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FRESHWATER FISH IN ONTARIO'S BOREAL:
STATUS, CONSERVATION AND POTENTIAL
IMPACTS OF DEVELOPMENT

David R. Browne

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Cover photographs:
Fish from top: northern pike – Engbretson Underwater Photography; sturgeon – Rob Criswell; brook trout – Mary Edwards; lake whitefish – © Shedd Aquarium, photo by Edward G. Lines; walleye – Engbretson Underwater Photography. Front cover landscape: Justina Ray; back cover: Carrie Sadowski, OMNR

ABOUT WILDLIFE CONSERVATION SOCIETY CANADA (WCS CANADA)

WCS Canada's mission is to save wildlife and wildlands by improving our understanding of — and seeking solutions to — critical issues that threaten key species and large wild ecosystems throughout Canada. It both implements and supports comprehensive field studies that gather information on wildlife needs and seeks to resolve key conservation problems by working with a broad array of stakeholders, including local community members, conservation groups, regulatory agencies, and commercial interests. It also provides technical assistance and biological expertise to local groups and agencies that lack the resources to address complex conservation issues. Major issues addressed to date include protected-area design, conservation-based land use planning, monitoring and management of wildlife and fish populations, recovery of endangered species, and impacts of climate change upon wildlife.

WCS Canada is independently registered and managed in Canada, while retaining a strong collaborative working relationship with sister WCS programs in more than 55 countries. The Wildlife Conservation Society is a recognized global leader in conservation, dedicated to saving wildlife and wildlands in order to assure a future for threatened species, such as elephants, tigers, sharks, macaws and lynx. For more than a century, WCS has worked in North America promoting such concepts as bison reintroduction, park establishment and legislation to protect endangered wildlife. Today, WCS Canada draws upon this legacy of experience and expertise to inform its conservation programs from Yukon to Labrador.

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ABOUT THE AUTHOR

David R. Browne completed this report while on contract with WCS Canada in 2006-2007. He is currently working as a policy analyst for the Canadian Wildlife Service in Ottawa while completing his doctorate in freshwater ecology at McGill University. His doctoral research was carried out in Alqonquin Park, Ontario and examined the food web dynamics of the interaction between brook trout and yellow perch. David holds a Masters degree in Geography and Geology in which he examined marine heavy metal pollution in Indonesia. He has co-authored a book chapter and three papers related to marine pollution and its effects on human health in Indonesia. David also holds a Masters degree in Environmental Studies in which he examined the policy-making process for air pollution and flood control in Los Angeles.

EXECUTIVE SUMMARY

The French translation of this executive summary is available from http://www. wcscanada.org/publications or by e-mailing wcscanada@wcs.org.

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Freshwater ecosystems are among the most threatened ecosystems on the planet. Physical alteration, water withdrawal, overexploitation, pollution, and the introduction of non-native species have caused widespread habitat loss, degradation in water quality, declines in the abundance of aquatic animals, and biodiversity loss. More than 20 percent of the world's 10,000 freshwater fish species have become threatened, endangered or extinct in recent decades.

In Ontario, the area north of the current limit for forestry activities (roughly straddling the 51st parallel) is one of the largest swaths of largely undisturbed boreal forest in Canada. This landscape is characterized as much by the network of lakes, rivers, swamps, and bogs that make up a large part of the surface area as it is by the coniferous forest expanses that the region is more commonly known for.

In fact, the lakes and rivers of northern Ontario are part of the single largest area of high fish biodiversity that has experienced the least human alteration of the natural landscape in Canada. Five of the 12 remaining undammed and unregulated watersheds in North America south of 55 degrees occur in northern Ontario, which also contains the third largest wetland on the planet — the Hudson Bay Lowlands, covering 25% of Ontario's land surface.

Unlike in more developed regions in southern Ontario, fish communities of the northern part of the province remain largely unaltered by species introductions, stocking, overexploitation, or pollution. In fact, the current intact condition of fisheries in this region provides a virtually unprecedented opportunity to conserve fish communities in their original abundance and diversity — a challenge that will require proactive land use planning and information gathering to be successful.

These freshwater ecosystems also have great cultural and economic importance: Approximately 10,000 people live in remote First Nations communities situated on the lakes and rivers of far northern Ontario with the water courses serving as the highways of the region in summer and winter and residents relying on plentiful walleye and whitefish populations as a major food source.

The high concentration of lakes containing walleye and northern pike in the region has also made it a top destination for fly-in sport fishing. The resource-based tourism industry is a major component of the northern Ontario economy. The total annual economic activity from resource-based tourism for all of northern Ontario is approximately $306 million with remote fly-in operations accounting for 25% of the tourism businesses in the region.

At the same time, the natural resources of far northern Ontario offer significant potential for economic development and commercial exploitation. The development of these resources — hydroelectricity, forestry, and mineral — is now of growing interest to industry, First Nations and the province This northern boreal landscape is therefore both an ecological gem, as yet largely unaffected by industrial development, and a likely target for much greater development pressures in the near future.

Due to recent efforts to plan for increased economic development in the region, such as the provincially-led Northern Boreal Initiative, scientists, resource managers, and conservationists have begun to identify priorities for conservation of the unique flora and fauna of the area. To date, these efforts have largely focused on terrestrial mammals, with a particular emphasis on wide-ranging terrestrial mammals native to the region, such as woodland caribou.

And while general life history and status information on northern boreal fisheries is available, one of the key impediments to ecosystem-based planning in the region is the profound lack of comprehensive baseline information on most species that have a demonstrated vulnerability to the land-use changes being contemplated. In the case of the region's fish species, very little information exists on their distribution, abundance, life history, and the history of harvesting or other impacts. Additionally, much of the knowledge about the region's fish communities lies with local residents and those involved in sport fisheries, such as remote tourism operators. As a consequence, fish are rarely given sufficient consideration in land use or resource planning initiatives.

This report represents a first step in expanding the dialogue on Boreal conservation to include aquatic ecosystems. The objectives of this report are to:

I.   present information on the region's fish species with a particular focus on those of high economic or cultural importance;
II. review what is known and what remains unknown regarding the effects of various types of resource development activities on freshwater environments and fish; and
III. offer policy and research recommendations toward the enhancement of freshwater fish conservation and management in the region.

Freshwater Fishes of Northern Ontario

The freshwater environments of northern Ontario can be divided into two major ecozones: the Boreal Shield zone and the Hudson Plains. The Boreal Shield is underlain by the bedrock of the Precambrian Canadian Shield and important fish habitat extends across its matrix of lake, river, and wetland habitats. The Hudson Bay lowlands are also dominated by freshwater, although

because most of the thousands of bogs and ponds that dot the landscape are shallow and freeze to the bottom in winter, fish diversity is mostly concentrated in the streams and rivers that dissect the area.

Fifty-three species of fish in 15 families occur in the region making it one of the more diverse regions of Canada. The distribution of 11 of these species is limited to the southern edge of the area or along the Hudson Bay coast, while 42 species are widely distributed throughout the lakes and rivers of the roadless portion of northern Ontario. Together, this diversity of fish species creates a mosaic of different fish communities distributed among the thousands of ponds, lakes, streams and rivers of northern Ontario.

At a regional scale, this diversity can be summarized into community types based on which top predator species are present in the environment. Three communities types — Walleye/Northern Pike, Lake trout/Whitefish/Cisco, and Brook trout — are profiled in this report, with descriptions of their distribution, ecology, life history, and current conservation status. Lake sturgeon — a species that migrates through rivers and lakes — is an additional focus here due to its status as a threatened species throughout much of North America.

Walleye and northern pike occur in most lakes and rivers of the region with most populations in a relatively unharvested, pristine state. The slow-growing northern walleye and pike populations are more vulnerable to overexploitation than their counterparts to the south, with populations in the north likely less able to withstand the increased exploitation that may accompany increased access due to their slower maturation in environments characterized by shorter growing seasons.

Small tributary streams and rivers throughout the area host abundant brook trout populations. Sea-run brook trout are also common in the rivers draining into Hudson and James Bay. Lake trout, a coldwater species inhabiting deep lakes with limited nutrients, are relatively rare in the northern region. Meanwhile, lake trout are in decline in southern Ontario, largely due to species introductions, eutrophication and fishing pressure.

Lake sturgeon occur in all of the major rivers of northern Ontario and, given the plight of most populations in the south, these may be the last populations remaining in the province that have not yet been affected by intensive human harvesting and habitat alteration. Lake sturgeon populations require large unfragmented watersheds to thrive, due to their lifetime migratory patterns. This is why populations located downstream from dams have, in particular, experienced negative impacts.

Impacts of forestry, hydroelectric development, mining, and roads on fish populations

The combined potential for forestry, hydroelectricity, and mineral extraction in the northern boreal region may represent a major economic opportunity for the province of Ontario. All three types of development, however, also affect aquatic ecosystems and fish thanks to a variety of associated impacts, including increased sedimentation in waterways, changes in water flow, habitat fragmentation, release of pollutants, and increased access for recreational fishing.

Forestry results in two major changes to the landscape that affect aquatic habitats:

- Forest removal alters groundwater flow and surface runoff, which can lead to the release of mercury, nutrients, dissolved organic carbon, and sediment to adjacent water bodies.
- Logging roads may result in fragmented (artificially divided) aquatic habitat due to poorly constructed water crossings, increased sedimentation due to the erosion of roads, and increased human exploitation of fish populations as a result of easier "drive in" access to lakes and rivers.

Clearcutting of boreal forest has been linked to increases in mercury concentrations in fish such as walleye and pike. This linkage is particularly strong in relatively flat landscapes with poor drainage and extensive wetland areas — the kind of landscape found in much of northern Ontario. Forest removal commonly leads to an influx of nutrients, minerals, and organic matter to lakes and rivers with significant differences between the effects of forest loss due to fire versus logging. Fire, for example, does not disturb soils or lead to the creation of roads and water crossings. Logging may also increase total runoff and change the flow regime of forest streams, thereby altering the physical stream habitat, species distributions and productivity.

Stream crossings (bridges and culverts) — of which there may be hundreds of thousands along the tens of thousands of kilometers of forestry roads in Ontario — have been shown to cause significant fragmentation of aquatic habitats. Such crossings can, for example, block upstream movement by fish, thereby causing habitat disconnections or fragmentation.

In the watersheds of the boreal forest of northern Ontario, species likely to be adversely affected by barriers in small streams include brook trout, white sucker, minnows, and darters. In large streams and rivers, species likely to be affected by poorly constructed water crossings include lake sturgeon, walleye, and brook trout.

While certain impacts may be mitigated by "best practices" and regulations — such as reducing sedimentation by leaving vegetated buffer strips around water bodies or minimizing barriers to fish movement by building appropriate water crossings — other impacts are more difficult to mitigate, such as the accumulation of mercury in surface waters of logged watersheds or increased human access due to logging road networks. Overall, the consequences of all such changes to aquatic environments for fish habitats and communities vary from minimal to severe, and most remain poorly understood.

Hydroelectric dams alter river systems in three primary ways:

- Reservoir creation: The creation of a reservoir above the dam has two main fisheries impacts: the loss of river habitat, and the release of mercury from the flooded land into the river ecosystem.
- Barriers to fish movement: Blocking the upstream and downstream movement of species affects populations in a number of ways: it blocks upstream migration to spawning grounds, prevents downstream migration of juveniles to rearing areas, prevents seasonal movement between winter and summer habitats, and isolates populations.

- Alteration of flow regime: Alteration of the magnitude, frequency, duration, timing, and rate of water flow below the dam has a wide variety of impacts on downstream aquatic systems, including changes in sediment accumulation or scouring of the river bed, and reduced spawning success through the loss or degradation of spawning habitat.

Northern Ontario contains a number of large rivers whose combined hydroelectric potential is over 4000 megawatts. Many of these sites are too distant from transmission lines to make development viable in the near future; however, two sites on the Albany River and several sites on the already highly developed Mattagami, Abitibi, and Moose rivers have been proposed for future development.

Hydroelectric dams result in long-term impacts to river ecosystems. In Ontario, lake sturgeon and brook trout are particularly sensitive to the effects of habitat fragmentation and changes in water flow caused by dams. River-spawning populations of cisco and lake whitefish from Hudson and James Bay may also be affected by hydroelectric development. The effects on walleye and pike appear to be mixed with some populations increasing and others suffering declines. For lake sturgeon, it is unclear whether populations can survive following dam construction: In the Moose River watershed, where dam construction occurred 40 to 60 years ago, many lake sturgeon populations appear to be in decline.

A second important effect of hydroelectric development is the associated increase in mercury concentrations of commonly consumed fish such as walleye. For remote northern community residents who rely on fish for a significant portion of their diet, the effects of increased mercury exposure are a serious concern.

Mining operations can adversely affect the aquatic environment in several ways:
- Release of mine effluent into lakes and rivers in the form of water pumped from the mine or used for processing the ore;
- Storage of resulting waste rock and processing waste, referred to as mine tailings, in piles or ponds on the mine site where precipitation and processing waste water leaches metals and other contaminants into adjacent surface water and groundwater;
- Physical alteration or destruction of aquatic habitat resulting from mine construction and operation in areas with abundant surface waters;
- Increased access to surrounding lakes and rivers through the construction of roads to the mining site.

Compared to forestry or hydroelectric development, mining has the potential for much greater acute and chronic environmental impacts when toxic contaminants are released into the environment. In northern Ontario, gold will likely continue to be the most common type of mineral being mined and the continued use of cyanide in the extraction of the gold will continue to pose a threat to aquatic ecosystems.

Mining operations also commonly leave behind large amounts of contaminated ore and acid generating rock, which both pose a long-term threat to aquatic biota. Monitoring and maintenance of waste-containment systems (e.g.

tailings ponds) in remote northern locations will pose an important challenge to those monitoring the impacts of mining on remote northern ecosystems.

Meanwhile, Canadian law requires that aquatic habitat destruction caused by mine construction be mitigated by the creation of equivalent habitat. However, after 20 years of implementation there are insufficient data to determine if this has been an effective approach to preventing negative impacts on fish populations. Likewise, it is too early to determine if the new regulations and monitoring programs will reduce the future impacts of mines on aquatic ecosystems.

New road networks can have a number of negative impacts on fish populations:

- "drive in" recreational fishing may lead to overharvesting and declining fish populations;
- stocking may be used to increase angler success with potential impacts on native populations (increased competition, introduction of non-native species, etc.); and
- increased access may reduce the economic viability of "fly in" or other remote fishing operations that rely on limited access to high-value fisheries.

All types of resource operations commonly lead to increased access to previously remote areas through new road construction. The network of primary, secondary and tertiary roads created during logging operations has the most widespread impact, but roads for other types of operations (mines, hydro facilities) may have dramatic local or regional impacts.

The status of sport fish populations across the province of Ontario ranges from collapsed to pristine, with three factors driving this gradient: ease of access; distance from human settlements; and regional population density. As road networks expand and human populations increase, the extent to which remoteness will serve to maintain quality fishing opportunities — defined as fish populations with large mean size and high catch rates per unit of effort — will decline. This reduction in fishing quality, i.e., smaller fish, lower catch rates or both, can take anywhere from years to decades in a given area depending on fish population size, fishing intensity, and the reproductive capacity of the species.

The likely outcome of increased access to lakes and rivers in northern Ontario can be surmised from looking at the status of sport fisheries in the south. In general, increased fishing pressure will lead to declines in the abundance and mean size of walleye, northern pike, lake trout, brook trout, and lake sturgeon. Development in previously roadless areas may therefore indirectly result in a loss of abundant fish populations and world class sport fisheries that are an important source of income for communities across the north.

