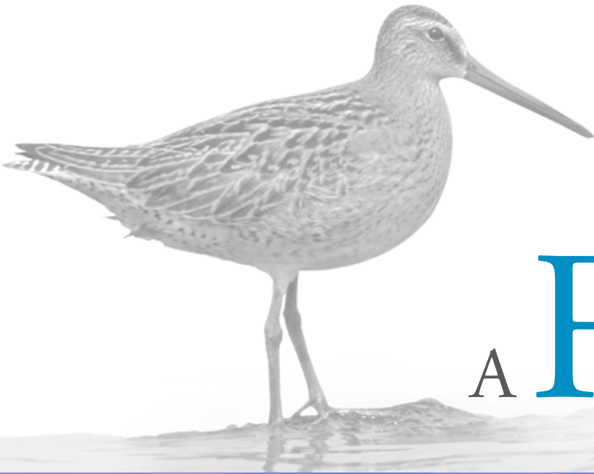

# A Forest of Blue

## Canada's Boreal

THE PEW ENVIRONMENT GROUP

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# Foreword

## Foreword

Water is the essence of life on our blue planet. Renewable fresh water is the most undervalued and overexploited of scarce, critical natural resources. Globally, readily available renewable fresh water comprises a small fraction of the global water pool.

The U.N. General Assembly recognized the importance of freshwater to humanity in its designation of 2005-2015 as the "International Decade for Action—Water for Life." Despite increasing global awareness of the importance of freshwater resources, human populations continue to alter hydrological cycles and hydrological connectivity, and degrade aquatic biological communities, threatening the integrity of freshwater systems. By 2025, it is predicted that humans will appropriate 70 percent of the renewable annual freshwater supply. Freshwater withdrawal and disruption of freshwater flow, primarily for agricultural, oil and mineral extraction, and hydroelectricity production, threaten the ability of the water cycle in the Canadian boreal forest to maintain freshwater biodiversity and may have unpredictable effects on ecosystem functioning. Climate change coupled with human impacts on watersheds is expected to further strain global water resources, causing greater discharge and water stress within altered watersheds.

Canada's boreal forest region provides one of the last opportunities for freshwater and intact forest protection that has globally significant implications. This region contains a significant proportion of the world's surface freshwater, including a relatively large proportion of the planet's wetlands intermingled with the most intact forest ecosystems on Earth. The boreal forest is defined by water as much as by forest, a fact that is too often underappreciated. The sheer abundance of water can make it seem limitless, but this is far from the case. Continued overexploitation and degradation of freshwater resources and ecosystems, particularly peatlands, across the boreal forest has consequences for climate cycles, nutrient cycles and livelihoods of the peoples that depend on this water for life.

Protecting large-scale intact aquatic and forest ecosystems will maintain abundant migratory and inland-water fish populations and aquatic biodiversity, intact headwaters, intact hydrologic and nutrient cycles, and carbon storage and sequestration in forested and non-forested peatland ecosystems.

The global freshwater accounting sheet between input and demand is becoming increasingly difficult to balance. Ever-increasing pressure on water resources globally can only be decreased by implementing new conservation and sustainable development policy and management strategies at big scales in places where political, social and water resource capital exists to do so. Canada, with its abundant water resources and informed citizenry, is one such place.

This report provides the facts and vision necessary to catalyze and to elevate the status of water to levels on par with conservation efforts historically focused on terrestrial habitats. Water is Canada's lifeblood; efforts to protect Canada's intact ecosystems must include an understanding of the interconnectedness between land and water in Canada's northern regions. To fail to protect the last free-flowing rivers, pristine lakes, and carbon-rich wetlands of Canada will impact the livability of our planet. Canada is at a crossroads and time to implement broad policy initiatives that protect vital water resources is running out. We applaud the efforts of this report and urge implementation of the recommendations therein.

*International Boreal Conservation Science Panel*

Pascal Badiou, John Jacobs, Jeremy Kerr, Micheline Manseau, Gordon Orions, Stuart Pimm, Peter Raven, Terry Root, Nigel Roulet, James Schaefer, David Schindler, Jim Strittholt, Nancy Turner, Andrew Weaver

## Executive Summary

Seen from above, Canada's boreal forest shimmers on a bright summer day. Much of the surface of Canada's boreal is comprised of countless lakes, rivers and wetlands. It is literally a forest of blue.

Stretching across the continent, Canada's boreal is the most intact forest remaining on earth. It provides a vital bulwark against the global loss of biodiversity, irreplaceable food and cultural benefits to rural communities, and slows the impacts of global warming. These ecosystem services have an estimated $700 billion annual value (Anielski and Wilson 2009).

Saving Canada's boreal forest is increasingly viewed as a global conservation priority. But until recently, the water resources of the boreal have garnered scant attention. This analysis is the first compilation of decades of research on Canadian boreal water reserves from diverse sources.

In the picture that emerges, superlatives abound: half the world's lakes larger than a square kilometer in size; 5 of the world's 50 largest rivers; almost 200 million acres of surface water; and the world's single largest remaining unpolluted fresh water body, Great Bear Lake. Canada's boreal contains 25 percent of the world's wetlands and more surface water than any other continental-scale landscape. The extensive undammed rivers of the boreal serve as last refuges for many of the world's sea-run migratory fish, including half of the remaining populations of North American Atlantic salmon.

Canada's boreal waters also influence global climate. The wetlands and peatlands store an estimated 147 billion tonnes of carbon, more than 25 years worth of current man-made emissions, and the delta of the Mackenzie River alone stores 41 billion tonnes. The input of fresh water from boreal rivers to the Arctic and other northern seas is critical to forming sea ice, which cools the atmosphere and provides the basis for much of arctic marine biodiversity.

Unfortunately, Canada's boreal forest is increasingly affected by large-scale industrial activities. The rapidly expanding development footprint already includes 728,000 km² (180 million acres) impacted by forestry, road building, mining, oil and gas extraction, and hydropower. If the water resources of the forest of blue are to be conserved, major policy changes will be needed.

Thankfully, progress is being made. The Pew Environment Group's International Boreal Conservation Campaign works closely with Canadian and international environmental organizations, corporations and aboriginal First Nations to build support for the Boreal Forest Conservation Framework, endorsed by 1,500 scientists around the world. The Boreal Framework calls for protecting a minimum 50 percent of the region's land and waters, and applying strict sustainable development rules on the remainder.

More than 12 percent of Canada's boreal has been strictly protected to date, through commitments from federal, provincial and First Nations governments, and support from industry and key stakeholder groups. More steps toward widespread adoption and implementation of the Boreal Framework are under way. Yet more must be done. This report calls for additional, water-focused conservation measures, including conservation of the entire Mackenzie River watershed.

As world leaders grapple with the loss of biological diversity, water pollution and supply problems, and global warming, they should turn their attention to the forests, wetlands and waterways of the Canadian boreal. This global treasure must be preserved.

# Introduction

*Freshwater ecosystems are considered the most endangered of all major global ecosystems.*
CREDIT: GARTH LENZ

## Introduction

Canada's boreal forest region is the most water-rich area in the world. Water reaches into the history of all Canadians and runs a long and fluid path connecting aboriginal lands and historical trade and migration routes to southern Canada's cities and industry. This "forest of blue"—Canada's boreal forest—is the source for many Canadian iconic animals, including loons, moose, beavers and fish. These symbols of Canadian history and cultural values reflect the deep connection of people to their land and water that resonates from Newfoundland and Labrador to the Yukon and the Northwest Territories.

Canada's water resources are not only vital to national identity, but also provide irreplaceable ecosystem services at local, provincial, national and international levels. Many of the waterways and wetlands of the boreal forest are among the most pristine in Canada, as well as globally, with low or undetectable levels of human-caused pollutants, little human-made nitrogen and phosphorus inputs, and few invasive plant and animal species.

Canada's boreal forest contains the world's highest concentrations of large wetlands, lakes and undammed rivers (Fig. 1). Its waterways and wetlands make vast and critical contributions to the global environment—stabilizing climate and feeding the productivity of the world's oceans, ultimately supporting the health and welfare of people across the Earth. Its ice-locked, saturated forests and peatlands and the sediments within its lakes and deltas store the largest amount of soil carbon on the planet.

Against a backdrop of abundance of water in Canada's boreal forest, a harsher reality of destruction, degradation and pollution of freshwater resources exists globally and in other regions of North America. Freshwater ecosystems are now considered the most endangered in the world (Dudgeon *et al.* 2005, Millennium Ecosystem Assessment 2005). The same is true for much of the continental United States and southern Canada.

A report estimated that 2.5 million dams impact river ecosystems across the United States (National Research Council 1992), while a 2010 analysis found more than 800 large dams in existence across Canada (Global Forest Watch Canada, unpublished analysis). In the United States alone, an estimated $14 billion to $15 billion has been spent on efforts to restore degraded river systems since 1990 (Bernhardt *et al.* 2005).

Wetlands have fared no better than rivers across much of North America. Wetland losses have been estimated at greater than 50 percent in the United States since pre-European settlement. In Canada, up to 68 percent of wetlands in southern Ontario and 70 percent of prairie wetlands have been lost during the past two centuries. In many areas these losses continue to this day (Environment Canada 2009a). Only a single large river system in the lower 48 U.S. states (the 130-km [81-mile]) Pascagoula River in Mississippi) is not significantly impaired by dams (Dynesius and Nilsson 1994).

Nearly 70 percent of freshwater mussel species (Williams *et al.* 1993) and 51 percent of freshwater crayfish species are endangered or threatened in North America (Taylor *et al.* 1996). More than half of Canada's endangered vertebrates are freshwater species, and a higher proportion of Canada's freshwater mussels are of global conservation concern than any other animal or plant group (Cannings *et al.* 2005). The number of imperiled freshwater fish species in Canada increased from 4 percent in 1979

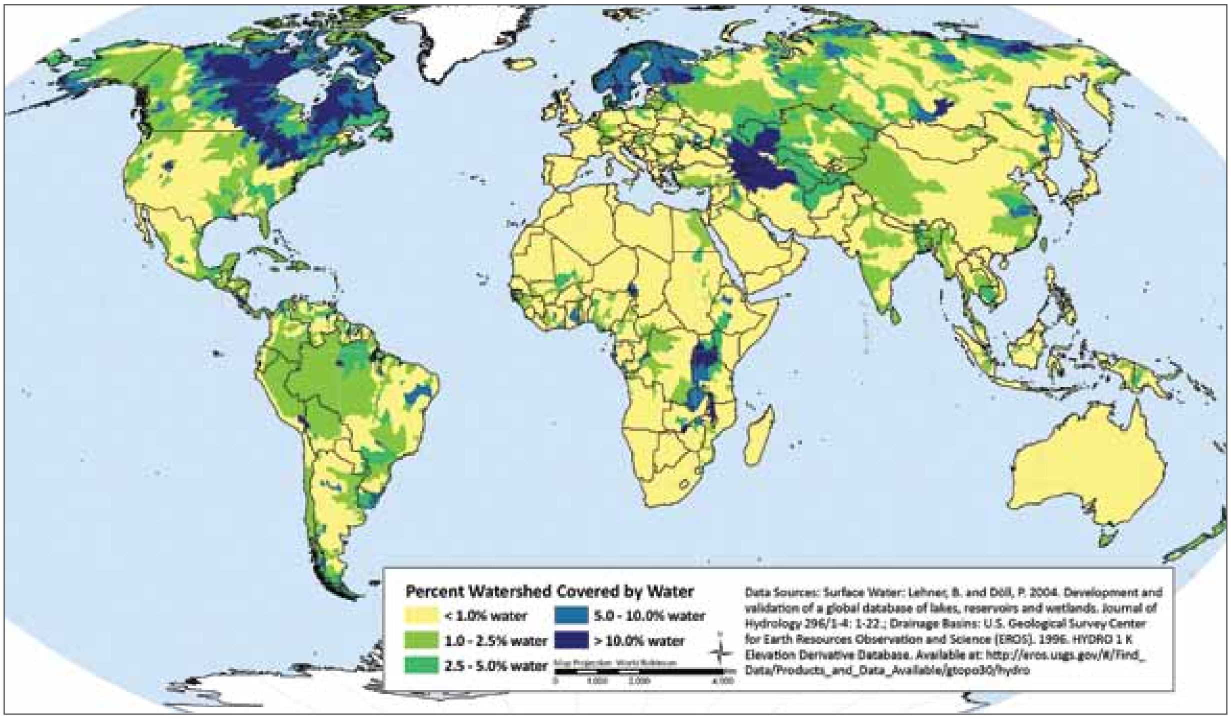



**Figure 1.** Global surface water represented by percentage of a watershed covered with water. Canada is the "World's Waterkeeper," housing more surface water than any other country.

to 10 percent in 2008, while the number of imperiled populations and subspecies increased from 10 percent to 26 percent (Environment Canada 2009a). The number of established invasive alien species in the Great Lakes increased from approximately 10 in the early 1800s to 180 by 2007 (Environment Canada 2009a).

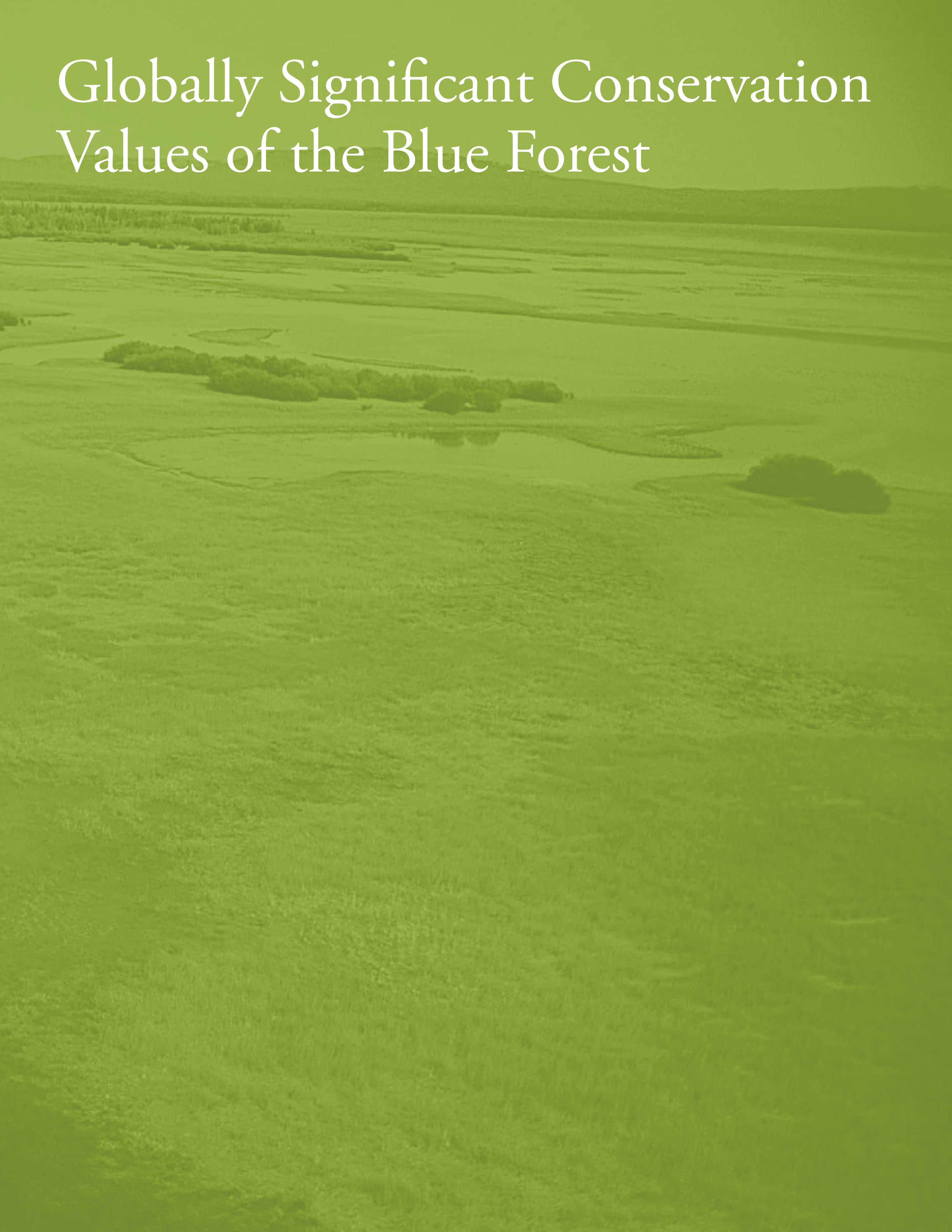
Despite the dire statistics and trends that present a worrisome picture of global freshwater resources, Canada's boreal forest offers a story of hope and abundance in a world of overuse, abuse and scarcity. While much of the globe spends billions of dollars annually to restore wetlands and river systems and provide clean water supplies, the boreal forest and its healthy wetlands and waterways provide more than $700 billion in ecosystem services every year (Anielski and Wilson 2009).

Canada's boreal forest region provides one of the last global opportunities to conserve large-scale, pristine aquatic ecosystems, the biodiversity they sustain, and the ecosystem services they provide. While the abundance and integrity of Canada's water resources are unmatched globally, the water richness of the boreal forest is delicately balanced. In much of the region, annual inputs of water from precipitation are offset by water loss from evaporation and evapotranspiration, and this is often equal to the amount of water that leaves the region in the form of runoff to the oceans. Only with careful planning and protections can this delicate balance be maintained.

This report highlights the unique status of the Canadian boreal forest in housing globally significant water resources. Maintaining the integrity and abundance of this "forest of blue" is still possible, and increasingly urgent. The report explores the ever-expanding list of threats to remote and abundant water resources across the Canadian boreal, and identifies opportunities to protect water resources at geographic scales that will maintain freshwater integrity and abundance into the future.

*Because it is largely intact, Canada's boreal forest presents a unique opportunity to set a model for large-scale aquatic conservation.*
CREDIT: IRENE OWSLEY

# Globally Significant Conservation Values of the Blue Forest



## Globally Significant Conservation Values Of the Blue Forest

Of the large forest ecosystems in the world, only five (Fig. 2) remain highly intact and free of significant human industrial development (Bryant *et al.* 1997, Sanderson *et al*. 2002, Mittermeier *et al.* 2003, Cardillo *et al.* 2006). North America's boreal forest ecoregion has been subject to some of the world's largest land conservation actions and commitments (Canadian Boreal Initiative 2005, Lee *et al.* 2006).

Recent assessments have been made of the Canadian boreal's intact forests (Lee *et al.* 2003, 2006), diversity and abundance of birds (Blancher and Wells 2005, Blancher 2003), natural capital values (Anielski and Wilson 2009), importance for woodland caribou (Environment Canada 2008b, Hummel and Ray 2008), and carbon storage and adaptation values (Bradshaw *et al.* 2009, Carlson *et al.* 2009, 2010). This is the first report to detail the breadth of globally significant conservation values from the boreal's aquatic resources and outline opportunities for conservation.

## Waterways And Wetlands

There are over 800,000 km$^2$ (197 million acres) of surface freshwater within Canada's boreal forest—an

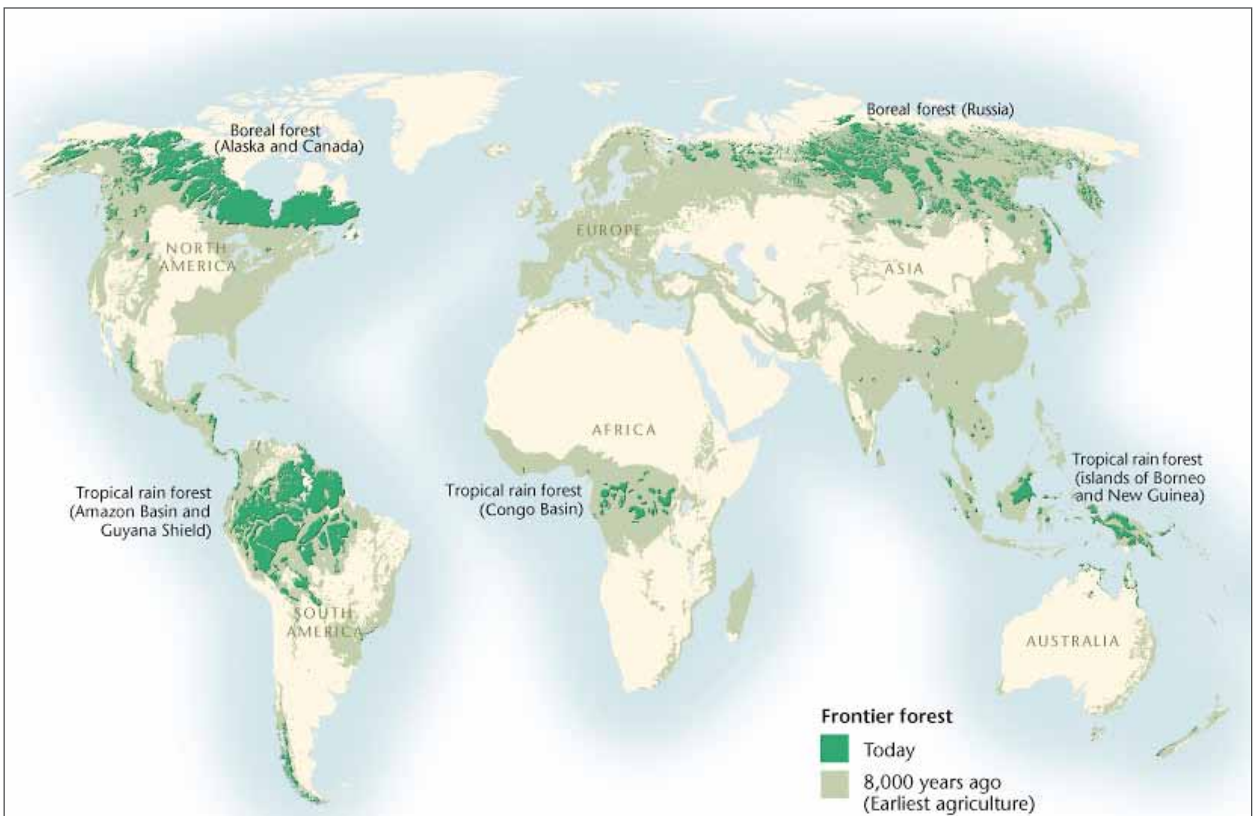



**Figure 2.** The largest intact forest regions on Earth are primarily in five regions. Canada's boreal forest region (with its adjoining region in Alaska) represents 54 percent of the world's intact boreal forests in 50,000-plus-hectare (123,500-plus-acre) blocks (www.IntactForests.org).

Map: Canadian Geographic

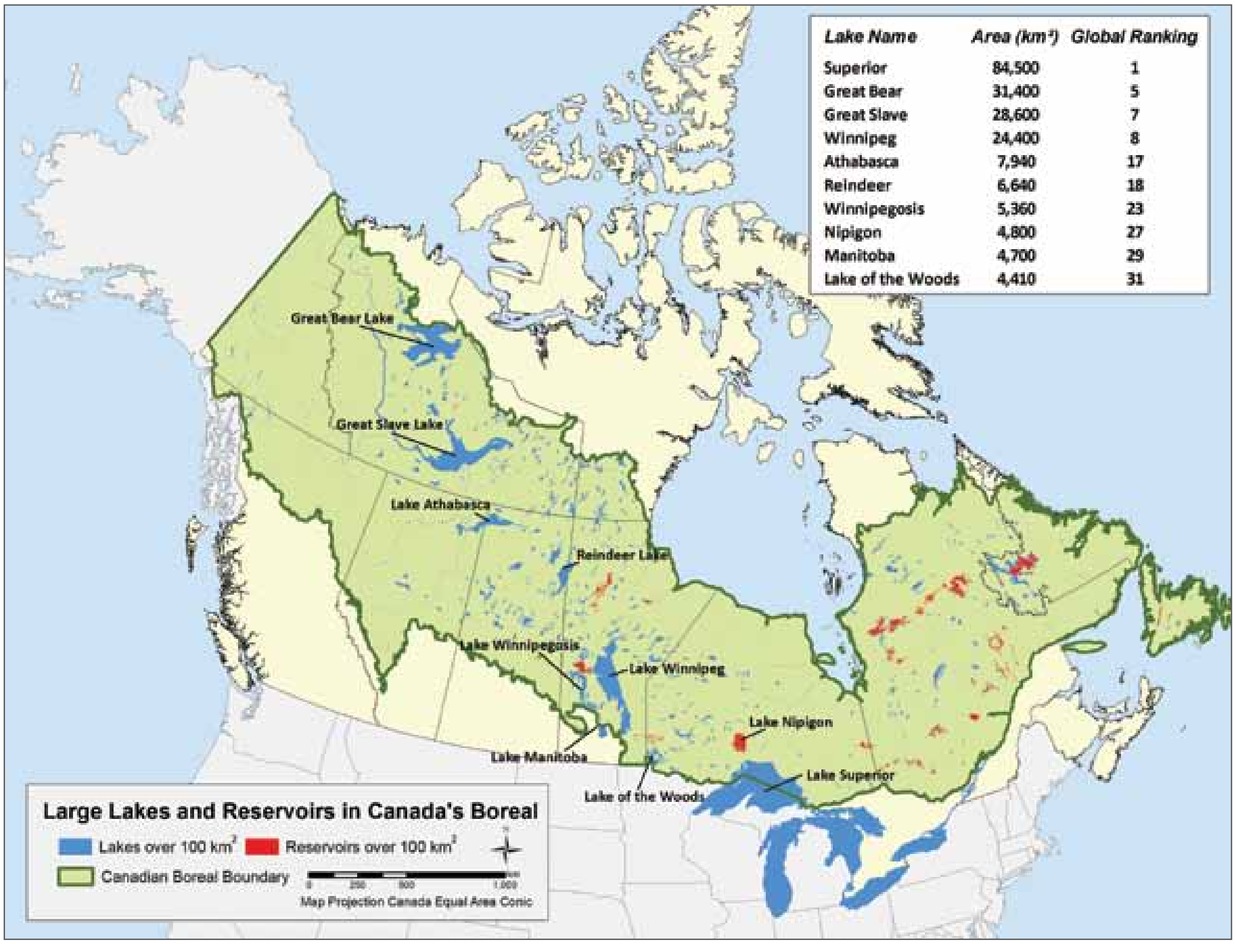



**Figure 3.** Canada's boreal forest region contains millions of lakes, including Lake Superior, Great Bear Lake and Great Slave Lake, which rank among the world's largest in both surface area and volume.

area larger than most of the world's nations (Environment Canada 2009a). This enormous volume of water gives life to diverse ecosystems, mitigates climate change and feeds some of the world's biggest and most economically important fisheries.

The boreal forest rivers and their watersheds—mosaics of interconnected forests, lakes, river valleys, wetlands, peatlands and tundra—drain into three oceans and the immense Hudson Bay. The Atlantic, Arctic and Pacific oceans receive huge volumes of freshwater from Canada's boreal forest. While the water is home to abundant fish, mussels and other species, the forests themselves provide critical habitat for wolves, grizzly bears, lynx and moose, and endangered species such as woodland caribou. Billions of songbirds and millions of waterfowl inhabit the interconnected boreal forests and wetlands.

