change, particularly in the estuary and Gulf of St. Lawrence.[49, 51]

Exotic wetland plants now comprise 14% of vascular plants in St. Lawrence River wetlands.[54] Their expansion can be attributed to shoreline alteration, excavation of the navigation channel, and water level regulation, which have reduced the magnitude of floods, decreased circulation in shallow littoral areas, and reduced the efficiency of the river to flush nutrients from sediments and to uproot robust emergent vegetation.[55]

WETLANDS

OLD CROW FLATS

Change in surface area of water



Source: adapted from Labrecque et al., 2009[56]

Designated as a wetland of international importance,[4] Old Crow Flats is a large, undeveloped complex (over 6,000 km^2) of more than 2,000 lakes and wetlands formed by thawed permafrost. It provides continentally significant habitat for up to half a million breeding and moulting waterbirds.[57, 58] The overall surface area of water decreased by 13 km^2 (3.5%) from 1951 to 2001, with greatest overall decreases found in large and very large lakes. Ponds increased in extent by 7% from 1951 to 1972, and decreased by 8.5% between 1972 and 2001. Changes are attributed to a mix of interacting processes with some lakes forming or expanding, and some suddenly draining due to collapse of permafrost – along with an overall drying trend due to increased evaporation from hotter summers in recent years.[56]

PEACE-ATHABASCA DELTA

The Peace-Athabasca Delta, covering over 5,000 km^2, is one of the largest inland freshwater deltas in the world. Made up of two large central lakes and over 1,000 small lakes and wetlands,[59] it is of international importance for waterbirds, bison, and fish.[4] The delta's dynamics are driven largely by short- and long-term fluctuations in water levels, including occasional spring floods caused by ice jams[60, 61] and summer open-water floods, with intervals of drying between flood events.[62] Studies have found recent ice-jam and flood frequency to be within the range of historical variability and intervals.[63-65] Nevertheless, although the delta has experienced several major ice-jam and open-water flooding episodes since the 1940s,[66] the most recent occurring in 1997,[60, 64] landscape analyses have found a significant overall drying trend from 1945 to 2001 in which wet communities declined in extent while dry communities increased.[63, 67]

Determining the cause of landscape change is difficult because the delta is constantly changing – driven by climate, hydrology, and deltaic processes, all of which are variable and influenced by natural and anthropogenic factors.[63, 65, 66] Influences over the past 45 years include:[60, 62, 66, 68-72]

- a warmer, drier climate;
- the prevention of a natural change in the course of the Athabasca River in 1972 and the natural occurrence of a channel breakthrough in 1982;
- flow regulation, including the construction of the Bennett Dam on the Peace River in 1968, and subsequent weirs on outflow channels built in 1975-76 in response to concerns about changes in connected lake levels;
- land use changes and development, including forestry, agriculture, and oil sands extraction;
- growing water uses; and
- cultural changes.

A projected reduction in ice-jam flood frequency over the next century due to climate change may result in further drying,[73] and additional upstream development may add additional stress to the delta's ecosystem.

Mamawi Creek, Peace-Athabasca Delta

Boreal peatlands

STATUS OF PEATLANDS

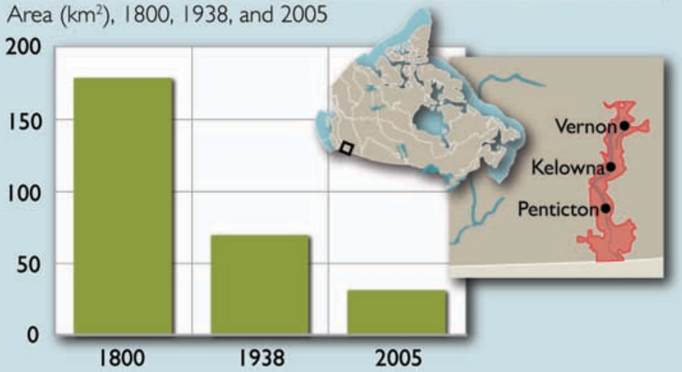
Canada has about 1.1 million km^2 of peatlands, which represents about 12% of its land area[74] and the majority of its total wetland area.[75] Ninety-seven percent occur in the boreal and subarctic regions.[74] In addition to their significance to biodiversity, Canadian peatlands, which are wetlands that have accumulated more than 40 cm of organic soil,[2, 76] are important globally as carbon stores.[77-79] Although it is estimated that 90% of Canada's peatlands remain intact in terms of total area,[13] comprehensive data do not exist. Some example estimates of peatland loss through direct human activity include:

- 9,000 km^2 flooded for hydroelectric development throughout Canada between 1960 and 2000;[13, 80]
- 250 km^2 drained for forestry in the Boreal Shield between 1980 and 2000;[80]
- 240 km^2 drained for horticultural peat across Canada by 2007, including a 56% increase in area under active extraction from 1990 to 2007;[81]
- 237 km^2 disturbed by oil sands mining in Alberta by mid-2009;[82]
- 110 km^2 converted to agriculture in Quebec prior to 2001.[83]

Approximately 60% of the peatlands in Canada, particularly those in Hudson/James Bay lowlands, Mackenzie River Basin, and parts of northern Alberta and Manitoba, lie within areas expected to be severely affected by climate change.[74, 84] Climate change is already affecting northern peatlands through permafrost thaw and other changes in hydrology. These impacts show rapid changes with lake expansion in some areas, shrinkage or disappearance in others,[85] including the replacement of forests in some areas by wet sedge meadows, bogs, and ponds and lakes[86] (see Ice Across Biomes). Climate change may also result in changes to the carbon balance of Canada's extensive peatlands.[74]

CHANGE IN EXTENT OF WETLANDS IN THE SOUTH OKANAGAN AND LOWER SIMILKAMEEN VALLEYS, B.C.

Area (km^2), 1800, 1938, and 2005



Source: adapted from Lea, 2008[87]

Wetlands occupy a small portion of the Western Interior Basin due to the region's climate, soil, and topographic features.[2, 88] Nevertheless, they play a crucial ecological role particularly because wetlands in arid areas support more species than other ecosystems.[88, 89] Wetlands of the southern interior of B.C. support many species at risk. Most wetlands in this area are located in valley bottoms where development is also concentrated and wetland loss has been extensive since European settlement mainly due to conversion for agriculture and more recently for urban development.[87, 90] Between 1800 and 2005, specific wetland communities suffered different degrees of loss, including, 92% of shrubby water birch/red-osier dogwood riparian wetlands, 63% of black cottonwood-red osier dogwood riparian wetlands, and 41% of cattail marshes from the south Okanagan and lower Similkameen valleys.[87] Wetlands continue to be lost and degraded by urbanization, intensive agriculture, and, in some areas, heavy recreational use.[87, 91, 92] In addition, invasive species and climate change pose serious threats.

LAKES AND RIVERS

KEY FINDING 4. Trends over the past 40 years influencing biodiversity in lakes and rivers include seasonal changes in magnitude of stream flows, increases in river and lake temperatures, decreases in lake levels, and habitat loss and fragmentation.

Status and Trends

river flows changing

good data for many rivers; short time lines for new stations, particularly in the North

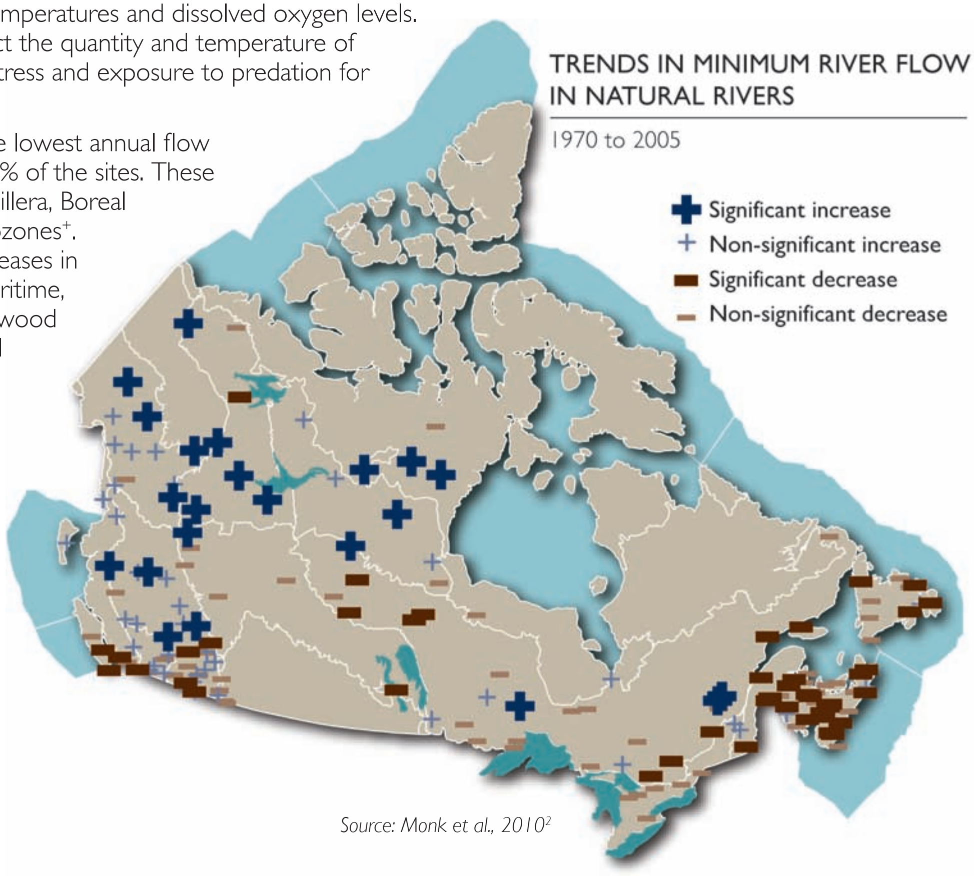
ecosystem consequences of climate change

Over 8,500 rivers and 2 million lakes cover almost 9% of Canada's total area.[1,2] The hydrology of these rivers and lakes influences the structure of aquatic habitats and the composition of ecological communities, including plankton, plants, benthic macroinvertebrates, and vertebrates such as fish, amphibians, reptiles, and birds.[2] In North America, species living in aquatic ecosystems have a higher risk of extinction than species living in other ecosystems.[3]

Status and trends of seasonal flows

Most rivers in Canada show pronounced seasonal variation in flows. Minimum annual flow occurs in late summer when precipitation is low and evaporation is high, and in late winter when precipitation is frozen in ice and snow. Minimum flows can limit the availability of specific aquatic habitats and also influence water temperatures and dissolved oxygen levels. For example, a decrease in minimum flow can affect the quantity and temperature of water for late-spawning fish and increase thermal stress and exposure to predation for all fish.

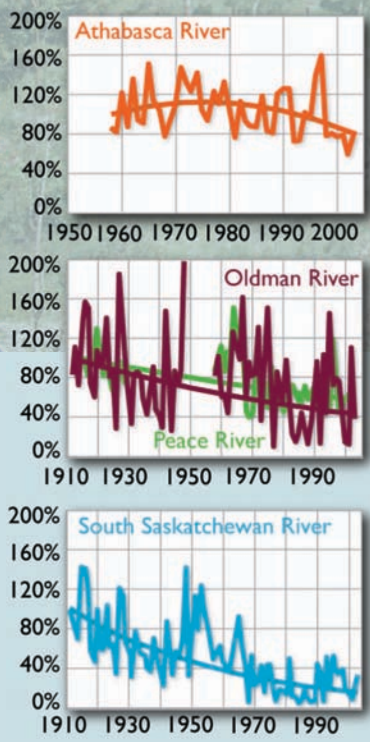
In a study of 172 sites in naturally flowing rivers, the lowest annual flow significantly increased between 1970 to 2005 at 13% of the sites. These sites were generally in the northern Montane Cordillera, Boreal Cordillera, Taiga Plains, Taiga Shield, and Arctic ecozones+. Twenty-six percent of the sites had significant decreases in minimum flow, generally in the southern Pacific Maritime, southern Montane Cordillera, Boreal Shield, Mixedwood Plains, Atlantic Maritime, and Newfoundland Boreal ecozones+. Sixteen percent of the sites, mostly in eastern Canada, Great Lakes, and the North, had later minimum flows, while 8%, mostly in the South and along the western coast, had earlier minimum flows.[2]



Source: Monk et al., 2010[2]

SUMMER FLOW OF FOUR RIVERS IN THE PRAIRIE PROVINCES

Percent of flow at start of timeline



Source: adapted from Schindler and Donahue, 2006[4]

The average flow of prairie rivers has been declining over the past 50 to 100 years, including:

- 20% reduction from 1958 to 2003 – 33% since 1970 – for the Athabasca River at Fort McMurray, Alberta;
- 42% reduction from 1915 to 2003 for the Peace River, near the town of Peace River, Alberta;
- 57% reduction from 1912 to 2003 for the Oldman River at Lethbridge, Alberta;
- 84% reduction from 1912 to 2003 for the South Saskatchewan River at Saskatoon, Saskatchewan.[4]

Reduced flows like these can impact biodiversity in many ways, including reducing habitat availability, not meeting the minimum flow requirements for aquatic species, and increasing summer temperatures.[5]

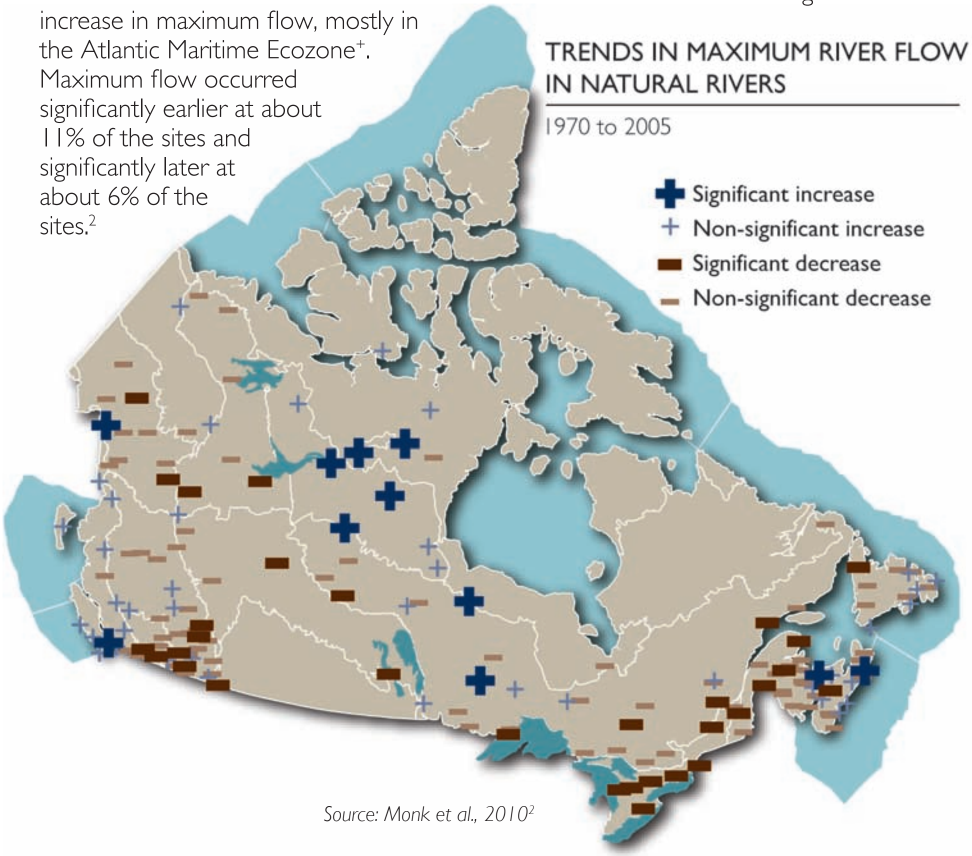
Oldman River, Alberta

Maximum annual flow, or spring freshet, generally occurs in late spring and in early summer and is driven by snow melt and seasonal rainstorms. A change in maximum flow can affect species with life cycles synchronized to the spring freshet and the rich foods provided by flood plains.

Seventeen percent of the sites showed a significant decrease in maximum flow. These sites were distributed across almost all ecozones+. About 6% showed a significant increase in maximum flow, mostly in the Atlantic Maritime Ecozone+. Maximum flow occurred significantly earlier at about 11% of the sites and significantly later at about 6% of the sites.[2]

TRENDS IN MAXIMUM RIVER FLOW IN NATURAL RIVERS

1970 to 2005

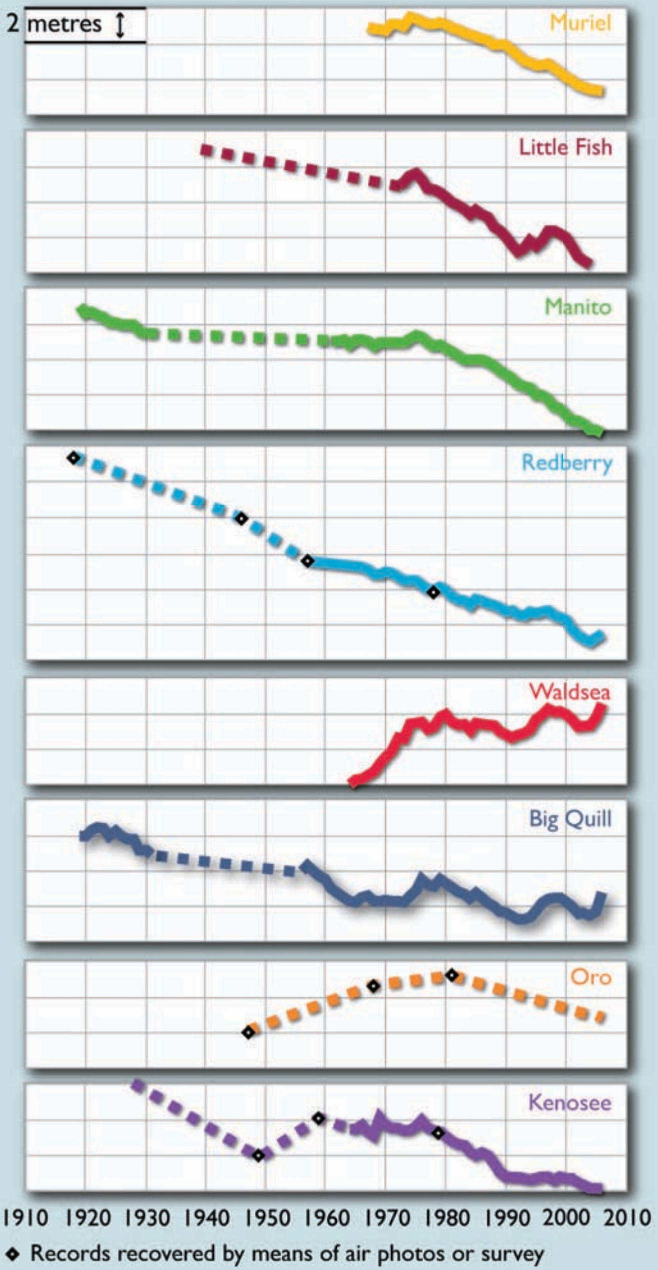


Source: Monk et al., 2010[2]

LAKES AND RIVERS

WATER LEVELS IN PRAIRIE CLOSED-BASIN LAKES

1910 to 2006

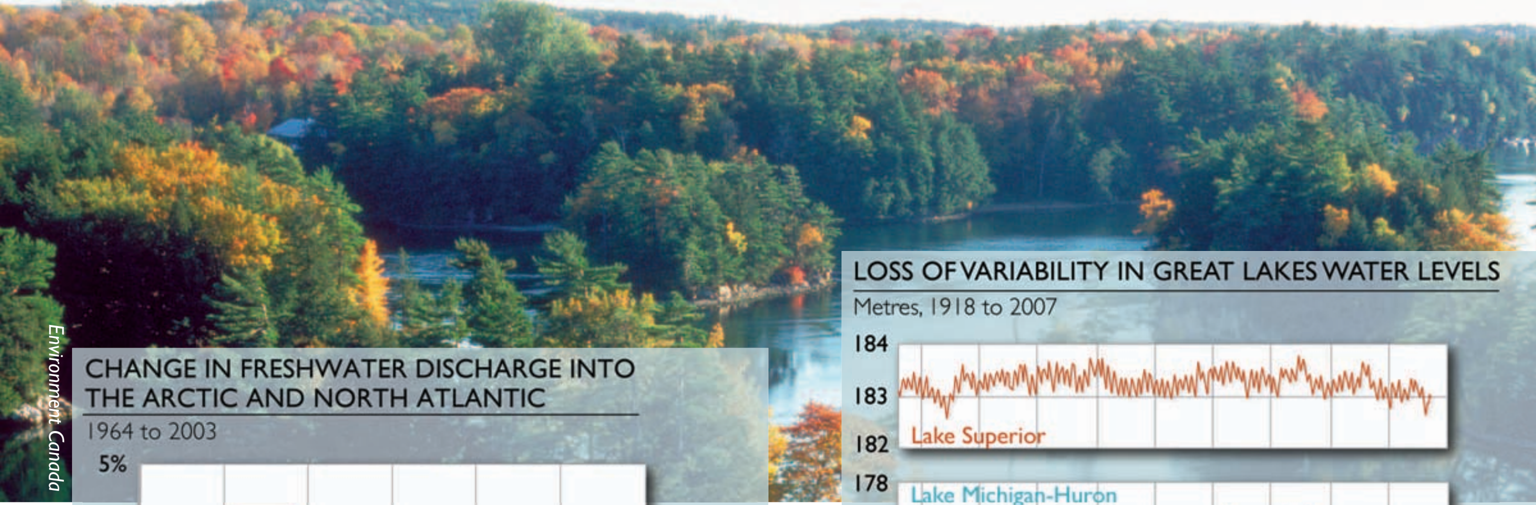


Source: adapted from van der Kamp et al., 2008[6]

In the Prairies, a combination of glaciation and dry climate has resulted in numerous closed-basin saline lakes, that drain internally, rarely spilling runoff. These lakes are sensitive to climate, with water levels and salinity driven by precipitation on the lake, local runoff to the lake, and evaporation off the lake.[6] Aquatic communities within these closed-basin lakes are sensitive to chemical changes that can be a result of changes in water levels. For example, water levels affect salinity and the diversity of aquatic species declines as salinity increases. When salinities reach extremely high values, species diversity becomes very low.[7]

From 1910 to 2006, water levels in 16 representative closed-basin lakes showed an overall pattern of decline by 4 to 10 metres.[6] Declines can be explained in part by climate,[6] including increases in spring temperatures, for example from 1950 to 2007,[8] potentially resulting in increased evaporation rates and declining stream runoff[9] to the lakes. However, climate variables alone cannot explain the declines, for example no significant change was evident in precipitation or in an index of drought severity, from 1950 to 2007.[8] Other contributing factors that reduce surface runoff to the lakes include land use changes, such as dams, ditches, wetland drainage, and dugouts, and changes in agricultural use and practices,[6] such as the decline in summer fallow,[10] increase in conservation till, and continuous cropping.[6]

An example of closed-basin lakes in southern Saskatchewan



Environment Canada

CHANGE IN FRESHWATER DISCHARGE INTO THE ARCTIC AND NORTH ATLANTIC

1964 to 2003

Note: Red triangles indicate a decrease in flow; green triangles indicate an increase in flow. The size of the triangle indicates the magnitude of change. Source: adapted from Déry and Wood, 2005[11]

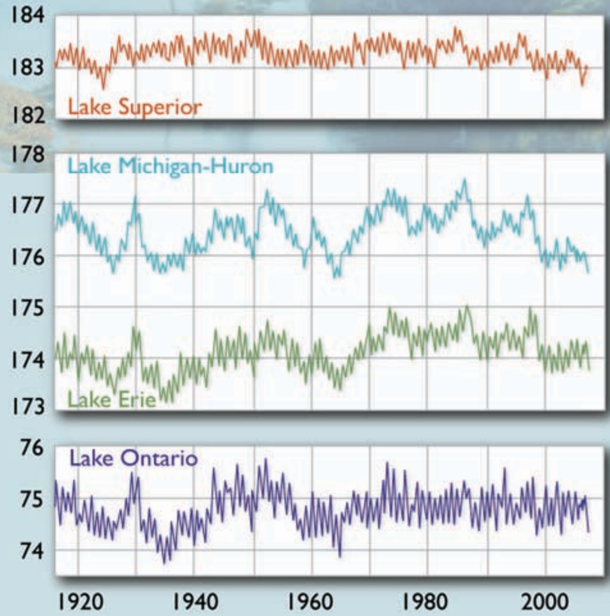
Freshwater discharge from Canadian rivers into the Arctic and North Atlantic Oceans has decreased by about 10% over the past 40 years. This has been attributed to a decrease in precipitation over the same period.[11, 12] In spite of this, an overall 5.3% increase in river discharge to the Arctic Ocean has been documented. The net increase is due to significant increases in annual discharge from the six largest Eurasian rivers.[13, 14] Freshwater discharge to northern seas can influence ocean processes that, in turn, influence the population dynamics of marine species.

Global Trends

More than 99% of the world's freshwater is frozen in glaciers, permafrost or permanent snow, or locked in underground aquifers.[15] The remaining accessible freshwater is not distributed evenly, with 40% of the world's population projected to live in water-scarce regions by 2020.[16]

LOSS OF VARIABILITY IN GREAT LAKES WATER LEVELS

Metres, 1918 to 2007



Note: Metres are in relation to the International Great Lakes Datum (IGLD), 1985, which is a lake reference level adjusted every 25 to 30 years to account for movement of the Earth's crust.
Source: adapted from Environment Canada and U.S. Environmental Protection Agency, 2009[17]

Diverse and varied plant communities inhabiting Great Lakes wetlands are dependent on the high seasonal and year-to-year variability in water levels found naturally,[18] in, for example lakes Huron and Michigan, which are unregulated. Natural water levels are affected by precipitation, evaporation from the lake surface, inflow from upstream, and outflow to the downstream lakes.

Water levels are also affected by direct regulation as well as dredging, control structures, dams, canals, and diversions.[19] The regulation of water levels in Lake Superior since 1914 and in Lake Ontario since about 1960 has reduced the variability of water levels. In Lake Ontario, this has adversely affected coastal wetland ecosystems, reduced plant species diversity, and altered habitat values for many animals that depend wholly or partly on wetlands to thrive.[18, 20] As water shortages become more common in the southern U.S., there may be pressure for water diversions from the Great Lakes, which could, if allowed, result in further impacts on biodiversity.

COASTAL

KEY FINDING 5. Coastal ecosystems, such as estuaries, salt marshes, and mud flats, are believed to be healthy in less-developed coastal areas, although there are exceptions. In developed areas, extent and quality of coastal ecosystems are declining as a result of habitat modification, erosion, and sea-level rise.

Status and Trends

most less developed coasts: healthy but under pressure	⇩ (green)
developed coasts: continuing habitat loss and modification	⇩ (red)
good data for some regions only	(layers)

Coastal ecosystems occur at the interface between land and sea. They include intertidal zones, estuaries, salt marshes, mud flats, seagrass meadows, beaches, cliffs, banks, and dunes. Bounded by three oceans, Canada has the longest marine coastline in the world, with 29% of the world's total coastline.[1] **Coastal ecosystems are important** as they are particularly productive environments. Canadian coastal ecosystems support a diversity of marine and terrestrial species, including members of all major groups of marine organisms, approximately 1,100 species of fish, and numerous marine mammals, birds, plants, and invertebrates.[2]

Developed coastlines In Canada, as elsewhere in the world, increasing human population and development of coastal regions is resulting in ongoing loss and degradation of coastal ecosystems. Infrastructure, industry, commercial activity, and settlements near the coast have depleted and altered natural systems and made coastlines more sensitive to erosion. Wetlands, including salt marshes and estuarine habitat, were severely depleted during early development of the populated areas of Canada's east and west coasts. Further losses will occur as sea levels rise, especially where development now leaves only a narrow margin of habitat. Inventories are available of extent and sensitivity of some coastal ecosystems,[3-5] but information on past and current rates of loss and alteration is sparse.

Less developed coastlines Sea-level rise and changes in sea ice are examples of emerging stressors that are altering ecosystems in coastal areas that are not greatly affected by development. For example, along the southwestern, western, and eastern coasts of Newfoundland, the combination of rising sea level and changing offshore winter ice conditions, along with increased human use of the coast for residences and tourism, has resulted in widespread acceleration of erosion and degradation of dunes and coastline.[6-9] In Quebec, from the upper estuary to the Gulf of St. Lawrence, rates of coastal erosion measured from 1990 to 2004 were higher than those measured before 1990. This was likely influenced by changes in climate-related processes such as ice scouring and wave action.[10] Erosion in sensitive areas of the Beaufort Sea coastline may also increase because of reduction in sea ice, melting ground ice, and increase in storms[11] as is currently happening along the coast of the Alaskan Beaufort Sea.[12]

Protected coastal wetlands at Lord Selkirk Provincial Park, P.E.I.

It is estimated that up to 65% of Atlantic coastal marshes have been lost since the 1700s as a result of dyking and drainage for agriculture and settlement, and more recently for industrial and recreational development as well.[15, 16]

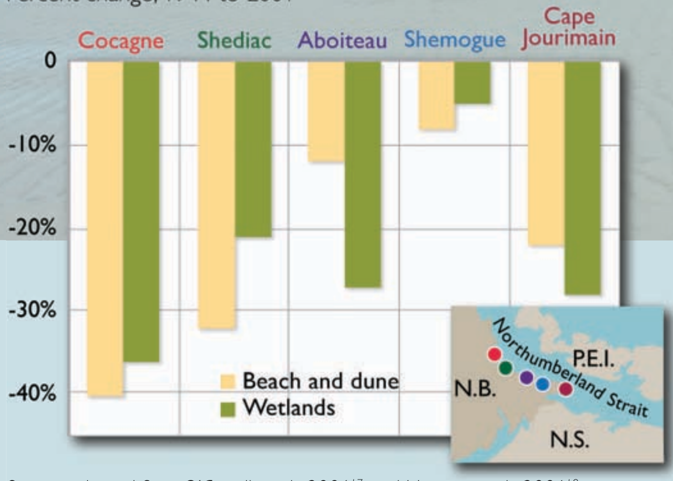
Global Trends

About 20% of the world's land area is coastal. An estimated 19% of land within 100 km of the coast (excluding Antarctica) has been converted for agriculture and urbanization. Important coastal habitats, including mangroves, wetlands, seagrasses, and coral reefs, are disappearing rapidly.[13, 14]

iStock.com

DECLINE IN WETLANDS AND BEACH AND DUNE HABITAT, ATLANTIC COAST

Percent change, 1944 to 2001

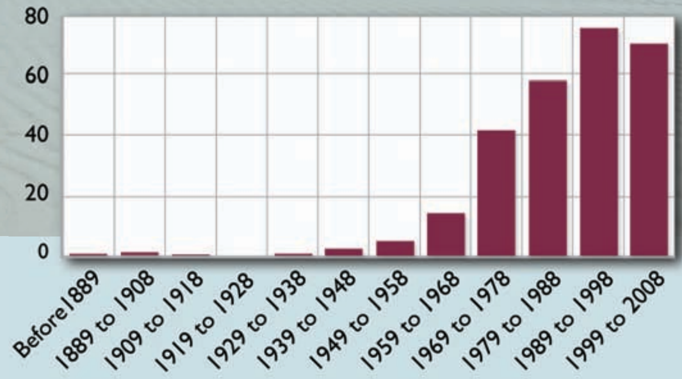


Source: adapted from O'Carroll et al., 2006[17] and Hanson et al., 2006[18]

Coastal wetlands and beach and dune habitats declined at five sites in southeastern New Brunswick between 1944 and 2001. Total losses at each site ranged from 7 to 18 ha for beaches and dunes, and from 30 to 55 ha for wetlands. Erosion, removal of sand for aggregate production, and increased hardening of the foreshore for development have contributed to these losses. Beaches and dunes provide important habitat for species such as the endangered Atlantic population of piping plovers, which decreased by 17% from 1991 to 2006, partly due to habitat loss and degradation from accelerating coastal development.[19-21]

INCREASE IN DEVELOPMENT ALONG ATLANTIC COASTS

Number of lot registrations (thousands), within 2 km of the Nova Scotia coastline



Source: adapted from CBCL Limited, 2009[3], data from N.S. Property Online Database

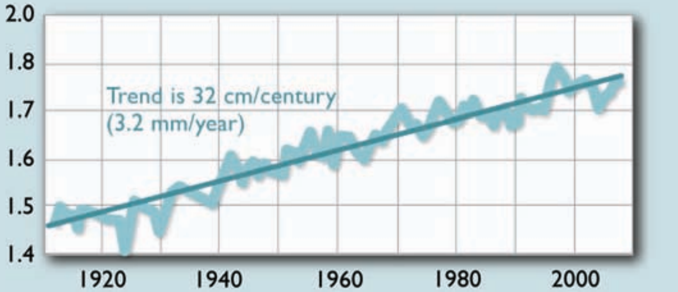
Coastal development, including converting natural ecosystems to built-up areas, often increases sensitivity to erosion, impairs coastal water quality, and alters wildlife habitat. In Nova Scotia, although increased urbanization has led to population declines in many rural areas, human population along the coast has increased.[3] In the more densely populated areas of Newfoundland, where human activity has been modifying the shoreline for more than 100 years,[22] many types of activities contribute to increasing rates of erosion.[9] For example, compaction of beach sediment by all-terrain vehicles leads to incoming waves washing further landward, increasing erosion above the mean high-tide line.[23]

SEA-LEVEL RISE, STORMS, AND COASTAL EROSION

Sea-level rise and associated storm impacts are likely to increase erosion along the Atlantic coast.[3, 17, 24, 25] Water level relative to land in six Atlantic harbours is currently rising at rates from 22 to 32 cm per century, over half of which is due to land subsidence.[3] (The land in this region is still affected by changing ice and water loads following glacier retreat.) The remainder of the increase, about 12 cm per century at Charlottetown, is a signal of global and regional sea-level rise. This rate is anticipated to increase due to climate change.[4, 26] Canada's Atlantic coast is particularly sensitive to ecological damage from sea-level rise because there are many low-lying areas with salt marshes, barrier beaches, and lagoons.[27] Impacts from sea-level rise are compounded by the effects of storm surges, which are increasing in number and intensity because of increases in tropical storms.[9, 28-31]

INCREASE IN WATER LEVEL IN CHARLOTTETOWN HARBOUR

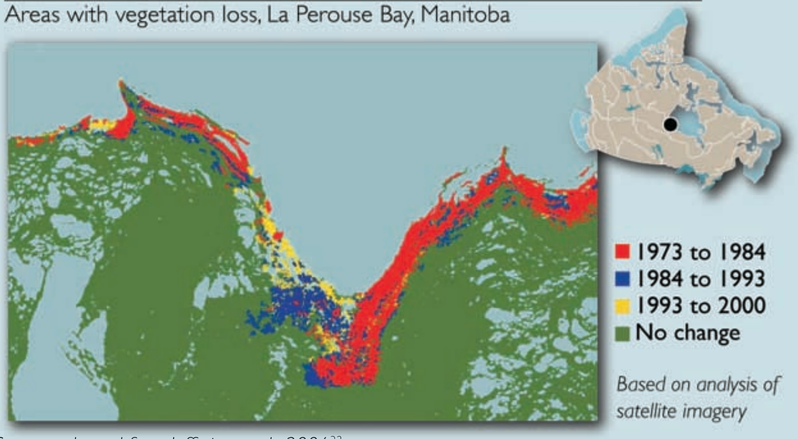
Metres above reference level on land, 1911 to 2008



Source: adapted from Marine Environmental Data Service, 2008 in CBCAL Limited, 2009[3]

LOSS OF SALT MARSH VEGETATION FROM SNOW GOOSE FORAGING, HUDSON PLAINS

Areas with vegetation loss, La Perouse Bay, Manitoba



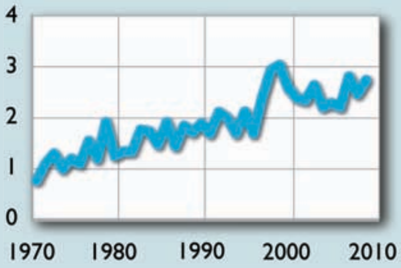
Source: adapted from Jefferies et al., 2006[32]

The salt marshes of the Hudson Plains are an exception to the general finding that coastal habitats in less-developed areas are healthy. These coastal marshes are under stress from the increasing population of mid-continent lesser snow geese. The goose population increase is mainly due to human influences outside of the region, including increased supply of agricultural food on wintering grounds in the United States and along migration routes, along with declining harvest and the development of refuges.[33, 34]

Intensive foraging by snow geese has led to vegetation loss, shifts in plant community composition, and exposure and sometimes erosion of sediment.[32, 34, 35] This results in large areas of exposed sediment that are resistant to re-colonization because few plants can germinate or establish themselves in the saline sediments. Approximately one third of the coastal salt marsh vegetation in the Hudson Plains Ecozone+ has been destroyed by geese and a far greater area will be severely damaged if this intense foraging pressure continues.[36]

MID-CONTINENT LESSER SNOW GOOSE POPULATION

Millions, 1970 to 2008



Source: adapted from Canadian Wildlife Service Waterfowl Committee, 2009[37]

LOSS OF INTERTIDAL WETLANDS IN SOUTHWESTERN BRITISH COLUMBIA

Loss of intertidal wetlands to urban, agricultural, and industrial development was greatest at the turn of the 20th century, but continues today due to the pressures of human population growth.[38, 39] About 76% of B.C.'s population lives in coastal communities, mainly in the Lower Mainland and southeastern Vancouver Island.[40] The population of coastal B.C. is projected to increase by almost one million people by 2025.[5]

Total loss of intertidal wetlands, mainly through dyking for agriculture in the early part of the 20th century, is estimated at 70% for the Fraser River estuary and 32% for major estuaries along the east coast of Vancouver Island.[39]

There are over 440 estuaries in the Pacific Maritime Ecozone+, most with fairly small intertidal zones of 1 to 10 ha.[41] The largest estuary is that of the Fraser River, with about 21,000 ha of intertidal wetlands remaining. Although estuaries occupy less than 3% of the coast,[41] an estimated 80% of coastal wildlife, including birds, fish, mammals, and invertebrates, use estuarine habitat at some point in their life cycle.[5] Estuaries are also important to surrounding land and water ecosystems because of their role in water filtration and nutrient cycling.[41]

Western sandpipers, Boundary Bay, B.C.

Boundary Bay is part of the Fraser River estuary. The extensive (5,000 ha)[42] *mud flats support the largest known migrant populations of western sandpipers and the largest Canadian winter populations of dunlins, black-bellied plovers, and great blue herons.*[43]

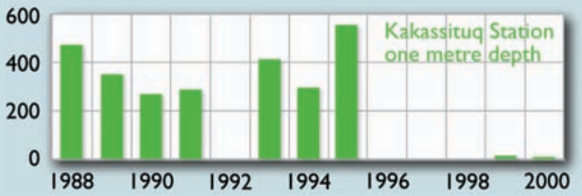
Pacific On the Pacific coast, where eelgrass beds are spawning grounds for herring and rearing habitat for salmon, some declines may be due to the Pacific oyster, which was introduced for oyster farming and has spread into the wild. Oysters alter habitat physically and may also cause sulphide to accumulate in sediments – the net result is that eelgrass is typically absent seaward of oyster beds.[51, 52] Other declines are related to development of coastal areas, for example for log storage and harbours.[41] A non-native dwarf species of eelgrass that thrives higher up in the intertidal zone than does native eelgrass has taken hold in some areas of southern B.C., with mixed ecological consequences. Colonization of mudflats by dwarf eelgrass meadows on Roberts Bank in the Fraser river estuary[53-55] has displaced migratory shorebirds that graze on the thin film of organic matter covering the mud.[55]

James Bay Eelgrass beds along the east coast of James Bay were among the most extensive in North America, covering 250 km^2 prior to their rapid decline around 1998.[56] Since the decline, eelgrass has shown signs of recovery,[57] but neither the cause of the decline nor the present status are well understood.[48] Alternative explanations for the decline in James Bay have been put forward, such as:

- an outbreak of eelgrass wasting disease triggered by a year with unusually high summer and winter temperatures, along with changes to habitat from coastal uplift and climate change;[57]
- impaired growth and survival due to reduced salinity of water in James Bay resulting from larger and more frequent discharges of fresh water via the La Grande River, due to diversions.[50]

DECLINE OF EELGRASS IN JAMES BAY

Dry leaf biomass (g/m^2)



Note: samples were taken at several depths at six sites – this figure shows results typical at all depths for five of the six sites. The sixth site showed no change. No data for 1992 and 1996-1997.

Source: adapted from Hydro-Quebec and GENIVAR Group Conseil Inc., 2005[57]

Eelgrass meadows: A coastal ecosystem at risk

Eelgrass meadows are among the most productive ecosystems in the world,[44] and among the most threatened.[45] They are declining globally, with mixed and often uncertain status along Canadian coasts. Seagrass meadows, which include eelgrass, have declined at an average rate of 7% per year around the world since 1990, an acceleration from an annual decline of less than 1% prior to 1940.[46] Declines are most often associated with stressors, such as eutrophication and increased turbidity of coastal waters, mainly related to the growth of coastal human populations. The global analysis on which these rates of decline are based[45] does not include Canada due to lack of adequate trend data.

Major regional declines have occurred in the past. In the early 1930s, thousands of hectares of eelgrass disappeared in eastern North America,[46] attributed to eelgrass wasting disease, although climatic conditions may also have played a role.[47]

Eelgrass, a flowering marine plant that forms extensive subtidal beds in sand and mud along coastlines, traps particulate matter and plankton and provides habitat for invertebrates, fish, and marine mammals. Eelgrass is an important food for migrating and wintering waterfowl, and provides foraging areas for other birds.[48-50]

Atlantic Coast and Gulf of St. Lawrence Compiling results from a number of mainly short-term studies provides a picture of a general decline in eelgrass and some abrupt die-offs, along with some areas with stable to increasing trends.[44, 49] One factor in declines on the Atlantic coast is the spread of the invasive green crab, which can uproot eelgrass plants.[53] Some study results:

LOCATION	YEARS	EELGRASS TRENDS
Lobster Bay, N.S.	1978 to 2000	estimated losses of 30% and 44% in two areas[58]
4 Nova Scotia inlets	1992 to 2002	loss of 80% of total intertidal area occupied by eelgrass[59]
13 southern Gulf of St. Lawrence estuaries	2001 to 2002	biomass decline of 40%[60]
Antigonish Harbour, N.S.	2000 to 2001	biomass decline of 95% followed by 50% decline in geese and ducks that feed on the eelgrass[61]
Newfoundland	past decade	increase in abundance, based on local knowledge, possibly due to milder temperatures and changes in sea ice[44]
Gulf of St. Lawrence in Quebec	various	Manicouagan Peninsula distribution expanded (1986 to 2004); generally also expanding or stable in other areas[62]

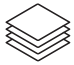
MARINE

KEY FINDING 6. Observed changes in marine biodiversity over the past 50 years have been driven by a combination of physical factors and human activities, such as oceanographic and climate variability, and overexploitation. While certain marine mammals have recovered from past overharvesting, many commercial fisheries have not.

Status and Trends

recovery of some marine mammals 

fish not recovering 

Good data, particularly for harvested species and mammals 

ecosystem consequences of climate change on ocean conditions and acidification 

The global marine ecosystem covers over 70% of the Earth's surface. It is a complex system, in constant motion, moving not only nutrients, dissolved oxygen, carbon, and water masses, but also bacteria, algae, plants, and animals, among regions. The millions of species estimated to live in the ocean dwell in a wide range of habitats, including the open ocean, sea floor, sea ice ridges, hydrothermal vents, cold seeps, coral and sponge communities, seamounts, ocean trenches, and continental shelves.[1]

Marine biodiversity is the foundation of the countless ecosystem services provided by the oceans. Marine plankton plays a major role in the global carbon cycle, and harvest of marine species provides an estimated $21 trillion per year in socioeconomic benefits to the world.[2] Marine biodiversity is essential for the functioning of marine ecosystems, their ability to persist under stress, their ability to recover from disturbances, and their ability to provide benefits to people.[3] With jurisdiction over 6.5 million km^2 of marine waters in three oceans,[4] Canada reaps immense benefits from the ocean.

Changes in the physical environment of marine ecosystems

Sea temperature, salinity, wind patterns, and ocean circulation have significant impacts on marine biodiversity. For example, zooplankton community composition and several fish trends are correlated with large-scale climate signals in the Pacific Ocean, including the El Niño Southern Oscillation and the Pacific Decadal Oscillation.[5]

Mean sea surface temperature has increased:[5]

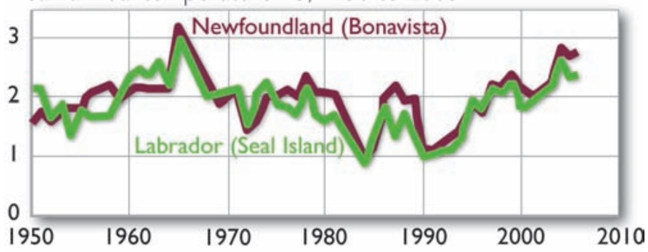
- from 1978 to 2006 in the North Coast and Hecate Strait and West Coast Vancouver Island, following a period of colder surface water in the previous 25 years, although 2007 and 2008 were cooler than average;[6]
- since the 1970s in the Beaufort Sea;
- since the late 1970s in the Canadian Arctic Archipelago and in the Hudson Bay, James Bay, and Foxe Basin;
- since the early 1990s in the Newfoundland and Labrador Shelves;
- since the 1980s in the Estuary and Gulf of St. Lawrence.

The ocean has become fresher (less saline)[5] in several ecozones[+]:

- since 1978 in the North Coast and Hecate Strait, following a 30-year period of high salinity;
- since the 1970s in the Beaufort Sea, as a result of melting sea ice, input from the Pacific Ocean, and surface water from the Arctic Ocean.

SEA TEMPERATURE, NEWFOUNDLAND AND LABRADOR SHELVES

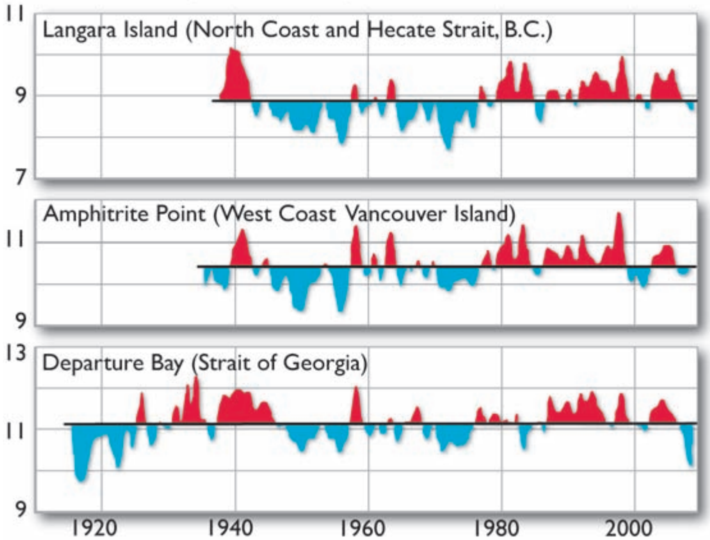
Mean annual temperature °C, 1950 to 2005



Source: adapted from Fisheries and Oceans Canada (DFO), 2007[7]

SEA TEMPERATURE, PACIFIC COAST

Mean annual temperature °C, up to 2006



Note: the horizontal line represents the average temperature for the reference period, 1961 to 1991.

Source: adapted from Fisheries and Oceans Canada (DFO), 2010[5]

Tidepool, Tofino, B.C.

OCEAN ACIDIFICATION

When carbon dioxide dissolves in the ocean, it lowers the pH, making the ocean more acidic.[8] Since pre-industrial times, the oceans have become more acidic by a pH of approximately 0.1. This seems like a small amount – but the biological effects of small changes in ocean acidity can be severe. For example, a pH change of 0.45 from pre-industrial times, which is predicted by the end of this century, could have dire consequences for marine organisms that build a calcium carbonate skeleton or shell, such as corals, molluscs (oysters, mussels, scallops), crustaceans (crabs, shrimp), echinoderms (starfish), and many species of plankton.[9] Impacts are expected to occur first in the polar regions.[10]

Ocean acidification is already occurring in four marine ecozones+: West Coast Vancouver Island, Beaufort Sea, Estuary and Gulf of St. Lawrence, and Gulf of Maine and Scotian Shelf. It is predicted to occur in all oceans and to have severe consequences for biodiversity as early as the end of this century.[5]

OXYGEN DEPLETION IN MARINE WATERS

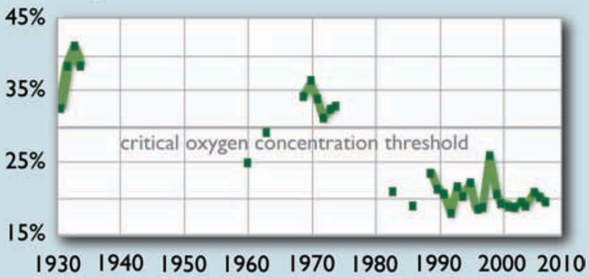
Critically low oxygen concentrations have been observed at some sampling points in the Estuary and Gulf of St. Lawrence and the three ecozones+ in the Pacific. In the St. Lawrence Estuary, low oxygen conditions have been observed since 1984.[5]

Declines in oxygen concentration are caused by a number of factors, including changes in ocean circulation patterns, freshwater inputs, rising temperatures, and increases in organic matter on the sea floor. The latter may be caused by increases in primary production on the surface and by human activities.[11]

Observed effects of low oxygen content on biodiversity in Canadian waters include declines and mortality of bottom-dwelling animals and altered food webs.[5] Some impacts observed globally include fish and crab kills,[12] more prevalent jellyfish blooms,[13] changes in marine biochemical pathways that favour some species over others,[11] creation of dispersal barriers for larval fish and crustaceans that are less tolerant of low oxygen than adults,[11] and altered food webs.[11]

DISSOLVED OXYGEN IN THE ST. LAWRENCE ESTUARY

Percentage, 1930 to 2008



Source: adapted from Dufour et al., 2010[14]

Global Trends

Low-oxygen zones where ocean species cannot live have increased globally by close to 5.2 million km² since the 1960s.[11]

MARINE

Marine food webs

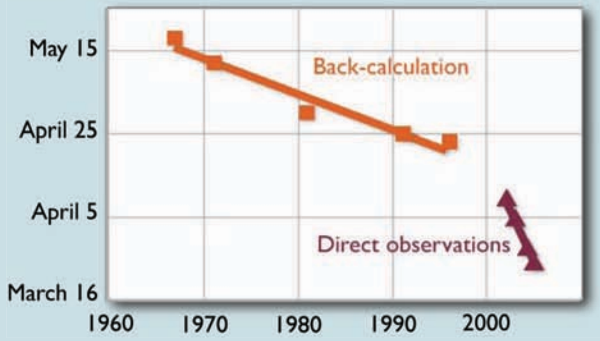
Plankton are passively drifting plants and animals that move on ocean currents. Some species can reach very high densities (up to 20 million cells per litre), over very large areas (thousands of square kilometres), and their "blooms" can be captured by satellite. Planktonic plants, bacteria, and algae (phytoplankton) are the foundation of the marine food web. Planktonic animals (zooplankton) provide a key link between the phytoplankton, that they eat, and the fish, seabirds, and other marine species that eat them.[2]

Global Trends

Over the past 50 years there has been a decline in size, a change in species composition, and earlier onset of phytoplankton blooms worldwide.[2]

SEASONAL CHANGE IN ZOOPLANKTON BLOOM, STRAIT OF GEORGIA

Date of peak bloom



Source: adapted from Fisheries and Oceans Canada (DFO), 2010[5]

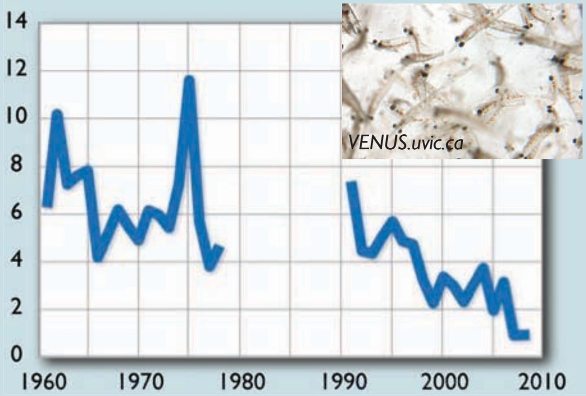
Saanich Inlet herring, predator of zooplankton

The timing and duration of the peak zooplankton bloom has changed over the past 40 years in all Pacific and Atlantic marine ecozones+. For example, the peak abundance of *Neocalanus*, the dominant zooplankton species in the Strait of Georgia, occurs approximately 50 days early in the 2000s compared to the 1960s to 1970s. This has created a mismatch in timing between small fish and their zooplankton prey. Juvenile salmon that enter the Strait early in the season, such as chum, pink, and sockeye, have benefitted, while species that arrive later in the season, such as chinook and coho, have declined.[15] *Neocalanus* has also declined sharply since 2001 and the decline in abundance may be accelerating and affecting species that depend on it for food.[15]

Spring phytoplankton blooms start earlier, are more intense, and last longer on the Scotian Shelf than they did in the 1960s and 1970s.[16]

DECLINE IN KRILL IN THE WESTERN NORTH ATLANTIC AND SCOTIAN SHELF

Mean number of krill (log (x+1)) per 3 m³ of filtered seawater, 1961 to 2008

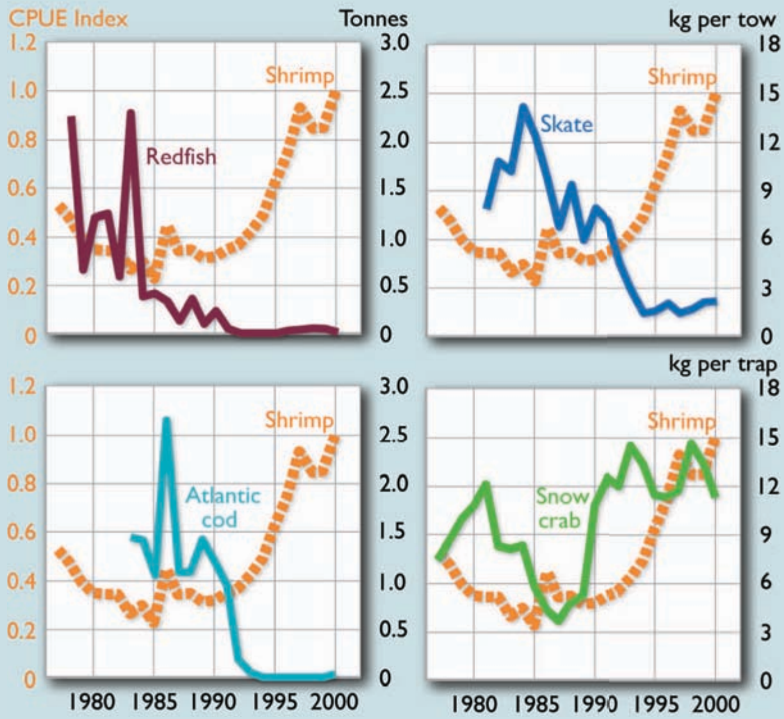


Note: no data are available for 1979 to 1990.
Source: adapted from Johns, 2010[17]

Several zooplankton species that are considered to have a key role in the marine food web are declining. *Euphausiids*, or krill, in the western North Atlantic and Scotian Shelf, feed on phytoplankton in their youngest stages and are preyed upon by juvenile groundfish, pelagic fish, and baleen whales. Their abundance has declined between the 1960s to 1970s and the 1990s to 2008.[18]

POPULATION TRENDS FOR NORTHERN SHRIMP AND FOUR OF THEIR PREDATORS

Population measures specific to each species, 1976 to 2000

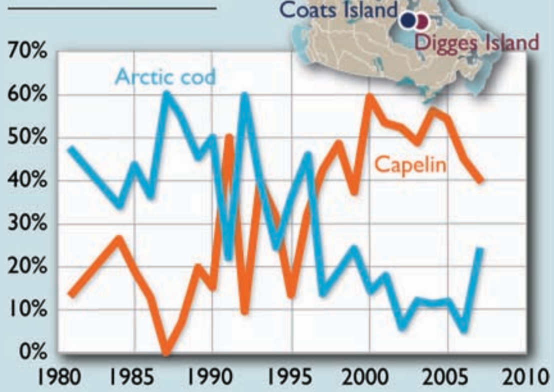


Note: Measures are: catch per unit effort (CPUE) for shrimp, millions tonnes for cod and redfish, kilograms per tow for skate and snow crab.
Source: adapted from Fisheries and Oceans Canada (DFO), 2010[5]

In the Newfoundland and Labrador Shelves Ecozone+, in the 1990s, a decrease in groundfish abundance was accompanied by a dramatic increase in invertebrates such as shrimp and crab. A combination of several factors has potentially led to these changes in the marine food web, including overfishing of groundfish, change in water temperatures, and decreased predation on the invertebrates. In response, the commercial fishery has shifted from groundfish to species lower on the food web, such as shrimp, snow crabs, and, more recently, sea cucumber, whelk, and hagfish. The shift from a higher to a lower trophic level fishery is a worldwide phenomenon often referred to as "fishing down the food chain".[5]

An equivalent shift in ecosystem structure occurred in the Gulf of Maine and Scotian Shelf, and the Estuary and Gulf of St. Lawrence ecozones+ between 1985 and 1990. The shift is reflected in decreases in groundfish and zooplankton and concurrent increases in seals, small pelagic fish, and invertebrates. A moratorium on the commercial groundfish fishery was implemented in the Gulf of Maine and Scotian Shelf in 1993, with only limited recovery of some groundfish species.[5]

DIET OF THICK-BILLED MURRE AT COATS AND DIGGES ISLANDS



Source: adapted from Gaston et al., 2009[19]

In Hudson Bay and James Bay, the small Arctic cod is recognized as a keystone species that plays a central role in food web dynamics. Arctic cod is important in the diet of seabirds and marine mammals such as ringed seals and belugas, although it does not appear to be the sole food of any one species.[20] Arctic cod can be extremely abundant – densities of 11 kg cod per square metre were recorded in ice-covered Franklin Bay in the Beaufort Sea.[21]

The major food of thick-billed murre nestlings at Coats and Digges islands shifted from Arctic cod to capelin in the mid-1990s. The shift reflects a change in the relative abundance of Arctic cod and capelin. As the extent and duration of sea ice declines, the abundance of Arctic cod, which is a sea-ice associated species, is declining, while capelin, which prefers warmer waters, is increasing.[19] In contrast to Hudson Bay, capelin is decreasing as a proportion of the diet for murres in the Newfoundland and Labrador Shelves,[19] where capelin abundance and size has declined.[22]

Thick-billed murre

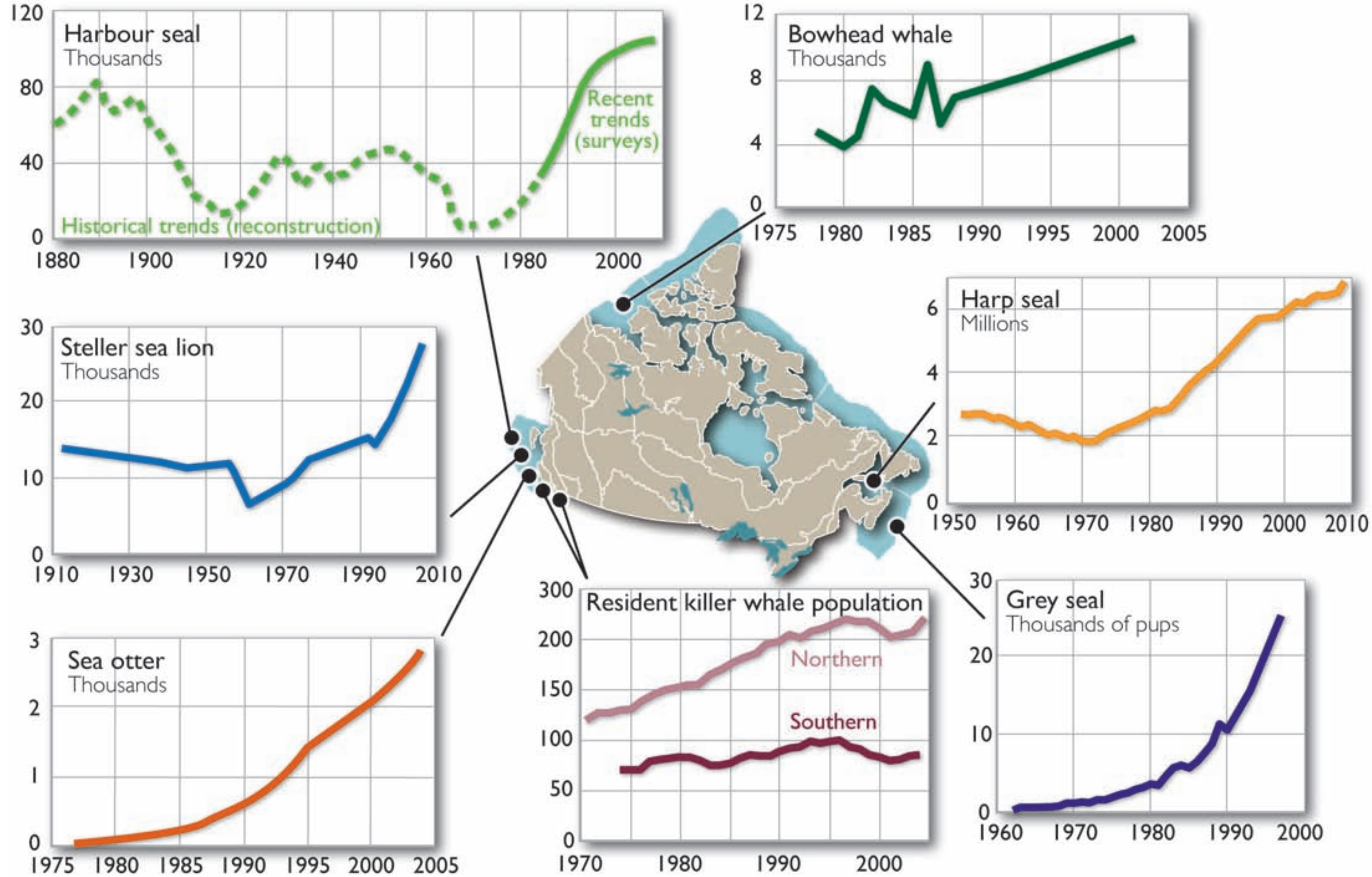
MARINE

Marine mammals

Marine mammals may play a role in structuring marine ecosystems as top predators (for example, killer whales, belugas), fish-eaters (for example, sea lions, seals), or bottom feeders (for example, sea otters, bowhead whales, gray whales). However, the effects of marine mammals on the functioning of marine ecosystems are poorly understood. Some marine mammals, such as sea otters, are known to be keystone species because their removal results in a significant ecosystem shift. Sea otters feed on sea urchins, which, in the absence of predation by sea otters, overgraze kelp.

Several marine mammal populations are recovering from past overharvesting including grey seals in the Scotian Shelf and Gulf of St. Lawrence,[23] harp seals in the Gulf of Maine and Scotian Shelf,[24] western Arctic bowhead whales in the Beaufort Sea,[25] the B.C./Alaska sea lions,[26] sea otters,[5] and the Pacific harbour seal.[27] Resident killer whale populations off the coasts of Vancouver Island have also recovered from previous commercial overexploitation but have begun to decline in recent years, possibly related to declines in chinook salmon, an important food source.[28]

Killer whales, west coast Vancouver Island, B.C.

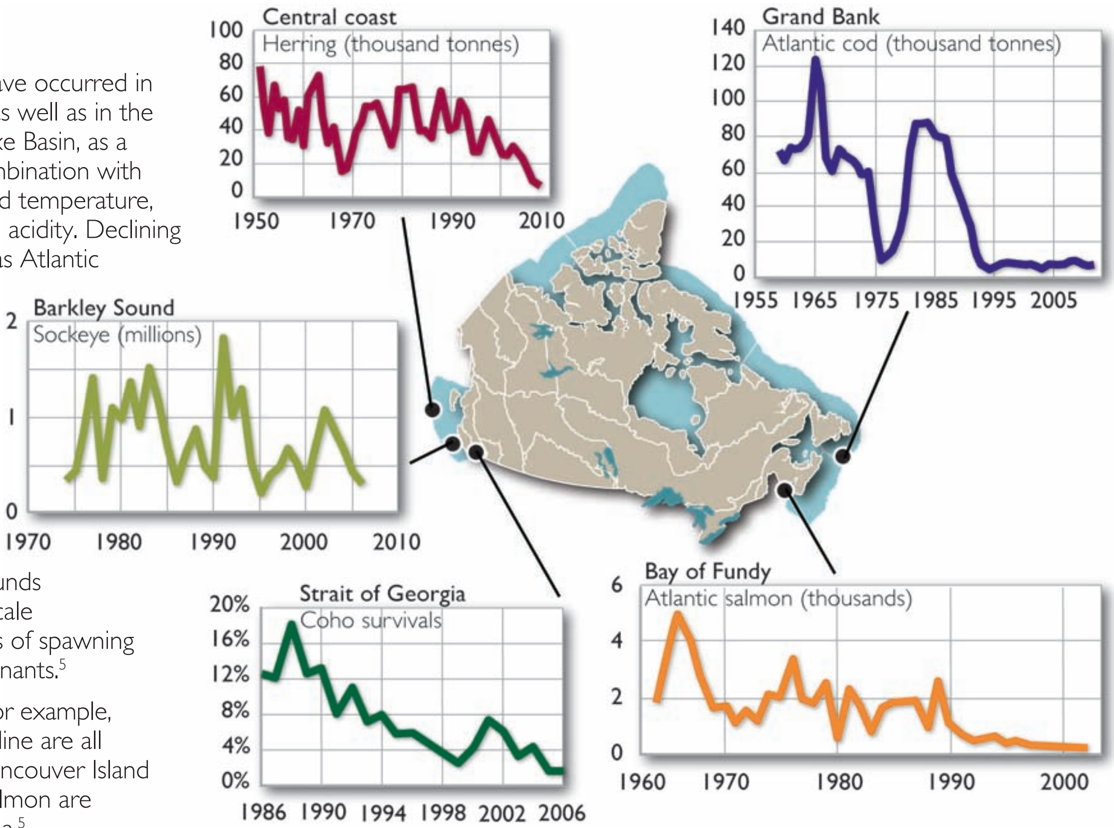


Source: adapted from Fisheries and Oceans Canada (DFO), 2010.[5] Primary references noted in the text.

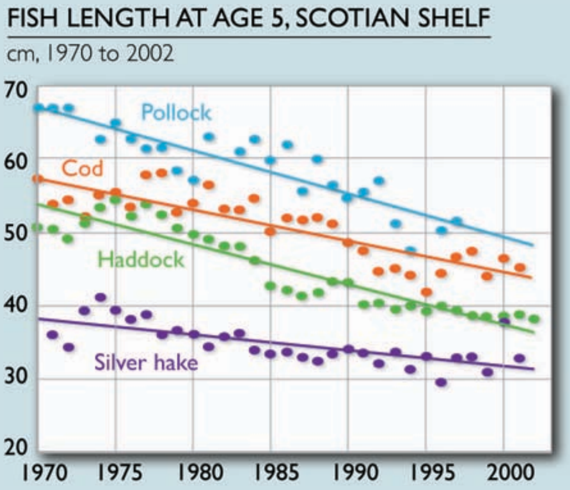
Marine fisheries

Declines in several fish stocks have occurred in the Atlantic and Pacific oceans as well as in the Hudson Bay, James Bay, and Foxe Basin, as a result of overexploitation in combination with other stressors, such as increased temperature, decreased salinity, and increased acidity. Declining stocks include groundfish, such as Atlantic and Pacific cod, lingcod and rockfish, pelagic fish such as herring and capelin, and anadromous fish such as coho, chinook salmon, Atlantic salmon, and Arctic char.[5] Management measures designed to reverse long-term fisheries declines have been largely unsuccessful. Depending on the fishery, rebounds have been hampered by large-scale oceanographic regime shifts, loss of spawning and rearing habitat, and contaminants.[5]

Not all fisheries are in decline. For example, turbot, sablefish, and Pacific sardine are all increasing in the West Coast Vancouver Island Ecozone+ and pink and chum salmon are increasing in the Strait of Georgia.[5]



Source: adapted from Fisheries and Oceans Canada (DFO), 2010,[5] Johannessen and McCarter, 2010,[15] and Worcester and Parker, 2010[16],



Source: adapted from Fisheries and Oceans Canada (DFO), 2010[5]

Size of fish is an important determinant of reproductive success. Since the 1970s, several species have been getting smaller, including Pacific herring in the Strait of Georgia and five species of groundfish in the Scotian Shelf. Smaller size is implicated as a factor hampering recovery of some fisheries.[5]

Global Trends

Over 30% of fish stocks are over-exploited, fully exploited, or depleted.[29]

ICE ACROSS BIOMES

KEY FINDING 7. Declining extent and thickness of sea ice, warming and thawing of permafrost, accelerating loss of glacier mass, and shortening of lake-ice seasons are detected across Canada's biomes. Impacts, apparent now in some areas and likely to spread, include effects on species and food webs.