Mapping current impacts

The health of freshwater ecosystems is largely determined by the presence and intensity of human impacts, including resource extraction, land transformation, human settlement, and industrial development.

In order to gauge the current threat to northern freshwater environments, we created a province-wide map of cumulative impacts on watersheds. We also mapped cumulative impacts for a larger number of factors specifically for northern watersheds.

The maps highlight the current low level of watershed impacts north of the managed forest boundary in Ontario, particularly compared to what has happened in the industrially allocated southern regions. They also help us identify northern watersheds where increased development may also have a major impact on freshwater ecosystems south of the boundary.

Climate change

An additional overarching threat to freshwater ecosystems in the boreal region is global climate change. Significant climatic changes, including warming and decreased precipitation, are expected in northern Ontario over the next 50 to 100 years. Climate change will influence boreal freshwater ecosystems by affecting ice cover, water temperatures, total water volumes, and the water quality of freshwater bodies, with the magnitude of these impacts differing depending on waterbody characteristics.

In particular, fish are directly affected by the temperature of their environment, as it plays a role in the regulation of all of their physiological processes. Therefore, fish species and individual populations will be adversely or positively affected in myriad ways by climate-driven changes to aquatic environments even in the absence of human development.

Recommendations and Information Needs

This report has highlighted a growing body of research that documents the potential for traditional resource-based industries and activities to have a serious negative impact on fish populations in one of the world's most intact areas for freshwater ecosystems.

Mitigation measures and policies meant to address these potential impacts have been subjected to little testing and their effectiveness remains, at best, unclear. Therefore, in the face of the steady northward march of development, we simply cannot be assured that we have the knowledge and regulatory systems to adequately safeguard globally significant aquatic systems.

Basic research is needed to determine the impact thresholds for various development activities. We currently cannot accurately predict, for example, the risk of mercury accumulation in aquatic ecosystems due to clearcutting or whether lake sturgeon populations can persist following habitat fragmentation caused by dams. Equally seriously, we cannot currently project the potential cumulative impacts on fish populations and habitats as new development projects follow on others.

In fact, we lack even the baseline information on distributions and population status of many fish species across the region that will be needed to monitor the impacts of future development projects, to say nothing of informing current planning processes (while some key attributes of fish community needs are known, much more site and species-specific work needs to be undertaken).

Therefore, our review leads us to the following recommendations:

- Establish a Fisheries Research and Assessment Unit for the area of northern Ontario above the current managed forest boundary;
- Enhance knowledge of the distribution and status of fish in the region, particularly those exhibiting demonstrated vulnerability to development in order to incorporate fish and aquatic considerations into conservation-based planning;
- Avoid piecemeal decisions on development projects by undertaking a comprehensive landscape-level assessment of lake sturgeon, brook trout, lake trout, walleye, and northern pike values north of the managed forest boundary and put in place adequate protection measures *before* development projects are initiated;
- Develop an understanding of the threshold for damaging effects, such as the impact of clearcutting on mercury accumulation in aquatic ecosystems of boreal forest regions, and develop forest management guidelines that will prevent cumulative effects of mercury contamination;
- Determine whether lake sturgeon can persist in dammed rivers, and, if so, the threshold of disturbance populations can tolerate.
- Maintain the current moratorium on hydroelectric development over 25 MW north of the managed forest boundary and undertake a comprehensive landscape-level assessment of lake sturgeon values north of the managed forest boundaries in order to ensure that adequate protection measures are put in place *before* development projects are initiated
- Improve the collection of fish production data prior to mine development to allow for an assessment of the effectiveness of habitat compensation measures.
- Investigate the relationship between logging road development and fishing pressure, including the effect of distance from human settlements and distance between roads and water bodies, to better understand how increased access affects species and populations
- Incorporate knowledge about high-quality fisheries into landscape-scale land use planning in order to identify areas that should be kept roadless and access-free;
- Establish restricted access fisheries in newly logged areas in partnership with anglers, local communities, and tourism operators, and plan road networks to allow for restricted access by constructing easily monitored single entry and exit points.

1. INTRODUCTION

Freshwater ecosystems are among the most threatened ecosystems on the planet. Physical alteration, water withdrawal, overexploitation, pollution, and the introduction of non-native species have caused widespread habitat loss, degradation in water quality, declines in the abundance of aquatic animals, and biodiversity loss (Revenga et al. 2000). More than 20 percent of the world's 10,000 freshwater fish species have become threatened, endangered or extinct in recent decades (Moyle and Leidy 1992).

Canada is rich in freshwater ecosystems, including over 3 million lakes containing 20% of the world's liquid freshwater, rivers discharging approximately 9% of the world's renewable water supply, and 25% of the world's wetlands (Natural Resources Canada 2007). Despite this abundance of freshwater ecosystems, degradation of the country's waters is increasingly evident. In urban areas, channelization of rivers, pollution from urban runoff and industry, and destruction of wetlands are common outcomes of urban development. In rural areas, high nutrient runoff from farming, pollution from pulp and paper mills and mine tailings, and the damming of rivers for hydroelectric power generation have adversely affected lakes and rivers across the country. Unlike many areas of the world, however, much of the Canadian land mass remains undeveloped. In fact, Canada stands out globally as having a vast roadless area with a minimal human footprint (Figure 1.1). One of the largest contiguous swaths of roadless boreal forest is situated in northern Ontario and Manitoba. Located at a distance of only 1,000 km from the approximately 40 million people living in the Great Lakes Basin, this area is an ecological gem.

The geographical scope of this report is Northern Ontario north of Sudbury, with a particular focus on the area north of the current limit of commercial forestry (Figure 1.2). The area is rich in freshwater, with tens of thousands of lakes, hundreds of rivers, and one of the largest wetland areas in the world . Principal ecological units in northern Ontario are the Boreal Shield and Hudson Plains Ecozones. Over 80% of the Boreal Shield Ecozone is forested, with the main tree species being white and black spruce (*Picea glauca* and *P. mariana*, respectively), jack pine (*Pinus banksiana*), balsam fir (*Abies balsamea*), tamarack (*Larix laricina*), birch (*Betula papyrifera*), trembling aspen (*Populus tremuloides*), and balsam poplar (*P. balsamifera*). Broadleaf trees and northern white cedar (*Thuja occidentalis*) are more widely distributed in the southern portion of the Boreal Shield Ecozone. In contrast, vegetative associations in the

Figure 1.1. The human footprint in North America, a quantitative evaluation of human influence on the land surface, based on geographic data describing human population density, land transformation, access, and electrical power infrastructure (based on Sanderson et al. 2002).

Human Footprint Value

🟩	0 - 1	Less Influence More Wild
🟩	1 - 10	
🟨	10 - 20	
🟧	20 - 30	
🟥	30 - 40	
🟥	40 - 60	
🟪	60 - 80	
⬛	80 - 100	More Influence Less Wild
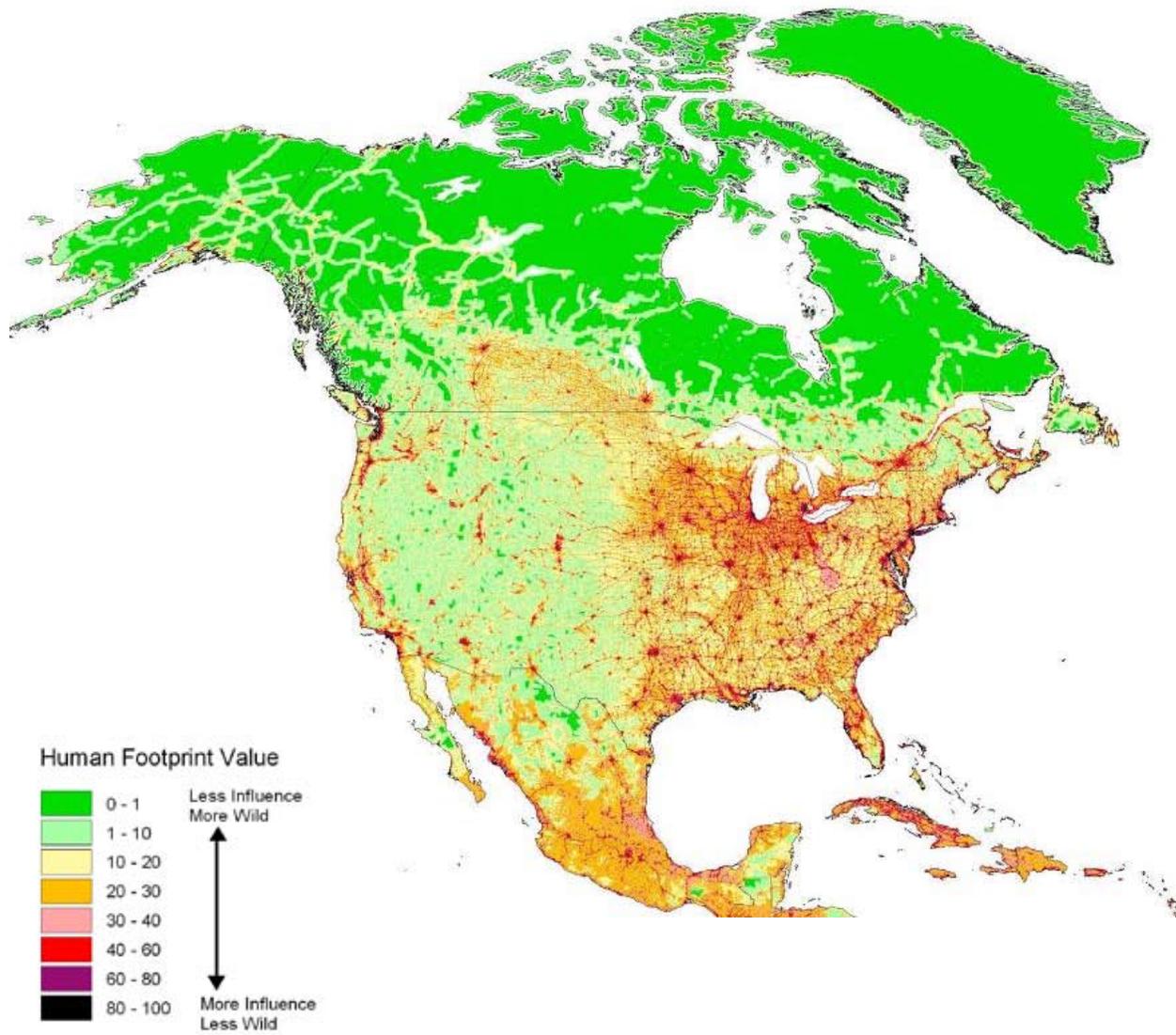
Figure 1.2. Map of northern Ontario indicating the managed forest boundary, primary settlements, major rivers, and lakes, rivers, and other places referred to in the report. Note: Lake Superior, Squeers Lake, Como Lake, Rainy Lake, Lake Simcoe, Lake Huron, Lake Eerie and Lake Ontario are referred to but appear south of this view.
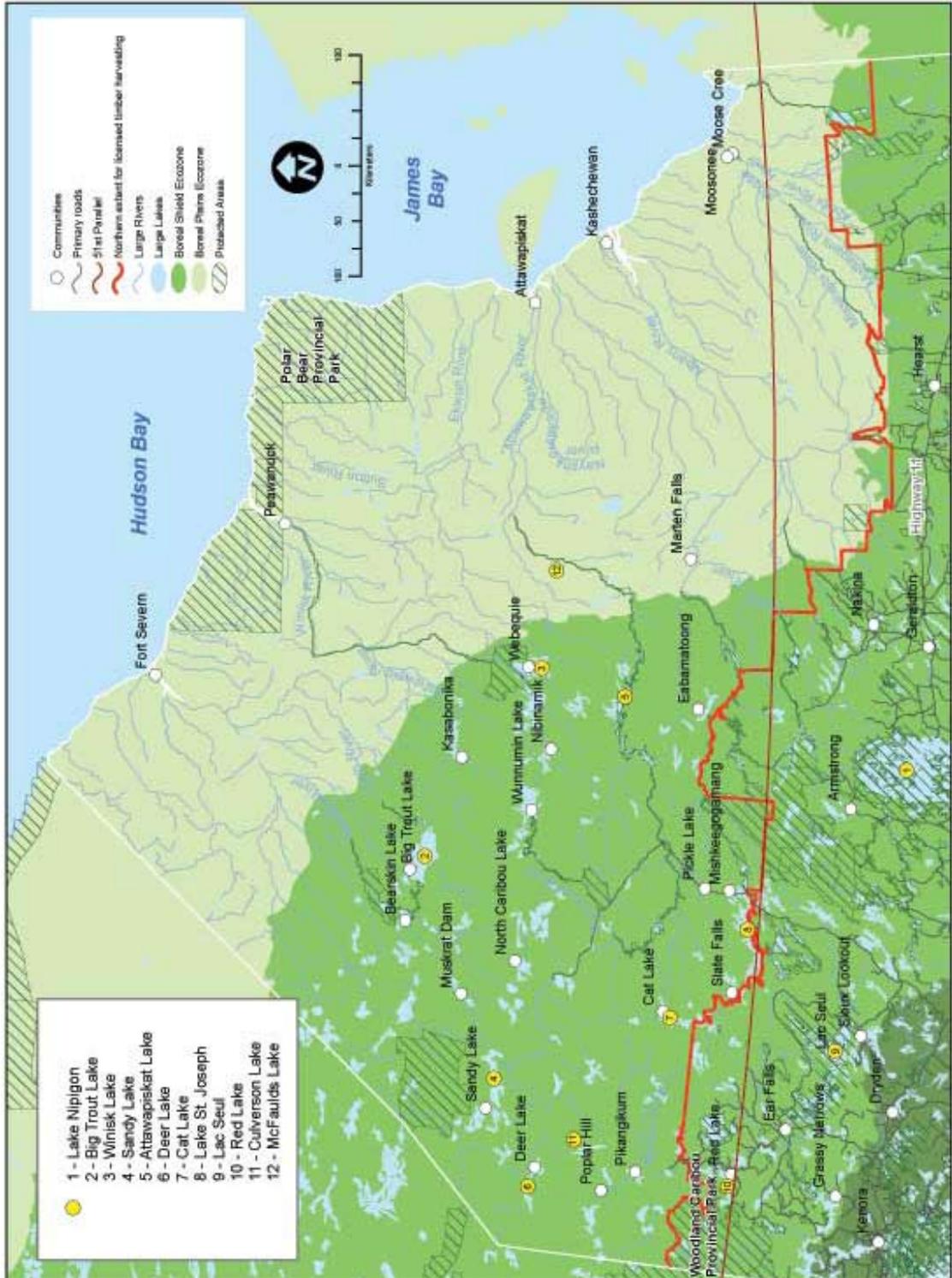
Hudson Plains Ecozone consist of arctic tundra and some boreal forest transition types. Details on vegetation, physiography, climate, and other ecological attributes of the study area are provided in Ecological Stratification Working Group (1996). Approximately 10,000 people live in 26 remote First Nations communities situated on the lakes and rivers of Ontario north of the managed forest boundary (Figure 1.2).