### Greatest Lakes

Canada's boreal forest lakes (Fig. 3) represent the largest global source of available freshwater based in one country (Minns *et al.* 2008). Lake Superior is the world's largest freshwater lake by surface area. Great Bear Lake is the fifth largest in the world and the largest lake that is still pristine, with no evidence of human-caused siltation, toxic contamination, eutrophication or acidification (Herbert 2002). Great Slave Lake is the world's seventh-largest and sixth-deepest lake, reaching a depth of 614 metres (Shiklomanov and Rodda 2003).

Nearly half of the world's lakes larger than 1 $km^2$ (247 acres) are found in Canada's boreal forest (Minns *et al.* 2008). The region holds 600,000 lakes larger than 0.1 $km^2$ (25 acres), more than one-quarter of the global total (Minns *et al.* 2008) and millions of smaller lakes and ponds. Quebec alone harbors at least 3.5 million water bodies (Ducks Unlimited Canada, unpublished data).

### Largest Free-Flowing Rivers

Ten percent of the world's 50 largest rivers are in Canada's boreal region (Dai and Trenberth 2002). The rivers of the boreal stand apart for their length, the volumes of freshwater they contribute on a global scale and, most importantly, their relatively free-flowing and unfragmented nature.

The region contains the greatest number of large undammed, free-flowing river systems in North America (Fig. 4) (Dynesius and Nilsson 1994). The lack of dams enables these rivers to retain their natural seasonal flows and the biological communities adapted to them.

It is no coincidence that the largest wild salmon runs left in the Northern Hemisphere correspond with these free-flowing rivers, particularly for the remaining large Pacific and Atlantic salmon runs (Scott and Crossman 1998, Augerot and Foley 2005). More than 50 percent of the remaining rivers that support migratory Atlantic salmon are found within the boreal of Quebec and Newfoundland and Labrador. In contrast, this species has been lost

*Lake Superior is the largest freshwater lake in the world.*

CREDIT: GARTH LENZ


**Figure 4.** Canadian and Alaskan boreal forest regions contain a majority of North America's free-flowing rivers, which maintain globally significant water, nutrient and migratory fish movements between terrestrial and ocean ecosystems.

*Ten percent of the world's 50 largest rivers lie within Canada's boreal forest region.*
CREDIT: INNU NATION

*Globally, boreal forests contain more carbon-rich peatlands and wetlands than any other ecosystem on Earth.*
CREDIT: GARTH LENZ

from or is endangered in more than 150 rivers in New England and the Canadian Maritimes (Atlantic Salmon Federation 2010). On the West Coast, the Yukon and Stikine rivers are among the many boreal rivers that contain healthy populations of spawning Pacific salmon. Healthy populations of many other species of fish that migrate between rivers and the sea or within freshwater watersheds occur in the pristine rivers of Canada's boreal forest, including Atlantic sturgeon, Arctic char, Arctic grayling, brook trout, lake sturgeon, lake whitefish, inconnu and various Pacific salmon species (Morin *et al.* 1982, Reist and Bond 1988, Page and Burr 1991). Many of the migratory routes for these species include thousands of kilometres of river systems. For example, inconnu tagged in the Liard River in British Columbia were later found nearly 1,800 km (1,120 miles) downstream near Inuvik and Tuktoyaktuk—communities near the outlet of the Mackenzie River into the Beaufort Sea (Stephenson *et al.* 2005).

The longest river in the Canadian boreal forest is the Mackenzie, draining a watershed of 1.7 million km$^2$ (420 million acres) and 4,200 km (2,620 miles) in length, finally emptying into the Beaufort Sea (Culp *et al.* 2005). Several other rivers, including the Yukon, Slave, Nelson, Liard, Koksoak and Churchill, rank among North America's 20 largest rivers by discharge (Benke and Cushing 2005).

**Boreal Wetlands and Peatlands**

Canada's boreal forest contains what may be the world's largest total area of wetland habitats extending over more than 1.19 million km$^2$ (294 million acres) and representing 25 percent of the world's wetlands (Natural Resources Canada 2009a, Tarnocai 2009). In many northern and western parts of the boreal forest, groundwater flow interconnects wetland ecosystems across vast areas (Price *et al.* 2005).

Boreal wetland habitats vary from seasonally flooded forests, shrublands, dunes and meadows to continually water-saturated peatlands, fens, forests, taiga, marshes and tundra. Wetlands recharge aquifers, absorb and filter contaminants, regulate river flow by absorbing and releasing excess water, provide habitats for waterfowl, fish and other wildlife (Zedler and Kercher 2005, Natural Resources Canada 2009a), and store and release greenhouse gases, making them key regulators of climate (Millennium Ecosystem Assessment 2005).

Canada contains one-third of the world's total peatlands (Fig. 5), whose water-logged layers of partially decomposed vegetation store immense amounts of carbon (Tarnocai 2006, 2009). Peatlands are concentrated in northern countries, and Canada's 1.19 million km$^2$ (294 million acres) of peatlands contain 147 billion tonnes of carbon (Tarnocai 2006, 2009), or roughly 56 percent of Canadian soil organic carbon (Tarnocai 1998). The world's largest peatland system is found in the Hudson and James Bay lowlands, an area of 373,700 km$^2$ (92 million acres) spanning 900 km (560 miles) from northeastern Manitoba across northern Ontario to northwestern Quebec (Abraham and Keddy 2005, Warner and Asada 2006). In comparison to other countries, Canada's peatlands remain largely intact and undrained (Gorham 1991).

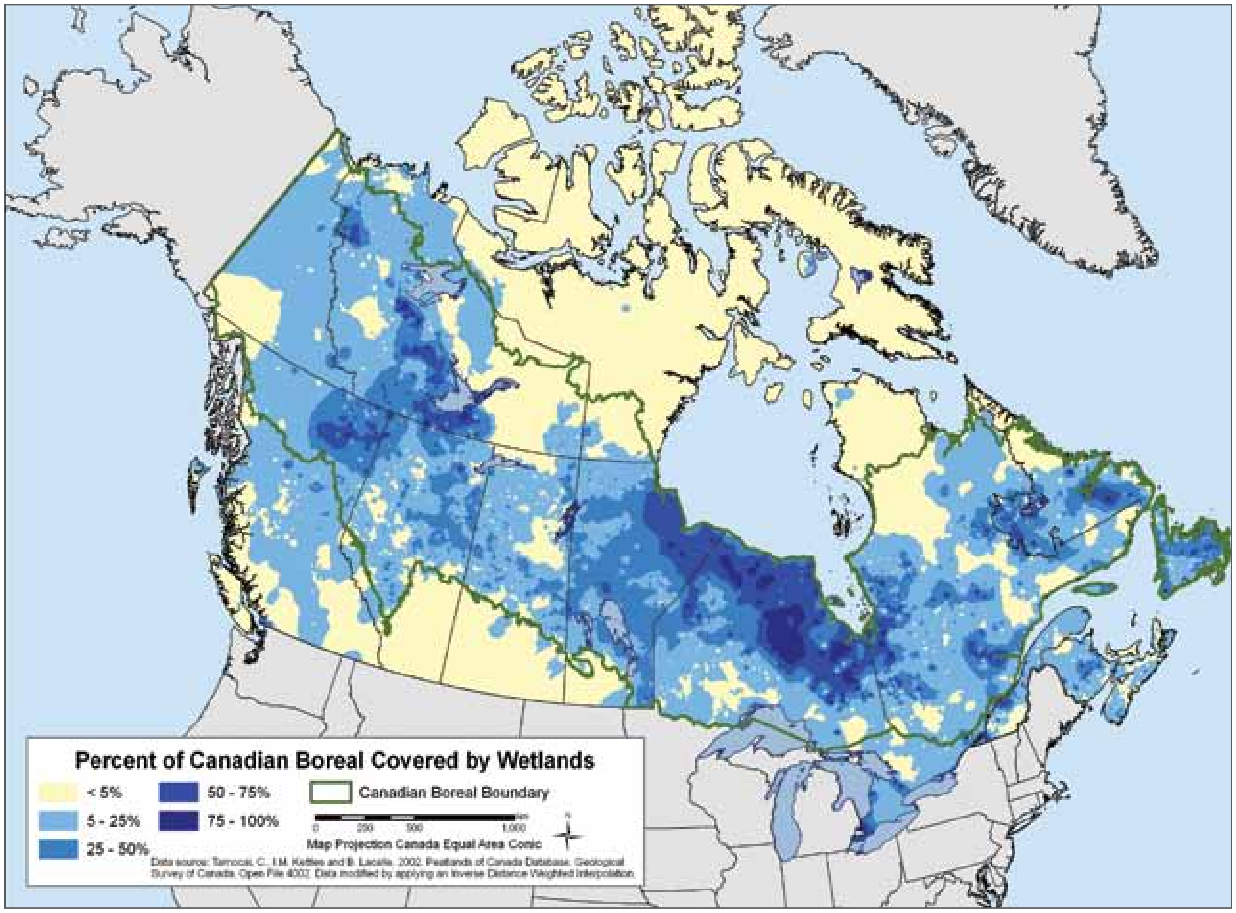



**Figure 5.** Peatlands across Canada store and sequester more carbon than any terrestrial ecosystem.

## How the Blue Forest Impacts Weather and Climate

The waterways, wetlands and forests of Canada's boreal forest have global, continental and regional impacts on short-term weather and long-term climate (Pielke and Vidale 1995, Taylor *et al.* 1998, Eugster *et al.* 2000). Modeling studies have demonstrated that the boreal has a complex and significant role in influencing global climate because of its large size and the interaction of forest cover and snow and ice cover on global energy budgets (Bonan 2008, Eugster *et al.* 2000, Pielke and Vidale 1995, Bonan *et al.* 1992). Evapotranspiration from forests is a known factor in heat transfer to the atmosphere, and large areas of forest, such as Canada's boreal, have a major cooling effect on climate during periods of active photosynthesis (Eugster *et al.* 2000). Large areas of respiring forest also increase humidity and precipitation at continental and regional levels (Pielke *et al.* 1998, Baldocchi *et al.* 2000, Eugster *et al.* 2000, Pielke 2001, Pielke 2007). Wetlands and large bodies of water, such as the many large lakes in the boreal, have profound impacts on regional weather by increasing precipitation, increasing local temperatures during winter, decreasing local temperatures during summer and generating local winds (Sun *et al.* 1997, Taylor *et al.* 1998, Lafleur 2008).

**THE CONFLICT OF WESTERN AND ABORIGINAL LAW OVER WATER RIGHTS**

Two diverging approaches to water rights and law in Canada: those that emerge from the western legal system, and those from aboriginal tradition. While both approaches recognize the importance of water as a common resource, differences between the two approaches are significant.

In aboriginal traditions, water is not to be owned, but must be protected and shared. No one use is paramount and the needs of all living things must be considered, in the effort to protect water for present and future generations.

Western law has come to view water as a commodity, with the Crown granting water rights to landowners and licensed users with different degrees of priority. Water quality is protected through federal laws prohibiting water pollution or habitat destruction (e.g., the Fisheries Act and the Canadian Environmental Protection Act), but other regulations fall under provincial jurisdiction. There are few enforceable legal standards for water quality, and permits and variations are routinely available to allow pollution or habitat loss to occur. *(Continued)*

*Evapotranspiration is one of many ways forests help regulate climate.*
CREDIT: GARTH LENZ

## Boreal Rivers, Sea Ice and Ocean Currents

The flux of freshwater from Canada's boreal forest into the world's oceans is a major contributor to northern sea ice conditions, which in turn help regulate global warming (Aagaard and Carmack 1989). This freshwater flow also serves as a hydrological engine that helps drive ocean currents, a major determinant of global weather dynamics and changes in temperature from global warming (Dai and Trenbeth 2002, Dai *et al.* 2009).

*Northern boreal rivers such as this one in Labrador contribute to ocean currents and sea ice as they flow into the open sea.*
CREDIT: LARRY INNES, CANADIAN BOREAL INITIATIVE

Freshwater flowing into the Arctic and other northern seas decreases the salinity of the water, allowing water to freeze more quickly and easily (Loeng *et al.* 2005). Sea ice supports much marine biodiversity including polar bears, ringed seals, walrus, bowhead whales, narwhals, belugas and many other species (Cobb *et al.* 2001, Reeves *et al.* 2002, Stewart and Lockhart 2005). It exerts a major cooling influence on global climate because it reflects large amounts of solar radiation back into space (Loeng *et al.* 2005).

The freshwater flow from the Mackenzie River alone contributes 12 percent of the Arctic Ocean's freshwater (Aagaard and Carmack 1989). This influences the strength and movement of major currents including the Beaufort Gyre. Freshwater masses from the Mackenzie have been traced throughout the Arctic Ocean over months and years as they move with the flow of the Beaufort Gyre and the Transpolar Drift (Rawlins *et al.* 2009), which carries cold, less-salty polar waters south into the deepwater North Atlantic Conveyer and back to the tropics, where the cycle is repeated (Meincke *et al.* 1997, Loeng *et al.* 2005).

Similar influences from other freshwater rivers in Canada's boreal forest support ice formation in the Hudson and James bays. This freshwater is carried northward to the Labrador Current and flows south into the North Atlantic (Myers *et al.* 1990, DeBoer and Nof 2004, Loeng *et al.* 2005).

Freshwater from the Yukon River flowing into the Bering Sea similarly contributes to the extensive sea ice of the Bering Sea and its rich marine life. After entering the Bering Sea, water from the Yukon River continues north, eventually contributing to the North Pacific Current that rushes through the Bering Strait into the Arctic Ocean (Loeng *et al.* 2005, Woodgate *et al.* 2006).

**Carbon Storage in Canada's Boreal Forest Waterways, Wetlands and Peatlands**

Globally, the boreal forest biome is the world's largest and most important forest carbon storehouse (Pimm *et al.* 2009, Tarnocai *et al.* 2009, Carlson *et al.* 2009, 2010), holding almost twice as much carbon per unit area as tropical forests (Intergovernmental Panel on Climate Change 2000).

Canada's boreal forest and peatland ecosystems are estimated to store 208.1 billion tonnes of carbon—the equivalent of 26 years of global carbon emissions from fossil fuel burning, as measured in 2006 (Carlson *et al.* 2009, 2010).

Vast carbon stores also occur in sediments of deepwater lakes and in alluvial river deposits (Tarnocai *et al.* 2009, Schindler and Lee 2010). Rivers play a large but historically underestimated role in the transfer of carbon from forests and soils to lakes and ocean basins (Battin *et al.* 2009, Schindler 2009). Inland waters globally have been recently estimated to transport and store in sediments approximately 2.7 billion tonnes of carbon annually (Battin *et al.* 2009). Lake sediments across the boreal forest biomes of North America, Russia and Scandinavia are estimated to contain at least 120 billion tonnes of carbon. Recent estimates place the amount of carbon stored in alluvial deposits for

*Boreal wetlands such as these in the Northwest Territories are some of the world's most significant storehouses of terrestrial carbon.*
CREDIT: CHAD DELANY

*(Continued)*
Despite the treaties between the Crown and First Nations, and the status of aboriginal and treaty rights and titles guaranteed by Section 35 of Canada's Constitution, there remains significant ambiguity over the question of aboriginal water rights in Canada. As a consequence, conflicts between aboriginal peoples and the Crown over industrial development and other economic activity that affect water quality and quantity are inevitable. Several such conflicts are now before the courts, addressing issues that include the validity of permits issued by the Crown to industries whose activities diminish or degrade water sources required for aboriginal subsistence, or challenging withdrawal from water flowing through aboriginal lands that result in alterations in rate, quantity or quality of water.

There is a pressing need in Canada to reconcile these two perspectives on water. Adopting a more inclusive and coherent system of regulation that reflects both aboriginal and western values can effectively steward this shared and essential resource.

major rivers in all boreal forest biomes globally at 241 billion tonnes (Tarnocai *et al.* 2009). Carbon storage has been estimated at 41 billion tonnes in deep sediments of the delta of the Mackenzie River and 16 billion tonnes in the delta of the Yukon River (Tarnocai *et al.* 2009).

## The Fabric of Life for Thousands of Years

The vast network of rivers, lakes and wetlands within Canada's boreal forest are the fabric of life for the hundreds of aboriginal communities that have made it their home for millennia. As stewards of the water for thousands of years, aboriginal peoples have long known the importance of respecting water and maintaining healthy ecosystems. The values the water provides, including drinking water, food and transportation, are just as important today as they were thousands of years ago (Notzke 1994).

*Willard Bitton of Poplar River First Nation crosses to his fall moose-hunting grounds.*
CREDIT: GARTH LENZ

Fish, waterfowl and freshwater-dependent mammals, such as beaver and moose, have been important staples for the aboriginal peoples of Canada's boreal forest since time immemorial. Freshwater plants, such as wild rice, are also important nutritional sources for a variety of groups (Karst 2010). Aboriginal peoples of the boreal forest continue to fish, trap, collect and hunt freshwater-dependent species of plants and animals for sustenance. Protecting the health of natural food sources is increasingly important as they provide healthy, cheap and abundant alternatives to shipped and packaged food. Commercial and recreational fishing and hunting have also provided income for many communities that have few other economic opportunities.

In the extensive parts of the Canadian boreal forest dominated by thick wetland forests, soggy marshes and peatlands, summertime overland travel can be difficult. Accordingly, the region's vast network of interconnected lakes and rivers is one of the most efficient transportation corridors. As a result, many aboriginal groups depend on water as their primary means for transportation and shipping. Many isolated communities rely entirely on boats and floatplanes for supplies and transportation. In the Northwest Territories, the majority of food and supplies brought to the aboriginal communities on and around the Mackenzie River are brought by barges from the south. In addition, many communities use small watercraft to travel to key fishing or hunting grounds.

Water is also a source of deep spiritual connections for aboriginal people so contamination and degradation of the water they use threatens not only the health and sustenance of their communities, but can also result in significant impacts on their well-being.

## CASE STUDY: FROM THE BOREAL FOREST TO THE SEA

The Earth's water cycle is a key factor in climate, ecology and biogeochemical cycles at both regional and global scales (Aagaard and Carmack 1989, Vorosmarty and Sahagian 2000). Rivers play a critical role in water cycling between land and ocean systems. Freshwater runoff from rivers into oceans maintains the balance of freshwater and affects ocean salinity, a key factor in the formation of sea ice at northern latitudes (Dai and Trenberth 2002, 2009). Rivers transport not only water, but also sediment, chemicals and nutrients from land to estuaries and ocean ecosystems.

The massive discharge of freshwater, sediments and nutrients from the many large, free-flowing rivers of Canada's boreal forest into the Atlantic, Pacific and Arctic oceans is a critical engine behind large ocean currents and productivity that influences global climate, marine biodiversity and food security (Fig. 6) (Dai and Trenbeth 2002).

The estuary and marine environments at the mouths of river systems draining Canada's boreal forest sustain healthy ecosystems that support rich marine fisheries, major seabird colonies and marine mammal populations. Beneficial influences that the boreal forest river systems have on the world's oceans (modified from Cobb *et al.* 2001) include:

- the nature and duration of ice cover;
- habitats of marine mammals, fish and migratory birds;
- drivers of major ocean currents;
- seasonal and annual loads of sediment and nutrients to marine ecosystems; and
- habitat that supports anadromous (species that migrate from oceans to freshwater to spawn) fish populations.

### St. Lawrence Basin

Boreal rivers flowing into the Gulf of St. Lawrence and the marine environments of Newfoundland and Labrador are crucial for maintaining ecosystems that support belugas, blue, humpback, fin and minke whales, as well as harbor, grey, hooded and harp seals, and many species of fish and invertebrates (Vincent and Dodson 1999, Fisheries and Oceans Canada 2005). Commercially important herring, mackerel, cod, capelin, striped bass, lobster, scallop and crab all use the St. Lawrence during some phase of their life cycle (Fisheries and Oceans Canada 2005). These rich marine fish communities also support world-famous seabird colonies (Gauthier and Aubry 1996).

### Hudson and James Bay Basin

Watersheds of rivers that flow into Hudson Bay and James Bay encompass over a third of Canada and together account for nearly 20 percent of freshwater flow into the Arctic Ocean (Dery *et al.* 2005, NTK 2008). The flow of freshwater and nutrients are critical inputs into the estuaries and marine ecosystems of Hudson Bay and James Bay, supporting rich wildlife and fish communities (Stewart and Lockhart 2005, Sherman

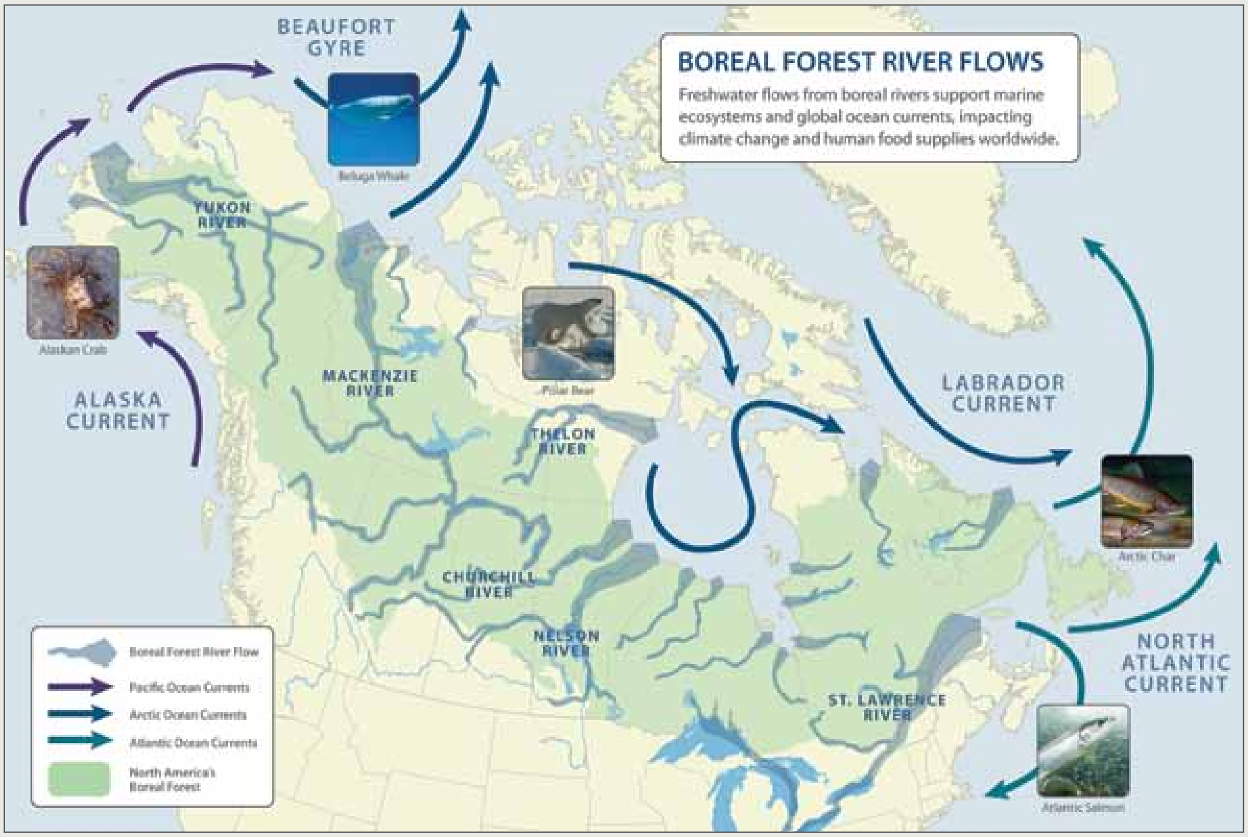



**Figure 6.** Large rivers that originate in and flow across Canada's boreal and Arctic regions contribute a majority of the freshwater input into the Arctic Ocean, Pacific Ocean and Hudson Bay, which through ocean currents feed into the Atlantic Ocean. These freshwater and nutrient inputs are vital to productivity of estuaries and to the maintenance of sea ice formation and biodiversity levels in freshwater and marine ecosystems.

and Hempel 2008). The region's salt marshes and eelgrass beds also support globally significant concentrations of birds including millions of geese, ducks and shorebirds, while the estuaries and river systems are home to at least six species of anadromous fish. Walrus and polar bears are common to the region, along with at least five species of whales (including belugas and narwhals) and five species of hair seals. Many of these species provide an important source of food to local aboriginal communities. A number of marine mammals have particular associations with the freshwater estuaries of the region. Beluga whales concentrate in many of these estuaries by the thousands, perhaps because the freshwater may assist in molting and the survival of calves (Stewart and Lockhart 2005). An unusual population of harbor seals that are year-round inhabitants of a number of the estuaries, rivers and lakes along Hudson and James Bay may be a distinct subspecies or species (Stewart and Lockhart 2005).

### Mackenzie River Basin

The Mackenzie is the longest river in the Canadian boreal. Its massive flows of freshwater and sediments into the Beaufort Sea play a major role in the functioning and support of the region's highly productive environment and have a major impact on Arctic ice formation and currents (Carmack and MacDonald 2002, Dunton *et al.* 2006). The Beaufort Sea supports one of the world's largest populations of belugas, more than 10,000 migrating bowhead whales, and hosts nesting and resting places for millions of birds including brant, thick-billed murres and snow geese (Dickson and Gilchrist 2002, Oceans North 2010). More than 70 species of fish occur here in abundance including Dolly Varden, wolffish, Arctic cod, Arctic char, cisco, whitefish and Pacific herring (Cobb *et al.* 2008, Oceans North 2010).

### Yukon River Basin

The Yukon, the second-longest river in Canada's boreal forest, is shared by Canada and Alaska and provides a major proportion of the input of freshwater and nutrients to the Bering Sea, one of the most ecologically and economically productive marine ecosystems on Earth. The headwaters of the Yukon River start in the mountains of the Yukon and British Columbia (Benke and Cushing 2005). About 40 percent of the Yukon's drainage basin lies within Canada's boreal forest, mostly in the Yukon Territory and includes the Porcupine and Old Crow rivers as well as Old Crow Flats, a massive freshwater marsh and lake complex of 600,000 hectares (1.5 million acres) (Benke and Cushing 2005). Old Crow Flats supports an estimated 500,000 nesting waterfowl annually among its more than 2,000 lakes and ponds (Ramsar Convention 2010).

The Yukon flows through Alaska to feed the Yukon-Kuskokwim Delta, a region that supports one of the most globally outstanding concentrations of nesting and migrating birds, including up to 750,000 swans and geese, 2 million ducks, and 100 million shorebirds and seabirds (Chipley *et al.* 2003). Many of the world's rarest waterfowl species breed here, including the emperor goose, Steller's eider and spectacled eider (Wells 2007). The Bering Sea, into which the Yukon discharges its freshwater, sediments and nutrients, is famously productive with at least 450 species of fish, 50 species of seabirds and 26 species of marine mammals. Among its seabirds are several species found nowhere else on Earth, including the red-legged kittiwake and red-faced cormorant. Among its many special marine mammals are Steller's (northern) sea lions, Pacific walrus, northern fur seals, spotted (largha) seals, ribbon seals, North Pacific right whales, bowhead whales, grey whales and beluga. About half of all commercial fish caught in U.S. fisheries come from the Bering Sea, as does about a third of Russia's commercial fisheries harvest (WWF 1999).