Status and Trends

rapid loss of ice and frozen ground across biomes

data limited for some ice types and permafrost, but trends are clear

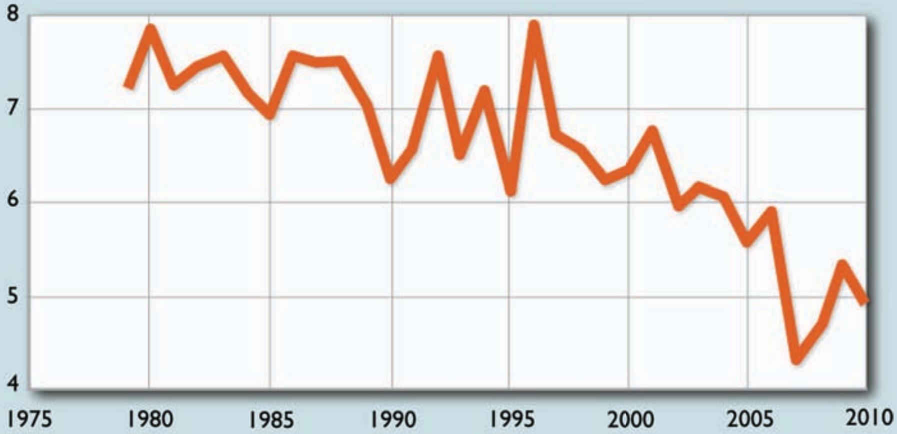
ecosystem consequences of ice loss

Ice is a defining feature of Canada's ecosystems – permafrost (frozen ground) underlies almost half the country. Arctic sea ice (increasingly seasonal) extends across the North and along parts of the east coast and most Canadian lakes and many rivers are seasonally frozen. Outside of the huge ice sheets of Antarctica and Greenland, Canada has the largest area of glaciers in the world (200,000 km^2), of which 75% is in the Arctic Archipelago.[1]

Ice ecosystems are important because they provide critical habitat for species adapted to living in, under, and on top of ice – from tiny one-celled organisms that live in the network of pores and channels within ice to polar bears. Sea ice helps regulate ocean circulation and air temperatures. Timing and duration of ice cover on rivers, lakes, and the sea are important factors in the types of plant and animal communities that water bodies support. Glaciers store fresh water and feed many of Canada's largest rivers. Permafrost stores carbon and influences the structure of the landscape and storage and flow of water.

CHANGES IN SEA-ICE EXTENT IN THE NORTHERN HEMISPHERE

Extent of sea ice in September (millions km^2), 1979 to 2010



Source: data from Fetterer et al., 2010[4]

The average of sea-ice extent for September (the month with the least ice cover) has declined over the Northern Hemisphere by 11.5% per decade since satellite measurements began in 1979.[4, 5] Average ice extent declined for all seasons over this period.[5] Ice is melting earlier in the year,[6] and its age and distribution are changing. Multi-year ice is being lost, meaning that a greater proportion of ice is younger, thinner, and more subject to rapid break-up.[7, 8]

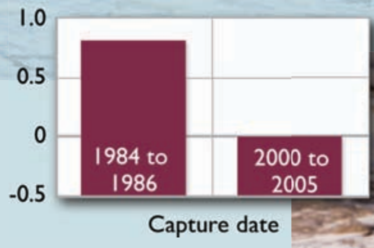
These changes in sea ice vary regionally. In the Canadian Arctic Archipelago, September ice extent declined by 9% per decade from 1979 to 2008, but the rate of decline varied from about 2% to 25% for different sub-regions.[7] In Hudson Bay, summer ice (July through September) declined by almost 20% per decade from 1979 to 2006.[5] For the Newfoundland and Labrador Shelves, ice extent declined in all seasons from 1979 to 2006, despite a period of greater ice cover in the 1990s.[5] The Gulf of St. Lawrence, with no summertime ice, has experienced less change.[5]

Global Trends

Worldwide, ice has been decreasing over the past several decades. Glaciers, including mountain glaciers that feed major rivers of China and India, are shrinking in mass and some have disappeared. Arctic sea-ice extent has decreased since 1979; Antarctic sea ice, while changing in some regions, does not show significant trends overall. Permafrost temperatures have increased in the past 20 to 30 years in most parts of the Northern Hemisphere.[2, 3]

DETERIORATION IN SOUTHERN HUDSON BAY POLAR BEAR BODY CONDITION

Mean body condition index



Source: adapted from Obbard et al., 2006[21]

Sea ice

Loss of sea ice has major ecological consequences for biodiversity. Open water has lower reflectivity than ice and holds more heat, increasing fog cover and reducing sunlight to near-shore plant and animal communities. Reduction of sea ice can expose shorelines to wave action and storms, leading to increased coastal erosion, as observed along the coast of the Beaufort Sea.[9, 10]

Species such as seals, polar bears,[11] Arctic foxes,[12] and some caribou herds[13] that rely on ice for breeding or feeding habitat, and/or for movement across the landscape are profoundly affected by changes in sea-ice distribution and extent. Some seabirds and gulls – for example, the ivory gull, which has declined dramatically since the 1980s – depend on ice-edge habitat for survival.[14, 15] Earlier break-up has been linked to shifts in trophic dynamics in some species assemblages – for example, reduced abundance of Arctic cod along with an increase in capelin.[16] Earlier break-up has also been linked to a shift to earlier breeding in seabirds such as thick-billed murres and glaucous gulls.[17-19]

An emerging issue for Arctic marine biodiversity is the anticipated increase in shipping through an ice-free Arctic, which will expose sensitive marine ecosystems and biota to risk from invasive species released in ballast, increasing noise and contact with ships, and oil spills.[11, 20]

Some 4,000 polar bears, or about 20% of the total world population, range over sea ice of Hudson and James bays in the winter, feeding mainly on seals.[22] When ice on these bays melts completely each summer, the bears come ashore where they spend up to five months (eight months for pregnant females) before the sea ice re-forms.[23] The annual ice-free period has increased by almost three weeks since the mid-1970s.[24] This has reduced the time that polar bears have on the ice to feed on seals and store fat for the summer.

The Southern Hudson Bay subpopulation is showing significant declines in body condition[21] as well as declines in survival rates of all age and sex classes.[25] Together these observations suggest that this subpopulation, which has been stable from the mid-1980s until at least 2003-2005, may decline in abundance in the future.[25] The adjacent Western Hudson Bay subpopulation of polar bears has already declined from about 1,194 bears in 1987 to 935 in 2004, a decline of 22%.[26] Coincident with this population decline were indications of declining body condition and reduced survival rates in some age classes.[26, 27] The impacts on polar bears documented in Hudson Bay are not yet occurring throughout the polar bear's range, though they may be a harbinger of changes to come as sea ice declines around the circumpolar Arctic. Currently polar bear trends are variable, with some subpopulations being stable, some increasing, and some not known.[28]

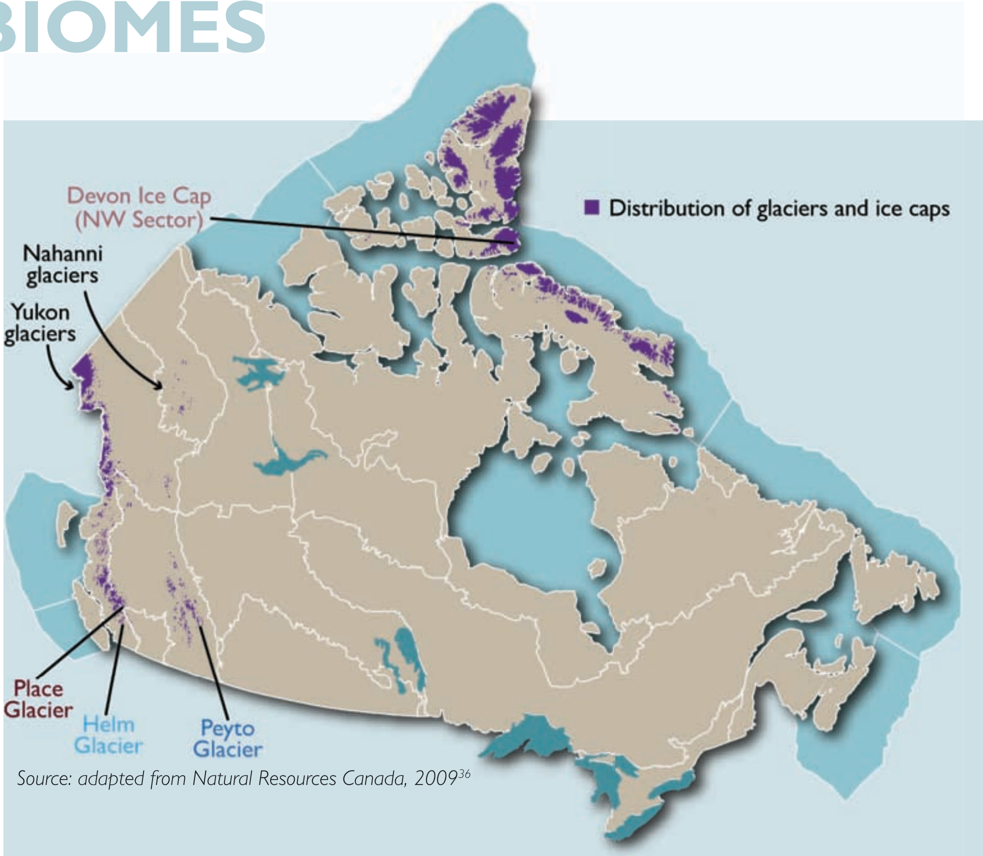
ICE ACROSS BIOMES

Glaciers

Mountain glaciers in southwestern Canada (including Peyto, Place, and Helm glaciers) show accelerating losses of ice starting in the mid-1970s, while Arctic glaciers (including Devon Ice Cap) began to show increased ice loss about 20 years later.[29] The magnitude of the loss has been much greater for mountain glaciers than for the much colder, more massive Arctic glaciers and ice caps. Glaciers have also shrunk in northwestern Canada, in the Boreal and Taiga Cordillera ecozones+, with 22% loss in the Yukon[30] (1958-60 to 2006-08) and 30% in the Nahanni Region[31] (1982 to 2008). In both these areas, many smaller glaciers at low elevations have completely melted away.

Western Canadian mountain glaciers drain into river systems,[32] regulating summer river flow and influencing ecosystem characteristics, such as water temperature and chemistry, that affect aquatic life. The influence of glaciers is especially important for cold-adapted species like salmonids.[33-35]

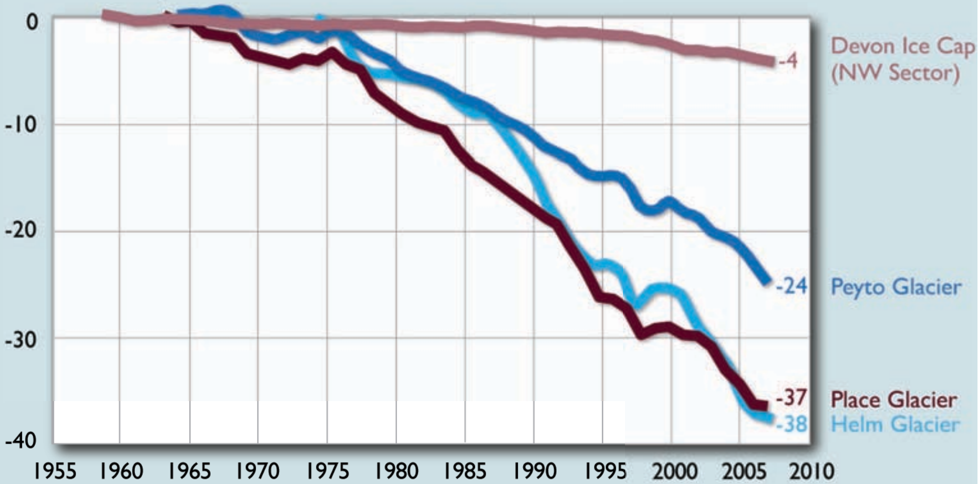
Angel Glacier, Jasper National Park, Alberta



Source: adapted from Natural Resources Canada, 2009[36]

CUMULATIVE LOSS OF ICE THICKNESS FOR THREE MOUNTAIN GLACIERS AND AN ARCTIC ICE CAP

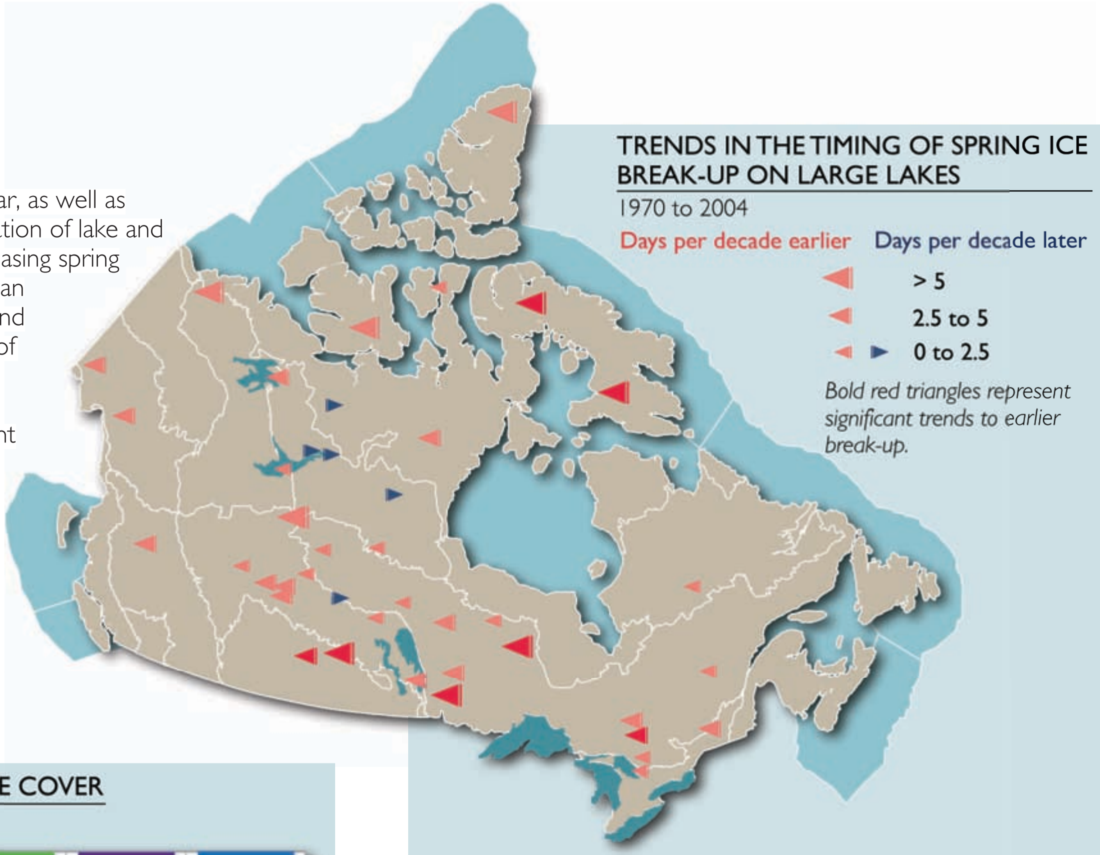
Metres water equivalent, 1959 to 2007



Note: the number at the end of each line is the total reduction in thickness of each ice mass.
Source: Burgess and Koerner, 2009[37] and Demuth et al., 2009[38-40]

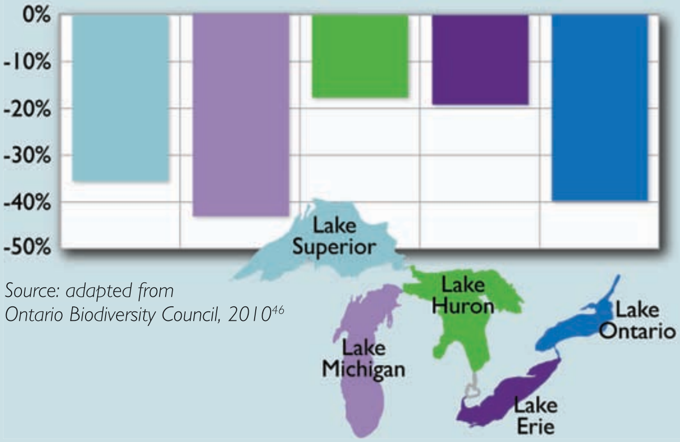
Lake and river ice

Greater variability from year to year, as well as overall trends toward shorter duration of lake and river ice, are closely linked to increasing spring and fall air temperatures.[41-43] Ice is an important part of aquatic habitat and changes in ice cover alter a range of conditions, including length of the growing season for algae, water temperature, and levels of sediment and dissolved oxygen.[44] Ice conditions also affect land animals by controlling access to the shoreline and to routes across lakes and rivers.[45]



Source: adapted from Latifovic and Pouliot, 2007[49]

Lake-ice break-up is generally occurring earlier in the spring (1.8 days earlier per decade, on average). Ice freeze-up for the same set of large lakes (over 100 km^2) shows a trend to later in the year (1.2 days per decade on average) for the majority of lakes – but less confidence is given to these fall measurements. The northern lakes showed the strongest rate of change, both in spring and in fall. This analysis is based on a combination of ground-based and remote-sensing data. Trends for the six most northerly lakes are based only on remote-sensing data from 1984 to 2004.[49]



Source: adapted from Ontario Biodiversity Council, 2010[46]

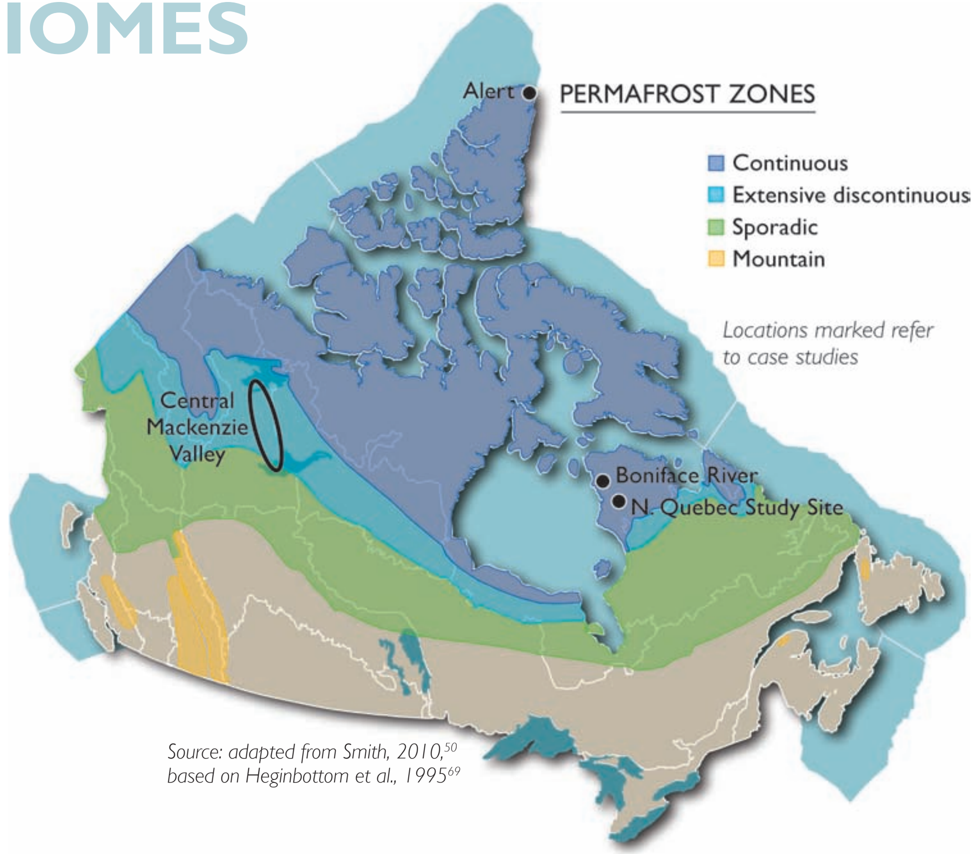
Ice cover forms in near-shore areas of the Great Lakes in December and January and in deeper offshore waters in February and March.[47] It affects the temperature of the lakes and the timing of spring overturn (the mixing of the top water layer to the bottom).[47] This in turn has an impact on the availability of coldwater habitat for coldwater species such as lake trout.[48] Less ice cover leads to earlier spring overturn, earlier warming of deep water, and less coldwater habitat.

ICE ACROSS BIOMES

Permafrost

Permafrost (rock or soil that remains below 0°C throughout the year) is warming across the northern half of Canada.[50] Since the 1980s, shallow permafrost has warmed at a rate of 0.3 to 0.6°C per decade in the central and northern Mackenzie Valley in response to an increase in air temperature.[51] In the Eastern and High Arctic, shallow permafrost has also warmed, by about 1°C per decade, mainly since the late 1990s.[52] In southern parts of the permafrost zone, the area of frozen ground and frozen peatlands has shrunk or disappeared in several ecozones+ – for example, along the Alaska Highway in the Boreal Cordillera,[53] in the northern peatlands of the Boreal Plains, and Boreal Shield[54, 55] and in the peatlands of the eastern Taiga Shield[56, 57] and the peatlands of Nunavik in the Arctic.[58]

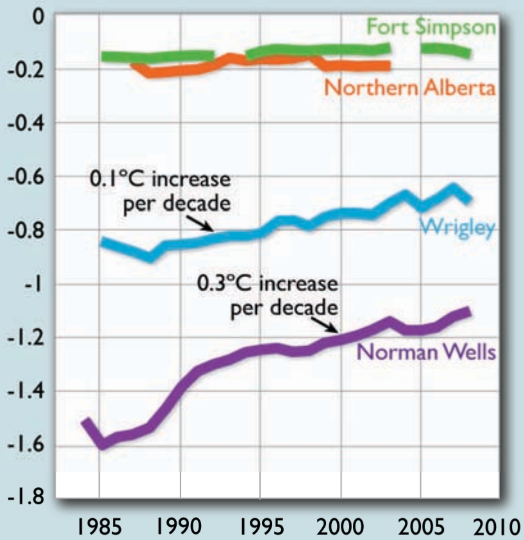
Ecological consequences of changes in permafrost conditions are evident now, especially along the southern edges of its distribution in Canada. In colder regions of the country, it is likely that widespread impacts will occur in coming decades as frozen ground and the ice within it continue to warm. In subarctic and boreal regions, thawing permafrost and collapse of frozen peatlands may flood the land, replacing forest ecosystems with wet sedge meadows, bogs, ponds, and fens[59, 60] – as is happening now in northern Quebec.[57, 61, 62] In colder areas, on the other hand, deepening of the ground layer that thaws in the summer (the active layer) or melting of ground ice can lead to collapse and drainage of channels and wetlands[63] or lower the water table and dry out the land,[64, 65] altering plant species and affecting wildlife.[64] There are signs of these ecological impacts now, especially in the Western Arctic.[66-68]



Source: adapted from Smith, 2010,[50] based on Heginbottom et al., 1995[69]

PERMAFROST TEMPERATURES IN THE CENTRAL MACKENZIE VALLEY

Temperature (°C) at 10 to 12 m depth, 1984 to 2008



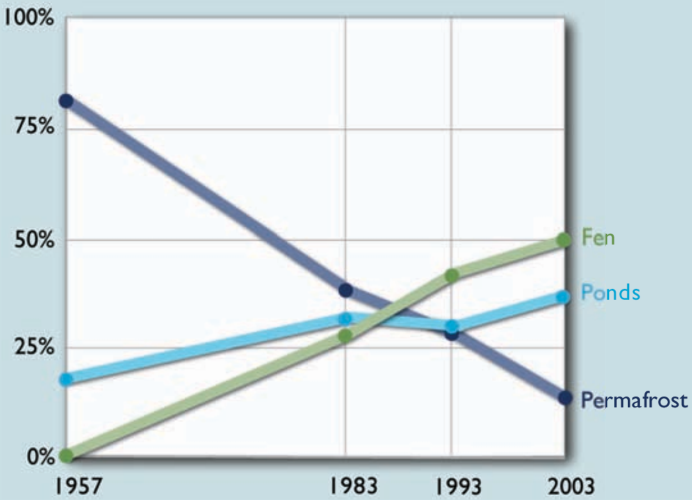
Source: adapted from Smith et al., 2010[52]

Permafrost in the south-central Mackenzie Valley (Fort Simpson and Northern Alberta) is likely being preserved by an insulating layer of peat.[70] Frozen peatlands are, however, decreasing in the southern part of the Mackenzie Valley, with an estimated loss of 22% at four study sites over the latter half of the 20th century. Permafrost further north (in the Mackenzie Delta) has warmed at a rate of 0.1 to 0.2°C per decade at a depth of 15 m since the 1960s.[71, 72] While these changes are consistent with changes in air temperature over the past few decades, changes in snow cover[73, 74] and in wildfires[75] are also affecting rates and locations of warming and thawing of permafrost.

Lichen and shrub-covered palsas surrounded by a pond resulting from thawing permafrost in a bog near the village of Radisson, Quebec

CHANGES IN LAND COVER WITH LOSS OF PERMAFROST, NORTHERN QUEBEC

Percent of land cover at study site, 1957 to 2003

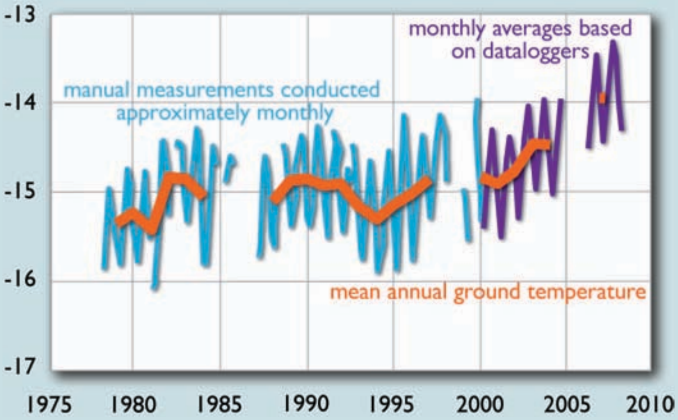


Note: based on ground surveys and 1957 air photos.
Source: adapted from Payette et al., 2004[61]

Permafrost has thawed at a rapid rate over the past 50 years in northern Quebec and the southern permafrost limit has retreated about 130 km north.[62] As a result, the landscape is changing from frozen peat plateaus and palsas (mounds of peat and soil containing ice lenses) which support dry, lichen-heath ecosystems and black spruce trees, to wetter landscapes characterized by ponds, fens, and bogs. The changes are widespread – from east of the southern part of James Bay north to the southern boundary of the "continuous" permafrost zone on the Ungava Peninsula, where, in a study area along the Boniface River, palsas decreased by 23% in area and permafrost-thaw ponds increased by 76% between 1957 and 2001.[57] Lichen, an important forage for caribou, is expected to decrease in abundance along with this transition.

PERMAFROST TEMPERATURES AT ALERT, NUNAVUT

Temperature (°C) at 15 m depth, 1978 to 2008



Source: adapted from Smith et al., 2010[52]

Trends at Alert are characteristic of the High Arctic – although air temperatures have been increasing since the 1980s, distinct warming of permafrost has only been observed since the mid-1990s. In the eastern Arctic[51] and Nunavik (northern Quebec),[76-78] shallow permafrost cooled up to the early 1990s in response to a period of cooler air temperatures, then it started to warm as air temperatures increased.

human/ecosystem interactions

KEY FINDINGS

8. Protected areas Both the extent and representativeness of the protected areas network have increased in recent years. In many places, the area protected is well above the United Nations 10% target. It is below the target in highly developed areas and the oceans.

9. Stewardship Stewardship activity in Canada is increasing, both in number and types of initiatives and in participation rates. The overall effectiveness of these activities in conserving and improving biodiversity and ecosystem health has not been fully assessed.

10. Invasive non-native species Invasive non-native species are a significant stressor on ecosystem functions, processes, and structure in terrestrial, freshwater, and marine environments. This impact is increasing as numbers of invasive non-native species continue to rise and their distributions continue to expand.

11. Contaminants Concentrations of legacy contaminants in terrestrial, freshwater, and marine systems have generally declined over the past 10 to 40 years. Concentrations of many emerging contaminants are increasing in wildlife; mercury is increasing in some wildlife in some areas.

12. Nutrient loading and algal blooms Inputs of nutrients into both freshwater and marine systems, particularly in urban and agriculture-dominated landscapes, have led to algal blooms that may be a nuisance and/or may be harmful. Nutrient inputs have been increasing in some places and decreasing in others.

13. Acid deposition Thresholds related to ecological impact of acid deposition, including acid rain, are exceeded in some areas, acidifying emissions are increasing in some areas, and biological recovery has not kept pace with emission reductions in other areas.

14. Climate change Rising temperatures across Canada, along with changes in other climatic variables over the past 50 years, have had both direct and indirect impacts on biodiversity in terrestrial, freshwater, and marine systems.

15. Ecosystem services Canada is well endowed with a natural environment that provides ecosystem services upon which our quality of life depends. In some areas where stressors have impaired ecosystem function, the cost of maintaining ecosystem services is high and deterioration in quantity, quality, and access to ecosystem services is evident.

PROTECTED AREAS

KEY FINDING 8. Both the extent and representativeness of the protected areas network have increased in recent years. In many places, the area protected is well above the United Nations 10% target. It is below the target in highly developed areas and the oceans.

Status and Trends

status for terrestrial good; improvements in representation continue

status for marine poor; progress in identifying areas for protection

trends are clear

Protected areas are usually set aside to protect biodiversity or cultural resources.[1] While some protected areas are managed exclusively for biodiversity, others allow recreational opportunities and still others allow resource use under management regimes that do not jeopardize the long-term sustainability of the natural environment. **Protected areas are important** because they provide places where ecological processes can evolve, refuges for species at risk, and repositories of genetic material. They also provide opportunities for recreation, spiritual renewal, and the conservation of places of cultural value. Protected areas are one tool for the protection of biodiversity. Sustainable management outside protected areas is equally important.

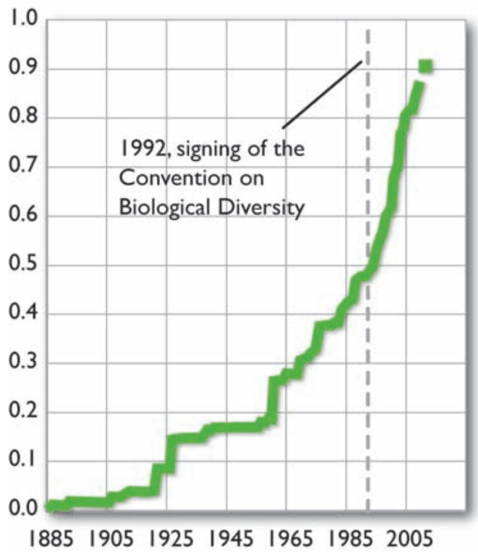
Terrestrial protected areas

Canada's terrestrial protected areas network has increased steadily since 1992, when the United Nations Convention on Biological Diversity was signed. As of May 2009, 4,826 protected areas, covering 9.4% (939,993 km^2) of the land base, had been designated.[2] This includes: some very old parks, such as Banff National Park, created in 1885 and covering 6,641 km^2; areas of international significance, such as Queen Maude Gulf Bird Sanctuary, covering 63,024 km^2 of Arctic tundra and marshes; and smaller areas representative of unique and endangered ecosystems, such as Point Pelee National Park, covering 15 km^2 in southeastern Ontario, with many at-risk species representative of the Carolinian forest. Protected areas established after May 2009, such as the expansion of Nahanni National Park Reserve from 4,766 km^2 to over 30,000 km^2, are not included in this analysis.

The majority (68%) of the protected areas in Canada are managed primarily for conservation of ecosystems and natural and cultural features. Over 1,500 protected areas (31%) have also been dedicated for sustainable use by established cultural tradition.[2]

TERRESTRIAL PROTECTED AREAS

Millions km^2, 1885 to May 2009



Note: the green dot is the total area protected, including protected areas with unknown dates of establishment. Source: Environment Canada, 2009[2]

Freshwater protected areas

In general, the protection of freshwater has not been a focus of protected area efforts, with the exception of Lake Superior National Marine Conservation Area, the largest freshwater protected area in the world. Located in the Canadian part of the Great Lakes, it consists of approximately 10,000 km^2 of lakebed and associated shoreline and 60 km^2 of islands and mainland.[2]

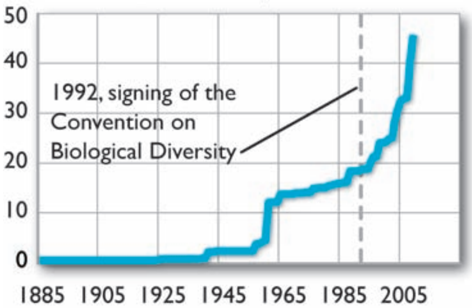
Steller sea lions

Marine protected areas

Approximately 45,280 km^2 (0.6%) of Canada's oceans are protected.[2] Although many protected areas on Canada's coasts have marine components, the designation of specific marine protected areas is more recent. This includes some marine areas of global significance, such as the Gully Marine Protected Area, the largest underwater canyon in eastern North America, situated 200 km off the coast of Nova Scotia, and the Bowie Seamount, a large submarine volcano 180 km west of Haida Gwaii, B.C.

MARINE PROTECTED AREAS

Thousand km^2, 1885 to May 2009



Source: Environment Canada, 2009[2]

Global Trends

More than 12% of the world's land and 5.9% of territorial seas are in protected areas. Protected areas are not distributed evenly. Fifty-six percent of global terrestrial ecoregions and 18% of the marine ecoregions have reached the 10% protected areas benchmark set by the Convention on Biological Diversity.[3]

GWAII HAANAS MARINE CONSERVATION AREA RESERVE AND HAIDA HERITAGE SITE

Gwaii Haanas Marine Conservation Area Reserve and Haida Heritage Site is Canada's newest marine protected area, covering 3,500 km^2 of water and seabed. With the adjacent Gwaii Haanas National Park Reserve, a contiguous protected area of 5,000 km^2 now extends from the alpine tundra of the mountaintops, through the temperate rainforest, to the deep ocean beyond the continental shelf. The marine area is noted for its diverse and unique ecosystems, which include deep-sea coral reefs, kelp forests, and eelgrass meadows. Nearly 3,500 marine species dwell in this area, including economically important fish and shellfish, breeding populations of seabirds, and marine mammals such as whales, dolphins, and sea lions. The area will be cooperatively managed by the Haida Nation and the federal government.[4, 5]

THE GULLY MARINE PROTECTED AREA

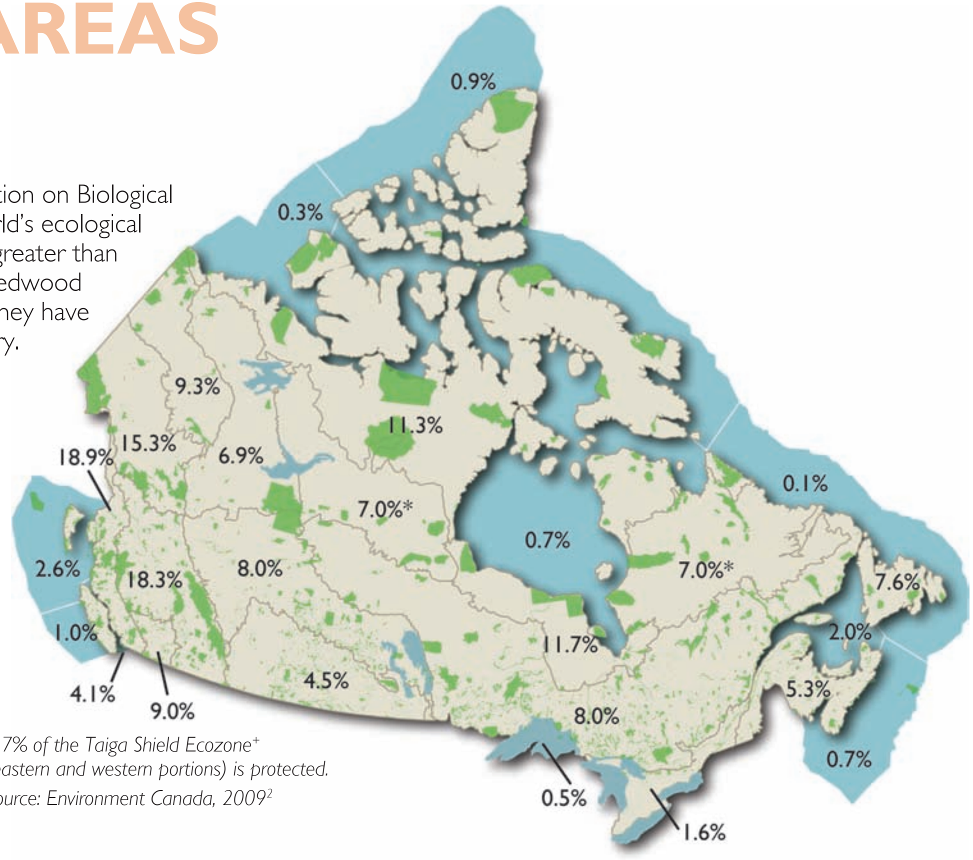
The Gully, comprising an area of 2,364 km^2, is located offshore of Nova Scotia, near Sable Island. Its ecological significance is well established and includes the highest known diversity of coral in Atlantic Canada, 14 species of marine mammals, including the endangered Scotian Shelf population of northern bottlenose whales, and a wide variety of fish, seabirds, and bottom-dwelling animals.[6, 7] The Gully is managed using a zonation system that protects the deep water from all extractive activities, allows some fishing in the canyon head and sides, feeder canyons, and on the continental slope, and allows activities in the adjacent sand banks if they do not disrupt the ecosystem beyond natural variability.[8]

PROTECTED AREAS

Percent protected by ecozone+

Canada's protected areas do not meet the Convention on Biological Diversity's target to protect 10% of each of the world's ecological regions. Although some terrestrial ecozones+ have greater than 10% protected, others, such as the Prairies and Mixedwood Plains, have a low percent protected, even though they have some of the highest biodiversity values in the country. No marine ecozones+ have 10% protected.

The use of conservation corridors to enhance the biodiversity value of current protected areas in a fragmented landscape is an important and more recent conservation tool.

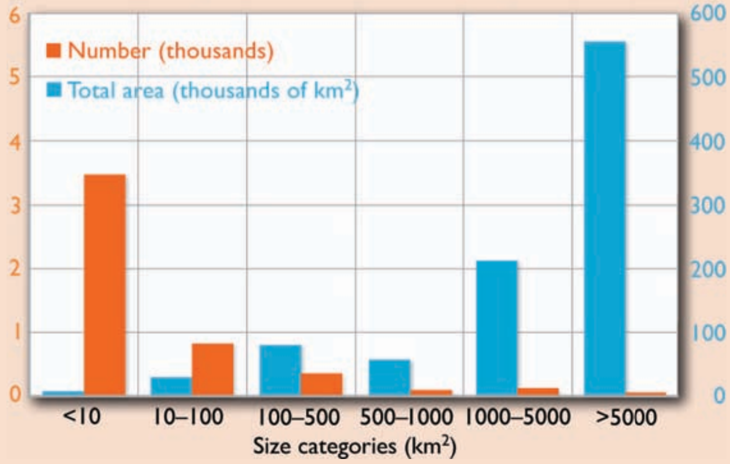


* 7% of the Taiga Shield Ecozone+ (eastern and western portions) is protected.

Source: Environment Canada, 2009[2]

SIZE OF TERRESTRIAL PROTECTED AREAS

Number and area of protected areas by size category



Source: Environment Canada, 2009[2]

Large protected areas are generally believed to have the greatest conservation value for the widest range of biodiversity. Less than 1% of Canada's protected areas are larger than 5,000 km^2, but these large areas comprise 59% of the total area protected. The 3% of protected areas larger than 1,000 km^2 comprise 82% of the total area protected. In some places, adjacent protected areas create large protected area complexes. One of several examples is the Tatshenshini-Alsek/Kluane/Glacier Bay/Wrangell-St. Elias complex, which exceeds 98,000 km^2 and crosses B.C., Yukon, and Alaska.

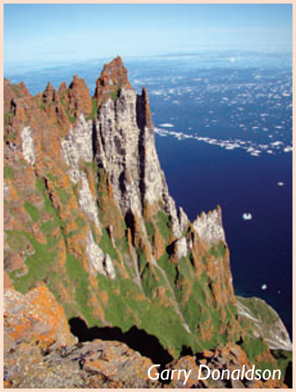
Small protected areas have a role in protecting rare species or species requiring specialized habitat. They can also serve as links between larger reserves. Most (72%) of the protected areas in Canada are less than 10 km^2 in size. Altogether these small protected areas contribute less than 1% to the total area protected.

Bowhead whales in Isabella Bay, Baffin Island, Nunavut

NATIONAL WILDLIFE AREAS IN NUNAVUT

National Wildlife Areas protect nationally significant habitat for migratory birds, support species or ecosystems at risk, or protect rare or unusual habitat. Critical natural features are conserved and activities considered harmful to species or habitats are prohibited. Three new National Wildlife Areas were created in Nunavut in June 2010 to protect critical habitat for Arctic seabirds, bowhead whales, and other species. They will be co-managed by local and federal governments, and were chosen based on advocacy and involvement from the communities of Qikiqtarjuak and Clyde River.[9]

Akpait National Wildlife Area (774 km^2) is an important area for migratory birds. It provides breeding habitat for one of Canada's largest thick-billed murre colonies, black-legged kittiwakes, glaucous gulls, and black guillemots. It is also home to polar bears, walruses, and several species of seals.[9]



Akpait National Wildlife Area

Qaqulluit National Wildlife Area (398 km^2) is home to Canada's largest colony of northern fulmars, representing an estimated 22% of the total Canadian population. Marine animals, including walrus and ringed seals, also use the waters of this National Wildlife Area.[9]

Ninginganiq National Wildlife Area (Isabella Bay) (336 km^2) protects critical summer habitat for the eastern Arctic population of bowhead whales, a Threatened species.[9]

B.C. NORTH AND CENTRAL COAST-LAND USE PLAN

In one of the largest coordinated land-use planning efforts on record, B.C. and the majority of First Nations of the North and Central Coast, along with industry, environmental, and community leaders, agreed in 2007 to a unique management approach for 64,000 km^2 of the B.C. coast.[10] Vast areas of temperate coastal rainforest have now been protected, including the largest intact temperate rainforest left on earth, home to thousands of species of plants, birds, and animals. The land-use planning agreement protects more than 30% of the land in 114 protected areas and recommends low-impact logging regulations that will conserve 50% of the natural range of old-growth forests outside of the protected areas. Applying this management approach recognizes the critical role played by land outside protected areas in the conservation of biodiversity. An adaptive management framework is in place to monitor, learn from, and improve the management of this area on an ongoing basis.

STEWARDSHIP

KEY FINDING 9. Stewardship activity in Canada is increasing, both in number and types of initiatives and in participation rates. The overall effectiveness of these activities in conserving and improving biodiversity and ecosystem health has not been fully assessed.

Status and Trends

good public engagement; increasing number and range of projects

effectiveness not well assessed and data limited; where data exist, trends are clear

Stewardship is the responsible management of land and water to ensure its values and services are maintained for future generations. Strong stewardship initiatives are based on ecological principles and involve long-term commitments. They build on a strong connection between people and their natural heritage and encompass a broad suite of strategies. **Stewardship is important** because, while protected areas are the most visible form of ecosystem conservation, they conserve only a small fraction of the land and seascape. With continued pressure on the land and oceans, effective conservation tools that encourage good stewardship are crucial to ensure long-term ecosystem viability and sustainability. Stewardship also contributes to the economy by creating jobs and sustainable businesses.

Although stewardship is not new, it has increased greatly since the 1980s.[1] There are now over a thousand stewardship groups and over one million people in Canada[2] participating in thousands of initiatives on private and public lands. These vary from small grassroots community projects to programs operated by corporations, environmental non-government organizations, and all levels of government. In the last ten years, the importance of stewardship to long-term sustainability has been increasingly recognized and is being translated into policy and practice.[1, 2] A good example is *Canada's Stewardship Agenda,*[3] endorsed in 2002 by Canada's resource ministers.

There are no comprehensive national data on stewardship activities in Canada, nor are there comprehensive analyses of trends in its overall success in conserving biodiversity. This key finding uses examples from across the wide spectrum of stewardship initiatives to provide evidence of its growth. Improved monitoring of stewardship activities is required to determine its success.

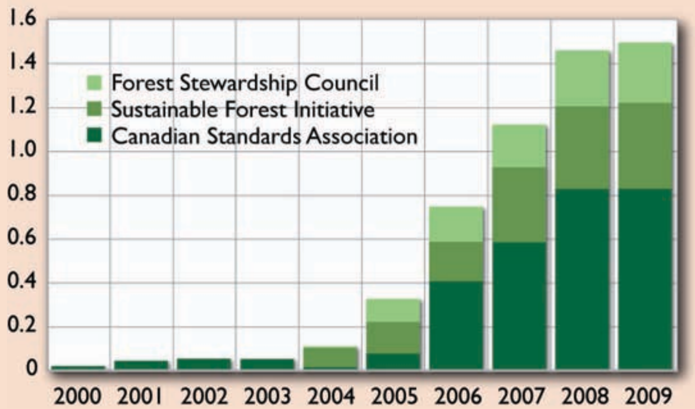
Standards and codes of practice

Over 94% of Canada's forests, 100% of water, and large areas of rangelands are publicly owned. A number of standards, codes of practice, and certification programs are available that encourage biodiversity conservation in these areas, and on private forest and agricultural land. Examples include:

- five Pacific coast and seven Atlantic coast fisheries that are certified as sustainable by the Marine Stewardship Council.[4] For some fisheries, this is related to success in reducing by-catch. Levels of by-catch of cod, Greenland halibut, and American plaice are less than 2.5%[5] and have been reported at lower levels in some areas;[6]
- 28% of farms in Canada indicated in 2006 that they had developed Environment Farm Plans to reduce the impact of agricultural practices on the environment.[7]

FOREST CERTIFICATION IN CANADA

Area (million km²), 2000 to 2009



Source: Metafore's Forest Certification Resource Centre, 2009[8]

To earn certification for their forest lands, forest companies must demonstrate stewardship activities and biodiversity conservation under a sustainable forest management framework. In Canada, the amount of forest land receiving such certification has been steadily increasing since 2000. As of 2009, almost 1.5 million km², 87% of the working forest area in Canada, had received certification. This represents 40% of the world's certified forest.[8]

© Ducks Unlimited Canada

Stewardship on private land

Approximately 50% of the 900,000 km^2 of private land in Canada was identified in 1994 as being at high risk of biodiversity loss due to ecosystem degradation and landscape fragmentation,[9] making stewardship very important. Private land stewardship takes many forms, including financial incentives; broad international, national, and regional programs delivered by non-government organizations; demonstration and extension programs; information and education support; and small community-driven projects. Many of these, particularly education-related initiatives that strive to develop a long-term stewardship ethic, are particularly difficult to monitor in terms of results for biodiversity.

SUPPORT THROUGH INFORMATION

Sharing of information and best practices that promote adoption and maintenance of sustainable land use is an important part of stewardship. The Stewardship Centre for British Columbia[10] is a virtual online centre that encourages environmental stewardship by providing technical support and capacity-building tools and resources. It fosters partnerships among stewardship organizations, government, and the private sector. The Centre's Stewardship Series provides guidelines for local governments, developers, and stewardship groups to support healthier and more sustainable development practices. The Centre also helps to build capacity of stewardship organizations by providing core funding. The Centre is affiliated with the Stewardship Canada Portal, the Land Stewardship Centre of Canada, and other stewardship centres across the country.

Stewardship centre for British Columbia

BROAD-SCALE, LONG-TERM COMMITMENT TO STEWARDSHIP: NORTH AMERICAN WATERFOWL MANAGEMENT PLAN

The North American Waterfowl Management Plan was established in 1986 in response to plummeting waterfowl numbers exacerbated by wetland drainage and drought. An initiative of Canada and the U.S., and joined in 1994 by Mexico, the plan recognized that waterfowl populations could not be restored without continental cooperation across a broad landscape. Its goal is to restore waterfowl populations to average 1970s levels by conserving habitat through regional public-private partnerships called "Joint Ventures" that are guided by the best available science and a continental landscape vision.[11] It includes a broad range of approaches, one of which is agricultural stewardship. For example, the Prairie Habitat Joint Venture works with farmers to encourage waterfowl-friendly cropping practices such as the planting of fall-seeded cereals like winter wheat. Winter wheat reduces disturbance and provides cover for early nesting species like northern pintail. The area seeded to winter wheat increased from 1992 to 2007.[12] Declines in the last two years are a result of a late fall harvest related to weather.

LAND SEEDED TO WINTER WHEAT IN THE PRAIRIES

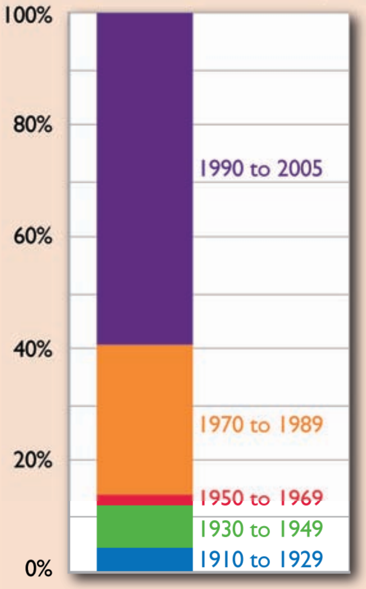
Area (thousands km^2), 1992 to 2009

Source: Statistics Canada, 2010[12]

Partners through the initiative influenced the stewardship of over 70,000 km^2 of wetland, shoreline, grassland, and agricultural habitat across southern Canada between 2000 and 2009.[13]

GROWTH OF LAND TRUSTS IN CANADA

Percent established in each time period, 1910 to 2005



Land trusts are non-profit organizations, usually community based, working for the long-term protection of natural heritage, and some more recently for protection of agricultural land. Taking many forms and using a variety of approaches, they are playing an increasingly important role in conservation of biodiversity in Canada. They have been growing in size and number over 85 years, with volunteers as their backbone. The number of land trusts in Canada roughly doubled from 1995 to 2005[14] to over 150 organizations.[1] As of June 2010, the 50 member groups of the Canadian Land Trust Alliance had protected over 27,000 km^2 of land through the involvement of almost 20,000 volunteers, over 200,000 members and supporters, and 800 staff.[15]

Note: data are based on a representative sample of 51 organizations of varying sizes and objectives from across Canada.
Source: adapted from Campbell and Rubec, 2006[14]

CONSERVATION EASEMENTS IN THE PRAIRIES

Number registered per year, 1996 to 2006

Source: adapted from Good and Michalsky, in press[16]

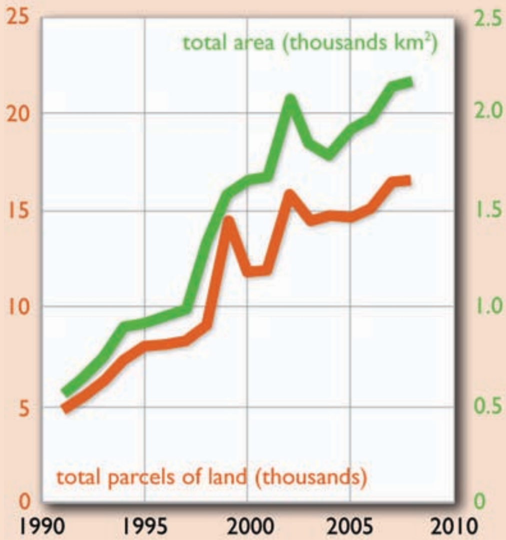
A conservation easement is a legal tool that imposes restrictions on current and future use of land by registering the restriction on the land title. Of the approximately 1,200 km^2 of land under 1,400 conservation easements across Canada in 2007, about 90% were in the Prairies (representing 70% of the total number of easements).[16] Much of the habitat important for biodiversity in the Prairies is on agricultural land, and this is where 90% of prairie easements are located. Some agricultural uses, such as grazing, continue under the easements. The number of conservation easements registered per year in the Prairies has increased from fewer than 10 in 1996 to over 180 in 2006.[16]

TAX INCENTIVE PROGRAMS: ONTARIO

Two voluntary programs in Ontario, the Managed Forest Tax Incentive Program and the Conservation Land Tax Incentive Program, provide examples of tax incentives to private landowners to encourage long-term stewardship and biodiversity conservation. Both programs provide property tax relief to landowners who protect conservation values – such as forests, wetlands, and endangered species habitat – on their lands.[17, 18] Participation in both has increased since their inception. By 2008, over 11,000 properties were enrolled in the Managed Forest Tax Incentive Program, covering 7,580 km^2, and over 16,000 properties covering over 2,170 km^2, were enrolled in the Conservation Land Tax Incentive Program.[19]

GROWTH OF THE CONSERVATION LAND TAX INCENTIVE PROGRAM

1991 to 2008



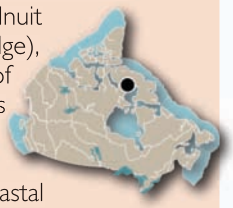
Source: adapted from Ontario Ministry of Natural Resources, 2008[19]

Habitat restoration at Blackie Spit, Surrey, B.C.

Community-based stewardship

Stewardship initiatives led by communities or individuals are one of the most promising areas of stewardship with great potential for expansion.[20] Grassroots stewardship projects inspired by local watershed and landscape issues work to protect and conserve biodiversity. The total number of community-led initiatives in Canada is not known.

LINKING TRADITIONAL KNOWLEDGE AND SCIENCE: NUNAVUT COASTAL RESOURCE INVENTORY



Knowledge co-produced by holders of Traditional Knowledge and scientists forms the basis of many northern resource management and stewardship initiatives.[21-23] Inuit Qaujimajatuqangit (Inuit Traditional Knowledge), for example, is based on many generations of experience and understanding of ecosystems and local conditions in the North and brings that perspective to stewardship initiatives. The Igloolik pilot project of the Nunavut Coastal Resource Inventory, a collaborative coastal monitoring program of the Government of Nunavut, the Nunavut Research Institute, and the Igloolik Hunters and Trappers Organization, initiated in 2007, used both community elders' knowledge and science to produce a database, including maps of mammal migration routes and a wealth of information on use of coastal locations by marine mammals. The information is available to all partners in the inventory and serves as a model for future collaborative work in other communities. The inventories can be used, for example, in the development of sustainable fisheries, coastal management plans, environmental impact assessments, sensitivity mapping, community planning, development of coastal parks, and as a means to preserve local ecological knowledge.[24]

PROTECTING EIDER DUCKS THROUGH COMMUNITY STEWARDSHIP, LABRADOR

Many coastal communities have a long history of settlement and use of coastal resources. The residents around St. Peter's Bay, Labrador, provide a good example of coastal community-based stewardship. Small islands provide critical nesting habitat for common eiders and reducing disturbance and predation during nesting is essential to their survival. St. Peter's Bay residents have been installing and maintaining nest shelters since 2003 to protect the nests and young, and educating their communities on good stewardship practices.[25] In 2009, recognizing the importance of the bay for up to 650 common eider nesting pairs,[25] three communities took their stewardship commitment one step further by signing a Coastal Stewardship Agreement with the provincial government to ensure the long-term sustainability of the eider population by conserving approximately 38 km^2 of habitat.

Community members installing eider shelters

INVASIVE NON-NATIVE SPECIES

KEY FINDING 10. Invasive non-native species are a significant stressor on ecosystem functions, processes, and structure in terrestrial, freshwater, and marine environments. This impact is increasing as numbers of invasive non-native species continue to rise and their distributions continue to expand.

Status and Trends

new introductions continue (status deteriorating), as does their impact

poor spatial and temporal coverage outside the Great Lakes

full impact of coastal marine invasive species just coming to light in some places

Invasive non-native species, also called **invasive alien species**, are species of plants, animals, and micro-organisms introduced by human action outside their natural past or present distribution, and whose spread threatens the environment, economy or society, including human health. Twelve percent of the 11,950 species assessed in *Wild Species 2010: the General Status of Species in Canada*[1] are not native. While only a small percentage of them become established and an even smaller number become invasive, the ecological and economic damage of those few species can be enormous.[2, 3] **Invasive non-native species harm biodiversity** because they can displace native species and compete with them for resources, degrade habitat, introduce diseases, and/or breed with native species to form hybrids. Numerous factors are responsible for the spread of invasive non-native species, including climate change, unintentional introductions from ship ballast and along roads, intentional introductions, and the increased susceptibility of altered or degraded ecosystems. The control of invasive non-native species is expensive and their eradication is seldom possible. They are considered the second greatest threat to biodiversity worldwide, after habitat destruction, and are an emerging threat to northern Canadian ecosystems as climate warms and species intolerant of current northern climatic conditions expand their ranges.

Coastal marine ecosystems

Although many non-native species have become established in Canada's coastal marine waters,[4-6] the impacts of invasive non-native species are most acute in the bays of P.E.I. Intensive agriculture and aquaculture activities have made P.E.I.'s coast more susceptible to the establishment and impacts of invaders. For example, since 1997, four species of sea squirts, or tunicates, have established, and are invasive, in P.E.I. Although established elsewhere in the southern Gulf of St. Lawrence, they are only invasive in P.E.I. There is also some evidence that another invasive species, the European green crab, preys on the predators of sea squirts, exacerbating the problem in P.E.I.[6, 7]

Colonial sea squirts

The European green crab is an aggressive competitor of native crabs and a predator of clams, mussels, juvenile fish, and many other species. It has recently become established on both the east and west coasts of Canada, although its establishment is too recent for its full impact to be known. The main source of coastal marine invasions in Canada has been transport on the hulls and in the ballast water of ships.[5, 7, 8] New regulations on ballast water are designed to prevent further introductions through this pathway.

Global Trends

Invasive non-native species have contributed to nearly 40% of all animal extinctions for which the cause is known.[2]

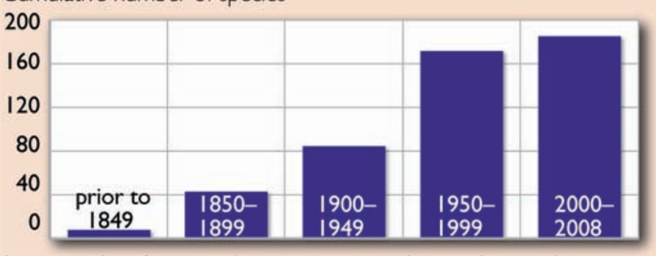
Zebra mussels

Great Lakes

Invasive non-native species are responsible for the loss of much of the original biotic community of the Great Lakes.[9] The demise of Great Lakes native biota started with the opening of the Welland Canal in 1829, the accidental introduction of sea lamprey in 1920, and the subsequent collapse of lake trout. Non-native species now dominate the Great Lakes, with enormous ecological and economic consequences.[10] One study estimated the economic loss caused by non-native invasive species in the Great Lakes to be as much as $5.7 billion annually.[11]

TRENDS IN NON-NATIVE SPECIES IN THE GREAT LAKES

Cumulative number of species



Source: data from Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS), 2009[12]

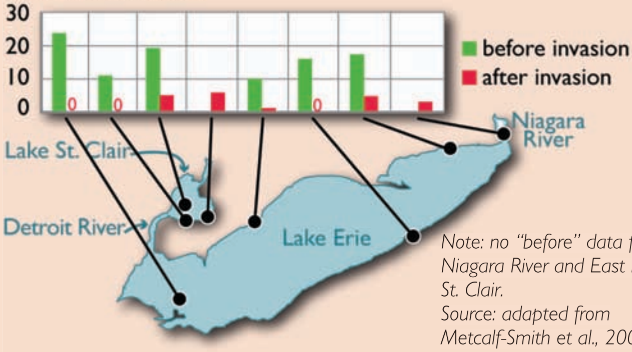
As of 2008, over 185 non-native aquatic species had been reported to have reproducing populations in the Great Lakes. Of these, at least 10% are considered to be invasive.[12] Examples of the impacts include the collapse of:

- the deepwater amphipod, *Diporeia,* and 33% of native mussels, after the introduction of zebra and quagga mussels;
- many lake fish after the introduction of alewife.[13]

Prevention of future introductions, such as Asian carps from the Mississippi Basin, is a critical challenge.[13]

NATIVE MUSSEL DECLINES

Numbers of freshwater mussel species before and after zebra mussel invasion



Note: no "before" data for Niagara River and East Lake St. Clair.
Source: adapted from Metcalf-Smith et al., 2002[14]

Native freshwater mussels are ecologically important as natural biological filters, food for aquatic species, and indicators of good water quality.[15] Nearly 72% of the 300 freshwater mussel species in North America are vulnerable to extinction or are already extinct.[15] Native freshwater mussels were virtually extirpated from the offshore waters of western Lake Erie between 1989 and 1991[16] and from Lake St. Clair between 1986 and 1994.[17] Their decline has been attributed to a number of human stressors such as pollution, overexploitation, and habitat destruction by dams,[18] in addition to declining water levels, and competition with non-native species such as zebra and quagga mussels.[15] Free-flowing rivers can provide a refuge for native mussel species by limiting zebra and quagga mussel colonization. However, non-native mussels can still establish in regulated rivers with reservoirs.[15] In a 2004/2005 survey, zebra mussels were noted at all sites sampled downstream from the Fanshawe Reservoir in the lower Thames River, a system that has one of the most diverse freshwater mussel communities in Canada.[19]

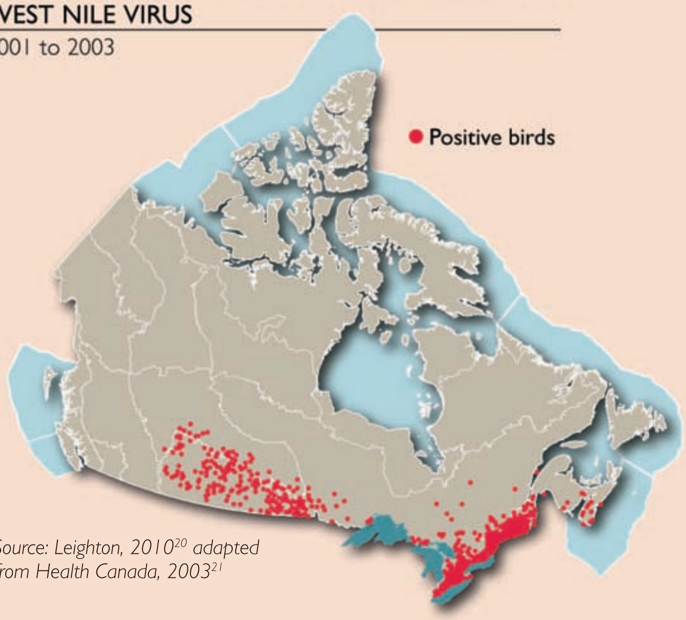
INVASIVE NON-NATIVE SPECIES

Pathogens and diseases of wildlife

Pathogens are disease-causing organisms. They come from a large spectrum of species groups, including worms, insects, fungi, protozoa, bacteria, and viruses. Many pathogens are native to Canada and the wildlife diseases they cause are part of the normal functioning of ecosystems. However, some recent disease outbreaks appear to be caused by invasive non-native pathogens or new strains of native pathogens. These include: a bacterium of poultry that also affects house finches; avian influenza, a usually benign virus of ducks that now exists in a strain deadly to poultry; duck plague, a virus native to Eurasia that can kill wild waterfowl; a chytrid fungus of amphibians; and West Nile virus, affecting mammals, birds, reptiles, and people.[20]

DISTRIBUTION OF BIRDS TESTING POSITIVE FOR WEST NILE VIRUS

2001 to 2003

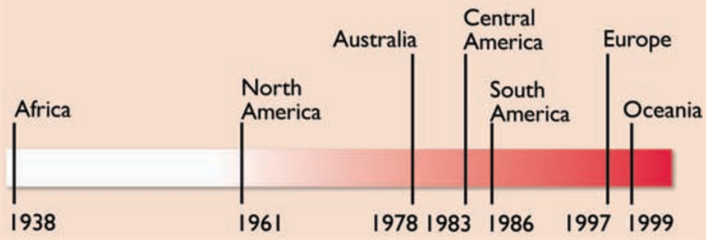


Source: Leighton, 2010[20] adapted from Health Canada, 2003[21]

West Nile virus cycles in nature between a wide range of wild bird species and a narrow range of mosquito species. It was transported to North America from Afro-Eurasia.[22] First detected in Canada in 2001, it affected all provinces from Nova Scotia to Alberta by 2003, and by 2009, it had reached British Columbia. West Nile virus has killed thousands of corvids (crows, jays, magpies, and their relatives) and fewer non-corvid birds.[23]

GLOBAL SPREAD OF CHYTRID FUNGUS OF AMPHIBIANS

Earliest occurrences of chytrid fungus in each major centre



Source: adapted from Weldon et al., 2004[24]

A chytrid fungus of the skin has been linked to worldwide declines in amphibian populations[25] and is generally believed to be the largest infectious disease threat to biodiversity.[26, 27] The origins of chytrid fungus in North America are unclear. It may have originated in Africa and spread through trade of African clawed frogs, which were widely used in human pregnancy tests.[24, 26] Trade of other species, such as the American bullfrog, may have contributed to its spread.[24] There is some evidence that chytrid fungus has always been present in North America, but that environmental stressors, such as pesticides and climate change, have made amphibians more susceptible to it.[28-30] The earliest record of chytrid fungus outside of Africa is from Quebec, in 1961.[31] Since then, chytrid fungus has been found in British Columbia,[31] Alberta,[20] Saskatchewan,[32] Ontario, Quebec, New Brunswick, Nova Scotia,[31] and, most recently, Prince Edward Island,[33] Yukon,[34] and the Northwest Territories.[35]

Northern leopard frog

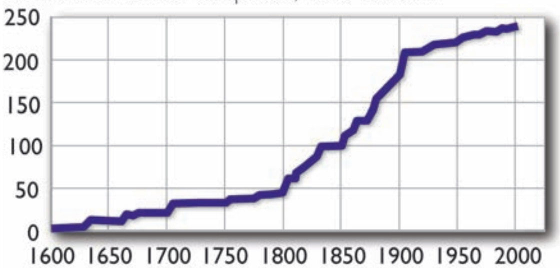

Steve Dewey, bugwood.org

Terrestrial plants

Invasive non-native plants are one of the greatest threats to Canada's croplands, rangelands, and natural areas. They degrade productivity and biological diversity; they are responsible for significant economic loss; and, they affect our trade with other countries. Approximately 1,229 (24%) of the 5,087 known plants in Canada are not native. Of these, 486 are considered weedy or invasive.[36]

INVASIVE NON-NATIVE PLANTS IN CANADA

Cumulative number of species, 1600 to 2005



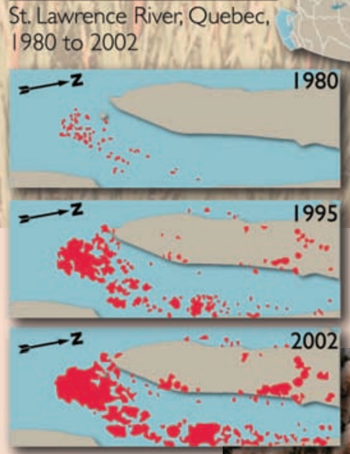
Note: This graph represents an estimate of temporal trends for the 245 invasive plant species for which dates of introduction can be estimated.
Source: adapted from Canadian Food Inspection Agency, 2010[36]

The most rapid accumulation of non-native plant species was between 1800 and 1900, a period of increased trade, immigration, and colonization. During this time many invasive plants were brought into Canada intentionally. The rate of new invasive plant introductions has slowed since the early 1900s, although range extension of established species is an ongoing problem. The geographic origin of most of the non-native plants in Canada is western Europe, reflecting dominant trade patterns of the past. Modern trade patterns point to new risks from the United States and Asia.[36]

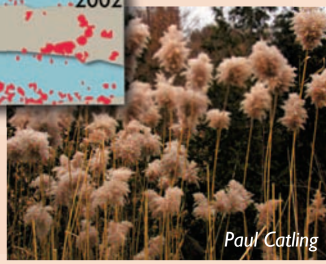
Invasive non-native plants can cause ecological damage over a wide area and economic damage to multiple sectors. Some of the most damaging non-native plants include Canada thistle, leafy spurge, and knapweeds.[37] Wetland plants are among the most aggressive invaders, changing vegetation structure, reducing the diversity of native plants and associated wildlife, and altering basic wetland functioning. Some of the most aggressive wetland invaders include purple loosestrife and European common reed.[38]

EXPANSION OF THE EUROPEAN COMMON REED

St. Lawrence River, Quebec, 1980 to 2002



Source: adapted from Hudon et al., 2005[39]


Paul Catling

European common reed, a subspecies of the native common reed, is one of the most dangerous non-native invaders of natural habitats in Canada.[40, 41] It is currently a major problem in the east, where it forms dense stands to the exclusion of most native species.[40] It first established in Nova Scotia in 1910,[40] but spread most significantly from 1980-2002.[39] Human-made linear wetlands, such as ditches, can act as dispersal corridors because they are rich in nutrients, extensively interconnected, and salt accumulation in them creates a competitive advantage for the salt-tolerant European common reed.[42] Expansion of the European common reed jeopardizes ecosystem functioning because it reduces biodiversity and is of lower nutritional[43] and habitat value[44] than the native species it replaces. The European common reed is expected to expand its range to the Prairie provinces within one or two decades, where it could impede water flow in irrigation canals.[40] Early knowledge allows for some time to conduct the research necessary to prevent its spread.[40]

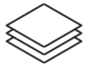
CONTAMINANTS

KEY FINDING 11. Concentrations of legacy contaminants in terrestrial, freshwater, and marine systems have generally declined over the past 10 to 40 years. Concentrations of many emerging contaminants are increasing in wildlife; mercury is increasing in some wildlife in some areas.