The freshwater ecosystems of northern Ontario are globally significant. Northern Ontario contains 5 of the 12 remaining undammed and unregulated watersheds in North America south of 55 degrees (Dynesius and Nilsson 1994; Figure 1.3). Hudson Bay Lowlands — the third largest wetland on the planet — covers 25% of Ontario's land surface, supports over 4.5 million geese, and serves as a migratory stopover for several hundred thousand other birds (Ramsar Convention Bureau 1990). The rivers of northern Ontario sustain populations of lake sturgeon (*Acipenser fulvescens*), a species that is threatened throughout most of its range (COSEWIC 2006). Together, the lakes and rivers of northern Ontario make up the single largest area of high fish biodiversity currently exposed to few or no human stressors in Canada (Figure 1.4).

Unlike in the more developed regions to the south, fish communities of northern Ontario remain largely unaltered by species introductions, stocking, overexploitation, or pollution. As a result, fish populations hold a wealth of information on the post-glacial dispersal of fish, evolutionary adaptation to local environments, the ecological functions of unaltered ecosystems, and act as a refuge for species threatened in more southern latitudes.

Freshwater ecosystems of northern Ontario also have great cultural and economic importance and freshwater fish are highly abundant in the region, which is characterized by low human population and limited access. As such, communities are able to rely on plentiful walleye *(Sander vitreus)* and whitefish *(Coregonus clupeaformis)* populations as a major source of food. The water courses serve as the highways of the region in winter and summer. The lake sturgeon is a highly prized fish and serves a ceremonial function for Aboriginal people. Fly-in sport fisheries for walleye, northern pike *(Esox lucius)*, and brook trout *(Salvelinus fontinalis)* are world class and with resource-based tourism industry comprising a major component of the northern Ontario economy. In some areas, such as Lake St. Joseph, commercial fisheries for walleye and whitefish provide an income for local residents.

At the same time, northern Ontario contains a wealth of resources of significant economic importance. Hydroelectric potential from four of the major rivers in the region is approximately 3,700 MW with 2,400 MW on the Albany River alone (Ontario Power Authority 2005). There are approximately 200,000 square kilometres of unexploited forest in northern Ontario or 18% of Ontario's total productive forest, although a good portion of this lies in relatively unproductive, transitional forests (OMNR 2001a). Perhaps most valuable are the mineral resources of the area. Gold, platinum, copper, and diamond deposits have been identified in the region. Two mines currently operate north of the managed forest boundary: Musselwhite Mine (owned and operated by Goldcorp Inc. and Kinross Gold), located along the headwaters of the Winisk River, began operation in 1997 and is expected to produce 655,000

Figure 1.3. Impact classification of North American watersheds based on river channel fragmentation and flow regulation by dams. (reprinted with permission from Dynesius and Nilsson 1994).
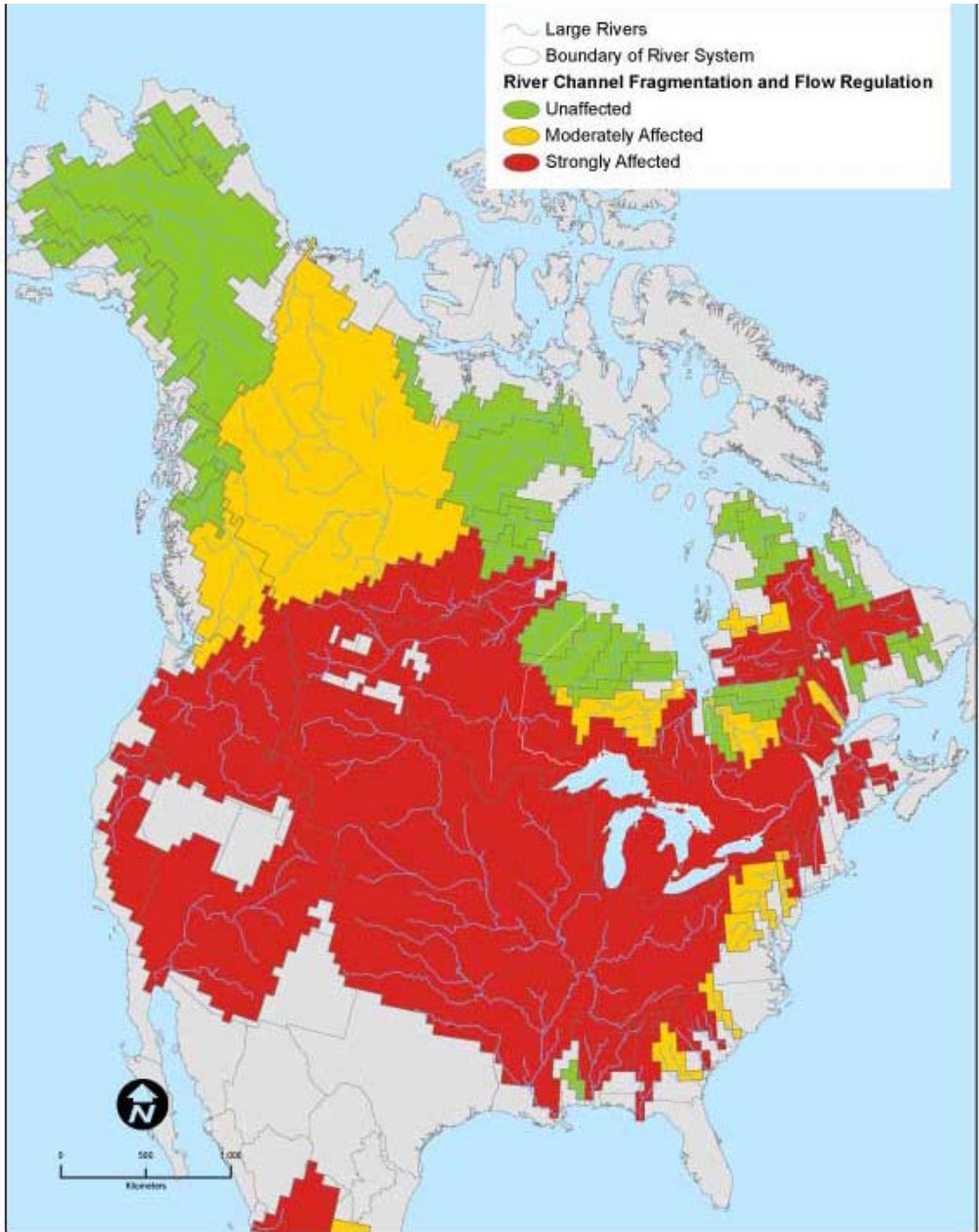
Figure 1.4. Classification of freshwater fish biodiversity in Canadian tertiary watersheds based on diversity rank, environmental diversity, and human stressors. In the legend, Rank is the diversity index, E is the environmental characteristics, Stress is an index of human stressors. High rank watersheds contain either many common species or mostly rare species, high E watersheds have greater than 1370 GDD5, within watershed elevation differences of 1350 m, greater than 1820 sunshine hours, and vapour pressures of 0.81 kPa, high Stress watersheds have high agricultural, industrial, and population stress values (reprinted with permission from Chu et al. 2003).
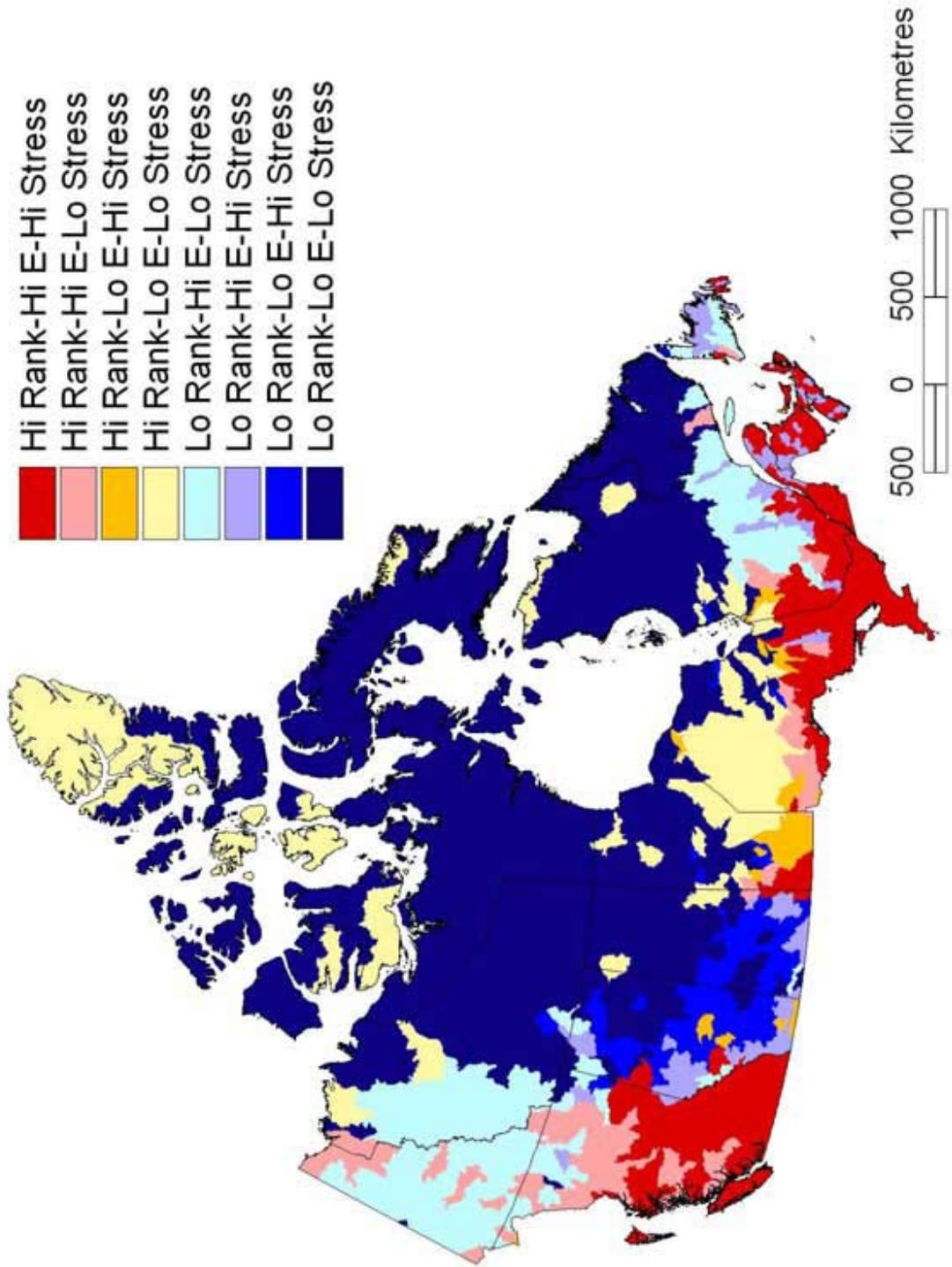
kg of gold over 15 years; and the Victor Diamond Mine (owned and operated by De Beers Canada, Inc.), located near the mouth of the Attawapiskat River, is expected to produce some of the world's highest quality diamonds over its projected 12 years of operation. Overall, mineral and hydrological resources of northern Ontario have the potential to provide a major boost to the provincial economy.

As they have elsewhere, the development and exploitation of hydroelectricity, mineral deposits, and forest resources will cause permanent changes to the freshwater ecosystems of northern Ontario. Ideally, what types of changes and which ecosystems will be affected will inform the discussion of when, where, and how development will occur. The development of land-use plans for the region is one way in which this will occur. This process will require knowledge of the ecology of the lakes and rivers in the region and the animals that inhabit them. Freshwater fish are a key component of the aquatic ecosystems in northern Ontario and an important resource to the people that live there. There is, however, very little baseline information available on the distribution, abundance, life history, and traditional exploitation patterns of the region's fish species. As a consequence, fish are rarely given sufficient consideration in land use or resource planning initiatives in the region.

The objectives of this report are to: 1) present information on fish species of the region with particular focus on those of high economic or cultural importance, 2) review what is known and remains unknown regarding the effects of various types of resource development activities on freshwater environments and fish, and 3) make policy and research recommendations towards the enhancement of freshwater fish conservation and management in the region. The report is aimed at those interested in the management and conservation of freshwater fish in northern Ontario. It is hoped that information contained in the report will be used to inform development decisions in the region, with an eye toward the conservation of freshwater fish and fisheries.

2. FRESHWATER FISHES OF NORTHERN ONTARIO

2.1 Fish Diversity in Northern Ontario

The area of Ontario north of the current boundary of industrial logging is home to 53 species of freshwater fish (Table 2.1), representing the second most diverse group of vertebrates in the region after birds. The distribution of 11 of these species is limited to the southern edge of the area or along the Hudson Bay coast, while 42 species are widely distributed throughout the lakes and rivers of the roadless portion of northern Ontario. Of the four areas of highest fish diversity in Canada — south-central British Columbia, southern Ontario, southern Quebec, and northern Ontario — northern Ontario is the only large area remaining characterized by both high diversity and low human impacts (Chu et al. 2003).

Fish diversity in the region is spread across 15 different families. The most diverse group of fish are the minnows (*Cyprinidae*) represented by 17 species. Other diverse groups within the area include the perches (*Percidae*), the whitefishes (*Coregoninae*), the sculpins (*Cottidae*), and the suckers (*Catostomidae*). Together, these families create a mosaic of different fish communities distributed among the thousands of ponds, lakes, streams and rivers of northern Ontario.

The Northern Ontario landscape is as much water as land.

Justina Ray

2.2 Freshwater Habitats of Northern Ontario

The freshwater environments of northern Ontario can be categorized into two major ecozones (Figure 1.2). The Boreal Shield zone is characterized by a mixture of lake, river, and wetland habitats carved into the bedrock of the Precambrian Canadian Shield. Much of the fish diversity of the region is con-

Table 2.1 Fish species that occur north of the managed forest boundary in Ontario. Species in bold have been assessed as at risk by the Committee on the Status of Endangered Wildlife in Canada. The species list was compiled from the Fish Species Distribution Data System of the Ontario Ministry of Natural Resources, Ryder et al. 1964, Scott and Crossman 1973, and Mandrak and Crossman 1992.