**RAMSAR WETLANDS IN CANADA'S BOREAL FOREST**

Canada has the largest number of internationally recognized wetlands in the world as designated by the Ramsar Convention on Wetlands (2008), with 10 sites close to or within Canada's boreal forest region (Fig. 7). Many of these wetlands are designated as critical sites for birds.

- **Polar Bear Provincial Park:** 2.4 million hectares (5.9 million acres) along Ontario's Hudson Bay shoreline, which supports at least 50,000 breeding waterfowl, the entire breeding population of a subspecies of marbled godwit and, during migration, more than a million geese and ducks (Ramsar Convention 2010).
- **Whooping Crane Summer Range in the Northwest Territories:** 1.7 million hectares (4.2 million acres), encompassing the entire natural breeding range of globally rare whooping crane.
- **Old Crow Flats:** 617,000 hectares (1.5 million acres, or nearly double the size of Rhode Island). Globally unique wetlands where 2,000 lakes and ponds support as many as 500,000 breeding waterfowl each summer;
- **Peace-Athabasca Delta in northern Alberta:** 321,300 hectares (794,000 acres). Three river deltas, four large lakes and an expanse of shallow ponds and wetlands provide habitat for millions of waterfowl, shorebirds and other wetland-dependent species. Open meadows support wild populations of wood bison.

*(Continued)*

# Biodiversity Of the Boreal

### Boreal Birds and Water

Birds are one of the most visible and well-known of the species groups for which Canada's boreal wetlands provide abundant habitat. The boreal forest of North America is estimated to support between 1 billion and 3 billion breeding birds each year and by fall, when adults are joined by young birds, as many as 3 billion to 5 billion birds migrate south to become the migrant and wintering birds of the United States, Mexico and the rest of the Americas. This means that, on average, from August to November, roughly 30 million to 50 million birds must fly over the Canada-U.S. border each day on their way south. Boreal forest wetlands of Canada and Alaska, in conjunction with adjacent and connected forest and riparian ecosystems, provide nesting habitat for an estimated 26 million waterfowl of 35 species (Blancher and Wells 2005). Eastern populations of harlequin duck and Barrow's goldeneye, both listed as of special concern by Canada's Committee on Status of Endangered Wildlife in Canada (COSEWIC 1990), are dependent upon rivers, lakes and ponds in eastern Canada's boreal forest.

Boreal forest wetlands are also vital breeding and migratory stopover locations for shorebirds—a term typically reserved for the sandpipers and plovers. Approximately 75 percent of all regularly occurring North American shorebird species use the boreal forest wetlands for migratory stopover and/or breeding. Seven million shorebirds are estimated to use wetlands in the boreal forest of Canada and Alaska for breeding, with millions more using the wetlands during migration. Shorebirds with greater than 50 percent of their breeding populations in the boreal forest of Canada and Alaska include: greater and lesser yellowlegs, solitary and spotted sandpiper, least sandpiper, wandering tattler, surfbird, whimbrel, semipalmated plover, Hudsonian godwit, short-billed dowitcher, Wilson's snipe and red-necked phalarope (Blancher and Wells 2005).

*The wetlands and waterways of Canada's boreal forest provide ideal habitat for a wide range of birds, including the short-billed dowitcher.*

CREDIT: JEFF NADLER

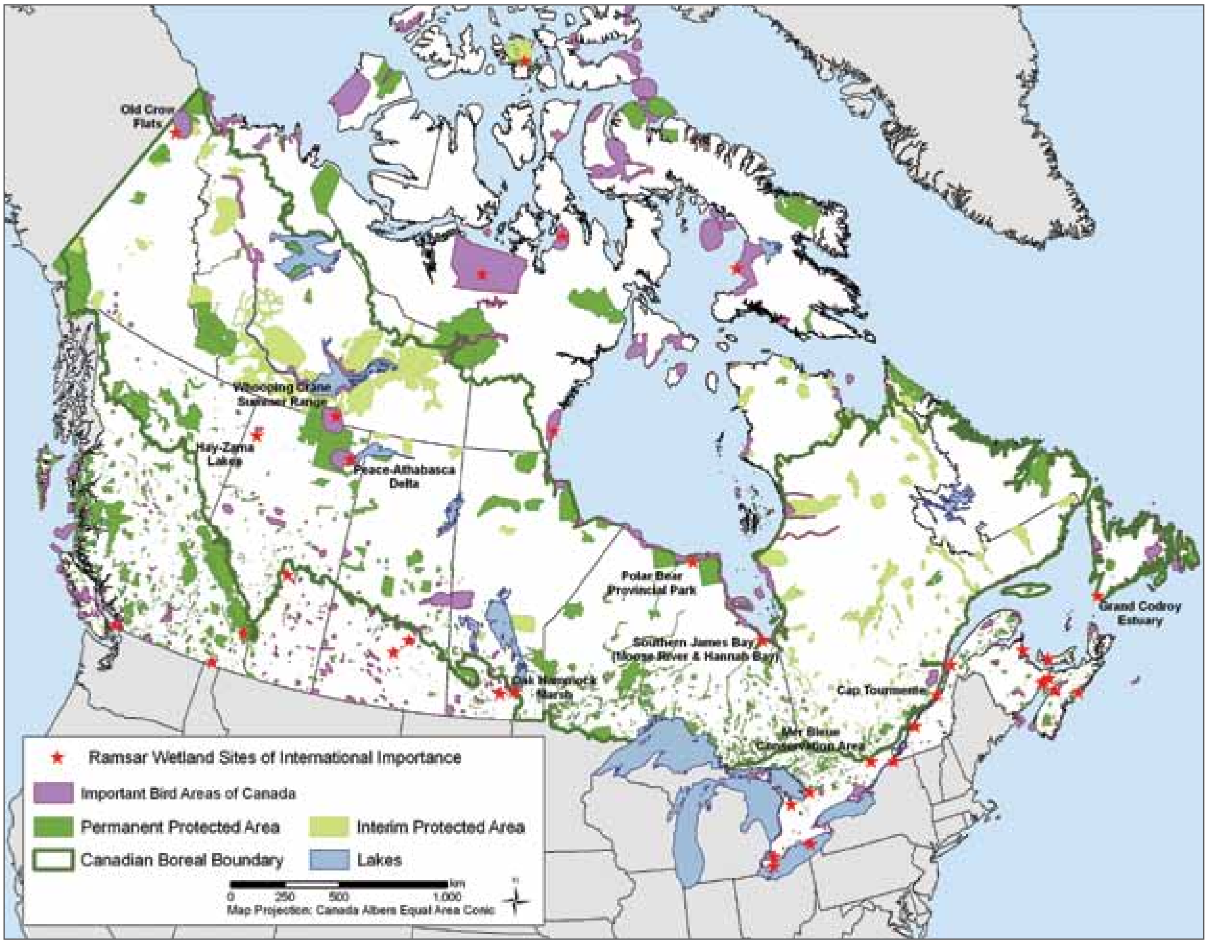



**Figure 7.** Ramsar Sites and Important Bird Areas in Canada's boreal forest.

Canada's boreal forest wetlands are similarly critical for a host of other wetland-dependent bird species. More than half of the world's Pacific loons, horned grebes, red-necked grebes, yellow rails, soras, mew gulls and Bonaparte's gulls, for example, all raise their young in boreal forest wetlands of Canada and Alaska. White pelicans and Caspian terns also have large nesting colonies at sites within Canada's boreal forest region. Many songbirds, including the alder flycatcher, palm warbler, northern waterthrush, Connecticut warbler and rusty blackbird, are particularly reliant on boreal wetlands for their survival because more than half of their breeding ranges are in the boreal forest of Canada and Alaska.

Within Canada's boreal forest region lie sites that have been recognized as among the world's most important wetlands for birds (Fig. 7). The Hudson Bay lowlands region of Ontario and Manitoba is the most significant breeding area for nesting shorebirds in central Canada (Environment Canada 2003). The Peace-Athabasca Delta in northern Alberta has been designated a Ramsar site of international significance as well as a global-level Important Bird Area. Surveys in the 1970s estimated up to 1.4 million waterbirds were using the Peace-Athabasca Delta during fall migration (Hennan 1974). Limited aerial surveys of shorebirds in the Delta in 1999 found single-day counts of 11,000 and 14,000 birds. Aerial surveys of the Peace-Athabasca Delta in late June and July 1998-2001 found as many as 400,000 molting ducks, coot and geese. In August and September in those same years, numbers peaked at 800,000—a

*(Continued)*

- **Southern James Bay (Moose River and Hannah Bay) in Ontario:** 25,290 hectares (62,500 acres).
- **Hay-Zama Lakes in Alberta:** 50,000 hectares (124,000 acres).
- **Grand Codroy Estuary in Newfoundland:** 925 hectares (2,285 acres).
- **Cap Tourmente in Quebec:** 2,398 hectares (5,925 acres).
- **Mer Bleue Conservation Area:** 3,343 hectares (8,260 acres).
- **Oak Hammock Marsh in Manitoba:** 3,600 hectares (8,900 acres).

*More than half of the world's horned grebes raise their young in Canada and Alaska's boreal forests.*
CREDIT: GLEN TEPKE

number that exceeds the human population of the city of Edmonton (Butterworth *et al.* 2002, Thomas 2002).

Other Ramsar sites include Old Crow Flats in the Yukon, which supports up to 500,000 breeding waterfowl in its more than 2,000 freshwater lakes and ponds, and Ontario's Polar Bear Provincial Park, which supports at least 50,000 breeding waterfowl, the entire breeding population of a disjunct subspecies of marbled godwit and, during migration, more than a million geese and ducks (Ramsar Convention 2010).

**Last Stand for World's Great Fish**

The fish that thrive in the lakes, rivers and estuaries of Canada's boreal forest region are legendary. Worldwide, freshwater fish communities have been severely altered by migration barriers, overfishing, pollution and introductions of alien species (Dudgeon *et al.* 2005). But with exception of the southern fringes and Great Lakes region, relatively few of these problems have affected aquatic communities in the boreal forest. As a result, many aboriginal communities continue to subsist on local fisheries while sport fisheries attract visitors from across the world. Migratory subsistence and sport fish, including Atlantic salmon, chum salmon, sea run brook trout, Arctic char, rainbow smelt and inconnu, still exist in healthy populations in rivers within Canada's boreal forest that provide hundreds of thousands of kilometres of access to spawning habitats unimpeded by dams and unaltered by pollutants and alien invaders (Scott and Crossman 1973, Morin *et al.* 1982, Page and Burr 1991, Parrish *et al.* 1998, Augerot and Foley 2005, Culp *et al.* 2005, Stephenson *et al.* 2005, Browne 2007).

More than 50 percent of North America's rivers that support Atlantic salmon are within the Canadian boreal (Fig. 8). The bulk of the original range with self-supporting populations (i.e., not stocked with hatchery-raised fish) of many other fish also occur in the forest region, including lake whitefish, inconnu, Arctic grayling, lake trout, brook trout and northern pike. The shortjaw cisco is confined virtually exclusively to the waters of Canada's boreal region and is listed as Threatened in Canada (Page and Burr 1991).

Canada's boreal forest fish are also famed for their abundance and size. The world record lake trout taken by sport fishers was a 72-pound trout taken on Great Bear Lake, where fish weighing 30 to 50 pounds are regularly taken by sport fishers. There are unconfirmed reports of lake trout as large as 100 pounds having been taken by commercial gill-netters on Great Bear Lake or Lake Athabasca (D. Schindler, personal communication). The world record brook trout (14 lbs. 8 oz.), Arctic grayling (5 lbs. 15 oz.) and round whitefish (6 lbs.) all came from rivers within the boreal forest (International Game Fish Association 2010).

Canada's boreal forest lakes often sustain abundant fish populations largely because they are free from heavy fishing pressure, pollutants and invasive species. And because of the cold temperatures and lower ecological productivity of these lakes and rivers, the fish that live in them are very slow growing. This means that the very large fish that occur in these waters are also very old fish (Sullivan 2003, Browne 2007). The low ecological productivity and skewed age distributions of fish populations in many of the lakes of the boreal forest means that their fish populations are unable to withstand intensive fishing pressures or other disturbances.

Fish species that migrate as juveniles from inland rivers to the sea and back to the same inland rivers as adults to spawn are vitally important in the

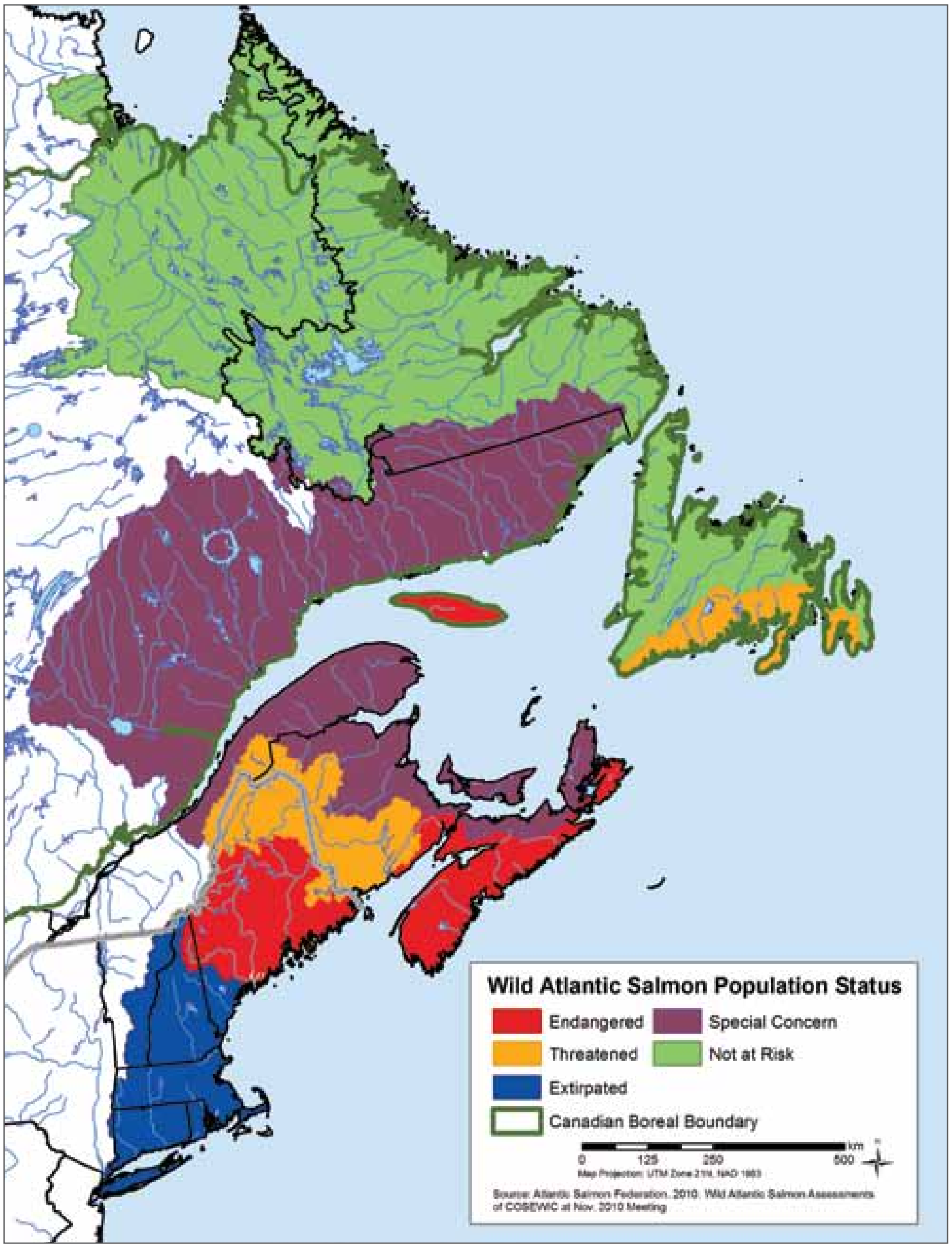



**Figure 8.** The intact watersheds and free-flowing rivers of Newfoundland and Labrador and Quebec provide critical spawning and rearing habitat for the largest populations of Atlantic salmon as compared with the original distributions in southern Canada and the United States, of which most are now extirpated or declining.

*Canada's boreal forest produces some of the largest and most abundant freshwater fish in the world.*

CREDIT: DAVID NUNUK

transfer of nutrients to upstream and inland watersheds. Salmon runs to some Alaskan lakes are estimated to add between 27 and 170 tonnes of phosphorus to the lakes in some years (Willson *et al.* 1998). Birds and mammals that prey on abundant migratory fish populations effectively transfer the nutrients that fish accumulate in marine environment to the lands surrounding the inland watersheds where the fish have come to spawn (Willson *et al.* 1998).

## Boreal Mammals and Water

The life cycles of many of Canada's boreal forest mammal species are closely tied to its waterways and wetlands. Caribou, brown bears, moose, elk and wolves use riparian areas and maintain trail networks, especially along riverbanks (Naiman and Decamps 1997).


*The world's largest beaver dam in Wood Buffalo National Park as seen from space. The dam spans an astonishing 850 metres (2,790 feet), or twice the length of the Hoover Dam.*
IMAGE: DIGITALGLOBE VIA GOOGLE EARTH

Moose are perhaps among the most emblematic of the large mammals that make significant use of boreal waterways and wetlands for foraging during the summer months; but beaver, otter, muskrat and mink are perhaps the mammals most reliant on the forest's waterways and wetlands. All of these species played an important economic and historical role in settlement across Canada (Naiman *et al.* 1988).

Many of the small mammals that provide the bulk of the food for predatory birds and mammals are found in highest densities in and near waterways and wetland habitats. These include the taiga vole, northern bog lemming, water shrew and cinereus shrew (Bowers *et al.* 2004).

Beavers are ecosystem engineers. They are recognized for their important ecological roles in structuring both physical and biological communities (Naiman *et al.* 1986, 1988). Beaver dams slow current, increasing lateral flow and enhancing nutrient deposit across broad areas. Presence of intact beaver dams increases habitat diversity as well as freshwater and adjacent terrestrial biodiversity. Insect biomass and abundance increases fivefold (Aznar and Desrochers 2008, Humphries and Winemiller 2009) in areas with beaver dams, increasing overall abundance of fish and amphibians while also providing abundant resources for breeding waterfowl, osprey and other bird species such as woodpeckers, kingfishers and flycatchers (Wright *et al.* 2002). During drought conditions, beaver dams can help retain water bodies critical for retention of biological communities on the landscape (Hood and Bayley 2008).

## Boreal Bugs

Canada's boreal forest is famous—or infamous—for the staggering abundance of water-dependent insects that develop in freshwater and hatch into flying adult forms during warm spring and summer months. Those that require blood meals, notably mosquitoes, black flies and biting midges, can make life difficult for humans and many large mammals. However, the sheer abundance of insects also provides the fuel that drives the survival and

*The boreal forest's vast networks of wetlands provide prime breeding habitat for wetland-dependent insects.*
CREDIT: GARTH LENZ

reproduction of billions of animals that breed within the boreal forest.

For example, a study of five species of diving ducks that commonly breed in the Canadian boreal showed that they produced more offspring in years of high aquatic insect abundance (Gardarsson *et al.* 2004). The billions of long-distance migratory songbirds that nest in the forest make extensive use of aquatic insects both during migration (Smith *et al.* 2004) and breeding. Most fish species are dependent on aquatic insects during some stage of their life cycle.

A large number of insects are found only or primarily in waterways, wetlands and peatlands within Canada's boreal forest region, including species of dragonflies, butterflies, beetles and chironomid flies (Fig. 9) (Spitzer and Danks 2006). The number of dragonfly species with distributions centered within Canada's boreal forest is impressive, and includes the lake darner, zigzag darner, boreal snaketail, Quebec emerald, Hudsonian emerald, Kennedy's emerald and boreal whiteface (Cannings and Cannings 1994, Dunkle 2000).

Wetland-dependent butterflies with most of their range within Canada's boreal forest include the cranberry blue, bog fritillary, titania fritillary, disa alpine and the jutta Arctic (Opler and Malikul 1992). Canada's peatlands also support specialized species, such as the bog katydid, sphagnum bog cricket, pitcher plant midge and pitcher plant mosquito (Capinera 2004, Spitzer and Danks 2006).

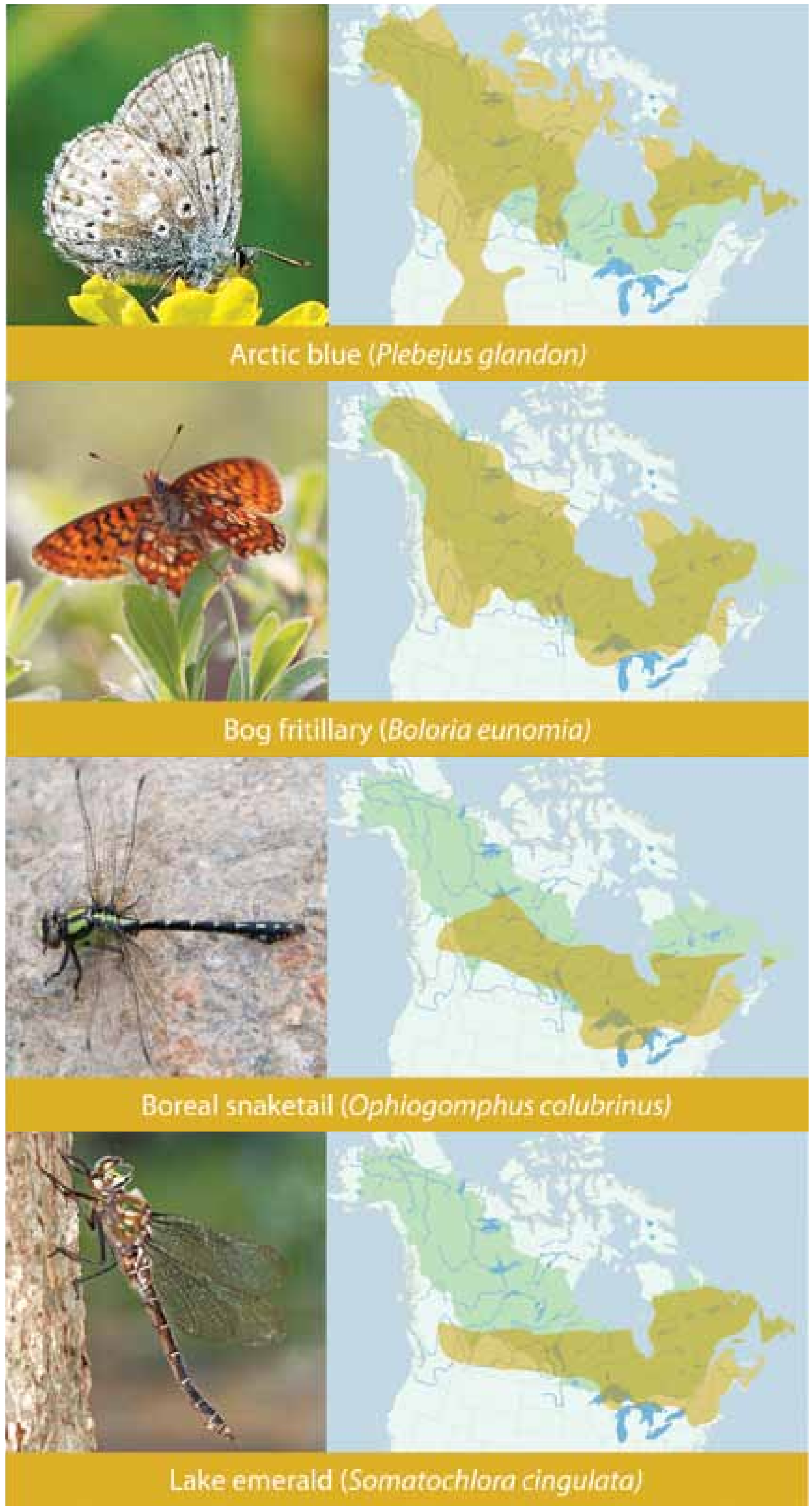
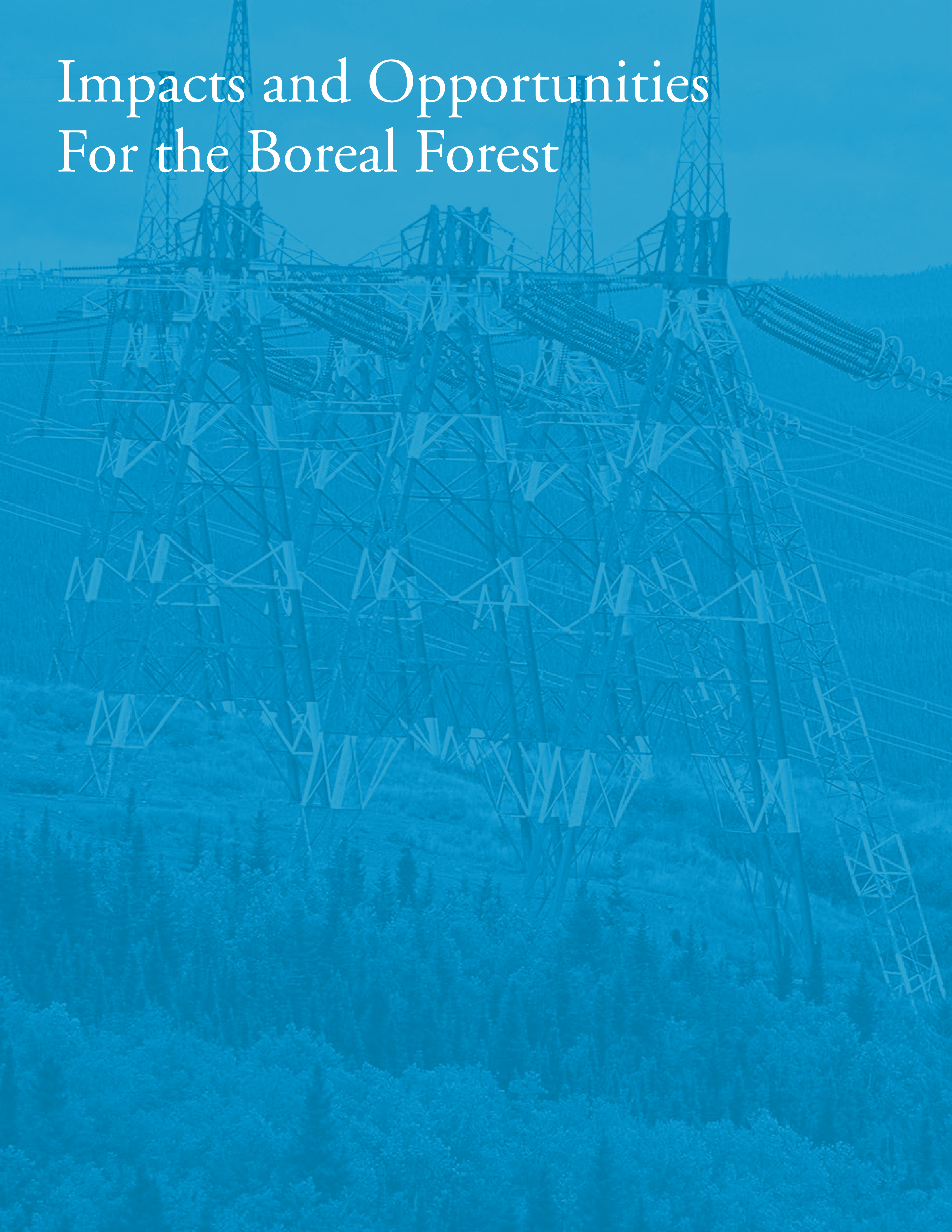



**Figure 9.** Range distributions of the Arctic blue, bog fritillary, boreal snaketail and lake emerald. The ranges of many insects are largely confined to the boreal forest region of Canada and Alaska.