Status and Trends

legacy contaminants generally decreasing (status improving); emerging contaminants generally increasing (status deteriorating)

some good data but spatial coverage poor



Contaminants are substances that are introduced into the environment through human activity. Some, like mercury, are naturally occurring but are increased in concentration through human activity to levels that could harm ecosystems and humans. Contaminants may travel great distances through the atmosphere and oceans and end up in ecosystems distant from their sources. This key finding considers only contaminants that persist in the environment and accumulate in the tissues of plants and animals. **Legacy contaminants** have been banned or restricted but are still widespread in the environment. **Emerging contaminants** are newer chemicals, or substances that have been in use for some time and have recently been detected in the environment – usually emerging contaminants are still in use or only partially regulated.

Contaminants can harm species and ecosystems and impair ecosystem services. They can directly affect animals when present in their diets, such as by impairing reproduction, and can also become a problem for humans who rely on them for food – particularly for Aboriginal people with diets heavily reliant on marine mammals and fish.[1] The widespread presence of contaminants in wildlife has been a concern in Canada since the 1970s and concentrations of selected contaminants have been monitored in some species and locations over various periods since then. There are long-term, ongoing datasets adequate for trend analysis, but these are restricted to a few areas, such as the Great Lakes and parts of the Arctic.

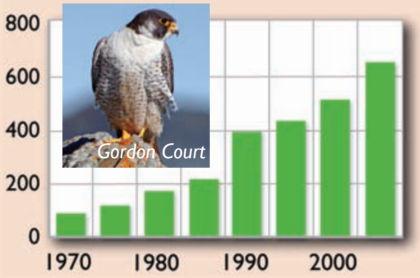
Several persistent organic pollutants, including the pesticide DDT and the industrial chemicals PCBs, are considered legacy contaminants. Despite being banned or restricted, some of these substances persist at levels that may impair animal health in some populations of long-lived top predators (including killer whales[2] and polar bears[3]) and in areas where there is a history of heavy use of some of these substances (such as the Great Lakes[4]).

Brominated flame retardants, for example PBDEs, are one class of emerging contaminants that have been detected in the environment, even in remote locations, at increasing levels since the mid-1980s. Concentrations of some brominated flame retardants show signs of stabilizing or declining in the last few years in response to new regulation and reductions in their use.[1] Other emerging contaminants include some pesticides and herbicides in current use.

Mercury is a third example of a contaminant that can accumulate in wildlife. While mercury is a naturally occurring element, much of the mercury in marine and freshwater systems is from industrial sources such as coal burning – and mercury releases are increasing in parts of the world.[5] Mercury levels in animals are highly variable and trends are mixed.[1]

RECOVERY OF PEREGRINE FALCONS IN CANADA

Number of sites occupied by peregrines, 1970 to 2005



Source: data from COSEWIC, 2007[6]

The story of the peregrine falcon shows that contaminants can have major effects on biodiversity and that banning and restricting contaminants works. Peregrines in Canada declined dramatically from the 1950s to 1970s, mainly from egg-shell thinning caused by DDT and its breakdown products.[6] With the banning of DDT in Canada in 1970, 1972 in the U.S., and 2000 in Mexico, DDT slowly declined in the environment. Conservation actions and reintroductions helped populations to increase once DDT levels were low enough for eggs to hatch successfully. Some parts of Canada such as the Okanagan Valley of British Columbia may still have too much legacy DDT for peregrine falcons to nest successfully.[7]

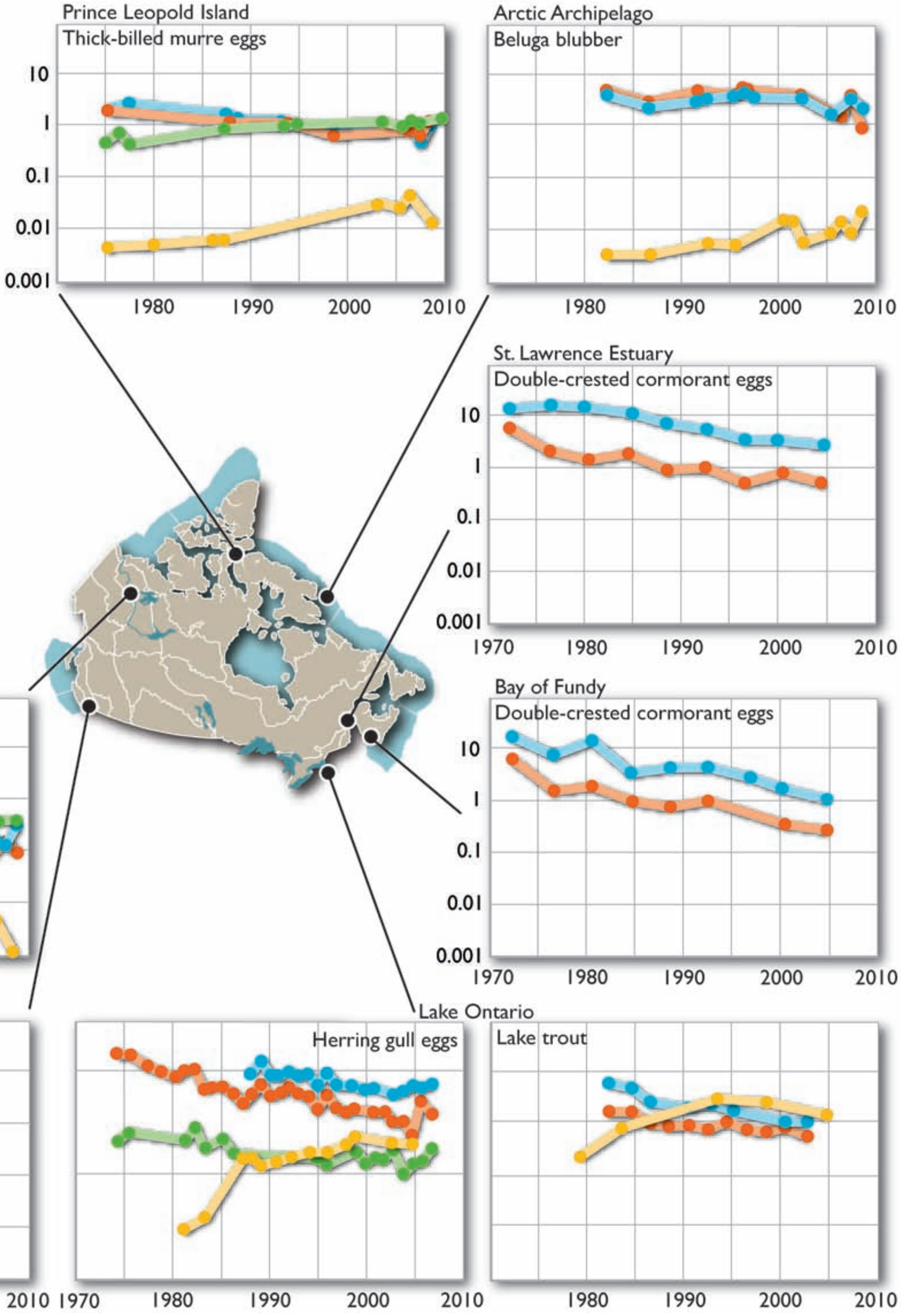
CONTAMINANT TRENDS

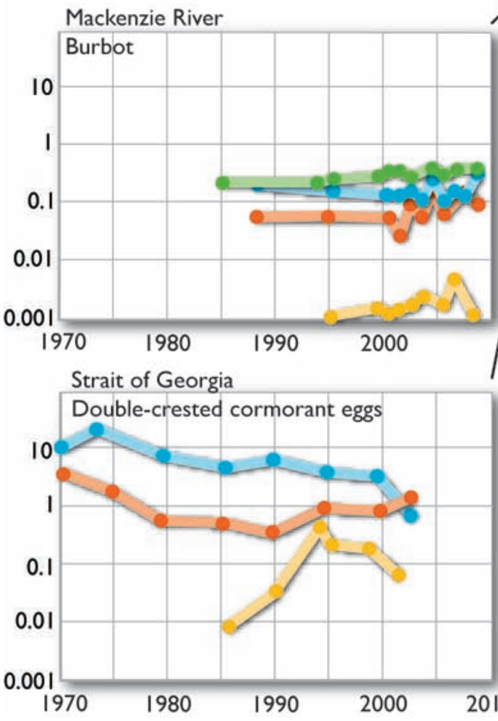
Parts per million, logarithmic scale

- PCBs
- DDE or DDTs
- PBDEs
- Mercury

The charts show a range of trends and levels of two legacy contaminants (PCBs and DDT), mercury, and an emerging contaminant (PBDEs) in wildlife. Amounts and trends are partly related to proximity to contaminant sources and partly to other factors that influence an animal's exposure to and uptake of contaminants, including position in the food web. Magnitudes of contaminant levels should be compared from chart to chart only in general terms – datasets are not all comparable in the types of tissues sampled and in analysis and data reporting methods.

Note: DDE is a breakdown product of DDT.





Sources: burbot: Stern, 2009;[8] murres: Braune, 2007[9] updated by author; beluga: Stern, 2009[10] and Tomy, 2009;[11] cormorants and gulls: Environment Canada, 2009;[12] lake trout: Carlson et al., 2010[13] and Ismail et al., 2009[14]

CONTAMINANTS

Interactions between contaminants and environmental change

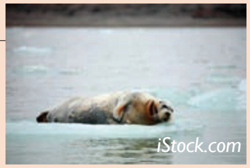
Changes in environmental conditions caused by stressors, including climate change and invasive non-native species, may, in some cases, make wildlife more vulnerable to contaminants. Environmental change can increase the exposure of some aquatic species to contaminants through changes in water flow and chemistry and through changes in food webs.[15, 16] Interactions may also make animals more vulnerable to the effects of contaminants. For example, salmonids in the Great Lakes have switched to a diet that includes alewife, an invasive non-native fish, leading to thiamine (vitamin B1) deficiencies that may interact with the effects of contaminants like PCBs to increase mortality rates in young fish.[17]

Trends in contaminants in the Great Lakes

Legacy contaminants and mercury are generally decreasing in the Great Lakes in response to clean-up of contaminated sites and improved pollution control.[4, 13] However, the large volumes of water and sediment in the system act as a storehouse – contaminants continue to be released from sediments and to recycle through the water, sediment, and food webs.[19, 20] Contaminants also continue to be deposited into the lakes through long-range atmospheric transport[21] and, in the case of mercury, from industrial emissions in the Great Lakes Basin.[4] The net result is that rates of decline of some legacy contaminants and mercury have slowed in areas of the Great Lakes, leaving some contaminants at levels that are of concern and likely to remain so for some time to come.[13, 20]

Brominated flame retardants (PBDEs) increased rapidly in fish and birds starting in the early 1980s,[22-24] but levels have now stabilized or are declining in response to action taken to curtail the use and release of these substances.[24, 25] Many other emerging contaminants have been detected more recently in environmental samples, often in trace amounts, but little is known about the risk to ecosystems from most of them.[26] Chemicals of concern include PFOS, originating in water-repellent coatings and fire-suppression foam, detected in fish samples throughout the Great Lakes, and known to build up in food webs.[27] Emerging contaminants also include endocrine disrupting substances, which come from a range of sources, including pharmaceuticals. Potential effects include abnormal gonad development in fish.[28] Many emerging contaminants do not originate in industrial emissions, but rather from use and disposal of health and personal-care products and consumer goods, leading to a need for new risk management approaches for contaminants in the Great Lakes.[26]

IMPACT OF LESS SEA ICE ON CONTAMINANTS IN SEALS AND POLAR BEARS



Bearded seal

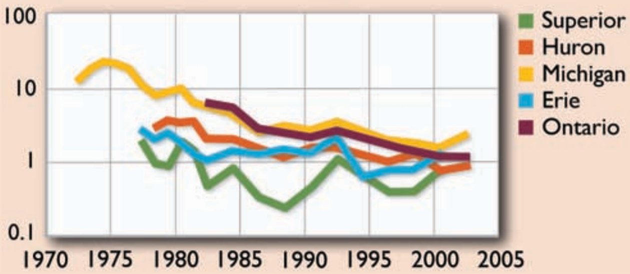
With changes in sea-ice conditions, western Hudson Bay polar bears are feeding less on ice-associated bearded seals (which eat invertebrates) and more on open-water seals (which eat fish).[18] Because fish-eating seals have higher levels of contaminants, some legacy contaminants in polar bears may not be declining as much as would be expected if their diet had not changed and levels of emerging contaminants may be increasing at a faster rate. Concentrations of brominated flame retardants (PBDEs) in western Hudson Bay polar bears are estimated to have increased 28% faster from 1991 to 2007 than would have occurred if the bears had not changed their diet.[18]

IMPACT OF CHANGES IN FIRE REGIMES ON MERCURY IN FISH

Changes in fire regimes can increase algae in lakes and contaminants in fish. A study in Jasper National Park[16] found that fire in the catchment area of a lake in 2000 increased the input of nutrients to the lake over a period of several years. This led to an increase in production of algae, which led to an increase in the abundance of invertebrates, making the lake's food web more complex. The outcome was an increase in mercury accumulating in lake trout and rainbow trout.

PCBs IN GREAT LAKES FISH

Total PCB concentrations in lake trout (walleye in Lake Erie)
Parts per million (logarithmic scale), 1972 to 2002



Source: adapted from Carlson et al., 2010[13]

PCBs in fish declined rapidly until the mid-1980s, halving in concentration every three to six years. Since then, PCBs in fish show either slow declines or no significant trend.[13]

Effects of contaminants on wildlife

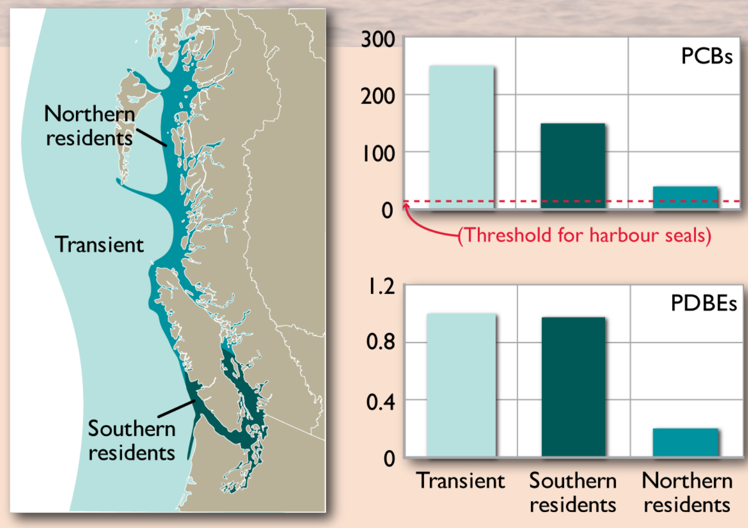
Persistent organic pollutants, as well as mercury, tend to accumulate in aquatic ecosystems more than in terrestrial ones. These levels are magnified as they move up the food web. This means that the highest levels of these contaminants are found in top predators – especially marine mammals and fish-eating birds.

There is no evidence of current widespread effects of contaminants on Canadian Arctic wildlife, though polar bears of southern and western Hudson Bay, as well as some high Arctic seabirds, have contaminant levels that may be placing them at risk.[3] However, what is known is based only on studies of a few species and is usually based on the effects of a single contaminant. Little is known about impacts of the contaminant mixtures that wildlife are exposed to, or about interactions of contaminants with other changes in ecosystems.[3]

Contaminant levels are much higher in some areas of southern Canada than they are in the Arctic (see graphs of contaminant trends earlier in this section). Levels of contaminants measured in wildlife often exceed thresholds beyond which biological effects are known to occur from laboratory studies (usually based on species other than those of concern in the wild). While direct evidence of impacts on wildlife populations is difficult to obtain, associations between high contaminant levels and observations of effects – like tumours, abnormal gonads, or poor reproductive success[17, 28] – underscore conservation-level concerns for some populations. The clearest example of known impacts is that of DDT-associated egg-shell thinning in birds[29] – but high levels of contaminants are suspected to contribute to declines in several wildlife populations, for example, herring gulls in the Great Lakes[30] and beluga whales in the St. Lawrence Estuary.[31, 32]

CONTAMINANTS IN KILLER WHALES OFF THE PACIFIC COAST

Average levels in killer whale biopsy samples, mid-1990s, parts per million



Source: adapted from Ross, 2006[33]

PCBs and PBDEs are known to adversely affect neurological development, reproductive development, and immune system function of marine mammals.[33] Because they are long-lived top predators, killer whales accumulate high concentrations of persistent organic pollutants, including PCBs and PBDEs.[29, 34, 35] The concentrations of PCBs in the three killer whale populations along the B.C. coast exceed levels known to affect the health of harbour seals,[33] and the PCB levels of two populations are among the highest in marine mammals in the world.[35]

The large variation in contaminant concentrations among the populations is related to their feeding habits. Transient whales feed on marine mammals, placing them higher in the food web, while both resident populations feed largely on salmon that acquire contaminants from global sources in the North Pacific Ocean.[29] Southern resident whales also feed on prey that pick up contaminants from the industrial coastal waters of southern B.C. and northwest Washington, leading to higher PCB and PBDE accumulation.[29] These or other contaminants may be a factor in the decline of this endangered population of killer whales (see Marine Biome).[36]

NUTRIENT LOADING AND ALGAL BLOOMS

KEY FINDING 12. Inputs of nutrients to both freshwater and marine systems, particularly in urban and agriculture-dominated landscapes, have led to algal blooms that may be a nuisance and/or may be harmful. Nutrient inputs have been increasing in some places and decreasing in others.

Status and Trends

- improving status where nutrient inputs successfully reduced
- deteriorating status where algal blooms increasing and nutrients not controlled
- some good data but spatial coverage limited; temporal trends often short
- algal blooms reappearing in some areas where nutrient inputs have been reduced

Nutrient loading refers to the release, through human activities, of nitrogen, phosphorus, and other nutrients into the environment.[1] Fertilizers from agriculture, phosphates from detergents, and sewage from urban development are examples of nutrients that can be loaded into aquatic systems. Although increased nutrients stimulate the growth of phytoplankton – the bacteria and algae at the foundation of aquatic food webs – this can have negative impacts on aquatic ecosystems.[2]

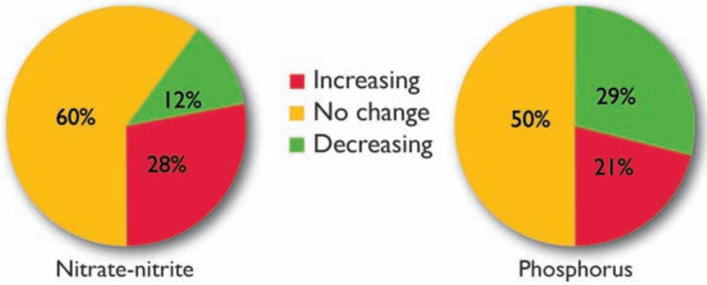
Nutrient loading can result in **algal blooms** – rapid increases in phytoplankton growth – and sometimes dead zones. Algal blooms can cause dead zones through two mechanisms: 1) they can consume so much oxygen that other plants and animals can no longer survive; and, 2) a few species of phytoplankton – primarily blue-green algae in freshwater and dinoflagellates in the ocean – can form harmful blooms that produce toxic compounds that kill other organisms.[3] Algal blooms have been the cause of many massive fish kills. However, only about 2% of the 2,000 described phytoplankton species in freshwater, and of the estimated 3,400-4,000 known phytoplankton species in marine systems, are toxic.[4, 5]

Although algal blooms do occur naturally, nutrient loading contributes to increases in the frequency, areal extent, and intensity of algal blooms.[6] Increasing water temperatures may also contribute, and climate change is expected to cause changes in the distribution, seasonality, and frequency of algal blooms.[7]

Algal blooms – both toxic and non-toxic – occur across Canada in lakes, reservoirs, ponds, rivers, swamps, and estuaries. They have been reported in coastal and inland B.C., the Prairies (Qu'Appelle Lake system[8]), central Canada (Lake Winnipeg[9] and Lake of the Woods), the Great Lakes and Boreal Shield of Ontario, the Mixedwood Plains, Boreal Shield and St. Lawrence River in Quebec, and the Atlantic Maritime.[4]

NITROGEN AND PHOSPHORUS LEVELS IN WATER BODIES

Percentage of sites with increasing, decreasing, and stable trends, between 1990 and 2006



Note: these are the results of 83 sites monitored for nitrogen and 76 sites monitored for phosphorus through federal and provincial water quality monitoring programs.
Source: adapted from Environment Canada, 2010[2]

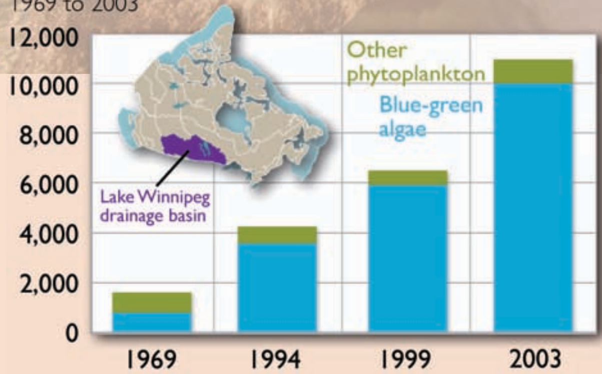
Global Trends

More than 400 dead zones have been reported in coastal waters worldwide.[6] Nutrient loading to terrestrial, freshwater, and coastal waters ecosystems are projected to increase substantially in the future.[1]

Algal bloom in Lake Winnipeg fouling a beach[3]

ALGAL BLOOMS IN LAKE WINNIPEG

Phytoplankton biomass (mg/m^3), late July to early September, 1969 to 2003



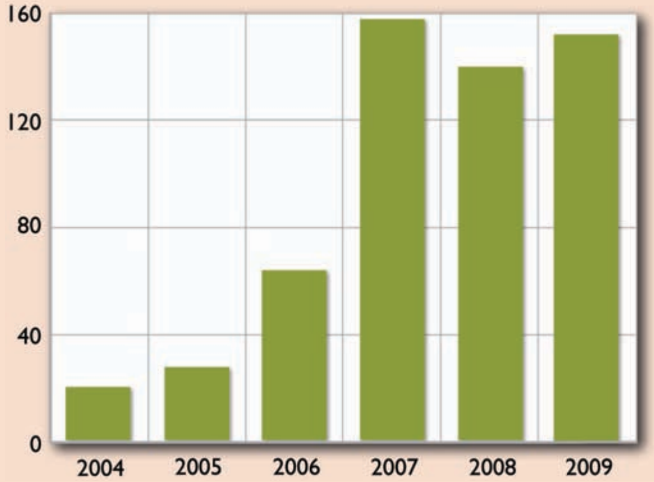
Source: adapted from Shipley and Kling, 2010[10]

The Lake Winnipeg drainage basin is the second largest in Canada, spanning 953,000 km^2 across four Canadian provinces and four U.S. states. Sixty-eight percent of the watershed is agriculture – cropland and pastureland. The watershed is also home to 6.6 million people and 20 million livestock.[11] Intensification of agriculture, land clearing, wetland drainage, and rapid growth of human populations has led to an increase in nitrogen and phosphorus in the lake.[11, 12] One of the most noticeable symptoms of increased nutrient loading has been the development of extensive surface algae blooms comprised largely of blue-green algae. Blooms have been as large as 10,000 km^2, at times covering much of the north basin of the lake. Between 1969 and 2003, the average biomass of phytoplankton increased five-fold. A shift in species composition towards blue-green algae has been particularly pronounced since the mid-1990s.[11]

Algal blooms in Lake Winnipeg are a concern to recreationists and commercial fishers, as they foul beaches and cover nets. Decomposition of large algal blooms can result in low oxygen conditions, which can negatively affect fish and other aquatic life. Nevertheless, algal blooms have not resulted in a decline in the valuable Lake Winnipeg fishery, and, in fact, walleye production in Lake Winnipeg is now the highest it has ever been in the history of the commercial fishery.[11]

HARMFUL ALGAL BLOOMS IN QUEBEC

Number of water bodies, 2004 to 2009



Source: adapted from Ministère du Développement durable, de l'Environnement et des Parcs, 2009[13]

Harmful algal blooms appear to be increasing in lakes and reservoirs across Canada, although long-term monitoring to verify this is weak. Available trends are usually for less than 10 years and reports of increases in algal blooms are often anecdotal. In Quebec, the number of water bodies experiencing harmful algal blooms increased from 21 in 2004 to 150 in 2009.[13]

In Alberta, 75% of lakes and reservoirs contain harmful algal blooms at least once in the open water season.[14] In Fort Smith, near the northern edge of the Boreal Plains, Aboriginal people have noticed an overabundance of algae covering river banks and clogging fishing nets.[15]

NUTRIENT LOADING AND ALGAL BLOOMS

GREAT LAKES ALGAL BLOOMS

With the exception of shallow bays and shoreline marshes, the Great Lakes were historically cool and clear – that is, they had naturally low productivity.[16] Urbanization and agricultural development have resulted in nutrient loading, particularly from sewage, phosphate detergents, and fertilizers.

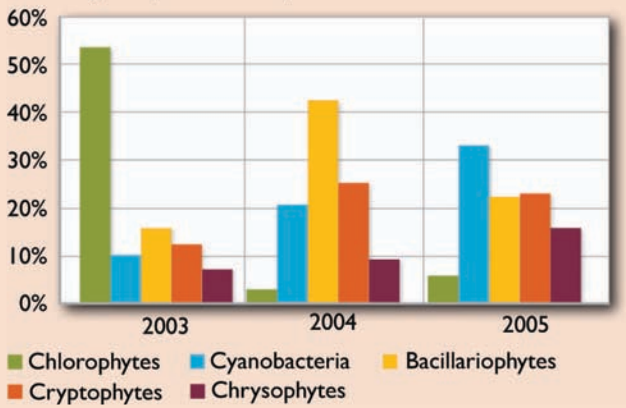
In the 1920s, Lake Erie was the first of the Great Lakes to demonstrate a serious problem from nutrient loading.[16] Not only is it the most vulnerable of the Great Lakes because it is the shallowest, warmest, and naturally most productive, but it was the first to have intense agricultural and urban development on its shorelines.

By the 1960s, public alarm was raised by the appearance of filamentous algae covering beaches in green, slimy, rotting masses and people feared that Lake Erie was "dying". Research showed that phosphorus was the main culprit, and the 1972 Great Lakes Water Quality Agreement introduced regulations that reduced point sources of phosphorus entering the lakes. Ten years later non-point sources of phosphorus were also controlled, leading to a clean-up of the lakes and one of the great success stories in international environmental cooperation.

In the past decade, massive toxic blue-green algae, or harmful algal blooms, have reappeared in lakes Erie, Ontario, Huron, and Michigan as well as some neighbouring lakes, such as Lake Champlain. The causes of recent algal blooms are more complex than in earlier times and the effects are more detrimental. Phosphorous inputs appear to be increasing again, particularly from agricultural watersheds in Ohio,[17] and an increasing proportion of the phosphorus is in a form that is biologically available to fuel near-shore algal blooms.[18] Invasive quagga mussels have compounded the problem due to their capacity to selectively remove edible algae, leaving behind the toxic blue-green algae, *Microcystis*.[19-21] Blooms of *Microcystis* are of particular concern for two reasons: 1) they are a poor food source for zooplankton that are, in turn, important food for fish larvae; and 2) they can contain a toxin that, when ingested by animals, including humans, may cause liver damage.[22]

Western Lake Erie algal bloom 25 August 2009

Source: adapted from Watson et al., 2008[24]

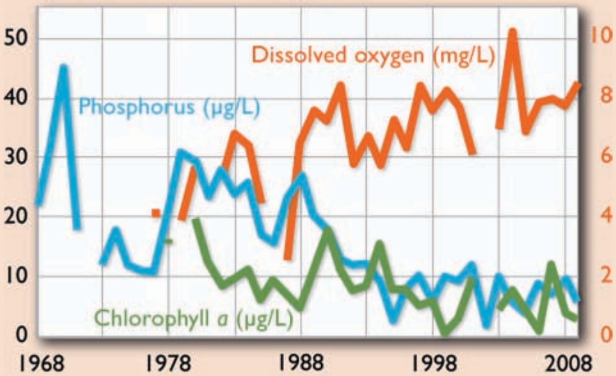


Significant decreases in chlorophytes (green algae) and increases in cyanobacteria (blue-green algae) have occurred from 2003 to 2005. Blue-green algae cause harmful algal blooms, green algae do not.
Source: Millie et al., 2009[25]

Michel Starr, Institut Maurice-Lamontagne, DFO

REDUCTIONS IN NUTRIENT LOADING IN SKAHA LAKE, B.C.

Micrograms/litre of phosphorus, chlorophyll *a* and milligrams/litre of dissolved oxygen, 1968 to 2008



Note: left axis is phosphorus and chlorophll a*;*
right axis is dissolved oxygen.
Source: updated from Jensen and Epp, 2002[26]

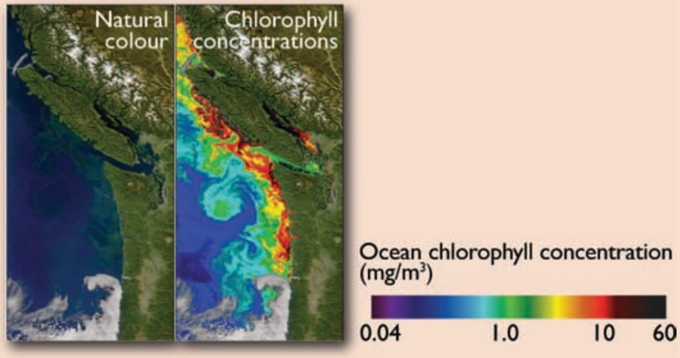
The Okanagan River Basin drains through a chain of lakes in the southern interior of B.C., ultimately leading to the Columbia River. Since the early 1970s, controls have been introduced to reduce nutrient pollution in the region, with the most significant reductions made in agricultural and sewage treatment inputs. This has resulted in significant declines in phytoplankton (measured as chlorophyll *a*) and phosphorous and an increase in dissolved oxygen. Skaha Lake is one of the lakes in the Okanagan where nutrient loading has been reduced.

HARMFUL ALGAL BLOOMS IN THE OCEANS

In marine systems, blooms of toxic phytoplankton are referred to as either red tides or harmful algal blooms. They can cause severe health effects in humans and they are also responsible for extensive mortality of fish and shellfish. They have been implicated in episodic mortalities of marine mammals, seabirds, and other animals dependent on the marine food web. Since the 1970s, harmful algal blooms have occurred more frequently, increased in size, and expanded their global distribution.[5]

The Bay of Fundy has a long history of algal blooms. Extended periods of low wind, fog, and warmer water conditions in the summer are conducive to algal blooms, which can discolour the water, form red tides, and result in shellfish toxicities harmful to the health of animal and human consumers.[27]

Harmful algal blooms have appeared in recent years on the west coast of North America, including the west coast of Vancouver Island. These algal blooms may be associated with declines in dissolved oxygen observed over the past 25 years. Massive fish kills, associated with these algal blooms, have been observed off the Washington and Oregon coasts but not off the west coast of Canada.[28]



Note: toxic algal bloom off the west coast of Vancouver Island and Washington State. Left is the natural colour; right has been enhanced to reveal chlorophyll concentrations.
Source: NASA, Earth Observatory, 2009[29]

ACID DEPOSITION

KEY FINDING 13. Thresholds related to ecological impact of acid deposition, including acid rain, are exceeded in some areas, acidifying emissions are increasing in some areas, and biological recovery has not kept pace with emission reductions in other areas.

Status and Trends

for eastern Canada, improving; for some parts of western Canada, getting worse

trends are clear

Acid deposition, sometimes referred to as acid rain, is produced when sulphur and nitrogen-based pollutants react with water in the atmosphere and are deposited on the Earth's surface.[1] More than just acid rain, it includes acidifying gases and dry particles. The pollutants originate from industrial processes and can travel thousands of kilometres. It is the combination of acid deposition and the sensitivity of the land, water, flora, and fauna to acid that determines the severity of the impact on biodiversity. **Acid deposition is important** because algae, invertebrates, fish, amphibians, and birds are affected by increased acidity through reduced survival, growth and reproductive success, and loss or alteration of prey species.[1-6] The acidification of aquatic systems can lead to increases in methylmercury, which bioaccumulates, affecting embryos and young animals.[7-10] Acidification may also negatively affect the growth rate and health of trees, for example, sugar maple and red spruce in northeastern North America.[11, 12]

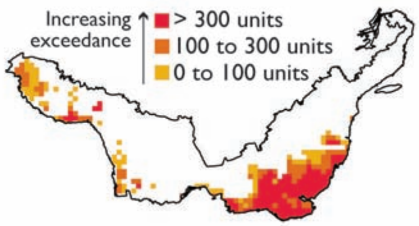
Terrain sensitivity and thresholds

Ecosystems have different sensitivities to acid depending upon their geology and soils. Thus the maximum level of acid deposition that terrain can withstand without harming ecological integrity, called the "critical load," differs across ecosystems.[13] Acid-sensitive terrain is generally underlain by slightly soluble bedrock and overlain by thin, glacially derived soils[14] and has less buffering capacity.

Critical loads can be exceeded either when extremely sensitive terrain receives low levels of acid deposition or when less-sensitive terrain receives high levels of acid deposition. The inset map shows where critical loads have been exceeded in the Boreal Shield Ecozone+. The potential for critical loads to be exceeded in northwest Saskatchewan is also a concern due to the high degree of acid sensitivity of many of the lakes in this area (68% of 259 lakes assessed in 2007/2008) and its location downwind of acidifying emissions from oil and gas developments.[15] Similarly, transportation-related sulphur emissions in southwest B.C. are an emerging issue, with terrestrial critical loads exceeded in 32% of the Georgia Basin in 2005/2006.[16]

AREAS WHERE THE CRITICAL LOAD HAS BEEN EXCEEDED IN THE BOREAL SHIELD

Number of units above critical load, 2009

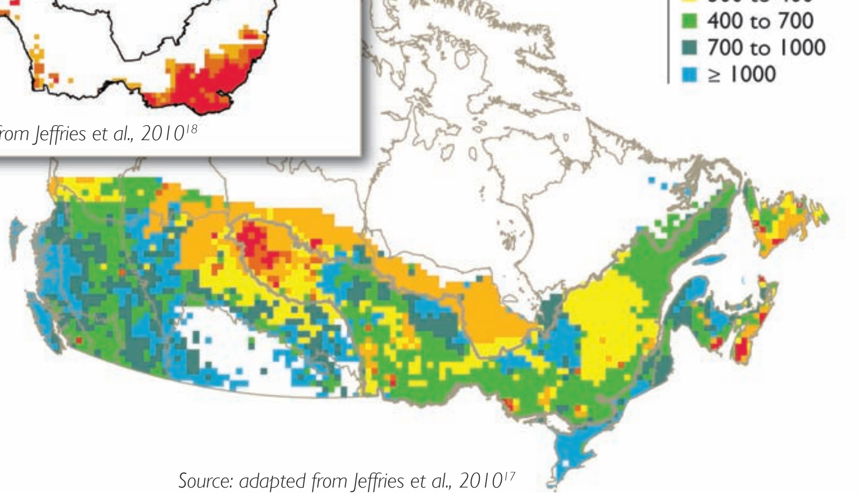


Source: adapted from Jeffries et al., 2010[18]

SENSITIVITY OF TERRAIN TO ACIDITY

Critical load index, 2008

Yellow through red categories are considered acid sensitive terrain

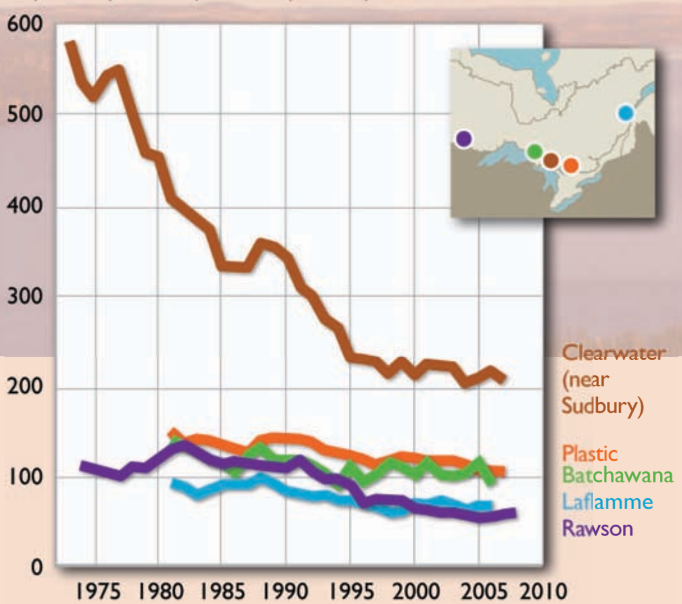


Source: adapted from Jeffries et al., 2010[17]

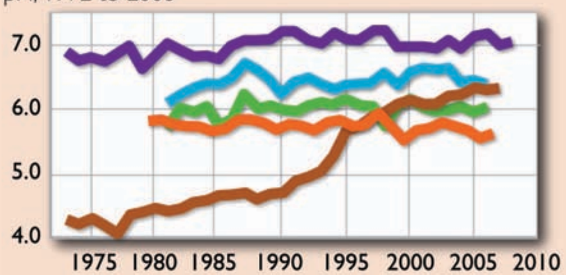
Roy Neureuther, EC/WS&T

TRENDS IN SULPHATE LEVELS AND ACIDITY IN BOREAL SHIELD LAKES

Sulphates (micro-equivalents per litre), 1972 to 2008



pH, 1972 to 2008



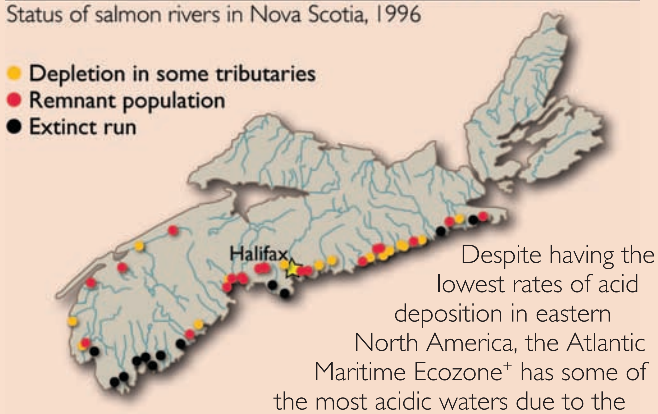
The response of Clearwater Lake is related to its proximity to the sulphur dioxide emission sources at Sudbury.
Source: adapted from Jeffries et al., 2003[19]

From 1980 to 2006, sulphur dioxide emissions in Canada and the U.S. declined by about 45% and emissions of nitrogen oxides declined by about 19%.[20] Although significant declines in lake sulphates followed closely behind the emission reductions,[19-21] the response of lake acidity, measured by pH, has been slow and less widespread, due in part to declines in calcium which are also related to acid deposition.[20] Declines in calcium also threaten keystone zooplankton species.[22]

Encouraging biological improvements have been seen in some locations.[1, 21, 23-26] Even with chemical recovery, however, biological communities are likely to remain altered from their pre-acidification state because many factors beyond acidity influence biological recovery.[23, 27]

IMPACT OF ACIDIFICATION ON ATLANTIC SALMON

Status of salmon rivers in Nova Scotia, 1996



Source: adapted from Watt et al., 2000[28]

Despite having the lowest rates of acid deposition in eastern North America, the Atlantic Maritime Ecozone+ has some of the most acidic waters due to the poor buffering ability of the terrain.[29, 30] There has been no measurable change in pH despite declines in sulphur dioxide emissions. This has resulted in the most heavily impacted fish habitat in North America.[29] Atlantic salmon are highly sensitive to acidity, and by 1996, 14 runs in coastal Nova Scotia were extinct because of water acidity, 20 were severely impacted, and a further 15 were lightly impacted.[28] Recovery of water chemistry and ecology is expected to take several more decades in Nova Scotia than in other parts of Canada.[28-30]

Global Trends

Once recognized as a problem only in Europe and parts of North America, acid deposition is now also an environmental issue in Asia and Pacific regions.[31] Significant reductions in sulphur emissions have been achieved in parts of Europe.[32]

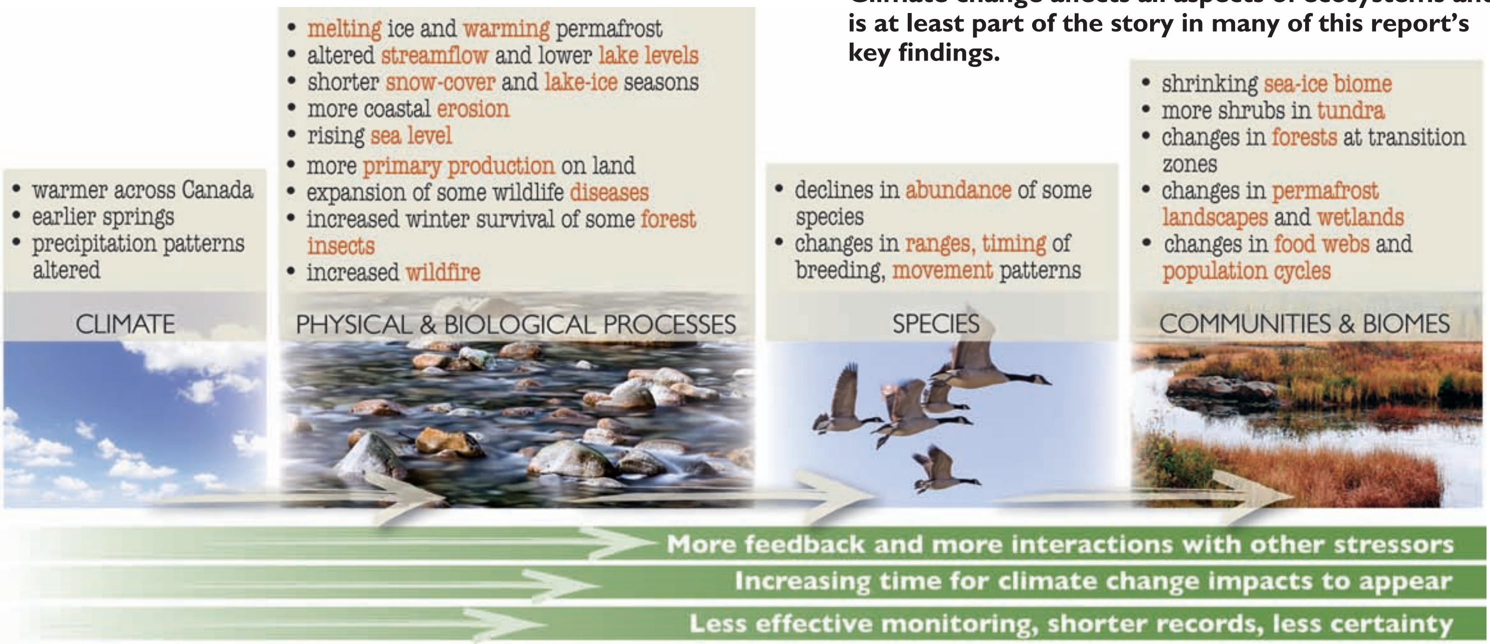
CLIMATE CHANGE

KEY FINDING 14. Rising temperatures across Canada, along with changes in other climatic variables over the past 50 years, have had both direct and indirect impacts on biodiversity in terrestrial, freshwater, and marine systems.

Status and Trends	
rapid warming trend (status deteriorating) with widespread biodiversity impacts	
some good data but often poor spatial and temporal coverage; trends are clear	
in many ecosystems, impacts are just starting to become apparent	

Climate change includes a rise in global temperatures and more frequent extreme weather events, due to human activities that alter the chemical composition of the atmosphere through the buildup of greenhouse gases that trap heat and radiate it back to the earth's surface.[1] **Climate change is important** because climate shapes the distribution of organisms and the nature and character of ecosystems.[2] Projected increases in temperature may exceed biological tolerances for many species and ecosystems in Canada, resulting in decreased capacity to recover from disturbances and increased risk of extinction for many species.[3]

Climate change affects all aspects of ecosystems and is at least part of the story in many of this report's key findings.



Photos: iStock.com

Global Trends

From 1906 to 2005, average global surface temperature rose by 0.74°C. The warming is widespread around the world, is greater in northern latitudes, and has been faster on land than in the oceans. Global average sea level has risen since 1961 at an average rate of 1.8 mm per year, increasing since 1993 to 3.1 mm per year.

Research provides us with understanding of how climate change affects ecosystems. Global climate models provide us with projections for future climates. Evidence of trends and abrupt changes, early warnings of deviations from established patterns, and local observations of ecological change, show us that impacts are happening now.

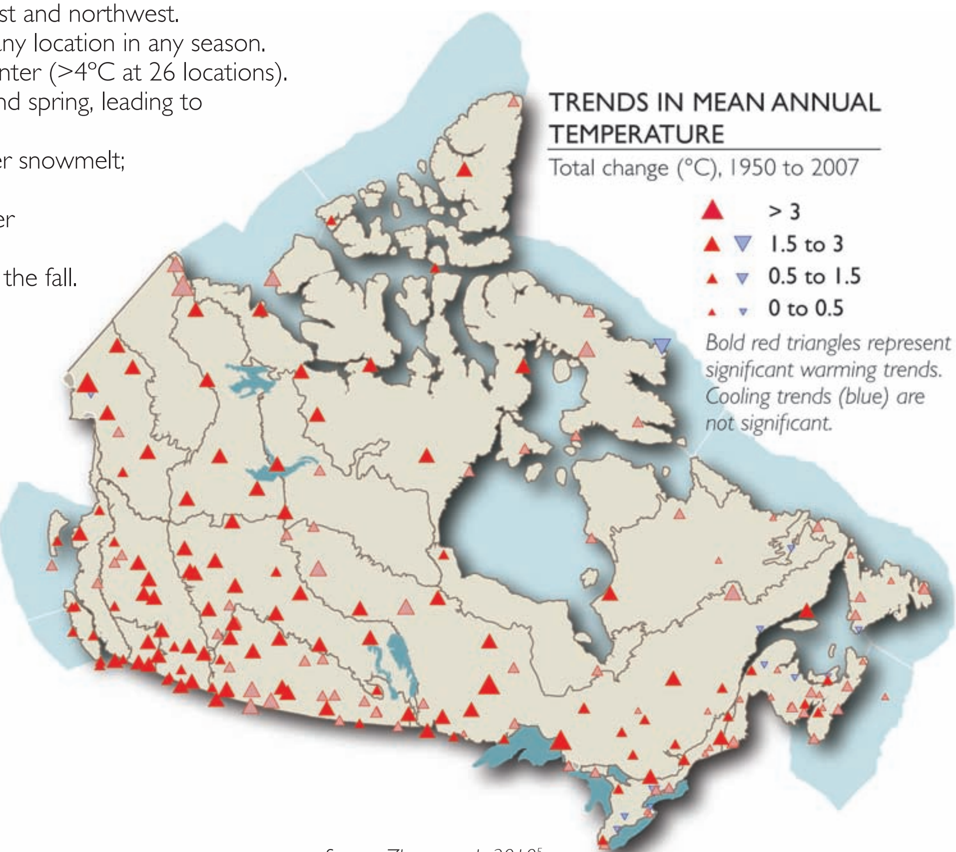
Climate trends for Canada, 1950 to 2007[5]

Temperature

- Average annual air temperature increased by 1.4°C.
- Strongest warming (>2°C) was in the west and northwest.
- No significant cooling trend occurred at any location in any season.
- Largest temperature increases were in winter (>4°C at 26 locations).
- Warming was most prevalent in winter and spring, leading to widespread:
  - decrease in winter snowpack and earlier snowmelt;
  - earlier start to the growing season.
- Summer warming trends were mainly over southwestern and southeastern Canada.
- Smallest temperature change occurred in the fall.

Precipitation

- Annual precipitation generally increased, most strongly in the northern half of Canada.
- Precipitation increased over the Arctic in all seasons except summer.
- Winter precipitation decreased in southwestern and southeastern Canada.
- The fraction of precipitation falling as snow decreased in southern Canada.



Source: Zhang et al., 2010[5]

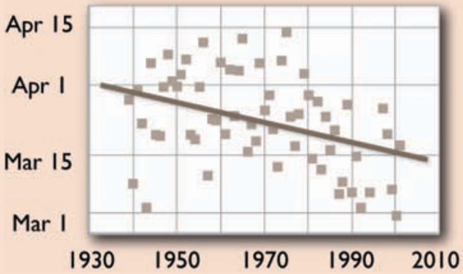
CLIMATE CHANGE

Earlier springs lead to changes in timing of bird migration and nesting

The trend to earlier, warmer springs appears to be leading to earlier arrival at prairie nesting grounds for some waterfowl and earlier hatching for some seabirds.

CANADA GEESE ARRIVAL DATES, DELTA MARSH

1939 to 2001

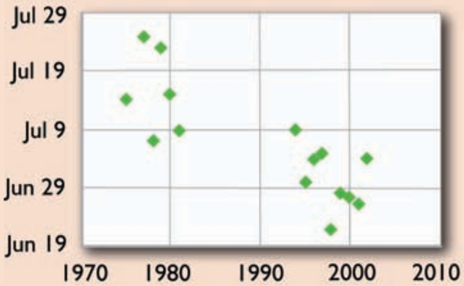


Source: adapted from Murphy-Klassen et al., 2005[6]

Timing of annual arrival at Delta Marsh, along the shore of Lake Manitoba, was strongly related to the average March temperature for about half of the 96 migratory bird species studied, including Canada geese. Spring arrival dates of most of these species shifted earlier at rates of 0.6 to 2.6 days for each 1°C rise in average March temperature.[6]

HATCHING DATES FOR TUFTED PUFFINS, TRIANGLE ISLAND

1975 to 2002



Source: adapted from Gjerdrum et al., 2003[7] *and Gaston et al., 2009*[8]

Tufted puffins, rhinoceros auklets, and Cassin's auklets at Triangle Island off the B.C. coast have shifted to an earlier breeding season in the past 30 years. The populations of these burrow-nesting seabirds declined from 1984 to 2004, likely due to changes in ocean conditions. The declines may be partly caused by a mismatch between timing of nest hatching and peak food availability, as has been confirmed for Cassin's auklets.[8]

MOVING NORTH

There are many observations throughout the country of shifts in species ranges, generally northward. Many of these shifts are likely related to climate change. Some examples include:

- The northern limit of the breeding range of landbirds that breed in southern Canada moved northward by an average of 2.4 km per year from 1964 to 2002 – for example, Swainson's thrush has extended its range 141 km northward over this period.[9]
- Declining sea ice in Arctic straits has led to killer whales expanding their range into Hudson Bay where they are now sighted every summer.[10]
- Northward range shifts have been noted since the 1960s in the Northwest Territories for white-tailed deer, coyote, wood bison, cougar, magpies, and the winter tick parasite.[11, 12]
- White-tailed deer have been expanding northward from B.C. to Yukon since 1974 and now range as far north as central Yukon.[13] They have also been observed to be expanding northward in Saskatchewan, Quebec, and Ontario.[14, 15]
- The Inuvialuit of Banks Island in the Arctic have noted new species of beetles and sand flies. Robins and barn swallows are also new to the region.[16]
- Northward expansion of racoons into the Prairies during the 20th century may be linked to longer growing seasons along with increased agricultural production.[17]

International Tundra Experiment (ITEX) site, showing open-topped greenhouses, Alexandra Fiord, Ellesmere Island, Nunavut

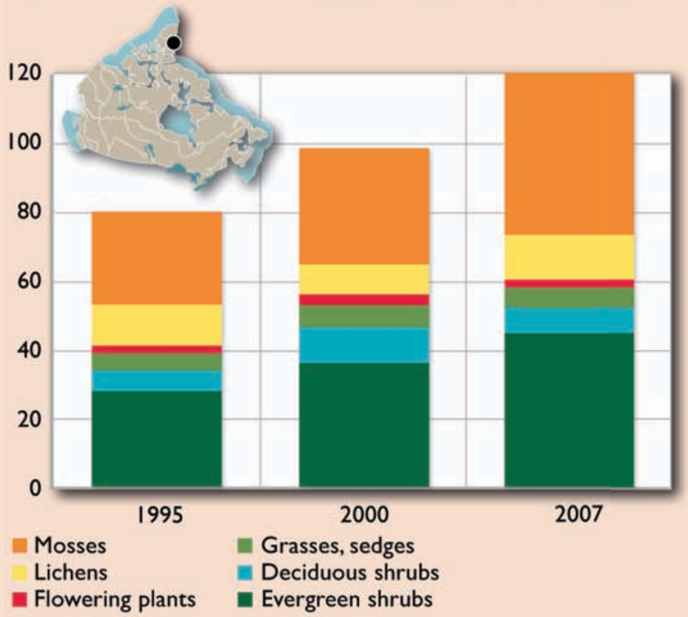
Warmer temperatures lead to changes in the tundra biome

Evidence from around the circumpolar Arctic indicates that tundra is changing.[18, 19] Climate records show that the particular conditions of cold temperatures and low precipitation needed to support polar tundra, barrens, and ice and snow biomes declined about 20% in the past 25 years.[20] This trend is linked with increases in primary productivity and increased biomass in tundra plant communities. This "greening" signal is particularly strong in the Canadian Western Arctic where there is evidence of shrub cover increasing in the forest-tundra and adjacent tundra. Studies based on satellite images from 1986 to 2005 along the treeline zone west of Hudson Bay show trends to increased shrubbiness, especially west of the Mackenzie Delta.[21] In the delta, the combination of warming temperatures and increasing permafrost degradation is creating new growing conditions suitable for colonization by tall deciduous shrubs such as alder.[21]

Several sites in Canada conduct research and monitoring on changes in tundra through the International Tundra Experiment (ITEX). Analysis of vegetation plots from ITEX sites around the circumpolar Arctic shows that, although changes vary from region to region, increases in vegetation canopy height and dominance of shrubs are common findings.[22] The ITEX program also includes passive warming experiments using small, open-topped greenhouses (see photograph) which increase plant-level air temperature by 1 to 3°C. Analysis of 11 ITEX warming experiments from around the Arctic indicates that future trends in tundra are likely to include increases in canopy height, changes in species composition and abundance, and reduction in species diversity.[23]

INCREASES IN EVERGREEN SHRUBS AND MOSSES, ELLESMERE ISLAND, NUNAVUT

Index of the mass of different vegetation categories, 1995 to 2007



Source: adapted from Hudson and Henry, 2009[22]

High Arctic tundra at the ITEX site on Ellesmere Island has become more productive, with biomass increasing by 50% over 13 years. This change was mainly due to an increase in growth of evergreen shrubs and moss. Because of the greater shrub growth, average canopy height increased, doubling from 17 to 34 cm between 2000 and 2007. Species diversity did not change.[22]

ECOSYSTEM SERVICES

KEY FINDING 15. Canada is well endowed with a natural environment that provides ecosystem services upon which our quality of life depends. In some areas where stressors have impaired ecosystem function, the cost of maintaining ecosystem services is high and deterioration in quantity, quality, and access to ecosystem services is evident.

Status and Trends

some deteriorations noted – status and trends vary with the specific ecosystem service in question

some good, relevant data, but little that measures trends of ecosystem services; understanding of topic beginning to grow

Ecosystems provide the direct goods and indirect services that ensure human well-being. These are collectively referred to as **ecosystem services**. Ecosystem services include: **regulating services**, such as the mitigation of flood and drought, the filtration of air and water, and the control of pest populations; **provisioning services**, such as food, fibre, and water; **cultural services**, such as education, recreation, psychological health, and spiritual experience; and the **supporting services** necessary for the production of all other ecosystem services, such as soil formation and nutrient cycling.[1]

Ecosystem services are important because they provide critical life support, they underpin our economy and quality of life, and the full suite of services cannot be duplicated with human-made alternatives.

SOME OBSERVED TRENDS THAT AFFECT ECOSYSTEM SERVICES

Examples of changes in biomes, habitat, wildlife, and ecosystem processes presented in other key findings that affect ecosystem services, as viewed through the Millennium Ecosystem Assessment framework[1]

REGULATING

- increasing temperature and changing precipitation patterns
- changes in wetlands
- melting ice and warming permafrost
- changes in river flows
- increasing coastal erosion
- increasing spread of wildlife diseases and parasites

PROVISIONING

- declining extent and abundance of most caribou populations
- declining abundance in certain commercial fisheries
- stable extent of forests
- declining legacy contaminants in wildlife, including harvest species, but increasing emerging contaminants

CULTURAL

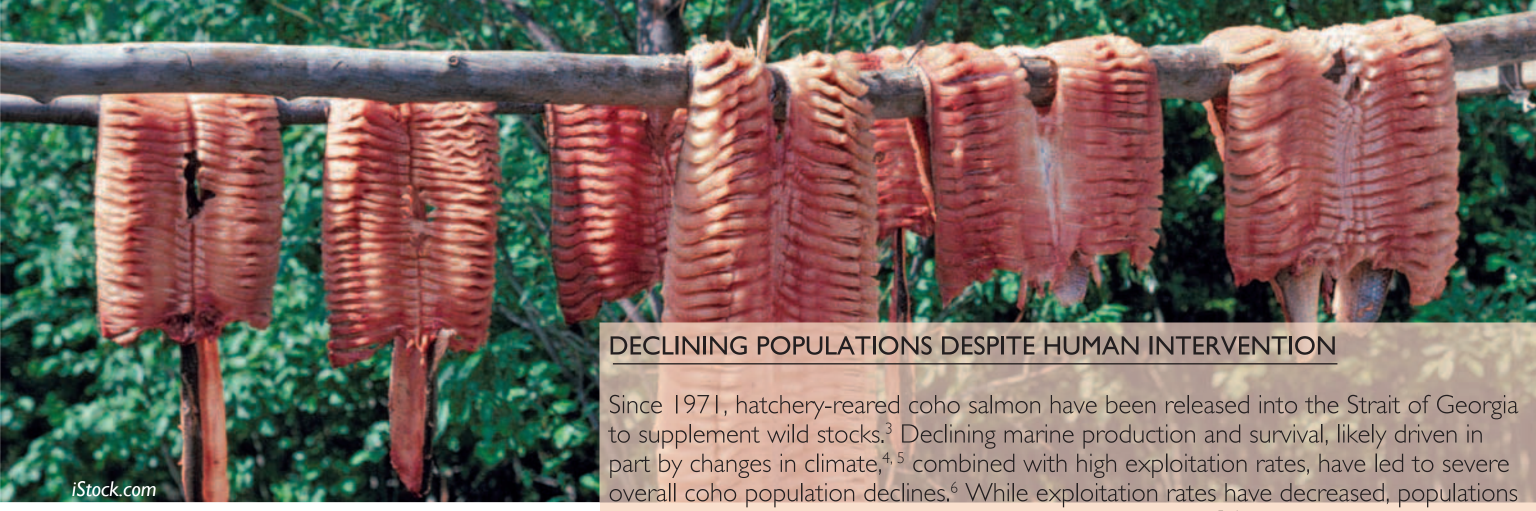
- changing availability and quality of traditional/country foods that can affect cultural traditions
- increasing stewardship initiatives on private lands
- increasing terrestrial protected areas
- little progress in marine protected areas
- decline in birds
- increasing frequency of algal blooms in many lakes

SUPPORTING

- fundamental changes in marine food webs
- greater primary productivity on land
- declining extent and condition of some forests, grasslands, and wetlands, affecting soils and nutrients
- melting ice and warming and thawing permafrost
- changes in nutrient loads
- changing climate

Global Trends

Approximately 60% of ecosystem services globally are being degraded or used unsustainably, including 70% of provisioning services.[2]



Provisioning services

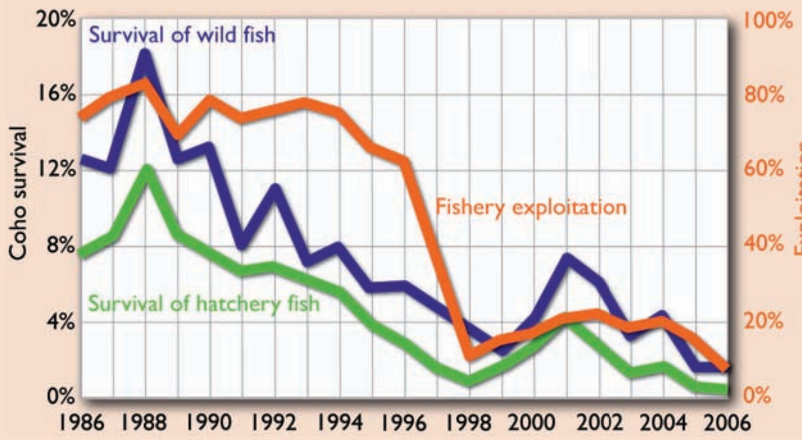
A range of ecosystem characteristics and socio-economic factors impact the delivery and maintenance of ecosystem services. While changes in provisioning services are usually the most obvious, they often result from changes in regulating and supporting services and can be closely tied to changes in cultural services. Many ecosystem services are complementary, with changes in multiple services being driven by a common factor. The following examples illustrate some types of threats to the ongoing provision of ecosystem services in Canada.

DECLINING POPULATIONS DESPITE HUMAN INTERVENTION

Since 1971, hatchery-reared coho salmon have been released into the Strait of Georgia to supplement wild stocks.[3] Declining marine production and survival, likely driven in part by changes in climate,[4,5] combined with high exploitation rates, have led to severe overall coho population declines.[6] While exploitation rates have decreased, populations have not recovered and overall abundance is still declining.[5,6]

MARINE SURVIVAL AND EXPLOITATION OF COHO IN THE GEORGIA STRAIT, B.C.

Percent survival and percent adults caught (exploitation), 1986 to 2006

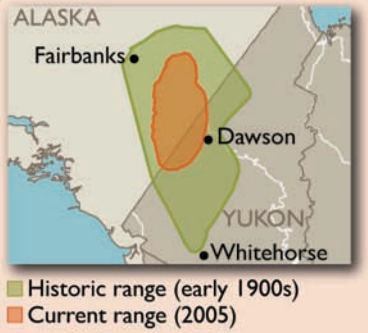


Source: updated from Simpson et al., 2001[7]

CONTRACTING RANGES AND SHRINKING POPULATIONS

The Fortymile caribou herd, once an important source of food and supplies for people in Yukon, declined from a population of 500,000 in the early 1900s to 7,000 in the late 1960s.[8] Declines were likely the result of bad winters, overharvesting, and fragmentation of the landscape. The population has rebounded to 43,000 since the early 1980s, attributed mainly to harvest restrictions and a wolf control program. The range of the herd is now a fraction of its historical extent, with the caribou rarely crossing the border into Canada.[8]

FORTYMILE CARIBOU HERD



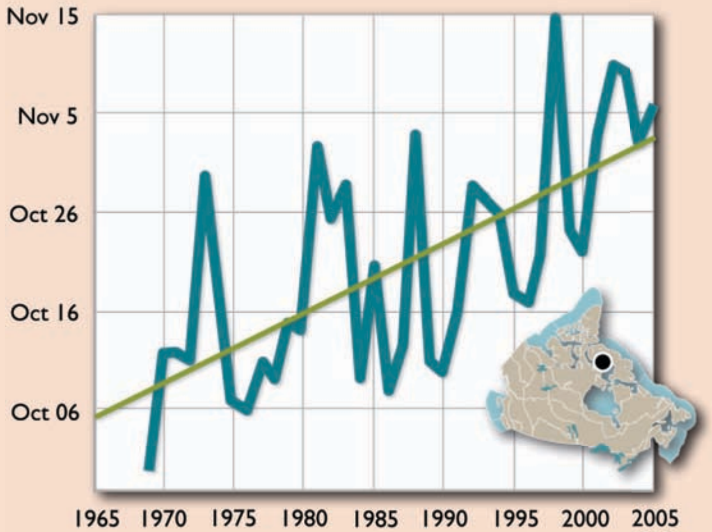
Source: adapted from Environment Yukon, 2005[8]

CHANGING ENVIRONMENTAL CONDITIONS

Changing sea-ice conditions have significant impacts on northern communities that depend on ice for harvest activities. Residents of Igloolik Island, for example, are essentially cut off from their surroundings while the ice is forming, unable to travel to harvest sites located off the island.[9] Freeze-up is starting significantly later in the year and it is taking longer for ice to fully form.[10] Igloolik residents are highly dependent on subsistence harvesting but there are limited opportunities on the island. As a result, residents are taking increasing risks to harvest seals at ice edges and are travelling across unstable ice to harvest caribou on the mainland. Similar decreases in access related to ice conditions have been noted for the communities of Sachs Harbour,[11] Ulukhaktok,[12] and Churchill,[9] though the impact on residents is community-dependent.

SEA ICE FREEZE-UP, IGLOOLIK, NUNAVUT

Date of freeze-up, 1969 to 2005



Source: adapted from Laidler et al., 2009[10]

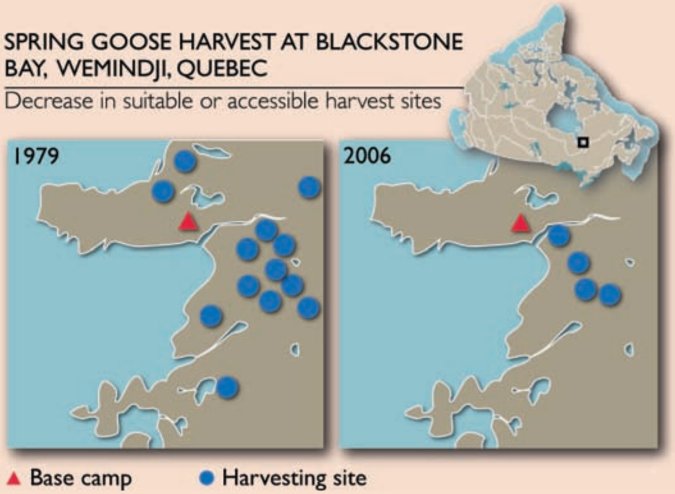
Other types of environmental change have also impaired access to provisioning services. For example, the development of the Lake Winnipeg Churchill-Nelson River diversion has reduced the ability of the Cree to navigate lakes and streams in order to harvest food and obtain supplies.[13]

CHANGING WILDLIFE BEHAVIOUR

Despite increases in the population of Canada geese in the eastern Taiga Shield since the mid-1990s,[14] success of the goose harvest among James Bay Cree has declined.[15] The Cree report that the geese fly higher and further inland and that the migration period is shorter in recent years. It is thought that these behavioural changes are caused by altered weather patterns, reduction of eelgrass meadows, and impacts from hydroelectric development.[16] Changes in goose behaviour are compounded by changes in environmental conditions during harvest, particularly less predictable spring ice break-up patterns on the coast. These factors combine to reduce the number of suitable or accessible harvest sites. Traditional harvest is based on the systematic rotation and "resting" of a number of harvest sites grouped around a base camp. A decrease in harvest sites, as shown between 1979 and 2006, leads to increased pressure on the remaining sites, further contributing to the problem.[16]

SPRING GOOSE HARVEST AT BLACKSTONE BAY, WEMINDJI, QUEBEC

Decrease in suitable or accessible harvest sites



Source: 1979 map adapted from Scott, 1983 in Peloquin, 2007;[16]
2006 map adapted from Peloquin, 2007[16]

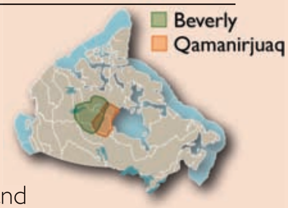

Tim Hagen

Holland Marsh, Ontario

Valuation of ecosystem services

Failure to recognize the economic value of healthy ecosystems has contributed to the continuing decline of biodiversity worldwide.[17] Duplication or replacement of ecosystem services with human-made alternatives is costly and can lack complementary services such as cultural value. Valuation of ecosystem services is a way to include biodiversity considerations in decision making about land use and economic activity and to measure the importance of biodiversity to people. The economic value of many provisioning services, such as the production of fish or timber, is often easily estimated because the products have well-defined prices. It is more complicated to place a value on non-market ecosystem services. A large-scale valuation study of ecosystems within the boreal region of Canada[18] provides a framework for more detailed valuations in specific areas.