Family	Common Name	Species
Sturgeons	**Lake Sturgeon**	***Acipenser fulvescens***
Charrs	Arctic Char[2]	*Salvelinus alpinus*
	Brook Trout	*Salvelinus fontinalis*
	Lake Trout	*Salvelinus namaycush*
Whitefishes	Cisco (Lake Herring)	*Coregonus artedi*
	Blackfin Cisco	*Coregonus nigripinnis*
	Shortjaw Cisco	*Coregonus zenithicus*
	Round Whitefish	*Prosopium cylindraceum*
	Lake Whitefish	*Coregonus clupeaformis*
Pikes	Northern Pike	*Esox lucius*
	Muskellunge[1]	*Esox masquinongy*
Mudminnows	Central Mudminnow[1]	*Umbra limi*

Family	Common Name	Species
Minnows	Creek Chub	*Semotilus atromaculatus*
	Fallfish	*Semotilus corporalis*
	Lake Chub	*Couesius plumbeus*
	Longnose Dace	*Rhinichthys cataractae*
	Blacknose Dace	*Rhinichthys atratulus*
	Pearl Dace	*Margariscus margarita*
	Northern Redbelly Dace	*Phoxinus eos*
	Finescale Dace	*Phoxinus neogaeus*
	Common Shiner	*Luxilus cornutus*
	Golden Shiner	*Notemigonus crysoleucas*
	Emerald Shiner	*Notropis atherinoides*
	Spottail Shiner	*Notropis hudsonius*
	Blacknose Shiner[1]	*Notropis heterolepis*
	Blackchin Shiner[1]	*Notropis heterodon*
Catfish	Brown Bullhead[1]	*Ameiurus nebulosus*

continued from previous page

Family	Common Name	Species		Family	Common Name	Species
Mooneyes	Goldeye	*Hiodon alosoides*		Cods	Burbot	*Lota lota*
	Mooneye[1]	*Hiodon tergisus*		Sticklebacks	Brook Stickleback	*Culaea inconstans*
Suckers	Longnose Sucker	*Catostomus catostomus*			Threespine Stickleback[2]	*Gasterosteus aculeatus*
	White Sucker	*Catostomus commersoni*			Ninespine Stickleback	*Pungitius pungitius*
	Silver Redhorse[1]	*Moxostoma anisurum*		Trout-perch	Trout-perch	*Percopsis omiscomaycus*
	Shorthead Redhorse	*Moxostoma macrolepidotum*		Sunfishes	Pumpkinseed[1]	*Lepomis gibbosus*
Perches	Yellow Perch	*Perca flavescens*			Rock Bass[1]	*Ambloplites rupestris*
	Sauger	*Sander canadensis*			Smallmouth Bass[1]	*Micropterus dolomieui*
	Walleye	*Sander vitreus*		Sculpins	Mottled Sculpin	*Cottus bairdi*
	Iowa Darter	*Etheostoma exile*			Slimy Sculpin	*Cottus cognatus*
	Johnny Darter	*Etheostoma nigrum*			Spoonhead Sculpin	*Cottus ricei*
	Logperch	*Percina caprodes*			Deepwater Sculpin	*Myoxocephalus thompsoni*
	River Darter	*Percina shumardi*			Fourhorn Sculpin[2]	*Myoxocephalus quadricornis*

[1]Occurs along the southern edge the region only. [2]Occurs along Hudson Bay coastline only.

Top: The watery expanse of the Hudson Bay Lowlands is noted for its small ponds and wetlands while the Boreal Shield region (bottom) contains more lakes and rivers.

centrated in the rich and varied freshwater habitats in this zone and several species reach the limit of their northern distribution here. To the north and east of the Boreal Shield lie the Hudson Plains. This low lying area overlying Devonian and Silurian limestone is the third largest wetland in the world after the West Siberian lowlands and the Amazon River floodplain (Keddy 2000), and the largest in Canada. Although the area is dominated by freshwater, most of the thousands of bogs and ponds that dot the landscape are shallow and freeze to the bottom in winter, thereby excluding fish populations from persisting year round. Fish diversity in this zone is therefore concentrated in the streams and rivers that dissect the land. In the following section we provide information on the main fish communities that dominate these distinct ecozones.

2.3 Fish Communities of Northern Ontario

Fish are distributed across the landscape in a variety of species groupings. Individual lakes, streams, and river sections contain unique combinations of fish species with distinctive food web interactions. Adjacent water bodies commonly differ in the composition of the small prey fish community and in the number of top predator species. At a regional scale, the diversity of individual fish assemblages can be summarized into community types based on which top predator species are present in the environment. In the lakes and rivers of the Boreal Shield zone, walleye and northern pike are the most common top predators and together define the most widely distributed community type. In Boreal Shield lakes, a second community type is defined by the presence of lake trout *(Salvelinus namaycush)*, often in association with lake whitefish and cisco *(Coregonus artedi)*. Lake trout occur in a relatively small number of lakes across the region with the majority of occurrences in the western half of northern Ontario. In streams of both the Boreal Shield and the Hudson Plains, brook trout are often the most abundant top predator and form a third community type. Finally in the bogs and ponds of the Hudson Plains, where predatory fish are often lacking and fish-eating birds are the top predators, fish communities commonly consist of 2 to 5 species with stickleback and white sucker as the dominant members.

This section begins with a review of the distribution, ecology, and population status of walleye-pike, lake trout-whitefish, and brook trout communities. Also included is a look at the ecology and status of lake sturgeon, a species of particular interest in fish conservation planning due to its status as a threatened species throughout much of North America (COSEWIC 2006). Lake sturgeon migrate throughout lake and river habitats and are therefore not associated with a particular fish assemblage.

Ontario is privileged to have an excellent fisheries research division in the Ministry of Natural Resources (OMNR) and much of what is written about fish species in this report is possible because of government research. Maps, compiled from OMNR and other relevant sources collected on tens of thousands of lakes, are provided for seven species and are displayed here for the first time along with relevant information to the conservation of individual species. These provide the most up-to-date information on the fish species of most socio-economic interest in Ontario.

2.3.1 Walleye and Pike Communities

Distribution and Composition
Walleye (*Sander vitreus*) and northern pike (*Esox lucius*) are two of the most widely distributed species in Canada (Scott and Crossman 1973). They are abundant in lakes and rivers across the Territories, Alberta, Saskatchewan, Manitoba, and Québec. It is in Ontario, however, where they coexist with the greatest number of other fish species and reside in the greatest number of lakes. North of the 51st parallel in Ontario, these two species are present in 83% of surveyed lakes and rivers and co-occur 72% of the time (OFDDS; Figures 2.1 and 2.2). In the majority of lakes and rivers, walleye and pike coexist with yellow perch (*Perca flavescens*), white sucker (*Catostomus commersoni*), and a variety of minnows. In deep (>8 m) lakes of the region, lake whitefish (*Coregonus clupeaformis*), cisco (*Coregonus artedi*), burbot (*Lota lota*), and sculpin (*Cottus spp.*) are also common members of this fish community.

Ecology
Walleye and northern pike are piscivores (fish-eating). They play an important structuring role in aquatic food webs as the top predators in most of the lakes and rivers of the region. Through their consumption of prey fish, they influence the dynamics of prey populations, which can have cascading impacts on other elements of the freshwater community. Northern pike are sit-and-wait predators that inhabit shallow inshore areas of lakes or slow moving portions of rivers characterized by abundant structure such as aquatic vegetation or fallen trees (Craig 1996). The diet of northern pike is dominated by minnows, white suckers, and yellow perch. Walleye, on the other hand, are roaming predators that inhabit slow and fast current areas of rivers and nearshore and offshore environments of lakes. Yellow perch, cisco, and minnows form the dominant components of their diet. Together, these two species can exert significant control over the abundance of their prey. Walleye predation suppresses yellow perch populations, and reductions in walleye abundance due to fishing have been linked to increases in yellow perch and minnow abundance (Colby et al. 1987, Olson et al. 2001). This can, in turn, lead to interesting reciprocal effects: In northern Alberta, where walleye fisheries have experienced widespread collapse, a resulting increased abundance of minnows is thought to be one factor preventing the recovery of the walleye populations due to their predation on walleye eggs (Post et al. 2002). Northern pike have also been shown to reduce white sucker and minnow abundance. Walleye and pike also prey on one another. This complex interaction of mutual predation and shared prey means

changes in the abundance of one species may affect the survival and growth of the other (Spencer et al. 2002).

Growth and Reproduction

Pike and walleye spawn in the spring shortly after the ice comes off the lakes. Both species require specific habitats to spawn successfully and often move to inflowing rivers or streams to find suitable spawning grounds. Pike spawn in shallow areas (less than 30 cm) at the mouth of inflow streams, in marshes, or in sheltered bays (Scott and Crossman 1973). In contrast, walleye spawn over rocky wave-swept shoals of lakes or rocky fast-moving river sections (Scott and Crossman 1973). Both species are sensitive to changes in the quality or availability of spawning habitat. Loss of wetlands and aquatic vegetation can have negative effects on northern pike populations (Craig 1996). Similarly, barriers that impede migration to riverine spawning sites or sedimentation of spawning shoals in lakes can affect population size and persistence of walleye (Fielder 2002). During spawning, walleye and pike are easily exploited in large numbers due to the dense aggregation of adults in shallow waters; hence, across Ontario the sport fishing season for both species is closed in early spring (OMNR 2005b).

Initial growth is rapid in both species. Juveniles commonly attain lengths of 10 to 20 cm by the end of the first 6 months of growth. An important consideration in the management of pike and walleye fisheries is the fact that growth rate declines as one moves north (Scott and Crossman 1973, Sullivan 2003). This pattern is driven by changes in the length and intensity of the growing season with latitude. The intensity of the growing season is commonly estimated by the amount of heat accumulated during spring, summer and fall. The most commonly utilized measure of this phenomenon is *growing degree days above 5°C* (GDD5). It is calculated as the sum over the entire growing season of the number of degrees by which the daily mean temperature exceeds 5° C (Annual GDD5 = Σ (daily mean temp - 5°)). For walleye, there is an abrupt drop in growth when GDD5 drops below 1400 (Baccante and Colby 1996, Sullivan 2003). As a result, age at which 50% of the females are mature (age at maturity) shifts from approximately 3 to 5 years at GDD5 > 1400 to between 6 and 9 years at GDD5 < 1400.

Age distribution also differs between southern and northern populations. Mean age in southern populations is in the range of 5 to 7 years versus northern populations where mean age is greater than 9 and may be as high as 16. The younger age in southern populations is due to both faster growth and higher exploitation in more populated areas. The slower growth and greater age of northern populations has led Mike Sullivan of the Alberta Fish and Wildlife Division to describe unexploited, northern populations as "old growth" populations (Sullivan 2003) — susceptible to overfishing due to their slow maturation. In southern lakes, populations do recover following intensive exploitation; however, the process may take approximately 15 years (Baccante and Colby 1996, Spencer et al. 2002). It is unclear whether the populations in northern regions recover following removal of older-aged fish (Post et al. 2002, Sullivan 2003). A similar pattern appears to hold true for northern pike. Pike

from northern latitudes grow slower, mature later, and may be more susceptible to overfishing (Griffiths et al. 2004).

The length of the growing season declines rapidly in Ontario north of Lake Superior (as a conservative indicator of the location of slow growing walleye and northern pike populations in Ontario, the line for GDD5=1250 is shown in Figures 2.1 and 2.2). Lakes and rivers north of this line likely contain old growth populations of walleye and pike. Most of these populations are currently inaccessible by road as forestry operations have yet to move north into these low productivity environments. Judging from patterns further south (see Section 3.4), extension of roads into this area will likely lead to increased access to old growth populations that are prone to overexploitation.

Current Status

Walleye is the most valuable freshwater fish in Canada with annual landings of 7,000 tonnes corresponding to an annual value of approximately 30 million dollars (Department of Fisheries and Oceans 2007). This species is commercially exploited in large lakes across Canada; however, the majority of the landings (> 90%) are from Manitoba and Ontario. When commercial fishing was common, between 1950-1980 (see "Transition from Commercial to Recreational Fishing in Northern Ontario" on page 71), walleye accounted for over 70% of the total value of the harvest. Currently, walleye and pike are commercially exploited in approximately 8 lakes in Ontario outside the Great Lakes and Lake Nipigon, although commercial licenses are still held for over 100 lakes in the region (J. Johnson, OMNR, pers. comm.). At present in the roadless portion of Ontario, most lakes large enough to land a float plane on are fished for sport. Overall, walleye account for approximately 25% of all fish caught in the recreational fishery of Ontario and northern pike for approximately 12% (Department of Fisheries and Oceans 2003). The Ontario Ministry of Natural Resources does not monitor the status of walleye and pike populations in most remote fly-in lakes; therefore, there are little to no data on the status of the populations. The fact that over 70% of customers to remote tourism camps are return customers who report excellent fishing as the primary reason for their choice of lodge (Lawson and Burkhardt 2005) suggests walleye and pike catch rates across the region have not been significantly affected by current fishing pressure. However, impacts on individual lakes are largely unknown as no assessment has been made of the effects of fly-in fishing on walleye and pike populations in Northern Ontario.

After lake whitefish, walleye is the second most important subsistence fishery for aboriginal communities in both the Boreal and the Hudson Bay Lowlands (Hopper and Power 1991, Berkes et al. 1994). The fisheries provide a major source of food in summer and fall as well as the main source of bait for traplines during the winter. A study of subsistence fisheries in the village of Webequie located on Winisk Lake conducted in 1989 found the total harvest

Healthy populations of northern pike and walleye support a valuable sport fishing industry and as top predators, play an important ecological role.

Engbretson Underwater Photography

Figure 2.1. Distribution of walleye *(Sander vitreus)* in lakes and rivers of northern Ontario mapped against Growing Degree Days < 1250 (see text) where populations are likely to be particularly slow-growing.

Legend:
- Surveyed lakes and river sections with walleye present
- Large northern rivers with walleye present
- Large rivers
- Large lakes
- Growing degree days < 1250