IMAGE CREDITS: RICH KELLY (ARCTIC BLUE), JOEL KITS (BOG FRITILLARY), DENIS DOUCET (BOREAL SNAKETAIL AND LAKE EMERALD)

# Impacts and Opportunities For the Boreal Forest



## What Future For the Blue Water Forest?

Clearly the pristine waterways and wetlands within Canada's boreal are not only influential to the world's climate and oceans but also contain globally unique biodiversity features and sustenance for human communities. However, even this last great intact ecosystem is increasingly affected by the same issues that threaten freshwater ecosystems worldwide. The footprint of natural resource extraction industries within the southern portion of the boreal forest already encompasses an area of 730,000 $km^2$ (180 million acres), largely from forestry, hydropower, mining industries, and oil and gas extraction. These industrial activities not only alter hydrology, remove water from systems, increase erosion and siltation, and increase pollutants in aquatic systems, but also increase access for human populations to once isolated lakes, rivers and wetlands through networks of roads and pipelines (Fig. 10). Increased human access to lakes, rivers and wetlands increases the chances of introductions of nonnative invaders and overexploitation of fisheries and other wildlife (Post *et al.* 2002, Allen *et al.* 2005, Leprieur *et al.* 2008). Hydropower installations establish barriers that prevent access of migratory fish to areas for reproduction, can cause dramatic changes in flows of freshwater, sediments and other nutrients to oceans, alter flow cycles that maintain aquatic ecosystems, and inundate massive areas of forest and peatland habitat (Dynesius and Nilsson 1994, Vorosmarty and Sahagian 2000, Dudgeon *et al.* 2005, Nilsson *et al.* 2005, Poff *et al.* 2007).

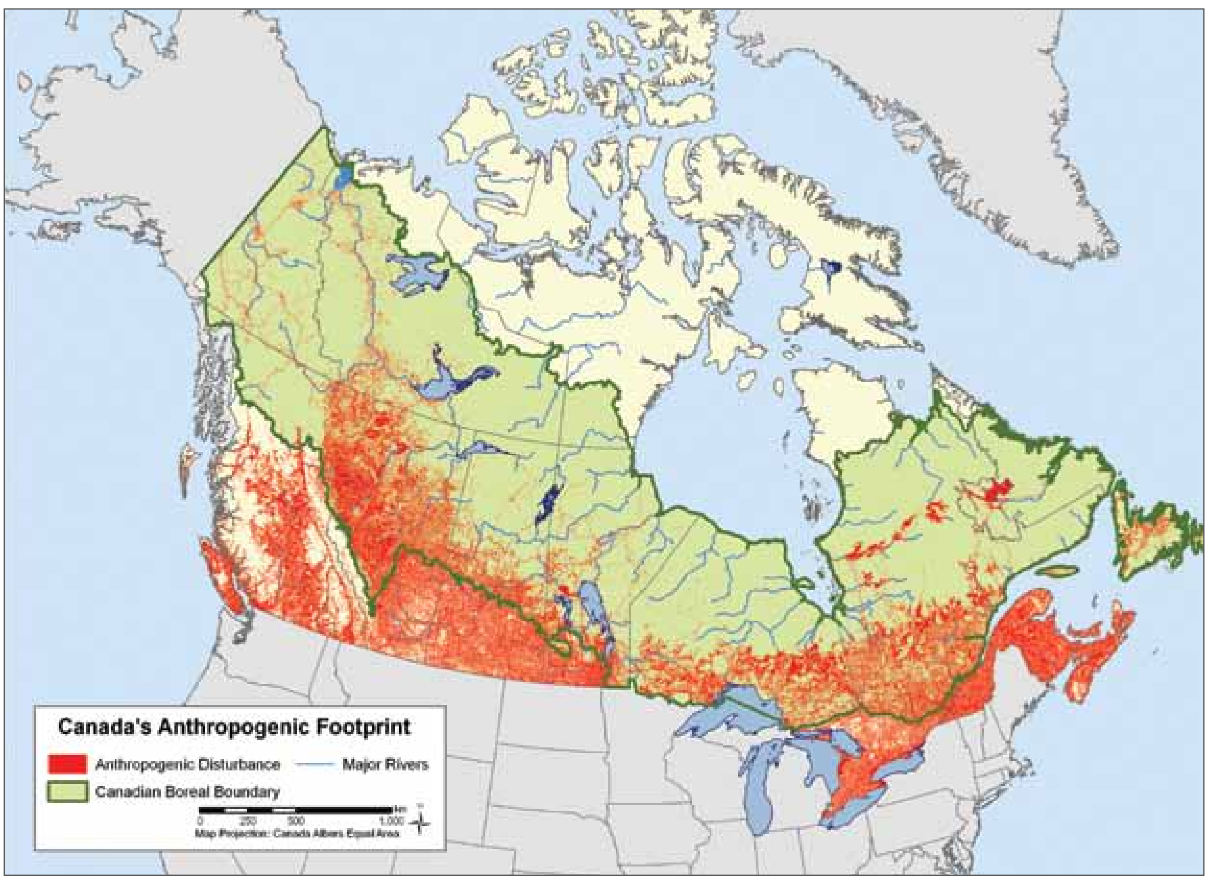



**Figure 10.** The anthropogenic footprint is most prominent in southern Canada but is rapidly expanding north into the last intact ecosystems of the country's boreal forest region. Expansion of natural resource extraction industries into boreal regions threatens freshwater ecosystem integrity and "free" ecosystem services.

*Outdated mining laws in many parts of Canada allow for free-entry mining, often lacking an application process or environmental review.*
CREDIT: GARTH LENZ

## Mining and Oil and Gas

The mineral resources of Canada's boreal forest region have been the focus of extractive industries for more than 200 years. This long history of development has left Canada's boreal forest region with approximately 7,000 abandoned mines requiring varying degrees of rehabilitation and 105 active mines. More than 3,000 of the abandoned mines are within one kilometre (0.62 miles) of a lake, river or stream (Global Forest Watch, unpublished analysis). Many continue to leak toxic byproducts into surrounding waters (Northwatch and MiningWatch Canada 2008, Canadian Boreal Initiative 2008).

Canada is the world's leading uranium producer and the third-largest producer of diamonds. The mining industry spends billions of dollars a year in exploration for new mineral deposits. In most provinces, prospectors acquire rights by staking under the antiquated free entry tenure system without prior review or application. In Quebec, 85 percent of the land is open for mineral exploration, with the number of claims doubling between 2004 and 2008 due to permissive regulations and incentives. Exploration rights in Quebec extend across 12 million hectares (30 million acres) (Canadian Boreal Initiative 2008).

Canada is the No. 1 source of foreign oil for the United States, with average U.S. imports of more than 2 million barrels of crude oil per day (U.S. Energy Information Administration 2010).

The oil and gas industries that support this export market are centered in the upper regions of the Mackenzie River Basin of western Canada. Oil and gas extraction processes impact water through the removal and degradation of wetland habitat, pollution and extraction of water. Over 155,000 active and 117,000 abandoned oil and gas wells exist in Canada's boreal forest, with 87 percent of them falling within five km (3.1 miles) of a river or lake (Global Forest Watch analysis 2010). Approximately 10,000 new oil and gas wells were drilled annually in Canada from 1999 to 2009 (Global Forest Watch analysis 2010). See the accompanying case study for a discussion of the implications of Alberta oil sands development to water and conservation opportunities.

### Mining's Water Legacy

Mining operations can greatly impact the water resources upon which human and biological communities rely (Bell and Donnelly 2006, Goudie 2006). Even in the exploratory phase of mining, fragmentation and loss of terrestrial wetland habitat occurs through road building and exploratory drilling and digging. Mining operations almost always cause some direct habitat loss due to the inherent need to access the resources and transport them back to processing and shipping hubs (Bell and Donnelly 2006). This can include the removal of "overburden" through the stripping of forests, wetlands and soils to access underlying mineral deposits directly. Some mines must drain lakes or divert rivers in order to access minerals underneath them or to dispose of tailings or other mine waste (Northwatch and MiningWatch Canada 2008, Canadian Boreal Initiative 2008).

Mines in areas with high concentrations of water must continually pump the water that drains from surrounding wetland habitats, effectively drying hundreds, sometimes thousands, of square kilometres of wetlands around the mine site (Kelly 1988, Northwatch and MiningWatch Canada 2008). Depending on the ore being mined and the processes used, mining and smelting operations can generate contaminants including arsenic, cyanide, mercury, cadmium and other heavy metals, as well as acids, salts and fine sediment particles (Northwatch and MiningWatch Canada 2008, Lottermoser 2003). The effects of these contaminants in aquatic systems can vary from direct lethality to sublethal changes in physiology, reproduction and behaviour of invertebrates, fish and other animals (Scheuhammer 1987, Kelly 1988, Thompson 1996, Bell and Donnelly 2006, Goudie 2006).

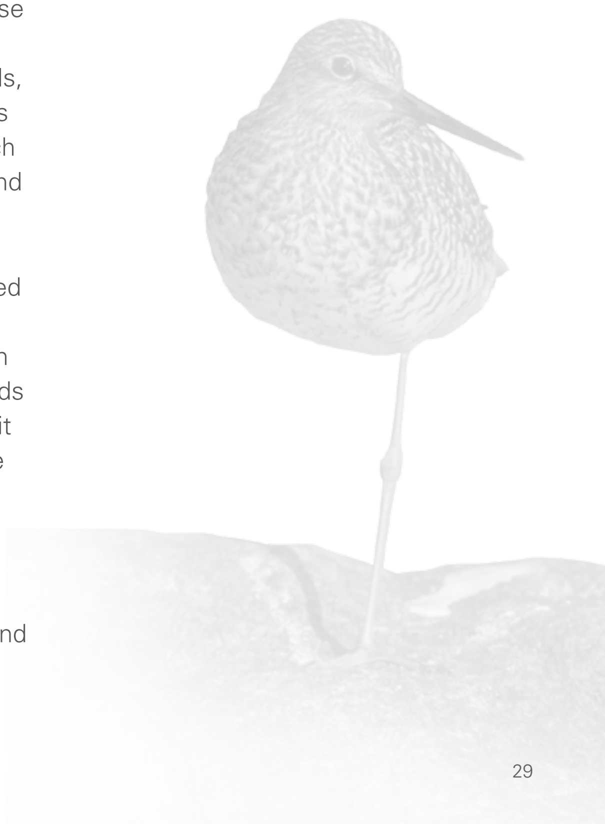
In the absence of often expensive remediation, some abandoned mines will continue to leach contaminants into aquatic systems long after operations cease. For example, the recently closed Giant Mine near Yellowknife, Northwest Territories, has more than 200,000 tonnes of arsenic dust in its underground chambers and will require hundreds of millions of dollars to remove or stabilize it to prevent contamination of nearby Great Slave Lake (Schindler and Lee 2010).

Contaminants from mining operations are typically contained in a variety of ways, including a technique that places them underwater in "tailings ponds." Some mines have converted natural lakes into tailings ponds, while others have been constructed using dam and drainage structures. Slowing or preventing the leakage of toxins from tailings ponds and preventing animals from using, being killed by or contaminated in tailings ponds is a major

*Contaminants that leak into waterways are a serious concern with mining in Canada's boreal forest.*
CREDIT: GARTH LENZ

focus of companies and government regulators (Lottermoser 2003). Smelting operations to refine minerals can release atmospheric pollutants, including nitric oxide, sulphur dioxide and heavy metals, that can cause acidification of wetlands and waterways (Kelly 1988, Northwatch and MiningWatch Canada 2008, Bell and Donnelly 2006).

In 2002 the federal government updated the Metal Mining Effluent Regulations (MMER) to set more stringent limits on the release of cyanide, suspended solids and pH levels of effluent and to prohibit the discharge of effluent that would be lethal to fish. Unfortunately, another aspect of MMER is that Schedule 2 allows for the use of natural water bodies as tailings impoundment areas (subject to assessment, consultation and authorization on a case-by-case basis).



Between 2002 and 2009, five natural water bodies were approved for tailings use in addition to the 10 other water bodies that had been operating previous to 2002.

In terms of meeting its objectives in regard to protection of fisheries, the news is not encouraging. In 2009, the federal Commissioner of the Environment and Sustainable Development report noted the Department of Fisheries and Oceans "lacks information on fish stocks, quantity, and quality of fish habitat, contaminants in fish and overall water quality" and as a result is unable to credibly assess whether it is meeting its goal of no net loss of fish habitat to development (Office of Audit General 2009).

In addition to industrial hard rock mining there are also regions within Canada's boreal forest where placer mining continues to be practiced. Placer mining involves extracting alluvial gold from the sediments of current and ancient riverbeds. This type of mining is generally confined to historic mining regions, such as Dawson City, Yukon and Atlin in northwest British Columbia, where gold rushes first occurred in the late 19th century. In practice, placer mining is a relatively low-tech process that involves "sluicing" of river sediments employing water to separate the gold dust from the silt using gravity-based technology. The main impacts associated with placer mining include the removal and destruction of riparian habitat and sediment loading where silt from tailings ponds are not properly contained.



### Mining Makeover?

In the world of responsible mining exploration, significant changes are under way in Ontario, where the government has passed a modernized Mining Act (Ontario Government 2009a). It is expected to implement a process of consultation with aboriginal communities and to significantly decrease the environmental impacts of mining (Ontario Government 2009b). The legislation was passed with an impressive level of support from industry, First Nations and environmental groups.

At the heart of the new plan is a change from the unchecked free entry system of mining exploration to a permitting process that requires aboriginal consultation and maintains conservation obligations (Canadian Boreal Initiative 2008). In Ontario's northern boreal forest region, mining will be subject to the conditions of land use plans.

Similar discussions on mineral exploration and mining reforms are under way in Quebec and British Columbia, where socially responsible investors, conservation groups and aboriginal communities are reaching out to progressive industrial leaders to improve social and environmental accountability for the industry as a whole. The industry, for its part, has begun to see the need for and the value of promoting better practices through voluntary measures, such as the "Environmental Excellence Exploration" guide published by the Prospectors and Developers Association of Canada (Prospectors and Developers Association of Canada 2010) and the Towards Sustainable Mining program of the Mining Association of Canada (Mining Association of Canada 2009). Broader and more rigorous application (through updated regulations) of these acknowledged "best practices" is necessary to avoid the negative impacts and associated conflicts of an ever-expanding industry across Canada's boreal forest.

## CASE STUDY: MIXING OIL AND WATER

More than half of the oil exported to the United States from Canada comes from the Alberta oil sands in northeastern Alberta. It is here that surface mining and the upgrading of bitumen deposits into usable oil consume huge volumes of water taken from the Athabasca River and underground saline aquifers. Surface mining in the oil sands region requires the total draining and removal of wetland habitats overlying the targeted bitumen deposit. An estimated 40 percent of the 2,994 $km^2$ (740,000 acres) of habitat that will be removed in the oil sand strip mining process are wetlands (Woynillowicz *et al.* 2005) and already 244 $km^2$ (60,000 acres) of wetlands have been lost (Timoney and Lee 2009).

*Surface mining in the Alberta oil sands has raised numerous environmental concerns related to water.*
CREDIT: DAVID DODGE, PEMBINA INSTITUTE

These surface mining operations also require groundwater to be pumped out from within the deposit and surrounding areas to decrease water pressure and prevent or slow water seepage into the open-pit mine (Woynillowicz *et al.* 2005, Griffiths *et al.* 2006). This process effectively lowers the water table in the surrounding area and causes the drying of wetlands nearby—particularly under drought conditions, which are expected to occur more frequently in this region because of global warming. Current oil sands mining operations are permitted to use 523 million cubic metres of water per year, with total water usage by oil sands mining operations projected to double by 2010 as planned oil sands projects become operational (Griffiths *et al.* 2006, Alberta Environment 2007).

There is increasing concern among many aquatic scientists and aboriginal communities that water removal from the Athabasca River during low-flow periods may increase mortality of fish and other aquatic organisms, a key food source to many birds, and damage aquatic habitats and adjoining habitat (Munk Centre and Environmental and Research Studies Centre 2007). Low flows may also prevent recharge of floodplain wetlands that require periodic inundation and can increase the concentration of pollutants in the water (Schindler and Donahue 2006). The Peace-Athabasca Delta has already experienced major habitat changes resulting from drier conditions, a situation that would likely be worsened by lower water flows in the Athabasca River and other parts of the Mackenzie River watershed (Schindler and Lee 2010).

*Toxic liquid byproducts created during the upgrading process are often pumped into large, open tailings ponds.*
CREDIT: DAVID DODGE, PEMBINA INSTITUTE

In addition to the impacts of water withdrawals from surface mining, "in situ" drilling operations have increased dramatically in recent decades (Fig. 11) and use substantial amounts of water, mostly from underground reservoirs. The process of in situ oil extraction involves the drilling of wells to reach deep underground tar deposits and the flushing of warmed water and solvents into the deposits to effectively melt the oil contained within them. Wells drilled at deeper downstream locations are then used to suck up the dissolved oil. The water used in drilling operations is mostly recycled but some amount is constantly required to move toxic mining wastes into tailings ponds. Direct contamination of natural aquatic systems from leakage of tailings ponds and experimental reclamation ponds in the tar sands is well documented and includes polycyclic aromatic hydrocarbons (PAHs) and napthenic acids (Timoney and Lee 2009, Gentes *et al.* 2007, 2006, Gurney *et al.* 2005, Bendell-Young *et al.* 2000). In many of these contaminated wetlands, fish and amphibians are unable to survive (Bendell-Young *et al.* 2000, Pollet and Bendell-Young 2001).

The oil refining process, known as "upgrading," also releases contaminants into the air, including nitrogen oxides, sulphur dioxide, heavy metals, particulates, PAHs and volatile organic compounds (VOCs), which eventually precipitate out into waterways and wetlands (Kelley *et al.* 2009, Bytnerowicz *et al.* 2010). Elevated levels of these pollutants have been documented within 25 km (15.5 miles) of oil sands upgrading plants (Kelly *et al.* 2009, Bytnerowicz *et al.* 2010). Acid rain emissions from tar sands operations are estimated to eventually impact a minimum of 500 to 1,000 km$^2$ (124,000-247,000 acres) of land habitat and a minimum of 25 lakes lacking the capacity to buffer against its acidity (Woynillowicz *et al.* 2005).

A proposed 800-mile Mackenzie River natural gas pipeline in the Northwest Territories would open up the world's wildest river valley to development and would likely be used largely to fuel more tar sands development (Schindler and Lee 2010). In addition, greenhouse gas emissions from oil sands operations were projected by Environment Canada to rise from 4 percent of national emissions in 2006 to 12 percent by 2020 and would account for 44 percent of the increase in Canada's greenhouse gas emissions from 2006 to 2020 (Environment Canada 2008c).

**Saving Land in the Oil Sands?**

Oil sands development issues have and continue to generate intense public debate (Nikiforuk 2008). Increasing the amount of protected area within the region that would become off-limits to industrial development has been proposed as one step that may mitigate future impacts and provide a balance that could allow the retention of more of the conservation values of the region (Dyer *et al.* 2008). The Cumulative Effects Management Agency, a nonprofit agency initiated by the Alberta Government, has recommended that 20 to 40 percent of the region be placed into protected areas off-limits to industrial development and that 46 percent of the region at any point in time be managed for forestry or other similar land uses (CEMA 2008). A process for establishing a plan for part of the region (the Lower Athabasca land use plan) has begun (Government of Alberta 2009) and many conservation groups have proposed setting aside at least 40 percent of the land base in the region for conservation to offset the habitat loss and degradation within areas now subject to industrial development.

Pressure on both the Alberta government and the federal government has grown significantly in both Canada and internationally, advocating for stronger measures to protect environmental and water quality relating to oil sands development (Nikiforuk 2008). Plans for reducing or eliminating tailings ponds, reducing the footprint on landscapes, creating wildlife habitat offsets and increasing resource revenue sharing with First Nations should be developed.

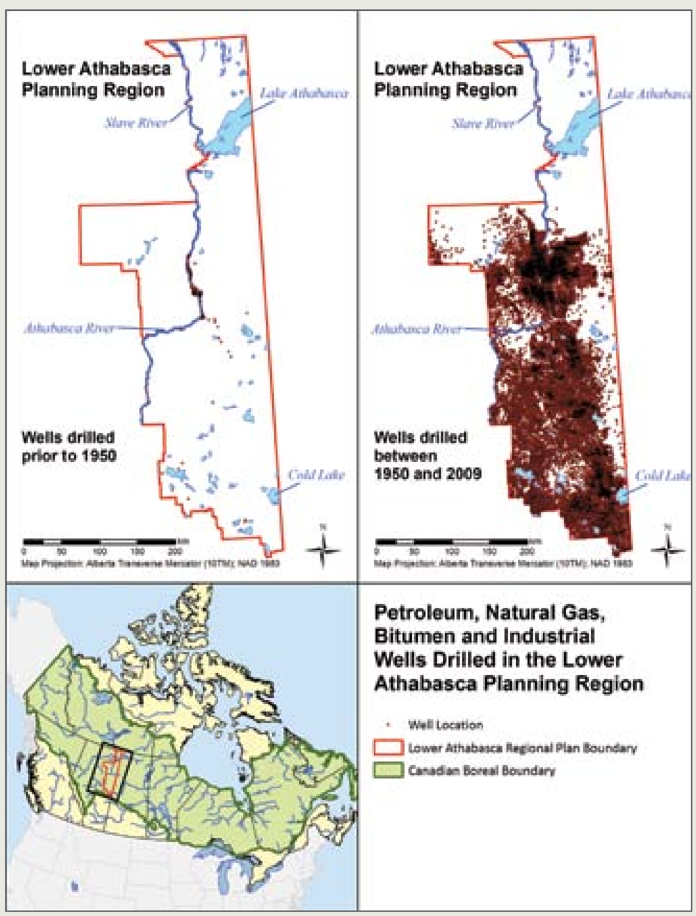



**Figure 11.** Time-series maps (before and after 1950) show the steep increase in drilling for petroleum, gas and oil in the Lower Athabasca region of Alberta.

## Forestry

Canada is the largest exporter of pulp and the second-largest pulp producing country in the world, producing 20.3 million tonnes per year; the largest fraction of it is sold as paper in the United States (Natural Resources Canada 2009b). Americans consume 80 percent of Canada's boreal forest product exports, with much of the timber used for throwaway items such as junk mail, catalogs and toilet paper (U.S. Fish and Wildlife Service 2006).

### Where the Tree Cutting Meets the Water

Due to the complex hydrology of Canada's boreal forest and freshwater ecosystems, timber harvesting can have pronounced effects on freshwater systems (Lindenmayer and Franklin 2002). Erosion after forest removal increases inputs of silt and water into waterways from surrounding land two or three times above pre-harvest levels, often with a pronounced rise in mercury levels for several years following tree harvest (Cross and Everest 1997, Schindler 1998a,b, Garcia and Carignan 2005, Bishop *et al.* 2009, Sørensen *et al.* 2009). Harvesting trees near streams and rivers has been shown to increase water temperatures and expose aquatic organisms to higher levels of damaging ultraviolet radiation (Berry 1994, McCart 1997, Schindler 1998a).

*Unsustainable forestry practices have been prevalent in Canada's boreal forest for decades, but recent improvements by major forestry companies have provided hope.*
CREDIT: GARTH LENZ

Large-scale logging is expected to cause decreases in regional precipitation, increases in regional temperatures and may increase the likelihood of formation of thunderstorms and lightning-caused fires at boundaries because of changes in atmospheric heat flux along cut-block boundaries (Eugster *et al.* 2000, Valentini *et al.* 2000). Logging can convert the age structure and species compositions of large regions (Cyr *et al.* 2009), which in turn impacts local, regional and global climate through changes in heat flux (Eugster *et al.* 2000).

Some of the biggest impacts of forestry operations on aquatic systems are from building road networks to access trees and transport logs to mills for processing. Roads themselves often stop or slow flows of surface and groundwater, especially in flatter, wetter areas, and can change ecosystem dynamics as wetlands become isolated from replenishing water and nutrient flows (Hammond 2009). Much of the erosion from forestry operations that result in siltation of streams and rivers is a result of road-building operations. Increased sediment loads in streams and rivers can destroy spawning and nursery habitat for fish (Lindenmayer and Franklin 2002, Croke and Hairsine 2006).

One of the most insidious effects of road building comes as a result of culverts under roads that, either because of improper installation or post-installation flooding, become barriers preventing the movement of fish and other organisms up and down waterways, and effectively decreasing available habitat and the ability of fish to escape degraded conditions (Fairless *et al.* 1994, Cross and Everest 1997). A study of a boreal forest watershed in Alberta found that up to 20 percent of originally available stream habitat for Arctic grayling and other fish had been lost because of "hanging" culverts (Park *et al.* 2008). Forest harvest has been shown to decrease the abundance and distribution of some fish species in harvested watersheds (Ripley *et al.* 2005). Between 24 and 43 percent of stream habitat in a boreal forest watershed in Alberta was predicted to lose its bull trout populations within 20 years as a result of forest harvesting (Ripley *et al.* 2005). Genetic diversity of trout was found to be lower in areas upstream of culvert barriers that formed virtual "islands" of aquatic habitat because fish movement was blocked (Neville *et al.* 2009).

**At the Leading Edge—Forest Products Association of Canada**

While many forestry companies have received major public criticism for unsustainable forestry practices, a number of companies have taken the initiative in developing leading-edge sustainable forestry management. An agreement announced in May 2010 places many of Canada's largest forest product companies at the leading edge globally for integrating conservation values and sustainable practices into industrial forestry operation.