VALUATION OF THE BEVERLY AND QAMANIRJUAQ CARIBOU HERDS



The relationship between people of northern Canada and caribou has developed over thousands of years and underpins many cultural values. People living in the range of the Beverly caribou herd, for example, have harvested caribou for approximately 8,000 years.[19]

An examination of the services provided by the Beverly and Qamanirjuaq caribou herds found that the value of harvest, including meat, hides, and antlers, is approximately $19.9 million per year.[20] Previous studies in the region, augmented with questionnaires and interviews, concluded that traditional harvest of caribou and associated activities were viewed by people throughout the range of the two herds as integral to the maintenance and transfer of knowledge, skills, and culture. Many people interviewed talked about how important the caribou harvest was to their identity and to the revitalization of their communities.[20]

The ecosystem services that people of the North derive from caribou are threatened. The Beverly herd has declined severely since the last survey in 1994.[21] As a result, people from northern Saskatchewan who traditionally harvest Beverly caribou have had to fly north or east for their harvest. These caribou may be from other declining herds, such as the Qamanirjuaq, Bathurst, or Ahiak.[21, 22]

ECOSYSTEM SERVICES OF ONTARIO'S GREENBELT

Ontario's *Greenbelt Act* of 2005 protected 7,604 km² of land from further urban development in the Golden Horseshoe region of southern Ontario. This area supports a quarter of Canada's population and is the fastest growing region in North America.[23] The greenbelt is made up of green spaces, farmlands, communities, forests, wetlands, and watersheds, and includes habitat for more than a third of Ontario's species at risk.[23]

The estimated total value of the area's measurable non-market ecosystem services is approximately $2.6 billion annually.[23] This estimate is likely low due to an incomplete understanding of all benefits provided by the greenbelt and the difficulty of assigning a value that represents and reflects the importance of the area to people. The value of the greenbelt is likely to increase with time as the ecosystems protected within it become increasingly rare.[23]

Ontario's greenbelt

Source: adapted from the Friends of the Greenbelt Foundation, 2009[24]

Ecosystem Service	Annual value (millions)
Habitat	$548
Flood control (wetlands)	$380
Carbon storage and uptake	$377
Agricultural pollination	$298
Water runoff control by forests	$278
Water filtration	$131
Natural regeneration	$98
Recreation and aesthetics	$95
Cultural/spiritual	$66
Biological control	$8
Soil formation	$6
Nutrient cycling	$2
Erosion control	$<1

Source: Wilson, 2008[23]

habitat, wildlife, and ecosystem processes

KEY FINDINGS

16. Agricultural landscapes as habitat The potential capacity of agricultural landscapes to support wildlife in Canada has declined over the past 20 years, largely due to the intensification of agriculture and loss of natural and semi-natural land cover.

17. Species of special interest: economic, cultural, or ecological Many species of amphibians, fish, birds, and large mammals are of special economic, cultural, or ecological interest to Canadians. Some of these are declining in number and distribution, some are stable, and others are healthy or recovering.

18. Primary productivity Primary productivity has increased on more than 20% of the vegetated land area of Canada over the past 20 years, as well as in some freshwater systems. The magnitude and timing of primary productivity are changing throughout the marine system.

19. Natural disturbances The dynamics of natural disturbance regimes, such as fire and native insect outbreaks, are changing and this is reshaping the landscape. The direction and degree of change vary.

20. Food webs Fundamental changes in relationships among species have been observed in marine, freshwater, and terrestrial environments. The loss or reduction of important components of food webs has greatly altered some ecosystems.

AGRICULTURAL LANDSCAPES AS HABITAT

Status and Trends

agricultural landscapes remain important as habitat but show signs of stress

only one indicator, but trend from indicator is clear

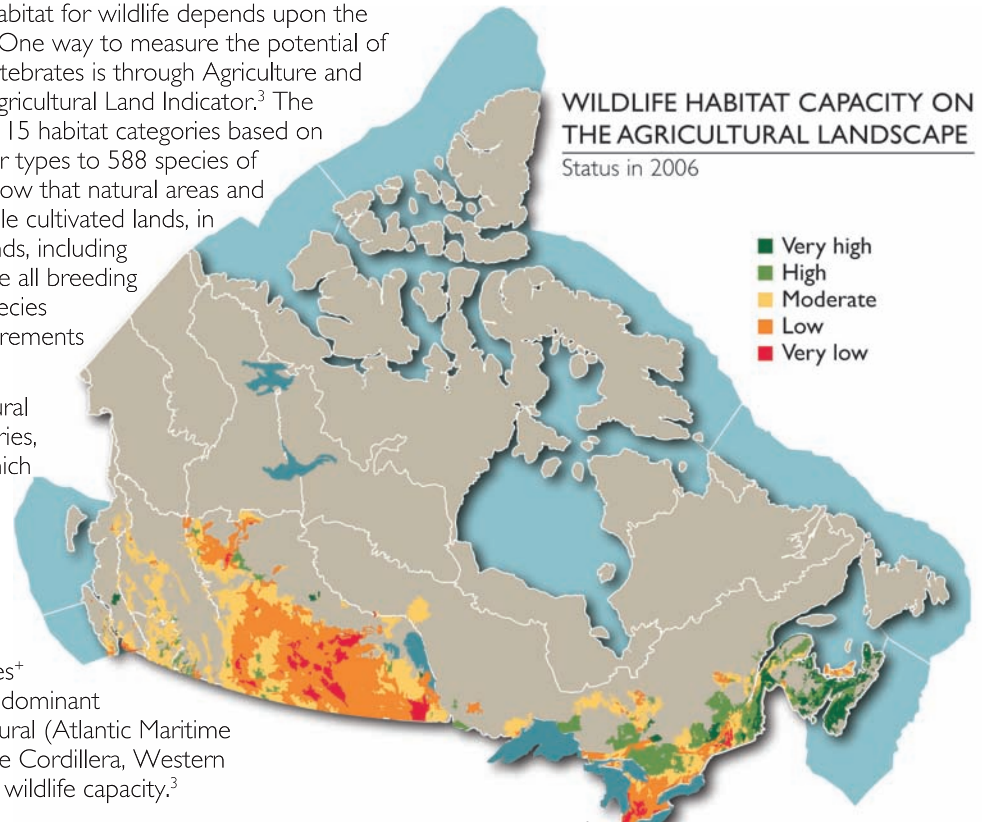
KEY FINDING 16. The potential capacity of agricultural landscapes to support wildlife in Canada has declined over the past 20 years, largely due to the intensification of agriculture and the loss of natural and semi-natural land cover.

Land within the **agricultural landscape** of Canada **includes** a variety of cover types – pasture and rangeland, summerfallow, 24 types of cropland, and woodlots, wetlands, windbreaks, and other non-farmed areas.[1, 2] **Agricultural landscapes are important** to biodiversity because they cover about 7% of Canada and provide habitat for over 550 species of terrestrial vertebrates,[3] including approximately half of those assessed in 2004 as at risk nationally.[4] Agricultural landscapes are concentrated in southern Canada, where biodiversity and numbers of species at risk are high and where ecosystem conversion is more extensive.

Wildlife Habitat Capacity Indicator

The capacity of agricultural landscapes to provide habitat for wildlife depends upon the mosaic of land-cover types and their management. One way to measure the potential of these lands to support populations of terrestrial vertebrates is through Agriculture and Agri-Food Canada's Wildlife Habitat Capacity on Agricultural Land Indicator.[3] The indicator ranks potential wildlife habitat capacity for 15 habitat categories based on an assessment of the use and value of 31 land-cover types to 588 species of birds, mammals, reptiles, and amphibians. Results show that natural areas and unimproved pasture provide the highest values, while cultivated lands, in particular croplands, provide the lowest. Natural lands, including woodlands, wetlands, and riparian areas, can provide all breeding and feeding habitat requirements for 75% of the species assessed, whereas croplands can only provide requirements for 13%.[3]

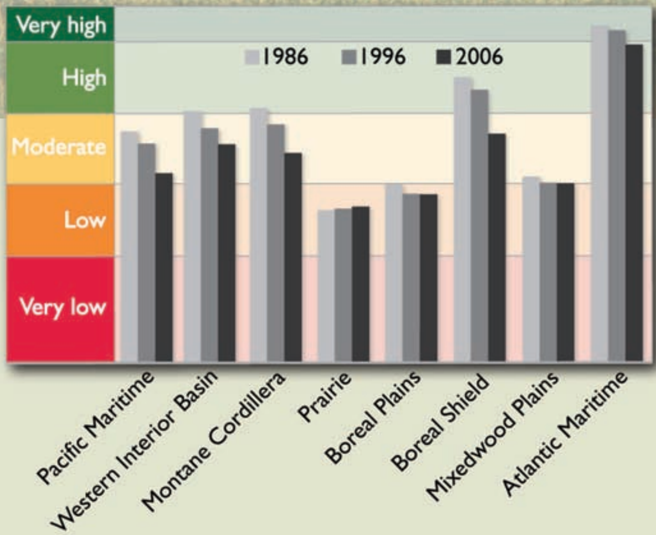
In 2006, the average potential ability of the agricultural landscape to support wildlife was lowest in the Prairies, Boreal Plains, and Mixedwood Plains ecozones[+], which together make up 92% of the agricultural landscape in Canada.[3] Trends for individual parcels of land are variable and depend upon changes in their particular use. Although individual parcels, particularly pasture, provide critical wildlife habitat, the dominance of cropland results in a low overall capacity for much of these ecozones[+]. The ecozones[+] where the agricultural footprint was lighter and the dominant land cover within the agricultural landscape was natural (Atlantic Maritime and Boreal Shield) or unimproved pasture (Montane Cordillera, Western Interior Basin, and Pacific Maritime) had the highest wildlife capacity.[3]



Source: adapted from Javorek and Grant, 2010[3]

CHANGE IN AVERAGE WILDLIFE HABITAT CAPACITY ON THE AGRICULTURAL LANDSCAPE BY ECOZONE+

Habitat capacity index, 1986 to 2006



Source: adapted from Javorek and Grant, 2010[3]

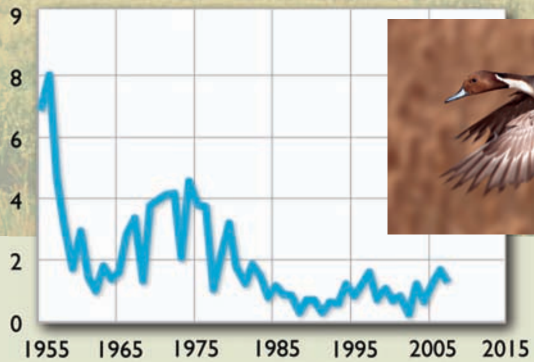
Trends

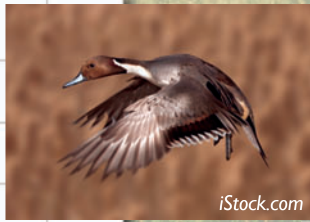
Average wildlife habitat capacity, considering both declines in capacity of some individual parcels and increases in others, declined significantly between 1986 and 2006 in all ecozones+ except the Prairies, where it remained low.[3] Conversion of small habitat parcels, such as on field margins in the Prairies,[5] are not always detected at this broad scale and could represent further degradation of habitat capacity.[3] Overall declines in Canada are due primarily to the intensification of farming and the conversion of natural lands to other land-cover types, such as cropland, that are less suitable to wildlife. From 1986 to 2006, the proportion of agricultural land classified as cropland increased from 46 to 53%.[3]

Management practices also influence the ability of the land to support wildlife and sound stewardship through best management practices has had positive results in some regions. The dynamic nature of agricultural landscapes results in beneficial and detrimental land-cover changes happening concurrently.

NORTHERN PINTAIL POPULATION, SOUTHERN CANADA

Millions, 1955 to 2007





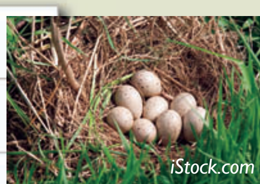
Source: U.S. Fish and Wildlife Service, 2007[6]

Intensification of agriculture in the Prairies over the last 40 years, including the decline of fallow land in summer and increased conversion to cropland, has impacted nest success of some species of breeding waterfowl.[7, 8] For example, a primary cause of the decline of northern pintail is their tendency to nest in standing stubble, mulched stubble, or fallow fields early in the season, often prior to seeding. The reduction of summerfallow and increase of spring-seeding since the 1970s[3] has been linked to reduced nest success and a decline in the Prairie northern pintail population.[9]

Farmers have been working with conservation agencies to reduce the impact of agricultural practices on waterfowl. The planting of winter wheat in the fall in a zero-till seeding practice eliminates the need for spring tillage, thereby reducing disruption to nesting ducks. Application of these practices has increased since the early 1990s[10, 11] (see Stewardship).

APPLICATION OF ZERO-TILL SEEDING PRACTICES IN SASKATCHEWAN

Percent of total hectares seeded, 1991 to 2006



Northern pintail nest in farmer's field

Source: Prairie Habitat Joint Venture, 2006[12]

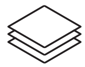
SPECIES OF SPECIAL INTEREST: Economic, Cultural, or Ecological

KEY FINDING 17. Many species of amphibians, fish, birds, and large mammals are of special economic, cultural, or ecological interest to Canadians. Some of these are declining in number and distribution, some are stable, and others are healthy or recovering.

Status and Trends

overall showing signs of stress; some improving, some deteriorating, and others unchanged

good data for some species in some areas showing clear trends; poor data for others



decline in amphibians and common landbirds

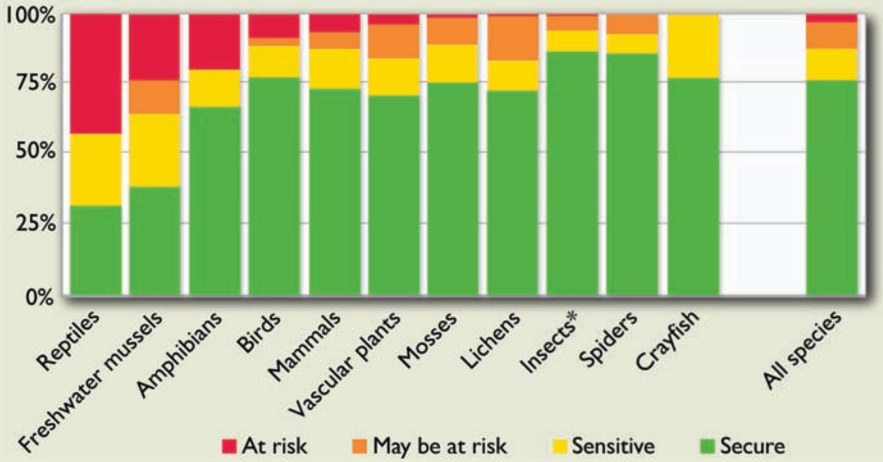
Species of special interest are those with particular relevance to Canadians because of their special economic, cultural, or ecological importance in addition to their biodiversity value. Some groups of species, for example fishes, are important because the economy of a region depends upon them. Others, like caribou, have widespread cultural significance.

These species are important because population declines often mean a loss of traditional lifestyles or a decline in economic sustainability. Species of special ecological importance play critical roles in shaping the ecosystems in which they live or provide early warnings of ecosystem stress.

This key finding provides a brief overview of wildlife status in Canada and then focuses on amphibians, fishes using freshwater, birds, and caribou. More information on status of wildlife in Canada can be found in a complementary Canadian Biodiversity report, *Wild Species 2010: the General Status of Species in Canada.*[1] More information on species at risk in Canada is provided by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC)[2], on the Species at Risk Public Registry,[3] and through provincial and territorial status committees.

STATUS OF WILDLIFE IN CANADA

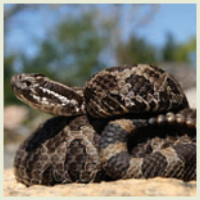
Percent of native species assessed, 2010
Data for fishes were not available for 2010



** Insects have not been fully assessed. Assessed groups include butterflies, mosquitoes, horse flies, black flies, bumblebees, lady beetles, ground beetles, predaceous diving beetles, odonates, and selected macromoths.*
Source: adapted from Canadian Endangered Species Conservation Council (CESCC), in press[1]

Canada is home to over 70,000 wild species. The risk of endangerment has been determined for 10,332 of these species, 8,613 of which are native. Seventy-seven percent of assessed native species were considered secure in 2010 and 12% were classified as At Risk or May be at Risk. Reptiles, freshwater mussels, and amphibians have the greatest percent of species at risk at 43, 24, and 20% respectively. In addition to these 8,613 species, Canada has assessed 5 Extinct, 35 Extirpated, and 1,426 non-native species, and 253 species outside their usual ranges. The major threats to Canadian wildlife are habitat loss, fragmentation and degradation, pollution and contamination, overexploitation, invasive species, disease, by-catch, and climate change.[1]

Canadian tiger swallowtail, Secure



Eastern massasauga rattlesnake, Threatened

Bunchberry, Secure

Photos: iStock.com

AMPHIBIANS

Amphibians are an integral part of aquatic food webs, feeding on algae and insects at different life stages and serving as food for a wide range of predators, including dragonflies, fish, snakes, and birds. They are particularly sensitive to pollutants absorbed through their skin, which makes them good indicators of wetland contamination and degradation.[1]

In the Great Lakes Basin, four amphibian species, American toad, western chorus frog, northern leopard frog, and green frog, may have declined since the mid-1990s. Spring peeper is the only species out of eight monitored that has been increasing. However, the timeline is too short to be certain that these are long-term trends and not part of natural variation.[1] In the St. Lawrence River, 27% of amphibians and reptiles are at risk within the highly developed river corridor.[2] The northern leopard frog is considered Threatened in Alberta, red-listed in B.C., and assessed as Endangered (Rocky Mountain population), Special Concern (Western Boreal/Prairie populations) or Not At Risk (Manitoba and eastern populations) by COSEWIC.[3]

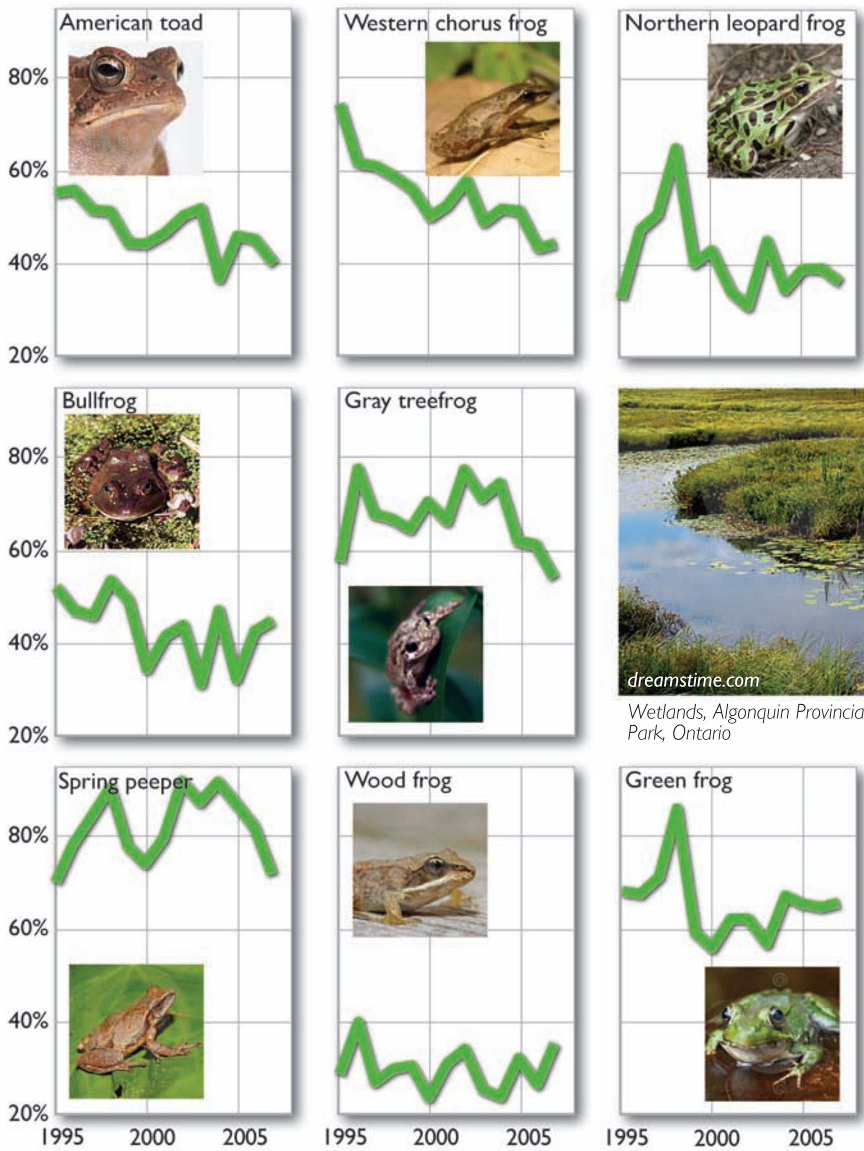
Batrachochytrium dendrobatids (Bd), a chytrid fungus of the skin, has been implicated in worldwide amphibian declines[4] (see Invasive Non-native Species). Ranaviruses have also been responsible for mass die-offs of amphibians worldwide.[5] Canada's Boreal Shield,[6] Prairies,[7] and Mixedwood Plains[6, 8] ecozones+ have documented cases of ranaviruses.

Global Trends

As of 2004, 43% of amphibian populations were in decline and 33% of all amphibian species were globally threatened. The dominant causes of declines worldwide are habitat reduction (North America and Europe), over-exploitation (Asia), and unexplained causes, possibly linked to disease (South America, Australia, and New Zealand).[9]

AMPHIBIANS IN THE GREAT LAKES BASIN

Annual occurrence index (percent of monitoring stations where the species was recorded) 1995 to 2007



Wetlands, Algonquin Provincial Park, Ontario

Source: Archer et al., 2009[1]

Photos: dreamstime.com: American toad, Spring peeper, Wood frog, and Green frog; and iStock.com: Western chorus frog, Northern leopard frog, Bullfrog, and Gray treefrog

SPECIES OF SPECIAL INTEREST

FISHES USING FRESHWATER HABITAT

Fishes occur in almost all aquatic habitats and represent the largest group of vertebrates in the world.[1] Although freshwater is relatively scarce globally, covering only 1% of the Earth's surface, about 43% of the 29,000 to 32,000 fish species live in freshwater for at least part of their lives.[2, 3] With over 8,500 rivers and two million lakes, covering almost 9% of the total land area,[4] Canada has a disproportionate amount of the global freshwater habitat, but only about 200 species of native freshwater and diadromous fish. (Diadromous fishes use both marine and freshwater.[2])

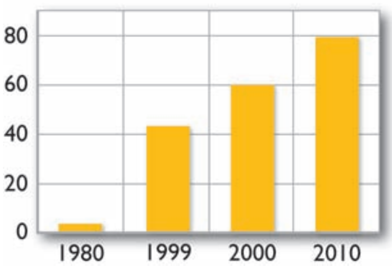
Fishes are among the world's most important natural resources, providing numerous goods and services, including an annual global harvest of 92 million tonnes; 10.1 million tonnes from inland waters, most of which is freshwater.[5] The commercial freshwater harvest in Canada is over 32,000 tonnes and valued at almost $68 million.[6]

Native freshwater and diadromous fishes at risk

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) has assessed 18% (35 species) of freshwater and diadromous fishes as Endangered or Threatened throughout all or parts of their ranges. Fifty-eight species (29%) have been assessed as at risk, which includes species assessed as Extirpated and of Special Concern, as well as those that are Endangered or Threatened.[7-9] The number of fishes at risk has been growing since the 1980s. The leading causes of declines in Canadian freshwater fishes are habitat loss and habitat fragmentation – caused by dams, weirs, roads and degradation of the riparian zone – and non-native aquatic species.[3, 10-12] Overfishing, pollution, climate change, and interactions between wild and farmed species are also linked to declining populations of freshwater fishes.[2]

FRESHWATER AND DIADROMOUS FISHES AT RISK

Number of Extirpated, Endangered, Threatened, or Special Concern species



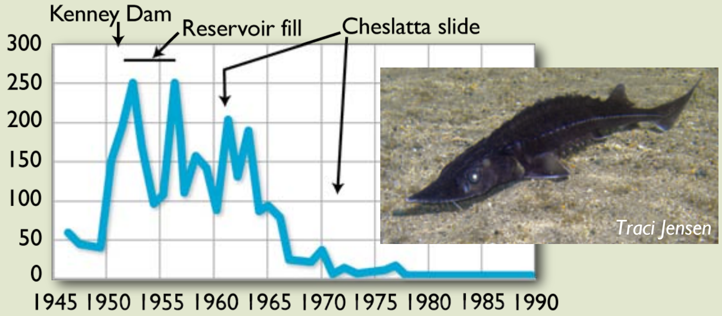
Note: Diadromous fish use both marine and freshwater. Trends reflect a combination of changes in the condition of species as well as the addition of new information.
Source: data compiled by Hutchings, 2010[8] from Hutchings and Festa-Bianchet, 2009[7] and COSEWIC, 2010[9]

STURGEON, SPECIES AT RISK

All 24 species of sturgeon in the world are at risk, although definitions of "at risk" vary. Two of the five species in Canada are classified as Endangered or Threatened.[13] White sturgeon, the largest freshwater fish in Canada, is restricted to the west coast of North America.[14] Its size (up to 6 metres), longevity (over 100 years), and late maturity (14 to 30 years), make it especially vulnerable to overexploitation and habitat degradation.[15] Of the six B.C. white sturgeon populations, three are declining (Columbia, Kootenay, Nechako), one is now more stable, with some fluctuations (lower Fraser), and two are stable (mid and upper Fraser). Poor juvenile survival, linked to river diversions, changes in sediment quantity and quality, and water flow regulation, associated with dams, are the primary reasons for endangerment of the three declining populations.[15, 16]

WHITE STURGEON, NECHAKO RIVER POPULATIONS

Juvenile production, 1945 to 1990



Source: McAdam et al., 2005[16]

Lake sturgeon once sustained large commercial fisheries. Reductions of 50 to 98% have been observed in western Canadian rivers and lake sturgeon have disappeared from the Red-Assiniboine River and Lake Winnipeg. Great Lakes populations have been reduced to a fraction of their original size, and populations in the Ottawa and St. Lawrence rivers are showing recent declines. Before the turn of the century, overfishing was the main threat to lake sturgeon. In recent years, declines are attributed to habitat fragmentation and degradation in the Great Lakes, as well as overfishing, dams, contaminants, and invasive species elsewhere.[13]

Global Trends

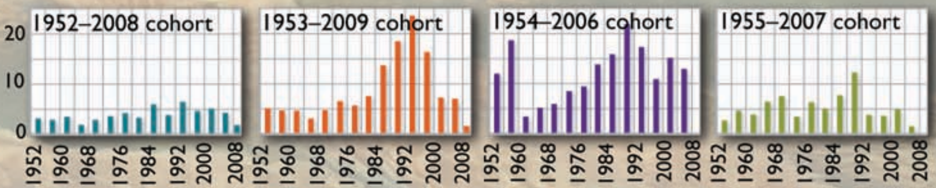
An estimated 37% of the world's freshwater fishes are threatened with extinction.[17]

Salmon

Canadian lakes and rivers provide spawning habitat for five species of wild salmon on the West Coast[18] and one on the East Coast. Wild salmon are a staple and a cultural foundation species for Aboriginal Peoples.[19, 20] They are the basis of commercial, recreational, and Aboriginal food, social, and ceremonial fisheries on both coasts.[20, 21] Wild salmon are revered by Canadians, in part because of the mystique of their life cycle – after growing in the ocean they migrate long distances to spawn in freshwater.

FRASER RIVER SOCKEYE RETURNS

Number of returning salmon (millions), 1952 to 2009



Note: it takes four years for most sockeye to return to spawn after hatching.
Source: adapted from Lapointe, 2010[22]

FRASER RIVER SOCKEYE SURVIVAL

Productivity index (returns/spawner)
4-year running average, 1952 to 2008

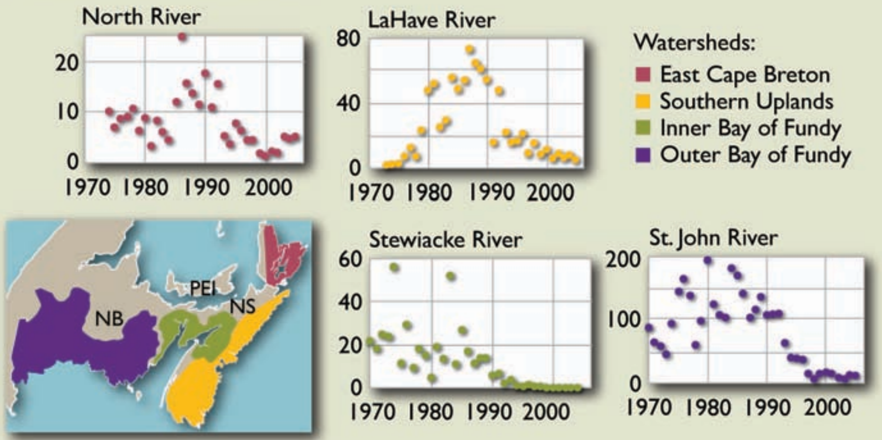
Source: Fisheries and Oceans Canada (DFO), 2010[23]

The Fraser River is legendary for its sockeye salmon runs. Since the 1990s, the number of returning sockeye has fluctuated widely, depending on the cohort (see graphs for the four cohorts above), while the survival rate – the proportion of fish that grow to adults and return to spawn – has been declining. In 2009, only 1.5 million adult sockeye returned – the lowest number since 1947. A scientific panel investigating the evidence for declining adult returns concluded that the major cause has been unfavourable physical and biological conditions in the Strait of Georgia, combined with freshwater and marine pathogens.[23, 24] In 2010, mid-summer estimates predicted the largest Fraser River sockeye run since 1913.[25]

In some years, warming water and reduced flows due to climate change have impacted salmon migration, spawning, and rearing success. Sockeye survival and spawning are impaired as river temperatures increase above stock-specific thresholds.[26, 27] Since the 1950s, mean summer temperatures in the Fraser River have increased by approximately 1.5°C.[26, 28] This trend is likely to continue, increasing the probability of sockeye being exposed to water temperatures that will impair their survival.[29]

ATLANTIC SALMON POPULATION TRENDS

Hundreds of fish, 1970 to 2005



Source: adapted from Gibson et al., 2006[30]

Returns of Atlantic salmon to many rivers in North America have declined since the 1980s or 1990s, with northern populations increasing and southern populations remaining at low levels.[30] For example, in inner Bay of Fundy rivers, runs of 30 to 40 thousand fish in the mid-1980s have been reduced to a few hundred fish, and in southern Nova Scotia, most salmon exist only as remnant populations or have been extirpated.[31, 32] Although the factors contributing to low marine survival are largely unknown, freshwater declines are a result of the effects of dams, loss of spawning habitat, invasive species, increases in stream temperatures, siltation, contaminants,[33] poaching[20] and, in southern Nova Scotia, acid deposition.[32, 20]

AMERICAN EEL

The American eel is an example of a once abundant species that is now listed as Special Concern by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Since the 1970s, populations have declined by 99% in the upper St. Lawrence[34] and less extreme declines have been observed in both the lower St. Lawrence and Gulf of St. Lawrence.[35, 36] The long life span of American eels, combined with their vast migration distances of up to 4,500 km, make them vulnerable to a wide range of stressors, such as mortality in hydro-electric turbines, physical barriers such as dams, overharvesting, and habitat alteration. Climate change, resulting in changes to ocean currents that carry eel larvae from the spawning grounds, may also contribute to population declines. American eels once provided both subsistence and commercial fisheries in Canada.[36]

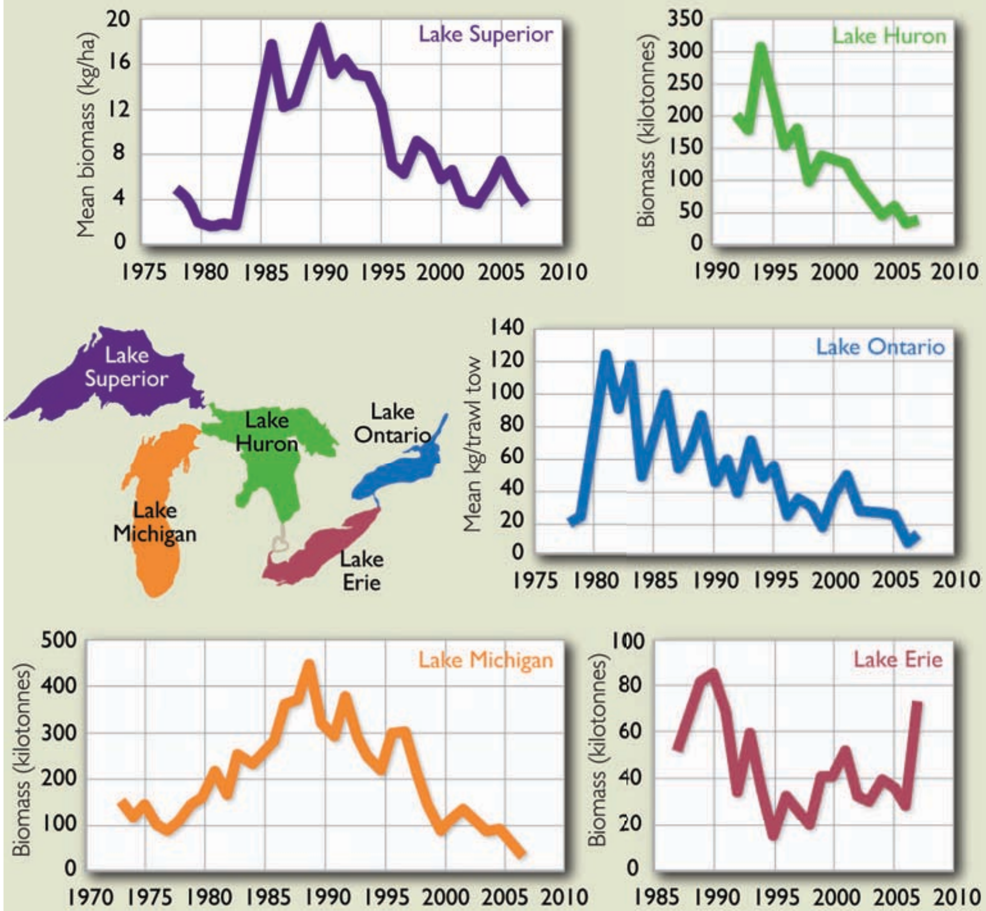
AMERICAN EEL IN ONTARIO

Average number (thousands) of eels per day at R.H. Saunders Hydroelectric Dam, 1974 to 2005

Note: no data are available for 1996.
Source: Ontario Ministry of Natural Resources, 2010[34]

PREY FISHES IN THE GREAT LAKES

Trends in prey fish biomass based on annual bottom trawl surveys



Source: adapted from Environment Canada and U.S. Environmental Protection Agency, 2009[37]

The term prey fish refers to fish species that are the main food items of popular commercial and sport fish. A fish is considered a prey fish if it remains small in size, usually feeds on zooplankton or bottom-dwelling species, and is abundant enough to feed a predator fish population.[38] Prey fish make up the majority of fish biomass and are the foundation of the Great Lakes fishery (see next page), as they are eaten by predatory fish such as trout, walleye, and bass. Prey fish include native species such as slimy sculpin, trout-perch, cisco, and bloater, and also non-native species such as alewife, rainbow smelt, and round goby. Declines in prey fish populations have been occurring since the 1980s and 1990s. The most likely causes are: stocking of Pacific salmon, which was done to reduce non-native prey fish; reductions in nutrients; and non-native zebra and quagga mussels, which filter nutrients from the water column and reduce food for the invertebrates that prey fish eat.[37]

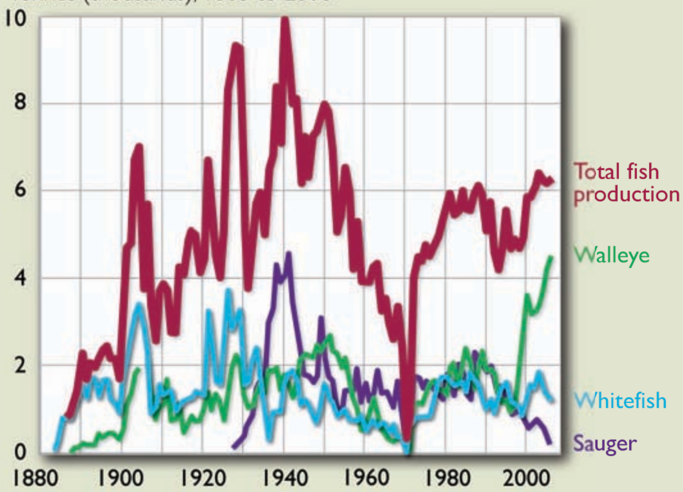
Interior British Columbia lake

COMMERCIAL FISHING

Lakes and rivers in Canada support significant commercial fisheries. Lake Winnipeg supports the largest commercial fishery in Manitoba, valued at approximately $20 million per year. Commercial fish production has been highly variable in Lake Winnipeg over the past 125 years, both in the amount of fish and the species harvested. For example, a dramatic decline in fish production from 1940 to the1960s was followed by an increase since the 1970s. Walleye production is now at historical highs and is the most important fishery species. Sauger, on the other hand, have been declining since the 1970s. Walleye are benefitting from the invasion of rainbow smelt and nutrient enrichment. These same factors are believed to be driving the decline in sauger.[39, 40]

COMMERCIAL FISH PRODUCTION IN LAKE WINNIPEG

Tonnes (thousands), 1883 to 2006

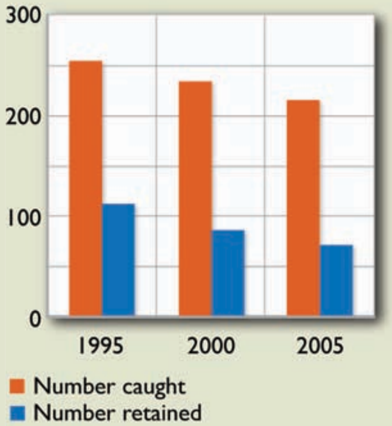


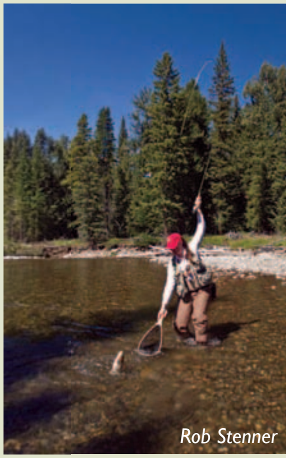
Source: adapted from Manitoba Water Stewardship Fisheries Branch as cited in Shipley and Kling, 2010[39]

The Great Lakes commercial fishery has an annual dockside value, in Ontario, that fluctuated between $29 and $37.5 million between 2004 and 2008,[41] contributing $850 million per year in direct and indirect benefits to the Ontario economy. The overall commercial harvest has been declining since the 1980s. The main species harvested today are walleye and yellow perch, both native species, and rainbow smelt, a non-native species.[42] Overfishing and predation by the non-native sea lamprey led to the collapse of lake trout in the late 1950s. Restoration, including stocking, has maintained a fishery, and lake trout are now reproducing in Lake Superior and Lake Huron.[37, 43]

RECREATIONAL FRESHWATER FISHING

Number of fish (millions), 1995 to 2005





Source: adapted from Orok and Johnson, 2005[44]

Approximately 3.2 million people participated in freshwater recreational fishing, or angling, in 2005, down from 4.2 million in 1995. The reduction in number of anglers has resulted in a reduction in the number of fish caught and the number of fish retained. It has also had an economic impact. Direct expenditures on angling were about $2.5 billion in 1995, 2000, and 2005. Although the dollar value of expenditures has not changed, this represents a 19% decrease in expenditures over 10 years, when adjusted for inflation. Anglers concentrate on some of the same species as the commercial fishery, namely walleye and yellow perch, although other species, such as brook trout, rainbow trout, bass, and northern pike, are also important. In 2000, the Year of the Volunteer, Canadian anglers dedicated over a million days to habitat clean-up and other activities related to improving recreational fishing.[44, 45]

SPECIES OF SPECIAL INTEREST

BIRDS

Birds are widespread, readily observed, feed at many levels of the food web, and are responsive to environmental change, making them good indicators of ecosystem health. **Birds play an important** ecological role, providing food for other species, dispersing seeds, controlling insects, pollinating plants, and modifying habitat. Many also have economic and cultural significance – providing humans with food, recreation, enjoyment, and study and playing an important role in many cultures.

Over the past 20 years, the status of the world's birds has deteriorated, with more species moving closer to extinction.[1] Of particular concern are declines in formerly common species.[1] In the last 40 years, 20 common North American bird species lost over 50% of their populations.[1, 2] Birds are also shifting their ranges northward in response to climate change – nearly 60% of the 305 species found in North America in winter moved northward by an average of 1.4 km per year (56 km over the last 40 years)[3] and breeding ranges of southern North American species have shifted north by an average of 2.4 km per year.[4]

Canada provides crucial breeding, migrating, and wintering habitat for a significant percentage of the world populations of many species. Nevertheless, the status and trends of birds in Canada are only partially understood. Good data exist for many species, particularly in southern Canada; however, only localized data exist for many others, particularly in the North.

SHOREBIRDS

Sixty percent of North American shorebirds breed in the Arctic, with the Canadian Arctic providing 75% of the breeding range for 15 of 49 common species.[5] Canada has migration sites of great importance as well, including at least three of hemispheric significance – the Bay of Fundy, the Fraser River estuary, and Chaplin/Old Wives/Reed Lakes in Saskatchewan.[6] Some southern breeding areas, for example the Prairies, are of global importance to some species.[7]

Data on shorebird populations are patchy in Canada, but most information indicates declining trends.[7-9] Of the 35 species examined in 2000, 49% showed significant declines somewhere in their range.[5] The most complete datasets in Canada include the Breeding Bird Survey and the Atlantic Canada Shorebird Survey. Results from these surveys indicate:

- Between 1976 and 2007, 4 of 12 species (33%) of shorebirds breeding in southern Canada declined significantly. There were no significant increases.[10]
- Between 1974 and 2006, 5 of 15 migrating shorebird species (33%) on the Atlantic coast showed significant declines.[11, 12]

Potential causes of declines of shorebirds include loss and degradation of habitat, climate change, changes in predator regimes (for example, increasing numbers of peregrine falcons may cause shorebirds to move through an area more quickly, leading to an apparent decline[13]), human disturbance, contaminants, and disease.[5] Changes are expected to accelerate due to anticipated changes in Arctic breeding habitat,[14] as well as flooding and droughts elsewhere in shorebird ranges[7] as a result of climate change.

Western sandpipers

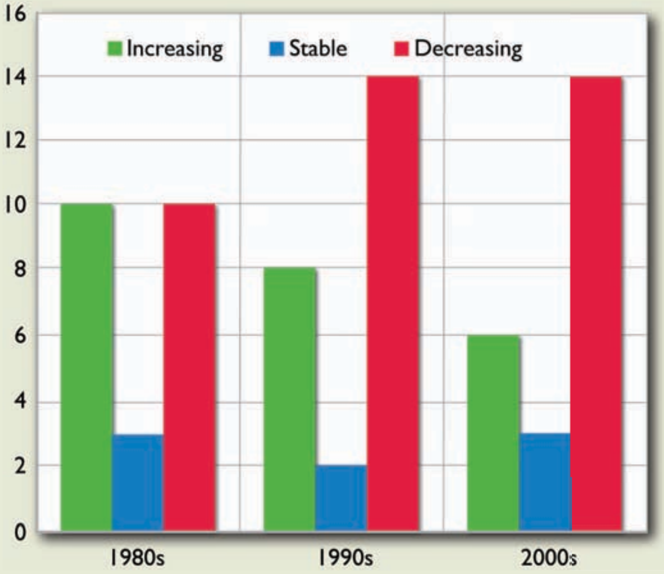
Global Trends

Globally, over 150 species of birds have been lost since the 16th century and one in eight is currently threatened with extinction. The last 20 years have witnessed a steady decline of bird species in terrestrial, freshwater, and marine ecosystems. Between 1988 and 2008, the status of 225 bird species was elevated to a higher level of risk.[1]

Populations of northern gannets like this one on Bonaventure Island, Quebec, have increased in North America since the 1950s

TRENDS IN STATUS OF BREEDING SEABIRD POPULATIONS IN CANADA

Number of populations in each category, 1980s to 2000s



Note: only populations with significant breeding populations, long-term datasets, and those unaffected by terrestrial human activities are included.
Source: adapted from Gaston et al., 2009[15]

Ivory gulls

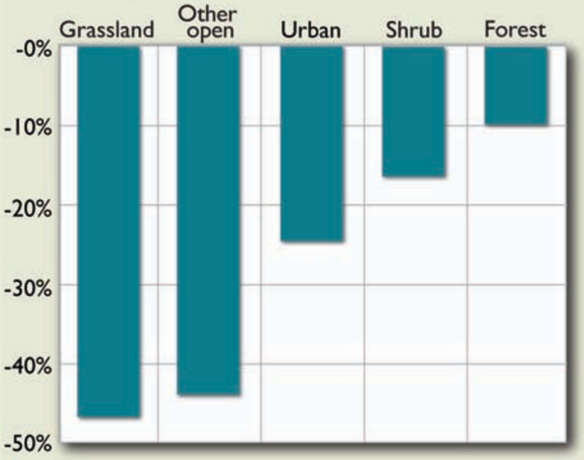
Worldwide, the status of seabirds is deteriorating faster than any other bird group.[1] In Canada, trends are regional in nature and result from a variety of factors, including climate change, fishing by-catch, resource extraction, transportation, and pollution.[15-20] A trend to an earlier breeding date has been found in several populations,[21-23] as have changes in diet and condition.[24]

- **Pacific** – southern populations, influenced by the changes in sea surface temperature related to the upwellings of the California Current, have been declining since the 1970s.[15] Declines may also be due in part to a mismatch in timing between breeding and peak of food availability.[25] Populations north of the influence of the current, however, have generally increased since the 1980s.[15]
- **Atlantic** – prior to 1990, populations generally showed positive trends. A major cold-water event in 1990, however, coinciding with overfishing, disrupted food webs,[26-29] resulting in immediate change in diet, condition, and population, particularly for gulls.[24] Populations of most diving seabirds increased over this period, in part due to closure of the gill-net fishery that had been drowning many birds.[30]
- **Arctic** – with the exception of ivory gulls, which are declining rapidly, change in Arctic seabird populations is slow and possibly the result of events on wintering grounds in the Northwest Atlantic.[31, 32] Changes in seabird diet and growth have been found to be related to reduction of Hudson Bay sea ice. This may have negative consequences for populations in the long term.[32] Conversely, in the High Arctic, less sea ice may benefit the birds.[33, 34]

SPECIES OF SPECIAL INTEREST

LANDBIRD POPULATIONS IN CANADA

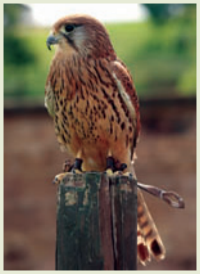
Percent change by habitat type, 1970s to 2000s



Note: data for the 2000s decade includes only 2000 to 2006. Source: Downes et al., 2010,[35] adapted from Breeding Bird Survey data, 2007[36]

Downy woodpecker, forest bird, increased by 30%

Eastern meadowlark, grassland bird, declined by 77%



American kestrel, bird of other open habitat, declined by 45%

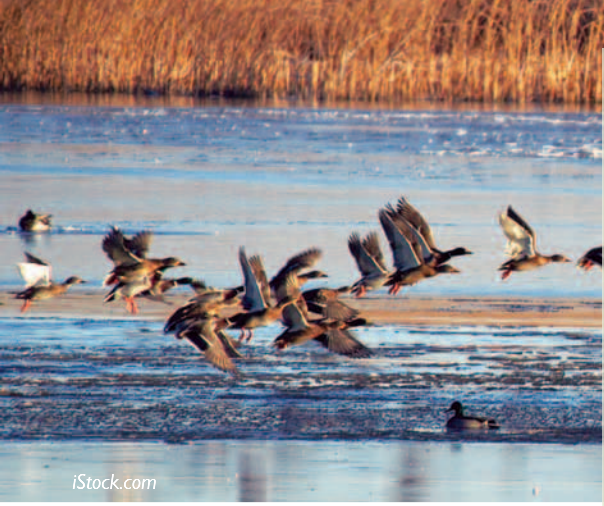
House finch, urban bird, increased by over 200%

Mourning warbler, shrub bird, declined by 48%

photos: iStock.com

Populations of landbirds in all habitat types except forest declined significantly from 1968 to 2006.[35] No significant positive trends in any landbird groupings (by habitat, by foraging, or by migration strategy) were evident between 1968 and 2006, although significant positive trends were found for some individual species.[35]

- **Grassland** birds, with more than 40% loss of total population since the 1970s, show significant steep declines in all regions of the country and for most species. This is consistent with declines throughout North America[10, 37] and is thought to be due to a combination of habitat loss and the intensification of agriculture.[35]
- Birds of **other open** habitats have been declining since the late 1980s. The assemblage contains several species of aerial-foraging insectivores, many of which are showing declines.[35]
- The **urban** group is heavily influenced by two introduced species, European starling and house sparrow, which, although still abundant, are showing declines in Canada and Europe.[35]
- The decline in **shrub/early succession** birds is strongly influenced by declines in relatively abundant sparrows.[35] Significant declines were found in the Atlantic Maritime, Boreal Plains, and Boreal Shield ecozones⁺.
- Similar to the U.S.,[37] **forest birds** show little change overall, although data indicate a decline since the 1990s.[35] Trends for individual species vary, with some showing declines while others are stable or increasing. There have been varying degrees of decline in the Pacific Maritime, Montane Cordillera, and Western Interior Basin ecozones⁺, and increases in the Prairie and Mixedwood Plains where birds have responded to increased forest cover. About 60% of Canada's landbirds breed in the boreal forest.[38]
- **Aerial and ground-foraging** birds show significant declines of 35 and 27% respectively since the 1970s.[35] **Aerial-foraging insectivores**, such as swallows and flycatchers, stand out as a group showing large declines.[39, 40] Causes remain unknown but likely include changes in food, climate, and habitat.
- **Long-distance and short-distance migrants** showed significant declines of 21 and 24% respectively, while **resident** birds were unchanged.[35] Short-distance migrants include many grassland species. Long-distance migrants include many aerial-foraging insectivores. Loss and fragmentation of habitat on the wintering grounds is one possible cause for decline.[41, 42]

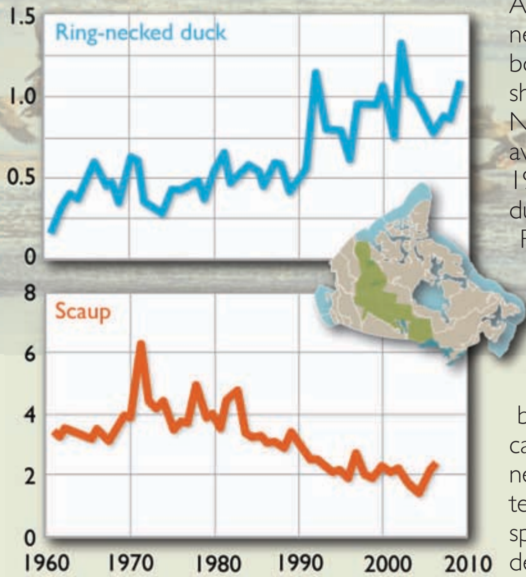


WATERFOWL

Waterfowl have been monitored cooperatively by Canada and the U.S. since 1948. Concern over declines in populations in the 1980s led to the development of a large international cooperative initiative, the North American Waterfowl Management Plan, to address the declines. Although many duck populations fluctuate widely among years and regions, overall trends for most inland breeding ducks show increases or no significant change between 1961 and 2009.[43, 44] Nevertheless, the populations of some species remain low; for example, northern pintail, American wigeon, and greater and lesser scaup have declined significantly in the prairie and western boreal regions.[43, 44]

POPULATION TRENDS FOR RING-NECKED DUCKS AND SCAUP, WESTERN BOREAL REGION

Millions, 1961 to 2009



Source: Canadian Wildlife Service Waterfowl Committee, 2009[43]

Approximately 70% of scaup and ring-necked ducks breed in the western boreal forest and the two species share many life history traits.[45] Nevertheless, scaup declined at an average of 1.7% per year between 1961 and 2009 while ring-necked ducks increased by 2.5% per year.[43] Reasons for the decline in scaup remain unclear but hypotheses include: contamination or change in food resources; and reduced female survival or reproductive success due to changes in the boreal forest.[46, 47] Another possible cause is a mismatch between timing of nesting and food availability due to temperature change for late-nesting species such as scaup.[45] Population declines have also been found in other late-nesting species such as scoters.[43, 45] Ring-necked ducks breed earlier.

AMERICAN BLACK DUCK

Over 90% of the world population of American black ducks breed in eastern Canada[48] and the population declined by almost 50% between 1955 and 1985.[49] One of the most abundant ducks in eastern Canada, the population has been stable at about 450,000 since 1990, although declines continue in the Mixedwood Plains.[43, 44] Causes for the decline are not clear but likely include habitat loss due to development and agriculture[49, 50] and displacement through competition with mallards,[51] which have been expanding in abundance and range.[49, 50, 52] Population increases in other areas could be due to changes in management practices, such as increased hunting restrictions.[53]

SEA DUCKS

Data for sea ducks are limited because most breed in remote, inaccessible areas in the North.[43] Existing data show a mix of trends. Reasons for declines are largely unknown,[43] but declines in eiders may be related to harvest and avian cholera may be an issue.[54]

King eider

- ↑ mergansers in prairie, boreal, and Atlantic regions
- ↑ common goldeneye in prairie and Atlantic regions
- ↑ bufflehead in prairie and boreal regions
- ↓ scoters in prairie and boreal; ↑ surf scoters in Atlantic[43] regions
- ↓ long-tailed duck in boreal regions
- ↓ Arctic breeding populations of eiders[54-58]

SPECIES OF SPECIAL INTEREST

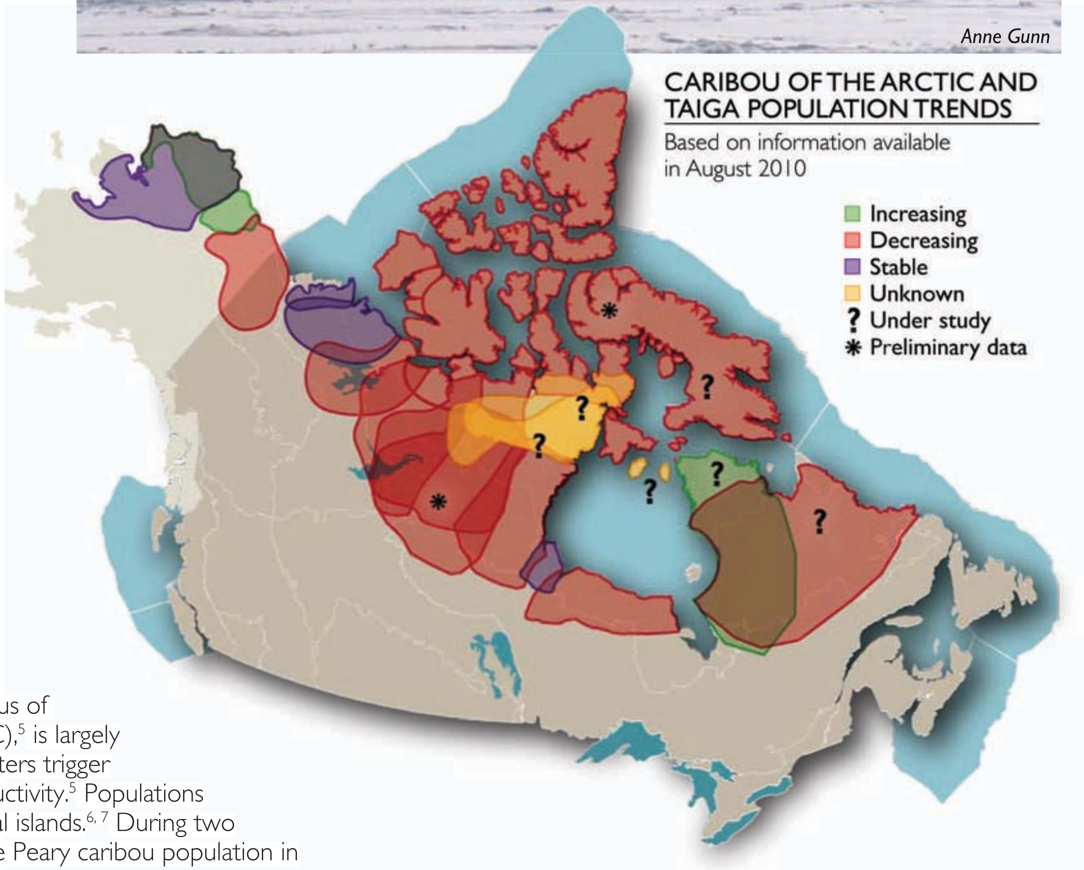
CARIBOU

Caribou are distributed across most of Canada and can play **important ecological roles** as herbivores influencing the structure of plant communities, as prey supporting populations of large and medium-sized predators and scavengers, and as a source of nutrients in otherwise nutrient-limited systems. Caribou are an integral part of many cultures, particularly Aboriginal cultures, which have developed with caribou over thousands of years.[1]

Caribou of the Arctic and taiga

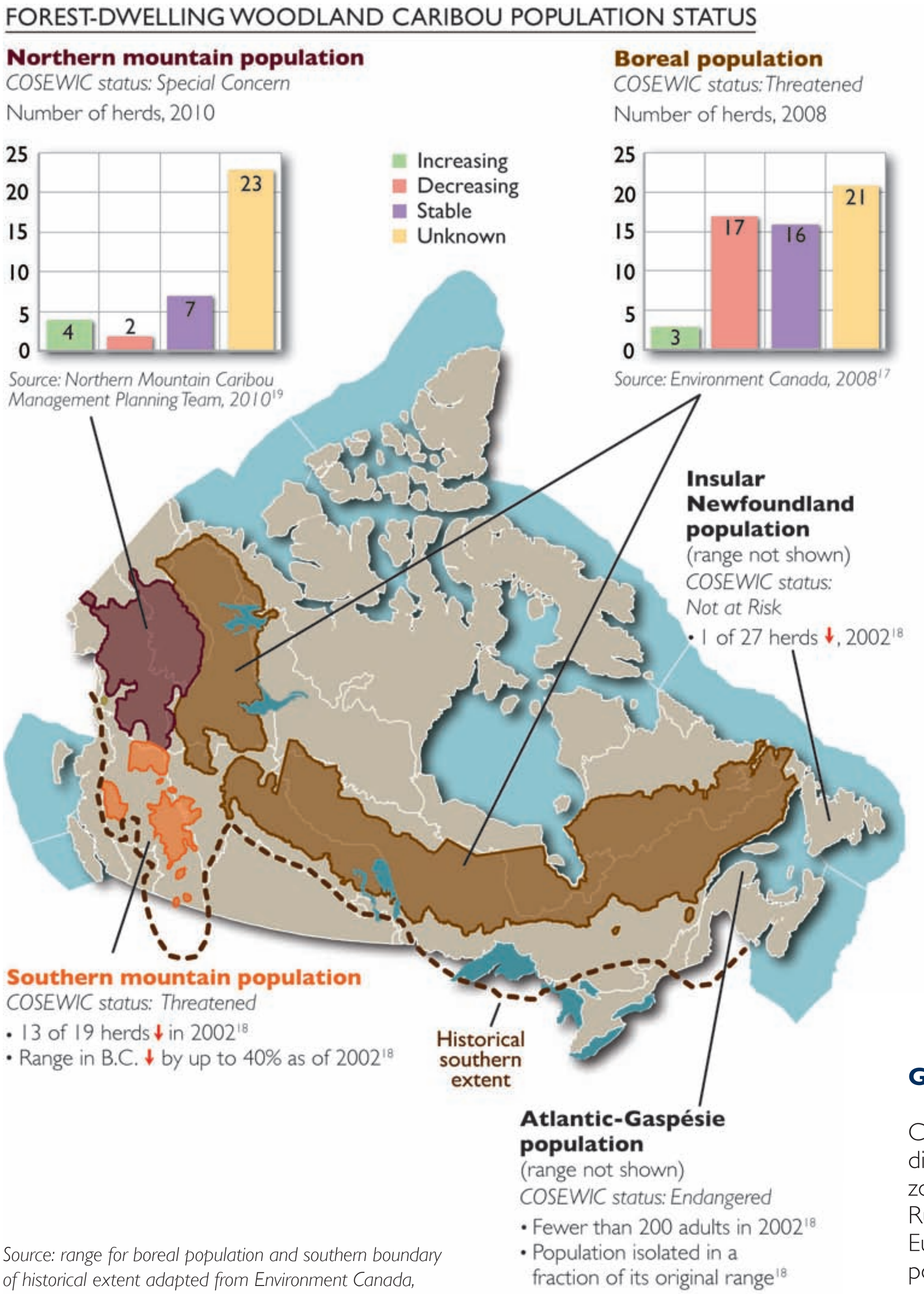
Abundance of northern caribou, like other northern herbivores, such as lemmings and hares, is cyclic. Caribou numbers generally increased from lows in the mid-1970s to peaks in the mid-1990s, returning to lows by 2009 that are, in some cases, similar to previous lows.[2] Some herds, notably the Bathurst and Beverly, which calve in the central Arctic, have experienced severe drops in the past few years.[3, 4] Current declining trends may be partly related to natural cycles in abundance.[2]

Abundance of Peary caribou, which live on the High Arctic islands and are listed as Endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC),[5] is largely influenced by weather. Periodic severe winters trigger large-scale mortality and reduction in productivity.[5] Populations have declined by as much as 98% on several islands.[6, 7] During two winters in the 1990s, more than 95% of the Peary caribou population in the western half of its range was devastated by heavy snow and the formation of ice layers in the snow.[6] Events like these are projected to become more frequent and more widely distributed with climate change.[6, 8, 9]



Source: adapted from Gunn and Russell, 2010,[2] CARMA, 2009,[10] Magoun et al., 2005,[15] Elliot, 1998[16]

Significant changes on caribou ranges since the 1970s could prevent a recovery of some herds to previous peak numbers.[10] These changes include the effects of climate change, including changes in wildfire,[11] and an increasing presence of people and development, particularly mining and oil and gas activity.[12-14] Caribou harvest by humans and predation are also known to affect abundance within some caribou herds.[5]



Source: range for boreal population and southern boundary of historical extent adapted from Environment Canada, 2008,[17] range for southern and northern mountain populations adapted from Thomas and Gray, 2002[18]

Forest-dwelling woodland caribou

Forest-dwelling woodland caribou are relatively non-migratory and live in smaller groups than their northern counterparts. They divide their time between lichen-rich mature forest and open areas, including alpine tundra.[18] Historically occurring over much of Canada, their distribution has retracted, with the southern boundary continuing to move northward.[18, 20] Caribou had completely disappeared from Nova Scotia and New Brunswick by 1930.[21]

The status of many herds remains unknown; however, where data exist, declines are evident, particularly for the boreal[17] and southern mountain populations.[22] Woodland caribou are declining primarily because of loss and degradation of habitat and landscape fragmentation due to roads and other linear features. This is resulting in the isolation of populations and increasing vulnerability to predators.[17, 23-25] Overharvest of the caribou, fire, and climate change are also considered factors in population decline.[17, 18, 26] Generally, populations that are stable or increasing occur in remote areas with little or no industrial activity or where predator control has been used as a management tool.[27]

Global Trends

Caribou and reindeer have a circumpolar distribution in the world's tundra and boreal zones. Wild populations have declined in Russia and are mostly extirpated from Europe, except for a small, stable reindeer population in Norway, and an increasing population in Finland.[28] Loss of habitat and climate change are threats worldwide.[29]

PRIMARY PRODUCTIVITY

KEY FINDING 18. Primary productivity has increased on more than 20% of the vegetated land area of Canada over the past 20 years, as well as in some freshwater systems. The magnitude and timing of primary productivity are changing throughout the marine system.

Status and Trends

impacts on ecosystems variable and not well understood

some good datasets

emerging issue with potential for major ecological impacts

Primary productivity is the conversion of the sun's energy into organic material through photosynthesis. On land, it is driven by temperature and availability of water and nutrients modified by land use. In aquatic ecosystems, primary productivity is driven by the availability of nutrients and light and, to a lesser extent, by temperature and other factors. **Primary productivity is important** because it is the process that forms the foundation of food webs in most ecosystems.

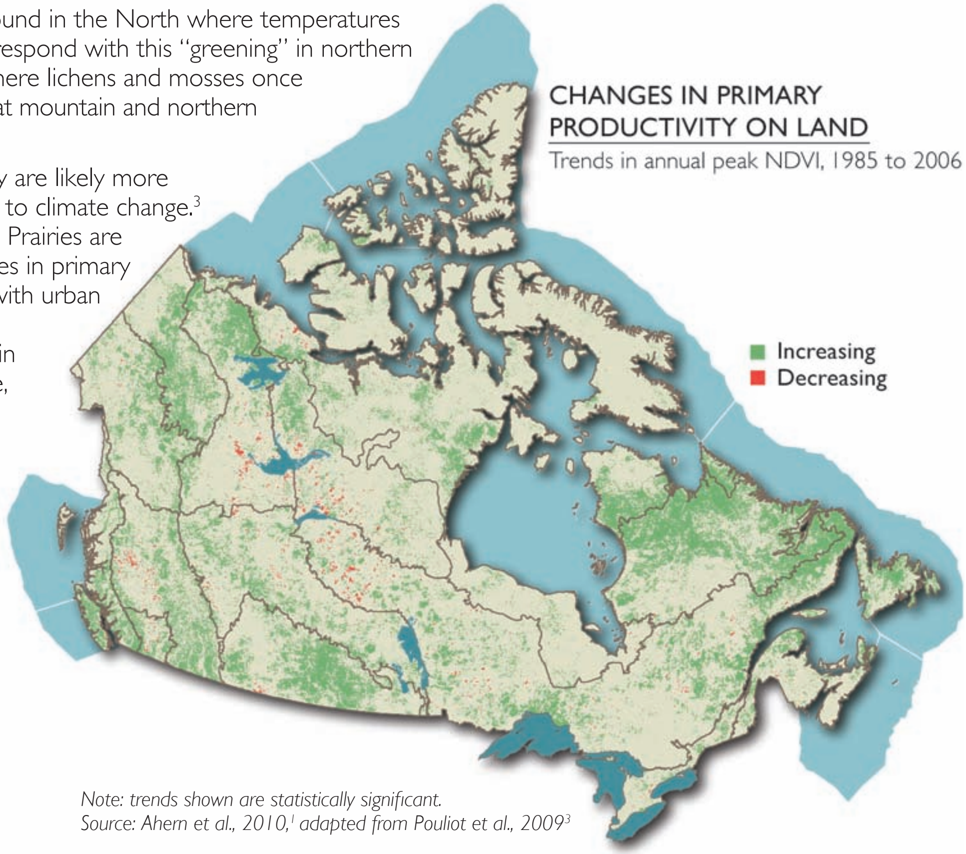
Primary productivity increased significantly on 22% of Canada's vegetated land area between 1985 and 2006 and decreased on less than 1% of land.[1] This trend in primary productivity is based on changes in the normalized-difference vegetation index (NDVI), a remote-sensing based measurement of photosynthetic activity – it is a good indicator of the amount of healthy green vegetation.[2-4]

The largest increases in primary productivity were found in the North where temperatures have risen the most. Changes in vegetation that correspond with this "greening" in northern Canada include a transition to shrubs and grasses where lichens and mosses once dominated,[5] and changes in tree growth and density at mountain and northern treelines.[6-8]

In southern Canada, increases in primary productivity are likely more strongly related to changes in land use than they are to climate change.[3] For example, increases in primary productivity in the Prairies are related to increases in crop area.[3] The small decreases in primary productivity seen in some areas may be associated with urban and industrial development, or, as in interior British Columbia, forest insect infestations. Some increases in primary productivity may also be associated with fire, as burns can have positive or negative NDVI trends, depending on the age of the burn.[3]

Global Trends

Photosynthetic activity was estimated to have increased on about 25% of the Earth's vegetated area and decreased over 7% of this area from 1982 to 1999. The greatest increases were in the tropics, as a result of fewer clouds and increased exposure to the sun, and in high latitudes of the Northern Hemisphere, attributed to increased temperature and water availability.[9]

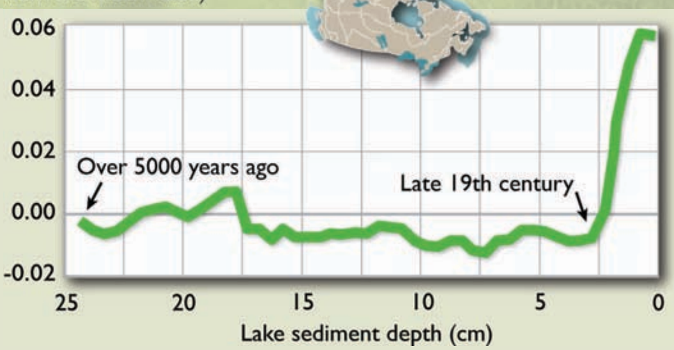


Note: trends shown are statistically significant.
Source: Ahern et al., 2010,[1] adapted from Pouliot et al., 2009[3]

dreamstime.com

PRIMARY PRODUCTION IN ARCTIC LAKES, LOST PACK LAKE, NUNAVUT

Chlorophyll *a* (mg/g, difference from the mean value)



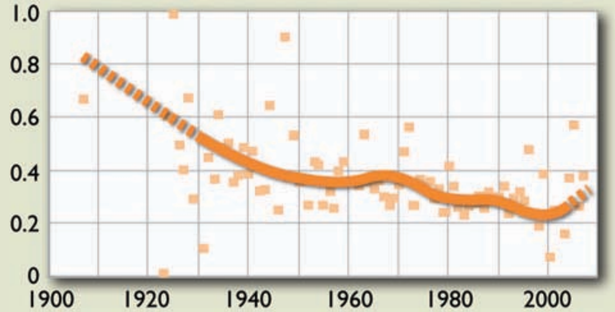
Note: chlorophyll a *is the main pigment found in plants and algae and is a measure of primary production. Values are inferred through spectral analysis of lake sediment cores.*
Source: adapted from Michelutti et al., 2005[10]

The figure shows chlorophyll *a* reconstructions from Lost Pack Lake, one of six Baffin Island lakes examined for long-term trends. All lakes show dramatic increases of inferred primary production within the most recently deposited sediment, following prolonged periods of comparatively low values.[10] Dating of the sediment cores indicates that these rapid increases started in the late 19th century and continue to the present. The increases are a departure, in most lakes, from relatively stable levels of primary production that persisted for millennia. A widespread increase in freshwater production over much of northern Canada is also inferred from major shifts in species composition of algae in ponds and small lakes in many areas (also detected from studies of sediment cores).[11, 12]

The best explanation for this change in algae is climatic warming leading to longer ice-free growing seasons and associated changes in lake ecosystems.[13, 14] The changes are most pronounced in the High Arctic, but similar shifts in algal species are found in many locations in the Northern Hemisphere – with changes being more recent in temperate latitudes.[15]

MARINE PRIMARY PRODUCTION

Total chlorophyll (mg/m³) in the North Pacific, 1908 to 2008



Note: trend (line) and average annual values (points) were estimated through statistical modeling. Dashed line represent parts of the trend based on limited data and hence with lower confidence.
Source: adapted from Boyce et al., 2010[16]

Satellite measurements of ocean colour have shown variable decade-scale trends in marine primary production, including a short-term increase in primary production in the Arctic Ocean from 1998 to 2008.[17, 18] A recent study[16] extended the record by also using longer-term measurements of water transparency and chlorophyll concentrations. This study concluded that, over the past 110 years, primary production has declined in most of the world's ocean regions.[16] High-latitude regions, including the North Pacific, showed the greatest long-term declines. The global decline in the amount of phytoplankton is estimated at 1% per year, with a total decline of 40% since 1950. Shorter-term trends were related to climate oscillations, while the long-term declines were most strongly related to increasing sea-surface temperatures – which leads to less mixing of ocean waters, reducing the nutrient supply for phytoplankton. The exceptions are the Arctic and Antarctic oceans, where the causes of the observed long-term decreases in primary production are less clear, but may be related to increased wind intensity.[16]

NATURAL DISTURBANCES

KEY FINDING 19. The dynamics of natural disturbance regimes, such as fire and native insect outbreaks, are changing and this is reshaping the landscape. The direction and degree of change vary.