Map is based on survey data from Ontario's Ministry of Natural Resources and does not include Indigenous Knowledge.
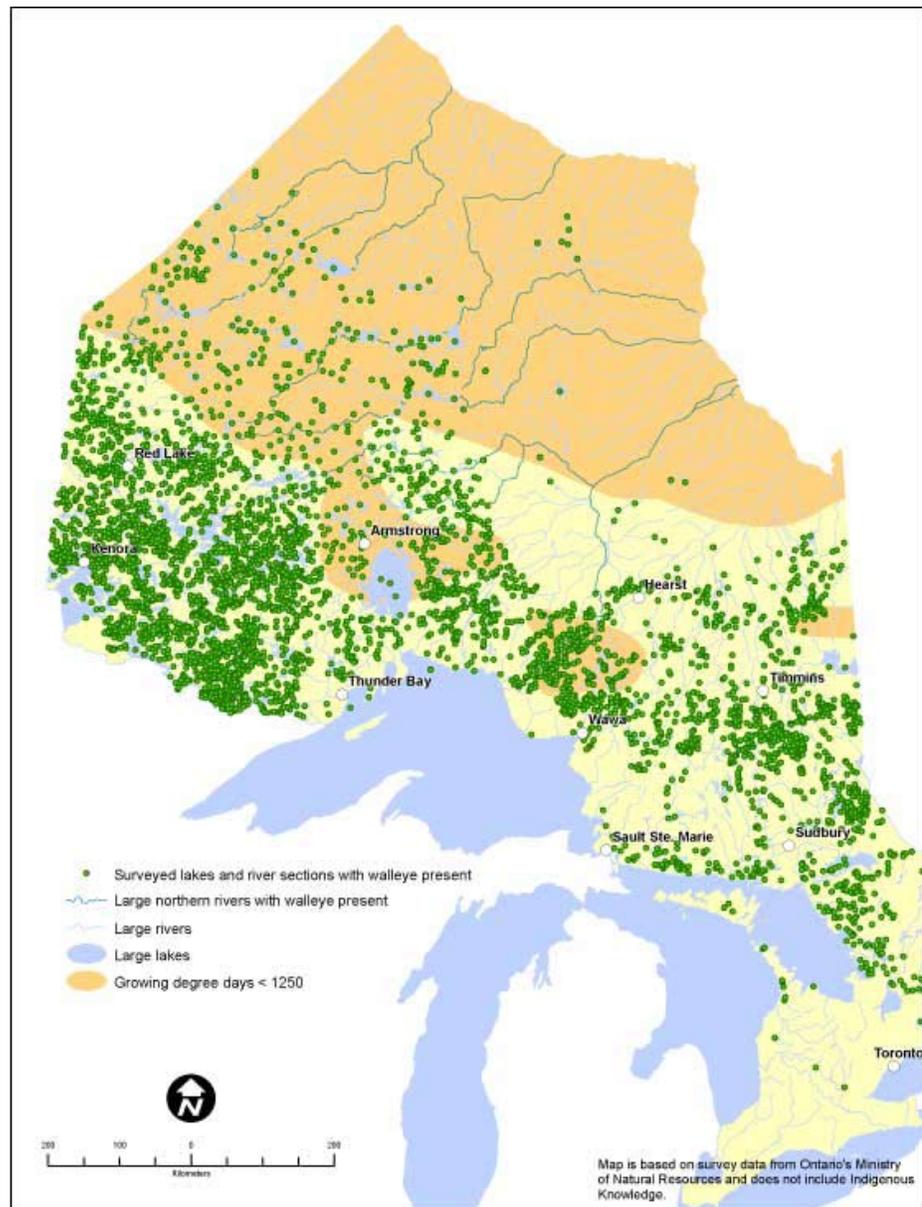
Figure 2.2. Distribution of northern pike *(Esox lucius)* in lakes and rivers of northern Ontario mapped against Growing Degree Days < 1250 (see text) where populations are likely to be particularly slow-growing.
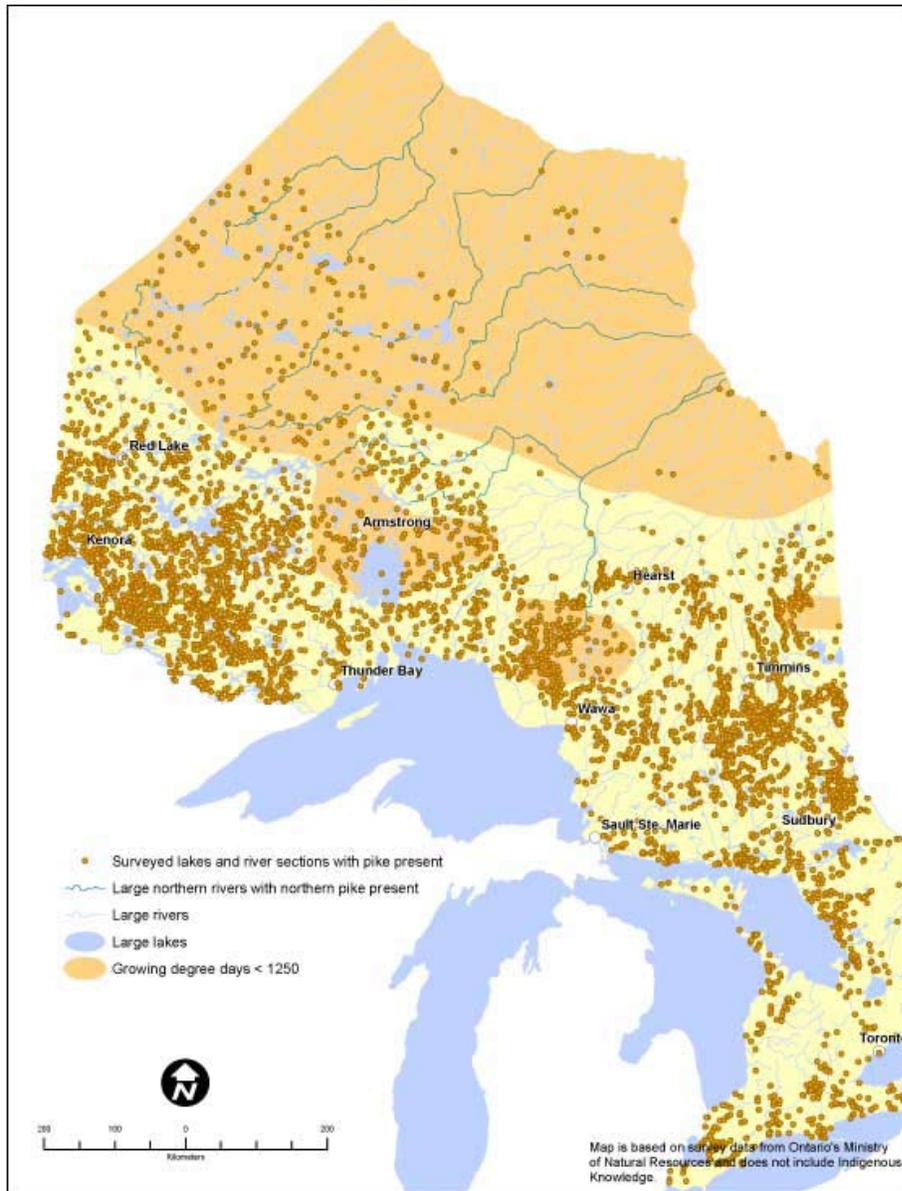
of walleye and pike to be 0.5 to 1.0 kg/ha (Hopper and Power 1991), which is at the upper end of the maximum sustainable yield for these species (Colby and Baccante 1996) and may cause some loss of ecological function. Across northern Ontario, walleye and pike may be subject to high exploitation rates in lakes on which human populations reside. There are no reports of collapse of local subsistence fisheries, which suggests current extraction levels have not affected fish recruitment. As the population of northern communities increases subsistence fishing pressure will likely also increase, and unless pressure is spread across a number of lakes or people continue to increase their use of alternative food sources, local fish populations may begin to decline.

Despite the importance of walleye in the subsistence fishery and the popularity of walleye as a sport fish in northern Ontario, northern walleye populations are likely in good to excellent condition at present (Table 2.2). In the road-accessible portion of northern Ontario, walleye abundance is 2 to 5 times higher than in southern Ontario (OMNR 2002b). Walleye abundance and fishing quality increases in Ontario from the southeast to the northwest of the province (OMNR 2005c). This is primarily due to the corresponding decline in human population density. All recreational fisheries in Ontario are open access; therefore, the number of anglers exploiting a lake is controlled chiefly through ease of access and distance from major human settlements. Fishing quality is known to decline with increased access (Hunt et al. 2002), and some remote outfitters explain how they have moved or attempted to move their operations northward to less populated areas with fewer access roads to maintain the experience their guests have come to expect (T. Eastman, Nature & Outdoor Tourism Ontario, pers. comm.).

2.3.2 Lake Trout and Whitefish/Cisco Communities

Lake trout populations are in trouble throughout more developed southern boreal regions.

Distribution and Composition

Lake trout (*Salvelinus namaycush*), lake whitefish (*Coregonus clupeaformis*), and cisco (*Coregonus artedii*) are widely distributed throughout Canada from the Arctic archipelago in the north to the Great Lakes in the south (Scott and Crossman 1973). North of the managed forest boundary in Ontario, lake trout have been poorly surveyed but appear to be relatively rare, occurring in only 80 of the over 500 surveyed lakes (Figure 2.3). Lake whitefish and cisco, on the other hand, are common across northern Ontario and occur in 50% of surveyed lakes and rivers (Figure 2.4). The large rivers of northern Ontario flowing into Hudson and James Bay are host to unique populations of migratory cisco and lake whitefish that move between river and estuary habitats (Morin et al. 1982). The greatest concentration of lake trout populations occurs in the southwest corner of the region in the Red Lake and Woodland Caribou Park area. There is also an isolated set of lake trout and whitefish populations in the Sutton River watershed of the northeast. Over 90% of lake trout populations coexist with lake whitefish

and/or cisco. Lake trout coexist with northern pike in approximately 87% of surveyed lakes and with walleye in approximately 50% of surveyed lakes north of the 51st parallel. Other species that commonly occur with lake trout include round whitefish (*Prosopium cylindraceum*), burbot, yellow perch, white sucker, several minnow species, and sculpins.

Ecology

Lake trout, lake whitefish and cisco inhabit deep (>8 m), low productivity lakes. They are coldwater species, restricted to the deep portion of the lake during summer months when surface water temperatures become warm (>15º C) (Scott and Crossman 1973, Dillon et al. 2004). All three species are unable to tolerate low oxygen environments and factors that reduce deepwater oxygen concentrations in lakes, such as nutrient input from agriculture or sewage, cause declines in lake trout and whitefish populations (Evans et al. 1996). Lake trout have highly flexible feeding habits and shift from zooplankton to insect larvae to fish

Table 2.2 Summary of the state of knowledge and potential threats to selected fish species of Northern Ontario.

Species	Knowledge of Distribution	Status	Potential Causes of Population Decline	Potential Causes of Local Extinction
Walleye	Very Good	Healthy Old Growth (Exploited near communities)	Exploitation > 1 kg/ha Loss of spawning habitat	Overfishing
Pike	Very Good	Healthy	Overexploitation Loss of inshore habitat Loss of spawning habitat	
Lake Trout	Good	Healthy Old Growth	Exploitation > 0.5 kg/ha Lake trout stocking Bass introduction High nutrient input	Lake acidification High nutrient input Overfishing
Lake Whitefish	Good (Unknown if dwarf forms occur in the region)	Healthy (Exploited near communities)	Overexploitation High nutrient input	High nutrient input
Cisco	Moderate (Poor knowledge of ecotype distribution)	Healthy	Overexploitation Smelt introduction High nutrient input	Smelt introduction
Lake Sturgeon	Poor (Poorly surveyed, movement in rivers unknown)	Healthy, Old Growth (In unharvested areas) Exploited or Recovering (In areas with harvesting)	Overexploitation Barriers to migration Loss of spawning habitat Pollution of running waters	Overexploitation Barriers to migration
Brook Trout	Poor (Surveys have overlooked small rivers and streams)	Healthy (Migratory populations are exploited)	Overexploitation Loss of spawning habitat Barriers to migration Species Introductions High nutrient loading Pollution of running waters	High nutrient loading Barriers to migration

Figure 2.3. Distribution of lakes containing self-reproducing lake trout *(Salvelinus namaycush)* populations classified by distance from the nearest primary or secondary road.
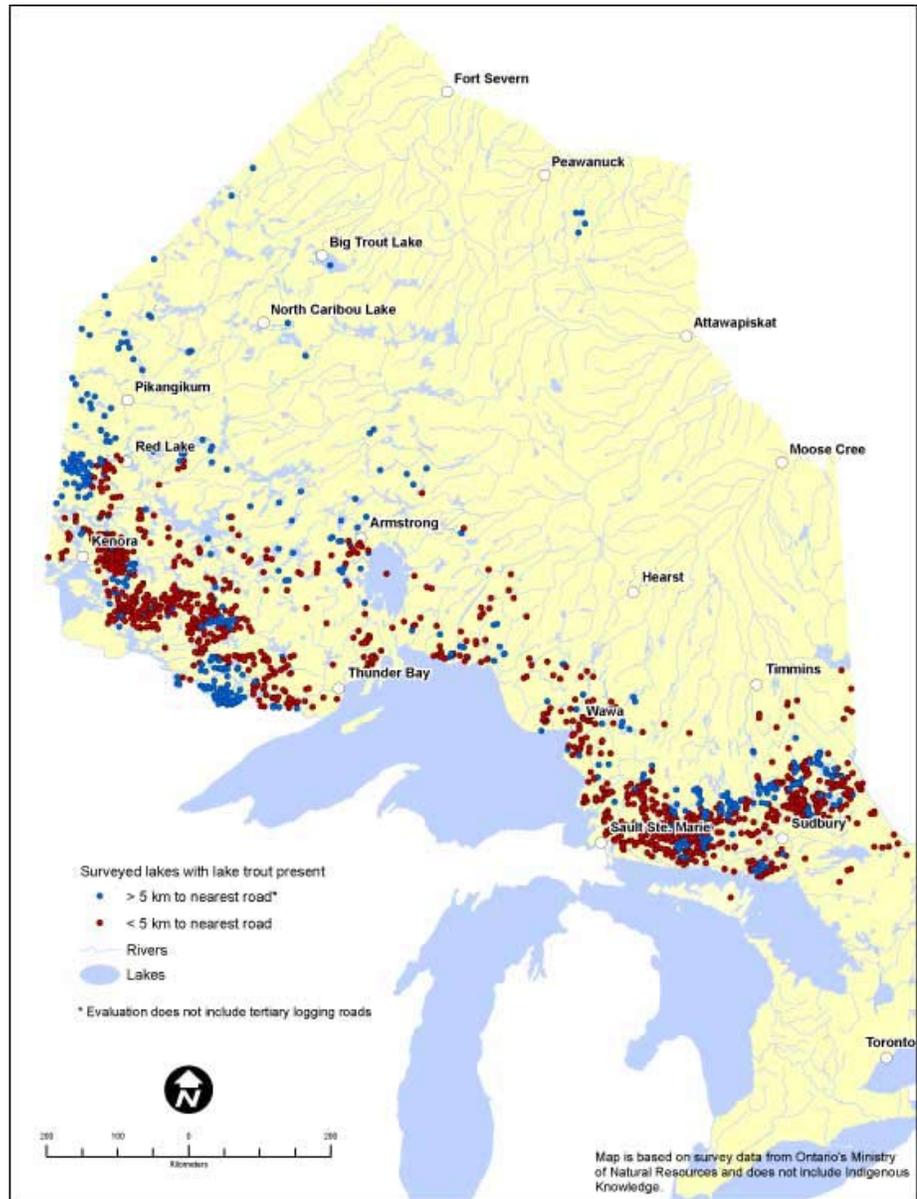
Figure 2.4 Distribution of lake whitefish *(Coregonus clupeaformis)* and cisco *(Coregonus artedii)* in northern Ontario.
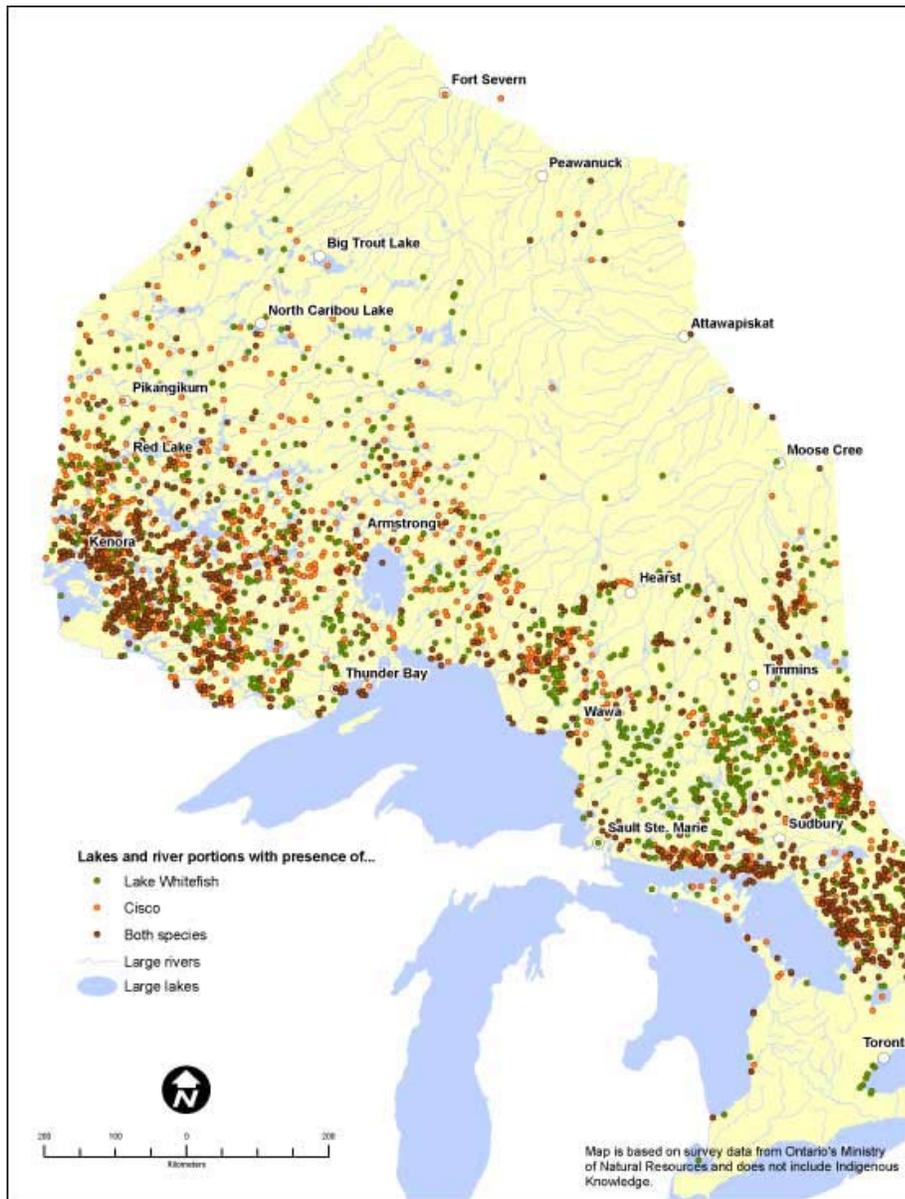
depending on prey availability. Consequently, lake trout occupy very different positions in the aquatic food web depending on the species composition of the fish community (Vander Zanden and Rasmussen 1999). For example, in lakes with yellow perch or cisco present, lake trout are piscivorous and feed primarily on one or both of these species (Martin 1952, Martin 1970). In the absence of pelagic (open water) prey fish, lake trout are planktivorous (Martin 1966). The planktivorous form of lake trout is generally smaller and has a slower growth rate (Pazzia et al. 2002). It also occupies a lower position in the food web and as a result accumulates lower concentrations of organic contaminants and mercury than the fish-eating form (Vander Zanden and Rasmussen 1999).