The Canadian Boreal Forest Agreement between nine environmental nonprofits and the Forest Products Association of Canada (FPAC) commits member forest companies to suspending logging on 29 million hectares (72 million acres) of forestry tenures (leases) caribou habitat and other values of the boreal. The agreement also commits them, over the next three years, to developing a plan for achieving the highest sustainable-development practices on the total area of operations for FPAC companies. This area covers 72 million hectares (178 million acres). In return, the nine environmental nonprofits agreed to suspend their "do not buy" and boycott campaigns (Kallick 2010, Pew Environment Group).

*The size and nature of the Canadian Boreal Forest Agreement makes the deal unprecedented on a global scale.*
CREDIT: GARTH LENZ

## Hydropower

Canada is the largest producer of hydroelectricity in the world, and accounts for about 15 percent of the world's total production (Environment Canada 2010a). As energy demands soar and coal-fired plants are shut down, Canadian provinces are planning more major hydro developments. Already there are 20 new hydropower dams

**PROPOSED SITE C DAM ON THE PEACE RIVER**

British Columbia's mighty Peace River has been irrevocably changed over the past 50 years by two large dams that have flooded tens of thousands of hectares of boreal forest and farmland, and caused the loss of First Nation's homes and cultural heritage.

On April 19, 2010, the Liberal government of Gordon Campbell surprised many by announcing it intended to proceed to develop a long-proposed but highly controversial third dam on the river—Site C. It launched a development-and-consultation stage, which is the third of five steps needed to make the dam a reality within a decade.

BC Hydro and the project's supporters say the proposed $6.6 billion, 60-metre-high dam/83-km-long (197-foot-high/52-mile-long) reservoir is the cleanest, greenest and cheapest option to meet British Columbia's growing energy needs. They estimate it will generate only 4 million tonnes of greenhouse gas emissions over its long lifetime, while generating 900 megawatts of renewable power—enough to keep 460,000 households running for 100 years. They project 7,500 person-years of local work and 35,000 direct and indirect jobs province-wide. The impact to the Peace-Athabasca Delta 1,000 km (621 miles) downstream is assessed as negligible because Site C would use water released from the bigger Williston Reservoir at the W.A.C. Bennett Dam upstream.

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*The Daniel-Johnson Dam in Quebec's boreal forest.*
CREDIT: GARTH LENZ

that have been formally proposed or are being planned across Canada, and more than 100 potential hydropower dam sites have been identified. The largest number of proposed and potential sites are in Quebec and British Columbia, but significant numbers are also found in Ontario, Manitoba, Saskatchewan and Newfoundland and Labrador (Global Forest Watch Canada, unpublished analysis).

There are at least 626 large dams generating hydropower across Canada (Environment Canada 2010), and nearly 40 percent of Canada's hydroelectricity comes from rivers originating from or flowing through the boreal forest, with especially high proportions in Quebec and Ontario (Fig. 12) (Global Forest Watch Canada, unpublished analysis).

Many of the largest hydropower projects include huge diversions of water from one watershed to another. In fact there are at least 62 inter-basin water diversion projects in Canada (Ghassemi and White 2007). Such diversions have often caused catastrophic changes to water resources, the lands they feed and the people who depend on them (McCutcheon 1991, Richardson 1991, Nilsson and Berggren 2000, Bunn and Arthington 2002, Dudley and Platania 2007). Overall in Canada, 4,400 $m^3$ of water are diverted each second that will not be returned to the watershed of origin (Ghassemi and White 2007). This is six times more water than is diverted in the United States, and the collective volume of diverted water in a hypothetical river would make that river the third largest in Canada (Ghassemi and White 2007). More water diversion occurs in Canada than in any other country in the world. (Dynesius and Nilsson 1994, Ghassemi and White 2007).

Two of the world's 10 largest hydroelectric facilities are in Canada's boreal forest. The largest in Canada is the James Bay project in northern Quebec, known today as the Le Grande Complex. The eight dams of the Le Grande Complex generate the second-highest amount of electricity of any

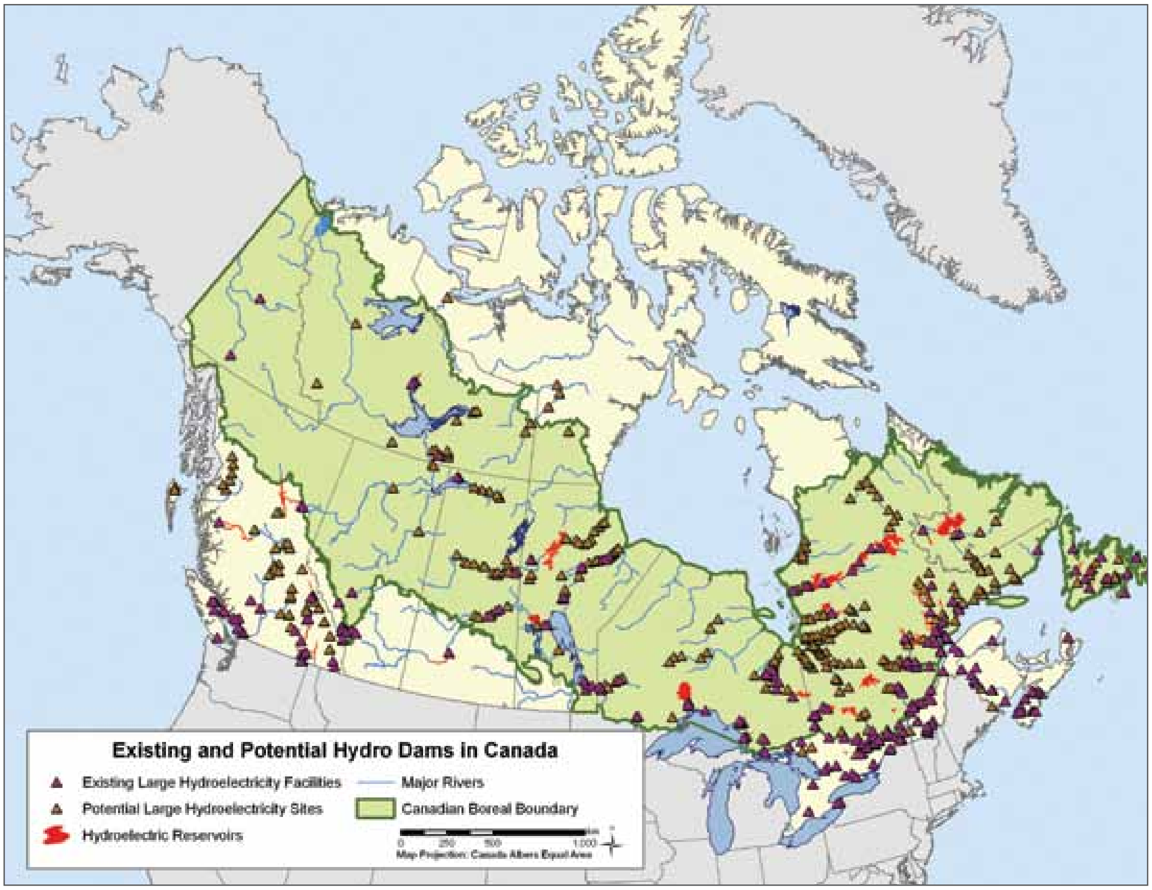


**Figure 12.** Current and proposed hydroelectric dams across Canada.

hydropower facility in the world (second only to China's Three Gorges project). The project required the diversion of 60 percent of the combined flow of Quebec's Eastmain, Opinaca and Caniapiscau, and inundated more than 11,355 km$^2$ (2.8 million acres) of wildlife habitat in the traditional territories of the Cree First Nation

The Churchill Falls project in Labrador is Canada's second-largest hydropower project of generating capacity, the third largest in North America and the 10th largest in the world. The impoundment created behind the Churchill Falls dam covers an area of nearly 7,000 km$^2$ (1.7 million acres).

Other large hydropower projects in watersheds with Canada's boreal forest include the multiple dams of Manitoba's Nelson River watershed and its tributaries, which entailed the diversion of 60 percent of the flow of Manitoba's Churchill River into the Nelson River, the dams on Quebec's Manicouagan River, which includes the Daniel-Johnson Dam (impoundment covers 2,000 km$^2$—nearly 500,000 acres), British Columbia's W.A.C. Bennett Dam (1,660 km$^2$ [410,000 acres]) impoundment) on the Peace River, and the dams of Ontario's Nipigon River and Lake complex.

### How Green Is It?

Although they are comparatively low carbon emitters in comparison to many conventional energy sources, hydropower projects have resulted in significant impacts to wildlife habitat, ecological processes and aboriginal communities (Rosenberg *et al.* 1995, Rosenberg *et al.* 1997, Bunn and Arthington 2002, Poff *et al.* 2007).

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Treaty 8 First Nations, whose homes and cultural sites were lost to the previous dams and who say they were ignored by the government again this time, are far more skeptical about the benefits and concerned about the costs. They refused to attend the Site C announcement, which was made by Premier Campbell at the W.A.C. Bennett Dam—still a symbol today to First Nations of everything they lost before.

Many conservation groups are equally skeptical, and fear BC Hydro's "clean energy calculations" do not factor in the lost carbon sequestration and oxygen generation contribution represented by the 9,000 hectares

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(22,240 acres) of land that will be destroyed by the project, or the $Co_2$, methane and nitrous oxide that will be emitted by the flooded forest and vegetation as it rots.

First Nations and environmental groups and others also believe that the power from the dam will be used to support increased mining and oil and gas development in the region, with the products from the latter serving the Alberta Tar Sands projects. All of this development would drastically compound the direct damage caused by the dam and reservoir itself. *(Continued)*

*A traditional cemetery in a remote part of northern Manitoba is slowly flooded by Hydro Manitoba.*

CREDIT: GARTH LENZ

Aboriginal communities where hydropower projects are located have historically suffered the brunt of the many negative impacts (McCutcheon 1991, Richardson 1991, Niezen 1993, Berkes *et al.* 2007, Desbiens 2007, Loo 2007). These have ranged from having to displace communities and individual camps, the loss of traditional hunting grounds from inundation through reservoir creation, increased mercury contamination in traditional food sources such as fish, degradation of habitat and subsequent declines in abundance of fish and game, decreased access to land and increased numbers of non-aboriginal visitors and workers within the region (Rosenberg *et al.* 1995, Rosenberg *et al.* 1997, Hornig 1999, Hayeur 2001).

Loss and degradation of wetlands and the damming of waterways has had profound negative impacts to biodiversity worldwide, including in the United States and Canada. Ecologically one of the most obvious impacts of dams is their blockage of the migrations of fish up and down river systems (Dudley and Platania 2007). Many dams render all spawning habitats upstream of their locations inaccessible, effectively destroying it from the perspective of a population of migratory fish. Hundreds of rivers have seen the extirpation or endangerment of runs of various salmon species. Many species of fish that migrate through river systems have been lost or are endangered (Musick *et al.* 2000), especially in rivers where dams have been constructed without or with inadequate fish passage (MacCrimmon and Gots 1979, Parrish *et al.* 1998, Carpenter *et al.* 1992). For example, Atlantic salmon, which must migrate up rivers to spawn, have been lost from all but eight of the U.S. rivers within their historic range, and in the Bay of Fundy numbers declined from 40,000 in the 1980s to a few hundred by 1999 (Musick *et al.* 2000). More than 100 native stocks of Pacific salmon species have been lost from North American rivers, and another 214 are endangered or of conservation concern, while total numbers have dropped by more than 90 percent (Nehlsen *et al.* 1991, Freeman *et al.* 2003). Migratory fish have been blocked by dams from 40 percent of their original range in California, Idaho, Oregon and Washington (Gresh *et al.* 2000). One unexpected result of declining numbers of migratory fish and other aquatic organisms affected by dams has been the rapid change in species composition and ecosystem productivity upstream of dam locations (Freeman *et al.* 2003, Greathouse *et al.* 2006).

Another impact from hydro projects is the flooding of terrestrial habitat from reservoir creation. The more than 52,000 $km^2$ (12.9 million acres) of land that has been inundated in Canada through reservoir creation could easily account for the loss of habitat for millions of birds even at modest bird density estimates (e.g., 160 birds per $km^2$ [Erskine 1977]), not to mention the vast numbers of small mammals and insects. The decay of vegetation in the resulting reservoirs has also resulted in extensive and persistent methyl mercury pollution, and the release of large quantities of greenhouse gases (Rosenberg *et al.* 1997).

Terrestrial habitat downstream of dams is also typically greatly changed, even at hundreds of kilometres away, because of the modification of natural flows. Canada's large dams have been estimated to have affected at least 130,000 km (81,000 miles) of rivers (McAllister 2000). Decreased flows can increase the distance of saltwater intrusion at the mouth of rivers, cause slumping and erosion of riverbank habitats, and change the density and species composition of river-edge plant communities (Roy and Messier 1989, Nilsson and Berggren 2000, Poff and Hart 2002). Flooding events are reduced after dam creation, which in turn decreases important ecological processes, including the scouring of vegetation, refilling of small ponds and shallow water areas (which are often important spawning areas for aquatic organisms) and the deposition of sediments and nutrients that feed wetlands and forests in floodplains and deltas (Poff *et al.* 1997, Bunn and Arthington 2002, Poff *et al.* 2007).

A further impact hydropower facilities, especially those in more remote regions, is the construction of large transmission lines. Sometimes stretching over thousands of kilometres, these transmission lines fragment forests, impact local predator-prey dynamics of mammal communities, and increase recreational fishing pressure and human access to once-pristine water bodies. Hydro Quebec maintains 130,000 km (81,000 miles) of transmission and distribution lines (Hydro Quebec 2009, Hayeur 2001) and Ontario Hydro (now renamed Hydro One) manages 150,000 km (93,000 miles) (Hydro One 2010). Not only can transmission lines cause direct mortality of birds from collisions with wires and towers, a more lasting effect is from the fragmentation of forest with its long list of undesirable impacts to birds and other animals (Donovan *et al.* 1995, Faaborg *et al.* 1995, Walters 1998, Hobson and Bayne 2000, Fahrig 2003, Stephens *et al.* 2003).

Aquatic habitats too are changed and lost from the effects of modification and regulation of flow caused by dams (Nilsson and Berggren 2000, Marty *et al.* 2008). The reservoir behind a dam increases water depth and slows water movement, creating less hospitable habitat for species adapted to shallow, fast-moving water (Nilsson and Berggen 2000, Bunn and Arthington 2002). Such changes often favour nonnative invasive species over native species, and impoundments behind dams appear to facilitate the invasions of alien species into nearby natural freshwater habitats (Leprieur *et al.* 2008, Johnson *et al.* 2008).

A well-known effect that follows dam building is a rapid rise in mercury levels within impoundments behind dams as well as downstream (Bodaly *et al.* 1984, Brouard *et al.* 1994, Morrison and Therien 1995, Rosenberg *et al.* 1995, Rosenberg *et al.* 1997, Hall *et al.* 2005). This is caused by the conversion of inorganic mercury to methylmercury by bacteria that decompose newly flooded organic soils and peat (Louchouarn *et al.* 1993). The methylmercury then enters the food chain starting with microorganisms that ingest bacteria, invertebrates that ingest the microorganisms and small fish that ingest invertebrates, and finally larger predatory fish, birds and mammals that eat the smaller fish. Because the

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There are also serious questions about whether the spending and destruction for Site C are necessary, and whether the desired new power could be found in large part or whole by using new technology to make existing dams more efficient. The Site C reservoir would be only 5 percent as large as W.A.C. Bennett's, yet recent technological advances will allow it to provide 33 percent of the power of the older dam. Could such technology be applied to dramatically increase the amount of power produced at older dams, rather than building a new one?

*Flooding from dams not only affects local wildlife habitat, but can also increase levels of mercury in water and even release greenhouse gases from the ground.*
CREDIT: GARTH LENZ

*Hydropower transmission lines are one of the lesser-known and less-discussed environmental impacts of hydropower.*
CREDIT: GARTH LENZ

methylmercury accumulates in each organism along the chain, the predatory fish, birds and mammals at the top of the food chain can end up with large concentrations of mercury, especially over many years (Verdon *et al.* 1991, Langlois *et al.* 1995, Doyon *et al.* 1998, Hayeur 2001). Mercury levels in predatory fish in northern hydroelectric impoundments virtually always greatly exceed background levels and suggested safety levels for human consumption. For example, mercury levels in pike and walleye in Quebec's La Grande reservoir system reached levels six times higher than natural background levels and six times the safe level for human consumption (Roebuck 1999, Hayeur 2001). Mercury levels in water and microorganisms may decline after 10 to 15 years following dam impoundment construction but levels in predatory fish usually remain elevated for 20 to 30 years (Rosenberg *et al.* 1995, Rosenberg *et al.* 1997, Schetagne and Verdon 1999, Schetagne *et al.* 2000).

Given the increased focus on developing hydropower as a form of "climate-friendly" energy, many are surprised to learn that they are also net-emitters of greenhouse gases (St. Louis *et al.* 2000). The largest ongoing source of emissions from hydro projects is the methane and carbon dioxide released from flooded organic soil carbon and peatlands in impoundments behind dams (St. Louis *et al.* 2000, Tremblay *et al.* 2004). The level of annual greenhouse gas emissions from a particular reservoir depends on a number of factors, including the carbon content of the area inundated, the depth, temperature and water chemistry of the reservoir, and the age of the reservoir (Rosenberg *et al.* 1997, St. Louis *et al.* 2000). Some tropical hydropower projects have been estimated to have produced more greenhouse gases than would have been emitted from generating an equivalent amount of electricity from the burning of fossil fuels (Fearnside 2004, Fearnside 2005). Hydropower projects in cold, northern regions have much less greenhouse gas emissions than those in tropical regions and far less than conventional energy sources. However, a full accounting of the levels of emissions of carbon dioxide and methane released in reservoir surfaces, spillways and downstream in comparison to the natural ecosystems present before hydro project development has yet to be completed (Duchemin *et al.* 2006, Tremblay *et al.* 2004).

Finally, dam building can have a major impact downstream by depleting nutrient and sediment flows into river deltas, estuaries and marine ecosystems, and the resulting decreases in fisheries production (Rosenberg *et al.* 1997, Sklar and Browder 1998, Loneragan and Bunn 1999, Bunn and Arthington 2002, Kimmerer 2002, Le Pape *et al.* 2003). For example, in the Gulf of St. Lawrence there has been a 20 to 30 percent reduction in the quantity of nutrients added to the system each spring as a result of dam withholdings of spring runoff (Rosenberg *et al.* 1997).

**Greening Decisions for Transmission Line Placement**

A recent decision by Newfoundland to route transmission lines around the Gros Morne National Park (a UNESCO World Heritage Site since 1987) and a decision in Manitoba to route lines away from the pristine boreal forest are two cases where routes were planned to circumvent ecologically and culturally important regions.

In Manitoba, a new BiPole III transmission line is planned to bring power from the north to southern markets. The Government of Manitoba decided to route it through the already fragmented west side of Lake Winnipeg rather than through the pristine and unfragmented forest and carbon-rich

*Climate change is expected to affect boreal forests at higher rates than lower-latitude forests such as tropical forests.*
CREDIT: GARTH LENZ

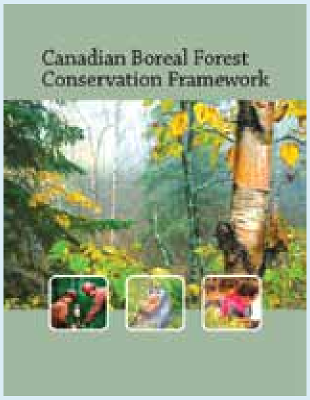
peatlands on the east side. Although the west-side route will be longer, the potential costs to east-side ecosystems would be greater, as they would impact the largest contiguous block of intact forests left in the world, which runs from the east side of Lake Winnipeg across to northeastern Ontario.

In addition, the government feared that east-side transmission lines would threaten approval of the proposed Pimachiowin Aki UNESCO World Heritage site, an initiative led by First Nations who want to protect their traditional lands and cultures.

## Climate Change and Threats to Boreal Freshwater

Canada's boreal forest is water-rich as a result of accumulation in peatlands, snowpacks, glaciers, permafrost and groundwater. In much of the forest, water from annual rain and snowfall (minus water lost to evaporation and evapotranspiration) has historically been only slightly higher than the volume of runoff that eventually flows into the oceans (Schindler and Lee 2010, Schindler 2009). Thus in drier and warmer years, more water is lost than is replenished. The water "bank" of the forest is therefore highly sensitive to changes from industrial disturbance and global warming (Schindler and Smol 2006, Schindler and Lee 2010).

The rise in global temperatures from climate change, predicted to increase by 2.5° C (global average) by 2100, is most pronounced at higher latitudes, including the northern regions of the Earth (IPCC 1995). Continental areas in the northern range of the Canadian boreal may rise to twice the global average at 50° N, and to 3.5 times the global average at 80° N by 2100 (Etkin *et al.* 1998). Major effects in Canada's boreal and Arctic ecosystems as a result of the warming that has occurred in the last 100 years have already been well documented (Serreze *et al.* 2000, Hinzman *et al.* 2005).




### BOREAL FOREST CONSERVATION FRAMEWORK

The Boreal Forest Conservation Framework calls for conservation of at least 50 percent of Canada's boreal forest in a network of interconnected, protected areas; and application of state-of-the-art ecosystem-based resource management practices across the remaining landscape.

It was developed by the Boreal Leadership Council (BLC), an unusual partnership of leading conservation organizations, resource companies, and First Nations, who joined together to promote the conservation and sustainable use of Canada's boreal forest region. Members of the BLC, convened by the Canadian Boreal Initiative, recognize that all who depend on the forest must come together to plan for its ecological, cultural, and economic future. The Framework is based on the best available principles of conservation biology and land use planning, and has been endorsed by 1,500 international scientists, 25 Canadian First Nations, international conservation groups, and major businesses with annual sales totaling over $30 billion.

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Significant progress has been made toward the goals set out in the Framework. Recent key land protection actions include the following:

- In September 2010, the Ontario Legislature passed a bill protecting 110 million acres of pristine boreal forest and wetlands in the northern half of the province. The Far North Act is one of the largest wildlands protection efforts in history. It mandates that the entire 110 million acres undergo conservation planning, and puts a minimum of 55 million acres permanently off limits to development.
- Quebec: Premier Charest pledged in March 2009 to protect at least 50% of northern Quebec's boreal forest; this commitment totals more than 645,000 km$^2$—160 million acres.
- Northwest Territories (NWT): Over 120,000 km$^2$—30 million acres has been slated for protection in the NWT since 2007; most recently in April, 2010, 33,000 km$^2$—8 million acres was set aside for creation of a new national park around the East Arm of Great Slave Lake, the tenth largest lake in the world.

These and other land protection actions represent a significant commitment to the future of Canada's boreal forest, although much remains to be done to ensure equal treatment of conservation, sustainable development and Aboriginal rights across the region.

For example, studies in the boreal forest and Arctic ecozones of Alaska show that the region has experienced a warming climate with longer growing seasons and permafrost warming (Serreze *et al.* 2000, Hinzman *et al.* 2005, McGuire *et al.* 2009). Closed-basin ponds decreased by as much as 31 percent in the study region and up to half of closed-basin ponds are disappearing (Riordan 2006). Similar trends are also being observed in Russia, where widespread disappearance of lakes is likely due to thawing permafrost (Smith *et al.* 2005).

Wetlands and waterways are among the ecosystems that will be most affected by continued global warming (Schindler *et al.* 1996, Poff *et al.* 2002). Already, records show that Canada's boreal forest lakes and rivers are responding to changes in climate with a shift toward shorter ice-cover periods and greater year-to-year variability (Schindler *et al.* 1990, 1996, Wrona *et al.* 2005, Schindler and Smol 2006, White *et al.* 2007). These changes can result in complicated and sometimes unpredictable ecosystem effects (Schindler *et al.* 1996, Schindler and Smol 2006, Schindler 2009).

In areas with decreased precipitation, drying lakes and ponds can become so low that they no longer have outflow and they begin to accumulate salts and show increased eutrophication (Schindler 2009) that can eventually cause widespread losses of aquatic organisms. Decreased flow in rivers and streams lowers movement of nutrients to lakes and marine estuaries affecting food webs and decreasing the ability of migratory and dispersal movements of fish and other aquatic species (Schindler and Smol 2006). Such decreased flows can also reduce input of organic matter in lakes, which serves as a natural "sunscreen" to lessen the penetration of solar radiation affecting both the depth of the photosynthetically active zone and the level of harmful UV radiation (Reist *et al.* 2006, Schindler 2009). Climate change can impact the acidity of lakes and streams in complex ways (Schindler 2009).

Climate change is expected to result in higher winter flows and lower spring and summer flows in river systems of Canada's boreal forest (Woo *et al.* 2008). Such changes in timing of peak flows are expected to cause major problems for species adapted to spawning under high water conditions in certain seasons (Reist *et al.* 2006, Schindler and Smol 2006). Thousands of closed basin lakes and ponds in globally important delta systems in the boreal forest, including the Peace-Athabasca Delta and the Mackenzie Delta, have historically been recharged with water and nutrients as a result of spring flooding that is already reduced and is projected to decline further (Schindler and Smol 2006, Schindler 2009).

Canada's boreal waterways and the fish and other organisms that inhabit them are expected to see increases in levels of various contaminants as a result of climate change. Various airborne industrial pollutants originally released in warmer, southern regions can condense in cold, northern regions in snow, ice and water. As global warming results in increased melting of glaciers and snowpacks, these compounds flush into lakes, ponds and rivers where they can be biomagnified to levels that harm or kill some organisms (Schindler and Smol 2006, Tarnocai 2009). Mercury levels are likely to rise from release of methylmercury in thawing peatlands and from atmospheric deposition of mercury from forest fires, which are expected to increase in frequency from global warming (Reist *et al.* 2006, Schindler 2009, Tarnocai 2009).

*Rising temperatures from global warming could cause large releases of greenhouse gases from wetlands.*
CREDIT: JEFF WELLS

One of the most obvious effects from global warming will be the loss of habitat for species reliant on lakes, rivers and wetlands. Many fish and other aquatic organisms are highly sensitive to water temperature. The higher air temperatures from global warming will increase water temperatures so that water bodies could either become too warm for some species to survive or the depth at which the cooler waters they require will increase. The species composition of waterways and wetlands will then change as some species disappear or are reduced in abundance, and those adapted to warmer, more southerly conditions increase in abundance and colonize new northerly locations (Reist *et al.* 2006, Schindler and Smol 2006, Rahel *et al.* 2008, Prowse *et al.* 2009a, b). Northern pike and Arctic char are two species predicted to undergo major declines in range and abundance with unchecked global warming (Reist *et al.* 2006a, b) and the salmonids (trout, salmon, whitefish) that inhabit the waters of Canada's boreal forest are among the fish species that are least able to tolerate rising water temperatures (Eaton and Scheller 1996).