Status and Trends

evidence of change but direction, interpretation, and biodiversity impacts not fully understood

data not comprehensive, but good data for fire and certain insects

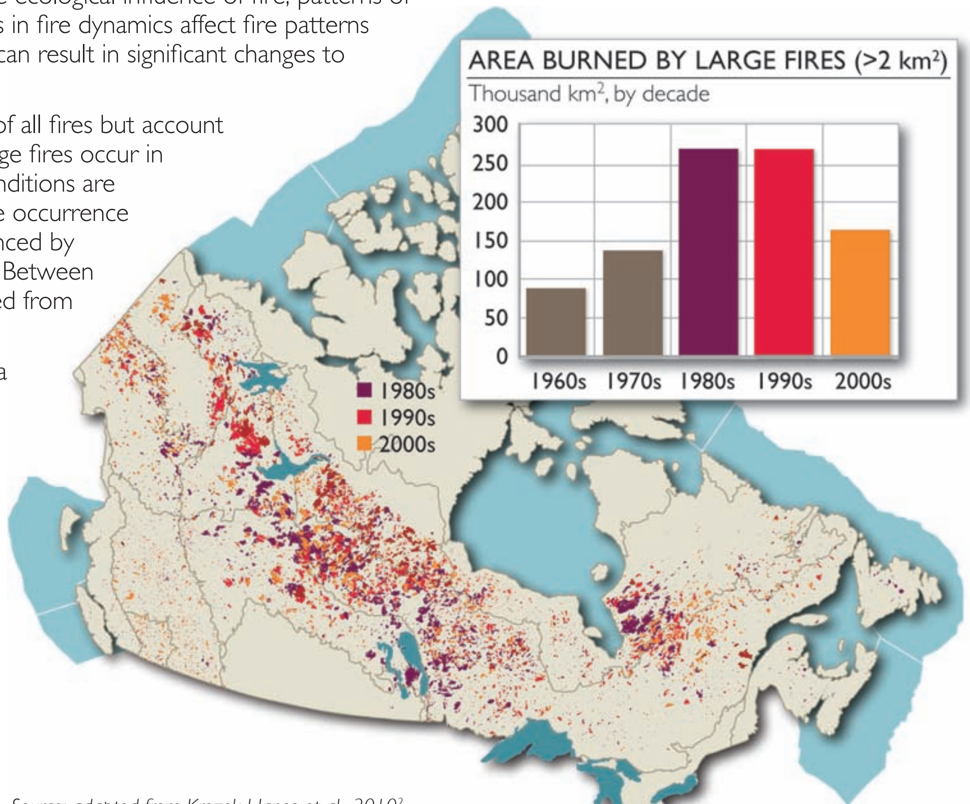
Natural disturbances are discrete, sometimes cyclical, events that cause significant change in ecosystem structure or composition. Size, frequency, severity, seasonality, and duration of the disturbance event determine the impact on biodiversity. **Large disturbance regimes are important** as they have shaped ecosystems. Although other disturbance agents are important, this key finding focuses on fire and native insect outbreaks which are widespread and particularly important ecological drivers in forests and grasslands. Fire and insect outbreaks affect each other and are influenced by weather, climate, vegetation dynamics, and human management.

FIRE

Fire plays an essential role in ecosystems, cycling nutrients, influencing species composition and age structure, maintaining productivity and habitat diversity, influencing insects and disease, and influencing the carbon flux. Due to the ecological influence of fire, patterns of past fires have shaped the forest of today. Changes in fire dynamics affect fire patterns (size, frequency, seasonality, severity, or type) and can result in significant changes to ecosystems.

Large fires (greater than 2 km^2) make up only 3% of all fires but account for 97% of the total area burned.[1] Over 90% of large fires occur in the boreal forest,[2] where extreme fire weather conditions are common and suppression efforts are lower.[1, 3, 4] Fire occurrence varies across years and across regions and is influenced by weather, climate, fuels, topography, and humans.[4-6] Between 1959 and 2009, the total annual area burned ranged from 1,500 km^2 to 75,000 km^2.[2]

Although a long-term decline in frequency and area burned by large fires is evident since the 1850s, particularly in eastern Canada,[7-10] annual area burned increased overall from the 1960s to 1980s/1990s. This has been attributed to greater forest use by humans, better fire detection, and increased temperatures over the last 40 years.[1, 3, 11, 12] The short-term decline from 2000 to 2009 may be the result of other climatic factors such as large-scale ocean circulation patterns from the North Pacific Ocean which entered a cool phase in the mid-1990s.[5, 8, 13, 14] Fire activity is most strongly linked to temperature[3, 6, 15] and as temperature increases, so should fire activity.



Source: adapted from Krezek-Hanes et al., 2010[2]
Data for 1959 to 1994 from Large Fire Database, in Stokes et al., 2003[1] and for 1995 to 2009 from the Canada Centre for Remote Sensing

iStock.com

Seasonality

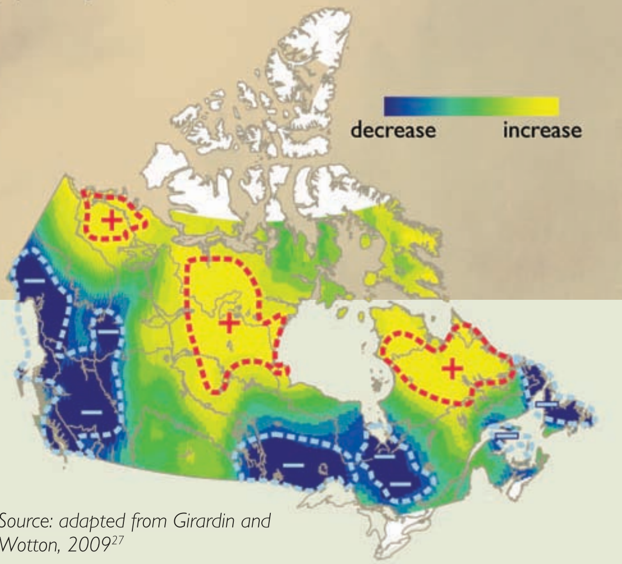
The fire season runs from April to mid-October.[2] The time of year that fires occur can affect forest regeneration capacity and intensity.[16] Humans cause approximately 65% of fires (large and small) in Canada; however, with most fires being smaller than 2 km^2, human-caused fires represented only 15% of the total area burned from 1959 to 1997.[1, 17] These fires occurred mainly in the spring and close to human settlements. The majority of boreal and taiga fires are caused by lightning and tend to occur later in the fire season.[1, 5, 18] These are often more severe because the fuel is dry, producing fires of great severity and intensity, and they are less likely to be suppressed.[19] Evidence from other countries, such as the western United States, indicates a lengthened fire season with wildfires starting earlier in the spring.[20] This is thought to be occurring in Canada as well.

LOSS OF FIRE AS A DISTURBANCE AGENT

Over the last century humans have had a significant influence on fire. Land conversion and fire suppression have resulted in the almost complete loss of large fire as an important disturbance agent in the Mixedwood Plains, Prairies, and Atlantic Maritime ecozones+.[2] The success of fire suppression since the 1970s[21, 22] has also affected other areas. For example, in the B.C. interior it has led to in-filling of grasslands and ponderosa pine forests with Douglas-fir and other trees and shrubs and increased the amount of fuel, making the forests more susceptible to fires of greater intensity,[23, 24] and increasing their vulnerability to insect outbreaks.[25] Active suppression now covers 90% of the Boreal Plains, 64% of the Boreal Shield, 41% of the Boreal Cordillera, 20% of the Taiga Plains, and 2% of the Taiga Shield.[4] The negative ecological consequences of fire suppression have been recognized and management authorities have started to reintroduce controlled burns on a limited basis in parts of Canada. Fire suppression is a balancing act between maintaining ecological function and protecting human life and property.[26]

CHANGE IN RISK OF WILDFIRE

July Drought Code, 1901 to 2001



Source: adapted from Girardin and Wotton, 2009[27]

Drought variables are correlated with fire activity and may be used to reconstruct fire history or predict future risk of wildfire.[28-30] Change in the risk of wildfire between 1901 and 2002 was inferred using the Drought Code, an index of water stored in the soil. This index is one of the measures used by fire management agencies to monitor risk.[27, 31] Results, based on changes in soil moisture, showed decreasing risk of wildfire south of Hudson Bay, in the eastern Maritimes, and in western Canada, largely due to significant increases in precipitation that resulted in a significant reduction in drought. In contrast, the Taiga Shield, Arctic, and northern Taiga Plains showed an increased risk of fire.[27, 31] This analysis only considers climate variables and does not include other factors such as human management and ignitions, insect outbreaks, and vegetation changes.[31]

Global Trends

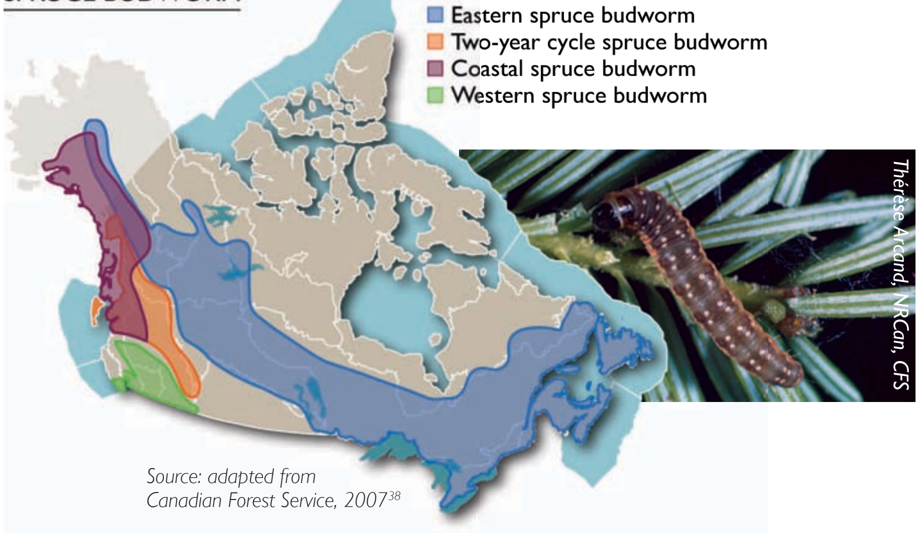
Globally, the total area burned annually has been increasing since the 1950s.[32] Both fire weather severity and area burned are expected to continue to increase in Europe,[33] Russia,[34] Canada and the United States,[6, 15, 35] South America, central Asia, southern Africa, and Australia,[36] due to increasing temperatures.[3, 37]

NATURAL DISTURBANCES

INSECTS

Large-scale insect outbreaks are an important natural disturbance regime in Canada. Changes in patterns of outbreaks of some insect species are evident but they are not uniform, with some increasing in severity, some decreasing, some showing no sign of change, and many without long-term data. Insect outbreaks and fire each affect the other and both are influenced by climate. For example, the suppression of wildfire has caused changes in forest structure in some areas, increasing their susceptibility to outbreaks of some insects. At the same time, insect outbreaks can influence fire dynamics, for example, increasing wildfire intensity in post-outbreak stands.

SPRUCE BUDWORM



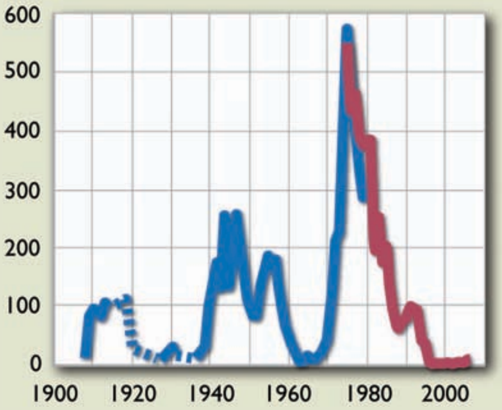
Source: adapted from Canadian Forest Service, 2007[38]

The spruce budworm, native to Canada's boreal and mixedwood forests, is one of Canada's most prevalent and influential insect defoliators. Of the four species that occur in Canada, the most widespread is the eastern spruce budworm. Its preferred hosts are balsam fir and white and red spruce, but it can also defoliate black spruce.[39] It is most damaging to older, denser forest stands although during severe outbreaks all host stands are vulnerable.[40] Together with fire, the eastern spruce budworm is the dominant natural disturbance in the boreal forest.[41] Cycles of spruce-budworm outbreaks, recurring approximately every 30 to 55 years,[42] influence species composition, age-class distribution, successional dynamics, and forest condition, thereby playing an important role in shaping forest ecosystems.[43, 44] Outbreaks occur somewhat synchronously over extensive areas, but outbreak duration varies regionally.[45] The last peak outbreak was in 1975, when over 510,000 km^2 were defoliated nationally.[46]

Western spruce budworm affects a much smaller area. The last peak defoliation was in 2007, when about 8,600 km^2 were defoliated nationally.[46] Severity of attack is low, for example, 95% of affected area in B.C. was classified as light in 2008.[47] One study mapped historical attack in the Kamloops Forest Region and found an increase in attack over the four outbreaks between 1916 and 2003, particularly after 1980.[48]

AREA DEFOLIATED BY EASTERN SPRUCE BUDWORM EAST OF THE MANITOBA BORDER AND IN MAINE, U.S.

Thousands km^2 of moderate to severe defoliation, 1909 to 2007



Source: pre-1909 to 1980 (blue line) adapted from Kettela, 1983;[49] *1974 to 2008 (red line) adapted from National Forestry Database, 2010*[46] *and Strubble, 2008*[50]

There is no consensus on whether there has been a change in frequency of eastern spruce budworm outbreaks.[44, 45, 51, 52] An overall increase in the area it has defoliated is apparent for Ontario and Quebec, however, which represented 98% of the area affected during the last peak outbreak.[46, 49] There is no consensus on whether this constitutes a trend. At the same time, the severity of outbreaks in New Brunswick decreased between 1949 and 2007.[53] Studies that conclude there have been changes in the pattern of attack have attributed them to fire suppression, forest harvesting practices, temperature increases in the spring, insecticide spraying, and less reliable reconstructions of historical outbreaks.[44, 54, 55]

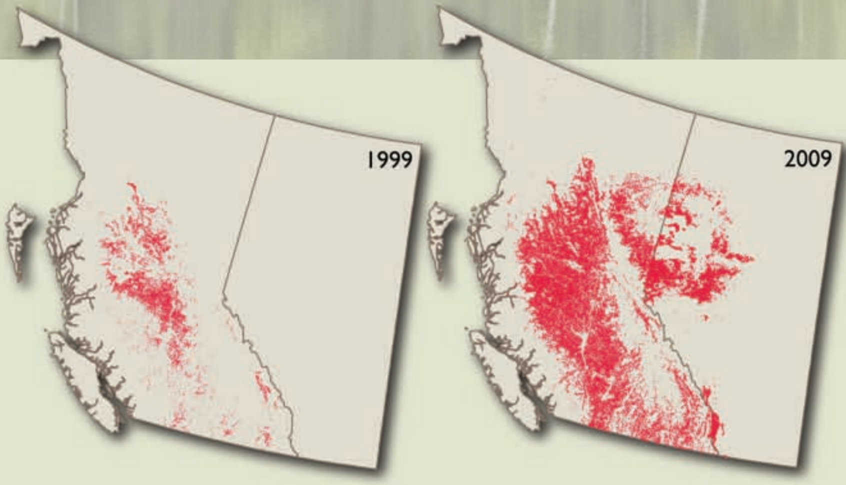

dreamstime.com

MOUNTAIN PINE BEETLE

The mountain pine beetle is native to western North America and at least four large-scale outbreaks have occurred in B.C. in the last 120 years.[25] The disturbance has changed in the last decade, however, with an infestation of unprecedented intensity in B.C.[58, 59] In 2005, it spread to Alberta,[60] where it has spread rapidly, including to jack pine/lodgepole pine hybrids.[61, 62] Attack results not only in changes to the forest, but can result in changes in water temperature and flow patterns, and increased soil and stream bank erosion.[63] Beetle-killed stands are also more vulnerable to fire,[64-67] and the combination of increased insect attack and past fire suppression can lead to an increase in intense, stand-replacing wildfires.[68] The infestation appears to have peaked in B.C., likely because most host trees in the central plateau have already been attacked, and because variable terrain and greater tree diversity have slowed the spread in other areas.[58]

CUMULATIVE AREA AFFECTED

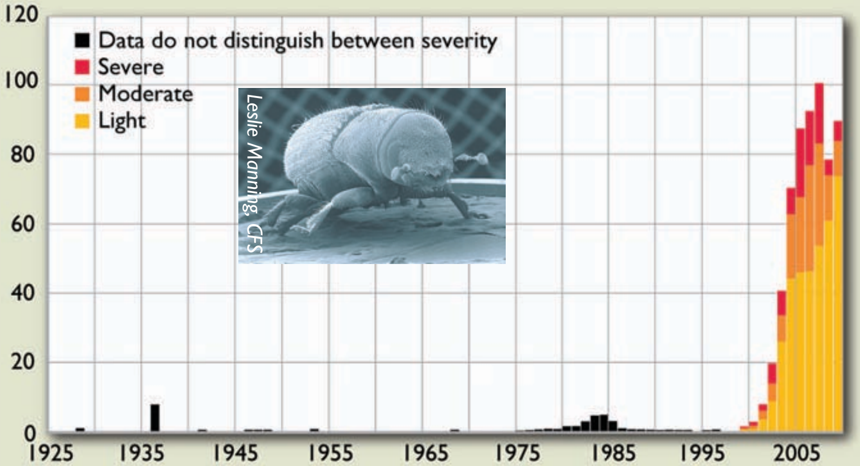
1999 and 2009



Source: adapted from B.C. Ministry of Forests and Range, 2010;[56] Alberta Sustainable Resource Development, 2010[57]

AREA AFFECTED ANNUALLY BY MOUNTAIN PINE BEETLE IN B.C.

Thousand km², 1928 to 2009



Source: adapted from National Forestry Database, 2010;[59] Forest Practices Branch, 2010;[69] Taylor et al., 2006[25]

Host availability, climate, and forest management practices all influence mountain pine beetle dynamics.[25] Changes that have contributed to the current infestation include:

- The proportion of older age classes of lodgepole pine stands, which are more susceptible to attack, increased from 17% in the early 1900s to 55% in 2002,[64] largely as a result of fire suppression,[25, 64, 67, 70] and harvest practices that change forest structure.[64, 67, 71]
- Climate has changed since 1920 to become more suitable for the beetle.[72] Warmer winters[73] have led to increased beetle survival. Temperatures in spring and late fall also affect mortality.[71] For example, earlier onset of spring has increased spring survival.[58, 72, 74]

FOOD WEBS

KEY FINDING 20. Fundamental changes in relationships among species have been observed in marine, freshwater, and terrestrial environments. The loss or reduction of important components of food webs has greatly altered some ecosystems.

Status and Trends

some major changes; trends for many unknown

data only for some parts of food webs and some regions

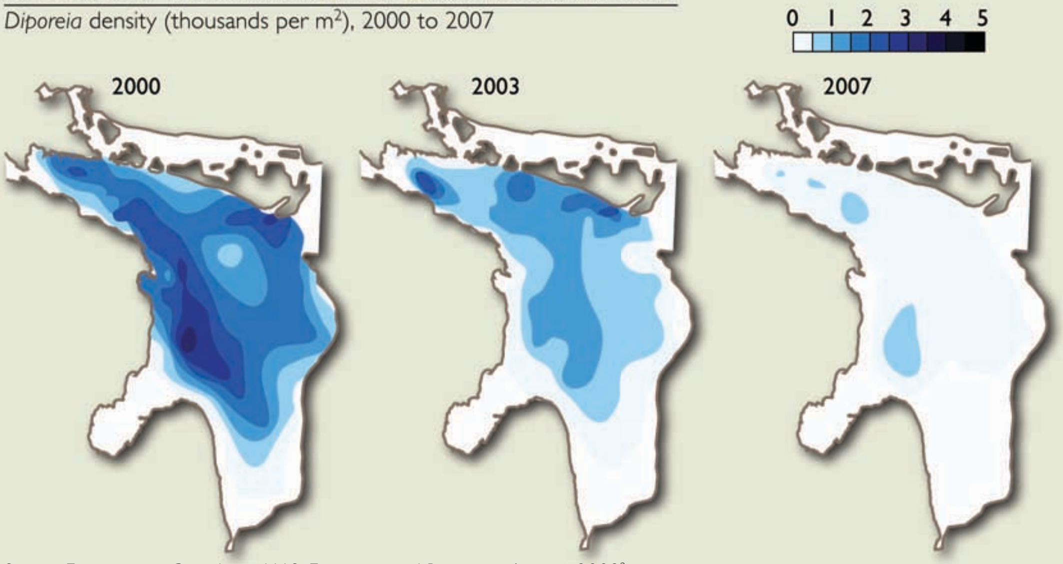
early indications of changes in some population cycles

Food webs are formed through linkages of the different organisms in a system, building on the primary producers (plants, algae, and microorganisms), and involving an array of consumers and decomposers.[1] **Population cycles are** regular periodic peaks and lows in animal abundance that are driven largely by the dynamics of some food webs. **Food webs and population cycles are important** because they shape the structure and function of ecosystems. Changes in species diversity are often related to changes in food webs.

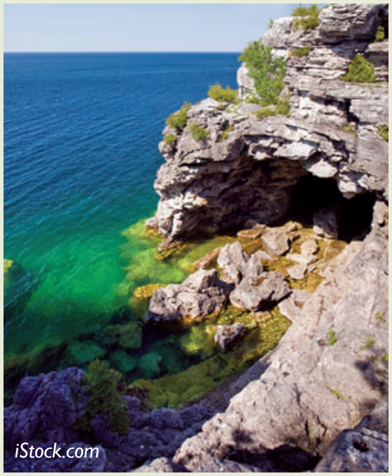
An example of the far-reaching effects of severe reductions in an important part of a food web is the decline of cod and other predatory fish off the Atlantic coast. This loss of fish predators led to further ecosystem shifts, with, for example, large increases in shrimp (see Marine Biome).

DECLINE OF THE AMPHIPOD *DIPOREIA* IN LAKE HURON

Diporeia density (thousands per m²), 2000 to 2007



Source: Environment Canada and U.S. Environmental Protection Agency, 2009[2]



Adult Diporeia *(size of a rice grain)*

Small invertebrates are important in Great Lakes food webs as they provide a link between the base of the web (algae, bacteria, and bits of dead organic matter) which they eat, and fish, which eat them. Since 1995, populations of *Diporeia* amphipods, historically abundant, widespread, and dominant in deep-water food webs, have declined drastically in all lakes except Lake Superior.[2] These declines coincide with the introduction of invasive zebra and quagga mussels, but the continuing downward trend is more complex, likely with several interacting causes. Declines in *Diporeia* have had major impacts on Great Lakes food webs, with both forage fish and commercial species negatively affected. For example, when *Diporeia* declined, growth and body condition of lake whitefish declined significantly in areas of lakes Huron, Ontario, and Michigan.[2]

SNOWSHOE HARE AND LYNX CYCLES, BOREAL FOREST, KLUANE, YUKON

Density of hares and lynx, 1976 to 2009

Source: data from Krebs, 2010[14]

Population density peaks in 2006 in Yukon were smaller and shorter than previous peaks. Similar dampening of hare cycles is emerging in the Northwest Territories.[15] Continued monitoring is needed to see if this is a change in the cycles or part of natural fluctuations.

Declines in terrestrial predators

Most large native carnivores, including wolverine, have severely declined in abundance or have been extirpated from much of their ranges in the more populated regions of North America. Remaining ranges and larger populations are generally in the north and west of the continent.[3]

In the Newfoundland Boreal Ecozone+, the wolf, a native top predator, was extirpated in the 1920s.[4] Eastern coyotes, first sighted in the ecozone+ in 1987, have become a major predator, feeding on a variety of species and competing with native predators such as bear, lynx, and red fox.[5]

NORTH AMERICAN RANGE OF THE WOLVERINE

Source: adapted from Hummel and Ray, 2008[3]

In the Mixedwood Plains Ecozone+, changes in predators and hunting, combined with milder winters and increased forage on lands altered by forestry and agricultural activities, have meant that populations of white-tailed deer have grown rapidly in recent decades.[6, 7] Foraging by high numbers of deer has altered forest plant communities,[8, 9] thereby affecting habitat for other species, including insects, birds, and small mammals.[6]

In the Prairies, the decline of the gray wolf began with the extirpation of the plains bison in the late 1800s and continued due to overharvest of ungulates and predator control.[10] The loss of the wolf has changed predator-prey dynamics. In southeastern Alberta, western coyote abundance increased 135% between the periods 1977 to 1989 and 1995 to 1996.[11]

The change in top predators from wolves, which mainly hunted ungulates, to western coyotes, which eat a wider range of foods[11, 12] and are not major ungulate predators,[13] has shifted the abundance and distribution of prey species.

ARCTIC SMALL MAMMAL POPULATION CYCLES

Long datasets are needed to detect and understand ecosystem change, especially when populations may be cyclic.[16] Small-mammal monitoring programs in the Northwest Territories and Nunavut, have not been in place long enough to detect trends. Lemming cycles at Bylot Island, Nunavut, showed signs of weakening in the mid-2000s[17] but high densities of lemmings in 2008 and 2010 returned the long-term trend to stable.[18]

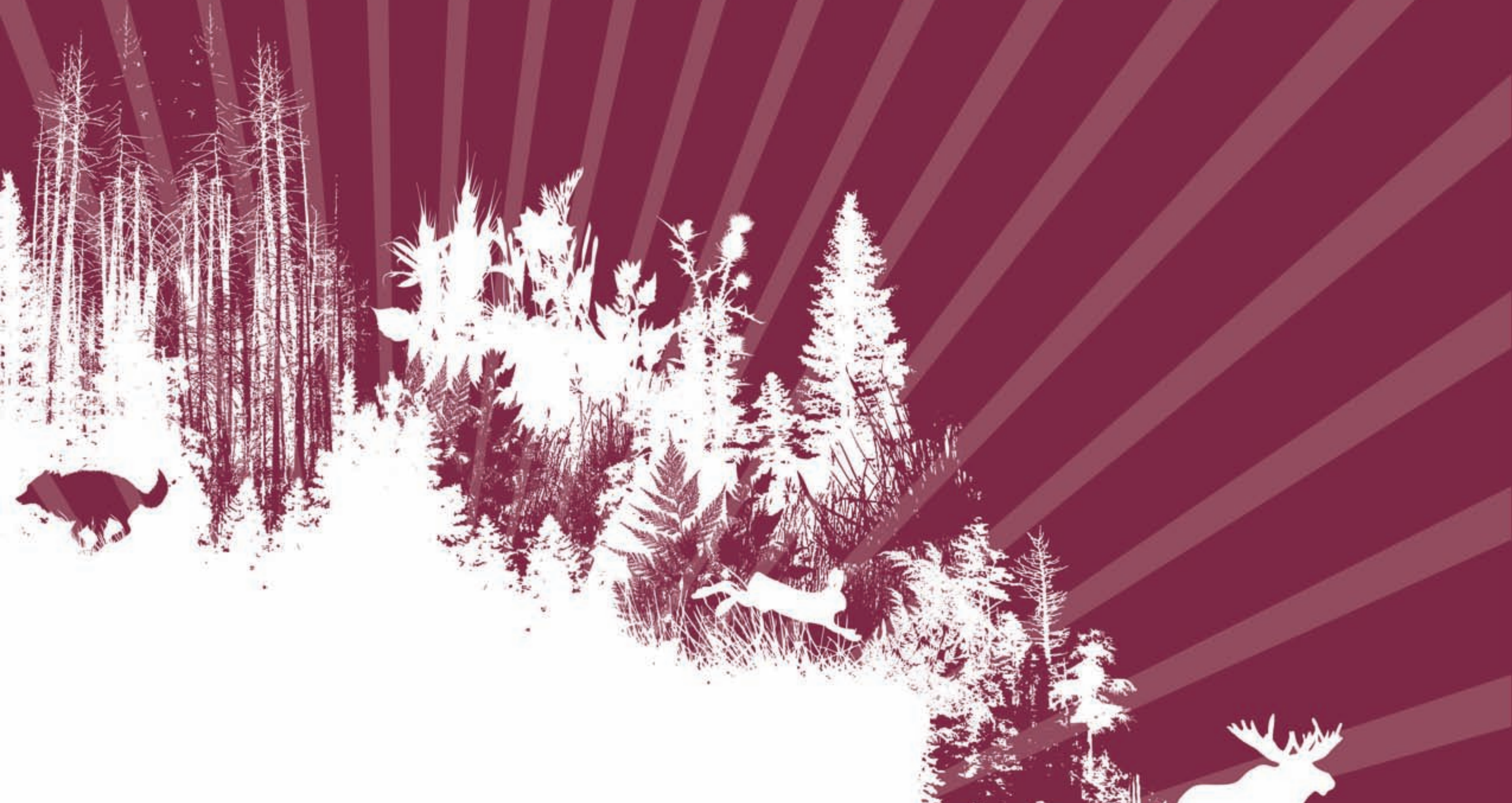
Trends in population cycles

Population cycles are especially important features in boreal forest and tundra,[1] Canada's largest terrestrial ecosystems. Herbivores are at the heart of these systems. The 10-year snowshoe hare cycle drives the cycles of many bird and mammal predators in the boreal forest,[19] particularly lynx and coyote. The hare cycle itself is a result of interaction between predation and the vegetation that forms the hares' food supply.[20] In Arctic tundra, lemmings and other small rodents drive population dynamics of many predators.[21]

Global Trends

In northern Europe, population cycles in lemmings, voles, grouse, and insects have been weakening over large areas since the early 1990s. Some studies show linkages to climate change, especially to the effects of warmer winters.[22, 23]

science/policy interface



KEY FINDINGS

21. Biodiversity monitoring, research, information management, and reporting Long-term, standardized, spatially complete, and readily accessible monitoring information, complemented by ecosystem research, provides the most useful findings for policy-relevant assessments of status and trends. The lack of this type of information in many areas has hindered development of this assessment.

22. Rapid changes and thresholds Growing understanding of rapid and unexpected changes, interactions, and thresholds, especially in relation to climate change, points to a need for policy that responds and adapts quickly to signals of environmental change in order to avert major and irreversible biodiversity losses.

BIODIVERSITY MONITORING, RESEARCH, INFORMATION MANAGEMENT, AND REPORTING

Status and Trends

generally fair to poor status with some good data; variable trends in state of monitoring and for ecosystem components

KEY FINDING 21. Long-term, standardized, spatially complete, and readily accessible monitoring information, complemented by ecosystem research, provides the most useful findings for policy-relevant assessments of status and trends. The lack of this type of information in many areas has hindered development of this assessment.

Biodiversity monitoring is the process of determining status and tracking changes in living organisms and the ecological complexes of which they are a part.[1] **Biodiversity monitoring is important** because it provides a basis for evaluating the integrity of ecosystems, their responses to disturbances, and the success of actions taken to conserve or recover biodiversity. **Research** addresses questions and tests hypotheses about how these ecosystems function and change and how they interact with stressors. Ecological **research** provides the context for interpreting these monitoring results. Policy and management needs guide the development of monitoring.

A comprehensive review of the status of Canada's ecological monitoring and information systems is beyond the scope of this report. This section presents observations and lessons learned about the strengths and weaknesses of information and its availability for assessing status and trends of Canada's ecosystems.

Global Trends

Measuring progress towards the global target of reducing the rate of biodiversity loss by 2010 relies on monitoring species abundance, threat of extinction, extent and condition of habitats, and ecosystem goods and services.[2] The United Nations reports that this global target has not been met.[1]

ECOSYSTEM TRENDS: HOW GOOD ARE THE DATA?

Good to fair for some trends

Includes climate trends, some animal population trends, and trends that can be measured across large areas using remote sensing (like sea-ice extent and mountain pine beetle effects) or through national databases (like protected areas). Quality of data can vary with region – for example, the majority of stream-flow monitoring stations are in the southern half of the country and near population centres.[3] There are excellent, valuable datasets for many local and regional trends. Some examples: geese arrival dates at Delta Marsh, acidity levels in Boreal Shield lakes, contaminants in Great Lakes fish, and status of commercially valuable fish species.

Poor for some trends

There are good data for some specific areas and time periods – but the big picture is often missing. Coverage is not good enough to understand some important trends at the biome level – such as changes in extent of coastal habitats and wetlands. Trends in many species groups and in ecosystem aspects important to biodiversity, such as permafrost, food web structures, and the spread of all but a few invasive species, are inferred from data from a few locations.

Missing for some trends

Includes trends in processes and species groups that are undoubtedly important for the maintenance of healthy ecosystems and that may be undergoing significant change. There is little to no information on trends in processes like decomposition and pollination and on trends for most non-commercial species, non-flowering plant species, invertebrates, and smaller organisms like soil bacteria. The result is that trends for these ecosystem components are not reported in this assessment.

Piecing together information from many disparate sources is currently the only way to assess ecosystem status and trends.


iStock.com

Current ecosystem monitoring is conducted at different spatial and time scales, measures different parameters, and uses different protocols for data collection and analysis. The result is a mosaic of information, reflected in the gaps in this assessment and in the mid to low confidence assigned to many key findings. This is a long-standing problem for Canada, as for other countries,[4, 5] and can only be resolved through attention to setting policy-relevant monitoring priorities and to design and consistent operation of long-term monitoring systems.

Assessment capacity can be improved through maintaining and building on existing long-term monitoring, but new initiatives may be required to meet policy needs.


S. Carrière

Monitoring programs most useful for this assessment had good statistical design, consistent protocols, and broad spatial coverage based on ecosystems, rather than jurisdictions. Their value in measuring trends and detecting rapid and unexpected change increased with consistency and length of records. Few such programs with long-term records exist in Canada, and none exist for many important ecological components. Some trend records are out of date due to cuts to environmental monitoring since the 1990s.[3, 6] Some new initiatives started in the past decade will provide trend information for future assessments – for example, monitoring and assessment of ecological integrity of national parks[7] and monitoring of cumulative impacts in Alberta ecosystems[8] – but many gaps remain. Canada also faces a shortage in taxonomic expertise, which hampers some biodiversity monitoring.[9-11]


Canadian Forest Service

Routine government monitoring programs designed for resource management also provide trend information on aspects of ecosystems – but are often limited in their applicability to biodiversity assessment. For example, some forest inventory systems group tree species by commercial use, while, for biodiversity assessment, trees need to be grouped by ecological significance. There is scope for adapting some management-focused monitoring to fill gaps in ecological monitoring.


Jim Leafloor

Ecological research is an important resource for trend data. Research programs based on multi-disciplinary approaches provided this assessment with some of the best insights into changes in ecosystem functions and structures. However, monitoring associated with research is often short term, ending when the research cycle is over. Monitoring programs that involve community volunteers,[12] such as the Breeding Bird Survey,[13] are another important resource. Investment in program design, data management and reporting, as well as ongoing training and support to volunteers, ensures that results are consistent, long-term, and relevant.[14, 15]

Traditional and local knowledge are rarely incorporated into monitoring programs and were underutilized in this assessment.


iStock.com

Documented Aboriginal Traditional Knowledge (ATK) available in the public domain was compiled for this assessment, but for the most part it was not incorporated effectively. Efforts to insert ATK into reports on status and trends raised concerns about presenting excerpts of knowledge out of their cultural context and concerns about representativeness of the knowledge, especially as time periods and spatial scales were often not specified.[16, 17] Local observation and knowledge of change (not restricted to Aboriginal Peoples) is a related, underutilized resource.[18, 19] Bringing different knowledge systems together in complementary ways remains a challenge for ecological monitoring and assessment.[17, 20-22]

BIODIVERSITY MONITORING

Improving publishing practices, as well as information management and archiving, would make monitoring results more accessible for policy and decision-making.

Overall, information on ecosystem status and trends in Canada is very scattered – it is difficult to find out what is available and where it is located and the information itself is of variable quality. Improvements require coordination and attention to data management and publication practices.

Information management is crucial to the integrity, long-term usefulness, and accessibility of monitoring results. Effective monitoring programs include organization and documentation of datasets, secure storage in long-term, searchable archives, and regular review and quality checks. With advances in technology, datasets have become larger and more complex, thereby requiring more resources to manage. At the same time, techniques for analyzing data spatially and for sharing data across networks present opportunities for viewing and synthesizing environmental information in new ways – and also increase the need for coordinated data policies and standards.


iStock.com

OBSERVATIONS ON THE ACCESSIBILITY OF INFORMATION FOR THIS ASSESSMENT

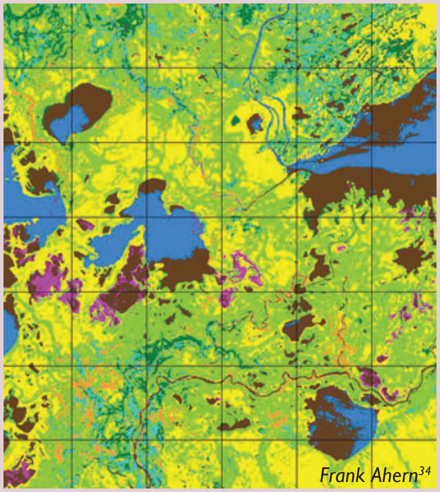
- Published scientific literature was the most accessible and useful source of information for most aspects of the assessment, particularly papers that presented monitoring results in relation to research on ecosystems and stressors.
- Also useful, though sometimes more difficult to locate, were well-referenced assessment reports (on regions and on themes) and results-oriented reports produced through monitoring programs.
- Some comprehensive datasets were accessible, mainly through government agencies, but other, especially older, datasets were difficult or impossible to track down. An advancement that contributed to this assessment is the move to including digital supplemental information, like data and maps, with publications.
- Many unpublished reports and websites accessed were out of date and/or did not have sufficient information about the data they were based on to make them useful and credible sources.

New technologies and applications are expanding horizons in biodiversity monitoring.

Remote sensing (using data collected by satellite) is increasing in usefulness for ecological monitoring, a trend that should continue with lengthening time series and if advances continue to be made in the development of applications and analytical capacity.[23, 24] Remote sensing, when verified and complemented with data from ground-based observations, can provide consistent, repeatable measurements of changes in ecosystems across broad scales. There are, however, limitations to what can be detected from space. For example, only major changes to prairie wetlands can be detected because small, dried-up wetlands are usually indistinguishable from the surrounding land.[25]

EXAMPLES OF USE OF REMOTE SENSING IN THIS ASSESSMENT

Analysis of ice-cover seasons on large lakes using remote sensing allowed trends to be derived for the Arctic, a region with few ground-based observations.[26] Remote sensing also improved detection of large forest fires,[27] provided trends for Arctic sea-ice extent,[28] measured broad-scale change in Western Arctic vegetation at treeline,[29] and provided trends in primary productivity across the country.[30] One-time analyses of land cover,[31] and forest fragmentation[32, 33] provided measures of status, with potential to provide trends in the future.


Frank Ahern[34]

Policy-relevant ecosystem status and trends information is best delivered through a partnership of policy, research, and monitoring.

Information gaps identified while developing this assessment are documented in thematic and ecozone+ technical reports. Common themes emerged:

1. Poor understanding of thresholds, baselines, and natural ranges of variability in ecosystems
2. Limited information on changes in food web structures
3. Little research and monitoring that addresses cumulative impacts over time and impacts from interacting stressors
4. Little information for assessing trends in capacity of ecosystems to provide goods and services
5. Growing need for information on responses of ecosystems to climate change
6. Trends in abundance and other measures, such as reproductive success, available for only a few species groups
7. Poor understanding of biodiversity status, trends, and ecological processes in some dominant biomes including aquatic ecosystems, wetlands, boreal forests, and coastal zones
8. Poor monitoring coverage for less-populated and harder-to-access regions

iStock.com

Specific information needs arise within ecozones+ that are often aspects of the more general information gaps. Well-designed biodiversity monitoring adapts to address regional needs while maintaining a set of core measurements for comparison across regions and over time.[35] Monitoring is needed to detect changes over time and space, and research is needed to understand the significance of these changes – this is an iterative process.[36] Networks based on ecosystem components (like permafrost) or species groups (like seabirds) play a strong role in fostering dialogue and coordination between these two aspects of ecosystem science.

SOME INFORMATION NEEDS FOR MARINE ECOZONES+

This summary shows examples of common themes and ecozone+-specific needs identified for the marine ecozones+.[37]

Research and monitoring, working together, are needed to fill these gaps.

CANADIAN ARCTIC ARCHIPELAGO
- Consequences of reduction/loss of multi-year ice
- Information on Arctic char and its habitat
- Trend data for water column structure

COMMON TO ALL ECOZONES+
- Status and trends related to coastal biome
- Long-term trends in fish and zooplankton, and their food web linkages
- Accurate population abundance estimates
- Accurate status and trends estimates, lacking for many species, particularly benthic and non-commercial species

iStock.com

BEAUFORT SEA
- Benthic community trends
- Status and trends of seabirds (poorly understood relative to Eastern Arctic)

NORTH COAST AND HECATE STRAIT
- Source of excessive marine mortality of some fish, including salmon, eulachon, and herring
- Trends in plankton (only available for the southern edge of the ecozone+)

WEST COAST VANCOUVER ISLAND
- Ecology and long-term trends for groundfish

STRAIT OF GEORGIA
- Trends in nutrient levels and changes in deepwater chemistry
- Cause of change in timing of zooplankton biomass peak and impact on food webs

HUDSON BAY, JAMES BAY, AND FOXE BASIN
- Ecological impact of decreasing freshwater inputs from rivers
- Impact of a new top predator, the killer whale

NEWFOUNDLAND AND LABRADOR SHELVES
- Population dynamics and distribution of capelin and other small pelagic species

ESTUARY AND GULF OF ST. LAWRENCE
- Significance of changes in zooplankton
- Coastal productivity and its contribution to productivity of the ecozone+

GULF OF MAINE AND SCOTIAN SHELF
- Ecology and trends in the deep water beyond the Scotian Shelf

RAPID CHANGES AND THRESHOLDS

KEY FINDING 22. Growing understanding of rapid and unexpected changes, interactions, and thresholds, especially in relation to climate change, points to a need for policy that responds and adapts quickly to signals of environmental change in order to avert major and irreversible biodiversity losses.

Ecosystems are dynamic complexes of plants, animals, and microorganisms, interacting with natural forces, human actions, and changing conditions. Ecosystems can adapt to certain levels of stress, however their capacity to recover from disturbance may be lowered by biodiversity loss and cumulative impacts. A point may be reached where the ecosystem undergoes a rapid, irreversible shift from one state to another. This is usually detected as a large, rapid, and persistent change in relative abundances of organisms, especially species that we notice (such as vegetation) or that we exploit (such as fish stocks).

The point at which a shift is inevitable is called a **threshold** or tipping point.[1, 2] Thresholds preceding rapid changes are often difficult to predict, but may themselves be preceded by early-warning signals like increased variability or slower recovery from a disturbance.[3] Climate change is very likely to lead to threshold-type ecosystem responses, many of them irreversible.[2] Many aspects of ecosystems are not currently, or regularly, monitored and much remains unknown about how Canada's ecosystems function. Climate change adds uncertainty and is projected to lead to responses that lie outside the ranges of historical records.[2]

Recognizing that rapid change occurs is important because it has implications for policy. Ecosystem responses are often unexpected, especially owing to interactions among stressors.

Early warning signals are not always detected in time, especially when ecosystem monitoring is absent or inadequate or when the measurement uncertainty is so large that change cannot be detected until a threshold has been crossed. Management policies need to be designed to minimize the social, economic, and environmental impacts of unpredictable change when it inevitably occurs. Designing "safe-fail" policies provides a measure of insurance.

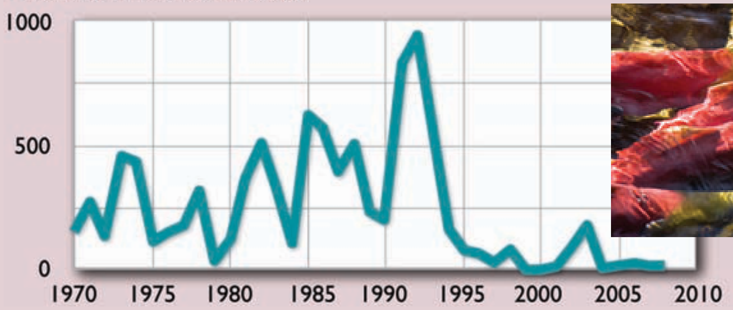
Action can, however, be taken before thresholds are crossed and policy options become restricted and expensive. This involves increasing Canada's capacity to detect and interpret the signals of ecological change and, at the same time, strengthening the science-policy interface by targeted and timely delivery of research results to policy and decision makers.

AN EXAMPLE OF RAPID AND UNEXPECTED CHANGE

The combined Smith and Rivers inlets sockeye salmon stock was historically one of the largest and most valuable salmon populations in B.C., supporting commercial fishing, canneries, and First Nations fisheries. Numbers of returning salmon declined suddenly in the early 1990s, likely due to poor marine survival during migration through the North Coast and Hecate Strait Ecozone+ and into the Gulf of Alaska.[4] The specific cause and location of this mortality is unknown.

SOCKEYE SALMON RETURNING TO SMITH AND RIVERS INLETS, B.C.

Thousands of fish, 1970 to 2008



Source: Crawford and Irvine, 2009[5]

DETECTING CHANGE AND TAKING ACTION

Three complementary decision points for biodiversity conservation

1. When thresholds are crossed
(it may be too late)

Action is delayed until the evidence of change is clear. For example, species decline below minimum viable numbers; too little habitat is left to support whole groups of species; extinctions. Options for action are limited and expensive. Interventions are drastic, with low likelihood of success. Recovery, if it occurs, is slow. Socio-economic impacts are inevitable.

2. When ecosystem changes are detected
(it is not too late)

Earlier action, based on evidence that ecosystem change is underway, provides more options to mitigate impacts. Action is taken when cause-and-effect relations are at least partly understood and when evidence from research creates confidence that biodiversity declines are likely if no action is taken. Leads to a high probability of reversing or stabilizing impacts and reducing stressors before it is too late.

photos: iStock.com

3. When early signals indicate there may be change
(prevention possible)

Early signals of change are a source of information to use when developing policy options, managing proactively, and ensuring appropriate monitoring and research are in place. Early signals might be detected in a few locations only or in just some animals or plants in a population. These changes may turn out to be part of natural fluctuations – or they may be signs of bigger changes to come. Early action now may prevent problems in the future, be less expensive, and consequences may be less severe.

Some examples from this assessment

Even with moratoria on fishing and reduced harvesting, action in response to declines in **marine fisheries** resulting from overfishing in the Atlantic and Pacific has not always been successful. The lack of recovery of some fish stocks is likely related to alteration of food webs and other aspects of ecosystems, making it difficult to return to past conditions. Earlier interventions might have improved prospects for recovery.

Since invasive non-native species and other changes took hold in the **Great Lakes**, large annual investments are needed to keep this altered system producing the ecosystem services that were provided naturally in the past.

Fragmentation of landscapes is known to lead to the loss of habitat and species. It is difficult to measure the incremental changes in species themselves – but action to maintain large, intact landscapes will likely slow the rate of biodiversity loss.

Fire and insect disturbances have strong relationships with temperature and with forest practices. Severity and spread of certain forest insects and incidence of fire are likely to increase due to climate change. Policy options are available and have a good chance of success, including adapting fire and forestry management practices.

Invasive non-native species, including parasites, are often detected when they are just beginning to spread. Monitoring and early intervention have prevented the spread of some potentially harmful invasive non-native species, such as the gypsy moth in western Canada.

About 20 common species of **birds** are showing signs of widespread decline and the causes are unclear. Adapting research and monitoring to find out why is a first step in taking action to halt or reverse these declines.

RAPID CHANGES AND THRESHOLDS

Slow, incremental change may not seem important until thresholds are taken into account.


iStock.com

Ocean acidification, caused by uptake of carbon dioxide from the atmosphere, occurs in some Canadian marine ecosystems and is an emerging issue in others; the rate of change is slow. Research and global change models provide good evidence that acidification will continue to increase as a result of climate change. Some ocean acidity thresholds are well known because they are chemical and physiological and are relatively easy to define – when the water becomes too acidic, calcium carbonate shells and skeletons cannot form properly, affecting shellfish, corals, and other sea creatures. (See Marine Biome.)


iStock.com

The historical distribution of native **grasslands**, the most endangered of Canada's biomes, has been greatly reduced, mainly through conversion for agriculture. There are several types of grasslands, each supporting a distinct mix of species, including many species at risk. The natural processes that maintained grasslands in the past, like fire and grazing by free-roaming bison herds, are now absent or modified. Development and recreation continue to convert and fragment the land in some areas and the spread of invasive non-native species and changes in grazing practices continue to alter the composition and structure of the vegetation. Each type of grassland will have its own threshold beyond which it will no longer be able to support its unique mix of species. (See Grasslands Biome.)

Stressors may interact in unexpected ways to produce surprises.


Greg McCullough

Nutrient loading to the Great Lakes was a problem that led to collaborative action between the United States and Canada, starting in the 1970s, to reduce nutrient inputs and clean up the lakes. These measures were successful – water quality improved, harmful algal blooms and oxygen depletion problems decreased, and diversity of native algal species increased. However, as lakeshore areas continued to be modified, human populations surrounding the lakes continued increasing and invasive non-native species have become more prevalent, altering many of the lakes' characteristics. Although regulation continues to limit nutrient inputs, some combination of the changes that are taking place in the lakes has resulted in reappearance of harmful algal blooms in some near-shore areas. (See Nutrient Loading.)

Global Trends

Pressures on global ecosystems are increasing the likelihood of rapid and unexpected changes such as outbreaks of pests and diseases, catastrophic floods and landslides, desertification, fisheries collapse, and species extinctions.[1]

Change in one ecosystem component brings with it a suite of widespread consequences.

Summer **sea-ice** extent is shrinking, a rapid change that is now well established. The decline of multi-year ice may have reached or crossed a threshold. Ecological consequences are emerging, especially in Hudson Bay, where the ice-free season has increased the most. Examples include a reduction in Arctic cod, a fish that is associated with ice; an increase in capelin, a fish more tolerant of warmer water; reduced body condition of polar bears; and range expansion of a new top predator, the killer whale, into the bay. (See Marine Biome and Ice Across Biomes.)

Large predators, including wolves, have declined or have been extirpated from much of their original ranges in the more populated areas of Canada. Smaller predators, like western coyotes and raccoons, have in turn expanded their ranges and increased in numbers. These more adaptable predators eat a wide range of food items, altering abundance of other species. In the Mixedwood Plains, with fewer predators, white-tailed deer have become more abundant, leading to major changes in forest vegetation. (See Food Webs.)

Damage to ecosystems may speed up because of interactions of stressors.

Coastal erosion in the Atlantic Maritime Ecozone+ is increasing, threatening wetlands, beach, and dune ecosystems. Development and hardening of the foreshore have made coastal ecosystems more susceptible to erosion. Rise in sea level, reduced sea ice, and more tropical storms in the Atlantic, all related to climate change, accelerate the rate of erosion. (See Coastal Biome.)

Thresholds are influenced by both environmental sensitivity and the severity of the threat.

Some lands and waters, due to their underlying geology, have greater capacity to buffer **acid deposition** than others, so the threshold beyond which ecosystem damage occurs varies from place to place, even with the same levels of acid deposition. Once the threshold is crossed, high levels of impacts occur rapidly. For example, certain salmon rivers in Nova Scotia have been particularly affected because of their lack of capacity to buffer acid. (See Acid Deposition.)

The information in *Canadian Biodiversity: Ecosystem Status and Trends 2010* draws on a series of technical background reports prepared and reviewed by many experts from across Canada. They are of two types, thematic reports and ecozone+-specific reports. Information on how to access these reports can be obtained from www.biodivcanada/ecosystems.

Technical thematic reports

Ecological classification system for the ecosystem status and trends report. R. Rankin, M. Austin and J. Rice. Technical Thematic Report No. 1.

Classifying threats to biodiversity. C. Wong. Technical Thematic Report No. 2.

Land classification scheme for the ecosystem status and trends report. J. Frisk. Technical Thematic Report No. 3.

Large-scale climate oscillations influencing Canada. B. Bonsal and A. Shabbar. Technical Thematic Report No. 4.

Canadian climate trends, 1950-2007. X. Zhang, R. Brown, L. Vincent, W. Skinner, Y. Feng, and E. Mekis. Technical Thematic Report No. 5.

Trends in large fires in Canada, 1959 to 2007. C.C. Krezek-Hanes, A. Cantin and M.D. Flannigan. Technical Thematic Report No. 6.

Wildlife pathogens and diseases in Canada. F.A. Leighton. Technical Thematic Report No. 7. *Contributors:* I.K. Barker, D. Campbell, P.-Y. Daoust, Z. Lucus, J. Lumsden, D. Schock, H. Schwantje, K. Taylor, and G. Wobeser.

Trends in breeding waterfowl in Canada. M. Fast, B. Collins and M. Gendron. Technical Thematic Report No. 8.

Trends in permafrost conditions and ecology in northern Canada. S. Smith. Technical Thematic Report No. 9.

Northern caribou population trends in Canada. A. Gunn and D. Russell. Technical Thematic Report No. 10.

Woodland caribou, boreal population, trends in Canada. C. Callaghan, S. Virc and J. Duffe. Technical Thematic Report No. 11.

Landbird trends in Canada, 1968-2006. C. Downes, P. Blancher and B. Collins. Technical Thematic Report No. 12.

Trends in Canadian shorebirds. C. Gratto-Trevor, R. Morrison, B. Collins, J. Rausch and V. Johnston. Technical Thematic Report No. 13.

Trends in wildlife habitat capacity on agricultural land in Canada, 1986-2006. S.K. Javorek and M.C. Grant. Technical Thematic Report No. 14.

Trends in residual soil nitrogen for agricultural land in Canada, 1981-2006. C.F. Drury, J.Y. Yang and R. De Jong. Technical Thematic Report No. 15.

Soil erosion on cropland – introduction and trends for Canada. B.G. McConkey, D.A. Lobb, S. Li, J.M.W. Black and P.M. Krug. Technical Thematic Report No. 16.

Monitoring biodiversity remotely: a selection of trends measured from satellite observations of Canada. F. Ahern, J. Frisk, R. Latifovic and D. Pouliot. Technical Thematic Report No. 17.

Inland colonial waterbird and marsh bird trends for Canada. C. Weseloh. Technical Thematic Report No. 18. *Contributors:* G. Beyersbergen, S. Boyd, A. Breault, P. Brousseau, S.G. Gilliland, B. Jobin, B. Johns, V. Johnston, S. Meyer, C. Pekarik, J. Rausch and S.I. Wilhelm.

Climate-driven trends in Canadian streamflow, 1961-2003. A. Cannon, T. Lai and P. Whitfield. Technical Thematic Report No. 19.

Ecosystem status and trends report: biodiversity in Canadian lakes and rivers. W.A. Monk and D.J. Baird. Technical Thematic Report No. 20. *Contributors:* R.A. Curry, N. Glozier and D.L. Peters.

Technical thematic report published elsewhere

Changes in Canadian seabird populations and ecology since 1970 in relation to changes in oceanography and food webs. A.J. Gaston, D.F. Bertram, A.W. Boyne, J.W. Chardine, G. Davoren, A.W. Diamond, A. Hedd, W.A. Montevecchi, J.M. Hipfner, M.J.F. Lemon, M.L. Mallory, J.-F. Rail and G.J. Robertson. Environmental Reviews 17:267-286.

Technical Ecozone+ Status and Trends Reports

Arctic *Lead authors:* J. Eamer, L. Harding and G. Henry
Contributing authors: S. Carrière, J. Goulet, C. Haas, J. Paquet, M. Reichard, R. Smith, and L. Torretti

Atlantic Maritime *Lead author:* S. Eaton
Contributing authors: J. Barr, T. Hayes, G. MacAskill, J.-P. Savard, R. Siron, I. Turcotte, and A.-M. Turgeon

Boreal Cordillera *Lead authors:* M. Nelitz and L. Harding
Contributing authors: M. Austin, B. Drinkwater, C. Eamer, T. Jung, G. Kuzyk and S. Leverkus

Boreal Plains *Lead authors:* D. Haughland and A. Lennie
Contributing authors: K. Hannah, H. Kling, N. McCutchen, and E. Shipley

Boreal Shield *Lead authors:* I. Turcotte, L. Venier, and D. Kirk
Contributing authors: S. Banducci, J. Boyd, N.M. Burgess, É. Cadieux, C. Curley, B. Dalton, M. Darveau, C. Eckley, D. Francoeur, M. Girardin, B. Greenwell, S. Hay, M. Hilderman, D.S. Jeffries, M.-C. Leblanc, R. Lussier, P. Masson, M. McLaughlan, R. Miller, E. Muto, T.L. Noland, K. Pawley, N. Peterson, V. Provost, J. Rodrigue, B. Rodrigues, M. Rogers, L. Royer, J.-P.L. Savard, J.-P. Savard, R. Schetagne R. Siron, J. Stewart, A.-M. Turgeon, R. Verdon, R.C. Weeber, W. Wistowsky, and I. Wong

Great Lakes *Lead author:* S. Garden
Contributing authors: J. Allair, S. Bailey, K. Bowen, S. Chong, P. Chow-Fraser, G. Christie, A. Cottrill, B. Cudmore, R. Dermott, S. Doka, J. Esbjerg, J. Fitzsimons, D. Gonder, S. Guilford, K. Hedges, B. Henson, K. Holeck, N. Hooseinny, T. Johnson, D. Kraus, W. Legere, R. MacGregor, N. Mandrak, P. Martin, E. Mills, K. Minns, T. Morris, I.F. Munawar, M. Munawar, S. Myer, H. Niblock, M. Oldham, T. Schaner, B. Shuter, R. Smith, J. Switzman, C. Weseloh, C. Wiley, E. Wright, and Y. Zhao

Hudson Plains *Lead authors:* K.F. Abraham, L.M. McKinnon, Z. Jumean, S.M. Tully, L.R. Walton, and H.M. Stewart
Contributing authors: D. Berezanski, F. Berkes, W. Bernhardt, L. Brown, V. Crichton, W.J. Crins, F.N. Dawson, L.A. Dredge, J. Duncan, R.A. Fleming, M.-P. Girardin, W.A. Gough, R.L. Jefferies, V. Kanya, G.J. Kayahara, R. Koes, S. Kowalchuk, R. Lalonde, C. Latremouille, R. Man, I.P. Martini, S. McGovern, J.W. McLaughlin, K. Middel, B. Mighton, K.M. Monson, M.E. Obbard, C. Paitre, R.D. Phoenix, M. Piercy-Normore, J.S. Price, E. Punter, J.C. Ray, R. Roughley, G.A.J. Scott, M. Vukelich, and K.L. Webster

Mixedwood Plains *Lead authors:* D. Krahn and K. Taylor
Contributing authors: W.D. Bakowsky, D. Bazley, M. Bevan, S. Bhavsar, J. Bowman, B. Boysen, B. Brownson, D.M. Burke, Q. Chiotti, B. Collins, A. Crook, B. Dalton, R. Dixon, L. Duchesne, D. DuMoulin, T. Dunkley, W. Dunlop, A. Dyk, A. Ecclestone, K. Elliot, A.K. Evers, K. Falk, D. Featherstone, K. Ferguson, M. Furrer, R. Gagnon, M. Garvin, M. Gatt, P. Gray, A. Handyside, I. Heathcote, M. Heaton, C. Heydon, N. Hooseinny, S. Hounsell, J. Hughes, T. Hutchinson, M. Irvine, S. Jarvie, F.C. Jones, G. Kaltenecker, P. Kor, B. Kowalyk, D. Leckie, A. MacIntosh, J. McHattie, T. McIntosh, F. McKay, G. McLaren, M. McMurtry, K. Milian, M. Nicol, G. Nielsen, C. Nielson, A.J. Norman, I. Ockenden, R. Pineo, B. Pond, S. Poser, D. Puric-Mladenovic, K. Reese, J.-A. Rzadki, T. Scarr, T. Schwan, P. Smith, R. Spence, L. Stanfield, S. Strobl, J. Switzman, D. Tailon, D. Tammadge, A. Tanentzap, J. Thompson, A. Todd, S. Voros, A. Wallace, P. Waring, O. Williams, R. Wilson, W. Wistowsky, A. Woodliffe, E. Wright, and R. Zeran

Montane Cordillera *Lead author:* L. Harding
Contributing author: B. Harrison

Newfoundland Boreal *Lead authors:* S. Pardy-Moores, J. Humber, and T. Leonard
Contributing authors: J. Blake, J. Gosse, C. Hanel, G. Luther, M. McGrath, D. Pelley, C. Sheffield, and S. Squires

Pacific Maritime *Lead authors:* A. Eriksson, F. Backhouse, and A. Leslie
Contributing authors: M. Austin, D. Buffett, and R. Smith

Prairies *Lead authors:* J. Thorpe and B. Godwin
Contributing authors: B. Dale, J. DeVries, M. Dubois, S. Hay, T. Hayes, N. Henderson, J. Karst, and S. Michalsky

Taiga Cordillera *Lead authors:* N. Maclean and J. Eamer
Contributing authors: S. Carrière, J. Hawkings, T. Jung, W. Nixon and B. Oosenbrug

Taiga Plains *Lead author:* A. Gunn
Contributing authors: S. Carrière and J. Eamer

Taiga Shield *Lead author:* A. Gunn
Contributing authors: D. Cantin, S. Carrière, J. Eamer, R. Lussier, A. Penn, R. Schetagne, and R. Verdon

Western Interior Basin *Lead authors:* D. Gayton, L. Harding, and T. Hayes
Contributing authors: K. Brock, B. Harrison, G. Kuzyk, and R. Rae

Arctic Marine (including the Beaufort Sea, Canadian Arctic Archipelago, and the Hudson Bay, James Bay, and Foxe Bay)
Lead authors: A. Niemi, J. Paulic, and D. Cobb

Estuary and Gulf of St. Lawrence *Lead authors:* R. Dufour, H. Benoit, M. Castonguay, J. Chassé, L. Devine, P. Galbraith, M. Harvey, P. Larouche, S. Lessard, B. Petrie, L. Savard, C. Savenkoff, L. St-Amand, and M. Starr

Gulf of Maine and Scotian Shelf *Lead authors:* T. Worcester and M. Parker

Newfoundland and Labrador Shelves *Lead author:* N. Templeman

North Coast and Hecate Strait *Lead authors:* P. Cummins and R. Haigh

Strait of Georgia *Lead authors:* S. Johannessen and B. McCarter

West Coast Vancouver Island *Lead authors:* D. Ianson and L. Flostrand

Other contributors

- R. Hélie, J.-F. Gobeil, and R. Vanderkam provided protected area data and analysis.
- Canadian Centre for Remote Sensing provided data.
- D. Hurlburt prepared a review and synthesis of Aboriginal Traditional Knowledge.
- V. Schaefer prepared a draft report on urban biodiversity.
- The International Institute for Sustainable Development and ESSA Technologies Ltd. prepared initial scoping and background work and assisted with workshop facilitation.
- G. Sheehy, J. Lord, and C. Eamer prepared first drafts of some of the evidence for key findings ecozone^{+} summary reports.
- Several contractors and government staff facilitated expert workshops that were held across Canada.
- A. Moores, K. Hodges, and J. Reynolds of the Canadian Society for Ecology and Evolution organized a symposium and peer review.
- Hundreds of experts from government, academia, and non-government organizations across Canada attended workshops to help guide the technical reports and identify issues.
- Hundreds of experts from academia, government, non-government organizations, and private consultants provided peer review for case studies, key findings, and technical background reports.

Photo credits

Cover (from left to right): Prairies, iStock/tbob; Lord Selkirk, Provincial Park, iStock/Photawa; wetland , Allen Woodliffe; Thousand Islands, Environment Canada; Arctic wildflowers, Government of Yukon; shorebirds, Jason Puddifoot; Maragee Valley, iStock/cworthy; Tombstone Mountains, YK, Trish Hayes; killer whales, Jason Ford, Fisheries and Oceans Canada; salmon, iStock/brytta; McIntyre Creek, Claire Eamer; Wood Buffalo National Park, Parks Canada; sunset, graphicjackson; fall leaves, Canadian Forest Service; polar bears, iStock/Visual Communications; canola field, iStock/graphicjackson; drying salmon, iStock/fkienas; Taiga Plains - Boreal forest, Canadian Forest Service; tidepool, Richard Cannings; lake reflection, iStock/kavram; maple leaves, Risa Smith

iStock.com: p.1, tidepool, scarletsnails; p.1, Maragee Valley, cworthy; p.1, polar bears, Visual Communications; p.2, Pacific Maritime, cathryn155; p.2, grasslands, 4loops; p.3, Lord Selkirk, Provincial Park, Photawa; p.3, tide pool, scarletsnails; p.3, sea ice, jwebb; p.4, children, andrewmedina; p.5, killer whales, ElsvanderGun; p.6, smoke stack, IanChrisGraham; p.6, alder buds, serg269; p.6, drying salmon, fkienas; p.7, canola field, graphicjackson; p.7, leopard frog, maimai; p.7, salmon, R_Koopmans; p.8, fire, cfarish; p.8, coyote, 4loops; p.9, sunset, graphicjackson; p.17, Gros Morne National Park, mmac72; p.19, grasshopper sparrow, WilliamSherman; p.30, Lord Selkirk, Provincial Park, Photawa; p.31, low tide, liquidfog; p.32, snow goose, stasvolik; p.35, tidepool, scarletsnails; p.35, mussels, eddyfish; p.36, great blue heron, BirdImages; p.39, fish, Irishka1; p.41, sea ice, jwebb; p.41, polar bears, Visual Communications; p.42, Angel glacier, aeropw; p.58, northern leopard frog, maimai; p.62, beared seal, micheldenijs; p.62, fireweed, kongxinzhu; p.63, killer whales, ElsvanderGun; p.70, sky, michieldb; p.70, creek, imagecreation; p.70, geese, niknikon; p.70, wetlands, Orchidpoet; p.71, alder buds, serg269; p.72, geese, scol22; p.74, bucket, huronphoto; p.74, ice, brytta; p.75, drying salmon, fkienas; p.76, bird, Whiteway; p.81, canola field, graphicjackson; p.81, northern pintail, LUGO; p.81, nest, nlimmen; p.82, tigerswallow, SoopySue; p.82, rattlesnake, RMBolton; p.82, bunchberry, eppicphotography; p.83, bullfrog, Valmol48; p.83, gray treefrog, HKPNC; p.83, northern leopard frog, maimai; p.83, western chorus frog, rmarnold; p.85, salmon, R_Koopmans; p.87, BC Interior, MarvinBeatty; p.90, downy woodpecker, brm1949; p.90, eastern meadowlark, Canon_Bob; p.90, American kestral, pollyconn; p.90, house finch, MichaelStubblefield; p.90, mourning warbler, PaulTessier; p.91, ducks, 4loops; p.91, king eider, eyebex; p.97, fire, cfarish; p.100, Lake Huron, janeff; p.101, coyote, 4loops; p.104, weather monitoring, DonNichols; p.104, wetlands, brytta; p.104, bee, icam; p.105, binder, molka; p.105, teepee, RyersonClark; p.106, data, nilsz; p.107, lake reflection, kavram; p.107, waves, LesHoward; p.108, salmon, RKoopmans; p.109, dead fish, OKRAD; p.109, road, wolv; p.109, trees, chapin31; p.110, rusty chain, syagci; p.110, grasslands, TreePhoto; p.111, sunset, graphicjackson; p.111, deer, KeithBinns; p.111, beach, onepony; p.111, smoke stacks, IanChrisGraham

dreamstime.com: p.8, leaves, Leif Algotsson; p.27, Oldman River, Bev Ramm; p.28, lakes, Andre Nantel; p.67, Skaha lake, Timothy Epp; p.83, Algonquin Provincial park, Elena Elisseeva; p.83, american toad, David Anderson; p.83, green frog, Electrochris; p.83, spring peeper, Jason Ross; p.83, wood frog, Mircea Costina; p.95, leaf, Leif Algotsson; p.99, beetle damage, Timothy Epp

REFERENCES

OVERVIEW

About this assessment

1. Environment Canada. 2006. Biodiversity outcomes framework for Canada. Canadian Councils of Resource Ministers. Ottawa, ON. 8 p.
2. Federal-Provincial-Territorial Biodiversity Working Group. 1995. Canadian biodiversity strategy: Canada's response to the Convention on Biological Diversity. Environment Canada, Biodiversity Convention Office. Ottawa, ON. 77 p.
3. United Nations Convention on Biological Diversity Conference of the Parties. 2001. COP 6 Decision VI/26: strategic plan for the Convention on Biological Diversity [online]. United Nations Environment Programme. http://www.cbd.int/decision/cop/?id=7200 (accessed 14 December, 2009).
4. Ecological Stratification Working Group. 1995. A national ecological framework for Canada. Agriculture and Agri-Food Canada, Research Branch, Centre for Land and Biological Resources Research and Environment Canada, State of the Environment Directorate, Ecozone Analysis Branch. Ottawa/Hull, ON. 117 p. Report and national map at 1:7 500 000 scale.
5. Rankin, R., Austin, M. and Rice, J. 2010. Ecological classification system for the ecosystem status and trends report. Canadian Biodiveristy: Ecosystem Status and Trends 2010, Technical Thematic Report Series No. 1. Canadian Councils of Resource Ministers. Ottawa, ON. In press.