Cisco are pelagic and feed primarily on zooplankton; whereas, lake whitefish are associated with the lake bottom and feed mainly on midge and mayfly larvae (Scott and Crossman 1973). Cisco have been shown to play an important role in determining zooplankton community characteristics. At high population densities, for example, cisco reduce zooplankton abundance and mean size (Rudstam et al. 1993). Thus lake food web interactions differ significantly between systems with and without cisco. Both cisco and lake whitefish are prey for lake trout and in some lakes lake trout control the abundance of these species (Trippel and Beamish 1993).

Perhaps the most unique aspect of cisco and whitefish ecology is the co-occurrence of multiple forms of the same species (often referred to as ecotypes) in the same lake. In some lakes, lake whitefish occur as both normal and dwarf body forms. The normal form feeds primarily on bottom dwelling organisms; whereas, the dwarf form feeds on zooplankton. These two forms are genetically distinct and research into their ecology has provided insight into the process of natural selection and parallel evolution (Bernatchez et al. 1996, Pigeon et al. 1997). The only known occurrence of the two forms in northern Ontario is in Como Lake near Chapleau; however, other occurrences are possible. Similar to lake whitefish, cisco in Ontario waters were thought to consist of 8 distinct species; however, genetic analysis indicated all 8 species should be thought of as ecotypes of a single cisco species (*Coregonus artedii*) (Turgeon and Bernatchez 2003). As with lake whitefish, the 8 different ecotypes are the result of ecological specialization over the past 12,000 years; further study may provide new insights into the process of speciation among fishes.

Growth and Reproduction

Lake trout spawn in October in depths less than 12 m. The characteristics of the spawning area vary considerably from lake to lake, ranging from sandy shores to large boulders, and bottom type does not appear to be an important feature of spawning areas (Gunn and Sein 2000). The most important criterion for spawning site selection is thought to be sedimentation rate with lake trout choosing zones of low sediment accumulation for egg deposition (Flavelle et al. 2002). Eggs hatch in March or April and the young move to deep waters within a month of hatching (Scott and Crossman 1973). Cisco and lake whitefish also spawn in the fall, typically after lake trout have spawned. Spawning occurs in shallow water, at depths of 1-3 m, over a variety of substrates. Spawning runs of cisco were famous in the Great Lakes during the 19th century with mil-

lions coming inshore at spawning sites along the shores of Lake Erie and Lake Ontario (Scott and Crossman 1973).

Lake trout are a long-lived species, commonly attaining ages greater than 20 years, with fish as old as 45 years reported in Ontario. Lake trout mature at 6 or 7 years of age at a length of approximately 35 cm (Scott and Crossman 1973). Unexploited populations in Ontario have a mean age of 13 to 15 years with the majority of adults aged 9 to 18 (K. Mills, Department of Fisheries and Oceans, pers. comm.). Growth is rapid during the first 5 years; however, beyond lengths of 35-40 cm, growth slows if pelagic prey fish are not present in the lake (Martin 1966). Lake whitefish are not as long-lived as lake trout, with maximum age in the range of 15 to 20 years. Growth rate varies considerably between lakes and average length ranges from 25 to over 60 cm by age 15 (Mills et al. 2004). Cisco are fast growing and short-lived. They do not typically live beyond 10 years of age and mature at age 3 to 4 and a length of 20 to 25 cm (Scott and Crossman 1973).

Current Status

Lake trout populations north of the managed forest boundary are not commonly targeted by sport fishermen (Hunt et al. 2002), nor do they appear to form a significant portion of the subsistence fishery (Hopper and Power 1991, Stewart and Lockhart 2005). There may, however, be some bycatch of lake trout in the commercial and subsistence fishery for lake whitefish. Due to the remoteness and the expected low level of exploitation of these populations, the Ontario Ministry of Natural Resources does not carry out regular population assessments. Given the expected low level of exploitation, it is likely that the majority of populations are in excellent condition (Table 2.2).

Lake whitefish prefer cold, deep lakes and do poorly in oxygen poor lakes with high nutrient levels.

South of the 51st parallel, lake trout populations are in decline (Lester et al. 2003). Approximately 5% of native lake trout populations have been extirpated from Ontario waters. Judging from the effects elsewhere, the greatest threats to lake trout appear to be increased angler access through road development, nutrient enrichment of the waters, and species introductions (Table 2.2). Access is an important contributing factor to the decline of lake trout populations due to the potential for over exploitation under an open access system. Although there have been few studies that have documented the relationship between fishery decline and enhanced access opportunities, one study conducted in the Sudbury area illustrates its potential importance: Within a three-month period following construction of a logging road to within a few kilometres of a lake trout lake, anglers removed 75% of the lake trout biomass (Gunn and Sein 2000). The initial effect of sport fisheries is to remove the largest fish in the population leaving behind an often abundant but smaller sized population (Fruetel 1998). Continued fishing pressure may cause lake trout numbers to decline to a level where juvenile recruitment is reduced and in some cases lake

trout may be extirpated by overfishing (M. Sullivan, University of Alberta, pers. comm.). If access to the fishery is controlled, there is evidence that a high yield of lake trout can be maintained for decades based on experience from the Squeers Lake fishery near Thunder Bay (T. Marshall, OMNR, pers. comm.).

Species introductions have been another important factor in the decline of lake trout populations. During growth from juvenile to adult size, lake trout feed extensively on small inshore prey fish such as minnows. The introduction of inshore fish predators such as smallmouth bass and rock bass results in a decline in prey fish abundance and a reduction of 25 to 30% in lake trout growth rates (Vander Zanden et al. 2004). Currently, the low average temperature of northern waters limits the northern spread of smallmouth bass to approximately 51 degrees north. Expected increases in average air temperature over the next 50 to 100 years will likely make conditions favorable for the northward dispersal of bass.

Given the sensitivity of lake trout to the dual threats of fishing pressure and environmental change, the species has been identified as a candidate for species assessment by COSEWIC (COSEWIC, 2007). Due to their relatively pristine state, the populations in the roadless area of northern Ontario not only provide unique fishing opportunities, but also provide a reference baseline for the state of lake trout populations prior to exploitation (Table 2.2).

Less is known about the status of cisco and lake whitefish populations in inland lakes than lake trout, walleye, or other major sport fish. Cisco are not fished recreationally. Lake whitefish, on the other hand, are a popular winter sport fish across Ontario. Historically, commercial fisheries and species introductions have had the largest impact on the two species. Cisco and lake whitefish populations in the Great Lakes collapsed in the 1950s due to a combination of commercial fishing pressure and species introductions (Scott and Crossman 1973). Eight types of cisco were once found in the Great Lakes; however, three of these forms (shortnose, shortjaw, and deepwater ciscos) have been lost or decreased to low levels. The introduction of alewife (*Alosa pseudoharengus*) and rainbow smelt (*Osmerus mordax*) to the Great Lakes and several smaller inland lakes is thought to have played a major role in the loss of cisco diversity and in the declines in lake whitefish abundance (Evans and Loftus 1987, Hrabik et al. 1998).

Despite historical declines in whitefish abundance in many large lakes, lake whitefish remains the most important commercial freshwater fish in Canada by weight (see Box 2). Approximately 10,000 tonnes are landed annually, 2,000 to 3,000 tonnes of which come from Ontario waters (Department of Fisheries and Oceans 2007). Commercial fisheries in inland lakes north of Lake Superior account for approximately 500 tonnes of the annual harvest in Ontario with the majority coming from Lake Nipigon, Rainy Lake, and Lac Seul (J. Johnson, OMNR, pers. comm.). From approximately 1950 until the early 1980s over 300 lakes in the roadless area of northern Ontario were commercially fished for lake whitefish and other species. Annual harvests of lake whitefish averaged approximately 3,000 kg per lake with an average yield of 0.5 kg/ha (Carlson

1979). The northern lake whitefish fisheries closed in the 1980s due to the high costs of flying the fish to market and the high rate of infestation with the unsightly but harmless parasite, *Triaenophorus crassus*. Lake whitefish has been the primary year-round subsistence fishery of First Nations communities in northern Ontario (Hopper and Power 1991). As discussed earlier, there is no comprehensive effort across the north to monitor the status of cisco and lake whitefish populations.

Past reports of collapse of lake whitefish or cisco populations were primarily the result of species introductions or high nutrient input (Scott and Crossman 1973). Intensive exploitation of lake whitefish can cause population collapse; however, recovery appears to be fairly rapid (5-10 years) if fishing pressure is reduced (Miller 1956). Other than for Lake Simcoe and the Great Lakes including Lake Nipigon, there is no provincial monitoring of lake whitefish populations. Cisco populations receive even less management attention. The status of lake whitefish and cisco populations in the developed portion of Ontario is unknown. Extremely limited recreational exploitation of cisco suggests healthy populations exist across the province where rainbow smelt or alewife have not been introduced. The status of lake whitefish will depend on the level of exploitation; however, too few assessments exist to determine population trends. Nevertheless, the Ontario Ministry of Natural Resources has proposed reducing the sport fishing catch limit from 25 to 12 fish per person per day across the province as a precautionary measure (OMNR 2005a). Due to extremely low exploitation rates, lake whitefish and cisco populations in the roadless area of northern Ontario are likely in excellent condition with some potential impacts due to exploitation near human settlements.

Cisco are of particular interest from a biodiversity conservation perspective as two of the ecotypes that occur in northern Ontario are considered threatened species in Canada. Blackfin cisco (*Coregonus nigripinnis*) is designated as threatened under the federal Species at Risk Act (SARA) and is currently under review by COSEWIC. Its occurrence outside of the Great Lakes and Lake Nipigon is not well documented. There are suspected occurrences in Deer Lake, Attawapiskat Lake, and Culverson Lake, all located north of the managed forest boundary in Ontario. Threats to this form of cisco are incidental catch in commercial fisheries and the introduction of rainbow smelt. These threats have adversely affected most populations in densely populated areas of Canada; therefore, the isolated populations of northern Ontario may serve as an important refuge and a sight for future research. Shortjaw cisco (*Coregonus zenithicus*) is assessed as threatened by COSEWIC but is not currently designated under SARA. It is reported to occur in 29 lakes in North America outside of the Great Lakes (COSEWIC 2005). North of the managed forest boundary in Ontario, shortjaw cisco are suspected to occur in Big Trout, Attawapiskat, Sandy, and Deer Lake. As with blackfin cisco, the distribution of this ecotype is poorly understood and the threats are human exploitation and exotic species introductions.

2.3.3 Brook Trout Communities

Distribution and Composition

Brook trout *(Salvelinus fontinalis)* are endemic to northeastern North America where they occur in a wide diversity of habitats from lakes and rivers to beaver ponds and ephemeral creeks (Scott and Crossman 1973). North of the managed forest boundary in Ontario, brook trout are abundant in all major rivers, and most tributary streams and creeks of the Boreal Shield and Hudson Plains ecozones (Figure 2.5). Lake-dwelling populations are rare in the north due to the presence of walleye, perch, and pike (all competitors and/or predators of brook trout) in most lakes. In the large rivers of the north, in which brook trout co-occur with walleye and pike, brook trout tend to reside in fast moving waters while pike and walleye occupy slower moving waters (Henschel 1989). In the small streams and creeks of the Hudson Bay lowlands, brook trout commonly coexist with white sucker, finescale dace (*Phoxinus neogaeus*) and longnose dace (*Rhinichthys cataractae*), stickleback, and darters. South of the managed forest boundary in Ontario, brook trout are widely distributed in lakes and rivers; however, species introductions and habitat degradation have reduced their original range.

Ecology, Growth, and Reproduction

Brook trout may adopt either resident or migrant life history strategies, and both forms often coexist in the same stream or river (Power 1980). Resident populations feed mainly on drifting insect larvae, although fish is a common food item for brook trout over 25 cm in length. Growth of resident populations is limited and length rarely exceeds 25 cm. However in the large rivers of northern Ontario, such as the Winisk and the Albany, resident brook trout over 40 cm in length are common (B. Cox, Canoe Frontier Expeditions, pers. comm., S. Liddle, Liddle's Fishing Adventures, pers. comm.). Migrant populations spend the first one or two years of life in rivers or streams, then migrate to the sea where they become piscivorous. Growth is rapid in marine environments where prey fish are abundant, and migrants frequently attain lengths over 45 cm. This is the case for the migrant population of the Sutton River where brook trout commonly attain lengths of over 55 cm (Steele 1986). Migrant populations are present in the lower reaches of the majority of rivers flowing into Hudson and James Bay (University of Toronto 1985)

Brook trout are most abundant in waters with depauperate fish communities. The presence of white sucker, yellow perch, northern pike, smallmouth bass, and other top predators results in reduced population size and, in some cases, reduced growth of brook trout (Kerr 2000). For this reason, this species tends to be most abundant in tributary rivers and streams with a lower number of species present, as opposed to mainstem rivers. This is true of northern Ontario, where brook trout are most abundant in smaller rivers such as the Asheweig, Sutton, Fawn, Ogoki, and Ekwan.

Figure 2.5 Distribution of brook trout *(Salvelinus fontinalis)* in the lakes and rivers of northern Ontario. Brook trout are present in small brooks and streams throughout watersheds in which they occur. Sea run brook trout mature in Hudson and James Bay and return to native rivers and streams to spawn. Sources: Ontario Ministry of Natural Resources and the University of Toronto (1985).