Peatland systems of the boreal forest are also expected to show major impacts from current predicted increases in global warming (McGuire *et al.* 2009). Approximately 667,000 $km^2$ (165 million acres) of Canadian peatlands are predicted to experience extremely severe or severe impacts under current climate change scenarios, and virtually all of the most vulnerable peatlands are within the boreal forest region (Tarnocai 2009). This includes the Hudson Bay-James Bay lowlands and most of the Mackenzie River Basin (Tarnocai 2009). For the many species of plants and animals reliant on peatland habitats, this will certainly entail a reduction in the amount and quality of available habitat and a likely decrease in their range and abundance. Without strong measures to reduce the rate of climate change and maintain these now-intact systems, some models suggest that peatlands could release massive amounts of carbon and methane, which would exacerbate global warming (McGuire *et al.* 2009, Tarnocai 2009, Schindler and Lee 2010) though major uncertainties exist in various model parametres (Zhuang *et al.* 2006, McGuire *et al.* 2009).

As species ranges shift northward across North America in response to global warming, it has become increasingly clear that large intact and healthy ecosystems are the most likely to be able to absorb climate impacts and to allow species to move across the landscape as they adapt to a warming world. Lakes, rivers, and wetlands are intrinsically isolated from each other because of the geographic features that allow their creation (i.e., mountains, ridges, valleys). Global warming impacts expected in rivers and lakes of the boreal forest include changes in discharge of freshwater and greater water stresses on wetlands, rivers and lakes (Palmer *et al.* 2008). Climate impacts coupled with human impacts, such as roads, dams, and habitat loss and degradation, will affect the ability of aquatic organisms to naturally disperse from one waterway or wetland to another—a process that will be required for species to shift the ranges in response to changing climate conditions. Large pristine, intact and unfragmented waterways and wetlands, such as those found in Canada's boreal forest, provide the best conditions for species to adapt to change and ensure large-scale terrestrial and freshwater ecosystem resilience in the face of global warming (Palmer *et al.* 2008).

## Protecting the World's Last Great Blue Water Forest

Within Canada's boreal forest region relatively few protected areas exist that specifically strive to maintain the full complement of ecosystem services, biodiversity features and traditional use needs of aquatic systems. Maintaining very large intact forests and peatlands is one of the best solutions for protecting aquatic systems as it prevents or slows human-caused alteration of hydrology from industrial land-use activities, and prevents or slows the spread of invasive species and pollutants. Ideally in landscapes where possible, the protection of entire watersheds from headwaters to the outlet should be the goal. Whole-basin protections are still rare, but not without precedent. For example in 2006 Russia designated the entire 2,000-$km^2$ (500,000-acre) watershed of the Kol River as a protected area specifically because of its importance for migratory salmon and other fish (Augerot and Foley 2005).

The Canadian Boreal Forest Conservation Framework envisions the implementation of these types of large-scale protections (Boreal Leadership Council 2003). The Canadian Boreal Conservation Framework spells out the need to maintain at least 50 percent of the boreal forest in a system of protected areas while implementing leading-edge sustainable development practices on areas outside of the protected area system (Boreal Leadership Council 2003). This vision will require linking terrestrial and freshwater conservation planning efforts at vast scales that encompass entire watersheds and riverine corridors that may stretch for thousands of kilometres.

# Fresh Opportunities for Water-Friendly Planning

Land-use and freshwater resource planning that is under way in many parts of Canada's boreal should consider the full-range of ecosystem services that wetlands and waterways provide. Measures to protect watersheds through precautionary regulation and adaptive stewardship practices need to be more broadly encouraged.

The Taku River Tlingit First Nation's land use planning process is now under way in British Columbia and includes a strong focus on protecting water quality as a core value. The draft land use plan of the Sahtu Dene First Nations is similarly focused, particularly on protecting water quality, cultural sites and fish populations in Northwest Territories' Great Bear Lake and its broader watershed. Protecting the entire Nahanni watershed in the Northwest Territories was a central land use planning objective for the Dehcho people.

Canada's federal government, although very active in southern lakes and watersheds such as the Great Lakes and the St. Lawrence River, has allowed initiatives in major northern watersheds such as the Mackenzie River Basin to languish. The Mackenzie River Basin Board established under the Mackenzie River Basin Transboundary Agreement in 1997 has never been adequately resourced or empowered to deliver on its mandate. Renewed commitments between all levels of government are urgently required to address the effects of oil sands operations and other development on water quality, ecological integrity and livelihood on downstream communities and world renowned natural areas such as the Peace-Athabasca Delta and Wood Buffalo National Park. The Northwest Territories' recently released Water Strategy provides an excellent foundation for addressing these challenges and could become the basis for a regional approach.

Canada's Great Lakes Action Plan should focus on the freshwater inflow of Canada's boreal forest watersheds to Lakes Superior and Huron. Balancing development with conservation in the watersheds of these Great Lakes will help ensure that they will maintain flows of uncontaminated water and balanced flows of sediments, nitrogen and phosphorus to those sensitive lake ecosystems over the long term.

*Water protection is a key part of the Taku River Tlingit First Nation land use planning process.*
CREDIT: DAVID NUNUK

**EAGLE RIVER WATERWAY PROVINCIAL PARK**

In February 2010, the Government of Newfoundland and Labrador announced it would create a 3,000-km$^2$ (741,000-acre) waterway provincial park on the Eagle River watershed to protect the significant Atlantic salmon population and the intact surrounding habitat. With Aboriginal, community and tourism industry support, this park will allow traditional pursuits to continue, while protecting the area from development that would diminish the natural and cultural character of the region.

# Summary of Policy Recommendations

## Summary of Policy Recommendations

Consistent with the terms of the Boreal Forest Conservation Framework, federal, provincial, territorial, and aboriginal governments should prioritize partnerships to protect entire river, lake, and wetland ecosystems from industrial activities, including hydropower development. All public land use policies and management plans should protect at least 50 percent of Canada's boreal forest from industrial activity and require state-of the-art sustainability practices on the remaining areas.

In addition, the following policy measures will ensure that the vision of the Boreal Framework is applied to Canadian boreal waterways:

**Reform Mining Legislation**—Mining legislation and regulations should be modernized in jurisdictions across Canada's boreal forest to require aboriginal consultation, improve habitat protection and water quality standards in all phases of mineral activities, from exploration to reclamation. Mines must be prohibited from dumping waste into lakes and streams. New rules should go beyond best practice codes to require safeguards against pollution, habitat destruction, and to ensure that operators negotiate benefits agreements with affected aboriginal communities. The Ontario Mining Act, which requires consultation and regulatory review at early stages of the mine development process, should be used as a model.

*Mountain River, a tributary of the Mackenzie River in the Northwest Territories.*
CREDIT: IRENE OWSLEY

**Reform Hydropower Policy**—Governments should not approve new hydroelectric facilities unless proponents can demonstrate meaningful participation and consent from affected aboriginal people and minimal impacts on affected ecosystems, following a comprehensive environmental review. All existing and planned facilities should have state-of-the art fish ladders to allow passage for migratory fish to and from their spawning grounds. The routing of transmission lines must minimize new disturbance, using existing corridors if possible. New protected watersheds should be established to compensate for freshwater habitat and biodiversity already lost to hydropower development.

**Protect Carbon-rich Peatlands and Wetlands—**Following Manitoba's lead, Canada should develop a national peatlands stewardship strategy. Canada should adopt new policies in line with federal policies in the United States of no net loss of wetlands and peatlands. Federal and provincial governments should work with aboriginal communities to implement carbon conservation projects and recognize and respect aboriginal carbon conservation rights. A portion of revenues derived from regulatory carbon pricing mechanisms should be allocated to boreal forest conservation and peatland protection.

**Protect the Mackenzie Basin and Implement the Mackenzie Basin Agreement—**The Mackenzie Basin Agreement links land use polices in several provinces and territories in order to protect the vast Mackenzie River watershed, but has not been fully implemented. All signatory governments must follow through on commitments to protect the Mackenzie Basin as signed in 1997 under the Mackenzie River Basin Transboundary Water Agreement.

A network of protected areas is advancing in the Northwest Territories, but needs to be completed to sustain wildlife and cultural values.  And following the Northwest Territories' lead, a new water management strategy with aboriginal participation must be developed to protect water quality and flow from effects of oil sands and other development on water ecosystems such as the Peace-Athabasca Delta.

*A grizzly bear anticipates lunch in the boreal forest.*
CREDIT: ROBERT PLOTZ

# **APPENDIX I:** Mackenzie River Basin

The Mackenzie River Basin covers 20 percent of Canada's land area, contains the largest north-flowing river in North America, and provides the fourth-largest freshwater discharge into the Arctic Ocean (Benke and Cushing 2005). From the headwaters of more than 10 major rivers within the Mackenzie Basin to the extensive Mackenzie Delta joining the Beaufort Sea, the Mackenzie River system is 4,200 km (2,600 miles) long and drains 1.79 million $km^2$ (442 million acres) of land from five of Canada's 13 provinces and territories.

*The Mackenzie River in the Northwest Territories.*
CREDIT: IRENE OWSLEY

Several major rivers (e.g., Peel, Liard, South Nahanni, Yellowknife, Slave, Athabasca, Peace, Hay and Smokey) join to form the Mackenzie River, the lifeline of the Mackenzie Basin. The Athabasca River drains in and out of the Peace-Athabasca Delta. The Athabasca River continues and joins with the Peace River to become the Slave River before emptying into the Slave River Delta and Great Slave Lake. The main stem of the Mackenzie River proper begins as the outflow of Great Slave Lake. When it terminates, after crossing the entire length of the Northwest Territories, it forms the Mackenzie Delta, the second-largest Arctic delta and the 10th-largest delta in the world, which covers approximately 13,135 $km^2$ (3.2 million acres) (Emmerton *et al.* 2007).

The Mackenzie Basin contains some of western Canada's most dramatic landscapes, such as the newly expanded Nahanni National Park and the Sahtu region. These intact landscapes house robust wildlife populations of both woodland and barren ground caribou, moose, Dall's sheep, grizzly and black bears, wolves, lynx, wolverines and at least 52 species of fish (Benke and Cushing 2005). Important commercial and subsistence fish species include chum salmon, lake trout, Arctic char, lake whitefish, walleye and pike. Several of these species migrate between headwaters of Mackenzie Basin's rivers and the Arctic Ocean. Maintaining the current free-flowing riverscapes throughout the region is critical for maintaining these migratory fish populations.

Individuals of the migratory fish species, the inconnu, tagged in the Liard River in northern British Columbia, were found 1,800 km (1,000 miles) downstream in the Mackenzie Delta where it joins the Beaufort Sea. The inconnu migrations are the longest recorded fish migration between fresh and marine waters in Canada (Stephenson *et al.* 2004).

In addition to the rich, estuarine Mackenzie Delta, the basin contains two critical freshwater deltas, the Peace-Athabasca and the Slave. These deltas straddle flyways that define the north-south flight corridors for millions of migratory waterfowl, waterbirds, cranes and songbirds.

**Basin Spotlight—Peace-Athabasca Delta: International Treasure Threatened**

Positioned in the Mackenzie Basin of the western part of Canada's boreal forest, the Peace-Athabasca Delta (PAD) (Fig. 13) is recognized under the Ramsar Convention (1982) for its contribution to "conservation of global biological diversity and for sustaining human life through its ecological and hydrological functions" (www.ramsar.org). Much of the PAD lies within Wood Buffalo National Park (WBNP), and the entire national park has been identified as a UNESCO World Heritage Site, but the remainder lies unprotected outside WBNP. The areas outside of WBNP are under the control of the Athabasca Chipewyan First Nation, which maintains summer settlements to hunt, fish, trap animals and gather plant resources of the PAD. The PAD provides nationally and internationally significant nesting and stopover habitat for millions of migratory birds. Large populations of commercially important fish species spawn in the PAD and migrate between the delta lakes and major rivers (Prowse and Conly 2000), including lake trout, lake whitefish, Arctic grayling, northern pike and the threatened shortjaw cisco. The Peace, Athabasca and Birch rivers provide freshwater input into the PAD to feed the productivity of resources that have supported aboriginal people for thousands of years.

Despite large protected reserves within the PAD, threats outside the protected reserves, but within the Mackenzie Basin, threaten this complex delta system. The W.A.C. Bennett Dam, a large hydroelectric dam constructed on the Peace River in the late 1960s and warming climate have reduced spring flows that feed the PAD while also reducing the frequency of ice jams that in the past rejuvenated its lakes and wetlands. As climate change impacts continue to trend toward drier conditions, a proposed new large hydroelectric dam, Site C, may further disrupt the hydrology and flow necessary to replenish vital wetlands and ponds within the PAD. Industrial demands on freshwater resources of the Athabasca River are rapidly expanding with increased development of oil sands within the river's watershed. Current methods entail consuming three to six barrels of water per barrel of oil (Griffiths *et al.* 2006). If industrial development continues unabated, by 2020, future water use will consume a high proportion of the Athabasca's flow during the critical winter period when flows are naturally low (Griffiths *et al.* 2006). Loss and fragmentation of habitat from strip mining, water and air pollution from processing bitumen and leakage of pollutants from tailings ponds further degrade the Mackenzie Basin's freshwater resources (Soderbergh *et al.* 2007). Aboriginal human communities that depend on clean water and abundant fish and wildlife throughout the PAD are increasingly affected by freshwater degradation from sources upstream of their communities (Schindler 1998). Protecting Canada's water resources will require large, catchment-level conservation and developing sustainable practices outside of protected areas but within interconnected water and hydrologic basins.


**Figure 13.** The Peace-Athabasca Delta in Alberta and surrounding area.

### Spotlight on Watershed Protection in the Mackenzie Basin

While catchment or watershed conservation is a relatively new concept, it is not without precedent. Recent conservation strategies to protect the vast water resources of Canada's boreal forest region include the completion of the Northwest Territories Water Strategy. The extraordinary water resources and landscapes of the Northwest Territories, which contain the largest portion of the Mackenzie Basin, is a rightful place to showcase how Canada is making advances toward solutions to complex water and development issues. The expansion of Nahanni National Park Reserve in the Northwest Territories is a forward-thinking example of federal and territorial governments supporting the Dehcho First Nation's desire to protect more of the watershed, in part to protect the water supply for its communities downstream.

### The Northwest Territories Water Strategy and the Mackenzie River Basin

During the past several years, the Government of the Northwest Territories (NWT) has developed a draft water stewardship strategy, in consultation with First Nations, scientists, water experts and stakeholders, along with Canada's Federal Government. At the heart of the strategy is a commitment to manage watersheds across jurisdictions by working broadly with provincial, other territorial and aboriginal governments. Water Keeper Gatherings were held in aboriginal communities to establish the guidelines for the strategy, helping to attract the respected Rosenberg International Forum on Water Policy to meet in Yellowknife, Northwest Territories, which provided a review of the Northwest Territories' water stewardship strategy (Rosenberg International Forum on Water Policy 2009).

A major impetus for the water strategy is the fact that in the territories' largest watershed—the Mackenzie River Basin—many communities lie downstream of large-scale oil sands extraction and associated industrial development, creating an urgent need to manage the basin across many jurisdictions to ensure that both water quality and quantity are maintained (Grant *et al.* 2010). Signed in 1997 by federal, provincial and territorial governments, the Mackenzie River Basin Transboundary Waters Master Agreement mandates protection of water resources. To date, however, only one bilateral agreement has been signed between the Northwest Territories and the Yukon, and the Northwest Territories and Alberta are due to start negotiations in 2010. Implementation of this agreement has been very slow and outside of the Northwest Territories the momentum is suffering from a low level of political and government support. Key jurisdictions, including Alberta and the federal government, must renew their commitment to the process and devote the necessary resources to achieving real outcomes from this agreement. Many scientists, non-governmental organizations, and others are calling on the federal government to think more broadly beyond water management when it looks at a national water strategy. Renewing the Mackenzie River Basin agreement to meet the challenges of the 21$^{st}$ century would be a great place to start.

# APPENDIX II: Quebec—Can Hydropower and Protected Areas Be Balanced?

The province of Quebec generates more electricity from hydroelectric projects than any other Canadian province and more than all but a few nations. To reach this point Quebec has built more than 300 large dams—13 of Quebec's 16 largest rivers have been dammed, the flow of at least four rivers has been diverted, at least 13,000 $km^2$ (3.2 million acres) of land have been flooded for reservoirs (Fig. 14) and 30,000 km (18,600 miles) of high voltage and over 100,000 km (62,000 miles) of medium- and low-voltage transmission lines have been constructed in the province to convey the electricity generated.

Hydroelectricity provides virtually all of the electricity used in the homes and businesses of the people of Quebec. Energy is also generated for export to other Canadian provinces (where it makes up 30 percent of electricity used in Canada) and to the northeastern United States where, for example, it makes up more than 25 percent of the electricity consumption in Vermont and substantial portions of the electricity used in other states.

The massive investment in hydroelectricity projects has allowed Quebec to achieve virtual energy independence (at least in the electricity sector) and become one of the world's largest electricity producers and exporters. Hydropower has become increasingly attractive because it does not require the burning of fossil fuels. Greenhouse gas emissions from reservoirs are still problematic, but at least in northern parts of the world, hydropower generates substantially less greenhouse gas emissions per megawatt of energy produced as compared to conventional plants that burn fossil fuels (Tremblay *et al.* 2004).

### Ecological and Aboriginal Impacts

Unfortunately, hydropower projects, especially very large ones, have had catastrophic impacts on biodiversity, ecosystem flows and cycles, and aboriginal communities (McCutcheon 1991, Richardson 1991, Niezen 1993, Rosenberg *et al.* 1995, Rosenberg *et al.* 1997, Bunn and Arthington 2002, Poff *et al.* 2007, Berkes *et al.* 2007, Desbiens 2007, Loo 2007). Often these impacts have been poorly accounted for, or have been downplayed in order to lessen the controversy generated by proposed projects.

*A Cree man and woman unload teepee poles from their boat in Quebec.*

CREDIT: NATASHA MOINE

The thousands of square kilometres of terrestrial habitat inundated by Quebec hydropower projects once supported millions of nesting birds, small mammals and invertebrates. Large dams can block fish migrations, effectively removing vast areas of habitat required for raising young and often leading to the destruction of genetically distinct fish populations (MacCrimmon and Gots 1979, Parrish *et al.* 1998, Freeman *et al.* 2003, Dudley and Platania 2007). To ensure that electricity is made available at peak times, and stored during lows, hydroelectric projects closely manage when they release water. This radically shifts the timing of peak and low flow in rivers, impacting the many fish and other aquatic species that have evolved to time important parts of their life cycles with natural peaks and flows (Nillson and Berggren 2002, Marty *et al.* 2008).

Dams also decrease or slow the movement of nutrients and freshwater from inland waterways to their outflows into marine systems where they are the primary driver of the ecosystem productivity that supports commercial fisheries and marine mammals (Poff *et al.* 1997, Bunn and Arthington 2002, Poff *et al.* 2007). Because freshwater flows influence the dynamics of long-distance ocean currents, changes in flow may impact global climate in unexpected ways. The timing and extent of ice formation in James and Hudson bays and along the Labrador coast, for example, are closely tied to freshwater flows from Canada's boreal forest rivers. Sea ice is critical for many species in marine ecosystems, as well as being an important influence on climate (Dery *et al.* 2005, Stewart and Lockhart 2005, NTK 2008, Sherman and Hempel 2008).

For aboriginal communities in Quebec, the impacts of hydropower projects are direct and personal. Ancient burial grounds and sacred sites have been flooded under reservoirs, the well-documented spike in mercury in fish after dam creation has made food supplies dangerous or unavailable, family hunting grounds used for thousands of years have been lost or fragmented, ecosystems have changed so that traditionally hunted fish and mammals are less available and places to hunt these animals are gone (McCutcheon 1991, Richardson 1991, Niezen 1993, Berkes *et al.* 2007, Desbiens 2007, Loo 2007).

### Hydro Quebec's James Bay—La Grande Complex Project

The hydroproject most known for its magnitude and high level of negative social and environmental impacts is the series of dams, reservoirs and diversions of the James Bay project (officially named the La Grande Complex by Hydro Quebec). As in other large hydroprojects around the world, the James Bay project required the relocation of a local community, in this case the 1,500-person Cree community of Fort George, which was relocated from its location on an island in the mouth of the La Grande River to a mainland location several kilometres upstream (McCutcheon 1991). The community experienced many social disruptions after the move that many attribute at least in part to the relocation and other changes related to the hydroproject (Berkes 1988, McCutcheon 1991, Richardson 1991, Rosenberg *et al.* 1995, Rosenberg *et al.* 1997, Hornig 1999). Changes in the volume and timing of freshwater flow from the project made ice conditions more unpredictable and increased the danger of traveling over the ice as has been practiced for thousands of years (McCutcheon 1991, Berkes *et al.* 2007). Hunting and fishing is a critical part of the economy and survival of Cree communities, so changes to access, travel, availability and abundance of fish, birds and mammals have major impacts on the health and well-being of Cree communities. The project inundated thousands of square kilometres of Cree lands, including sacred areas and family hunting grounds (Hayeur 2001). This disrupted not only access to the land, but also diminished the available habitat for wildlife. Mercury contamination made fish from much of the region, a critical food source for the Cree, unsafe to eat for at least 20 to 30 years

(Verdon *et al.* 1991, Langlois *et al.* 1995, Doyon *et al.* 1998, Schetagne and Verdon 1999, Schetagne *et al.* 2000, Hayeur 2001). The building of roads into the region has opened Cree lands to recreational hunters and anglers that compete for game on Cree hunting grounds, and mineral prospectors and others interested in the industrial exploitation of Cree lands (Berkes 1988, Rosenberg *et al.* 1995, Rosenberg *et al.* 1997).

**Quebec's Remaining Intact Lakes and Rivers**

Despite these extensive negative impacts, Quebec still contains some of the world's most magnificent and pristine waterways and wetlands. Two of its undammed rivers, the George, which flows 560 km (348 miles) into Ungava Bay, and the Moisie, a 400-km (249-mile) river that flows into the Gulf of St. Lawrence, are part of interim protected areas that will be largely set aside from industrial development, including dams. A

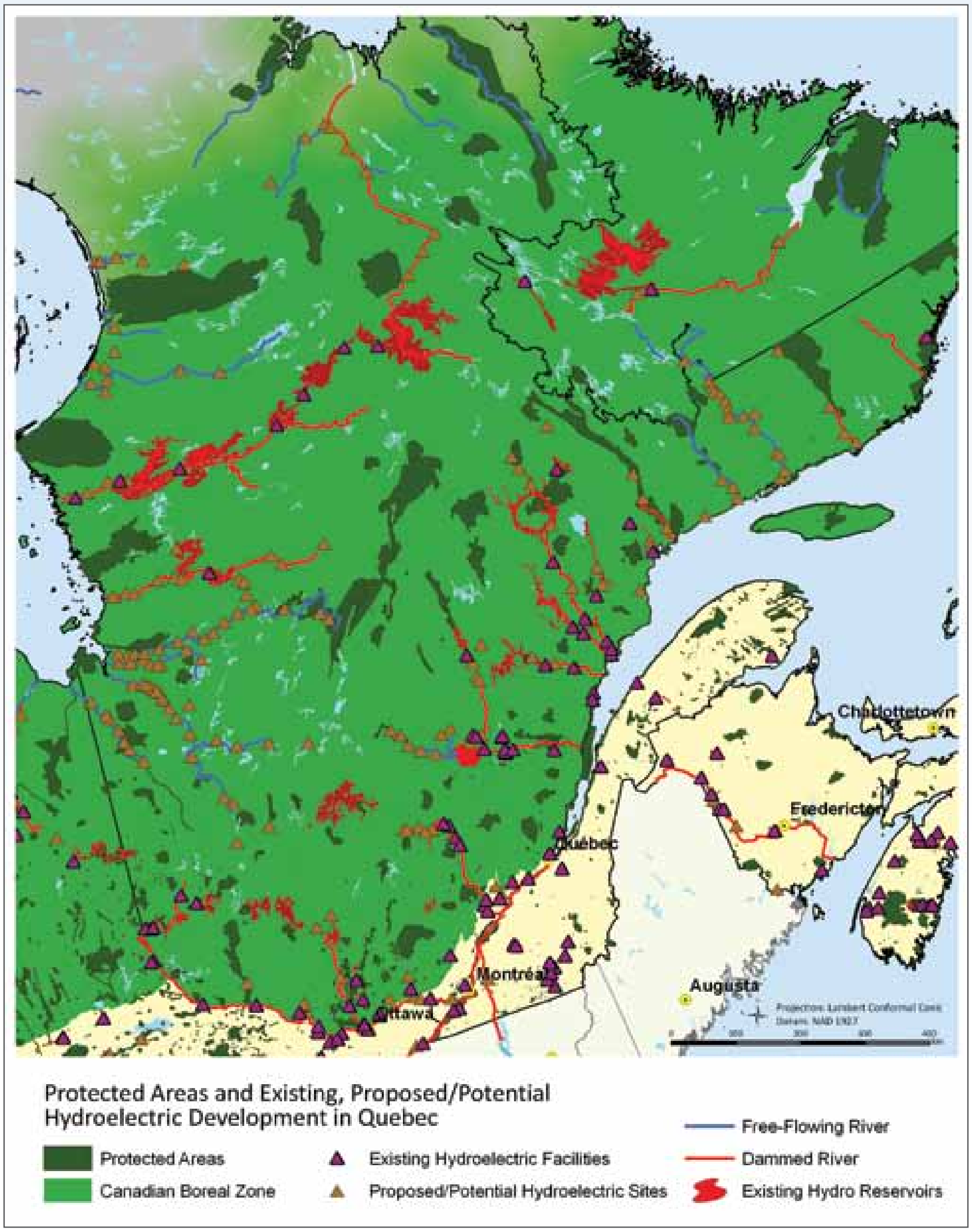


**Figure 14.** Hydropower facilities, impoundments and protected areas in Quebec.

*Quebec is home to some of the world's most intact lakes and river networks.*
CREDIT: GARTH LENZ

number of free-flowing, undammed rivers flow through intact, unfragmented watersheds in the North Shore of the Gulf of St. Lawrence, although many of these are imminently threatened with development including the 500-km (311-mile) Romaine River, the 400-km (249-mile) Natashquan River and the 550-km (342-mile) Petit Mecatina River. In the James Bay region, free-flowing rivers include the 770-km (478-mile) Nottaway River, the 530-km (329-mile) Harricana River (shared with Ontario) and the 450-km (280-mile) Broadback River, all of which flow through the Quebec portion of the James Bay lowlands' extensive carbon-rich peat deposit. Free-flowing rivers that flow into Hudson Bay in the boreal forest region of northern Quebec include the Great Whale River (420-km [261-miles])—though a portion of the river's flow has been diverted into the La Grande hydropower project) and the Little Whale River (380 km [236-miles]). Among the remaining large lakes in the boreal forest region of Quebec that have not been impounded behind dams are Lake Mistassini (largest natural lake in Quebec at 2,000 $km^2$ [494,000 acres]), Clearwater Lake (1,200 $km^2$ [297,000 acres]), Lake Bienville (1,000 $km^2$ [247,000 acres]) and Lake Minto (700 $km^2$ [173,000 acres]).