BIOMES

1. Forests

1. Brandt, J.P. 2009. The extent of the North American boreal zone. Environmental Reviews 17:101-161.
2. Natural Resources Canada. 2009. Biodiversity [online]. Natural Resources Canada. http://canadaforests.nrcan.gc.ca/article/biodiversity (accessed 10 February, 2010).
3. Food and Agriculture Organization of the United Nations. 2001. Global forest resources assessment 2000. Main report. FAO Forestry Paper No. 140. Food and Agriculture Organization of the United Nations. Rome, Italy. 479 p.
4. Food and Agriculture Organization of the United Nations. 2010. Global forest resources assessment 2010. Main report. FAO Forestry Paper No. 163. Food and Agriculture Organization of the United Nations. Rome, Italy. 340 p.
5. National Forest Inventory. 2010. Unpublished analysis of data by ecozone+ from: Canada's national forest inventory standard reports [online]. https://nfi.nfis.org/standardreports.php?lang=en (accessed 22 March, 2010).
6. Girard, F., Payette, S. and Gagnon, R. 2008. Rapid expansion of lichen woodlands within the closed-crown boreal forest zone over the last 50 years caused by stand disturbances in eastern Canada. Journal of Biogeography 35:529-537.
7. Hearnden, K.W., Millson, S.V. and Wilson, W.C. 1992. A report on the status of forest regeneration. Ontario Ministry of Natural Resources. Toronto, ON. 117 p.
8. Manitoba Conservation – Forestry Branch. 2009. Manitoba forest inventory: area by cover type in the Pineland forest management unit, 1970-2000. Unpublished data.
9. Duchesne, L. and Ouimet, R. 2008. Population dynamics of tree species in southern Quebec, Canada: 1970-2005. Forest Ecology and Management 255:3001-3012.
10. Boucher, Y., Arseneault, D. and Sirois, L. 2006. Logging-induced change (1930-2002) of a preindustrial landscape at the northern range limit of northern hardwoods, eastern Canada. Canadian Journal of Forest Research-Revue Canadienne de Recherche Forestiere 36:505-517.
11. Ahern, F., Frisk, J., Latifovic, R. and Pouliot, D. 2010. Monitoring ecosystems remotely: a selection of trends measured from satellite observations of Canada. Canadian Biodiversity: Ecosystem Status and Trends 2010, Technical Thematic Report Series No. 17. Canadian Councils of Resource Ministers. Ottawa, ON. In press.
12. Butchart, S.H.M., Walpole, M., Collen, B., van Strien, A., Scharlemann, J.P.W., Almond, R.E.A., Baillie, J.E.M., Bomhard, B., Brown, C., Bruno, J., Carpenter, K.E., Carr, G.M., Chanson, J.S., Chenery, A.M., Csirke, J., Davidson, N.C., Dentener, F., Foster, M., Galli, A., Galloway, J.N., Genovesi, p., Gregory, R., Hockings, M., Kapos, V., Lamarque, J.-F., Leverington, F., Loh, J., McGeoch, M.A., McRae, L., Minasyan, A., Morcillo, M.H., Oldfield, T.E.E., Pauly, D., Quder, S., Revenga, C., Sauer, J.R., Skolnik, B., Spear, D., Stanwell-Smith, D., Stuart, S.N., Symes, A., Tierney, M., Tyrrell, T.D., Vie, J.-C. and Watson, R. 2010. Global biodiversity: indicators of recent declines. Science 328:1164-1168. doi:10.1126/science.1187512.
13. Environment Canada. 2009. National inventory report: greenhouse gas sources and sinks in Canada, 1990-2007. Government of Canada. Ottawa, ON. 620 p.
14. Natural Resources Canada. 2008. Statistical data: forest management [online]. Natural Resources Canada. http://canadaforests.nrcan.gc.ca/statsprofile (accessed 12 May, 2009).
15. National Forest Inventory. 2010. Canada's national forest inventory standard reports: area (1000 ha) of forest and non-forest land by terrestrial ecozone in Canada [online]. Canadian Council of Forest Ministers. https://nfi.nfis.org/publications/standard_reports/NFI_T4_FOR_AREA_en.html (accessed 13 May, 2010).
16. Food and Agriculture Organization of the United Nations. 2009. State of the world's forests 2009. Food and Agriculture Organization of the United Nations. Rome, Italy. 152 p.
17. Austin, M., Buffett, D., Nicolson, D., Stevens, V. and Scudder, G.G.E. 2008. Taking nature's pulse: the status of biodiversity in British Columbia. Biodiversity B.C. Victoria, BC. 268 p.
18. Ontario Biodiversity Council. 2010. State of Ontario's biodiversity 2010. A report of the Ontario Biodiversity Council. Peterborough, ON. 121 p.
19. Gamache, I. and Payette, S. 2004. Height growth response of tree line black spruce to recent climate warming across the forest-tundra of eastern Canada. Journal of Ecology 92:835-845.
20. Gamache, I. and Payette, S. 2005. Latitudinal response of subarctic tree lines to recent climate change in eastern Canada. Journal of Biogeography 32:849-862.
21. Payette, S. 2007. Contrasted dynamics of northern Labrador tree lines caused by climate change and migrational lag. Ecology 88:770-780.
22. Danby, R.K. and Hik, D.S. 2007. Evidence of recent treeline dynamics in southwest Yukon from aerial photographs. Arctic 60:411-420.
23. Olthof, I. and Pouliot, D. 2010. Treeline vegetation composition and change in Canada's western subarctic from AVHRR and canopy reflectance modeling. Remote Sensing of Environment 114:805-815.
24. Pisaric, M.F.J., Carey, S.K., Kokelj, S.V. and Youngblut, D. 2007. Anomalous 20th century tree growth, Mackenzie Delta, Northwest Territories, Canada. Geophysical Research Letters 34:L05714.1-L05714.5.
25. Harsch, M.A., Hulme, p.E., McGlone, M.S. and Duncan, R.P. 2009. Are treelines advancing? A global meta-analysis of treeline responce to climate warming. Ecology Letters 12:1040-1049.

26. Long, J.A., Nelson, T.A. and Wulder, M.A. 2010. Characterizing forest fragmentation: distinguishing change in composition from configuration. Applied Geography 30:426-435.

27. Lee, P.G., Smith, W., Hanneman, M., Gysbers, J.D. and Cheng, R. 2010. Atlas of Canada's intact forest landscapes. Global Forest Watch Canada 10th Anniversary Publication No. 1. Edmonton, AB. 70 p.

28. Alberta Biodiversity Monitoring Institute. 2009. The status of biodiversity in Alberta-Pacific forest industries' forest management agreement area: preliminary assessment 2009. Alberta Biodiversity Monitoring Institute. Edmonton, AB. 23 p.

29. Ecological Stratification Working Group. 1995. A national ecological framework for Canada. Agriculture and Agri-Food Canada, Research Branch, Centre of Land and Biological Resources Research and Environment Canada, State of the Environment Directorate, Ecozone Analysis Branch. Ottawa, ON. 117 p. Report and national map at 1:7 500 000 scale.

30. Fleishman, E. and Mac Nally, R. 2007. Measuring the response of animals to contemporary drivers of fragmentation. Canadian Journal of Zoology 85:1080-1090.

31. Coops, N.C., Gillanders, S.N., Wulder, M.A., Gergel, S.E., Nelson, T. and Goodwin, N.R. 2010. Assessing changes in forest fragmentation following infestation using time series Landsat imagery. Forest Ecology and Management 259:2355-2365.

32. Wulder, M.A., White, J.C., Andrew, M.E., Seitz, N.E. and Coops, N.C. 2009. Forest fragmentation, structure and age characteristics as a legacy of forest management. Forest Ecology and Management 258:1938-1949.

33. Schmiegelow, F.K.A., Machtans, C.S. and Hannon, S.J. 1997. Are boreal birds resilient to forest fragmentation? An experimental study of short-term community responses. Ecology 1914-1932.

34. Jalkotzy, J.G., Ross, p.I. and Nasserden, M.D. 1997. The effects of linear developments on wildlife: a review of selected scientific literature. Canadian Association of Petroleum Producers. Calgary, AB. 132 p.

35. Hilbert, J., Wiensczyk, A. and . 2007. Old-growth definitions and management: a literature review. BC Journal of Ecosystems and Management 8:15-31.

36. Timoney, K.P. 2003. The changing disturbance regime of the boreal forest of the Canadian Prairie Provinces. Forestry Chronicle 79:502-516.

37. BC Ministry of Forests. 2003. Old growth forests. British Columbia, Canada. Fact Sheet. British Columbia Ministry of Forests. Victoria, BC.

38. BC Ministry of Environment. 2006. Population and economic activity: land cover status of BC's coastal forests. In Alive and inseparable: British Columbia's coastal environment 2006. State of Environment Reporting Office. Victoria, BC. Chapter 1.8. pp. 48-53.

39. Pannozza, L. and Coleman, R. 2008. GPI forest headline indicators for Nova Scotia. GPI Atlantic. 54 p.

40. Newfoundland and Labrador Department of Natural Resources. 2009. Forest inventory. Unpublished data.

41. Ministère des Ressources naturelles et de la Faune. 2010. Unpublished analysis of data by ecozone+ from: Ministère des Ressources naturelles et de la Faune. 2009. Le portrait de l'évolution de la forêt publique sous aménagement du Québec méridional des années 1970 aux années 2000. Ministère des Ressources naturelles et de la Faune, Forêt Québec,. Québec. 142 p.

2. Grasslands

1. Heidenreich, B. 2009. What are global temperate grasslands worth? A case for their protection: a review of current research on their total economic value. The World Temperate Grasslands Conservation Initiative. Vancouver, BC. 51 p.

2. Gauthier, D.A., Lafon, A., Toombs, T.P., Hoth, J. and Wiken, E. 2003. Grasslands: toward a North American conservation strategy. Canadian Plains Research Center, University of Regina, Regina, SK, and Commission for Environmental Cooperation, Montreal, QC. 99 p.

3. White, R., Murray, S. and Rohweder, M. 2000. Pilot analysis of global ecosystems: grassland ecosystem. World Resources Institute. Washington, DC. 69 p.

4. Riley, J.L., Green, S.E. and Brodribb, K.E. 2007. A conservation blueprint for Canada's prairies and parklands. Nature Conservancy of Canada. Toronto, ON. 226 p. and DVD-ROM.

5. Koper, N., Mozel, K.E. and Henderson, D.C. 2010. Recent declines in northern tall-grass prairies and effects of patch structure on community persistence. Biological Conservation 143:220-229. doi:10.1016/j.biocon.2009.10.006.

6. Watmough, M.D. and Schmoll, M.J. 2007. Environment Canada's Prairie and Northern Region habitat monitoring program phase II: recent habitat trends in the Prairie Habitat Joint Venture. Technical Report Series No. 493. Environment Canada, Canadian Wildlife Service. Edmonton, AB. 135 p.

7. Agriculture and Agri-Food Canada. Agri-geomatics programs and services. Derived from census of agriculture 2006 data. [online]. Agriculture and Agri-Food Canada. http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1226330737632&lang=eng (accessed 8 July, 2008).

8. Samson, F.B., Knopf, F.L. and Ostlie, W.R. 2004. Great Plains ecosystems: past, present, and future. Wildlife Society Bulletin 32:6-15.

9. Joyce, J. and Morgan, J.P. 1989. Manitoba's tall-grass prairie conservation project. Prairie pioneers: ecology, history and culture. August, 1988. Proceeding of the Eleventh North American Prairie Conference, held August 7-11, 1988. Edited by Bragg, T.B. and Stubbendieck, J. University of Nebraska Printing. Lincoln, NE.

10. Ontario Ministry of Natural Resources. 2009. Natural Heritage Information Center (NHIC) database. Ontario Ministry of Natural Resources. Peterborough, ON.

11. Grasslands Conservation Council of British Columbia. 2004. B.C. grasslands mapping project: a conservation risk assessment final report. Grasslands Conservation Council of British Columbia. Kamloops, BC. 108 p.

12. British Columbia Ministry of Environment. 2007. Environmental trends in British Columbia: 2007. Government of British Columbia. Victoria, BC. 352 p.

13. Lea, T. 2008. Historical (pre-settlement) ecosystems of the Okanagan Valley and lower Similkameen Valley of British Columbia – pre-European contact to the present. Davidsonia 19:3-36.

14. Watts, F.B. 1969. The natural vegetation of the southern great plains of Canada. *In* Vegetation, soils and wildlife. Edited by Nelson, J.G. and Chambers, M.J. Methuen Publications. Toronto, ON. Chapter 5. pp. 93-111.

15. Samson, F. and Knopf, F. 1994. Prairie conservation in North America. Bioscience 44:418-421.

16. Bakowsky, W.D. 1993. A review and assessment of prairie, oak savannah and woodland in Site Regions 7 and 6 (Southern Region). Gore and Storrie Ltd., Ontario Ministry of Natural Resources, Southern Region. Aurora, ON. 89 p.

17. Grasslands Conservation Council of British Columbia. 2009. B.C. historic grassland distribution. Grasslands Conservation Council of British Columbia.

18. Ontario Tallgrass Prairie and Savanna Association. Historical extent of prairie and savannah vegetation in southern Ontario. Tallgrass and savanna in Ontario [online]. http://www.tallgrassontario.org/TS_SAR.htm (accessed 5 May 2010).

19. Scott, J.M., Davis, F.W., McGhie, R.G., Wright, R.G., Groves, C. and Estes, J. 2001. Nature reserves: do they capture the full range of America's biological diversity? Ecological Applications 11:999-1007.

20. Davies, H. 2008. Data on range conditions in Saskachewan. Saskatchewan Watershed Authority. Unpublished data.

21. Willoughby, M. 2008. Data on range conditions in Alberta. Alberta Sustainable Resouce Development. Unpublished data.

22. Canadian Wildlife Service. 2007. Breeding Bird Survey in Canada [online]. Environment Canada. http://www.cws-scf.ec.gc.ca/nwrc-cnrf/Default.asp?lang=En&n=416B57CA (accessed 20 October, 2009).

23. Downes, C., Blancher, P. and Collins, B. 2010. Landbird trends in Canada, 1968-2006. Canadian Biodiversity: Ecosystem Status and Trends 2010, Technical Thematic Report Series No. 12. Canadian Councils of Resource Ministers. Ottawa, ON. In press.

24. Sauer, J.R., Hines, J.E. and Fallon, J. 2008. The North American Breeding Bird Survey, results and analysis 1966-2007. [online]. U.S. Geological Survey Patuxent Wildlife Research Center. http://www.mbr-pwrc.usgs.gov/bbs/ (accessed 20 October, 2009).

25. North American Bird Conservation Initiative, U.S. Committee (NABCI-US). 2009. The state of the birds, United States of America, 2009. U.S. Department of Interior. Washington, DC. 36 p.

26. Government of Canada. 1996. The state of Canada's environment. Environment Canada. Ottawa, ON. 817 p.

27. Thorpe, J. 2009. Unpublished analysis of source data from: Thorpe, J. 2007. Saskatchewan rangeland ecosystems, publication 1: ecoregions and ecosites. Saskatchewan Research Council Pub. No. 11881-1E07. Saskatchewan Prairie Conservation Action Plan. 40 p.

28. Forest Practices Board. 2007. The effect of range practices on grasslands: a test case for upper grasslands in the south central interior of British Columbia. Special Investigation Report No. 19. Forest Practices Board. Victoria, BC. 59 p.

29. Daubenmire, R. 1970. Steppe vegetation of Washington. Washington State Agricultural Experiment Station. Pullman, WA. 131 p.

30. Gayton, D. 2004. Native and non-native plant species in grazed grasslands of British Columbia's Southern Interior. B.C. Journal of Ecosystems and Management 5:51-59.

31. Peart, B. 2008. Life in a working landscape: towards a conservation strategy for the world's temperate grasslands. A record of the World Temperate Grasslands Conservation Initiative Workshop, Hohhot, China – June 28 and 29, 2008. Temperate Grasslands Conservation Initiative. Vancouver, BC. 21 p.

32. Millennium Ecosystem Assessment. 2005. Ecosytems and human well-being: biodiversity synthesis. Millennium Ecosystem Assessment Series. World Resources Institute. Washington, DC. 100 p.

33. Robertson, K.R., Anderson, R.C. and Schwartz, M.W. 1997. The tallgrass prairie mosaic. *In* Conservation *In* highly fragmented landscapes. Edited by Schwartz, M.W. Chapman and Hall. New York, NY. pp. 55-87.

34. Nuzzo, V.A. 1986. Extent and status of Midwest oak savanna: presettlement and 1985. Natural Areas Journal 6:6-36.

3. Wetlands

1. National Wetlands Working Group. 1997. The Canadian wetland classification system. 2nd edition. Edited by Warner, B.G. and Rubec, C.D.A. The Wetlands Research Centre, University of Waterloo. Waterloo, ON. 68 p.

2. National Wetlands Working Group. 1988. Wetlands of Canada. Ecological Land Classification Series No. 24. Sustainable Development Branch, Environment Canada, Ottawa, ON and Polyscience Publications Inc., Montreal, QC. Ottawa, ON. 452 p.

3. Davidson, I., Vanderkam, R. and Padilla, M. 1999. Review of wetland inventory information in North America. *In* Global review of wetland resources and priorities for wetland inventory. Edited by Finlayson, C.M. and Spiers, A.G. Wetlands International Publication 53, Supervising Scientist. Canberra, Australia. Chapter 144. pp. 457-492.

4. Ramsar Sites Information Service. 2008. Wetlands International [online]. http://www.wetlands.org/rsis/ (accessed 27 October, 2009).

5. Zedler, J.B. and Kercher, S. 2005. Wetland resources: status, trends, ecosystem services and restorability. Annual Review of Environment and Resources 30:39-74.

6. Fournier, R.A., Grenier, M., Lavoie, A. and Hélie, R. 2007. Towards a strategy to implement the Canadian Wetland Inventory using satellite remote sensing. Canadian Journal of Remote Sensing 33:S1-S16.

7. Rubec, C. 1994. Wetland policy implementation in Canada. Proceedings of National Workshop, June 1994. Report Series No. 94-1. North American Wetlands Conservation Council (Canada). Ottawa, ON. 127 p.

8. Environment Canada. 1991. The federal policy on wetland conservation. Minister of Supply and Services. Ottawa, ON. 14 p.

9. Moore, K., Ward, p. and Roger, K. 2004. Urban and agricultural encroachment onto Fraser lowland wetlands – 1989 to 1999. Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference. Edited by Droscher, T.W. and Fraser, D.A. Vancouver, BC.

10. Manitoba Conservation Data Centre and Manitoba Remote Sensing Centre. 2002. Land use/land cover Landsat TM Maps – Provisional Data (Arc/INFO). Manitoba Remote Sensing Centre. Winnipeg, MB.

11. Ducks Unlimited Canada. 2010. Southern Ontario wetland conversion analysis: final report. Ducks Unlimited. Barrie, ON. 23 p.

12. Watmough, M.D. and Schmoll, M.J. 2007. Environment Canada's Prairie and Northern Region habitat monitoring program phase II: recent habitat trends in the Prairie Habitat Joint Venture. Technical Report Series No. 493. Environment Canada, Canadian Wildlife Service. Edmonton, AB. 135 p.

13. Poulin, M., Rochefort, L., Pellerin, S. and Thibault, J. 2004. Threats and protection for peatlands in eastern Canada. Geocarrefour 79:331-344.

14. Natural Resources Canada. 2009. The atlas of Canada, wetlands [online]. http://atlas.nrcan.gc.ca/site/english/learningresources/theme_modules/wetlands/index.html (accessed 23 October, 2009).

15. Mitsch, W.J. and Gosselink, J.G. 2007. Wetlands. Edition 4. John Wiley and Sons Inc. New Jersey, NY.

16. Lehner, B. and Doll, P. 2004. Development and validation of a global database of lakes, reservoirs and wetlands. Journal of Hydrology 296:1-22.

17. Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being: wetlands and water – synthesis. Millennium Ecosystem Assessment Series. World Resources Institute. Washington, DC. 80 p.

18. Dugan, P.J. 1990. Wetlands conservation: a review of current issues and required action. IUCN. Gland, Switzerland. 94 p.

19. Prairie Habitat Joint Venture. 2008. Prairie Habitat Joint Venture implementation plan: 2007-2012. Environment Canada. Edmonton, AB. 34 p. (Revised May 2009).

20. Batt, B.D.J., Anderson, M.G., Anderson, C.D. and Caswell, F.D. 1989. The use of prairie potholes by North American ducks. *In* Northern prairie wetlands. Edited by Vander, V. Iowa State University Press. Ames, IA. pp. 204-227.

21. Conly, F.M. and Van der Kamp, G. 2001. Monitoring the hydrology of Canadian prairie wetlands to detect the effects of climate change and land use changes. Environmental Monitoring and Assessment 67:195-215.

22. Johnson, W.C., Millett, B.V., Gilmanov, T., Voldseth, R.A., Guntenspergen, G.R. and Naugle, D.E. 2010. Vulnerability of northern prairie wetlands to climate change. Bioscience 55:863-872.

23. Cornell Lab of Ornithology. 2010. Birds in forested landscapes [online]. Cornell Lab of Ornithology. http://www.birds.cornell.edu/bfl/gen_instructions/fragmentation.html (accessed 8 May, 2010).

24. Lynch-Stewart, p. 1983. Land use change on wetlands in southern Canada: review and bibliography. Working Paper No. 29. Lands Directorate, Environment Canada. Ottawa, ON. 115 p.

25. Dahl, T.E. and Watmough, M.D. 2007. Current approaches to wetland status and trends monitoring in prairie Canada and the continental United States of America. Canadian Journal of Remote Sensing 33:S17-S27.

26. Mosquin, T., Whiting, p.G. and McAllister, D.E. 1995. Canada's biodiversity: the variety of life, its status, economic benefits, conservation costs and unmet needs. Canadian Museum of Nature. Ottawa, ON.

27. Millar, J.B. 1989. Perspectives on the status of Canadian prairie wetlands. Freshwater Wetlands and Wildlife 61:829-852.

28. Bartzen, B.A., Dufour, K.W., Clark, R.G. and Caswell, F.D. 2010. Trends in agricultural impact and recovery of wetlands in prairie Canada. Ecological Applications 20:525-538.

29. Reynolds, R.E., Cohan, D.R. and Johnson, M.A. 1996. Using landscape information approaches to increase duck recruitment in the prairie pothole region. Transactions of the North American Wildlife and Natural Resource Conference 52:86-93.

30. Snell, E. 1987. Wetland distribution and conservation in southern Ontario. Working Paper No. 48. Inland Waters and Land Directorate, Environment Canada. Ottawa, ON.

31. Krieger, K.A., Klarer, D.M., Heath, R.T. and Herdendorf, C.E. 1992. Coastal wetlands of the Laurentian Great Lakes: current knowledge and research needs. Journal of Great Lakes Research 18:525-528.

32. Bedford, K.W. 1992. The physical effects of the Great Lakes on tributaries and wetlands. Journal of Great Lakes Research 18:571-589.

33. Wilcox, D.A. 1995. The role of wetlands in nearshore habitats in Lake Huron. *In* The Lake Huron ecosystem: ecology, fisheries, and management. Edited by Munawar, M., Edsall, T. and Leach, J. SPB Academic Publishing. Amsterdam, The Netherlands. pp. 223-245.

34. McCullough, G.B. 1985. Wetland threats and losses in Lake St. Clair. *In* Coastal Wetlands. Edited by Prince, H.P. and d'Itri, F.M. Lewis Publishers. Chelsea, MI. pp. 201-208.

35. Whilans, T.J. 1982. Changes in marsh area along the Canadian shore of Lake Ontario. Journal of Great Lakes Research 8:570-577.

36. Ball, H., Jalava, J., King, T., Maynard, L., Potter, B. and Pulfer, T. 2003. The Ontario Great Lakes coastal wetland atlas: a summary of information (1983-1997). Environment Canada and Ontario Ministry of Natural Resources. ON. 49 p.

37. Timmermann, S.T., Badzinski, S.S. and Ingram, J.W. 2008. Association between breeding marsh bird abundances and Great Lakes hydrology. Journal of Great Lakes Research 34:351-364.

38. Ontario Biodiversity Council. 2010. State of Ontario's biodiversity 2010. A report of the Ontario Biodiversity Council. Peterborough, ON. 121 p.

39. Meadows, G.A., Goforth, R.R., Mickelson, D.M., Edil, T.B., Fuller, J., Guy, D.E., Meadows, L.A., Brown, E., Carman, S.M. and Liebenthal, D.L. 2005. Cumulative habitat impacts of nearshore engineering. Journal of Great Lakes Research 31:90-112.

40. Environment Canada and U.S. Environmental Protection Agency. 2009. State of the Great Lakes 2009. 432 p.

41. Burton, T.M. 1985. Effects of water level fluctuations on Great Lakes coastal marshes. *In* Coastal wetlands. Edited by Prince, H.P. and d'Itri, F.M. Lewis Publishers. Chelsea, MI. pp. 3-13.

42. Shabica, C. and Pranschke, F. 1994. Survey of littoral drift sand deposits along the Illinois and Indiana shores of Lake Michigan. Journal of Great Lakes Research 20:61-72.

43. Mackey, S.D. and Goforth, R.R. 2005. Special issue on Great Lakes nearshore and coastal habitats. Journal of Great Lakes Research 31:1-5.

44. Minns, C.K. and Wichert, G.A. 2005. A framework for defining fish habitat domains in Lake Ontario and its drainage. Journal of Great Lakes Research 31:6-27.

45. Chow-Fraser, P. 2006. Development of the Wetland Water Quality Index (WQI) to assess effects of basin-wide land-use alteration on coastal marshes of the Laurentian Great Lakes. *In* Coastal wetlands of the Laurentian Great Lakes: health, habitat and indicators. Edited by Simon, T.P. and Stewart, P.M. Indiana Biological Survey. Bloomington, IN. Chapter 5. pp. 137-166.

46. Chow-Fraser, P. 2008. Wetlands status and trends – for coastal wetlands. Wetland Inventory for Research and Education Network (WIRENet), McMaster University. http://wirenet.mcmaster.ca/publications/papyrus/Coastal_Wetland_ESTR.pdf (accessed 25 August, 2010).

47. Seilheimer, T.S. and Chow-Fraser, P. 2007. Application of the Wetland Fish Index to northern Great Lakes marshes with emphasis on Georgian Bay coastal wetlands. Journal of Great Lakes Research 33:154-171.

48. Canadian Wildlife Service, Environment Canada, Ontario Region. 2010. Great Lakes Water Quality Index scores, 2009. Unpublished data.

49. Lehoux, D. and Chamard, L. 2002. Biodiversity portrait of the St. Lawrence, anthropogenic modification to the St. Lawrence: loss of wetlands [online]. Environment Canada. http://www.qc.ec.gc.ca/faune/biodiv/en/anthropo/wetlands.html (accessed 20 July, 2010).

50. Jean, M. and Létourneau, G. 2007. Monitoring wetland area along the St. Lawrence River (Canada): from state to functions and values. International Society of Wetland Scientists, 2007 Annual Meeting, June 10-15, 2007. Sacramento, CA.

51. Jean, M. and Létourneau, G. 2010. Changes to the wetlands of the St. Lawrence River, 1970-2002. Scientific and Technical Report Series. Environment Canada, Science and Technology Branch, Quebec Water Quality Monitoring and Surveillance Section. 323 p. In Press.

52. Kessel-Taylor, I. 1984. The application of the Canada Land Data System for quantitative analysis of land use dynamics on wetlands for twenty-three urban centered regions in Canada. Canada Land Data Systems Report No. R003200. Environment Canada, Lands Directorate. Ottawa, ON. 143 p.

53. Hudon, C., Gagnon, P., Amyot, J.P., Létourneau, G., Jean, M., Plante, C., Rioux, D. and Deschênes, M. 2005. Historical changes in herbaceous wetland distribution induced by hydrological conditions in Lake Saint-Pierre (St. Lawrence River, Quebec, Canada). Hydrobiologia 539:205-224.

54. Lavoie, C., Jean, M., Delisle, F. and Létourneau, G. 2003. Exotic plant species of St. Lawrence River wetlands: a spatial and historical analysis. Journal of Biogeography 30:537-549.

55. Hudon, C. 2004. Shift in wetland composition and biomass following low-level episodes in the St. Lawrence River: looking into the future. Canadian Journal of Fisheries and Aquatic Sciences 61:603-617. doi:10.1139/F04-031.

56. Labrecque, S., Lacelle.D., Duguay, C.R., Lauriol, B. and Hawkings, J. 2009. Contemporary (1951-2001) evolution of lakes in the Old Crow Basin, northern Yukon, Canada: remote sensing, numerical modeling and stable isotope analysis. Arctic 62:225-238.

57. U.S. Fish and Wildlife Service. 2007. Waterfowl breeding population and habitat survey [online]. Division of Migratory Birds Management, U.S. Department of the Interior. http://migbirdapps.fws.gov/ (accessed 20 July, 2010).

58. Gray, D.R. and Alt, B.T. 2000. Resource description and analysis for Vuntut National Park of Canada. Parks Canada. Western Canada Service Centre. Haines Junction, YT.

59. Peters, D.L., Prowse, T.D., Marsh, P.M., LaFleur, P.M. and Buttle, J.M. 2006. Persistence of water within perched basins of the Peace-Athabasca delta, northern Canada. Wetlands Ecology and Management 14:1-23.

60. Timoney, K. 2002. A dying delta? A case study of a wetland paradigm. Wetlands. 22:282-300.

61. Beltaos, S. 2003. Numerical modelling of ice-jam flooding on the Peace-Athabasca delta. Hydrological Processes 17:3685-3702.

62. Peters, D.L., Prowse, T., Pietroniro, A. and Leconte, R. 2006. Flood hydrology of the Peace-Athabasca delta, northern Canada. Hydrological Processes 20:4073-4096.

63. Timoney, K.P. 2006. Landscape cover change in the Peace-Athabasca delta, 1927-2001. Wetlands 26:765-778.

64. Hugenholtz, C.H., Smith, D.G. and Livingston, J.M. 2009. Application of floodplain stratigraphy to determine the recurrence of ice-jam flooding along the lower Peace and Athabasca rivers, Alberta. Canadian Water Resources Journal 34:79-94. doi:10.4296/cwrj3401079.

65. Wolfe, B.B., Hall, R.I., Last, W.M., Edwards, T.W.D., English, M.C., Karst-Riddoch, T.L., Paterson, A. and Palmini, R. 2006. Reconstruction of multi-century flood histories from oxbow lake sediments, Peace-Athabasca delta, Canada. Hydrological Processes 20:4131-4153.

66. Timoney, K.P. 2009. Three centuries of change in the Peace-Athabasca delta, Canada. Climatic Change 93:485-515. :doi:10.1007/s10584-008-9536-4.

67. Timoney, K. 22 July, 2010. Personal communication.

68. Prowse, T.D., Beltaos, S., Gardner, J.T., Gibson, J.J., Granger, R.J., Leconte, R., Peters, D.L., Pietroniro, A., Romolo, L.A. and Toth, B. 2006. Climate change, flow regulation and land-use effects on the hyrdology of the Peace-Athabasca-Slave system; findings from the Northern Rivers Ecosystem Initiative. Environmental Monitoring and Assessment 113:167-197.

69. Prowse, T.D. and Conly, F.M. 2002. A review of hydroecological results of the Northern River Basins Study, Canada. Part 2. Peace-Athabasca delta. River Research and Applications 18:447-460.

70. Prowse, T.D., Conly, F.M., Church, M. and English, M.C. 2002. A review of hydroecological results of the Northern River Basins Study, Canada. Part 1. Peace and Slave rivers. River Research and Applications 18:429-446.

71. Kelly, E.N., Short, J.W., Schindler, D.W., Hodson, P.V., Ma, M.S., Kwan, A.K. and Fortin, B.L. 2009. Oil sands development contributes polycyclic aromatic compounds to the Athabasca River and its tributaries. Proceedings of the National Academy of Sciences of the United States of America 106:22346-22351.

72. Kelly, E.N., Schindler, D.W., Hodson, P.V., Short, J.W., Radmanovich, R. and Nielsen, C.C. 2010. Oil sands development contributes elements toxic at low concentrations to the Athabasca River and its tributaries. Proceedings of the National Academy of Sciences of the United States of America 107:16178-16183. doi:10.1073/pnas.1008754107.

73. Beltaos, S., Prowse, T.D., Bonsal, B.R., Mackay, R., Romolo, L., Pietroniro, A. and Toth, B. 2006. Climatic effects on ice-jam flooding of the Peace-Athabasca delta. Hydrological Processes 20:4031-4050.

74. Tarnocai, C. 2006. The effect of climate change on carbon in Canadian peatlands. Global and Planetary Change 53:222-232. doi:10.1016/j.gloplacha.2006.03.012.

75. Natural Resources Canada. 2009. Biodiversity [online]. Natural Resources Canada. http://canadaforests.nrcan.gc.ca/article/biodiversity (accessed 10 February, 2010).

76. Zoltai, S.C. and Tarnocai, C. 1975. Perennially frozen peatlands in the Western Arctic and subarctic of Canada. Canadian Journal of Earth Sciences 12:28-43.

77. Warner, B.G. and Asada, T. 2006. Biological diversity of peatlands in Canada. Aquatic Sciences 68:240-253.

78. Tarnocai, C. 2006. The effect of climate change on carbon in Canadian peatlands. Global and Planetary Change 53:222-232. doi:10.1016/j.gloplacha.2006.03.012.

79. Carlson, M., Chen, J., Elgie, S., Henschel, C., Montenegro, A., Roulet, N., Scott, N., Tarnocai, C. and Wells, J. 2010. Maintaining the role of Canada's forests and peatlands in climate regulation. The Forestry Chronicle 86:434-443.

80. Urquizo, N., Bastedo, J., Brydges, T. and Shear, H. 2000. Ecological assessment of the Boreal Shield Ecozone. Minister of Public Works and Government Services Canada. Ottawa, ON.

81. Environment Canada. 2009. National inventory report: greenhouse gas sources and sinks in Canada, 1990-2007. Government of Canada. Ottawa, ON. 620 p.

82. Lee, P. and Cheng, R. 2009. Bitumen and biocarbon: land use conversions and loss of biological carbon due to bitumen operations in the boreal forests of Alberta, Canada. Global Forest Watch Canada. Edmonton, AB. 40 p.

83. Parent, L.-É. 2001. L'utilisation agricole. *In* Écologie des tourbières du Québec-Labrador. Edited by Payette, S. and Rochefort, L. Les Presses de l'Université Laval. Saint-Nicolas, QC. pp. 411-421.

84. Tarnocai, C., Kettles, I.M. and Lacelle, B. 2002. Peatlands of Canada database. Geological Survey of Canada.

85. Smith, L.C., Sheng, Y. and MacDonald, G.M. 2007. A first pan-Arctic assessment of the influence of glaciation, permafrost, topography and peatlands on northern hemisphere lake distribution. Permafrost and Periglacial Processes 18:201-208.

86. Turetsky, M.R., Wieder, R.K., Vitt, D.H., Evans, R.J. and Scott, K.D. 2007. The disappearance of relict permafrost in boreal North America: effects on peatland carbon storage and fluxes. Global Change Biology 13:1-13.

87. Lea, T. 2008. Historical (pre-settlement) ecosystems of the Okanagan Valley and lower Similkameen Valley of British Columbia – pre-European contact to the present. Davidsonia 19:3-36.

88. British Columbia Ministry of Forests Research Program. 2000. The ecology of wetland ecosystems. Extension Note No. 45. B.C. Ministry of Forests. Smithers, BC.

89. Brinson, M.M. 2008. Temperate freshwater wetlands: response to gradients in moisture regime, human alterations and economic status. *In* Aquatic ecosystems: trends and global prospects. Edited by Polunin, N.V.C. Cambridge University Press. New York, NY. pp. 127-140.

90. British Columbia Ministry of Water, Land and Air Protection. 1998. Habitat atlas for wildlife at risk: South Okanagan and Lower Similkameen. Government of British Columbia. Victoria, BC. 124 p.

91. British Columbia Ministry of Sustainable Resource Management and Ministry of Water, Land and Air Protection. 2004. Wetlands of the southern interior valleys. Ecosystems in British Columbia at risk. Government of British Columbia. Victoria, BC. 6 p.

92. Sarell, M. 1990. Survey of relatively natural wetlands in the South Okanagan. Habitat Conservation Trust Fund. Victoria, BC. 7 p.

4. Lakes and rivers

1. The Canadian Encyclopedia. 2010. Lake [online]. http://www.thecanadianencyclopedia.com/index.cfm?PgNm=TCE&Params=A1ARTA0004471 (accessed 15 February, 2010).

2. Monk, W.A., Baird, D.J., Curry, R.A., Glozier, N. and Peters, D.L. 2010. Ecosystem status and trends report: biodiversity in Canadian lakes and rivers. Canadian Biodiversity: Ecosystem Status and Trends 2010, Technical Thematic Report Series No. 20. Canadian Councils of Resource Ministers. Ottawa, ON. In press.

3. Ricciardi, A. and Rasmussen, J.B. 1999. Extinction rates of North American freshwater fauna. Conservation Biology 13:1220-1222.
4. Schindler, D.W. and Donahue, W.F. 2006. An impending water crisis in Canada's western Prairie Provinces. Proceedings of the National Academy of Sciences of the United States of America 103:7210-7216.
5. Schindler, D.W. 1997. Widespread effects of climate warming on freshwater ecosystems in North America. Hydrological Processes 11:1043-1067.
6. Van der Kamp, G., Keir, D. and Evans, M.S. 2008. Long-term water level changes in closed-basin lakes of the Canadian prairies. Canadian Water Resources Journal 33:23-38.
7. Last, W.M. and Ginn, F.M. 2005. Saline systems of the Great Plains of Western Canada: an overview of the limnogeology and paleolimnology. Saline Systems 1:10.
8. Zhang, X., Brown, R., Vincent, L., Skinner, W., Feng, Y. and Mekis, E. 2010. Canadian climate trends 1950-2007. Canadian Biodiversity: Ecosystem Status and Trends 2010, Technical Thematic Report Series No. 5. Canadian Councils of Resource Ministers. Ottawa, ON. In press.
9. Zhang, X.B., Harvey, K.D., Hogg, W.D. and Yuzyk, T.R. 2001. Trends in Canadian streamflow. Water Resources Research 37:987-998.
10. Javorek, S.K. and Grant, M.C. 2010. Trends in wildlife habitat capacity on agricultural land in Canada, 1986-2006. Canadian Biodiversity: Ecosystem Status and Trends 2010, Technical Thematic Report Series No. 14. Canadian Councils of Resource Ministers. Ottawa, ON. In press.
11. Déry, S.J. and Wood, E.F. 2005. Decreasing river discharge in northern Canada. Geophysical Research Letters 32:1-4. doi:10.1029/2005GL022845, 2005.
12. McClelland, J.W., Dery, S.J., Peterson, B.J., Holmes, R.M. and Wood, E.F. 2006. A Pan-Arctic evaluation of changes in river discharge during the latter half of the 20th century. Geophysical Research Letters 33:1-4.
13. Peterson, B.J., Holmes, R.M., McClelland, J.W., Volosmarty, C.J. and Lammers, R.B. 2002. Increasing river discharge to the Arctic Ocean. Science 298:2171-2173.
14. Peterson, B.J., McClelland, J., Curry, R., Holmes, R.M., Walsh, J.E. and Aargaard, K. 2006. Trajectory shifts in the Arctic and Subarctic freshwater cycle. Science 313:1061-1066.
15. Postel, S.L. 1992. Last oasis: facing water scarcity. Worldwatch Institute. New York, NY. 240 p.
16. World Resources Institute, United Nations Environmental Programme and World Business Council for Sustainable Development. 2002. Tomorrow's markets: global trends and their implications for business. Paris, France. 61 p.
17. Environment Canada and U.S. Environmental Protection Agency. 2009. State of the Great Lakes 2009. 432 p.
18. Heaton, D. 2003. Effects of water level fluctuations. *In* State of the Great Lakes 2003. Edited by Environment Canada and U.S. Environmental Protection Agency. Governments of Canada and the United States. pp. 86-87.
19. Wilcox, D.A., Thompson, T.A., Booth, R.K. and Nicholas, J.R. 2007. Lake-level variability and water availability in the Great Lakes. U.S. Geological Survey Circular No. 1311. 25 p.
20. Commision for Environmental Cooperation. 2008. The North American mosaic: an overview of key environmental issues. Commision for Environmental Cooperation. Montreal, QC. 62 p.

5. Coastal

1. Natural Resources Canada. 2010. Coastline and shoreline (the atlas of Canada) [online]. http://atlas.nrcan.gc.ca/site/english/learningresources/facts/coastline.html (accessed 23 May, 2010).
2. Centre for Marine Biodiversity. 2010. Marine biodiversity in Canada [online]. http://www.marinebiodiversity.ca/cmb/education/what-is-marine-biodiversity/marine-biodiversity-in-canada (accessed 23 May, 2010).
3. CBCL Limited. 2009. The 2009 state of Nova Scotia's coast technical report. Nova Scotia Department of Fisheries and Aquaculture and Nova Scotia Provincial Oceans Network. 245 p.
4. McCulloch, M.M., Forbes, D.L., Shaw, R.W. and CAFF-A041 Scientific Team. 2002. Coastal impact of climate change and sea-level rise on Prince Edward Island. Synthesis Report (File 4261). Meteorological Service of Canada, Environment Canada and Geological Survey of Canada. 62 p.
5. B.C. Ministry of Environment. 2006. Alive and inseparable: British Columbia's coastal environment: 2006. State of Environment Reporting Office. Victoria, BC. 322 p.
6. Catto, N.R. 2002. Anthropogenic pressures on coastal dunes, southwest Newfoundland. The Canadian Geographer 46:17-32.
7. Ingram, D. 2005. An investigation of the role of tidal variation on storm surge elevation and frequency in Port-aux-Basques, Newfoundland. Department of Environmental Science, Memorial University of Newfoundland. St. John's, NL. Unpublished research report.
8. Catto, N.R. 1994. Anthropogenic pressures and the dunal coasts of Newfoundland. Coastal Zone Canada 1994 Conference: Co-operation in the Coastal Zone, proceedings. Edited by Wells, P.G. and Ricketts, P.J. Bedford Institute of Oceanography. Vol. 5, pp. 2266-2286.
9. Vasseur, L. and Catto, N. 2008. Atlantic Canada. *In* From impacts to adaptation: Canada in a changing climate 2007. Edited by Lemmen, D.S., Warren, F.J., Lacroix, J. and Bush, E. Government of Canada. Ottawa, ON. pp. 119-170.
10. Bernatchez, P. and Dubois, J.-M.M. 2004. Bilan des connaissances de la dynamique de l'érosion des côtes du Québec maritime laurentien. Géographie physique et Quaternaire 58:45-71.
11. Lantuit, H. and Pollard, W.H. 2008. Fifty years of coastal erosion and retrogressive thaw slump activity on Herschel Island, southern Beaufort Sea, Yukon Territory, Canada. Geomorphology 95:84-102.
12. Mars, J.C. and Houseknecht, D.W. 2007. Quantitative remote sensing study indicates doubling of coastal erosion rate in past 50 yr along a segment of the Arctic coast of Alaska. Geology 35:583-586.
13. Burke, L., Kura, Y., Kassem, K., Revenga, C., Spalding, M. and McAllister, D. 2001. Pilot analysis of global ecosystems: coastal ecosystems. World Resources Institute. Washington, DC. 93 p.
14. Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being: wetlands and water – synthesis. Millennium Ecosystem Assessment Series. World Resources Institute. Washington, DC. 80 p.
15. Wiken, E., Smith, W.G.B., Cinq-Mars, J., Latsch, C. and Gauthier, D. 2003. Habitat integrity in Canada: wildlife conservation in Canada. Background paper for the national conference on guidelines and tools for the evaluation of Natura 200 sites in France, Montpellier, March 3-5, 2003. Wildlife Habitat Canada. 30 p.

16. Lynch-Stewart, P. 1983. Land use change on wetlands in southern Canada: review and bibliography. Working Paper No. 29. Lands Directorate, Environment Canada. Ottawa, ON. 115 p.

17. O'Carroll, S., Berube, D., Hanson, A., Forbes, D., Ollerhead, J. and Olsen, L. 2006. Temporal changes in beach and dune habitat in southeastern New Brunswick, 1944-2001. *In* Impacts of sea-level rise and climate change on the coastal zone of southeastern New Brunswick. Edited by Daigle, R.J. Environment Canada. Dartmouth, NS. Chapter 4.6.4. pp. 421-426.

18. Hanson, A., Berube, D., Forbes, D., O'Carroll, S., Ollerhead, J. and Olsen, L. 2006. Impacts of sea-level rise and residential development on salt-marsh area in southeastern New Brunswick, 1944-2001. *In* Impacts of sea-level rise and climate change on the coastal zone of southeastern New Brunswick. Edited by Daigle, R.J. Environment Canada. Dartmouth, NS. Chapter 4.6.3. pp. 408-421.

19. Canadian Wildlife Service and Canadian Wildlife Federation. Hinterland who's who: bird fact sheets: piping plover [online]. http://www.hww.ca/hww2.asp?id=61 (accessed 6 July, 2010).

20. Amirault, D.L. 2005. The 2001 international piping plover census in Canada. Technical Report Series No. 436. Canadian Wildlife Service (Atlantic Region), Environment Canada. 126 p.

21. Canadian Wildlife Service. 2006. Number of adult piping plovers in Atlantic Maritime Ecozone. Canadian Wildlife Service (Atlantic Region), Environment Canada. Unpublished data.

22. Catto, N.R., Scruton, D.A. and Ollerheard, L.M.N. 2003. The coastline of eastern Newfoundland. Canadian Technical Report of Fisheries and Aquatic Science No. 2495. DFO. St. John's, NL. 241 p.

23. Anders, F.J. and Leatherman, S.P. 1987. Effects of off-road vehicles on coastal fore-dunes at Fire Island, New York. Environmental Management 11:45-52.

24. Forbes, D.L., Parkes, G.S. and Ketch, L.A. 2006. Sea-level rise and regional subsidence. *In* Impacts of sea level rise and climate change on the coastal zone of southeastern New Brunswick. Edited by Daigle, R.J. Environment Canada. Dartmouth, NS. Chapter 4.1. pp. 34-94.

25. Daigle, R.J. (ed.). 2006. Impacts of sea-level rise and climate change on the coastal zone of southeastern New Brunswick. Environment Canada. Dartmouth, NS. 611 p.

26. Intergovernmental Panel on Climate Change. 2007. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment. Synthesis Report. Edited by Pachauri, R.K. and Reisinger, A. IPCC Secretariat. Geneva, Switzerland. 104 p.

27. Shaw, J., Taylor, R.B., Forbes, D.L., Ruz, M.H. and Solomon, S. 1998. Sensitivity of the coasts of Canada to sea-level rise. Bulletin No. 505. Geological Survey of Canada. 79 p.

28. Elsner, J.B., Kossin, J.P. and Jagger, T.H. 2008. The increasing intensity of the strongest tropical cyclones. Nature 455:92-95.

29. Saunders, M.A. and Lea, A.S. 2008. Large contribution of sea surface warming to recent increase in Atlantic hurricane activity. Nature 451:557-561.

30. Environment Canada. 2002. Atlantic hurricanes breaking records. Science and the Environment Bulletin 31:4-5.

31. Forbes, D.L., Parkes, G.S., Manson, G.K. and Ketch, L.A. 2004. Storms and shoreline retreat in the southern Gulf of St. Lawrence. Marine Geology 210:169-204.

32. Jefferies, R.L., Jano, A.P. and Abraham, K.F. 2006. A biotic agent promotes large-scale catastrophic change in the coastal marshes of Hudson Bay. Journal of Ecology 94:234-242.

33. Abraham, K.F. and Jefferies, R.L. 1997. Part II: high goose populations: causes, impacts and implications. *In* Arctic ecosystems in peril: report of the Arctic Goose Habitat Working Group. Edited by Batt, B.D.J. U.S. Fish and Wildlife Service and Canadian Wildlife Service. Washington DC and Ottawa, ON. pp. 7-72.

34. Jefferies, R.L., Rockwell, R.F. and Abraham, K.F. 2003. The embarrassment of riches: agricultural food subsidies, high goose numbers and loss of Arctic wetlands – a continuing saga. Environmental Reviews 11:193-232.

35. Jefferies, R.L. and Rockwell, R.F. 2002. Foraging geese, vegetation loss and soil degradation in an Arctic salt marsh. Applied Vegetation Science 5:7-16.

36. Bertness, M.D., Silliman, B.R. and Jefferies, R.L. 2004. Salt marshes under siege. American Scientist 92:54-61.

37. Canadian Wildlife Service Waterfowl Committee. 2009. Population status of migratory game birds in Canada (and regulation proposals for overabundant species). CWS Migratory Birds Regulatory Report No. 28. Environment Canada. Ottawa, ON. 95 p.

38. Moore, K., Ward, P. and Roger, K. 2004. Urban and agricultural encroachment onto Fraser lowland wetlands – 1989 to 1999. Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference. Edited by Droscher, T.W. and Fraser, D.A. Vancouver, BC.

39. Prentice, A.C. and Boyd, S.W. 1988. Intertidal and adjacent upland habitat in estuaries located on the east coast of Vancouver Island – a pilot assessment of their historical changes. Technical Report Series No. 38. Environment Canada, Canadian Wildlife Service. Delta, BC. 75 p.

40. BC Ministry of Environment. 2006. Population and economic activity: introduction. *In* Alive and inseparable: British Columbia's coastal environment 2006. State of Environment Reporting Office. Victoria, BC. Chapter 1. pp. 2-5.

41. Austin, M., Buffett, D., Nicolson, D., Stevens, V. and Scudder, G.G.E. 2008. Taking nature's pulse: the status of biodiversity in British Columbia. Biodiversity B.C. Victoria, BC. 268 p.

42. Pomeroy, A.C., Butler, R.W. and Ydenberg, R.C. 2006. Experimental evidence that migrants adjust usage at a stopover site to trade off food and danger. Behavioral Ecology 17:1041-1045.

43. Butler, R. and Campbell, R.W. 1987. The Birds of the Fraser River delta: populations, ecology and international significance. Occasional Paper No. 65. Government of Canada, Canadian Wildlife Service. Ottawa, ON. 72 p.

44. DFO. 2009. Does eelgrass (*Zostera marina*) meet the criteria as an ecologically significant species? Canadian Science Advisory Secretariat Science Advisory Report No. 2009/018. 11 p.

45. Waycott, M., Duarte, C.M., Carruthers, T.J.B., Orth, R.J., Dennison, W.C., Olyarnik, S., Calladine, A., Fourqurean, J.W., Heck, K.L., Hughes, A.R., Kendrick, G.A., Kenworthy, W.J., Short, F.T. and Williams, S.L. 2009. Accelerating loss of seagrasses across the globe threatens coastal ecosystems. Proceedings of the National Academy of Sciences of the United States of America 106:12377-12381.

46. Cottam, C. and Addy, C.E. 1947. Present eelgrass condition and problems on the Atlantic Coast of North America. Transactions of 12th North American Wildlife Conference. Vol. 12, pp. 387-398.

47. Martin, A.C. 1954. A clue to the eelgrass mystery. Transactions of 19th North American Wildlife Conference. Vol. 19, pp. 441-449.

48. Standing Committee on Fisheries and Oceans. 2008. Fifth report of the Standing Committee on Fisheries and Oceans to the House of Commons. Government of Canada. Ottawa, ON.

49. Hanson, A.R. 2004. Status and conservation of eelgrass (*Zostera marina*) in eastern Canada. Technical Report Series No. 412. Canadian Wildlife Service, Atlantic Region. 40 p.

50. Short, F.T. 2008. Report to the Cree Nation of Chisasibi on the status of eelgrass in James Bay. Jackson Estuarine Laboratory. Durham, NH. 30 p.

51. Kelly, J.R. and Volpe, J.R. 2007. Native eelgrass (*Zostera marina L.*) survival and growth adjacent to non-native oysters (*Crassostrea gigas Thunberg*) in the Strait of Georgia, British Columbia. Botanica Marina 50:143-150.

52. Kelly, J.R., Proctor, H. and Volpe, J.P. 2008. Intertidal community structure differs significantly between substrates dominated by native eelgrass (*Zostera marina L.*) and adjacent to the introduced oyster *Crassostrea gigas* (Thunberg) in British Columbia, Canada. Hydrobiologia 596:57-66.

53. Williams, S.L. 2007. Introduced species in seagrass ecosystems: status and concerns. Journal of Experimental Marine Biology and Ecology 350:89-110.

54. Baldwin, J.R. and Lovvorn, J.R. 1994. Expansion of seagrass habitat by the exotic *Zostera japonica*, and its use by dabbling ducks and brant in Boundary Bay, British Columbia. Marine Ecology Progress Series 103:119-127.

55. Kuwae, T., Beninger, P.G., Decottignies, P., Mathot, K.J., Lund, D.R. and Elner, R.W. 2008. Biofilm grazing in a higher vertebrate: the western sandpiper, *Calidris mauri*. Ecology 89:599-606.

56. Lalumière, R., Messier, D., Fournier, J.J. and Mcroy, C.P. 1994. Eelgrass meadows in a low Arctic environment, the northeast coast of James Bay, Quebec. Aquatic Botany 47:303-315.

57. Hydro-Québec and GENIVAR Groupe Conseil inc. 2005. Eelgrass meadows of the northeast coast of James Bay. *In* Environmental monitoring at the La Grande complex: abridged summary report 1988-2000. Joint report by Hydro-Québec and GENIVAR Groupe Conseil inc. pp. 1-42.

58. Sharp, G. and Semple, R. 2004. Status of eelgrass beds in south-western Nova Scotia. *In* Status and conservation of eelgrass (*Zostera marina*) in Eastern Canada. Edited by Hanson, A.R. Canadian Wildlife Service, Atlantic Region. p. 8.

59. Chapman, A. and Smith, J. 2004. Quantifying the rapid decline of eelgrass beds on the eastern shore of Nova Scotia between 1992 and 2002. *In* Status and conservation of eelgrass (*Zostera marina*) in Eastern Canada. Edited by Hanson, A.R. Canadian Wildlife Service, Atlantic Region. p. 9.

60. Locke, A. and Hanson, J.M. 2004. Changes in eelgrass in southern Gulf of St. Lawrence estuaries. *In* Status and conservation of eelgrass (*Zostera marina*) in Eastern Canada. Edited by Hanson, A.R. Canadian Wildlife Service, Atlantic Region. pp. 10-12.

61. Seymour, N.R., Miller, A.G. and Garbary, D.J. 2002. Decline of Canada geese (*Branta canadensis*) and common goldeneye (*Bucephala clangula*) associated with a collapse of eelgrass (*Zostera marina)* in a Nova Scotia estuary. Helgoland Marine Research 56:198-202.

62. Martel, M.-C., Provencher, L., Grant, C., Ellefsen, H.-F. and Pereira, S. 2009. Distribution et description des herbiers de zostère du Québec. Document de recherche No. 2009/050. Secrétariat canadien de consultation sciéntifique. Ottawa, ON. 37 p.

6. Marine

1. Office of Marine Programs. 2010. Census of marine life [online]. University of Rhode Island, Graduate School of Oceanography. http://www.coml.org/ (accessed 5 May, 2010).

2. Hays, G.C., Richardson, A.J. and Robinson, C. 2005. Climate change and marine plankton. Trends in Ecology and Evolution 20:337-344. doi:10.1016/j.tree.2005.03.004.

3. Worm, B., Barbier, E.B., Beaumont, N., Duffy, J.E., Folke, C., Halpern, B.S., Jackson, J.B.C., Lotze, H.K., Micheli, F., Palumbi, S.R., Sala, E., Selkoe, K.A., Stachowicz, J.J. and Watson, R. 2006. Impacts of biodiversity loss on ocean ecosystem services. Science 314:787-790.

4. McAllister, D.E. 2000. Biodiversity in Canadian fresh and marine waters. *In* Biodiversity in Canada: ecology, ideas, and action. Edited by Bocking, S. University of Toronto Press. pp. 81-105.

5. DFO. 2010. 2010 Canadian marine ecosystem status and trends report. DFO Canadian Science Advisory Secretariat Science Advisory Report No. 2010/030. Fisheries and Oceans Canada. 37 p.

6. Crawford, W.R. and Irvine, J.R. 2009. State of physical, biological and selected fishery resources of Pacific Canadian marine ecosystems. DFO Canadian Science Advisory Secretariat Research Document No. 2009/022. Fisheries and Oceans Canada. vi + 121 p.

7. DFO. 2007. 2006 State of the ocean: physical oceanographic conditions in the Newfoundland and Labrador region. Canadian Science Advisory Secretariat Science Advisory Report No. 2007/025. Fisheries and Oceans Canada. 11 p.

8. Caldeira, K. and Wickett, M.E. 2003. Oceanography: anthropogenic carbon and ocean pH. Nature 425:365-365.

9. Blackford, J., Turley, C., Widdicombe, S., Orr, J. and Gattuso, J.-P. 2007. Ocean acidification – the other half of the CO_2 problem. Fact Sheet No. 7. Plymouth Marine Laboratory, Marine Environment Laboratories (IAEA), Observatoire Océanologique (CNRS). Plymouth, United Kingdom.

10. James, C.O., Jutterström, S., Bopp, L., Anderson, L.G., Cadule, P., Fabry, V.J., Frölicher, T., Jones, E.P., Joos, F., Lenton, A., Maier-Reimer, E., Segschneider, J., Steinacher, M. and Swingedouw, D. 2009. Amplified acidification of the Arctic Ocean. IOP Conference Series: Earth and Environmental Science. Vol. 6.

11. Stramma, L., Schmidtko, S., Levin, L.A. and Johnson, G.C. 2010. Ocean oxygen minima expansions and their biological impacts. Deep Sea Research Part I: Oceanographic Research Papers 57:587-595. doi:10.1016/j.dsr.2010.01.005.

12. Whitney, F. 2009. Spreading hypoxia in deep waters along the west coast. *In* State of physical, biological, and selected fishery resources of Pacific Canadian marine ecosystems. Edited by Crawford, W.R. and Irvine, J.R. Fisheries and Oceans Canada. pp. 55-56. DFO Canadian Science Advisory Secretariat Research Document No. 2009/022. vi + 121 p.

13. Purcell, J.E., Uye, S. and Lo, W.T. 2007. Anthropogenic causes of jellyfish blooms and their direct consequences for humans: a review. Marine Ecology-Progress Series 350:153-174.

14. Dufour, R., Benoit, H., Castonguay, M., Chasse, J., Devine, L., Galbraith, P., Harvey, M., Larouche, P., Lessard, S., Petrie, B., Savard, L., Savenkoff, C., St-Amand, L. and Starr, M. 2010. Ecosystem status and trends report: Estuary and Gulf of St. Lawrence Ecozone$^+$. DFO Canadian Science Advisory Secretariat Research Document No. 2010/030. Fisheries and Oceans Canada. v + 187 p.

15. Johannessen, S.C. and McCarter, B. 2010. Ecosystems status and trends report for the Strait of Georgia Ecozone$^+$. DFO Canadian Science Advisory Secretariat Research Document No. 2010/010. Fisheries and Oceans Canada. vi + 45 p.

16. Worcester, T. and Parker, M. 2010. Ecosystem status and trends report for the Gulf of Maine and Scotian Shelf. DFO Canadian Science Advisory Secretariat Research Document No. 2010/070. Department of Fisheries and Oceans. vi + 59 p.

17. Johns, D.G. 2010. Monthly means for total dinoflagellates, total euphausiids, total *Calanus*, phytoplankton colour index and total copepods, (40N to 60N, 46W to 66W), 1959-2008, as recorded by the Continuous Plankton Recorder. Sir Alister Hardy Foundation for Ocean Science. Plymouth, UK.

18. Harrison, G., Sameoto, D., Spry, J., Pauley, K., Maass, H., Kennedy, M., Porter, C. and Soukhovtsev, V. 2007. Optical, chemical and biological oceanographic conditions in the Maritimes region in 2006. Canadian Science Advisory Secretariat Research Document No. 2007/050. Fisheries and Oceans Canada. 48 p.
19. Gaston, A.J., Bertram, D.F., Boyne, A.W., Chardine, J.W., Davoren, G., Diamond, A.W., Hedd, A., Montevecchi, W.A., Hipfner, J.M., Lemon, M.J.F., Mallory, M.L., Rail, J.-F. and Robertson, G.J. 2009. Changes in Canadian seabird populations and ecology since 1970 in relation to changes in oceanography and food webs. Environmental Reviews 17:267-286.
20. Niemi, A., Paulic, J. and Cobb, D. 2010. Ecosystem status and trends report: Arctic marine ecozones+. DFO Canadian Science Advisory Secretariat Research Document No. 2010/066. Fisheries and Oceans Canada. viii + 66 p.
21. Benoit, D., Simard, Y. and Fortier, L. 2008. Hydroacoustic detection of large winter aggregations of Arctic cod (*Boreogadus saida*) at depth in ice-covered Franklin Bay (Beaufort Sea). Journal of Geophysical Research-Oceans 113.
22. DFO. 2008. Assessment of capelin in SA2 + Div. 3KL in 2008. DFO Canadian Science Advisory Secretariat Science Advisory Report No. 2008/054. 13 p.
23. Zwanenburg, K.C.T., Bundy, A., Strain, P., Bowen, W.D., Breeze, H., Campana, S.E., Hannah, C., Head, E. and Gordon, D. 2006. Implications of ecosystem dynamics for the integrated management of the eastern Scotian Shelf. Canadian Technical Report of Fisheries and Aquatic Sciences No. 2652. Fisheries and Oceans Canada. xiii + 91 p.
24. DFO. 2010. Current status of northwest Atlantic Harp seals, *Pagophilus groenlandicus*. Canadian Science Advisory Secretariat Science Advisory Report No. 2009/074. Fisheries and Oceans Canada. iv + 10 p.
25. Zeh, J.E. and Punt, A.E. 2005. Updated 1978–2001 abundance estimates and their correlations for the Bering-Chukchi-Beaufort Seas stock of bowhead whales. Journal of Cetacean Research and Management 7:169-175.
26. DFO. 2008. Population assessment: Steller sea lion (*Eumetopias Jubatus*). DFO Canadian Science Advisory Secretariat Science Advisory Report No. 2008/047. 11 p.
27. DFO. 2010. Population assessment: Pacific Harbour seal (*Phoca vitulina richardsi*). DFO Canadian Science Advisory Secretariat Science Advisory Report No. 2009/011. 10 p.
28. Ford, J.K.B., Ellis, G.M. and Olesiuk, P.F. 2005. Linking prey and population dynamics: did food limitation cause recent declines of "resident" killer whales (*Orcinus orca*) in British Columbia? Canadian Science Advisory Secretariat Research Document No. 2005/042. Fisheries and Oceans Canada. 27 p.
29. Butchart, S.H.M., Walpole, M., Collen, B., van Strien, A., Scharlemann, J.P.W., Almond, R.E.A., Baillie, J.E.M., Bomhard, B., Brown, C., Bruno, J., Carpenter, K.E., Carr, G.M., Chanson, J.S., Chenery, A.M., Csirke, J., Davidson, N.C., Dentener, F., Foster, M., Galli, A., Galloway, J.N., Genovesi, P., Gregory, R., Hockings, M., Kapos, V., Lamarque, J.-F., Leverington, F., Loh, J., McGeoch, M.A., McRae, L., Minasyan, A., Morcillo, M.H., Oldfield, T.E.E., Pauly, D., Quder, S., Revenga, C., Sauer, J.R., Skolnik, B., Spear, D., Stanwell-Smith, D., Stuart, S.N., Symes, A., Tierney, M., Tyrrell, T.D., Vie, J.-C. and Watson, R. 2010. Global biodiversity: indicators of recent declines. Science 328:1164-1168. doi:10.1126/science.1187512.

7. Ice across biomes

1. Environment Canada. 2010. The Atlas of Canada: glaciers [online]. National Hydrology Research Institute. http://atlas.nrcan.gc.ca/site/english/learningresources/facts/glaciers.html (accessed 25 July, 2010).
2. Intergovernmental Panel on Climate Change. 2007. The physical science basis. Contribution of Working Group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. Edited by Solomon, S., Qin, S., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L. Cambridge University Press. Cambridge, UK and New York, NY.
3. UNEP. 2007. Global outlook for ice and snow. United Nations Environment Programme. Nairobi, Kenya. 235 p.
4. Fetterer, F., Knowles, K., Meier, W. and Savoie, M. 2010. Sea ice index [online]. National Snow and Ice Data Center, Boulder, CO. http://nsidc.org/data/g02135.html (accessed 4 October, 2010).
5. Parkinson, C.L. and Cavalieri, D.J. 2008. Arctic sea ice variability and trends, 1979-2006. Journal of Geophysical Research-Oceans 113:1-28.
6. Stroeve, J., Markus, T., Meier, W.N. and Miller, J. 2006. Recent changes in the Arctic melt season. Annals of Glaciology 44:367-374.
7. Howell, S.E.L., Duguay, C.R. and Markus, T. 2009. Sea ice conditions and melt season duration variability within the Canadian Arctic Archipelago: 1979-2008. Geophysical Research Letters 36:1-6.
8. Rampal, P., Weiss, J. and Marsan, D. 2009. Positive trend in the mean speed and deformation rate of Arctic sea ice, 1979-2007. Journal of Geophysical Research-Oceans 114:1-14.
9. Jolly, D., Berkes, F., Castledon, J., Nichols, T. and The Community of Sachs Harbour. 2002. We can't predict the weather like we used to: Inuvialuit observations of climate change, Sachs Harbour, Western Canadian Arctic. *In* The Earth is faster now: Indigenous observations of Arctic climate change. Edited by Krupnik, I. and Jolly, D. Arctic Research Consortium of the United States and Arctic Resource Studies Center, Smithsonian Institution. Fairbanks, AK. pp. 93-125.
10. Manson, G.K. and Solomon, S.M. 2007. Past and future forcing of Beaufort Sea coastal change. Atmosphere-Ocean 45:107-122.
11. Tynan, C.T. and DeMaster, D.P. 1997. Observations and predictions of Arctic climatic change: potential effects on marine mammals. Arctic 50:308-322.
12. Pamperin, N.J., Follmann, E.H. and Person, B.T. 2008. Sea-ice use by arctic foxes in northern Alaska. Polar Biology 31:1421-1426.
13. Gunn, A. and Russell, D. 2010. Northern caribou population trends in Canada. Canadian Biodiversity: Ecosystem Status and Trends 2010, Technical Thematic Report Series No. 10. Canadian Councils of Resource Ministers. Ottawa, ON. In press.
14. Gilchrist, H.G. and Mallory, M.L. 2005. Declines in abundance and distribution of the ivory gull *(Pagophila eburnea)* in Arctic Canada. Biological Conservation 121:303-309.
15. COSEWIC. 2006. COSEWIC Assessment and update status report on the ivory gull *Pagophila eburnea* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa, ON. 42 p.
16. Gaston, A.J., Woo, K. and Hipfner, J.M. 2003. Trends in forage fish populations in northern Hudson Bay since 1981, as determined from the diet of nestling thick-billed murres *Uria lomvia*. Arctic 56:227-233.
17. Gaston, A.J., Gilchrist, H.G. and Hipfner, J.M. 2005. Climate change, ice conditions and reproduction in an Arctic nesting marine bird: Brunnich's guillemot *(Uria lomvia L.)*. Journal of Animal Ecology 74:832-841.

18. Gaston, A.J., Glichrist, H.G., Mallory, M.L. and Smith, P.A. 2009. Changes in seasonal events, peak food availability and consequent breeding adjustment in a marine bird: a case of progressive mis-matching. The Condor 111:111-119.