Brook trout are a short-lived species. In many populations, few individuals exceed 6 years of age, although ages of 10 to 12 years have been reported (Power 1980). Sexual maturity is commonly attained by age 2 or 3. Spawning occurs in autumn in rivers, streams and lakes, exclusively in zones of high groundwater upwelling (Ridgway and Blanchfield 1998). Loss or degradation of spawning habitat due to changes in stream morphology or groundwater flow has caused declines in brook trout populations in densely populated areas of Ontario (Power 1980). Newly hatched brook trout commonly move into small ephemeral streams of depths less than 30 cm to avoid predation and competition from other species. Their tendency to disperse into the smallest headwater streams has led some to refer to brook trout as the "forest fish" of the Boreal.

Brook trout are ubiquitous throughout the region occurring in everything from small streams a few centimetres deep to large lakes.

Engbretson Underwater Photography

Current Status

There is very little information available on the status of brook trout populations north of the 51st parallel in Ontario. Sport fish outfitters report that populations appear healthy in the Severn, Fawn, Winisk, Asheweig, Sutton, and Albany rivers with no obvious change in fishing quality over the past 25 years (B. Cox, Canoe Frontier Expeditions, pers. comm., S. Liddle, Liddle's Fishing Adventures, pers. comm.). Fishing pressure on brook trout in the roadless area of Ontario is generally low. Fly-in sport fishing for brook trout is commonly catch-and-release. Brook trout have never been commercially harvested in the region. Brook trout populations close to First Nations communities are sometimes exploited as a subsistence fishery, particularly during spawning. Migrant brook trout form a major portion of the subsistence fisheries for communities at the mouth of the Severn, Winisk, and Moose Rivers (Stewart and Lockhart 2005). A small number of population estimates exist for northern rivers. Henschel (1989) estimated the adult population in a 3 km section of the Winisk River at 223. Steele (1986) captured over 3000 adult brook trout during their migration up the Sutton River and suggested that this was a small fraction of the total population. Overall, anecdotal evidence suggests resident brook trout populations are in excellent condition in northern rivers (Table 2.2). Again, there are no data to allow the assessment of population status, e.g. to evaluate possible harvest impacts near sport fishing lodges and communities in the roadless portion of northern Ontario. Changes in flow regime and barriers to fish movement due to the high fragmentation from hydroelectric development may have negatively affected migrant brook trout populations in the Moose River basin; however, there are no pre-dam data on brook trout population status to allow for an assessment of impacts.

South of the managed forest boundary in Ontario, the distribution of brook trout has been greatly reduced over the past century. Lake Huron and Lake Superior once supported highly abundant brook trout populations that spawned in the many tributary streams flowing into the two lakes. The creation

of migration barriers such as road crossings and dams, the introduction of non-native species such as rainbow trout and west coast salmon, and reductions in water quality, all contributed to the collapse of the brook trout populations in the Great Lakes. Populations in small inland lakes have also declined. The introduction of yellow perch and smallmouth bass to hundreds of lakes in southern Ontario has led to the loss of many native populations. Smallmouth bass prey on brook trout juveniles and result in the loss of lake-dwelling populations. Currently, smallmouth bass are in the Mattagami and Missinaibi River systems of northeastern Ontario and one has been caught in the Moose River (C. Chenier, OMNR, pers. comm.). The expansion of smallmouth bass into more northern watersheds is limited by the cool temperatures and short growing season; nevertheless, this has occurred in some areas, e.g., Red Lake and several surrounding lakes. Climate warming over the next 50 to 100 years may allow for the establishment of populations in more northern waters (see Box 3). Algonquin Park and the area east of Wawa, Ontario hold the highest concentration of lake-dwelling brook trout populations. Brook trout also remain a common resident of thousands of relatively undisturbed streams in northern Ontario from Cochrane to Kenora.

2.3.4 Lake Sturgeon

Distribution

Lake sturgeon are unique to northeastern North America, reaching the limit of their northern distribution in the Severn and Winisk rivers of Ontario and in the rivers of northern Manitoba (Scott and Crossman 1973). Lake sturgeon occur in all the major rivers of northern Ontario, their main tributaries, and connecting lakes (Figure 2.6); however, their distribution throughout the river systems is poorly understood. As a consequence, it is unknown how many distinct populations of lake sturgeon exist in northern Ontario. Lake sturgeon were once common throughout the Great Lakes watershed; however, many populations have been extirpated from their native rivers.

Ecology, Growth, and Reproduction

Lake sturgeon are an ancient form of fish with cartilaginous rather than bony skeletons. They are specialized bottom feeders and will consume any type of benthic food source from algae to fish to mollusks; however, insect larvae are the dominant prey item (Scott and Crossman 1973, Peterson et al. 2007). Their role in aquatic ecosystems is poorly understood. Due to their ability to feed on all types of prey, their large size, and their method of feeding, which involves filtering prey out of sand, gravel and mud, it is thought that at high densities they may have played an important role in structuring bottom habitat and zoo-benthos communities (LeBreton et al. 2004).

A defining characteristic of lake sturgeon is their extremely long life span. Individuals have been aged at over 150 years. In northern populations, sexual maturity of females may be reached as late as age 23. Females reproduce once every 4 to 6 years (Scott and Crossman 1973, Peterson et al. 2007). Unexploited
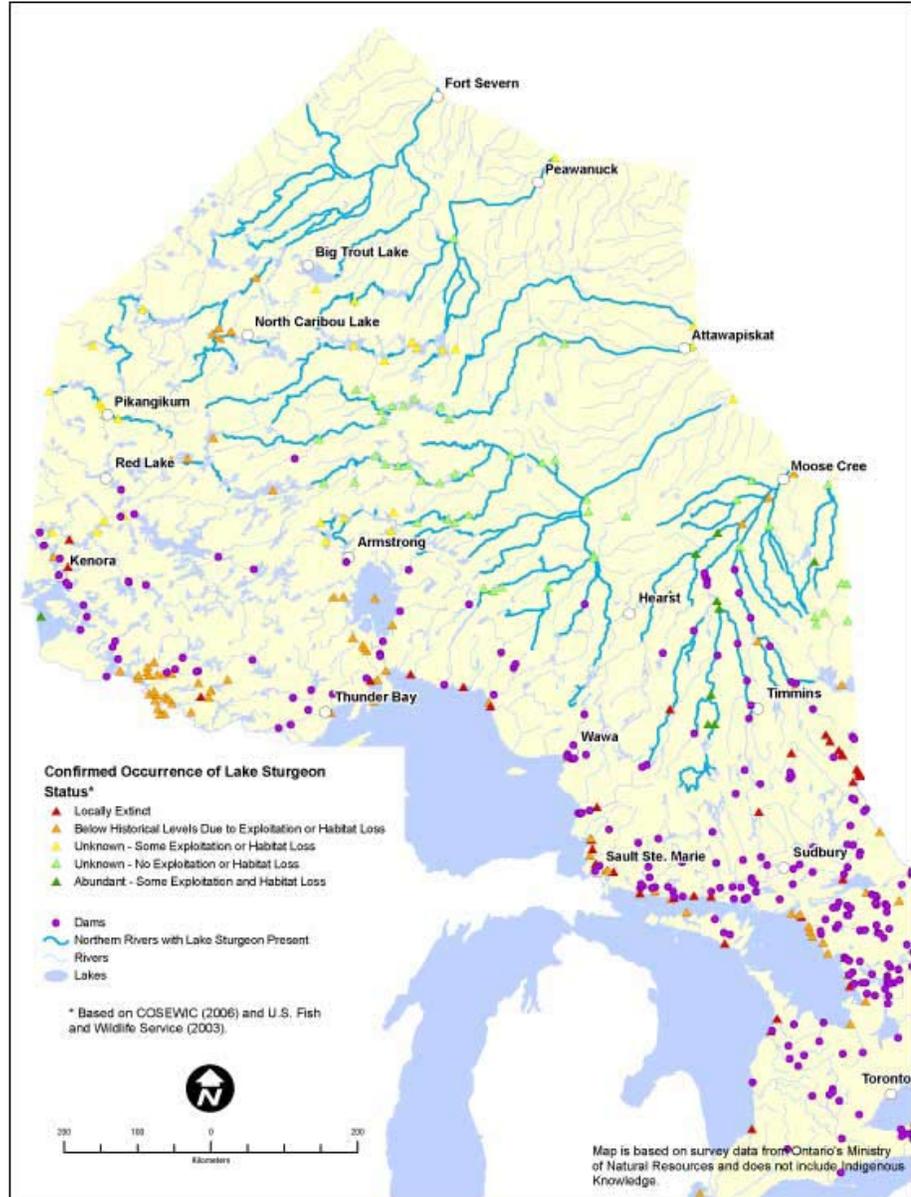
lake sturgeon populations are the ultimate old growth populations of freshwater fish in Canada, often having large portions of the population older than 30 years (Scott and Crossman 1973). Their late age at maturity and infrequent spawning makes lake sturgeon extremely susceptible to overexploitation.

Lake sturgeon are a migratory species. In early spring, adults that are ready to spawn migrate upstream to areas of fast-flowing water, often at the base of waterfalls. Sturgeon commonly migrate up to 100 km or more to reach spawning sites. Immediately following spawning, lake sturgeon migrate to summer feeding grounds in rivers and lakes. A third migration occurs in the fall when sturgeon move to over-wintering sites (McKinley et al. 1998). Apart from seasonal migrations, lake sturgeon are relatively sedentary: for example, 80% of individuals tagged in the Moose River were recaptured in the original tagging area (Threader and Brousseau 1986). Due to their migratory life history, lake sturgeon populations require large unfragmented watersheds to thrive, a characteristic that has been lost in most southern watersheds (Figure 2.5).

Current Status

Lake sturgeon are in decline or extirpated from all developed areas of North America (LeBreton et al. 2004). Historically sturgeon were seen as a pest and were harvested by the thousands in the Great Lakes to be used, for among other things, as fuel for steamships. Subsequently, the damming of rivers for flood control, transportation, and hydroelectricity eliminated much of the lake sturgeon spawning grounds and caused further declines in populations (LeBreton et al. 2004, COSEWIC 2006). Currently, lake sturgeon in the Berens River, north of Red Lake, is assessed as endangered as part of the Red-Assiniboine Rivers - Lake Winnipeg conservation unit (COSEWIC 2006). In the Great Lakes and Upper St. Lawrence, lake sturgeon is considered

Lake sturgeon's migratory needs puts them in conflict with hydroelectric development.

threatened. Finally, lake sturgeon is assessed as special concern for the southern Hudson Bay and James Bay watersheds (COSEWIC 2006). The designation of special concern is the result of insufficient information on the status of the populations, habitat loss due to hydroelectric development, and exploitation associated with increased access to the region. Human impacts on lake sturgeon are concentrated in the Moose River Basin due to extensive hydroelectric development and greater road access in this area. The Severn River population may have suffered from overexploitation by local communities during the 1980s (COSEWIC 2006); however, exploitation rates are thought to have declined. On the other hand, lake sturgeon populations in the Albany, Attawapiskat, and Winisk rivers are thought to be in good condition overall although localized over-exploitation has the potential to occur within the vicinity of population centers (C. Hendry, OMNR, pers. comm.). No data exist, however, on the current size of the populations or the rate of exploitation (Table 2.2).

Lake sturgeon are extremely valuable for both their eggs and their flesh. With the recent decline in Caspian Sea sturgeon harvest, there is an anticipated increase in demand for lake sturgeon caviar. This may increase illegal harvest of the species and put further pressure on already declining populations. The populations of the northern rivers of Ontario are thought to contain some of the few remaining healthy populations; however, there is almost no information on their status (COSEWIC 2006). The two major threats to lake sturgeon north of the managed forest boundary in Ontario are dam construction for hydroelectricity and overexploitation for local and foreign markets (Table 2.2).

3. RESOURCE EXTRACTION IN THE ROADLESS PORTION OF ONTARIO

For the purposes of this report, the roadless area of northern Ontario is defined as that portion of Ontario beyond the legal limit of commercial forestry. This zone — the Northern Limit of the Area of the Undertaking for MNR's Forest Management Class Environmental Assessment for Timber Management on Crown Lands in Ontario (1987) — includes all the land north of the Albany River from the Manitoba border to north of Geraldton, and all of the land north of highway 11 from just east of Geraldton to the Québec border (Figure 1.2). As of this writing, three all-weather roads penetrate 50 to 150 km into the region, heading north from the towns of Red Lake, Pickle Lake, and Kapuskasing. A winter road network provides access to northern aboriginal communities, extending approximately 100 km north from the end of the Red Lake and Pickle Lake roads. A railway penetrates northward 250 km from Cochrane to Moosonee at the southern tip of James Bay. Other than these access points the area is accessible only by air or water.

Although northern Ontario remains relatively inaccessible and undeveloped, the resource potential of the region is of considerable interest to a variety of resource development sectors and community residents, with some activities already underway:

Carrie Sadowski, OMNR

The area north of roughly 51 degrees latitude has remained largely undeveloped and is currently unallocated for forestry.

- The Northern Boreal Initiative (OMNR 2002a) was initiated by OMNR in 2000 to establish a process for providing First Nations north of current forestry operations with commercial forestry opportunities. As such, several First Nations within this region have undertaken comprehensive forest resource inventories of their traditional use areas, one Land Use Strategy has been developed and approved (Pikangikum First Nation and OMNR 2006) and the environmental assessment process for this project has been initiated.

- The flow regimes of all the major rivers have been monitored and potential hydroelectric sites have been identified. The Moose River basin currently supports 16 hydroelectric dams, with a combined capacity of approximately 1000 MW. Approximately 17% of the annual flow of the Albany River has been diverted to Lake Superior and Lake Winnipeg for hydroelectric production.

- The Ontario Ministry of Northern Development and Mines (OMNDM) has developed a provincial mineral development strategy (OMNDM 2006), identifying Ontario as an "international mining powerhouse" by virtue of its status as a top producer of base metals, precious metals, and industrial minerals. The Fraser Institute's most recent survey of mining companies likewise includes Ontario among the top 10 jurisdictions in the world with regard to mineral potential (Fraser Institute 2007). Mineral exploration is taking place across the region and the process is underway for identifying areas of provincially significant mining potential in the North. Two mines are currently in operation: 1) The Musselwhite gold mine jointly owned and operated by Goldcorp Inc. and Kinross Gold Inc located north of Pickle Lake on a tributary to the Pipestone River, and 2) the Victor Diamond Mine owned and operated by De Beers Canada, Inc., located along the Attawapiskat River approximately 90 km west of the river mouth. Some other promising mineral deposits include platinum on the shores of Big Trout Lake, diamond deposits near Attawapiskat and Kassabonika, and a large sulphide ore body near McFaulds Lake along the Attawapiskat River which contains copper, gold, and silver.

- Very little oil and gas exploration has occurred in the area, despite the similarity of the underlying geology of the Hudson Bay Lowlands to other oil-producing regions of North America. Coal and coal bed methane deposits exist in the vicinity of Moosonee but are not currently considered to be economically viable.

The combined potential for forestry, hydroelectricity, and mineral extraction in the region (Figure 3.1) means that development of all three industries is likely. All three types of development affect aquatic ecosystems and fish through a variety of processes, including increased sedimentation, changes in water flow, habitat fragmentation, release of pollutants, and increased access for recreational fishing. The following sections present a review and analysis of the potential impacts of forestry, hydroelectric power generation, mining, and accompanying road access on aquatic environments and fish in the boreal forest of northern Ontario. This discussion is followed by a brief overview of the likely impacts of climate change. The report is organized to highlight the most important potential agents of change to aquatic systems in Ontario's northern boreal forest and is therefore not exhaustive as to impacts experienced by fish populations, many of which are characteristic of southern Ontario and Great Lakes environments, including species introductions, pollution and environmental contaminants from human settlement, and bait fishing (Box 1).