### Plans for Future Hydro

In addition to this already vast footprint, there are projects under way or under consideration for many more of Quebec's rivers. Under Plan Nord, the Quebec government envisions increasing Quebec's energy production by another 4,500 megawatts (MW) by 2035. Construction began in 2009 on a project that will eventually include four dams on the Romaine River (Hydro Quebec 2010a). Construction began in 2009 on the Rupert River, a famous historic Cree travel route and once-popular recreational wilderness canoe trip destination (Hodgins and Hoyle 1997), to divert 50 percent of its flow to the La Grande complex (Hydro Quebec 2010b). At least eight large structures will be built downstream of the diversion to try to maintain water levels and flow in the remainder of the river. More diversions and facilities are also under construction on the Eastmain River to increase the capacity of the La Grande complex (Hydro Quebec 2010b). Site review is under way to construct additional dams on the Magpie River (there is one run-of-river dam near the mouth), the Manic River, the St. Marguerite and a series of dams are under consideration on the now free-flowing Petit Mecatina River (Hydro Quebec 2009).

More than 60 sites have also been identified as potential locations for new hydroelectric facilities. Hydro Quebec's recent strategic plan proposes that an additional 3000 MW of additional energy be generated in Quebec's northern region by 2032 (Hydro Quebec 2009). Though no specific project locations are named, the James Bay Northern Quebec Agreement signed in 1975 and the Sanarrutik agreement with the Inuit of Nunavik signed in 2002 together allow for the consideration of hydropower projects on the Great Whale River and the Nottoway, Broadback, Meleze, Leaf, Nastapoka, Caniapiscau and Rupert rivers.

**Quebec's World-Class Vision for Conservation**

The Quebec Government's Plan Nord vision also includes the promise of establishing protected areas to encompass 50 percent of Northern Quebec. In the past eight years, 87,575.82 km$^2$ (21.6 million acres) of protected areas have been added, for a total of 135,636.67 km$^2$ (33.5 million acres)—just over 8 percent of the province (Brassard *et al.* 2009). The vision for the Plan Nord includes raising the percentage of protected areas from 8 to 12 percent by 2015 and protecting an additional 38 percent of the north from all industrial activities.

Quebec's Natural Heritage Conservation Act, signed into law in 2002, provides a legal framework for provincial designation of aquatic reserves, biodiversity reserves and ecological reserves in which industrial land-use activities are generally prohibited. Since 2002, one aquatic reserve, five biodiversity reserves and 70 ecological reserves have been formally designated. There are now also eight proposed aquatic reserves, 78 proposed biodiversity reserves and six proposed ecological reserves that have been made off-limits to industrial activity while the proposals are considered. Quebec also has 24 national parks that, with the addition of Parc Marin du Saguenay-Saint-Laurent, together encompass 12,000 km$^2$ (3 million acres) and at least eight areas proposed or under study for consideration as national parks of Quebec. Other lands have been set aside from industrial activity by the Quebec Government with the intent of establishing other future protected areas. Such sites include a proposed 8,000-km$^2$ (2-million-acre) protected area that encompasses much of the George River that flows north into Ungava Bay near the Labrador border.

### Potential Protected Areas in the James Bay-Hudson Bay Watershed

Many of the proposed protected areas are particularly important for Quebec's waterways and wetlands. For example, together with the Kativik Regional Government, and in partnership with Makivik Corp., and local Inuit and Cree communities, the Quebec government has proposed the 15,000-$km^2$ (3.7-million-acre) Tursujuq National Park, which would include Richmond Gulf and Clearwater Lake, Quebec's second-largest natural lake (unfortunately, the Seal Lakes with their rare inland seals and the Nastapoka River with its landlocked salmon and beluga whale sanctuary are not included). An area of 8,750-$km^2$ (2.2-million-acre) has been proposed as a new national park north of the La Grande hydro complex at the intersection of James and Hudson bays including Lake Burton. The proposed Paakumshumwaau-Maatuskaau biodiversity reserve would encompass 4,200-$km^2$ (1-million-acre) from the shore of James Bay inland approximately 100 km (62 miles) and including most of the watersheds of two small undammed rivers. An independent group has also proposed a 19,000-$km^2$ (4.7-million-acre) Tawich Marine Conservation Area offshore from the proposed Paakumshumwaau-Maatuskaau Provincial Biodiversity Reserve. The proposed 894-$km^2$ (221,000-acre) Ministikawatin peninsula biodiversity reserve lies along the shore of the southern end of James Bay and abuts the Ontario border. At least two-thirds of the proposed reserve is covered with carbon-rich peatlands.

*The proposed Albanel-Témiscamie-Otish national park in Quebec.*

CREDIT: GARTH LENZ

Much of the Quebec portion of the Harricana River, which flows into the southern end of James Bay, has been proposed as an aquatic reserve along with the adjacent proposal for an 800-km$^2$ (498,000-acre) Muskuuchii Hills biodiversity reserve. About 80 km (50 miles) of the undammed 248-km (154-mile) Pontax River's main stem and most of its tributary, the roughly 100-km (62-mile) Machisakahikanistikw River, which flows into James Bay just north of the Rupert River, are contained with the proposed 1,000-km$^2$ (247,000-acre) Waskaganish biodiversity reserve.

### Potential Protected Areas in Quebec's North Shore Region

Along the North Shore region, several proposals for protected areas are under review. All but the last 37-km (23-miles) of the main bed Moisie River would be protected from hydropower and other industrial development within the proposed Moisie River Aquatic Reserve. The Natashquan-Aguanus-Kenamu National Park proposal is under study that encompasses parts of the headwaters of the Natashquan and Petit Mecatina rivers within the 16,000-km$^2$ (4-million-acre) study area. The upper valley of the Natashquan River is also proposed as a provincial biodiversity reserve. A 3,670-km$^2$ (907,000-acre) area of shoreline near the mouth of the Petit Mecatina River is being studied as the proposed Harrington Harbour National Park as well as a potential 1,200-km$^2$ (297,000-acre) biodiversity reserve.

### A Balancing Act

Clearly there are world-class opportunities for conservation within the boreal forest region of Quebec that will ensure the future of some of the world's last great waterways and wetlands. Taking advantage of these opportunities will require a careful consideration of the impact of hydropower development on ecological services and biodiversity.

This case study addresses only the direct impacts of industrial development on aquatic ecosystems. It does not address the larger context of trade-offs regarding greenhouse gas emissions and the impacts of fossil fuel consumption on global warming, which, unless quickly addressed, will also have dramatic impacts on these same aquatic ecosystems.

These other impacts and their implications on policy decisions are extremely complex and must be viewed in a larger context. While it is clear that allowing our societies to be powered by carbon fuels is not sustainable, this does not mean that alternative or renewable energy sources can simply be viewed as having no cost whatsoever.

In order to make the best and most informed decisions, we must understand as many of the implications and complexities of the issues as possible, and understand that all of our choices—with the exclusion of energy conservation and increased efficiency—involve difficult trade-offs. Only by taking all of this information into consideration can we work to maximize social, economic and environmental benefits while minimizing the costs.

# References

## References


Aagaard, K., and E.C. Carmack. 1989. The role of sea ice and other freshwater in the Arctic circulation. *Journal of Geophysical Research* 94:14485-14498.

Abraham, K.F., and C.J. Keddy. 2005. The Hudson Bay Lowland. Pp. 118-148. In: L.H. Fraser and P.A. Keddy (eds.), *The world's largest wetlands*. Cambridge, UK: Cambridge University Press.

Alberta Environment. 2007. *Current and future water use in Alberta.* Chapter 11: Athabasca River Basin. www.assembly.ab.ca/lao/library/egovdocs/2007/alen/164708.pdf.

Allen, J.D., *et al*. 2005. Overfishing of inland waters. *Bioscience* 55:1041-1051.

Anielski, M., and S.J. Wilson. 2009. *Counting Canada's natural capital: Assessing the real value of Canada's boreal ecosystems.* Pembina Institute and Canadian Boreal Initiative, Ottawa, Ontario.

Atlantic Salmon Federation. 2010. *Atlantic salmon in North America*. Maps of fate of North America Atlantic salmon rivers. www.asf.ca/docs/uploads/%20rivers/introduction.html.

Augerot, X., and D.N. Foley. 2005. *Atlas of Pacific Salmon.* Berkeley, Calif.: University of California Press.

Aznar, J.C., and A. Desrochers. 2008. Building for the future: Abandoned beaver ponds promote bird diversity. *Écoscience* 15:250-257.

Baldocchi, D., *et al*. 2000. Climate and vegetation controls on boreal zone energy exchange. *Global Change Biology* 6 (Suppl. 1):69-83.

Battin, T.J., *et al*. 2009. The boundless carbon cycle. *Nature Geoscience* 2:598-600.

Bell, F.G., and L.J. Donnelly. 2006. *Mining and its impact on the environment.* London: Taylor & Francis Group.

Bendell-Young, L.I., *et al*. 2000. Ecological characteristics of wetlands receiving an industrial effluent. *Ecological Applications* 10:310-332.

Benke, A.C., and C.E. Cushing. 2005. *Rivers of North America*. New York: Elsevier Press.

Berkes, F. 1998. The intrinsic difficulty of predicting impacts: Lessons from the James Bay Hydro Project. *Environmental Impact Assessment Review* 8:201-220.

Berkes, F., M.K. Berkes and H. Fast. 2007. Collaborative integrated management in Canada's North: The role of local and traditional knowledge and community-based monitoring. *Coastal Management* 35:143-162.

Bernhardt, E.S., *et al.* 2005. Synthesizing U.S. river restoration efforts. *Science* 308:636-637.

Berry, D.K. 1994. *Alberta's bull trout management and recovery plan.* Alberta Environmental Protection, Fish and Wildlife Services, Fisheries Management Division, Edmonton, Alberta.

Bishop, K., *et al.* 2009. The effects of forestry on Hg bioaccumulation in nemoral/boreal waters and recommendations for good silvicultural practice. *Ambio* 38(7):373-380.

Blancher, P. 2003. *Importance of Canada's boreal forest to landbirds.* Canadian Boreal Initiative and Boreal Songbird Initiative, Ottawa, Ontario, and Seattle.

Blancher, P., and J.V. Wells. 2005. The boreal forest region: North America's bird nursery. In: *American birds: The 105th Christmas bird count*. www.audubon.org/BIRD/CBC/105thSummary.html.

Bodaly, R.A., R.E. Hecky and R. J.P. Fudge. 1984. Increases in fish mercury levels in lakes flooded by the Churchill River Diversion, Northern Manitoba. *Canadian Journal of Fisheries and Aquatic Sciences* 41:682-691.

Bonan, G.B. 2008. Forests and climate change: Forcings, feedback and climate benefits of forests. *Science* 320:1444-1449.

Bonan, G.B., D. Pollard, S.L. Thompson. 1992. Effects of boreal forest vegetation on global climate. *Nature* 359:716-718.

Boreal Leadership Council. 2003. *Canadian boreal forest conservation framework*. Canadian Boreal Initiative, Ottawa, Ontario. www.borealcanada.ca/documents/CBI_Framework_EWeb_0509.pdf.

Bowers, N., R. Bowers and K. Kaufman. 2004. *Mammals of North America.* Boston: Houghton Mifflin.

Bradshaw, C.J.A., I.G. Warkentin and N.S. Sodhi. 2009. Urgent preservation of boreal carbon stocks and biodiversity. *Trends in Ecology and Evolution* 24:541-548. 62

Brassard, F., *et al*. 2009. *Overview of Quebec's protected areas network, period 2002/2009.* Quebec Développement durable, Environnement et des Parcs, Quebec City.

Brouard, D., J.-F. Doyon and R. Schetagne. 1994. Amplification of mercury concentration in lake whitefish (*Coregonus clupeaformis*) downstream from the La Grande 2 reservoir, James Bay, Quebec. In: *Mercury Pollution: Integration and Synthesis*, C.J. Watras and J.W. Huckabee (eds.). Boca Raton, Fla.:Lewis Publishers. Pp. 369-380.

Brown, L.E., D.M. Hannah and A.M. Milner. 2007. Vulnerability of alpine stream biodiversity to shrinking glaciers and snowpacks. *Global Change Biology* 13:958-966.

Browne, D.R. 2007. Freshwater fish in Ontario's boreal: Status, conservation and potential impacts of development. *WCS Canada Conservation Report No. 2.* www.wcscanada.org/publications.

Bryant, D., D. Nielsen and L. Tangley. 1997. *The last frontier forests: Ecosystems and economies on the edge.* Washington: World Resources Institute.

Bunn, S.E., and A.H. Arthington. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management* 30(1).

Butterworth, E., *et al*. 2002. *Peace-Athabasca Delta waterbird inventory program: 1998-2001* final report. Ducks Unlimited Canada, Edmonton, Alberta.

Bytnerowicz, A., *et al*. 2010. Spatial and temporal distribution of ambient nitric acid and ammonia in the Athabasca Oil Sands Region, Alberta. *Journal of Limnology* 69(Suppl. 1):11-21. DOI: 10.3274/JL10-69-S1-03.

Canadian Boreal Initiative. 2005. *The boreal in the balance: Securing the future of Canada's boreal region.* Canadian Boreal Initiative, Ottawa, Ontario.

Canadian Boreal Initiative. 2008. *Mineral exploration conflicts in Canada's boreal forest*. Canadian Boreal Initiative, Ottawa, Ontario.

Cannings, S.G., and R.A. Cannings. 1994. The *Odonata* of the Northern Cordilleran peatlands of North America. *Memoirs of the Entomological Society of Canada* 126(169):89-110.

Cannings, S., *et al*. 2005. *Our home and native land: Canadian species of global conservation concern.* NatureServe Canada. Ottawa, Ontario.

Capinera, J.L., R.D. Scott and T.J. Walker. 2004. *Field guide to grasshoppers, katydids and crickets of the United States.* Ithaca, N.Y.: Cornell University Press.

Cardillo, M., *et al*. 2006. Latent extinction risk and the future battlegrounds of mammal conservation. *Proceedings of the National Academy of Sciences* 103:4157-4161.

Carlson, M., J. Wells and D. Roberts. 2009. *The carbon the world forgot: Conserving the capacity of Canada's boreal forest region to mitigate and adapt to climate change*. Boreal Songbird Initiative and Canadian Boreal Initiative, Seattle and Ottawa, Ontario. 33 pp.

Carlson, M., *et al*. 2010. Maintaining the role of Canada's forests and peatlands in climate regulation. *Forestry Chronicle* 86(4):1-10.

Carmack, E.C., and R.W. MacDonald. 2002. Oceanography of the Canadian Shelf of the Beaufort Sea: A setting for marine life. *Arctic* 56(Suppl. 1):29-45.

Carpenter, S.R., *et al*. 1992. Global change and freshwater ecosystems. *Annual Review of Ecology and Systematics* 23:119-139.

Chipley, R.M., *et al*. 2003. *The American Bird Conservancy guide to the 500 most important bird areas in the United States.* New York: Random House.

Cobb, D.G., S. Eddy and O. Banias. 2001. Examining the health of the Hudson Bay Ecosystem. Proceedings of the Western Hudson Bay Workshop, Winnipeg, Manitoba, October 25-26, 2000. *Canadian Manuscript Report of Fisheries and Aquatic Sciences* 2589:xvii + 37 p.

Cobb, D., *et al*. 2008. *Beaufort Sea Large Ocean Management Area: Ecosystem overview and assessment report.* Fisheries and Oceans Canada, Canadian Technical Report of Fisheries and Aquatic Sciences 2780.

Croke, J.C., and P.B. Hairsine. 2006. Sediment delivery in managed forests: A review. *Environmental Reviews* 14:59-87.

Cross, D., and L. Everest. 1997. Fish habitat attributes of reference and managed watersheds, with special reference to the location of bull trout (*Salvelinus confluentus*) spawning sites in the upper Spokane River ecosystem, northern Idaho. Pp. 381-386. In: W.C. Mackay, M.K. Bewin and M. Monita (eds.), *Friends of the Bull Trout Conference Proceedings*. Bull Trout Task Force (Alberta), Trout Unlimited Canada, Calgary, Alberta.

Culp, J.M., T.D. Prowse and E.A. Luiker. 2005. Mackenzie River Basin. Pp. 805-852. In: A.C. Benke and C.E. Cushing (eds.). *Rivers of North America*. London: Elsevier Academic Press.

Cumulative Environmental Management Association (CEMA). 2008. *Terrestrial ecosystem management framework for the Regional Municipality of Wood Buffalo.* Prepared by the CEMA Sustainable Ecosystem Working Group, Fort McMurray, Alberta. http://cemaonline.ca/terrestrial-ecosystem-management-framework.html.

Cyr, D., *et al*. 2009. Forest management is driving the eastern North American boreal forest outside its natural range of variability. *Frontiers in Ecology and the Environment* 7:519-524.

Dai, A., and K.E. Trenberth. 2002. Estimates of freshwater discharge from continents: Latitudinal and seasonal variations. *Journal of Hydrometeorology* 3:660-683.

Dai, A., T. Qian and K.E. Trenberth. 2009. Changes in continental freshwater discharge from 1948 to 2004. *Journal of Climate* 23:2773-2792.

De Boer, A.M., and D. Nof. 2004. The exhaust valve of the North Atlantic. *Journal of Climate* 17:417-422.

Dery, S.J., *et al*. 2005. Characteristics and trends of river discharge into Hudson, James and Ungava bays, 1964-2000. *Journal of Climate* 18:2540-2557.

Desbiens, C. 2007. "Water all around, you cannot even drink": The scaling of water in James Bay/Eeyou Istchee. *Area* 39:259-267.

Dickson, R., *et al*. 2007. Current estimates of freshwater flux through Arctic and sub-Arctic seas. *Progress in Oceanography*, in press.

Dickson, D.L., and H.G. Gilchrist. 2002. Status of marine birds of the southeastern Beaufort Sea. *Arctic* 55(Supp. 1):46-58.

Dise, N.B. 2009. Peatland response to global change. *Science* 326:810-811.

Donovan, T.M., *et al*. 1995a. Modelling the effects of habitat fragmentation on source and sink demography of neotropical migrant birds. *Conservation Biology* 9:1396-1407.

Doyon, J.F., R. Schetagne and R. Verdon. 1998. Different mercury bioaccumulation rates between sympatric populations of dwarf and normal lake whitefish (*Coregonus clupeaformis*) in the La Grande complex watershed, James Bay, Quebec. *Biogeochemistry* 40:203-216.

Doyon, J.F., *et al*. 1998. Comparison of normal and dwarf populations of lake whitefish (*Coregonus clupeaformis*) with reference to hydroelectric reservoirs in northern Quebec. *Advances in Limnology* 50:97-108.

Duchemin, E., *et al*. 2006. First assessment of methane and carbon dioxide emissions from shallow and deep zones of boreal reservoirs upon ice break-up. *Lakes & Reservoirs Research and Management* 11(1):9–19.

Dudgeon, D., *et al.* 2005. Freshwater biodiversity: Importance, threats, status and conservation challenges. *Biological Review* 81:163-182.

Dudley, R.K., and S.P. Platania. 2007. Flow regulation and fragmentation imperil pelagic-spawning riverine fishes. *Ecological Applications* 17:2074-2086.

Dunkle, D.W. 2000. Dragonflies through binoculars: A field guide to dragonflies of North America. New York: Oxford University Press.

Dunton, K.H., T. Weingartner and E.C. Carmack. 2006. The nearshore western Beaufort Sea ecosystem: Circulation and importance of terrestrial carbon in Arctic coastal food webs. *Progress in Oceanography* 71:362-378.

Dyer, S., *et al*. 2008. *Catching up: Conservation and biodiversity offsets in Alberta's boreal forest.* Canadian Boreal Initiative, Ottawa, Ontario.

Dynesius, M., and C. Nilsson. 1994. Fragmentation and flow regulation of river systems in the northern third of the world. *Science* 256:753-762.

Eaton, J.G., and R.M. Scheller. 1996. Effects of climate warming on fish thermal habitat in streams of the United States. *Limnology and Oceanography* 41:1109-1115.

Emmerton, C.A., L.F.W. Lesack and P. Marsh. 2007. Lake abundance, potential water storage and habitat distribution in the Mackenzie River Delta, western Canadian Arctic. *Water Resources Research* 43, W05419. DOI: 10.1029/2006WR005139.

Environment Canada. 2003. Ontario shorebird conservation plan. Canadian Wildlife Service, Downsview, Ontario. www.on.ec.gc.ca/wildlife/plans/shorebirdplan-e.html.

Environment Canada. 2005. *Narrative descriptions of terrestrial ecozones and ecoregions of Canada.* Ottawa, Ontario. www.ec.gc.ca/soer-ree/English/Framework/Nardesc/default.cfm (accessed November 2008).

Environment Canada. 2008a. *Aquatic ecosystems: Groundwater.* Ottawa, Ontario. www.ec.gc.ca/Water/en/nature/grdwtr/e_gdwtr.htm (accessed May 2009).

Environment Canada. 2008b. *Scientific review for the identification of critical habitat for woodland caribou* (Rangifer tarandus caribou)*, boreal population, in Canada.* Environment Canada, Ottawa, Ontario. 72 pp. plus 180 pp. appendices.

Environment Canada. 2008c. *Turning the corner: Regulatory framework for industrial greenhouse gas emissions.* www.ec.gc.ca/doc/virage-corner/2008-03/571/tdm_toc_eng.htm (accessed 29 July 2010).

Environment Canada. 2009a. *Canada's 4th national report to the United Nations Convention on Biological Diversity*. Ottawa, Ontario.

Environment Canada. 2009b. *Wetlands*. Ottawa, Ontario. www.ec.gc.ca/default.asp?lang=En&n=540B1882-1 (accessed May 2009).

Environment Canada. 2010a. www.canadainternational.gc.ca/can-am/bilat_can/energy-energie.aspx?lang=eng#Hydroelectric (accessed August 2010).

Environment Canada. 2010b. dams and diversions: Number of large dams in Canada. www.ec.gc.ca/eau-water/default.asp?lang=En&n=9D404A01-1 (accessed August 2010).

Erskine, A.J. 1977. *Birds in boreal Canada: Communities, densities and adaptations.* Canadian Wildlife Service report series No. 41, Minister of Supply and Services, Ottawa, Ontario.

Etkin, D., G. Paoli and D. Riseborough. 1998. *Climate change impacts of permafrost engineering design.* Environment Canada, Toronto.

Eugster, W., *et al.* 2000. Land-atmosphere energy exchange in Arctic tundra and boreal forest: Available data and feedbacks to climate. *Global Change Biology* 6 (Suppl 1):84-115.

Faaborg, J., *et al*. Habitat fragmentation in the temperate zone. Pp. 357-380. In: T.E. Martin and D.M. Finch (eds.), *Ecology and Management of Neotropical Migratory Birds*. Oxford, UK: Oxford University Press.

Fairless, D.M., S.J. Herman and P.J. Rhem. 1994. *Characteristics of bull trout* (Salvelinus confluentus) *spawning sites in five tributaries of the Upper Clearwater River, Alberta.* Fish and Wildlife Services, Alberta Environmental Protection, Rocky Mountain House, Alberta.

Fahrig, L. 2003. Effects of habitat fragmentation on biodiversity. *Annual Review of Ecology, Evolution and Systematics* 34:487-515.

Fearnside, P.M. 2004. Greenhouse gas emissions from hydroelectric dams: Controversies provide a springboard for rethinking a supposedly clean energy source. *Climatic Change* 66:1-8.

Fearnside, P.M. 2005. Do hydroelectric dams mitigate global warming? The case of Brazil's Curua-Una Dam. *Mitigation and Adaptation Strategies for Global Change* 10:675-691.

Fisheries and Oceans Canada. 2005. *The Gulf of St. Lawrence, a unique ecosystem.* Ottawa, Ontario. 60 pp.

Freeman, M.C., *et al*. 2003. Ecosystem-level consequences of migratory faunal depletion caused by dams. *American Fisheries Society Symposium* 35:255-266.

Garcia, E., and R. Carignan. 2005. Mercury concentrations in fish from forest harvesting and fire-impacted Canadian boreal lakes compared using stable isotopes of nitrogen. *Environmental Toxicology and Chemistry* 24:685-693.

Gardarsson, A., *et al*. 2004. Population fluctuations of chironomid and simuliid Diptera at Myvatn in 1977-1996. *Aquatic Ecology* 38(2):209-217.

Gauthier, J., and Y. Aubry. 1996. *The breeding birds of Quebec.* Quebec Society for the Protection of Birds and the Canadian Wildlife Service, Environment Canada, Quebec region, Montreal.

Gentes, M.-L., *et al*. 2006. Effects of oil sands tailings compounds and harsh weather on mortality rates, growth and detoxification efforts in nestling tree swallows (*Tachycineta bicolor*). *Environmental Pollution* 142(1):24-33.

Gentes, M.-L., *et al*. 2007. Tree swallows (*Tachycineta bicolor*) nesting on wetlands impacted by oil sands mining are highly parasitized by the bird blow fly *Protocalliphora spp. Journal of Wildlife Diseases* 43:167-178.

Ghassemi, F., and I. White. 2007. *Inter-basin water transfer: Case studies from Australia, United States, Canada, China and India*. Cambridge, UK: Cambridge University Press.

Gorham, E. 1991. Northern peatlands: Role in the carbon cycle and probable responses to climatic warming. *Ecological Applications* 1(2):182-195.

Goudie, A. 2006. *The human impact on the natural environment*, 3rd ed., Cambridge, Mass.: Blackwell.

Government of Alberta. 2009. *Terms of reference for developing the Lower Athabasca land use plan.* Edmonton, Alberta.

Grant, J., *et al*. 2010. Northern lifeblood: Empowering northern leaders to protect the Mackenzie River Basin from oil sands risks. Pembina Institute, Drayton Valley, Alberta. 75 pp.

Greathouse, E.A., *et al*. 2006. Indirect upstream effects of dams: Consequences of migratory consumer extirpation in Puerto Rico. *Ecological Applications* 16:339-352.

Gresh, T.U., J. Lichatowich and P. Schoonmaker. 2000. An estimation of historic and current levels of salmon production in the northeast Pacific ecosystem: Evidence of a nutrient deficit in the freshwater systems of the Pacific Northwest. *Fisheries* 25:15-21.

Griffiths, M., A. Taylor and D. Woynillowicz. 2006. *Troubled waters, troubling trends: Technology and policy options to reduce water use in oil and oil sands development in Alberta.* Pembina Institute. Alberta.

Gurney, K.E., *et al*. 2005. Impact of oil-sands-based wetlands on the growth of mallard (*Anas platyrhynchos*) ducklings. *Environmental Toxicology and Chemistry* 24(2):457-463.

Hall, B.D., *et al*. 2005. Impacts of reservoir creation on the biogeochemical cycling of methyl mercury and total mercury in boreal upland forests. *Ecosystems* 8:248-266.

Hammond, H. 2009. *Maintaining whole systems on Earth's Crown: Ecosystem-based conservation planning for the boreal forest*. Silva Forest Foundation, Slocan Park, B.C.