19. Gaston, A.J., Bertram, D.F., Boyne, A.W., Chardine, J.W., Davoren, G., Diamond, A.W., Hedd, A., Montevecchi, W.A., Hipfner, J.M., Lemon, M.J.F., Mallory, M.L., Rail, J.-F. and Robertson, G.J. 2009. Changes in Canadian seabird populations and ecology since 1970 in relation to changes in oceanography and food webs. Environmental Reviews 17:267-286.

20. The Arctic Council. 2009. Arctic marine shipping assessment: scenarios of the future. Institute of the North, AMSA, Arctic Council and PAME. 189 p.

21. Obbard, M.E., Cattet, M.R.L., Moody, T., Walton, L.R., Potter, D., Inglis, J. and Chenier, C. 2006. Temporal trends in the body condition of southern Hudson Bay polar bears. Climate Change Research Information Note No. 3. Ontario Ministry of Natural Resources. 8 p.

22. Thiemann, G.W., Iverson, S.J. and Stirling, I. 2008. Polar bear diets and Arctic marine food webs: insights from fatty acid analysis. Ecological Monographs 78:591-613.

23. Stirling, I., Lunn, N.J., Iacozza, J., Elliott, C. and Obbard, M. 2004. Polar bear distribution and abundance on southwestern Hudson Bay coast during open water season, in relation to population trends and annual ice patterns. Arctic 57:15-26.

24. Gagnon, A.S. and Gough, W.A. 2005. Trends in the dates of ice freeze-up and breakup over Hudson Bay, Canada. Arctic 58:370-382.

25. Obbard, M.E. 2007. Ontario polar bear report for the Federal-Provincial Polar Bear Technical Committee. Ontario Ministry of Natural Resources, Wildlife Research and Development Section. Peterborough, ON. 14 p.

26. Regehr, E.V., Lunn, N.J., Amstrup, S.C. and Stirling, I. 2007. Effects of earlier sea-ice breakup on survival and population size of polar bears in western Hudson Bay. Journal of Wildlife Management 71:2673-2683.

27. Stirling, I., Lunn, N.J. and Iacozza, J. 1999. Long-term trends in the population ecology of polar bears in western Hudson Bay in relation to climatic change. Arctic 52:294-306.

28. COSEWIC. 2008. COSEWIC Assessment and update on status report on the polar bear *Ursus maritimus* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa, ON. 75 p.

29. UNEP and WGMS. 2008. Global glacier changes: facts and figures. United Nations Environment Programme and World Glacier Monitoring Service. Nairobi and Zurich. 88 p.

30. Barrand, N.E. and Sharp, M.J. 2010. Sustained rapid shrinkage of Yukon glaciers since the 1957-1958 International Geophysical Year. Geophysical Research Letters 37:5.

31. Haggarty, D. and Tate, D. 2009. Nahanni National Park Reserve of Canada: state of the park report 2009. Parks Canada. 67 p.

32. Demuth, M.N., Pinard, V., Pietroniro, A., Luckman, B.H., Hopkinson, C., Dornes, P. and Comeau, L. 2008. Recent and past-century variations in the glacier resources of the Canadian Rocky Mountains – Nelson River System. Terra Glacialis Special Issue: mountain glaciers and climate changes of the last century:27-52.

33. Petts, G.E., Gurnell, A.M. and Milner, A.M. 2006. Eco-hydrology: new opportunities for research on glacier fed rivers. *In* Peyto Glacier: one century of science. Edited by Demuth, M.N., Munro, D.S. and Young, G.J. pp. 255-275.

34. Milner, A.M., Brown, L.E. and Hannah, D.M. 2009. Hydroecological response of river systems to shrinking glaciers. Hydrological Processes 23:62-77.

35. Moore, R.D. and Demuth, M.N. 2001. Mass balance and streamflow variability at Place Glacier, Canada, in relation to recent climate fluctuations. Hydrological Processes 15:3473-3486.

36. Natural Resources Canada. 2009. North American atlas - glaciers [online]. http://www.geogratis.ca/geogratis/en/option/select.do?id=B2BA9B9F-3890-EB98-4E47-D12D0964B9AB (accessed 4 July, 2010).

37. Burgess, D.O. and Koerner, R.M. 2009. Glacier mass balance observations for Devon Ice Cap NW Sector, NU, Canada (updated to 2007); spatially referenced data set contribution to the National Glacier-Climate Observing System, State and Evolution of Canada's Glaciers [online]. Geological Survey of Canada. http://pathways.geosemantica.net/WSHome.aspx?ws=NGP_SECG&locale=en-CA (accessed 4 July, 2010).

38. Demuth, M.N., Sekerka, J. and Bertollo, S. 2009. Glacier mass balance observations for Peyto Glacier, Alberta, Canada (updated to 2007); spatially referenced data set contribution to the National Glacier-Climate Observing System, State and Evolution of Canada's Glaciers [online]. Geological Survey of Canada. http://pathways.geosemantica.net/WSHome.aspx?ws=NGP_SECG&locale=en-CA (accessed 4 July, 2010).

39. Demuth, M.N., Sekerka, J., Bertollo, S. and Shea, J. 2009. Glacier mass balance observations for Place Glacier, British Columbia, Canada (updated to 2007); spatially referenced data set contribution to the National Glacier-Climate Observing System, State and Evolution of Canada's Glaciers [online]. Geological Survey of Canada. http://pathways.geosemantica.net/WSHome.aspx?ws=NGP_SECG&locale=en-CA (accessed 4 July, 2010).

40. Demuth, M.N., Sekerka, J., Bertollo, S. and Shea, J. 2009. Glacier mass balance observations for Helm Glacier, British Columbia, Canada (updated to 2007); spatially referenced data set contribution to the National Glacier-Climate Observing System, State and Evolution of Canada's Glaciers [online]. Geological Survey of Canada. http://pathways.geosemantica.net/WSHome.aspx?ws=NGP_SECG&locale=en-CA (accessed 4 July, 2010).

41. Zhang, X., Brown, R., Vincent, L., Skinner, W., Feng, Y. and Mekis, E. 2010. Canadian climate trends 1950-2007. Canadian Biodiversity: Ecosystem Status and Trends 2010, Technical Thematic Report Series No. 5. Canadian Councils of Resource Ministers. Ottawa, ON. In press.

42. Schindler, D.W., Beaty, K.G., Fee, E.J., Cruikshank, D.R., Debruyn, E.R., Findlay, D.L., Linsey, G.A., Shearer, J.A., Stainton, M.P. and Turner, M.A. 1990. Effects of climatic warming on lakes of the central boreal forest. Science 250:967-970.

43. Duguay, C.R., Prowse, T.D., Bonsal, B.R., Brown, R.D., Lacroix, M.P. and Menard, P. 2006. Recent trends in Canadian lake ice cover. Hydrological Processes 20:781-801.

44. Monk, W.A., Baird, D.J., Curry, R.A., Glozier, N. and Peters, D.L. 2010. Ecosystem status and trends report: biodiversity in Canadian lakes and rivers. Canadian Biodiversity: Ecosystem Status and Trends 2010, Technical Thematic Report Series No. 20. Canadian Councils of Resource Ministers. Ottawa, ON. In press.

45. ACIA. 2005. Arctic climate impact assessment. Cambridge University Press. New York, NY. 1042 p.

46. Ontario Biodiversity Council. 2010. State of Ontario's biodiversity 2010. A report of the Ontario Biodiversity Council. Peterborough, ON. 121 p.

47. Edsall, T.A. and Charlton, M.N. 1997. Nearshore waters of the Great Lakes. Environment Canada and Environmental Protection Agency. 162 p.

48. King, J.R., Shuter, B.J. and Zimmerman, A.P. 1999. Empirical links between thermal habitat, fish growth, and climate change. Transactions of the American Fisheries Society 128:656-665.

49. Latifovic, R. and Pouliot, D. 2007. Analysis of climate change impacts on lake ice phenology in Canada using the historical satellite data record. Remote Sensing of Environment 106:492-507.

50. Smith, S. 2010. Trends in permafrost conditions and ecology in northern Canada. Canadian Biodiversity: Ecosystem Status and Trends 2010, Technical Thematic Report Series No. 9. Canadian Councils of Resource Ministers. Ottawa, ON. In press.

51. Smith, S.L., Burgess, M.M., Riseborough, D. and Nixon, F.M. 2005. Recent trends from Canadian permafrost thermal monitoring network sites. Permafrost and Periglacial Processes 16:19-30.

52. Smith, S.L., Romanovsky, V.E., Lewkowicz, A.G., Burn, C.R., Allard, M., Clow, G.D., Yoshikawa, K. and Throop, J. 2010. Thermal state of permafrost in North America: a contribution to the International Polar Year. Permafrost and Periglacial Processes 21:117-135. doi:10.1002/ppp.690.

53. James, M. 2010. Historic change in permafrost distribution in northern British Columbia and southern Yukon, Canada . Thesis (M Sc). Department of Geography, University of Ottawa. Ottawa, ON.

54. Beilman, D.W., Vitt, D.H. and Halsey, L.A. 2001. Localized permafrost peatlands in Western Canada: definition, distributions, and degradation. Arctic Antarctic and Alpine Research 33:70-77.

55. Camill, P. 2005. Permafrost thaw accelerates in boreal peatlands during late-20th century climate warming. Climatic Change 68:135-152.

56. Beaulieu, N. and Allard, M. 2003. The impact of climate change on an emerging coastline affected by discontinuous permafrost: Manitounuk Strait, Northern Quebec. Canadian Journal of Earth Sciences 40:1393-1404.

57. Vallée, S. and Payette, S. 2007. Collapse of permafrost mounds along a subarctic river over the last 100 years (northern Quebec). Geomorphology 90:162-170.

58. Fortier, R. and Aub-Maurice, B. 2008. Fast permafrost degradation near Umiujaq in Nunavik (Canada) since 1957 assessed from time-lapse aerial and satellite photographs. 9th International Conference on Permafrost. Edited by Kane, D.L. and Hinkel, K.M. Institute of Northern Engineering, University of Alaska Fairbanks. Fairbanks, AK. Vol. 1, pp. 457-462.

59. Jorgenson, M.T., Racine, C.H., Walters, J.C. and Osterkamp, T.E. 2001. Permafrost degradation and ecological changes associated with a warming climate in central Alaska. Climatic Change 48:551-579.

60. Jorgenson, M.T. and Osterkamp, T.E. 2005. Response of boreal ecosystems to varying modes of permafrost degradation. Canadian Journal of Forest Research 35:2100-2111.

61. Payette, S., Delwaide, A., Caccianiga, M. and Beauchemin, M. 2004. Accelerated thawing of subarctic peatland permafrost over the last 50 years. Geophysical Research Letters 31:L18208.

62. Thibault, S. and Payette, S. 2009. Recent permafrost degradation in bogs of the James Bay area, northern Quebec, Canada. Permafrost and Periglacial Processes 20:383-389.

63. Marsh, P. and Neumann, N.N. 2001. Processes controlling the rapid drainage of two ice-rich permafrost-dammed lakes in NW Canada. Hydrological Processes 15:3433-3446.

64. Woo, M.K., Young, K.L. and Brown, L. 2006. High Arctic patchy wetlands: hydrologic variability and their sustainability. Physical Geography 27:297-307.

65. Woo, M.K. and Young, K.L. 2006. High Arctic wetlands: their occurrence, hydrological characteristics and sustainability. Journal of Hydrology 320:432-450.

66. Lantz, T.C. and Kokelj, S.V. 2008. Increasing rates of retrogressive thaw slump activity in the Mackenzie Delta region, NWT, Canada. Geophysical Research Letters 35:L06502. doi:10.1029/2007GL032433.

67. Marsh, P., Russell, M., Pohl, S., Haywood, H. and Onclin, C. 2009. Changes in thaw lake drainage in the Western Canadian Arctic from 1950 to 2000. Hydrological Processes 23:145-158.

68. Kershaw, G.P. 2003. Permafrost landform degradation over more than half a century, Macmillan/Caribou Pass region, NWT/Yukon, Canada. *In* Proceedings of 8th International Conference on Permafrost. Edited by Phillips, M., Springman, S.M. and Arenson, L.U. A.A. Balkema, Lisse, CH. pp. 543-548.

69. Heginbottom, J.A., Dubreuil, M.A. and Harker, P.A.C. 1995. Canada – permafrost (map) *In* National atlas of Canada, 5th edition. Geomatics Canada, National Atlas Information Service, and Geological Survey of Canada. Ottawa.

70. Halsey, L.A., Vitt, D.H. and Zoltai, S.C. 1995. Disequilibrium response of permafrost in boreal continental western Canada to climate change. Climatic Change 30:57-73.

71. Kanigan, J.C.N. 2007. Variation of mean annual ground temperature in spruce forests of the Mackenzie Delta, Northwest Territories. Thesis (M. Sc.). Geography Department, Carleton University. 131 p.

72. Kanigan, J.C.N., Burn, C.R. and Kokelj, S.V. 2008. Permafrost response to climate warming south of treeline, Mackenzie Delta, Northwest Territories, Canada. 9th International Conference on Permafrost. Edited by Kane, D.L. and Hinkel, K.M. Institute of Northern Engineering, University of Alaska Fairbanks. Fairbanks, AK. Vol. 1, pp. 901-906.

73. Burgess, M.M. and Smith, S.L. 2000. Shallow ground temperatures. *In* The Physical environment of the Mackenzie Valley, Northwest Territories: a baseline for the assessment of environmental change. Edited by Dyke, L.D. and Brooks, G.R. Bulletin 547, Geological Survey of Canada. pp. 89-103.

74. Goodrich, L.E. 1982. The influence of snow cover on the ground thermal regime. Canadian Geotechnical Journal 19:421-432.

75. Smith, S.L., Burgess, M.M. and Riseborough, D. 2008. Ground temperature and thaw settlement in frozen peatlands along the Norman Wells pipeline corridor, NWT Canada – 22 years of monitoring. 9th International Conference on Permafrost. Edited by Kane, D.L. and Hinkel, K.M. Institute of Northern Engineering, University of Alaska Fairbanks. Fairbanks, AK. pp. 1665-1670.

76. Allard, M., Fortier, R., Gagnon, O. and Michaud, Y. 2004. Problématique du développement du village de Salluit, Nunavik, rapport final. Centre d'études nordiques, Université Laval. Québec, QC. 121 p.

77. Ouranos. 2004. Adapting to climate change. Consortium on Regional Climatology and Adaptation to Climate Change. Montreal, QC. 83 p.

78. Chouinard, C., Fortier, R. and Mareschal, J.C. 2007. Recent climate variations in the subarctic inferred from three borehole temperature profiles in northern Quebec, Canada. Earth and Planetary Science Letters 263:355-369.

HUMAN/ECOSYSTEM INTERACTIONS

8. Protected areas

1. International Union for Conservation of Nature. 2008. Guidelines for applying protected area management categories. Edited by Dudley, N. IUCN. Gland, Switzerland. 86 p.

2. Canadian Council on Ecological Areas. 2009. Unpublished analysis of data by ecozone$^+$ from: Conservation Areas Reporting and Tracking System (CARTS), v.2009.05 [online]. Canadian Council on Ecological Areas. http://ccea.org (accessed 5 November, 2009).

3. Secretariat of the Convention on Biological Diversity. 2010. Global biodiversity outlook 3. Montreal, QC. 94 p.

4. Parks Canada. Establishing Gwaii Haanas National Marine Conservation Area reserve and Haida Heritage site. Backgrounder [online]. Parks Canada. http://www.pc.gc.ca/apps/cp-nr/release_e.asp?bgid=1352&andor1=bg (accessed 31 August, 2010).
5. World Wildlife Fund. 2010. Today's Gwaii Haanas announcement sets the stage for new model of oceans stewardship [online]. World Wildlife Fund. http://wwf.ca/newsroom/?7380/Todays-Gwaii-Haanas-Announcement-Sets-the-Stage-for-New-Model-of-Oceans-Stewardship (accessed 31 August, 2010). News release.
6. DFO. 2008. Marine protected area: the Gully [online]. Fisheries and Oceans Canada. http://www.dfo-mpo.gc.ca/oceans/marineareas-zonesmarines/mpa-zpm/atlantic-atlantique/factsheets-feuillets/gully-eng.htm (accessed 31 August, 2010).
7. DFO. 2004. The Gully Marine Protected Area. Backgrounder [online]. Fisheries and Oceans Canada. http://www.dfo-mpo.gc.ca/media/back-fiche/2004/hq-ac61a-eng.htm (accessed 31 August, 2010).
8. DFO. 2010. Regulations for the Gully Marine Protected Area [online]. Fisheries and Oceans Canada. http://www.mar.dfo-mpo.gc.ca/e0010439
9. Latour, P.B., Leger, J., Hines, J.E., Mallory, M.L., Mulders, D.L., Gilchrist, H.G., Smith, P.A. and Dickson, D.L. 2010. Key migratory bird terrestrial habitat sites in the Northwest Territories and Nunavut, Third Edition. Occasional Paper No. 114. Edited by Gaston, A.J. Environment Canada.
10. Government of British Columbia. 2010. Land and Resource Management Planning [online]. http://www.llbc.leg.bc.ca/public/pubdocs/bcdocs/403777/management_planning.pdf (accessed 31 August, 2010).

9. Stewardship

1. The Centre for Environmental Stewardship and Conservation. 2009. The state of stewardship in Canada. Land Stewardship Centre of Canada. Edmonton, AB. 45 p.
2. The Centre for Environmental Stewardship and Conservation 2009. A stewardship road map for Canada. Proceedings of the Strengthening Stewardship...Investing at Every Step Conference. Calgary, AB. September, 2009. Edited by The Land Stewardship Centre of Canada. Edmonton, AB. 42 p.
3. Federal-Provincial-Territorial Stewardship Working Group. 2002. Canada's stewardship agenda: naturally connecting Canadians – a federal-provincial-territorial initiative. Environment Canada. Ottawa, ON. 8 p.
4. Marine Stewardship Council. 2010. Certified fisheries [online]. http://www.msc.org/track-a-fishery/certified (accessed 8 July, 2010).
5. Northwest Atlantic Fisheries Organization. 2009. Northwest Atlantic Fisheries Organization conservation and enforcement measures. NAFO/FC Doc No. 10/1. Northwest Atlantic Fisheries Organization. 95 p.
6. Fisheries Council of Canada. 2008. Avoiding and eliminating by-catch [online]. Fisheries Council of Canada. http://www.fisheriescouncil.ca/page.cfm?ID=5 (accessed 8 July, 2010).
7. Agricultural and Agri-Food Canada. 2010. Derived from Statistics Canada, 2006 Farm Environmental Management Survey. Environmental farm planning in Canada: a 2006 overview. Agri-Environmental Services Branch, Agriculture and Agri-Food Canada. Ottawa, ON.
8. Metafore's Forest Certification Resource Centre. 2009. CFM certification in Canada 1999-2009 [online]. http://www.certifiedwood.org (accessed
9. Biodiversity Science Assessment Team. 1994. Biodiversity in Canada: a science assessment for Environment Canada. Environment Canada. Ottawa, ON. 245 p.
10. Stewardship Centre for British Columbia. 2010. Stewardship Centre for British Columbia [online]. http://www.stewardshipcentre.bc.ca/ (accessed 14 April, 2010).
11. North American Waterfowl Management Plan. 2004. Strengthening the biological foundation: 2004 strategic guidance. Environment Canada, U.S. Fish and Wildlife Service, Secretaría de Medio Ambiente y Recursos Naturales. Canada. 22 p.
12. Statistics Canada. 2010. CANSIM Table 001-0017: estimated areas, yield, production, average farm price and total farm value of principal field crops, in imperial units, annual. Seeded winter wheat for prairie provinces [online]. Statistics Canada. http://cansim2.statcan.ca/cgi-win/CNSMCGI.EXE?regtkt=&C2Sub=&ARRAYID=10017&C2DB=PRD&VEC=&LANG=E&SDDSLOC=//www.statcan.ca/english/sdds/*.htm&ROOTDIR=CII/&RESULTTEMPLATE=CII/CII_PICK&ARRAY_PICK=1&SDDSID=&SDDSDESC#TFtn (accessed 8 July, 2010).
13. North American Waterfowl Management Plan. 2010. Canadian NAWMP National Tracking System. Environment Canada. Ottawa, ON.
14. Campbell, L. and Rubec, C.D.A. 2006. Land trusts in Canada: building momentum for the future. Wildlife Habitat Canada. Ottawa, ON. 26 p.
15. Canadian Land Trust Alliance. 2010. 2010 CLTA land trust census final report. Canadian Land Trust Alliance.
16. Good, K. and Michalsky, S. 2010. Summary of Canadian experience with conservation easements and their potential application to agri-environmental policy. Agriculture and Agri-Food Canada. Ottawa, ON. In press.
17. Ontario Ministry of Natural Resources. 2009. Managed forest tax incentive program [online]. Ontario Ministry of Natural Resources. http://www.mnr.gov.on.ca/en/Business/Forests/2ColumnSubPage/STEL02_166346.html (accessed 5 November, 2009).
18. Ontario Ministry of Natural Resources. 2009. Conservation land tax incentive program [online]. Ontario Ministry of Natural Resources. http://www.mnr.gov.on.ca/en/Business/CLTIP/ (accessed 5 November, 2009).
19. Ontario Ministry of Natural Resources. 2008. Participation in Ontario tax incentive programs. Unpublished data.
20. The Centre for Environmental Stewardship and Conservation. 2009. A review of stewardship programs and activities in Canada's provinces and territories. Alberta Environment. Edmonton, AB. 83 p.
21. Berkes, F. 2009. Indigenous ways of knowing and the study of environmental change. Journal of the Royal Society of New Zealand 39:151-156.
22. Berkes, F., Mathias, J., Kislalioglu, M. and Fast, H. 2001. The Canadian Arctic and the Oceans Act: the development of participatory environmental research and management. Ocean and Coastal Management 44:451-469.
23. Gagnon, C.A. and Berteaux, D. 2009. Integrating traditional ecological knowledge and ecological science: a question of scale. Ecology and Society 14: Article 19.
24. Government of Nunavut and Indian and Northern Affairs Canada. 2008. Nunavut Coastal Resource Inventory, Igloolik pilot project. Government of Nunavut. Iqaluit, NU.
25. Montevecchi, W.A., Coffey, J., Burke, C. and Chaffey, H. 2004. A conservation initiative: nest shelters for common eiders on islands in St. Peter's Bay, Labrador. Cognitive and Behavioral Ecology, Psychology Department, and Coasts Under Stress, Memorial University of Newfoundland. St. John's, NL.

10. Invasive non-native species

1. Canadian Endangered Species Conservation Council (CESCC). Wild species 2010: the general status of species in Canada. National General Status Working Group. In press.
2. Secretariat of the Convention on Biological Diversity. 2006. Global biodiversity outlook 2. Convention on Biological Diversity. Montreal, QC. 81 p.
3. Secretariat of the Convention on Biological Diversity. 2010. Global biodiversity outlook 3. Convention on Biological Diversity. Montreal, QC. 94 p.
4. Johannessen, S.C. and McCarter, B. 2010. Ecosystems status and trends report for the Strait of Georgia Ecozone+. DFO Canadian Science Advisory Secretariat Research Document No. 2010/010. Fisheries and Oceans Canada. vi + 45 p.
5. Mouland, D. 2008. Overview of aquatic invasive species (AIS) prepared for The Exotic and Invasive Species Workshop-Corner Brook, Jan 22-23, 2008. Newfoundland and Labrador Department of Fisheries and Aquaculture. Cornerbrook, NL. 8 p.
6. MacNair, N., Mills, C., Gillis, B., Smith M., Landry, T., Locke, A., Smith, A., Davidson, J. and Warris, P. 2010. History of the tunicate invasions in PEI, their impact on the cultured mussel industry and mitigation strategies employed since 1998 [online]. Woods Hole Oceanographic Institution. http://www.whoi.edu/page.do?pid=17276&tid=282&cid=33372 (accessed 8 September, 2010).
7. Locke, A., Hanson, J.M., Ellis, K.M., Thompson, J. and Rochette, R. 2007. Invasion of the southern Gulf of St. Lawrence by the clubbed tunicate *(Styela clava* Herdman): potential mechanisms for invasions of Prince Edward Island estuaries. Journal of Experimental Marine Biology and Ecology 342:69-77.
8. Gillespie, G.E., Phillips, A.C., Paltzat, D.L. and Therriault, T.W. 2007. Status of the European green crab, *Carcinus maenas*, in British Columbia – 2006. Canadian Technical Report of Fisheries and Aquatic Sciences No. 2700. Fisheries and Oceans Canada. vii + 39 p.
9. Schindler, D.W. 2001. The cumulative effects of climate warming and other human stresses on Canadian freshwater in the new millennium. Canadian Journal of Fisheries and Aquatic Sciences 58:18-29. doi:10:1139/cjfas-58-1-18.
10. Ricciardi, A. 2001. Facilitative interactions among aquatic invaders: is an "invasional meltdown" occurring in the Great Lakes? Canadian Journal of Fisheries and Aquatic Sciences 58:2513-2525.
11. Great Lakes Commission. 2007. Great Lakes aquatic invasions. Aquatic invasive species prevention and control: outreach, research, management and policy. Environmental Protection Agency. 11 p.
12. Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS). 2009. Great Lakes nonindigenous species list [online]. National Oceanic and Atmospheric Administration. http://www.glerl.noaa.gov/res/Programs/glansis/great_lakes_list.html (accessed 20 November, 2009).
13. Environment Canada and U.S. Environmental Protection Agency. 2009. State of the Great Lakes 2009 highlights. 13 p.
14. Metcalfe-Smith, J.L., Zanatta, D.T., Masteller, E.C., Dunn, H.L., Nichols, S.J., Marangelo, P.J. and Schloesser, D.W. 2002. Some nearshore areas in Lake Erie and Lake St. Clair provide refuge for native freshwater mussels (Unionidae) from the impacts of invading zebra and quagga mussels (*Dreissena* spp.). IAGLR 2002 Conference. University of Manitoba. Winnipeg, Manitoba. June 2-6, 2002.
15. Environment Canada and U.S. Environmental Protection Agency. 2009. State of the Great Lakes 2009. 432 p.
16. Schloesser, D.W. and Nalepa, T.F. 1994. Dramatic decline of unionid bivalves in offshore waters of western Lake Erie after infestation by the zebra mussel, *Dreissena polymorpha*. Canadian Journal of Fisheries and Aquatic Sciences 51:2234-2242.
17. Nalepa, T.F., D.J.Hartson, G.W.Gostenik, D.L.Fanslow and G.A.Lang. 1996. Changes in the freshwater mussel community of Lake St. Clair: from Unionidae to *Dreissena polymorpha* in eight years. Journal of Great Lakes Research 22:354-369.
18. Bogan, A.E. 1993. Freshwater bivalve extinctions (Mollusca: Unionidae): a search for causes. American Zoology 33:599-609.
19. Morris, T.J. and Edwards, A. 2007. Freshwater mussel communities of the Thames River, Ontario 2004-2005. Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 2810. 28 p.
20. Leighton, F.A. 2010. Wildlife pathogens and diseases in Canada. Canadian Biodiversity: Ecosystem Status and Trends 2010, Technical Thematic Report Series No. 7. Canadian Councils of Resource Ministers. Ottawa, ON. In press.
21. Health Canada. 2003. Average summer temperatures and incidence of West Nile virus in Canada. Map.
22. McLean, R.G. and Ubico, S.R. 2007. Arboviruses in birds. *In* Infectious diseases of wild birds. Edited by Thomas, N.J., Hunter, D.B. and Atkinson, C.T. Blackwell Publishing. Ames, IA. Chapter 2. pp. 17-62.
23. Canadian Cooperative Wildlife Health Centre. 2010. West Nile virus [online]. http://www.ccwhc.ca/west_nile_virus.php (accessed 31 July, 2010).
24. Weldon, C., du Preez, L., Hyatt, A., Muller, R. and Speare, R. 2004. Origin of the amphibian chytrid fungus. Emerging Infectious Diseases 10:2100-2105.
25. Skerratt, L.F., Berger, L., Speare, R., Cashins, S., McDonald, K.R., Phillott, A.D., Hines, H.B. and Kenyon, N. 2007. Spread of chytridiomycosis has caused the rapid global decline and extinction of frogs. Ecohealth 4:125-134.
26. Kilpatrick, A.M., Briggs, C.J. and Daszak, P. 2010. The ecology and impact of chytridiomycosis: an emerging disease of amphibians. Trends in Ecology and Evolution 25:109-118.
27. Daszak, P., A.A.Cunningham and A.D.Hyatt. 2003. Infectious disease and amphibian population declines. Diversity and Distributions 9:141-150.
28. Carey, C., Cohen, N. and Rollins-Smith, L. 1999. Amphibian declines: an immunological perspective. Developmental and Comparative Immunology 23:427-458.
29. Gantress, J., Maniero, G.D. and Cohen, N. 2003. Development and characterization of a model system to study amphibian immune responses to iridoviruses. Virology 311:254-262.
30. Relyea, R. 2009. A cocktail of contaminants: how mixtures of pesticides at low concentrations affect aquatic communities. Oecologia 159:363-376.
31. Ouellet, M., Mikaelian, I., Pauli, B., Rodrigue, J. and Green, D. 2005. Historical evidence of widespread chytrid infection in North American amphibian populations. Conservation Biology 19:1431-1440. doi:10.1111/j.1523-1739.2005.00108.x.
32. Canadian Cooperative Wildlife Health Centre. 2008. Canada's national wildlife disease database [online]. http://www.ccwhc.ca/ccwhc_database.php (accessed 23 January, 2009).
33. Forzán, M.J., Vanderstichel, N.S., Hogan, N.S., Teather, K. and Wood, J. 2010. Prevalence of *Batrachochytrium dendrobatidis* in three species of wild frogs on Prince Edward Island, Canada. Diseases of Aquatic Organisms 91:91-96. doi:10.3354/dao02244.
34. Olson, D.H. 2009. Herpetological conservation in northwestern North America. Northwestern Naturalist 90:61-96.

35. Schock, D.M., Ruthig, G.R., Collins, J.P., Kutzl, S.J., Carrière, S., Gau, R.J., Veitch, A.M., Larter, N.C.T.D.P., Guthrie, G.A.D.G. and Popko, R.A. 2009. Amphibian chytrid fungus and ranaviruses in the Northwest Territories, Canada. Diseases of Aquatic Organisms DAO Special 4:10. doi:10.3354/dao02134.
36. Canadian Food Inspection Agency. 2010. Invasive alien plants in Canada – technical report [online]. Canadian Food Inspection Agency. http://www.inspection.gc.ca/english/plaveg/invenv/techrpt/techrese.shtml#t6 (accessed 13 September, 2010).
37. Canadian Food Inspection Agency. 2008. Invasive alien plants in Canada – summary report [online]. Canadian Food Inspection Agency. http://www.inspection.gc.ca/english/plaveg/invenv/techrpt/summrese.shtml#a3 (accessed 13 September, 2010).
38. Blossey, B., Skinner, L.C. and Taylor, J. 2001. Impact and management of purple loosestrife (*Lythrum salicaria*) in North America. Biodiversity and Conservation 10:1787-1807.
39. Hudon, C., Gagnon, P. and Jean, M. 2005. Hydrological factors controlling the spread of common reed (*Phragmites australis*) in the St. Lawrence River (Quebec, Canada). Ecoscience 12:347-357.
40. Catling, P.M. and Mitrow, G. 2010. The recent spread and potential distribution of *Phragmites australis* ssp. *australis* in Canada. Canadian Field-Naturalist. In press.
41. Saltonstall, K. 2002. Cryptic invasion by a non-native genotype of the common reed, *Phragmites australis*, into North America. Proceedings of the National Academy of Sciences of the United States of America 99:2445-2449.
42. Maheu-Giroux, M. and DeBlois, D. 2007. Landscape ecology of *Phragmites australis* invasion in networks of linear wetlands. Landscape Ecology 22:285-301.
43. Chambers, R.M., L.A.Meyerson and K.Saltonstall. 1999. Expansion of *Phragmites australis* into tidal wetlands of North America. Aquatic Botany 64:261-273.
44. Meyer, D.L., Johnson, J.M. and Gill, J.W. 2001. Comparison of nekton use of *Phragmites australis* and *Spartina alterniflora* marshes in the Chesapeake Bay, USA. Marine Ecology-Progress Series 209:71-84.

11. Contaminants

1. Arctic Monitoring and Assessment Programme. 2009. AMAP assessment 2009: human health in the Arctic. Arctic Monitoring and Assessment Programme. Oslo, Norway. 256 p.
2. Hickie, B.E., Ross, P.S., Macdonald, R.W. and Ford, J.K.B. 2007. Killer whales (*Orcinus orca*) face protracted health risks associated with lifetime exposure to PCBs. Environmental Science and Technology 41:6613-6619.
3. Letcher, R., Bustnes, J.O., Dietz, R., Jenssen, B.M., Jorgensen, E.H., Sonne, C., Verreault, J., Vijayan, M. and Gabrielsen, G.W. 2010. Exposure and effects assessment of persistent organohalogen contaminants in arctic wildlife and fish. Science of the Total Environment 408:2995-3043.
4. Environment Canada and U.S. Environmental Protection Agency. 2009. State of the Great Lakes 2009. Governments of Canada and the United States of America. 432 p.
5. Wong, C.S.C., Duzgoren-Aydin, N.S., Aydin, A. and Wong, M.H. 2006. Sources and trends of environmental mercury emissions in Asia. Science of the Total Environment 368:649-662.
6. COSEWIC. 2007. COSEWIC assessment and update status report on the peregrine falcon *Falco peregrinus* (*Falco peregrinus pealii* subspecies, *Falco peregrinus anatum* subspecies, and *Falco peregrinus tundrius*) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa, ON. 45 p.
7. Elliott, J.E., Miller, M.J. and Wilson, L.K. 2005. Assessing breeding potential of peregrine falcons based on chlorinated hydrocarbon concentrations in prey. Environmental Pollution 134:353-361.
8. Stern, G.A. 2009. Temporal trend studies of trace metals and halogenated organic contaminants (HOCs), including new and emerging persistent compounds, in Mackenzie River burbot, Fort Good Hope, NWT. *In* Synopsis of research conducted under the 2008-2009 Northern Contaminants program. Edited by Smith, S., Stow, J. and Edwards, J. Indian and Northern Affairs Canada. Ottawa, ON. pp. 164-171.
9. Braune, B.M. 2007. Temporal trends of organochlorines and mercury in seabird eggs from the Canadian Arctic, 1975-2003. Environmental Pollution 148:599.
10. Stern, G. 2009. Temporal trends of halogenated organic compounds in Canadian Arctic beluga. *In* Synopsis of research conduced under the 2008-2009 Northern Contaminants Program. Edited by Smith, S., Stow, J. and Edwards, J. Indian and Northern Affairs Canada. Ottawa, ON. pp. 123-130.
11. Tomy, G. 2009. Temporal trends of halogenated chemicals of emerging concern in beluga whales (*Delphinapterus leucas*) from Hendrickson Island and Pangnirtung. *In* Synopsis of research conduced under the 2008-2009 Northern Contaminants Program. Edited by Smith, S., Stow, J. and Edwards, J. Indian and Northern Affairs Canada. Ottawa, ON. pp. 99-107.
12. Environment Canada. 2009. Concentrations of contaminants in wildlife compiled from data provided by Canadian Wildlife Service and Fisheries and Oceans Canada. Unpublished data.
13. Carlson, D.L., De Vault, D.S. and Swackhamer, D.L. 2010. On the rate of decline of persistent organic contaminants in lake trout (*Salvelinus namaycush*) from the Great Lakes, 1970-2003. Environmental Science and Technology 44:2004-2010.
14. Ismail, N., Gewurtz, S.B., Pleskach, K., Whittle, D.M., Helm, P.A., Marvin, C.H. and Tomy, G.T. 2009. Brominated and chlorinated flame retardants in Lake Ontario, Canada, lake trout (*Salvelinus namaycush*) between 1979 and 2004 and possible influences of food-web changes. Environmental Toxicology and Chemistry 28:910-920.
15. Couillard, C.M., Macdonald, R.W., Courtenay, S.C. and Palace, V.P. 2008. Chemical-environment interactions affecting the risk of impacts on aquatic organisms: a review with a Canadian perspective – interactions affecting exposure. Environmental Reviews 16:1-17.
16. Kelly, E.N., Schindler, D.W., St Louis, V.L., Donald, D.B. and Vlaclicka, K.E. 2006. Forest fire increases mercury accumulation by fishes via food web restructuring and increased mercury inputs. Proceedings of the National Academy of Sciences of the United States of America 103:19380-19385.
17. Couillard, C.M., Courtenay, S.C. and Macdonald, R.W. 2008. Chemical-environment interactions affecting the risk of impacts on aquatic organisms: a review with a Canadian perspective – interactions affecting vulnerability. Environmental Reviews 16:19-44.
18. Mckinney, M.A., Peacock, E. and Letcher, R.J. 2009. Sea ice-associated diet change increases the levels of chlorinated and brominated contaminants in polar bears. Environmental Science and Technology 43:4334-4339.
19. Government of Canada and United States Environmental Protection Agency. 1995. The Great Lakes: an environmental atlas and resource book, 3rd edition [online]. Government of Canada, United States Environmental Protection Agency. http://www.epa.gov/glnpo/atlas/index.html (accessed 15 August, 2010).

20. Gewurtz, S.B., Bhavsar, S.P., Jackson, D.A., Fletcher, R., Awad, E., Moody, R. and Reiner, E.J. 2010. Temporal and spatial trends of organochlorines and mercury in fishes from the St. Clair River/Lake St. Clair corridor, Canada. Journal of Great Lakes Research 36:100-112.

21. Environment Canada and Ontario Ministry of the Environment. 2002. Atmospheric deposition in the Great Lakes: there's something in the air. Canada-Ontario Agreement Respecting the Great Lakes Basin Ecosystem. 4 p.

22. Champoux, L., Moisey, J. and Muir, D.C.G. 2010. Polybrominated diphenyl ethers, toxaphenes, and other halogenated organic pollutants in great blue heron eggs. Environmental Toxicology and Chemistry 29:243-249.

23. Gauthier, L.T., Hébert, C.E., Weseloh, D.V.C. and Letcher, R.J. 2008. Dramatic changes in the temporal trends of polybrominated diphenyl ethers (PBDEs) in herring gull eggs from the Laurentian Great Lakes: 1982-2006. Environmental Science and Technology 42:1524-1530.

24. Batterman, S., Chernyak, S., Gwynn, E., Cantonwine, D., Jia, C., Begnoche, L. and Hickey, J.P. 2007. Trends of brominated diphenyl ethers in fresh and archived Great Lakes fish (1979-2005). Chemosphere 69:444-457.

25. Environment Canada and U.S.Enviromental Protection Agency. 2005. State of the Great Lakes 2005. 305 p.

26. International Joint Commission. 2009. Work group report on chemicals of emerging concern. Great Lakes Water Quality Agreement Priorities 2007-09 Series. 15 p.

27. Environment Canada. 2006. Ecological screening assessment report on perfluorooctane sulfonate, its salts and its precursors [online]. http://www.ec.gc.ca/CEPARegistry/documents/part/PFOS/ (accessed 20 October, 2009).

28. Kavanagh, R.J., Balch, G.C., Kiparissis, Y., Niimi, A.J., Sherry, J., Tinson, C. and Metcalf, D. 2004. Endocrine disruption and altered gonadal development in white perch (*Morone americana*) from the lower Great Lakes region. Environmental Health Perspective 112:898-202.

29. Ross, P.S., Stern, G.A. and Lebeuf, M. 2007. Trouble at the top of the food chain: environmental contaminants and health risks in marine mammals – a white paper on research priorities for Fisheries and Oceans Canada. Fisheries and Oceans Canada. Sidney, BC. 30 p.

30. Breton, A.R., Fox, G.A. and Chardine, J.W. 2008. Survival of adult herring gulls (*Larus argentatus*) from a Lake Ontario colony over two decades of environmental change. Waterbirds 31:15-23.

31. Lebeuf, M., Noel, M., Trottier, S. and Measures, L. 2007. Temporal trends (1987-2002) of persistent, bioaccumulative and toxic (PBT) chemicals in beluga whales (*Delphinapterus leucas*) from the St. Lawrence Estuary, Canada. Science of the Total Environment 383:216-231.

32. Martineau, D., Lemberger, K., Dallaire, A., Labelle, P., Lipscomb, T.P., Michel, P. and Mikaelian, I. 2002. Cancer in wildlife, a case study: beluga from the St. Lawrence estuary, Quebec, Canada. Environmental Health Perspectives 110:285-292.

33. Ross, P.S. 2006. Fireproof killer whales (*Orcinus orca*): flame-retardant chemicals and the conservation imperative in the charismatic icon of British Columbia, Canada. Canadian Journal of Fisheries and Aquatic Sciences 63:224-234.

34. Grant, S.C.H. and Ross, P.S. 2002. Southern resident killer whales at risk: toxic chemicals in the British Columbia and Washington environment. Fisheries and Oceans Canada. Sidney, B.C. 111 p.

35. Ross, P.S., Ikonomou, M.G., Barrett-Lennard, L.G. and Addison, R.F. 2000. High PCB concentrations in free-ranging Pacific killer whales, *Orcinus orca*: effects of age, sex and dietary preference. Marine Pollution Bulletin 40:504-515.

36. Krahn, M.M., Hanson, M.B., Schorr, G.S., Emmons, C.K., Burrows, D.G., Bolton, J.L., Baird, R.W. and Ylitalo, G.M. 2009. Effects of age, sex and reproductive status on persistent organic pollutant concentrations in "Southern Resident" killer whales. Marine Pollution Bulletin 58:1522-1529.

12. Nutrient loading and algal blooms

1. Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being: biodiversity synthesis. Millennium Ecosystem Assessment Series. World Resources Institute. Washington, DC. 100 p.

2. Environment Canada. 2010. Canadian environmental sustainability indicators: water quality [online]. Environment Canada. http://www.ec.gc.ca/indicateurs-indicators/default.asp?lang=En&n=68DE8F72-1 (accessed 31 August, 2010).

3. Codd, G.A., Lindsay, J., Young, F.M., Morrison, L.F. and Metcalf, J.S. 2005. Harmful cyanobacteria: from mass mortalities to management measures. *In* Harmful cyanobacteria. Aquatic Ecology Series. Edited by Huisman, J., Matthijs, H.C.P. and Visser, P.M. Springer. Dordrecht, The Netherlands. pp. 1-23.

4. Environment Canada. 2008. Cyanobacteria in the Great Lakes-St. Lawrence Basin [online]. http://www.qc.ec.gc.ca/csl/inf/inf073_e.html (accessed 27 May, 2010).

5. Van Dolah, F.M. 2000. Marine algal toxins: origins, health effects, and their increased occurrence. Environmental Health Perspectives 108:133-141.

6. Diaz, R.J. and Rosenberg, R.. 2008. Spreading dead zones and consequences for marine ecosystems. Science 321:926-929.

7. Hallegraeff, G. 2009. Impacts of climate change on harmful algal blooms [online]. Elsevier. http://www.scitopics.com/Impacts_of_Climate_Change_on_Harmful_Algal_Blooms.html (accessed 1 August, 2010).

8. Hall, R.I., Leavitt, P.R., Quinlan, R., Dixit, A.S. and Smol, J.P. 1999. Effects of agriculture, urbanization, and climate on water quality in the northern Great Plains. Limnology and Oceanography 44:739-756.

9. Lake Winnipeg Stewardship Board. 2006. Reducing nutrient loading to Lake Winnipeg and its watershed: our collective responsibility and commitment to action. Report to the Minister of Water Stewardship. 78 p.

10. Shipley, E. and Kling, H. 2010. Unpublished analysis in: Lake Winnipeg and its watershed, a report prepared for Canadian biodiversity: ecosystem status and trends 2010. Manitoba Water Stewardship. Unpublished report.

11. Lake Winnipeg Stewardship Board. 2005. Our collective responsibility: reducing nutrient loading to Lake Winnipeg. An interim report to the Minister of Manitoba Water Stewardship. Lake Winnipeg Stewardship Board. Winnipeg, MB. 52 p.

12. Manitoba Water Stewardship. 2008. Water Quality Management Section. Unpublished data.

13. Ministère du Développement durable, de l'Environnement et des Parcs. 2009. Bilan des lacs et cours d'eau touchés par une fleur d'eau d'algues bleu-vert au Québec. De 2004 à 2008 [online]. http://www.mddep.gouv.qc.ca/eau/algues-bv/bilan/liste_comparative.asp (accessed July, 2009).

14. Zurawell, R. 2010. Cyanobacteria and cyanotoxins: Alberta's experience with a global issue. Alberta Environment. Presentation available at http://www.msss.gouv.qc.ca/sujets/santepub/environnement/download.php?f=3832fe1a34056c4aa74ac90d8a8ec3d9.

15. Northern River Basins Study. 1996. Northern River Basins Study: the legacy. Volume 1: collective findings. Alberta Department of the Environment, Environment Canada, and Northwest Territories Department of Renewable Resources. Edmonton, AB. CD-Rom.

16. Government of Canada and U.S. Environmental Protection Agency. 1995. The Great Lakes today: concerns. *In* The Great Lakes: an environmental atlas and research book. Toronto, ON and Chicago, IL.

17. Richards, R.P., Baker, D.B., Crumrine, J.P. and Kramer, J.W. 2008. Record-setting phosphorus loads from agricultural watersheds in Ohio. 2008 USDA-CSREES National Water Conference. Sparks, NV. February 3-6, 2008.

18. Commission for Environmental Cooperation. 2008. The North American mosaic: an overview of key environmental issues. Montreal, QC. 62 p.

19. Vanderploeg, H.A., Liebig, J.R., Carmichael, W.W., Agry, M.A., Johengen, T.H., Fahnenstiel, G.L. and Nalepa, T.F. 2001. Zebra mussel (*Dreissena polymorpha*) selective filtration promoted toxic *Microcystis* blooms in Saginaw Bay (Lake Huron) and Lake Erie. Canadian Journal of Fisheries and Aquatic Sciences 58:1208-1221.

20. Samelle, O., Wilson, A.E., Hamilton, S.K., Knoll, L.B. and Rainkow, D.F. 2005. Complex interactions between the zebra mussel, *Dreissena polymorpha*, and the harmful phytoplankter *Microcystis aureginosa*. Limnology and Oceanography 50:896-904.

21. Vanderploeg, H.A., Johengen, T.H. and Liebig, J.R. 2009. Feedback between zebra mussel selective feeding and algal composition affects mussel condition: did the regime changer pay a price for its success? Freshwater Biology 54:47-63.

22. U.S .Environmental Protection Agency. 2009. Algal blooms in western Lake Erie [online]. http://www.epa.gov/med/grosseile_site/indicators/algae-blooms.html (accessed 21 September, 2010).

23. NOAA. 2009. Great Lakes CoastWatch node [online]. http://www.glerl.noaa.gov/res/Task_rpts/1994/cmleshk03-1.html August 25, 2009 MODIS imagery on Terra satellite.

24. Watson, S.B., Boyer, G. and Ridal, J. 2008. Taste and odour and cyanobacterial toxins: impairment, prediction and management in the Great Lakes. Canadian Journal of Fisheries and Aquatic Sciences 65:1-18.

25. Millie, D.F., Fahnenstiel, G.L., Bressie, J.D., Pigg, R.J., Rediske, R.R., Klarer, D.M., Tester, P.A. and Litaker, R.W. 2009. Late-summer phytoplankton in western Lake Erie (Laurentian Great Lakes): bloom distributions, toxicity, and environmental influences. Aquatic Ecology 43:915-934.

26. Jensen, E.V. and Epp, P.F. 2002. Water quality trends in Okanagan, Skaha and Osoyoos lakes in response to nutrient reductions and hydrologic variation. Ministry of Water Land and Air Protection. Penticton, BC. 17 p.

27. Martin, J.L., Hanke, A.R. and LeGresley, M.M. 2009. Long term phytoplankton monitoring, including harmful algal blooms, in the Bay of Fundy, eastern Canada. Journal of Sea Research 61:76-83.

28. DFO. 2010. 2010 Canadian marine ecosystem status and trends report. DFO Canadian Science Advisory Secretariat Science Advisory Report No. 2010/030. Fisheries and Oceans Canada. 37 p.

29. NASA Earth Observatory. 2009. SeaWiFS project/ORBIMAGE [online]. NASA/Goddard Space Flight Centre and ORBIMAGE. http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=14023 (accessed 30 July, 2010).

13. Acid deposition

1. Environment Canada. 2005. Canadian acid deposition science assessment 2004. Environment Canada, Meterological Service of Canada. Ottawa, ON. 440 p.

2. Jeffries, D.S., McNicol, D.K. and Weeber, R.C. 2005. Effects on aquatic chemistry and biology. *In* Canadian acid deposition science assessment 2004. Environment Canada. Ottawa, ON. Chapter 6. pp. 203-278.

3. Holt, C.A., Yan, N.D. and Somers, K.M. 2003. pH 6 as the threshold to use in critical load modeling for zooplankton community change with acidification in lakes of south-central Ontario: accounting for morphometry and geography. Canadian Journal of Fisheries and Aquatic Sciences 60:151-158.

4. Jeffries, D.S. 1997. 1997 Canadian acid rain assessment. Volume 3: the effects on Canada's lakes, rivers and wetlands. Environment Canada. Ottawa, ON. 178 p.

5. Doka, S.E., McNicol, D.K., Mallory, M.L., Wong, I., Minns, C.K. and Yan, N.D. 2003. Assessing potential for recovery of biotic richness and indicator species due to changes in acidic deposition and lake pH in five areas of southeastern Canada. Environmental Monitoring and Assessment 88:53-101.

6. Gardner, T. 2001. Declining amphibian populations: a global phenomenon in conservation biology. Animal Biodiversity and Conservation 24:25-44.

7. Wiener, J.G., Krabbenhoft, D.P., Heinz, G.H. and Scheuhammer, W.M. 2003. Ecotoxicology of mercury. *In* Handbook of ecotoxicology. Edited by Hoffman, D.J., Rattner, B.A., Burton, G.A. and Cairns, J. Lewis Publishers. Boca Raton, FL. Chapter 16. pp. 409-463.

8. Drysdale, C., Burgess, N.M., d'Entremont, A., Carter, J. and Brun, G. 2005. Mercury in brook trout, white perch and yellow perch in Kejimkujik National Park and National Historic Site. *In* Mercury cycling in a wetland dominated ecosystem: a multidisciplinary study. Edited by O'Driscoll, N.J., Rencz, A.N. and Lean, D.R.S. SETAC Press. Pensacola, FL. pp. 321-346.

9. Kamman, N.C., Burgess, N.M., Driscoll, C.T., Simonin, H.A., Goodale, W., Linehan, J., Estabrook, R., Hutcheson, M., Major, A., Scheuhammer, A.M. and Scruton, D.A. 2005. Mercury in freshwater fish of northeast North America – a geographic perspective based on fish tissue monitoring databases. Ecotoxicology 14:163-180.

10. Burgess, N.M. and Meyer, M.W. 2008. Methylmercury exposure associated with reduced productivity in common loons. Ecotoxicology 17:83-91.

11. Duchesne, L., Ouimet, R. and Houle, D. 2002. Basal area growth of sugar maple in relation to acid deposition, stand health, and soil nutrients. Journal of Environmental Quality 31:1676-1683.

12. Driscoll, C.T., Lawrence, G.B., Bulger, A.J., Butler, T.J., Cronan, C.S., Eagar, C., Lambert, K.F., Likens, G.E., Stoddard, J.L. and Weathers, K.C. 2001. Acidic deposition in the northeastern United States: sources and inputs, ecosystem effects, and management strategies. BioScience 51:180-198.

13. Jeffries, D.S. and Ouimet, R. 2005. Critical loads – are they being exceeded? *In* Canadian acid deposition science assessment 2004. Environment Canada. Ottawa, ON. Chapter 8. pp. 341-368.

14. National Atlas of Canada. 1991. The potential of soils and bedrock to reduce the acidity of atmospheric deposition. 5th Edition, 1978-1995. Natural Resources Canada. Ottawa, ON.

15. Scott, K.A., Wissel, B.J., Gibson, J.J. and Birks, S.J. 2010. Chemical characteristics and acid sensitivity of boreal headwater lakes in northwest Saskatchewan. Journal of Limnology 69:33-44.

16. Nasr, M., Castonguay, M., Ogilvie, J., Raymond, B.A. and Arp, P.A. 2010. Modelling and mapping critical loads and exceedances for the Georgia Basin, British Columbia, using a zero base-cation depletion criterion. Journal of Limnology 69(Suppl. 1):181-192.

17. Jeffries, D., Wong, I., Dennis, I. and Sloboda, M. 2010. Terrestrial and aquatic critical loads map. Environment Canada, Water Science and Technology Branch. Unpublished.

18. Jeffries, D., Wong, I. and Sloboda, M. 2010. Boreal Shield steady-state exceedances for forest soils or lakes map. Prepared for Boreal Shield Ecozone status and trends report. Environment Canada, Water Science and Technology Branch. Unpublished.

19. Jeffries, D.S., Clair, T.A., Couture, S., Dillon, P.J., Dupont, J., Keller, W., McNicol, D.K., Turner, M.A., Vet, R. and Weeber, R. 2003. Assessing the recovery of lakes in southeastern Canada from the effects of acidic deposition. Ambio 32:176-182.

20. Canada-United States. 2008. Canada - United States Air Quality Agreement. 2008 progress report. International Joint Commission. Ottawa, ON and Washington, DC. 72 p.

21. Weeber, R.C., Jeffries, D.S. and McNicol, D. 2005. Recovery of aquatic ecosystems. In Canadian acid deposition science assessment 2004. Environment Canada. Ottawa, ON. Chapter 7. pp. 279-340.

22. Jeziorski, A., Yan, N.D., Paterson, A.M., DeSellas, A.M., Turner, M.A., Jeffries, D.S., Keller, B., Weeber, R.C., McNicol, D.K., Palmer, M.E., McIver, K., Arseneau, K., Ginn, B.K., Cumming, B.F. and Smol, J.P. 2008. The widespread threat of calcium decline in fresh waters. Science 322:1374-1377.

23. Yan, N.D., Somers, K.M., Girard, R.E., Paterson, A.M., Keller, W., Ramcharan, C.W., Rusak, J.A., Ingram, R., Morgan, G.E. and Gunn, J.M. 2008. Long-term trends in zooplankton of Dorset, Ontario lakes: the probable interactive effects of changes in pH, total phosphorus, dissolved organic carbon, and predators. Canadian Journal of Fisheries and Aquatic Sciences 65:862-877.

24. Snucins, E. 2003. Recolonization of acid-damaged lakes by the benthic invertebrates *Stenacron interpunctatum*, *Stenonema femoratum* and *Hyalella azteca.* Ambio 32:225-229.

25. Snucins, E. and Gunn, J.M. 2003. Use of rehabilitation experiments to understand the recovery dynamics of acid-stressed fish populations. Ambio 32:240-243.

26. Aurora Trout Recovery Team. 2006. Recovery strategy for Aurora trout (*Salvelinus fontinalis timagamiensis*) in Canada. Species at Risk Act Recovery Strategy Series. Fisheries and Oceans Canada. Ottawa, ON. 35 p.

27. Yan, N.D., Paterson, A.M., Somers, K.M. and Scheider, W.A. 2008. An introduction to the Dorset special issue: transforming understanding of factors that regulate aquatic ecosystems on the southern Canadian Shield. Canadian Journal of Fisheries and Aquatic Sciences 65:781-785.

28. Watt, W.D., Scott, C.D., Zamora, P.J. and White, W.J. 2000. Acid toxicity levels in Nova Scotian rivers have not declined in synchrony with the decline in sulfate levels. Water, Air, and Soil Pollution 118:203-229.

29. Clair, T.A., Dennis, I.F., Scruton, D.A. and Gilliss, M. 2007. Freshwater acidification research in Atlantic Canada: a review of results and predictions for the future. Environmental Reviews 15:153-167.

30. Clair, T.A., Dennis, I.F., Amiro, P.G. and Cosby, B.J. 2004. Past and future chemistry changes in acidified Nova Scotian Atlantic salmon (*Salmo salar*) rivers: a dynamic modeling approach. Canadian Journal of Fisheries and Aquatic Sciences 61:1965-1975.

31. Zho, Y., Duan, L., Xing, J., Larssen, T., Nielsen, C.P. and Halo, J. 2009. Soil acidification in China: is controlling SO_2 emissions enough? Environmental Science and Technology 43:8021-8026.

32. United Nations Environment Programme. 2002. State of the environment and policy retrospective, 1972-2002: atmosphere. *In* Global environment outlook 3: past, present and future perspectives. Edited by Clarke, R., Lamb, R. and Roe Ward, D. Earthscan Publications. London, UK. Chapter 2. pp. 210-239.

14. Climate change

1. Environment Canada. 2010. Canadian environmental sustainability indicators glossary [online]. http://www.ec.gc.ca/indicateurs-indicators/default.asp?lang=En&n=54C113A2-1#glossaryc (accessed 17 April, 2010).

2. Secretariat of the Convention on Biological Diversity. 2006. Global biodiversity outlook 2. Convention on Biological Diversity. Montreal, QC. 81 p.

3. Prowse, T.D., Furgal, C., Wrona, F.J. and Reist, J.D. 2009. Implications of climate change for northern Canada: freshwater, marine, and terrestrial ecosystems. AMBIO: a Journal of the Human Environment 38:282-289.

4. Intergovernmental Panel on Climate Change. 2007. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment. Synthesis Report. Edited by Pachauri, R.K. and Reisinger, A. IPCC Secretariat. Geneva, Switzerland. 104 p.

5. Zhang, X., Brown, R., Vincent, L., Skinner, W., Feng, Y. and Mekis, E. 2010. Canadian climate trends 1950-2007. Canadian Biodiversity: Ecosystem Status and Trends 2010, Technical Thematic Report Series No. 5. Canadian Councils of Resource Ministers. Ottawa, ON. In press.

6. Murphy-Klassen, H.M., Underwood, T.J., Sealy, S.G. and Czyrnyj, A.A. 2005. Long-term trends in spring arrival dates of migrant birds at Delta Marsh, Manitoba, in relation to climate change. Auk 122:1130-1148.

7. Gjerdrum, C., Vallée, A.M.J., St.Clair, C.C., Bertram, D.F., Ryder, J.L. and Blackburn, G.S. 2003. Tufted puffin reproduction reveals ocean climate variability. Proceedings of the National Academy of Sciences of the United States of America 100:9377-9382.

8. Gaston, A.J., Bertram, D.F., Boyne, A.W., Chardine, J.W., Davoren, G., Diamond, A.W., Hedd, A., Montevecchi, W.A., Hipfner, J.M., Lemon, M.J.F., Mallory, M.L., Rail, J.-F. and Robertson, G.J. 2009. Changes in Canadian seabird populations and ecology since 1970 in relation to changes in oceanography and food webs. Environmental Reviews 17:267-286.

9. Hitch, A.T. and Leberg, p.L. 2007. Breeding distributions of North American bird species moving north as a result of climate change. Conservation Biology 21:534-539.

10. Higdon, J.W. and Ferguson, S.H. 2009. Loss of Arctic sea ice causing punctuated change in sightings of killer whales (*Orcinus orca*) over the past century. Ecological Applications 19:1365-1375.

11. Cluff, H.D. 2006. Extension of coyote, *Canis latrans*, breeding range in the Northwest Territories, Canada. Canadian Field-Naturalist 120:67-70.

12. Veitch, A.M. 2001. An unusual record of a white-tailed deer (*Odocoileus virginianus*) in the Northwest Territories. Canadian Field-Naturalist 15:172-175.

13. Slough, B. and Jung, T.S. 2007. Diversity and distribution of the terrestrial mammals of the Yukon Territory: a review. The Canadian Field-Naturalist 121:119-127.

14. Roseberry, J.L. and Woolf, A. 1998. Habitat-population density relationships for white-tailed deer in Illinois. Wildlife Society Bulletin 26:252-258.

15. Ermine, W., Nilson, R., Sauchyn, D., Sauve, E. and Smith, R.Y. 2006. Isi Askiwan – the state of the land: Prince Alberta Grand Council elders' forum on climate change. Prairie Adaptation Research Collaborative, Report No. 05-04. 49 p.

16. Ashford, G. and Castleden, J. 2001. Final report: Inuit observations on climate change. International Institute for Sustainable Development. 27 p.
17. Larivière, S. 2004. Range expansion of raccoons in the Canadian Prairies – review of hypotheses. Wildlife Society Bulletin 32:955-963.
18. Hinzman, L.D., Bettez, N.D., Bolton, W.R., Chapin, F.S., Dyurgerov, M.B., Fastie, C.L., Griffith, B., Hollister, R.D., Hope, A., Huntington, H.P., Jensen, A.M., Jia, G.J., Jorgenson, T., Kane, D.L., Klein, D.R., Kofinas, G., Lynch, A.H., Lloyd, A.H., McGuire, A.D., Nelson, F.E., Oechel, W.C., Osterkamp, T.E., Racine, C.H., Romanovsky, V.E., Stone, R.S., Stow, D.A., Sturm, M., Tweedie, C.E., Vourlitis, G.L., Walker, M.D., Walker, D.A., Webber, P.J., Welker, J.M., Winker, K. and Yoshikawa, K. 2005. Evidence and implications of recent climate change in northern Alaska and other Arctic regions. Climatic Change 72:251-298.
19. Jia, G.S.J., Epstein, H.E. and Walker, D.A. 2009. Vegetation greening in the Canadian Arctic related to decadal warming. Journal of Environmental Monitoring 11:2231-2238.
20. Wang, M.Y. and Overland, J.E. 2004. Detecting Arctic climate change using Köppen climate classification. Climatic Change 67:43-62.
21. Olthof, I. and Pouliot, D. 2010. Treeline vegetation composition and change in Canada's western subarctic from AVHRR and canopy reflectance modeling. Remote Sensing of Environment 114:805-815.
22. Hudson, J.M.G. and Henry, G.H.R. 2009. Increased plant biomass in a High Arctic heath community from 1981 to 2008. Ecology 90:2657-2663.
23. Walker, M.D., Wahren, C.H., Hollister, R.D., Henry, G.H.R., Ahlquist, L.E., Alatalo, J.M., Bret-Harte, M.S., Calef, M.P., Callaghan, T.V., Carroll, A.B., Epstein, H.E., Jónsdóttir, I.S., Klein, J.A., Magnússom, B., Molau, U., Oberbauer, S.F., Rewa, S.P., Robinson, C.H., Shaver, G.R., Suding, K.N., Thompson, C.C., Tolvanen, A., Totland, O., Turner, P.L., Tweedie, C.E., Webber, P.J. and Wookey, P.A. 2006. Plant community responses to experimental warming across the tundra biome. Proceedings of the National Academy of Sciences. National Academy of Sciences. Washington DC. Vol. 103, pp. 1342-1346.

15. Ecosystem services

1. Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being: a framework for assessment. Millennium Ecosystem Assessment Series. Island Press. Washington, DC. 245 p.
2. Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being: synthesis. Millennium Ecosystem Assessment Series. Island Press. Washington, DC. 137 p.
3. Cross, C.L., Lapi, L. and Perry, E.A. 1991. Production of chinook and coho salmon from British Columbia hatcheries, 1971 through 1989. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1816. Fisheries and Oceans Canada. 48 p.
4. Beamish, R.J., Noakes, D.J., McFarlane, G.A., Pinnix, W., Sweeting, R. and King, J. 2000. Trends in coho marine survival in relation to the regime concept. Fisheries Oceanography 9:114-119.
5. Crawford, W.R. and Irvine, J.R. 2009. State of physical, biological and selected fishery resources of Pacific Canadian marine ecosystems. DFO Canadian Science Advisory Secretariat Research Document No. 2009/022. Fisheries and Oceans Canada. vi + 121 p.
6. Sweeting, R.M., Beamish, R.J., Noakes, D.J. and Neville, C.M. 2003. Replacement of wild coho salmon by hatchery-reared coho salmon in the Strait of Georgia over the past three decades. North American Journal of Fisheries Management 23:492-502.
7. Simpson, K., Dobson, D., Semple, R., Lehmann, S., Baillie, S. and Matthews, I. 2001. Status in 2000 of coho stocks adjacent to the Strait of Georgia. Canadian Science Advisory Secretariat Research Document No. 2001/144. Fisheries and Oceans Canada. 91 p.
8. Environment Yukon. 2005. Yukon state of the environment report 2005. Government of Yukon. Whitehorse, YT. 60 p.
9. Ford, J.D., Pearce, T., Gilligan, J., Smit, B. and Oakes, J. 2008. Climate change and hazards associated with ice use in northern Canada. Arctic Antarctic and Alpine Research 40:647-659.
10. Laidler, G.J., Ford, J.D., Gough, W.A., Ikummaq, T., Gagnon, A.S., Kowal, S., Qrunnut, K. and Irngaut, C. 2009. Travelling and hunting in a changing Arctic: assessing Inuit vulnerability to sea ice change in Igloolik, Nunavut. Climatic Change 94:363-397.
11. Berkes, F. and Jolly, D. 2001. Adapting to climate change: social-ecological resilience in a Canadian western Arctic community. Ecology and Society 5.
12. Pearce, T., Smit, B., Duerden, F., Ford, J.D., Goose, A. and Kataoyak, F. 2010. Inuit vulnerability and adaptive capacity to climate change in Ulukhaktok, Northwest Territories, Canada. Polar Record 46:157-177.
13. Hertlein, L. 1999. Lake Winnipeg regulation Churchill-Nelson river diversion project in the Crees of northern Manitoba, Canada. World Commission on Dams. Cape Town, South Africa. 28 p.
14. Harvey, W.F. and Rodrigue, J. 2009. A breeding pair survey of Canada geese in northern Quebec – 2009. Maryland Department of Natural Resources and Canadian Wildlife Service. 12 p.
15. Peloquin, C. and Berkes, F. 2009. Local knowledge, subsistence harvests, and social-ecological complexity in James Bay. Human Ecology 37:533-545.
16. Peloquin, C. 2007. Variability, change and continuity in social-ecological systems: insights from James Bay Cree cultural ecology. Thesis (Master of Natural Resource Management). Natural Resources Institute, University of Manitoba. Winnipeg, MB. 155 p.
17. European Commission. 2008. The economics of ecosystems and biodiversity: an interim report. European Communities. Wesseling, Germany.
18. Anielski, M. and Wilson, S. 2005. Counting Canada's natural capital: assessing the real value of Canada's boreal ecosystems. The Pembina Institute and the Canadian Boreal Initiative. Drayton Valley, AB. 78 p.
19. Gordon, B.C. 2005. 8,000 years of caribou and human seasonal migration in the Canadian barrenlands. Rangifer Special Issue No. 16:155-162.
20. InterGroup Consultants Ltd. 2008. Economic valuation and socio-cultural perspectives of the estimated harvest of the Beverly and Qamanirjuaq caribou herds, submitted to the Beverly and Qamanirjuaq Caribou Management Board. 28 p.
21. Beverly and Qamanirjuaq Caribou Management Board. 2009. 27th Annual report 2008-2009. Beverly and Qamanirjuaq Caribou Management Board. Stonewall, MB. 66 p.
22. Wakelyn, L. 13 April, 2010. Beverly and Quamanirjuaq Caribou Management Board. Personal communication.
23. Wilson, S.J. 2008. Ontario's wealth, Canada's future: appreciating the value of the greenbelt's eco-services. Consultant report on behalf of Friends of the Greenbelt Foundation and David Suzuki Foundation. David Suzuki Foundation. Vancouver, BC. 70 p.
24. Friends of the Greenbelt Foundation. 2009. Ontario's greenbelt. As the Crow Flies cARTography. Map.

HABITAT, WILDLIFE, AND ECOSYSTEM PROCESSES

16. Agricultural landscapes as habitat

1. Statistics Canada. 2008. 2006 census of agriculture [online]. Government of Canada. http://www.statcan.gc.ca/ca-ra2006/index-eng.htm (accessed 8 August, 2010).
2. Huffman, T., Ogston, R., Fisette, T., Daneshfar, B., Gasser, P.Y., White, L., Maloley, M. and Chenier, R. 2006. Canadian agricultural land-use and land management data for Kyoto reporting. Canadian Journal of Soil Science 86:431-439.
3. Javorek, S.K. and Grant, M.C. 2010. Trends in wildlife habitat capacity on agricultural land in Canada, 1986-2006. Canadian Biodiversity: Ecosystem Status and Trends 2010, Technical Thematic Report Series No. 14. Canadian Councils of Resource Ministers. Ottawa, ON. In press.
4. COSEWIC. 2004. Canadian species at risk, November 2004. Committee on the Status of Endangered Wildlife in Canada. Ottawa, ON. 49 p.
5. Watmough, M.D. and Schmoll, M.J. 2007. Environment Canada's Prairie and Northern Region habitat monitoring program phase II: recent habitat trends in the Prairie Habitat Joint Venture. Technical Report Series No. 493. Environment Canada, Canadian Wildlife Service. Edmonton, AB. 135 p.
6. U.S. Fish and Wildlife Service. 2007. Waterfowl breeding population and habitat survey [online]. Division of Migratory Birds Management, U.S. Department of the Interior. http://migbirdapps.fws.gov/ (accessed 20 July, 2010).
7. Drever, M.C., Nudds, T.D. and Clark, R.G. 2007. Agricultural policy and nest success of prairie ducks in Canada and the United States. Avian Conservation and Ecology 2:5-21.
8. Emery, R.B., Howerter, D.W., Armstrong, L.M., Anderson, M.G., Devries, J.H. and Joynt, B.L. 2005. Seasonal variation in waterfowl nesting success and its relation to cover management in the Canadian prairies. Journal of Wildlife Management 69:1181-1193.
9. Podruzny, K.M., Devries, J.H., Armstrong, L.M. and Rotella, J.J. 2002. Long-term response of northern pintails to changes in wetlands and agriculture in the Canadian prairie pothole region. Journal of Wildlife Management 66:993-1010.
10. North American Waterfowl Management Plan. 2010. Canadian NAWMP National Tracking System. Environment Canada. Ottawa, ON.
11. Statistics Canada. 2010. CANSIM Table 001-0017: estimated areas, yield, production, average farm price and total farm value of principal field crops, in imperial units, annual. Seeded winter wheat for prairie provinces [online]. Statistics Canada. http://cansim2.statcan.ca/cgi-win/CNSMCGI.EXE?regtkt=&C2Sub=&ARRAYID=10017&C2DB=PRD&VEC=&LANG=E&SDDSLOC=//www.statcan.ca/english/sdds/*.htm&ROOTDIR=CII/&RESULTTEMPLATE=CII/CII_PICK&ARRAY_PICK=1&SDDSID=&SDDSDESC#TFtn (accessed 8 July, 2010).
12. Prairie Habitat Joint Venture. 2006. Percent of total hectares seeded using zero-till in Saskatchewan, PHJV database (accessed May 2010). Prairie Habitat Joint Venture. Edmonton, AB.

17. Species of special interest: economic, cultural, or ecological

1. Canadian Endangered Species Conservation Council (CESCC). Wild species 2010: the general status of species in Canada. National General Status Working Group. In press.
2. COSEWIC. 2010. COSEWIC Committee on the Status of Endangered Wildlife in Canada [online]. Government of Canada. http://www.cosewic.gc.ca (accessed 7 July, 2010).
3. Government of Canada. 2010. Species at Risk Public Registry [online]. Government of Canada. http://www.sararegistry.gc.ca/default_e.cfm (accessed 7 July, 2010).

Amphibians

1. Archer, R., Wheeler, H. and Sass, D.J. 2009. Coastal wetland amphibian communities, indicator # 4504. *In* State of the Great Lakes 2009. Environment Canada and U.S. Environmental Protection Agency. pp. 210-215.
2. DesGranges, J.-L. 2002. Biodiversity portrait of the St. Lawrence [online]. Environment Canada. http://www.qc.ec.gc.ca/faune/biodiv/en/table_contents.html (accessed 7 July, 2010).
3. Matsuda, B., Green, D.M. and Gregory, P.T. 2006. Amphibians and reptiles of British Columbia. Royal British Columbia Museum (RBCM) Handbook. Victoria, B.C. 266 p.
4. Daszak, P., Cunningham, A.A. and Hyatt, A.D. 2003. Infectious disease and amphibian population declines. Diversity and Distributions 9:141-150.
5. Chinchar, V.G. 2002. Ranaviruses (family Iridoviridae): emerging cold-blooded killers – brief review. Archives of Virology 147:447-470.
6. Duffus, A.L.J., Pauli, B.D., Wozney, K., Brunetti, C.R. and Berrill, M. 2008. Frog virus 3-like infections in aquatic amphibian communities. Journal of Wildlife Diseases 44:109-120.
7. Schock, D.M., Bollinger, T.K., Chinchar, V.G., Jankovich, J.K. and Collins, J.P. 2008. Experimental evidence that amphibian ranaviruses are multi-host pathogens. Copeia 2008:131-141.
8. Environment Canada and U.S. Environmental Protection Agency. 2009. State of the Great Lakes 2009. 432 p.
9. Stuart, S.N., Chanson, J.S., Cox, N.A., Young, B.E., Rodrigues, A.S.L., Fischman, D.L. and Waller, R.W. 2004. Status and trends of amphibian declines and extinctions worldwide. Science 306:1783-1786.

Fishes using freshwater habitat

1. Nelson, J.S. 2006. Fishes of the world, 4th ed. Edited by Hoboken, J.J. John Wiley and Sons. 624 p.
2. Canadian Endangered Species Conservation Council (CESCC). 2006. Wild species 2005: the general status of species in Canada [online]. Government of Canada. http://www.wildspecies.ca/wildspecies2005/index.cfm?lang=e (accessed 1 May, 2009).
3. Jelks, H.L., Walsh, J., Burkhead, N.M., Contreras-Balderas, S., Díaz-Pardo, E., Hendrickson, D.A., Lyons, J., Mandrak, N.E., McCormick, F., Nelson, J.S., Platania, S.P., Porter, B.A., Renaud, C.B., Schmitter-Soto, J.J., Taylor, E.B. and Warren Jr, M.L. 2008. Conservation status of imperiled North American freshwater and diadromous fishes. Fisheries 33:372-407.

4. Monk, W.A., Baird, D.J., Curry, R.A., Glozier, N. and Peters, D.L. 2010. Ecosystem status and trends report: biodiversity in Canadian lakes and rivers. Canadian Biodiversity: Ecosystem Status and Trends 2010, Technical Thematic Report Series No. 20. Canadian Councils of Resource Ministers. Ottawa, ON. In press.
5. FAO Fisheries and Aquaculture Department. 2009. The state of world fisheries and aquaculture 2008. Food and Agriculture Organization of the United Nations. Rome. 176 p.
6. Department of Fisheries and Oceans. 2009. Commercial fisheries: landings: freshwater [online]. Fisheries and Oceans Canada. http://www.dfo-mpo.gc.ca/stats/commercial/land-debarq/freshwater-eaudouce/2006-eng.htm (accessed 16 August, 2010).
7. Hutchings, J.A. and Festa-Bianchet, M. 2009. Canadian species at risk (2006-2008), with particular emphasis on fishes. Environmental Reviews 17:53-63.
8. Hutchings, J.A. 2010. Collation of freshwater and diadromous fish species assessed from April 1980 to April 2010 by COSEWIC.
9. COSEWIC. 2010. COSEWIC wildlife species assessments [online]. Committee on the Status of Endangered Wildlife in Canada. http://www.cosewic.gc.ca/eng/sct0/index_e.cfm (accessed 7 September, 2010).
10. Dextrase, A.J. and Mandrak, N.E. 2006. Impacts of alien invasive species on freshwater fauna at risk in Canada. Biological Invasions 8:13-24.
11. Lévesque, L.M. and Dubé, M.G. 2007. Review of the effects of in-stream pipeline crossing construction on aquatic ecosystems and examination of Canadian methodologies for impact assessment. Environmental Monitoring and Assessment 132:395-409.
12. Reid, S.M., Mandrak, N.E., Carl, L.M. and Wilson, C.C. 2008. Influence of dams and habitat condition on the distribution of redhorse (*Moxostoma*) species in the Grand River watershed, Ontario. Environmental Biology of Fishes 81:111-125.
13. Committee on the Status of Endangered Wildlife in Canada. 2009. Wildlife species search: sturgeon [online]. Environment Canada, Canadian Wildlife Service. http://www.cosewic.gc.ca/eng/sct1/SearchResult_e.cfm?commonName=Sturgeon (accessed 16 August, 2010).
14. Welch, D.W., Turo, S. and Batten, S.D. 2006. Large-scale marine and freshwater movements of white sturgeon. Transactions of the American Fisheries Society 135:386-389.
15. COSEWIC. 2003. COSEWIC Assessment and update status report on the white sturgeon *Acipenser transmontanus* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa, ON. 51 p.
16. McAdam, S.O., Walters, C.J. and Nistor, C. 2005. Linkages between white sturgeon recruitment and altered bed substrates in the Nechako River, Canada. Transactions of the American Fisheries Society 134:1448-1456.
17. Species Survival Commission. 2009. Freshwater fish facts. IUCN red list of threatened species, 2009 update. IUCN. 3 p.
18. Department of Fisheries and Oceans. 2009. Pacific salmon [online]. Fisheries and Oceans Canada. http://www.dfo-mpo.gc.ca/decisions/fm-2009-gp/pac-salmon-saumon-eng.htm (accessed 23 August, 2010).
19. Hurlburt, D. 2008. Synthesis of Aboriginal Traditional Knowledge (prepared for the Ecosystem Status and Trends Report Secretariat). 170 p. Unpublished report.
20. Fisheries and Oceans Canada. 2009. The wild Atlantic salmon conservation policy – a snapshot. Canada's policy for conservation of wild Atlantic salmon [online]. http://www.dfo-mpo.gc.ca/fm-gp/policies-politiques/wasp-pss/wasp-psas-2009-eng.htm#toc-was-what (accessed 8 July, 2010).
21. Wolfe, B.B., Karst-Riddoch, T.L., Vardy, S.R., Falcone, M.D., Hall, R.I. and Edwards, T.W.D. 2005. Impacts of climate and river flooding on the hydro-ecology of a floodplain basin, Peace-Athabasca Delta, Canada since A.D. 1700. Quaternary Research 64:147-162.
22. Lapointe, M. 2010. Overview of the Fraser sockeye situation. Appendix C. *In* Synthesis of evidence from a workshop on the decline of Fraser River Sockeye June 15-17, 2010. A report to the Pacific Salmon Commission, Vancouver, B.C. Edited by Peterman, R.M., Marmorek, D., Beckman, B., Bradford, M., Mantua, N., Riddell, B.E., Scheuerell, M., Staley, M., Wieckowiski, K., Windon, J.R. and Wood, C.C. Pacific Salmon Commission. 35 p. + appendices.
23. DFO. 2010. Pre-season run size forecasts for Fraser River sockeye salmon in 2010. DFO Canadian Science Advisory Secretariat Advisory Report 2010/031. 11 p.
24. Peterman, R.M., Marmorek, D., Beckman, B., Bradford, M., Mantua, N., Riddell, B.E., Scheuerell, M., Staley, M., Wieckowiski, K., Windon, J.R. and Wood, C.C. 2010. Synthesis of evidence from a workshop on the decline of Fraser River sockeye, June 15-17, 2010. A report to the Pacific Salmon Commission, Vancouver, B.C. 123 p. + appendices.
25. Department of Fisheries and Oceans. 2010. Management of Fraser River Sockeye Fisheries [online]. Department of Fisheries and Oceans. http://www.dfo-mpo.gc.ca/media/back-fiche/2010/hq-ac35a-eng.htm (accessed 19 August, 2010).
26. Patterson, D.A., Macdonald, J.S., Skibo, K.M., Barnes, D., Guthrie, I. and Hills, J.A. 2007. Reconstructing the summer thermal history of the lower Fraser River, 1941 to 2006, and implications for adult sockeye salmon (*Oncorhynchus nerka*) spawning. Canadian Technical Report of Fisheries and Aquatic Sciences No. 2724. 43 p.
27. Rand, P.S., Hinch, S.G., Morrison, J., Foreman, M.G.G., MacNutt, M.J., Macdonald, J.S., Healey, M.C., Farrell, A.P. and Higgs, D.A. 2006. Effects of river discharge, temperature, and future climates on energetics and mortality of adult migrating Fraser River sockeye salmon. Transactions of the American Fisheries Society 135:655-667.
28. Fraser River Environmental Watch data provided by J. Morrison. 2010. Fraser River mean summer temperature, update to Patterson *et al.,* 2007. Unpublished data.
29. Morrison, J., Quick, M.C. and Foreman, M.G.G. 2002. Climate change in the Fraser River watershed: flow and temperature projections. Journal of Hydrology 263:230-244.
30. Gibson, J., Hubley, B., Chaput, G., Dempson, J.B., Caron, F. and Amiro, P. 2006. Summary of status and abundance trends for eastern Canadian Atlantic salmon (*Salmo salar*) populations. Canadian Science Advisory Secretariat Research Document No. 2006/026. Canadian Science Advisory Secretariat. 31 p.
31. Nova Scotia Salmon Federation. 2009. Nova Scotia salmon federation news and issues: acid rain [online]. http://www.novascotiasalmon.ns.ca/newsandissues/acidrain.htm (accessed 1 March, 2009).
32. Watt, W., Scott, C.D., Zamora, P.J. and White, W.J. 2000. Acid toxicity levels in Nova Scotian rivers have not declined in synchrony with the decline in sulfate levels. Water, Air and Soil Pollution 118:203-229.
33. Miramichi River Environmental Assessment Committee and Atlantic Coastal Action Program. 2007. Statement of the environment report for the Miramichi watershed 2007. Environment Canada. 134 p.
34. Ontario Ministry of Natural Resources. 2010. State of resources reporting, American eel in Ontario, February 2007 report and 2010 update. Government of Ontario. Peterborough, ON. 6 p.
35. COSEWIC. 2006. COSEWIC assessment and status report on the American eel *Anguilla rostrata* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa, ON. 71 p.

36. de Lafontaine, Y., Gingras, F., Labonte, D., Marchand, F., La Croix, E. and Lagace, M. 2009. Decline of the American eel in the St. Lawrence River: effects of local hydroclimatic conditions on CPUE Indices. American Fisheries Society Symposium No. 58. Edited by Casselman, J. and Cairns, D.K. 228 p.
37. Environment Canada and U.S. Environmental Protection Agency. 2009. State of the Great Lakes 2009. 432 p.
38. McCullough, R. and Stegemann, E.C. 2010. Common prey fish of New York [online]. New York Department of Environmental Conservation. http://www.dec.ny.gov/animals/7031.html (accessed 24 August, 2010).
39. Shipley, E. and Kling, H. 2010. Unpublished analysis in: Lake Winnipeg and its watershed, a report prepared for Canadian biodiversity: ecosystem status and trends 2010. Manitoba Water Stewardship. Unpublished report.
40. Johnston, T.A., Lysack, W. and Leggett, W.C. 2010. Abundance, growth, and life history characteristics of sympatric walleye (*Sander vitreus*) and sauger (*Sander canadensis*) in Lake Winnipeg, Manitoba. Journal of Great Lakes Research In Press, Corrected Proof. doi:10.1016/j.jglr.2010.06.009.
41. Ontario Ministry of Natural Resources. 2009. Great Lakes fishery data. Unpublished data.
42. Baldwin, N.S., Saalfeld R.W., Dochoda, M.R., Buettner, H.J. and Eshenroder, R.L. 2009. Commercial fish production in the Great Lakes 1867-2006 [online]. Great Lakes Fishery Commission. http://www.glfc.org/databases/commercial/commerc.php (accessed 24 August, 2010).
43. Jude, D.J. and Leach, J. 1999. The Great Lakes fisheries, 2nd edition. *In* Inland fisheries management in North America. Edited by Kohler, C.C. and W.A.Hubert. American Fisheries Society. Bethesda, Maryland. pp. 623-656.
44. Orok, R. and Johnson, N. 2005. Survey of recreational fishing in Canada [online]. Department of Fisheries and Oceans Canada. http://www.dfo-mpo.gc.ca/stats/rec/can/2005/index-eng.htm (accessed 10 August, 2010).
45. Hofmann, N. 2008. Gone fishing: a profile of recreational fishing in Canada. EnviroStats 2:7-13.

Birds

1. BirdLife International. 2010. State of the world's birds. [online]. BirdLife International. http://www.biodiversityinfo.org (accessed 28 April, 2010).
2. Butcher, G.S. and Niven, D.K. 2007. Combining data from the Christmas Bird Count and the Breeding Bird Survey to determine the continental status and trends of North America birds. National Audubon Society. Ivyland, PA. 34 p.
3. Niven, D.K., Butcher, G.S., Bancroft, G.T., Monahan, W.B. and Langham, G. 2009. Birds and climate change: ecological disruption in motion. National Audubon Society. New York, NY. 15 p.
4. Hitch, A.T. and Leberg, P.L. 2007. Breeding distributions of North American bird species moving north as a result of climate change. Conservation Biology 21:534-539.
5. Donaldson, G., Hyslop, C., Morrison, R.I.G., Dickson, D.L. and Davidson, I. 2000. Canadian shorebird conservation plan. Canadian Wildlife Service, Environment Canada. Ottawa, ON. 28 p.
6. Western Hemisphere Shorebird Reserve Network (WHSRN). 2009. WHSRN list of sites [online]. Manomet Center for Conservation Sciences. http://www.whsrn.org/sites/list-sites (accessed 30 July, 2010).
7. Gratto-Trevor, C., Morrison, R., Collins, B., Rausch, J. and Johnston, V. 2010. Trends in Canadian shorebirds. Canadian Biodiversity: Ecosystem Status and Trends 2010, Technical Thematic Report Series No. 13. Canadian Councils of Resource Ministers. Ottawa, ON. In press.
8. Morrison, R.I.G. 2001. Shorebird population trends and issues in Canada – an overview. Bird Trends Newsletter # 8: Shorebirds 1-5.
9. Morrison, R.I.G., McCaffery, B.J., Gill, R.E., Skagen, S.K., Jones, S.L., Page, G.W., Gratto-Trevor, C.L. and Andres, B.A. 2006. Population estimates of North American shorebirds, 2006. Wader Study Group Bulletin 111:67-85.
10. Sauer, J.R., Hines, J.E. and Fallon, J. 2008. The North American Breeding Bird Survey, results and analysis 1966 - 2007 [online]. U.S. Geological Survey Patuxent Wildlife Research Center. http://www.mbr-pwrc.usgs.gov/bbs/ (accessed 20 October, 2009).
11. Morrison, R.I.G. and Collins, B.T. 2010. Atlantic Canada Shorebird Survey data. Unpublished data.
12. Morrison, R.I.G., Downes, C. and Collins, B. 1994. Population trends of shorebirds on fall migration in eastern Canada 1974-1991. Wilson Bulletin 106:431-447.
13. Ydenberg, R., Butler, R.W., Lank, D.B., Smith, B.D. and Ireland, J. 2004. Western sandpipers have altered migration tactics as peregrine falcon populations have recovered. Proceedings of the Royal Society B: Biological Sciences 271:1263-1269. doi:10.1098/rspb.2004.2713.
14. Bart, J., Brown, S., Harrington, B. and Morrison, R.I.G. 2007. Survey trends of North American shorebirds: population declines or shifting distributions? Journal of Avian Biology 38:73-82.
15. Gaston, A.J., Bertram, D.F., Boyne, A.W., Chardine, J.W., Davoren, G., Diamond, A.W., Hedd, A., Montevecchi, W.A., Hipfner, J.M., Lemon, M.J.F., Mallory, M.L., Rail, J.-F. and Robertson, G.J. 2009. Changes in Canadian seabird populations and ecology since 1970 in relation to changes in oceanography and food webs. Environmental Reviews 17:267-286.
16. Coe, J.M. and Rogers, D.B. 1997. Marine debris: sources, impacts and solutions. Springer Publishers. New York, NY. 432 p.
17. 2001. Seabird bycatch: trends, roadblocks and solutions. Edited by Melvin, E.F. and Parrish, J.K. University of Alaska Sea Grant, AK-SG-01-01. Fairbanks, AK. 206 p.
18. Schreiber, E.A. and Burger, J. 2002. Biology of marine birds. CRC Press. New York, NY. 722 p.
19. Stenseth, N.C., Ottersen, G., Hurrell, J.W. and Belgrano, A. 2004. Marine ecosystem and climate variation. Oxford University Press. Oxford, UK. 264 p.
20. ACIA. 2005. Arctic climate impact assessment. Cambridge University Press. New York, NY. 1042 p.
21. Bertram, D.F., Mackas, D.L. and McKinnell, S.M. 2001. The seasonal cycle revisited: interannual variation and ecosystem consequences. Progress in Oceanography 49:283-307.
22. Gjerdrum, C., Vallée, A.M.J., St.Clair, C.C., Bertram, D.F., Ryder, J.L. and Blackburn, G.S. 2003. Tufted puffin reproduction reveals ocean climate variability. Proceedings of the National Academy of Sciences of the United States of America 100:9377-9382.
23. Hipfner, J.M. and Greenwood, J.L. 2008. Breeding biology of the common murre at Triangle Island, British Columbia, 2002-2007. Northwestern Naturalist 89:76-84.
24. Parsons, M., Mitchell, I., Butler, A., Ratchliffe, N., Frederiksen, M., Foster, S. and Reid, J.B. 2008. Seabirds as indicators of the marine environment. ICES Journal of Marine Science 65:1520-1526.
25. Hipfner, J.M. 2008. Matches and mismatches: ocean climate, prey phenology and breeding success in a zooplanktivorous seabird. Marine Ecology Progress Series 368:295-304.
26. Hutchings, J.A. and Myers, R.A. 1994. What can be learned from the collapse of a renewable resource – Atlantic cod, *Gadus morhua*, of Newfoundland and Labrador. Canadian Journal of Fisheries and Aquatic Sciences 51:2126-2146.
27. Montevecchi, W.A. and Myers, R.A. 1996. Dietary changes of seabirds indicate shifts in pelagic food webs. Sarsia 80:313-322.

28. Mann, K.H. and Drinkwater, K.F. 1994. Environmental influences on fish and shellfish production in the Northwest Atlantic. Environmental Reviews 2:16-32.

29. Carscadden, J.E., Montevecchi, W.A., Davoren, G.K. and Nakashima, B.S. 2002. Trophic relationships among capelin (*Mallotus villosus*) and seabirds in a changing ecosystem. ICES Journal of Marine Science 59:1027-1033.

30. Benjamins, S., Kulka, D.W. and Lawson, J. 2008. Incidental catch of seabirds in Newfoundland and Labrador gillnet fisheries, 2001-2003. Endangered Species Research 5:149-160.

31. Gaston, A.J. 2002. Results of monitoring thick-billed murre populations in the eastern Canadian Arctic, 1976-2000. Occasional Paper No. 106. Canadian Wildlife Service, Environment Canada. Ottawa, ON. 50 p.

32. Gaston, A.J., Woo, K. and Hipfner, J.M. 2003. Trends in forage fish populations in northern Hudson Bay since 1981, as determined from the diet of nestling thick-billed murres *Uria lomvia*. Arctic 56:227-233.

33. Gaston, A.J., Gilchrist, H.G. and Hipfner, J.M. 2005. Climate change, ice conditions and reproduction in an Arctic nesting marine bird: Brunnich's guillemot *(Uria lomvia L.)*. Journal of Animal Ecology 74:832-841.

34. Gaston, A.J., Glichrist, H.G., Mallory, M.L. and Smith, P.A. 2009. Changes in seasonal events, peak food availability and consequent breeding adjustment in a marine bird: a case of progressive mis-matching. The Condor 111:111-119.

35. Downes, C., Blancher, P. and Collins, B. 2010. Landbird trends in Canada, 1968-2006. Canadian Biodiversity: Ecosystem Status and Trends 2010, Technical Thematic Report Series No. 12. Canadian Councils of Resource Ministers. Ottawa, ON. In press.

36. Canadian Wildlife Service. 2007. Breeding Bird Survey in Canada [online]. Environment Canada. http://www.cws-scf.ec.gc.ca/nwrc-cnrf/Default.asp?lang=En&n=416B57CA (accessed 20 October, 2009).

37. North American Bird Conservation Initiative, U.S. Committee (NABCI-US). 2009. The state of the birds, United States of America, 2009. U.S. Department of Interior. Washington, DC. 36 p.

38. Blancher, P. 2003. Importance of Canada's boreal forest to landbirds. Canadian Boreal Inititative and Boreal Songbird Initiative. Ottawa, ON and Seattle, WA. 43 p.

39. Blancher, P.J., Phoenix, R.D., Badzinski, D.S., Cadman, M.D., Crewe, T.L., Downes, C.M., Fillman, D., Francis, C.M., Hughes, J., Hussell, D.J.T., Lepage, D., McCracken, J.D., McNicol, D.K., Pond, B.A., Ross, R.K., Russells, R., Venier, L.A. and Weeber, R.C. 2009. Population trend status of Ontario's forest birds. Forestry Chronicle 85:184-201.

40. Nebel, S., Mills, A.M., McCracken, J.D. and Taylor, P.D. Declines of aerial insectivores in North America follow a geographic gradient. Submitted for publication.

41. Robbins, C.S., Droege, S. and Sauer, J.R. 1989. Monitoring bird populations with Breeding Bird Survey and atlas data. Annales Zoologici Fennici 26:297-304.

42. Terborgh, J. 1989. Where have all the birds gone? Essay on the biology and conservation of birds that migrate to the American tropics. Princeton University Press. Princeton, NJ. 224 p.

43. Canadian Wildlife Services Waterfowl Committee. 2009. Population status of migratory game birds in Canada (and regulation proposals for overabundant species). CWS Migratory Birds Regulatory Report No. 28. Environment Canada. Ottawa, ON. 95 p.

44. Fast, M., Collins, B. and Gendron, M. 2010. Trends in breeding waterfowl in Canada. Canadian Biodiversity: Ecosystem Status and Trends 2010, Technical Thematic Report Series No. 8. Canadian Councils of Resource Ministers. Ottawa, ON. In preparation.

45. De Vink, J.M.A., Clark, R.G., Slattery, S.M. and Trauger, D.L. 2008. Are late-spring boreal lesser scaup (*Aythya affinis*) in poor body condition? Auk 125:297-298.

46. Austin, J.E., Afton, A.D., Anderson, M.G., Clark, R.G., Custer, C.M., Lawrence, J.S., Pollard, J.B. and Ringelman, J.K. 2000. Declining scaup populations: issues, hypotheses, and research needs. Wildlife Society Bulletin 28:254-263.

47. North American Waterfowl Management Plan. 2004. Strengthening the biological foundation: 2004 implementation framework. United States Fish and Wildlife Service, Canadian Wildlife Service and Secretaria de Medio Ambiente y Recursos Naturales. 106 p.

48. BDJV. 2010. Black Duck Joint Venture 2009 annual report. North American Waterfowl Management Plan. 13 p. Unpublished.

49. Lepage, C. and Bordage, D. 2003. The American black duck. Environment Canada, Canadian Wildlife Service, Quebec Region. Quebec, QC.

50. OEHJV. 2007. Ontario Eastern Habitat Joint Venture five-year implementation plan 2006-2010. Ontario Eastern Habitat Joint Venture. Ottawa, ON. 94 p.

51. Petrie, M.J., Drobney, R.D. and Sears, D.T. 2000. Mallard and black duck breeding parameters in New Brunswick: a test of the reproductive rate hypothesis. Journal of Wildlife Management 64:832-838.

52. Zimmerling, J.R. 2007. Mallard. *In* Atlas of the breeding birds of Ontario, 2001-2005. Edited by Cadman, M.D., Sutherland, D.A., Beck, G.G., Lepage, D. and Couturier, A.R. Bird Studies Canada, Environment Canada, Ontario Field Ornithologists, Ontario Ministry of Natural Resources and Ontario Nature. Toronto, ON. pp. 78-79.

53. Longcore, J.R., Mcauley, D.G., Hepp, G.R. and Rhymer, J.M. 2000. The birds of North America online: American black duck (*Anas rubripes*) [online]. Cornell Lab of Ornithology. http://bna.birds.cornell.edu/bna/species/481/articles/introduction (accessed 30 July, 2010).

54. Canadian Wildlife Service Waterfowl Committee. 2008. Population status of migratory game birds in Canada: November 2008. CWS Migratory Birds Regulatory Report No. 25. Environment Canada. Ottawa, ON. 92 p.

55. Raven, G.H. and Dickson, D.L. 2006. Changes in distribution and abundance of birds on western Victoria Island from 1992-1994 to 2004-2005. Technical Report Series No. 456. Canadian Wildlife Service, Environment Canada, Prairie and Northern Region. Edmonton, AB. 60 p.

56. Gratto-Trevor, C.L., Johnston, V.H. and Pepper, S.T. 1998. Changes in shorebird and eider abundance in the Rasmussen Lowlands, NT. Wilson Bulletin 110:316-325.

57. Suydam, R.S., Dickson, D.L., Fadely, J.B. and Quakenbush, L.T. 2000. Population declines of king and common eiders of the Beaufort Sea. The Condor 102:219-222.

58. Dickson, D.L., Cotter, R., Hines, J.E. and Kay, M.F. 2010. Distribution and abundance of king eiders *Somateria spectabilis* in the Western Canadian Arctic. Canadian Wildlife Service Occassional Paper No. 94. Edited by Dickson, D.L. Environment Canada, Canadian Wildlife Service. Ottawa, ON. 39 p.

Caribou

1. Gordon, B.C. 2005. 8,000 years of caribou and human seasonal migration in the Canadian barrenlands. Rangifer Special Issue No. 16:155-162.

2. Gunn, A. and Russell, D. 2010. Northern caribou population trends in Canada. Canadian Biodiversity: Ecosystem Status and Trends 2010, Technical Thematic Report Series No. 10. Canadian Councils of Resource Ministers. Ottawa, ON. In press.

3. Beverly and Qamanirjuaq Caribou Management Board. 2009. 27th annual report 2008-2009. Beverly and Qamanirjuaq Caribou Management Board. Stonewall, MB. 66 p.

4. Northwest Territories Environment and Natural Resources. 2009. Bathurst caribou herd [online]. http://www.enr.gov.nt.ca/_live/pages/wpPages/Bathurst_Caribou_Herd.aspx (accessed 18 August, 2010).
5. COSEWIC. 2004. COSEWIC Assessment and update status report on the Peary caribou *Rangifer tarandus pearyi* and the barren-ground caribou *Rangifer tarandus groenlandicus* (Dolphin and Union population) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa, ON. 91 p.
6. Miller, F.L. and Gunn, A. 2003. Catastrophic die-off of Peary Caribou on the Western Queen Elizabeth Islands, Canadian High Arctic. Arctic 56:381-390.
7. Gunn, A., Miller, F.L., Barry, S.J. and Buchan, A. 2006. A near-total decline in caribou on Prince of Wales, Somerset, and Russell Islands, Canadian Arctic. Arctic 59:1-13.
8. Rennert, K.J., Roe, G., Putkonen, J. and Bitz, C.M. 2009. Soil thermal and ecological impacts of rain on snow events in the circumpolar Arctic. Journal of Climate 22:2302-2315.
9. Rinke, A. and Dethloff, K. 2008. Simulated circum-Arctic climate changes by the end of the 21st century. Global and Planetary Change 62:173-186.
10. CARMA. 2009. Caribou herd information, CircumArctic Rangifer Monitoring and Assessment Network [online]. http://carmanetwork.com/display/public/Herds (accessed 24 June, 2010).
11. Krezek-Hanes, C.C., Cantin, A. and Flannigan, M.D. 2010. Trends in large fires in Canada, 1959 to 2007. Canadian Biodiversity: Ecosystem Status and Trends 2010, Technical Thematic Report Series No. 6. Canadian Councils of Resource Ministers. Ottawa, ON. In press.
12. Wolfe, S.A., B.Griffith and C.A.G.Wolfe. 2000. Response of reindeer and caribou to human activities. Polar Research 19:63-73.
13. Johnson, C.J., Boyce, M.S., Case, R.L., Cluff, H.D., Gau, R.J., Gunn, A. and Mulders, R. 2005. Cumulative effects of human developments on arctic wildlife. Wildlife Monographs 1-36.
14. Cameron, R.D., Smith, W.T., White, R.G. and Griffith, B. 2005. Central Arctic caribou and petroleum development: distributional, nutritional, and reproductive implications. Arctic 58:1-9.
15. Magoun, A.J., Abraham, K.F., Thompson, J.E., Ray, J.C., Gauthier, M.E., Brown, G.S., Woolmer, G., Chenier, C.J. and Dawson, F.N. 2005. Distribution and relative abundance of caribou in the Hudson Plains Ecozone of Ontario. Rangifer 16:105-121.
16. Elliott, C. 1998. Cape Churchill caribou: status of herd and harvest 1997/98. Manuscript Report No. 98-05. Manitoba Natural Resources.
17. Environment Canada. 2008. Scientific review for the identification of critical habitat for woodland caribou (*Rangifer tarandus caribou*), boreal population, in Canada. Environment Canada. Ottawa, ON. 72 p.
18. Thomas, D.C. and Gray, D.R. 2002. Update COSEWIC status report on the woodland caribou *Rangifer tarandus caribou* in Canada. *In* COSEWIC assessment and update status report on the woodland *caribou Rangifer tarandus* caribou in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa, ON. 98 p.
19. Northern Mountain Caribou Management Planning Team. 2010. Management plan for the northern mountain population of woodland caribou (*Rangifer tarandus caribou)* in Canada [draft]. *Species at Risk Act* Management Plan Series. Environment Canada. Ottawa, ON. 74 p.
20. Schaefer, J.A. 2003. Long-term range recession and the persistence of caribou in the taiga. Conservation Biology 17:1435-1439.
21. Bergerud, A.T. and Mercer, W.E. 1989. Caribou introductions in eastern North America. Wildlife Society Bulletin 17:111-120.
22. B.C. Mountain Caribou Science Team. 2005. Mountain caribou in British Columbia: A situation analysis. 9 p.
23. James, A.R.C. and Stuart-Smith, A.K. 2000. Distribution of caribou and wolves in relation to linear corridors. Journal of Wildlife Management 64:154-159.
24. Seip, D.R. 1992. Factors limiting woodland caribou populations and their interrelationships with wolves and moose in southeastern British Columbia. Canadian Journal of Zoology 70:1494-1503.
25. McLoughlin, P.D., Dzus, E., Wynes, B. and Boutin, S. 2003. Declines in populations of woodland caribou. Journal of Wildlife Management 67:755-761.
26. Racey, G.D. 2005. Climate change and woodland caribou in northwestern Ontario: a risk analysis. Rangifer 123-136.
27. Callaghan, C., Virc, S. and Duffe, J. 2010. Woodland caribou, boreal population, trends in Canada. Canadian Biodiversity: Ecosystem Status and Trends Report 2010, Technical Thematic Series No. 11. Canadian Councils of Resource Ministers. Ottawa, ON. In press.
28. Henttonen, H and Tikhonov, A. 2008. IUCN red list of threatened species version 2010.1: *Rangifer tarandus* [online]. http://www.iucnredlist.org/apps/redlist/details/29742/0 (accessed 7 May, 2010).
29. Vors, L.S. and M.S.Boyce. 2009. Global declines of caribou and reindeer. Global Change Biology 15:2626-2633.

18. Primary productivity

1. Ahern, F., Frisk, J., Latifovic, R. and Pouliot, D. 2010. Monitoring ecosystems remotely: a selection of trends measured from satellite observations of Canada. Canadian Biodiversity: Ecosystem Status and Trends 2010, Technical Thematic Report Series No. 17. Canadian Councils of Resource Ministers. Ottawa, ON. In press.
2. Wang, J., Rich, P.M. and Price, K.P. 2003. Temporal responses of NDVI to precipitation and temperature in the central Great Plains, USA. International Journal of Remote Sensing 24:2345-2364.
3. Pouliot, D, Latifovic, R. and Olthof, I. 2009. Trends in vegetation NDVI from 1 km AVHRR data over Canada for the period 1985-2006. International Journal of Remote Sensing 30:149-168.
4. Slayback, D.A., Pinzon, J.E., Los, S.O. and Tucker, C.J. 2003. Northern Hemisphere photosynthetic trends 1982-99. Global Change Biology 9:1-15.
5. Olthof, I., Pouliot, D., Latifovic, R. and Chen, W.J. 2008. Recent (1986-2006) vegetation-specific NDVI trends in northern Canada from satellite data. Arctic 61:381-394.
6. Gamache, I. and Payette, S. 2004. Height growth response of tree line black spruce to recent climate warming across the forest-tundra of eastern Canada. Journal of Ecology 92:835-845.
7. Olthof, I. and Pouliot, D. 2010. Treeline vegetation composition and change in Canada's western subarctic from AVHRR and canopy reflectance modeling. Remote Sensing of Environment 114:805-815.
8. Szeicz, J.M. and MacDonald, G.M. 1995. Recent white spruce dynamics at the subarctic alpine treeline of northwestern Canada. Journal of Ecology 83:873-885.
9. Nemani, R.R., Keeling, C.D., Hashimoto, H., Jolly, W.M., Piper, S.C., Tucker, C.J., Myneni, R.B. and Running, S.W. 2003. Climate driven increases in global terrestrial net primary production from 1982 to 1999. Science 300:1560-1563.
10. Michelutti, N., Wolfe, A.P., Vinebrooke, R.D., Rivard, B. and Briner, J.P. 2005. Recent primary production increases in arctic lakes. Geophysical Research Letters 32. doi:10.1029/2005GL023693.

11. Smol, J.P., Wolfe, A.P., Birkds, H.J.B., Douglas, M.S.V., Jones, V.J., Korhola, A., Pienitz, R., Ruhland, K., Sorvari, S., Antoniades, D., Brooks, S.J., Fullu, M.A., Huges, M., Keatley, B.E., Laing, T.E., Michelutti, N., Nazarova, L., Nyman, J., Paterson, A.M., Perren, B., Quinlan, R., Ruatio, M., Saulnier-Talbot, E., Sutonen, S., Solvieva, N. and Weckstrom, J. 2005. Climate-driven regime shifts in the biological communities of Arctic lakes. Proceedings of the National Academy of Sciences 102:4397-4402.

12. Antoniades, D., Crawley, C., Douglas, M.S.V., Pienitz, R., Andersen, D., Doran, P.T., Hawes, I., Pollard, W. and Vincent, W.F. 2007. Abrupt environmental change in Canada's northernmost lake inferred from fossil diatom and pigment stratigraphy. Geophysical Research Letters 34. doi:10.1029/2007GL030947.

13. Smol, J.P. and Douglas, M.S.V. 2007. From controversy to consensus: Making the case for recent climate change using lake sediments. Frontiers in Ecology and the Environment 5:466-474.

14. Antoniades, D., Douglas, M.S.V. and Smol, J.P. 2005. Quantitative estimates of recent environmental changes in the Canadian High Arctic inferred from diatoms in lake and pond sediments. Journal of Paleolimnology 33:349-360.

15. Rühland, K., Paterson, A.M. and Smol, J.P. 2008. Hemispheric-scale patterns of climate-related shifts in planktonic diatoms from North American and European lakes. Global Change Biology 14:2740-2754.

16. Boyce, D., Lewis, M. and Worm, B. 2010. Global phytoplankton decline over the past century. Nature 466:591-596. doi:10.1038/nature09268.

17. Pabi, S., van Dijken, G.L. and Arrigo, K.R. 2008. Primary production in the Arctic Ocean, 1998-2006. Journal of Geophysical Research-Oceans 113. doi:10.1029/2007JC004578.

18. Arrigo, K.R., van Dijken, G. and Pabi, S. 2008. Impact of a shrinking Arctic ice cover on marine primary production. Geophysical Research Letters 35:L19603.

19. Natural disturbances

1. Stocks, B.J., Mason, J.A., Todd, J.B., Bosch, E.M., Wotton, B.M., Amiro, B.D., Flannigan, M.D., Hirsch, K.G., Logan, K.A., Martell, D.L. and Skinner, W.R. 2003. Large forest fires in Canada, 1959-1997. Journal of Geophysical Research 108:8149-8161.

2. Krezek-Hanes, C.C., Cantin, A. and Flannigan, M.D. 2010. Trends in large fires in Canada, 1959 to 2007. Canadian Biodiversity: Ecosystem Status and Trends 2010, Technical Thematic Report Series No. 6. Canadian Councils of Resource Ministers. Ottawa, ON. In press.

3. Gillett, N.P., Weaver, A.J., Zwiers, F.W. and Flannigan, M.D. 2004. Detecting the effect of climate change on Canadian forest fires. Geophysical Research Letters 31. doi:10.1029/2004GL020876.

4. Parisien, M.A., Peters, V.S., Wang, Y., Little, J.M., Bosch, E.M. and Stocks, B.J. 2006. Spatial patterns of forest fires in Canada, 1980-1999. International Journal of Wildland Fire 15:361-374.

5. Flannigan, M.D. and Wotton, B.M. 2001. Climate, weather and area burned. *In* Forest fires-behaviour and ecological effects. Edited by Johnson, E.A. and Miyanishi, K. Academic Press. San Diego, CA. pp. 335-357.

6. Flannigan, M., Logan, K., Amiro, B., Skinner, W. and Stocks, B. 2005. Future area burned in Canada. Climatic Change 72:1-16.

7. Girardin, M.P., Tardif, J. and Flannigan, M.D. 2006. Temporal variability in area burned for the Province of Ontario, Canada, during the past 200 years inferred from tree rings. Journal of Geophysical Research 111. doi:10.1029/2005 JD006815.

8. Girardin, M.P., Tardif, J., Flannigan, M.D. and Bergeron, Y. 2006. Synoptic-scale atmospheric circulation and boreal Canada summer drought variability of the past three centuries. Journal of Climate 19:1922-1947.

9. Bergeron, Y., Flannigan, M., Gauthier, S., Leduc, A. and Lefort, P. 2004. Past, current, and future fire frequency in the Canadian boreal forest: implications for sustainable forest management. Ambio 33:356-360.

10. Bergeron, Y., Cyr, D., Drever, C.R., Flannigan, M., Gauthier, S., Kneeshae, D., Lauzon, E., Leduc, A., Le Goff, H., Lesieur, D. and Logan, K. 2006. Past, current, and future frequencies in Quebec's commercial forests: implications for the cumulative effects of harvesting and fire on age-class structure and natural disturbance-based management. Canadian Journal of Forest Research 36:2737-2744.

11. Skinner, W.R., Shabbar, A., Flannigan, M.D. and Logan, K. 2006. Large forest fires in Canada and the relationship to global sea surface temperatures. Journal of Geophysical Research 111. doi:10.1029/2005JD006738.

12. Girardin, M.P. 2007. Interannual to decadal changes in area burned in Canada from 1781 to 1982 and the relationship to Northern Hemisphere land temperatures. Global Ecology and Biogeography 16:557-566.

13. Skinner, W.R., Flannigan, M.D., Stocks, B.J., Martell, D.L., Wotton, B.M., Todd, J.B., Mason, J.A., Logan, K.A. and Bosch, E.M. 2002. A 500 hPa synoptic wildland fire climatology for large Canadian forest fires, 1959-1996. Theoretical and Applied Climatology 71:157-169.

14. Macias Fauria, M. and Johnson, E.A. 2008. Climate and wildfires in the North American boreal forest. Philosophical Transactions of the Royal Society B 363:2317-2329. doi:10.1098/rstb.2007.2202.

15. Balshi, M.S., McGuire, A.D., Duffy, P., Flannigan, M., Walsh, J. and Melillo, J. 2009. Modeling historical and future area burned of western boreal North America using a multivariate adaptive regression splines (MARS) approach. Global Change Biology 15:578-600.

16. de Groot, W.J., Bothwell, P.M., Carlsson, D.H. and Logan, K.A. 2003. Simulating the effects of future fire regimes on western Canadian boreal forests. Journal of Vegetation Science 14:355-364.

17. Weber, M.G. and Flannigan, M.D. 1997. Canadian boreal forest ecosystem structure and function in a changing climate: impact on fire regimes. Environmental Reviews 5:145-166.

18. Kasischke, E.S. and Turetsky, M.R. 2006. Recent changes in the fire regime across the North American boreal region – spatial and temporal patterns of burning across Canada and Alaska. Geophysical Research Letters 33. doi:1029/2006GL025677.

19. Amiro, B.D., Todd, J.B., Wotton, B.M., Logan, K.A., Flannigan, M.D., Stocks, B.J., Mason, J.A., Martell, D.L. and Hirsch, K.G. 2001. Direct carbon emissions from Canadian forest fires, 1959-1999. Canadian Journal of Forest Research 31:512-525.

20. Westerling, A.L., Hidalgo, H.G., Cayan, D.R. and Swetnam, T.W. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. Science 313:940-943.

21. Martell, D.L. and Sun, H. 2008. The impact of fire suppression, vegetation, and weather on the area burned by lightning-caused forest fires in Ontario. Canadian Journal of Forest Research 38:1547-1563.

22. Cumming, S.G. 2005. Effective fire suppression in boreal forests. Canadian Journal of Forest Research 35:772-786.

23. Gayton, D. 1996. Fire-maintained ecosystems and the effects of forest ingrowth – December 1996 research summary. Nelson Forest Region, B.C. Ministry of Forests. Nelson, BC. 4 p.

24. Daigle, P. 1996. Fire in the dry interior forests of British Columbia. Extension Note No. 8. B.C. Ministry of Forests Research Program. Victoria, BC. 5 p.

25. Taylor, S.W., Carroll, A.L., Alfaro, R.E. and Safranyik, L. 2006. Forest, climate and mountain pine beetle outbreak dynamics in western Canada. *In* The mountain pine beetle: a synthesis of biology, management and impacts in lodgepole pine. Edited by Safranyik, L. and Wilson, W.R. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre. Victoria, BC. Chapter 2. pp. 67-94.

26. Flannigan, M.D., Stocks, B.J., Turetsky, M.R. and Wotton, B.M. 2009. Impact of climate change on fire activity and fire management in the circumboreal forest. Global Change Biology 15:549-560.

27. Girardin, M.P. and Wotton, B.M. 2009. Summer moisture and wildfire risks across Canada. Journal of Applied Meteorology and Climatology 48:517-533.

28. Girardin, M.P., Bergeron, Y., Tardif, J.C., Gauthier, S., Flannigan, M.D. and Mudelsee, M. 2006. A 229-year dendroclimatic-inferred record of forest fire activity for the Boreal Shield of Canada. International Journal of Wildland Fire 15:375-388.

29. Beverly, J.L. and Martell, D.L. 2005. Characterizing extreme fire and weather events in the Boreal Shield Ecozone of Ontario. Agricultural and Forest Meteorology 133:5-16.

30. Wotton, B.M. and Flannigan, M.D. 1993. Length of the fire season in a changing climate. Forestry Chronicle 69:187-192.

31. Girardin, M.P., Ali, A.A., Carcaillet, C., Mudelsee, M., Drobyshev, I. and Bergeron, Y. 2009. Heterogeneous response of circumboreal wildfire risk to climate change since the early 1900s. Global Change Biology 15:2751-2769. doi:10.1111/j.1365-2486.2009.01869.x.

32. Flannigan, M.D., Krawchuk, M.A., de Groot, W.J., Wotton, B.M. and Gowman, L.M. 2009. Implications of changing climate for global wildland fire. International Journal of Wildland Fire 18:483-507.

33. Flannigan, M.D., Bergeron, Y., Engelmark, O. and Wotton, B.M. 1998. Future wildfire in circumboreal forests in relation to global warming. Journal of Vegetation Science 9:469-476.

34. Stocks, B.J., Fosberg, M.A., Lynham, T.J., Mearns, L., Wotton, B.M., Yang, Q., Jin, J.Z., Lawrence, K., Hartley, G.R., Mason, J.A. and Mckenney, D.W. 1998. Climate change and forest fire potential in Russian and Canadian boreal forests. Climatic Change 38:1-13.

35. Flannigan, M.D., Stocks, B.J. and Wotton, B.M. 2000. Climate change and forest fires. The Science of the Total Environment 262:221-230.

36. Liu, Y. and Stanturf, J. 2010. Trends in global wildfire potential in a changing climate. Forest Ecology and Management 259:685-697.

37. Scholze, M., Knorr, W., Arnell, N.W. and Prentice, I.C. 2006. A climate-change risk analysis for world ecosystems. Proceedings of the National Academy of Sciences of the United States of America 103:13116-13120.

38. Canadian Forest Service. 2007. Spruce budworm and sustainable management of the boreal forest: Summary of a project funded under British Columbia's Forestry Innovation Investment Program [online]. Natural Resources Canada. http://cfs.nrcan.gc.ca/subsite/budworm (accessed 26 August, 2010).

39. Nealis, V.G. and Régnière, J. 2004. Insect-host relationships influencing disturbance by the spruce budworm in a boreal mixedwood forest. Canadian Journal of Forest Research 34:1870-1882.

40. MacLean, D.A. 1980. Vulnerability of fir spruce stands during uncontrolled spruce budworm outbreaks: a review and discussion. Forestry Chronicle 56:213-221.

41. Fleming, R.A., Candau, J.N. and McAlpine, R.S. 2002. Landscape-scale analysis of interactions between insect defoliation and forest fire in central Canada. Climatic Change 55:251-272.

42. Volney, W.J.A. and Fleming, R.A. 2007. Spruce budworm (*Choristoneura spp.)* biotype reactions to forest and climate characteristics. Global Change Biology 13:1630-1643.

43. Gray, D.R. and MacKinnon, W.E. 2006. Outbreak patterns of the spruce budworm and their impacts in Canada. The Forestry Chronicle 82:550-561.

44. Boulanger, Y. and Arseneault, D. 2004. Spruce budworm outbreaks in eastern Quebec over the last 450 years. Canadian Journal of Forest Research 34:1035-1043. doi:10.1139/X03-269.

45. Royama, T., MacKinnon, W.E., Kettela, E.G., Carter, N.E. and Hartling, L.K. 2005. Analysis of spruce budworm outbreak cycles in New Brunswick, Canada, since 1952. Ecology 86:1212-1224.

46. National Forestry Database. 2010. Forest insects – quick facts. Area of moderate to severe defoliation and beetle-killed trees by major insects, 2008 – spruce budworm [online]. Canadian Council of Forest Ministers. http://nfdp.ccfm.org/insects/quick_facts_e.php (accessed 7 July, 2010). Reports generated for spruce budworm and western spruce budworm.

47. Westfall, J. and Ebata, T. 2008. 2008 summary of forest health conditions in British Columbia. B.C. Ministry of Forests and Range. Victoria, BC. 85 p.

48. MacLauchlan, L.E., Brooks, J.E. and Hodge, J.C. 2006. Analysis of historic western spruce budworm defoliation in south central British Columbia. Forest Ecology and Management 226:351-356.

49. Kettela, E.G. 1983. A cartographic history of spruce budworm defoliation from 1967 to 1981 in eastern North America. Information Report No. DPC-X-14. Canadian Forestry Service, Environment Canada. Hull, QC. 9 p.

50. Strubble, D. 2008. Spruce budworm defoliation in Maine from 1955 to 2008. Maine Forest Service. Unpublished data.

51. Blais, J.R. 1983. Trends in the frequency, extent and severity of spruce budworm outbreaks in eastern Canada. Canadian Journal of Forest Research 13:539-545.

52. Gray, D.R. and MacKinnon, W.E. 2007. Historical spruce budworm defoliation records adjusted for insecticide protection in New Brunswick, 1965-1992. Journal of the Acadian Entomological Society 3:1-6.

53. Carter, N., Hartling, L., Lavigne, D., Gullison, J., O'Shea, D., Proude, J., Farquhar, R. and Winter, D. 2008. Preliminary summary of forest pest conditions in New Brunswick in 2007 and outlook for 2008. Department of Natural Resources, Forest Pest Management Section. Fredericton, NB.

54. Neily, P.D., Quigley, E.J., Stewart, B.J. and Keys, K.S. 2007. Forest disturbance ecology in Nova Scotia: Draft report. Renewable Resources Branch, Forestry Division Ecosystem Management Group. Truro, NS.

55. Loo, J. and Ives, N. 2003. The Acadian forest: historical condition and human impacts. The Forestry Chronicle 79:462-474.

56. British Columbia Ministry of Forests and Range. 2010. Provincial-level projection of the current mountain pine beetle outbreak. GIS maps. Cumulative pine volume killed by mountain pine beetle, 1999-2009. Version 7 [online]. Research Branch, B.C. Ministry of Forests and Range. http://www.for.gov.bc.ca/hre/bcmpb/Year7.htm (accessed 14 July, 2010).

57. Alberta Sustainable Resource Development. 2010. Area affected by mountain pine beetle in Alberta, 2009. Map. Government of Alberta.

58. BC Ministry of Forests and Range. 2010. Beetle facts [online]. Government of British Columbia. http://www.for.gov.bc.ca/hfp/mountain_pine_beetle/facts.htm (accessed 6 April, 2010).

59. National Forestry Database. 2010. Forest insects – quick facts. Areas within which moderate to severe defoliation occurs including area of beetle-killed trees by insects and province/territory, 1975-2009: mountain pine beetle [online]. Canadian Council of Forest Ministers. http://nfdp.ccfm.org/insects/quick_facts_e.php (accessed May, 2010).

60. Alberta Sustainable Resource Development. 2006. 2006 annual report: forest health in Alberta. Government of Alberta. 58 p.

61. Alberta Sustainable Resource Development. 2009. 2009 annual report: forest health in Alberta. Government of Alberta.

62. Tyssen, B. 2009. Mountain pine beetle aerial survey 2009. Map. Government of Alberta.

63. Winkler, R.D., Rex, J., Tetl, P., Maloney, D. and Redding, T. 2008. Mountain pine beetle, forest practices and watershed management. Extension Note No. 88. B.C. Ministry of Forests and Range, Research Branch. Victoria, BC. 11 p.

64. Taylor, S.W. and Carroll, A.L. 2004. Disturbance, forest age, and mountain pine beetle outbreak dynamics in BC: a historical perspective. Mountain pine beetle symposium: challenges and solutions. October 30-31, 2003, Kelowna, British Columbia. Edited by Shore, T.L., Brooks, J.E. and Stone, J.E. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre. Victoria, BC. Information Report BC-X-399. pp. 41-51.

65. Li, C., Barclay, H.J., Hawkes, B.C. and Taylor, S.W. 2005. Lodgepole pine forest age class dynamics and susceptibility to mountain pine beetle attack. Ecological Complexity 2:232-239.

66. Allen, E. 2001. Forest health assessment in Canada. Ecosystem Health 7:27-34.

67. Shore, T.L., Safranyik, L., Hawkes, B.C. and Taylor, S.W. 2006. Effects of the mountain pine beetle on lodgepole pine stand structure and dynamics. *In* The mountain pine beetle: a synthesis of biology, management, and impacts in lodgepole pine. Edited by Safranyik, L. and Wilson, B. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre. Victoria, BC. Chapter 3. pp. 95-114.

68. McCullough, D.G., Werner, R.A. and Neumann, D. 1998. Fire and insects of northern and boreal forest ecosystems of North America. Annual Review of Entomology 43:107-127.

69. Forest Practices Branch. 2010. Forest health conditions: 2009 aerial overview survey summary table [online]. B.C. Ministry of Forests and Range. http://www.for.gov.bc.ca/hfp/health/overview/2009table.htm (accessed 22 April, 2010).

70. BC Ministry of Forests, Forest Analysis Branch. 2003. Timber supply and the mountain pine beetle infestation in British Columbia. BC Ministry of Forests. 23 p.

71. Safranyik, L. and Carroll, A.L. 2006. The biology and epidemiology of the mountain pine beetle in lodgepole pine forests. *In* The mountain pine beetle: a synthesis of biology, management, and impacts on lodgepole pine. Edited by Safranyik, L. and Wilson, B. Natural Resources Canada, Canadian Forest Service, Pacific Forest Centre. Victoria, BC. Chapter 1. pp. 3-66.

72. Carroll, A.L., Taylor, S.W., Régnière, J. and Safranyik, L. 2004. Effects of climate change on range expansion by the mountain pine beetle in British Columbia. Mountain pine beetle symposium: challenges and solutions. October 30-31, 2003, Kelowna, British Columbia. Edited by Shore, T.L., Brooks, J.E. and Stone, J.E. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre. Victoria, BC. Information Report BC-X-399. pp. 223-232.

73. Zhang, X., Brown, R., Vincent, L., Skinner, W., Feng, Y. and Mekis, E. 2010. Canadian climate trends 1950-2007. Canadian Biodiversity: Ecosystem Status and Trends 2010, Technical Thematic Report Series No. 5. Canadian Councils of Resource Ministers. Ottawa, ON. In press.

74. Stahl, K., Moore, R.D. and McKendry, I.G. 2006. Climatology of winter cold spells in relation to mountain pine beetle mortality in British Columbia, Canada. Climate Research 32:13-23.

20. Food webs

1. Smith, R.L. and Smith, T.M. 2001. Ecology and field biology. Edition 6. Benjamin Cummings. 771 p.

2. Environment Canada and U.S. Environmental Protection Agency. 2009. State of the Great Lakes 2009. 432 p.

3. Hummel, M. and Ray, J.C. 2008. Caribou and the North: a shared future. Dundurn Press. 320 p.

4. Dodds, D. 1983. Terrestrial mammals. *In* Biogeography and ecology of the island of Newfoundland. Edited by South, G.R. Junk Publishers. The Hague, The Netherlands.

5. Blake, J. and McGrath, M. 2006. Coyotes in insular Newfoundland: current knowledge and management of the island's newest mammalian predator. Wildlife Division, Department of Environment and Conservation, Government of Newfoundland and Labrador. Corner Brook, NL. 11 p.

6. Cote, S.D., Rooney, T.P., Tremblay, J.P., Dussault, C. and Waller, D.M. 2004. Ecological impacts of deer overabundance. Annual Review of Ecology Evolution and Systematics 35:113-147.

7. Ontario Ministry of Natural Resources. 2004. Strategy for preventing and managing human-deer conflicts in southern Ontario. Queen's Printer. Toronto, ON. 20 p.

8. Bazely, D. 2010. White-tailed deer induced changes in the germinable seedbanks of Ontario's Carolinian (deciduous) forest communities. 95th ESA Annual Meeting, Pittsburgh, PA, August 1-6 2010.

9. Koh, S., Bazely, D., Tanetzap, A., Voight, D. and Da Silva, E. 2010. *Trillium grandiflorum* height is an indicator of white-tailed deer density at local and regional scales. Forest Ecology and Management 259:1472-1479.

10. Paquet, P.C. and Carbyn, L.N. 2003. Gray wolf. *In* Wild mammals of North America: biology, management and conservation. Edited by Feldhamer, G.A., Thompson, B.C. and Chapman, J.A. Johns Hopkins University Press. Chapter 23. pp. 482-510.

11. Cotterill, S.E. 1997. Status of the swift fox (*Vulpes velox*) in Alberta. Alberta Wildlife Status Report No. 7. Alberta Environmental Protection, Wildlife Management Division. Edmonton, AB. 17 p.

12. Emery, R.B., Howerter, D.W., Armstrong, L.M., Anderson, M.G., Devries, J.H. and Joynt, B.L. 2005. Seasonal variation in waterfowl nesting success and its relation to cover management in the Canadian Prairies. Journal of Wildlife Management 69:1181-1193.

13. Bekoff, M. and Gese, E.M. 2003. Coyote. *In* Wild mammals of North America: biology, management and conservation. Edited by Feldhammer, G.A., Thompson, B.C. and Chapman, J.A. Johns Hopkins University Press. pp. 467-481.

14. Krebs, C.J. 2010. Kluane monitoring data [online]. http://www.zoology.ubc.ca/~krebs/kluane.html (accessed 15 July, 2010).

15. Environment and Natural Resources. 2009. NWT small mammal and hare transect surveys: update 2009. Government of Northwest Territories. Yellowknife, NT. Unpublished report.

16. Predavec, M., Krebs, C.J., Dannell, K. and Hyndman, R.J. 2001. Cycles and synchrony in the collared lemming *(Dicrostonyx groenlandicus)* in Arctic North America. Oecologia 126:216-224.

17. Cadieux, M.-C., Gauthier, G., Gagnon, C.A., Lévesque, E., Bêty, J. and Berteaux, D. 2008. Monitoring the environmental and ecological impacts of climate change on Bylot Island, Sirmilik National Park, 2004-2008 final report. Université Laval; UQAR; Université du Québec à Trois-Rivières; Centre d'études nordiques. Québec, QC. 113 p.
18. Berteaux, D. 15 June, 2010. Université du Québec à Rimouski. Personal communication.
19. Krebs, C.J., Boutin, S. and Boonstra, R. 2001. Ecosystem dynamics of the boreal forest. Oxford University Press. New York, NY. 511 p.
20. Krebs, C.J., Boonstra, R., Boutin, S. and Sinclair, A.R.E. 2001. What drives the 10-year cycle of snowshoe hares? BioScience 51:25-35.
21. Callaghan, T.V., Bjorn, L.O., Chapin, F.S.I., Chernov, Y., Christensen, T.R., Huntley, B., Ims, R.A., Johansson, M., Riedlinger, D.J., Jonasson, S., Matveyeva, N.V., Oechel, W., Panikov, N., Shaver, G.R., Elster, J., Henttonen, H., Jonsdottir, I.S., Laine, K., Schaphoff, S., Taulavuori, E., Taulavuori, K. and Zockler, C. 2005. Arctic tundra and polar desert ecosystems. *In* Arctic Climate Impact Assessment. Edited by ACIA. Cambridge University Press. Chapter 7. pp. 243-352.
22. Ims, R.A., Henden, J.A. and Killengreen, S.T. 2008. Collapsing population cycles. Trends in Ecology and Evolution 23:79-86.
23. Hörnfeldt, B., Hipkiss, T. and Eklund, U. 2005. Fading out of vole and predator cycles? Proceedings of the Royal Society B: Biological Sciences 272:2045-2049. doi:10.1098/rspb.2005.3141.

SCIENCE/POLICY INTERFACE

21. Biodiversity monitoring, research, information management, and reporting

1. Secretariat of the Convention on Biological Diversity. 2010. Global biodiversity outlook 3. Convention on Biological Diversity. Montreal, QC. 94 p.
2. Dobson, A. 2005. Monitoring global rates of biodiversity change: challenges that arise in meeting the Convention on Biological Diversity (CBD) 2010 goals. Philosophical Transactions of the Royal Society B-Biological Sciences 360:229-241.
3. Monk, W.A., Baird, D.J., Curry, R.A., Glozier, N. and Peters, D.L. 2010. Ecosystem status and trends report: biodiversity in Canadian lakes and rivers. Canadian Biodiversity: Ecosystem Status and Trends 2010, Technical Thematic Report Series No. 20. Canadian Councils of Resource Ministers. Ottawa, ON. In press.
4. Bartzen, B.A., Dufour, K.W., Clark, R.G. and Caswell, F.D. 2010. Trends in agricultural impact and recovery of wetlands in prairie Canada. Ecological Applications 20:525-538.
5. Boutin, S., Haughland, D.L., Schieck, J., Herbers, J. and Bayne, E. 2009. A new approach to forest biodiversity monitoring in Canada. Forest Ecology and Management 258:S168-S175.
6. Vaughan, H., Whitelaw, G., Craig, B. and Stewart, C. 2003. Linking ecological science to decision-making: delivering environmental monitoring information as societal feedback. Environmental Monitoring and Assessment 88:399-408.
7. Parks Canada Agency. 2007. State of protected heritage areas report: April 1, 2005 to March 31, 2007. Parks Canada. 14 p.
8. Nielsen, S., Haughland, D., Bayne, E. and Schieck, J. 2009. Capacity of large-scale, long-term biodiversity monitoring programmes to detect trends in species prevalence. Biodiversity and Conservation 18:2961-2978.
9. Langor, D.W. and Spence, J.R. 2006. Arthropods as ecological indicators of sustainability in Canadian forests. Forestry Chronicle 82:344-350.
10. Mace, G.M. 2004. The role of taxonomy in species conservation. Philosophical Transactions of the Royal Society of London Series B-Biological Sciences 359:711-719.
11. Packer, L., Grixti, J.C., Roughley, R.E. and Hanner, R. 2009. The status of taxonomy in Canada and the impact of DNA barcoding. Canadian Journal of Zoology-Revue Canadienne de Zoologie 87:1097-1110.
12. Lepczyk, C.A., Boyle, O.D., Vargo, T.L., Gould, P., Jordan, R., Liebenberg, L., Masi, S., Mueller, W.P., Prysby, M.D. and Vaughan, H. 2009. Symposium 18: Citizen Science in Ecology: the Intersection of Research and Education. Bulletin of the Ecological Society of America 90:308-317.
13. Canadian Wildlife Service. 2007. Breeding Bird Survey in Canada [online]. Environment Canada. http://www.cws-scf.ec.gc.ca/nwrc-cnrf/Default.asp?lang=En&n=416B57CA (accessed 20 October, 2009).
14. Whitelaw, G., Vaughan, H., Craig, B. and Atkinson, D. 2003. Establishing the Canadian Community Monitoring Network. Environmental Monitoring and Assessment 88:409-418.
15. Bonney, R., Cooper, C.B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K.V. and Shirk, J. 2009. Citizen Science: a developing tool for expanding science knowledge and scientific literacy. Bioscience 59:977-984.
16. Hurlburt, D. 2008. Synthesis of Aboriginal Traditional Knowledge (prepared for the Ecosystem Status and Trends Report Secretariat). 170 p. Unpublished report.
17. Berkes, F. 2009. Indigenous ways of knowing and the study of environmental change. Journal of the Royal Society of New Zealand 39:151-156.
18. Gadgil, M., Olsson, P., Berkes, F. and Folke, C. 2003. Exploring the role of local ecological knowledge in ecosystem management: three case studies. *In* Navigating social-ecological systems: building resilience for complexity and change. Edited by Berkes, F., Colding, J. and Folke, C. Cambridge University Press. Cambridge. Chapter 8. pp. 189-209.
19. Boudreau, S.A. and Worm, B. 2010. Top-down control of lobster in the Gulf of Maine: insights from local ecological knowledge and research surveys. Marine Ecology-Progress Series 403:181-191.
20. Gagnon, C.A. and Berteaux, D. 2009. Integrating Traditional Ecological Knowledge and ecological science: a question of scale. Ecology and Society 14: Article 19.
21. Usher, P.J. 2000. Traditional ecological knowledge in environmental assessment and management. Arctic 53:183-193.
22. Eamer, J. 2006. Keep it simple and be relevant: the first ten years of the Arctic Borderlands Ecological Knowledge Co-op. *In* Bridging scales and knowledge systems: concepts and applications in ecosystem assessment. Edited by Reid, W.V., Berkes, F., Wilbanks, T. and Capistrano, D. Island Press. Washington, DC. Chapter 10. pp. 186-204.
23. Duro, D., Coops, N.C., Wulder, M.A. and Han, T. 2007. Development of a large area biodiversity monitoring system driven by remote sensing. Progress in Physical Geography 31:235-260.
24. Whitfield, P.H. and Cannon, A.J. 2000. Recent climate moderated shifts in Yukon hydrology. 1 May, 2000. AWRA Spring Specialty Conference Proceedings. American Water Resource Association. Anchorage, AK. pp. 257-262.
25. Dahl, T.E. and Watmough, M.D. 2007. Current approaches to wetland status and trends monitoring in prairie Canada and the continental United States of America. Canadian Journal of Remote Sensing 33:S17-S27.

26. Latifovic, R. and Pouliot, D. 2007. Analysis of climate change impacts on lake ice phenology in Canada using the historical satellite data record. Remote Sensing of Environment 106:492-507.
27. Krezek-Hanes, C.C., Cantin, A. and Flannigan, M.D. 2010. Trends in large fires in Canada, 1959 to 2007. Canadian Biodiversity: Ecosystem Status and Trends 2010, Technical Thematic Report Series No. 6. Canadian Councils of Resource Ministers. Ottawa, ON. In press.
28. Fetterer, F., Knowles, K., Meier, W. and Savoie, M. 2010. Sea ice index [online]. National Snow and Ice Data Center, Boulder, CO. http://nsidc.org/data/g02135.html (accessed 4 October, 2010).
29. Olthof, I. and Pouliot, D. 2010. Treeline vegetation composition and change in Canada's western subarctic from AVHRR and canopy reflectance modeling. Remote Sensing of Environment 114:805-815.
30. Pouliot, D., Latifovic, R. and Olthof, I. 2009. Trends in vegetation NDVI from 1 km AVHRR data over Canada for the period 1985-2006. International Journal of Remote Sensing 30:149-168.
31. Latifovic, R. and Pouliot, D. 2005. Multitemporal land cover mapping for Canada: methodology and products. Canadian Journal of Remote Sensing 31:347-363.
32. Wulder, M.A., White, J.C., Han, T., Coops, N.C., Cardille, J.A., Holland, T. and Grills, D. 2008. Monitoring Canada's forests. Part 2: national forest fragmentation and pattern. Canadian Journal of Remote Sensing 34:563-584.
33. Lee, P., Gysbers, J.D. and Stanojevic, Z. 2006. Canada's forest landscape fragments: a first approximation. Global Forest Watch Canada. Edmonton, AB. 97 p.
34. Ahern, F. 2010. Detail of Peace Athabasca Delta, based on data from Global Forest Watch Canada.
35. Lindenmayer, D.B. and Likens, G.E. 2009. Adaptive monitoring: a new paradigm for long-term research and monitoring. Trends in Ecology and Evolution 24:482-486.
36. Lovett, G.M., Burns, D.A., Driscoll, C.T., Jenkins, J.C., Mitchell, M.J., Rustad, L., Shanley, J.B., Likens, G.E. and Haeuber, R. 2007. Who needs environmental monitoring? Frontiers in Ecology and the Environment 5:253-260.
37. DFO. 2010. 2010 Canadian marine ecosystem status and trends report. DFO Canadian Science Advisory Secretariat Research Document No. 2010/030. Fisheries and Oceans Canada. 38 p.

22. Rapid changes and thresholds

1. Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being: biodiversity synthesis. Millennium Ecosystem Assessment Series. World Resources Institute. Washington, DC. 100 p.
2. Intergovernmental Panel on Climate Change. 2007. Climate change 2007: impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Edited by Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E. Cambridge University Press. Cambridge, UK. 976 p.
3. Sheffer, M., Bascompte, J., Brock, W.A., Brovkin, V. and Carpenter, S.R. 2009. Early warning signs for critical transitions. Nature 461:53-59.
4. Beamish, R.J., Noakes, D.J., McFarlane, G.A., Pinnix, W., Sweeting, R. and King, J. 2000. Trends in coho marine survival in relation to the regime concept. Fisheries Oceanography 9:114-119.
5. Crawford, W.R. and Irvine, J.R. 2009. State of physical, biological and selected fishery resources of Pacific Canadian marine ecosystems. DFO Canadian Science Advisory Secretariat Research Document No. 2009/022. Fisheries and Oceans Canada. vi + 121 p.

Printed in Canada

ENVIRONMENTAL CHOICE • CHOIX ENVIRONNEMENTAL

EcoLogo℠