Hayeur, G. 2001. *Summary of knowledge acquired in northern environments from 1970 to 2000.* Hydro-Québec, Montreal.

Hebert, P.D.N. (ed.). 2002. *Canada's aquatic environments* (Internet). CyberNatural Software, University of Guelph. www.aquatic.uoguelph.ca.

Hennan, E.G. 1974. Peace Athabasca Delta: Breeding and fall staging census results, 1974. Ducks Unlimited.

Hinzman, L.D., *et al.* 2005. Evidence and implications of recent climate change in northern Alaska and other arctic regions. *Climate Change* 72:251- 298.

Hobson, K.A., and E.M. Bayne. 2000. Effects of forest fragmentation by agriculture on avian communities in the southern boreal mixed woods of western Canada. *Wilson Bulletin* 112:373-387.

Hodgins, B.W., and G. Hoyle. 1997. Canoeing north into the unknown: A record of river travel, 1874-1974. *Natural Heritage*. Toronto. 278 pp.

Hood, G.A., and S.E. Bayley. 2008. Beaver (*Castor canadensis*) mitigate the effects of climate on the area of open water in boreal wetlands in western Canada. *Biological Conservation* 141:556-557.

Hornig, J.F. (ed.). 1999. Social and environmental impacts of the James Bay hydroelectric project. Montreal: McGill-Queen's University Press.

Hummel, M., and J.C. Ray. 2008. *Caribou and the north: A shared future.* Toronto: Dundurn Press.

Humphries, P., and K.O. Winemiller. 2009. Historical impacts on river fauna, shifting baselines and challenges for restoration. *Bioscience* 59:673-684.

Hydro One. 2010. www.hydroone.%20com/OurCompany/Pages/OurSubsidiaries.aspx (accessed 11 June 2010).

Hydro-Québec. 2009. Hydro Québec: The strategic plan 2009-2013. www.hydroquebec.com (accessed 11 June 2010).

Hydro-Québec 2010a. Projet de la Romaine. www.hydroquebec.com/romaine/index.html (accessed 29 July 2010).

Hydro-Québec. 2010b. Eastmain-1-A/Sarcelle/Rupert Project. www.hydroquebec.com/ rupert/en/index.html (accessed 29 July 2010).

Intergovernmental Panel on Climate Change (IPCC). 1995. IPCC second assessment—climate change 1995. Synthesis Report and Summaries for Policymakers, WMO, United Nations Environment Program, Geneva, Switzerland.

Intergovernmental Panel on Climate Change. 2000. Land use, land-use change and forestry. R.T. Watson *et al.* (eds.). Cambridge, UK: Cambridge University Press.

International Game Fish Association. 2010. World record fish. www.igfa.org/records/World- Records-Fish-List.aspx?LC=ATR (accessed 8 June 2010).

Johnson, P.T.J., J.D. Olden and M.J. Vander Zanden. 2008. Dam invaders: Impoundments facilitate biological invasions into freshwaters. *Frontiers in Ecology and the Environment* 6:357-363.

Kallick, S. 2010. *World-class forest protection*. Huffington Post. www.huffingtonpost.com/ steven-kallick/world-class-forest-protec_b_587798.html.

Karst, A. 2010. Importance of Canada's boreal forest from an ethnobotanical perspective. Boreal Songbird Initiative, Canadian Boreal Initiative, David Suzuki Foundation, Seattle, Ottawa, Ontario, and Vancouver, B.C.

Kelly, M. 1988. Mining and the freshwater environment. New York: Elsevier.

Kelly, E.N., *et al*. 2009. Oil sands development contributes polycyclic aromatic compounds to the Athabasca River and its tributaries. *Proceedings of the National Academy of Sciences*, DOI:10.1073/pnas.0912050106.

Kemp, A., L. Bernatchez and J.J. Dodson. 1989. A revision of coregonine fish distribution and abundance in eastern James Bay. *Environmental Biology of Fishes* 26:247-255.

Kimmerer, W.J. 2002. Effects of freshwater flow on abundance of estuarine organisms: Physical effects or trophic linkages? *Marine Ecology Progress Series* 243:39-55.

Lafleur, P.M. 2008. Connecting atmosphere and wetland: Energy and water vapour exchange. *Geography Compass* 2/4:1027-1057.

Langlois, C., R. Langis and M. Pérusse. 1995. Mercury contamination in northwest Quebec environment and wildlife. *Water, Air and Soil Pollution* 80:1021-1024.

Lee, P., *et al.* 2003. *Canada's large intact forest landscapes*. Global Forest Watch Canada, Edmonton, Alberta, and World Resources Institute, Washington.

Lee, P.D. *et al*. 2006. *Canada's large intact forest landscapes*. Global Forest Watch Canada, Edmonton, Alberta.

Le Pape, O., *et al*. 2003. Relationship between interannual variations of the river plume and the extent of nursery grounds for the common sole (*Solea solea*) in Vilaine Bay. Effects on recruitment variability. *Journal of Sea Research* 50:177-185.

Leprieur, F., *et al*. 2008. Fish invasions in the world's river systems: When natural processes are blurred by human activities. *Public Library of Science Biology* 6(2): e28, DOI:10.1371/journal.pbio.0060028.

Lindenmayer, D.B., and J.F. Franklin. 2002. *Conserving forest biodiversity: A comprehensive multiscaled approach.* Washington: Island Press.

Loeng, H., *et al.* 2005. Marine systems. Pp. 453-538. In *Arctic Climate Impacts Assessment.* Cambridge, UK: Cambridge University Press.

Loneragan, N.R., and S.E. Bunn. 1999. River flows and estuarine ecosystems: Implications for coastal fisheries from a review and a case study of the Logan River, southeast Queensland. *Australian Journal of Ecology* 24:431-440.

Louchouarn, P., *et al*. 1993. Geochemistry of mercury in two hydroelectric reservoirs in Quebec, Canada. *Canadian Journal of Fisheries and Aquatic Sciences* 50:269-281.

Loo, T. 2007. Disturbing the peace: Environmental change and the scales of justice on a northern river. *Environmental History* 12:895-919.

Lottermoser, B. 2003. *Mine wastes: Characterization, treatment and environmental impacts*. New York: Springer.

MacCrimmon, H.R., and B.L. Gots. 1979. World distribution of Atlantic salmon (*Salmo salar*). *Journal of the Fisheries Research Board of Canada* 36:422-457.

Marty, J., K. Smokorowski and M. Power. 2008. The influence of fluctuating ramping rates on the food web of boreal rivers. *River Research and Applications*. DOI:10.1002/rra.1194.

McAllister, D.E. 2000. Biodiversity in Canadian fresh and marine waters. Pp. 81-106. In Bocking, S. (ed.), *Biodiversity in Canada: Ecology, ideas and action*. Peterborough, Ontario: Broadview Press.

McCart, P. 1997. Bull trout in Alberta: A review. Pp. 191-208. In W.C. Mackay, M.K. Bewin and M. Monita (eds.). *Friends of the Bull Trout Conference Proceedings.* Bull Trout Task Force, Trout Unlimited Canada, Calgary, Alberta.

McCutcheon, S. 1991. Electric rivers: *The story of the James Bay Project*. Montreal: Black Rose Books.

McGuire, A.D., *et al*. 2009. Sensitivity of the carbon cycle in the Arctic to climate change. *Ecological Monographs* 79:523-555.

Meincke, J., B. Rudels and H.J. Friedrich. 1997. The Arctic Ocean-Nordic Seas thermohaline system—ICES Journal of Marine Science, 54: 283-299.

Millennium Ecosystem Assessment. 2005. *Ecosystems and human well-being: Synthesis.* Washington: Island Press.

Mining Association of Canada. 2009. *Towards sustainable mining: Progress report.* www.mining.ca/www/media_lib/TSM_Publications/2009_Annual_Report/2009_MAC_TSM_English.pdf

Minns, C.K., *et al*. 2008. A preliminary national analysis of some key characteristics of Canadian lakes. *Canadian Journal of Fisheries and Aquatic Science* 65:1763-1778.

Mittermeir, R.A., *et al*. 2003. Wilderness and biodiversity conservation. *Proceedings of the National Academy of Sciences* 100:10309-10313.

Morin, R., J.J. Dodson and G. Power. 1982. Life-history variations of anadromous cisco (*Coregonus artedii*), lake whitefish (C*. clupeaformis*) and round whitefish (*Prosopium cylindraceum*) populations of eastern James Bay-Hudson Bay. *Canadian Journal of Fisheries and Aquatic Sciences* 39:958-967.

Morrison, K.A., and N. Therien. 1995. Changes in mercury levels in lake whitefish (*Coregonus clupeaformis*) and northern pike (*Esox lucius*) in the LG-2 reservoir since flooding. *Water, Air and Soil Pollution* 80:819-828.

Munk Centre and Environmental and Research Studies Centre. 2007. *Running out of steam: Oil sands development and water use in the Athabasca River watershed.* University of Toronto, University of Alberta.

Musick, J.A., *et al.* 2000. Marine, estuarine and diadromous fish stocks at risk of extinction in North America (exclusive of Pacific salmonids). *Fisheries* 25:6-30.

Myers, R.A., S.A. Akenhead and K. Drinkwater. 1990: The influence of Hudson Bay runoff and ice-melt on the salinity of the inner Newfoundland Shelf. *Atmosphere-Ocean* 28(2):241-256.

Naiman, R.J., J.M. Melillo and J.E. Hobbie. 1986. Ecosystem alteration of boreal forest streams by beaver (*Castor canadensis*). *Ecology* 67:1254-1269.

Naiman, R.J., C.A. Johnston and J.C. Kelley. 1988. Alteration of North American streams by beaver. *Bioscience* 38:753-762.

Naiman, R.J., and H. Decamps. 1997. The ecology of interfaces: Riparian zone. *Annual Review of Ecology and Systematics* 28:621-658.

Naiman, R.J., *et al*. 2006. Freshwater biodiversity: Challenges for freshwater biodiversity research. *DIVERSITAS Report No. 5*. www. divertas-international.org/cross_freshwater.html.

National Research Council. 1992. *Restoration of aquatic ecosystems: Science, technology and public policy.* Washington: National Academy Press.

Natural Resources Canada. 2009a. The atlas of Canada: Wetlands. http://atlas.nrcan.gc.ca/site/ english/learningresources/theme_modules/wetlands/ index.html (accessed July 2009).

Natural Resources Canada. 2009b. The state of Canada's forests: 2009 annual report. http://warehouse.pfc.forestry.ca/ HQ/30071.pdf (accessed June 2010).

Nehlsen, W., J.E. Williams and J.A. Lichatowich. 1991. Pacific salmon at the crossroads: Stocks at risk from California, Oregon, Idaho and Washington. *Fisheries* 16:4-21.

Neville, H., *et al*. 2009. Influences of wildfire, habitat size and connectivity on trout in headwater streams revealed by patterns of genetic diversity. *Transactions of the American Fisheries Society* 138:1314-1327.

Niezen, R. 1993. Power and dignity: The social consequences of hydro-electric development for the James Bay Cree. *Canadian Review of Sociology and Anthropology* 30:510-529.

Nikiforuk, A. 2008. Tar sands: Dirty oil and the future of a continent. Vancouver, B.C.: Greystone Books.

Nilsson, C., and M. Dynesius. 1994. Ecological effects of river regulation on mammals and birds: A review. *Regulated Rivers: Research and Management* 9:45-53.

Nilsson C., and K. Berggren. 2000. Alterations of riparian ecosystems caused by river regulation. *BioScience* 50:783-792.

Nilsson, C., *et al*. 2005. Fragmentation and flow regulation of the world's large river systems. *Science* 308:405-408.

Northwatch and MiningWatch Canada 2008. The boreal below: Mining issues and activities in Canada's boreal forest. Ottawa, Ontario. www.web. ca/~nwatch/ (accessed August 2010).

Notzke, C. 1994. Aboriginal peoples and natural resources in Canada. North York, Ontario: Captus University Press and Centre for Aboriginal Management, Education and Training.

Nunavuummi Tasiujarjuamiuguqatigiit Katutjiqatigiingit (NTK)/Nunavut Hudson Bay Inter-Agency Working Group. 2008. A life vest for Hudson Bay's drifting stewardship. *Arctic* 61 (Suppl. 1):35-47.

Oceans North. 2010. Beaufort Sea. www.oceansnorth. org/beaufort-sea (accessed June 2010).

Office of Audit General of Canada. 2009. *Protecting fish habitat.* www.oag-bvg.gc.ca/internet/ English/parl_cesd_200905_01_e_32511.html#hd5l (accessed August 2010).

Ontario Government. 2009a. Amendment to Mining Act. C. 33, Sched. 23, s. 1. www.e-laws.gov.on.ca/html/ statutes/english/elaws_ statutes_90m14_e.htm (accessed June 2010).

Ontario Government. 2009b. (News release) McGuinty government prepares to gather input on regulations. www.news.ontario.ca/mndmf/ en/2009/12/a-new-phase-of-consultation-begins-onmining- act.html (accessed June 2010).

Opler, P.A., and V. Malikul. 1992. A field guide to eastern butterflies. Boston: Houghton Mifflin.

Page, L.M., and B.M. Burr. 1991. A field guide to freshwater fishes of North America north of Mexico. Boston: Houghton Mifflin.

Palmer, M.A., *et al*. 2008. Climate change and the world's river basins: Anticipating management options. 6:81-89.

Park, D., *et al*. 2008. Landscape-level stream fragmentation caused by hanging culverts along roads in Alberta's boreal forest. *Canadian Journal of Forest Research* 38:566-575.

Parrish, D.L., *et al*. 1998. Why aren't there more Atlantic salmon? *Canadian Journal of Fisheries and Aquatic Sciences* 55(Suppl. 1):281-287.

Pew Environment Group. 2010. Canadian forest industry and environmental groups sign world's largest conservation agreement applying to area twice the size of Germany. www.pewtrusts.org/news_room_detail. aspx?id=58950.

Pielke, R.A., and P.L. Vidale. 1995. The boreal forest and the polar front. *Journal of Geophysical Research* 100:755-758.

Pielke, R.A., *et al*. 1998. Interactions between the atmosphere and terrestrial ecosystems: influence on weather and climate. Global Change Biology 4: 461-475.

Pielke, R.A. 2001. Influence of the spatial distribution of vegetation and soils on the prediction of cumulus convective rainfall. *Review of Geophysics* 39:151-177.

Pielke, R.A., *et al*. 2007. An overview of regional land-use and land-cover impacts on rainfall. *Tellus* 59B:587-601.

Pienitz, R., J.P. Smol and D.R.S. Lean. 1997. Physical and chemical limnology of 59 lakes located between the southern Yukon and the Tuktoyaktuk Peninsula, Northwest Territories (Canada). *Canadian Journal of Fisheries and Aquatic Science* 54:330-346.

Pimm, S.L., N. Roulet and A. Weaver. 2009. Boreal forests' carbon stores need better management. *Nature* 462:276.

Poff, N.L., M.M. Brinson and J.W. Day, 2002. *Aquatic ecosystems and global climate change*. Pew Center on Global Climate Change, Arlington, Va.

Poff, N.L., and D.D. Hart. 2002. How dams vary and why it matters for the emerging science of dam removal. *Bioscience* 52:659-668.

Poff, N.L., *et al*. 2007. Homogenization of regional river dynamics by dams and global biodiversity implications. *Proceedings of the National Academy of Sciences* 104:5732-5737.

Pollet, I., and L.I. Bendell-Young. 2001. Amphibians as indicators of wetland quality as applied to wetlands based on oil-sands effluent. *Environmental Toxicology & Chemistry* 19:2589–2597.

Post, J.R., *et al*. 2002. Canada's recreational fisheries: The invisible collapse? *Fisheries* 27:6-17.

Price, J.S., *et al*. 2005. Advances in Canadian wetland hydrology, 1999-2003. *Hydrological Processes* 19:201-214.

Prospectors and Developers Association of Canada. 2010. A framework for responsible exploration. http://pdac.ca/e3plus (accessed June 2010).

Prowse, T., *et al*. 2009a. Climate impacts on northern Canada: Regional background. *Ambio* 38(5):248-256.

Prowse, T., *et al*. 2009b. Implications of climate change for northern Canada: Freshwater, marine and terrestrial ecosystems. *Ambio* 38(5):282-289.

Rahel, F.J., B. Rierwagen and Y. Taniguchi. 2008. Managing aquatic species of conservation concern in the face of climate change and invasive species. *Conservation Biology* 22:551-561.

Ramsar Convention on Wetlands. 1971. Ramsar Convention Secretariat, Ramsar, Iran, 1971. www.ramsar.wetlands.org.

Rawlins, M.A., *et al*. 2009. Tracing freshwater anomalies through the air-land-ocean system: A case study from the Mackenzie River Basin and the Beaufort Gyre. *Atmosphere-Ocean* 47:79-97.

Reeves, R.R., *et al*. 2002. Guide to marine mammals of the world. New York: Alfred A. Knopf.

Reist, J.D., and W.A. Bond. 1988. Life history characteristics of migratory coregonids of the lower Mackenzie River, Northwest Territories, Canada. *Finnish Fisheries Research* 9:133-144.

Reist, J.D., *et al*. 2006. Climate change impacts on Arctic freshwater ecosystems and fisheries. *Ambio* 35(7):370-380.

Richardson, B. 1991. Strangers devour our land. White River Junction, Vt.: Chelsea Green Publishing Co. 376 pp.

Riordan, B., and D. Verbyla. 2006. Shrinking ponds in sub-Arctic Alaska based on 1950-2002 remotely sensed images. *Journal of Geophysical Research* 11:G04002, DOI: 10.1029/2005JG000150.

Ripley, T., G. Scrimgeour and M. S. Boyce. 2005. Bull trout (*Salvelinus confluentus*) occurrence and abundance influenced by cumulative industrial developments in a Canadian boreal forest watershed. *Canadian Journal of Fisheries and Aquatic Sciences* 62:2431-2442.

Roebuck, B.D. 1999. Elevated mercury in fish as a result of the James Bay hydroelectric development: Perception and reality. Pp 73-92. In: J.F. Hornig (ed.), Social and environmental impacts of the James Bay hydroelectric project. Montreal: McGill-Queen's University Press.

Rosenberg, D.M., R.A. Bodaly and P.J. Usher. 1995. Environmental and social impacts of large-scale hydro-electric development: Who is listening? *Global Environmental Change* 5:127-148.

Rosenberg, D.M., *et al*. 1997. Large-scale impacts of hydroelectric development. *Environmental Reviews* 5:27-54.

Rosenberg International Forum on Water Policy. 2009. *Report of the Rosenberg International Forum on Water Policy to the Government of the Northwest Territories*. University of California-Berkeley.

Roy, D., and D. Messier. 1989. A review of the effects of water transfers in the La Grande hydroelectric complex (Quebec, Canada). *Regulated Rivers* 4:299–316.

Sanderson, E.W., *et al*. 2002. The human footprint and the last of the wild. *BioScience* 52:891-904.

Schetagne, R., J.-F. Doyon and J.-J. Fournier. 2000. Export of mercury downstream from reservoirs. *Science of the Total Environment* 260:135-145.

Schetagne, R., and R. Verdon. 1999. Post-impoundment evolution of fish mercury levels at the La Grande complex, Quebec, Canada, from 1978 to 1996. In: M. Lucotte *et al.* (eds.), *Mercury in the biogeochemical cycle: Natural environments and hydroelectric reservoirs of northern Quebec.* Environmental science series. Berlin:Springer. pp. 235-258.

Scheuhammer, A.M. 1987. The chronic toxicity of aluminum, cadmium, mercury and lead in birds: A review. *Environmental Pollution* 46:265-295.

Schindler, D.W., *et al*. 1990. Effects of climatic warming on lakes of the central boreal forest. *Science* 250:967-970.

Schindler, D.W., *et al*. 1996. The effects of climatic warming on the properties of boreal lakes and streams at the Experimental Lakes Area, northwestern Ontario. *Limnology and Oceanography* 41(5):1004-1017.

Schindler, D.W. 1998a. A dim future for boreal waters and landscapes. BioScience 48:157-164.

Schindler, D.W. 1998b. Sustaining aquatic ecosystems in boreal regions. *Conservation Ecology* 2:18.

Schindler, D.W. 2005. *Boreal fresh waters.* Natural Resources Canada, Ottawa, Ontario.

Schindler, D.W., and W.F. Donahue. 2006. An impending water crisis in Canada's western prairie provinces. *Proceedings of the National Academy of Sciences* 103:7210-7216.

Schindler, D.W., and J.P. Smol. 2006. Cumulative effects of climate warming and other human activities on freshwaters of Arctic and Subarctic North America. *Ambio* 35(4):160-168.

Schindler, D.W. 2009. Lakes as sentinels and integrators for the effects of climate change on watersheds, airsheds and landscapes. *Limnology and Oceanography* 54:2349-2358.

Schindler, D., and P. Lee. 2010. Comprehensive conservation planning to protect biodiversity and ecosystem services in Canadian boreal regions under a warming climate and increasing exploitation. *Biological Conservation* 143:1571-1586.

Schuur, E.A.G., *et al.* 2008. Vulnerability of permafrost carbon to climate change: Implications for the global carbon cycle. *Bioscience* 58(8):701-714.

Scott, W.B., and E.J. Crossman. 1973. *Freshwater Fishes of Canada*. Bulletin 184, Fisheries Research Board of Canada, Ottawa, Ontario.

Serreze, M.C., *et al.* 2000. Observational evidence of recent change in the northern high latitude environment. *Climatic Change* 46:159–207.

Sherman, K., and G. Hempel (eds.). 2008. The UNEP large marine ecosystem report: A perspective on changing conditions in LMEs of the world's regional seas. UNEP Regional Seas Report and Studies No. 182. U.N. Environment Program. Nairobi, Kenya.

Shiklomanov, I.A., and J.C. Rodda. 2003. World water resources at the beginning of the twenty-first century. Cambridge, UK: Cambridge University Press.

Sklar, F.H., and J.A. Browder. 1998. Coastal environmental impacts brought about by alterations to freshwater flow in the Gulf of Mexico. *Environmental Management* 22:547-562.

Smith, R.J., *et al*. 2004. Spatial foraging differences in American redstarts along the shoreline of northern Lake Heron during springtime. *Wilson Journal of Ornithology* 116(1):48-55.

Smith, L.C., *et al*. 2005. Disappearing Arctic Lakes. *Science* 308:1429.

Sobek, S., *et al.* 2009. Organic carbon burial efficiency in lake sediments controlled by oxygen exposure time and sediment source. *Limnology and Oceanography* 54:2243-2254.

Soderbergh, B., F. Robelius and K. Aleklett. 2007. A crash program scenario for the Canadian oil sands industry. *Energy Policy* 35:1931-1947.

Sørensen, R., *et al*. 2009. Forest harvest increases runoff most during low flows in two boreal streams. *Ambio* 38(7):357-363.

Spitzer, K., and H.V. Danks. 2006. Insect biodiversity of boreal peat bogs. *Annual Review of Entomology* 51:137-161.

Spracklen, D.V., B. Bonn and K.S. Carslaw. 2008. Boreal forests, aerosols and the impacts on clouds and climate, *Philosophical Transactions of the Royal Society* 366:4613–4626. DOI:10.1098/rsta.2008.0201.

St. Louis, V.L., *et al.* 2000. Reservoir surface as sources of greenhouse gases to the atmosphere: A global estimate. *Bioscience* 50:766–775.

Steedman, R.J., *et al*. 2003. Pp. 59-81. In: J.M. Gunn, R.J. Steedman and R.A. Ryder (eds.). *Boreal shield watersheds: Lake trout ecosystems in a changing environment*. Boca Raton, Fla.: Lewis Publishers.

Stephens, S.A., *et al*. 2003. Effects of habitat fragmentation on avian nesting success: A review of the evidence at multiple spatial scales. *Biological Conservation* 115:101-110.

Stephenson, S.A., J.A. Burrows and J.A. Babaluk. 2005. Long-distance migration by inconnu (*Stenodus leucichthys*) in the Mackenzie River system. *Arctic* 58:21-25.

Stewart, D.B., and W.L. Lockhart. 2005. An overview of the Hudson Bay marine ecosystem. *Canadian Technical Report Fisheries and Aquatic Sciences* 2586:vi + 487 pp.

St. Louis, V.L., C.A. Kelly, E. Duchemin, J.W.M. Rudd and D.M. Rosenberg. 2000. Reservoir surfaces as sources of greenhouse gases to the atmosphere: a global estimate. *BioScience* 50:766-775.

Sullivan, M.G. 2003. Active management of walleye fisheries in Alberta: Dilemmas of managing recovering fisheries. *North American Journal of Fisheries Management* 23:1343-1358.

Sun, J., *et al*. 1997. Lake-induced atmospheric circulations during BOREAS. *Journal of Geophysical Research* 102(D24):29. Pp. 155–129, 166.

Sun, L., J.M. Webb and W.P. McCafferty. 2002. Cercobrachys cree: A new species (*Ephemeroptera: caenidae*) from western North America. *Entomological News* 113:80-86.

Tarnocai, C. 1998. The amount of organic carbon in various soil orders and ecological provinces in Canada. In: Lal, R., *et al.* (eds.), *Soil processes and the carbon cycle.* Boca Raton, Fla.: CRC Press.

Tarnocai, C. 2006. The effect of climate change on carbon in Canadian peatlands. *Global and Planetary Change* 53:222-232.

Tarnocai, C. 2009. The impact of climate change on Canadian peatlands. *Canadian Water Resources Journal* 34:453-466.

Tarnocai, C., *et al*. 2009. Soil organic carbon pools in the northern circumpolar permafrost region. Global Biogeochemical Cycles 23, GB2023, DOI:10.1029/2008GB003327.

Taylor, C.A., *et al*. 1996. Conservation status of crayfishes of the United States and Canada. *Fisheries* 21:25-38.

Taylor, C.M., *et al*. 1998. Snow breezes in the boreal forest, *Journal of Geophysical Research* 103:23,087–23.

Thomas, R.G. 2002. *An updated provisional bird inventory for the Peace Athabasca Delta, Northeastern Alberta*. Final report to BC Hydro, Burnaby, British Columbia.

Thompson, D.R. 1996. *Mercury in birds and terrestrial mammals. Environmental contaminants in wildlife: Interpreting tissue concentrations*. W.N. Beyer, G.H. Heinz and A.W. Redmon-Norwood (eds.). SETA C Spec. Publ. Lewis Publishers, Boca Raton, Fla.

Timoney, K., and P. Lee. 2009. Does the Alberta Tar Sands industry pollute? The scientific evidence. *Open Conservation Biology Journal* 2009 (3).

Tranvik, L.J., *et al.* 2009. Lakes and reservoirs as regulators of carbon cycling and climate. *Limnology and Oceanography* 54:2298-2314.

Tremblay, A., M. Lambert and L. Gagnon. 2004. Do hydroelectric reservoirs emit greenhouse gases? *Environmental Management* 33 (Supplement 1):S509-S517.

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