Figure 3.1 Existing and potential natural resource development in northern Ontario. Winter roads, which are made fresh every year, are not depicted in the map, nor are routes for potential all-weather access roads.

Legend:

Communities
Primary roads
51st Parallel
Northern extent for licensed timber harvesting
Large Rivers
Large Lakes
Protected Areas

Existing mines
Recent mineral exploration activity (winter 2007)
Existing hydroelectric dam
Water retention dam
Proposed hydro development
Proposed hydro corridor (direct route to Sudbury)
Potential new commercial timber harvesting

Polar Bear Provincial Park
Peawanuck
Fort Severn
Attawapiskat
Kashechewan
Moosonee Moose Cree
Hearst
Victor Diamond Mine
Marten Falls
Nakina
Geraldton
Webequie
Nibinamik
Kasabonika
Wunnumin Lake
Eabamatoong
Armstrong
Big Trout Lake
Bearskin Lake
North Caribou Lake
Musselwhite Mine
Pickle Lake
Mishkeegogamang
Wabakimi Provincial Park
Lac Seul
Sioux Lookout
Muskrat Dam
Cat Lake
Slate Falls
Sandy Lake
Deer Lake
Poplar Hill
Pikangikum
Woodland Caribou Provincial Park
Red Lake
Ear Falls
Grassy Narrows
Dryden
Kenora

James Bay

Ekwan River
Albany River
Sutton River
Winisk River
Attawapiskat River
Fawn River
Severn River
Berens River
Kilometers
100 50 0 50 100
Highway 11

Box 1: Mapping Current Impacts

The status of freshwater ecosystems is determined by several factors that vary in intensity across the landscape, including resource extraction, land transformation, human settlement, and industrial development. In order to situate northern Ontario in a provincial context of current impacts to freshwater environments, we developed a map of cumulative watershed impacts for the province of Ontario (Figure 3.2). The map integrates four proxies of cumulative watershed impacts: 1) Proportional land transformation of the watershed in terms of recent forestry cuts, cropland, and human settlement, 2) Road density, 3) Human population density, and 4) Hydroelectric and flood control dams. The total impact score for each tertiary watershed is the sum of the scores for each of the proxies (see Appendix I for description of the scoring method).

The resulting map provides a picture of the current distribution of aquatic ecosystem disturbance in watersheds across Ontario. Not surprisingly, there is a gradient of watershed alteration from high in the southeast to low in the north and northwest. Areas with low impact score in the south of the province correspond to Provincial Parks such as Algonquin Park and Killarney Park. Areas with high impact score in the north correspond with those watersheds containing relatively high road densities and recent forestry cuts.

Factors driving watershed impacts in northern and southern Ontario are quite different. Population density, human settlement and conversion of forests to cropland are the primary drivers of watershed impacts in the south. In northern Ontario, resource industries play a more important role. In order to examine the distribution of watershed impacts in northern Ontario in more detail, we developed a second map focused on the area north of the 49th parallel (Figure 3.3). This second map uses the four proxies for watershed impacts from the Ontario wide map and integrates three more indicators: 1) pulp and paper mills, 2) acid mine drainage sites, and 3) resource-based tourism outpost density (see Appendix I for methods). It provides a picture of watershed impacts more specific to northern Ontario. Watersheds with high cumulative impact scores occur where pulp and paper, forestry, and mining overlap, such as near Dryden, Kapuskasing, and Cochrane.

Together, the two maps highlight the current low level of watershed impacts north of the managed forest boundary in Ontario and identify watersheds with potentially high impacts on freshwater ecosystems south of the boundary. In sum, the combined potential for forestry, hydroelectricity, mineral extraction, and associated roads in the region could affect aquatic ecosystems and fish through a variety of processes, such as increased sedimentation, changes in water flow, habitat fragmentation, release of pollutants, and increased access for recreational fishing.

An additional overarching threat to freshwater ecosystems in the boreal region is global climate change. Significant climatic changes, including warming and decreased precipitation, are expected in northern Ontario over the next 50 to 100 years (see Box 3 for an overview of the possible impacts of climate change on freshwater fish).

Figure 3.2 Classification of tertiary watersheds in Ontario by watershed impact score based on population density, percent land transformation, road density, and number of dams. Higher watershed impacts scores and darker colours indicate greater human impact on aquatic environments (see Appendix 1 for scoring methodology).
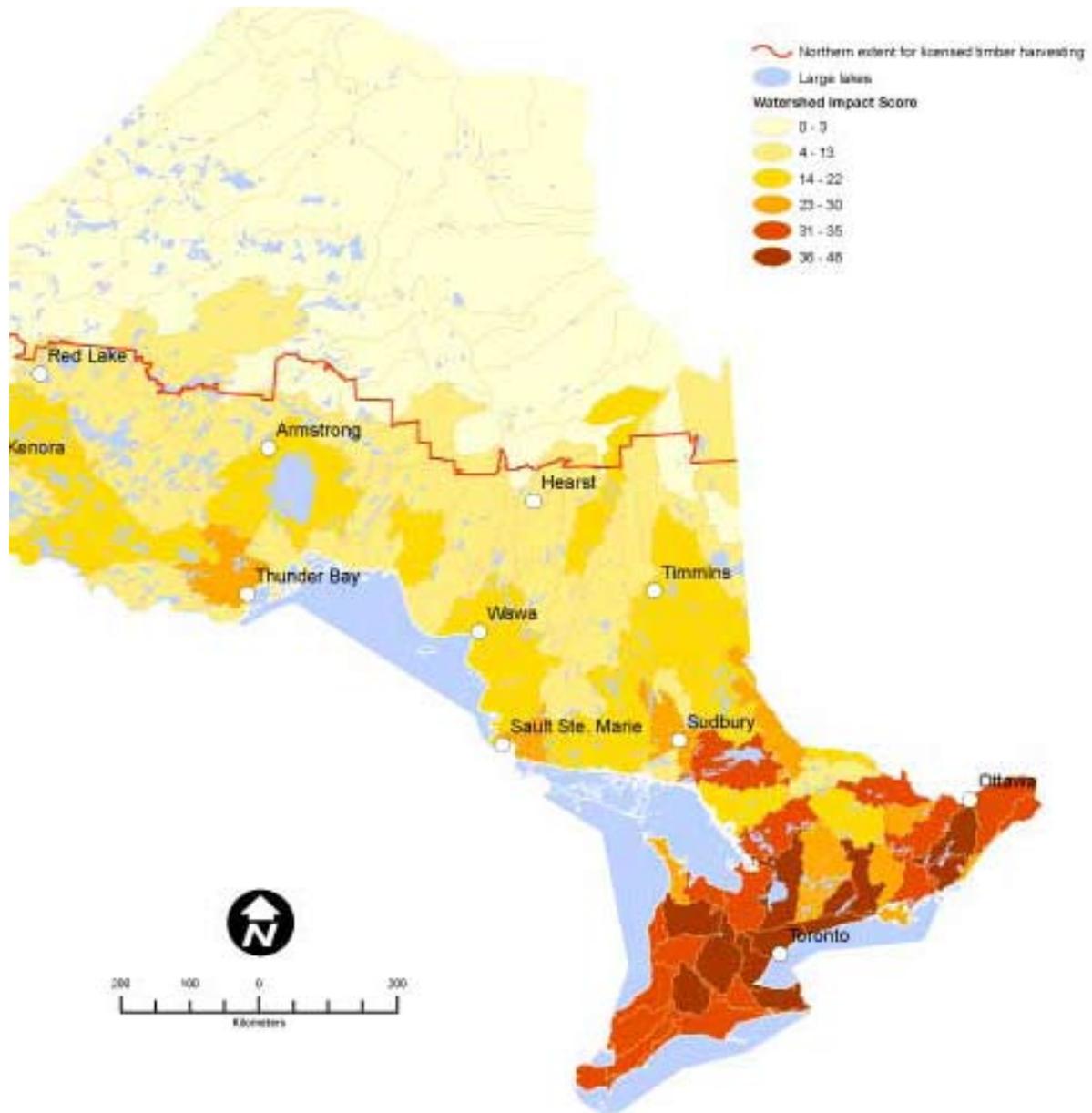
Figure 3.3 Classification of tertiary watersheds in northern Ontario by watershed impact score based on population density, percent land transformation, road density, and number of dams, number of acid mine drainage sites, number of pulp and paper mills, and tourism outpost density. Higher watershed impacts scores and darker colours indicate greater human impact on aquatic environments (see Appendix 1 for scoring methodology).
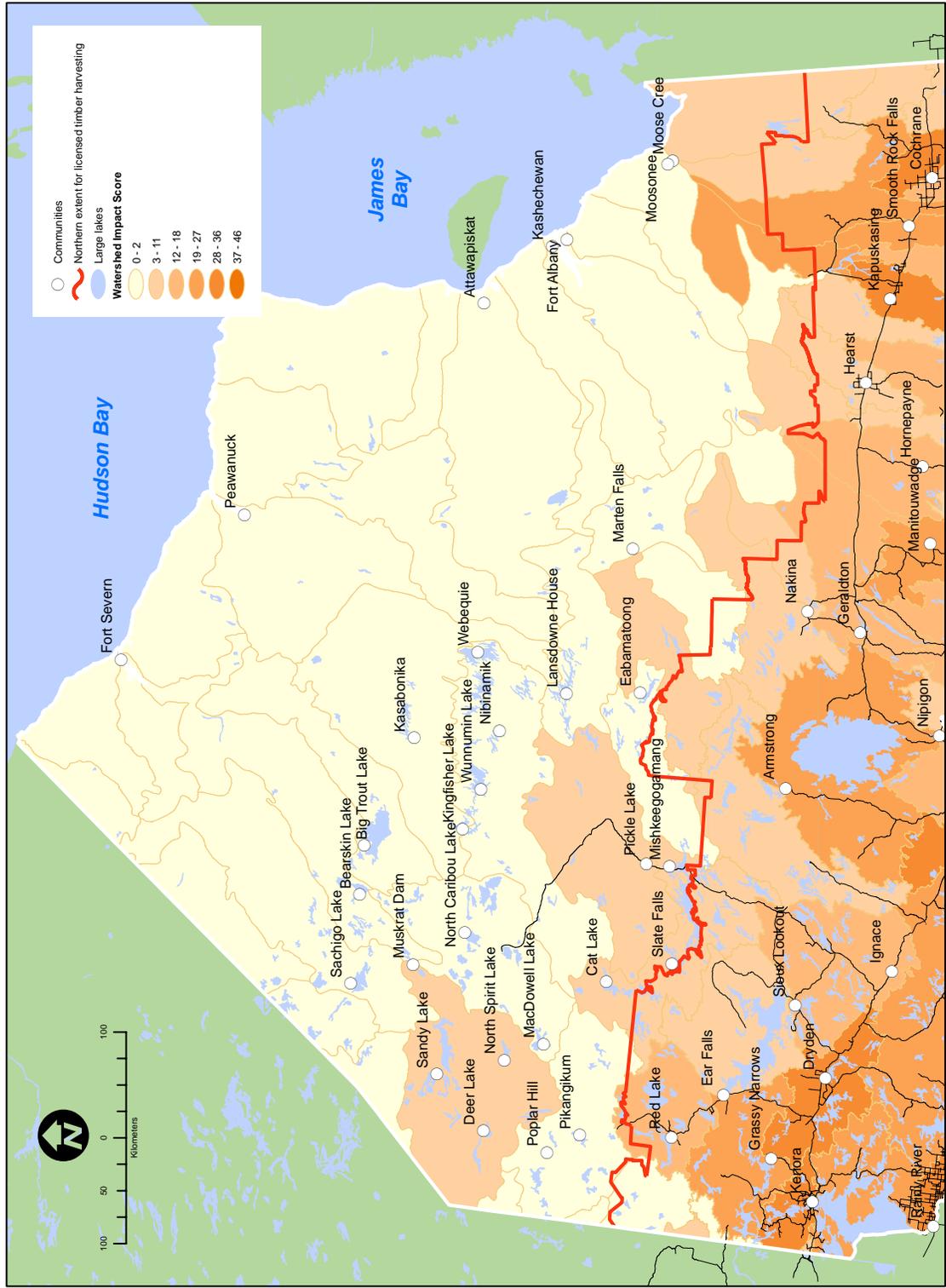
3.1 Forestry

Forestry results in two major changes to the landscape that may affect aquatic ecosystems:

1) the removal of large areas of forest and exposure of soils to erosion

2) the creation of logging roads.

Forest removal alters groundwater flow and surface runoff which has been documented to lead to the release of mercury, nutrients, decaying organic matter, and sediment to adjacent water bodies with associated impacts on fish and other aquatic organisms. Logging roads, on the other hand, may fragment aquatic habitat due to poorly constructed water crossings, increase sedimentation arising from erosion of the road surface, and increased human exploitation of fish populations due to enhanced access to lakes and rivers.

3.1.1 Effects of Forest Removal

Forest removal exposes forest soils to erosion, results in increased rates of decay of organic matter, and increases runoff. The result is an influx of nutrients, minerals, sediment, and pollutants such as mercury to receiving water bodies. Forest removal can occur through natural processes (e.g., fire, windstorms, or insect outbreaks), or human activities (e.g., forestry or land clearing). Concern about the need for forestry operations to approximate natural disturbance has resulted in the adoption of logging systems in some regions that are designed to simulate the pattern, but not

Forestry can change water flow regimes, lead to sedimentation of waterways and increase access to previously remote water bodies.

stand level dynamics or chemistry, of wild fire (McRae et al. 2001). However, it is important to understand the extent to which the respective ecological roles of forestry and fire differ in their impacts on resident biota and their habitats. In the following sections we present the potential effects of forestry operations on aquatic environments and discuss the similarities and differences between the effects of fire and forestry.

Mercury

Mercury is a highly toxic chemical, widely distributed in the environment and naturally present in aquatic environments in very low concentrations. Long-range atmospheric transport of mercury from coal burning and other sources has led to increased concentrations in soils and freshwater systems (Ullrich et al. 2001). Mercury is biomagnified upward in the food chain, and can attain high concentrations in top predators such as fish and fish-eating birds. In North America, mercury is the most common reason for human fish consumption advisories.

Forest removal increases mercury loading to aquatic environments via a number of processes. Mercury stored in catchment soil is liberated through direct soil erosion and the transformation of mercury into more soluble forms

as organic matter in the soil decays (Porvari et al. 2003). Increases in nutrient and dissolved organic carbon (DOC) loading coincide with the pulse of mercury originating from the landscape. Nutrient loading may increase primary production, which in turn may increase mercury incorporation into aquatic biota, as has been demonstrated following forest fire in Jasper Park, Alberta (Kelly et al. 2006). Similarly, higher DOC concentrations leads to greater mercury methylation, rendering mercury more able to be taken up and accumulated in the tissues of aquatic organisms (Ullrich et al. 2001). Because methylmercury is easily absorbed and is retained in lipid and muscle tissue, mercury incorporated into organisms at the base of the aquatic food chain, such as algae and plankton, ultimately becomes concentrated in top predators. As a result, piscivorous fish such as pike, walleye, bass and trout obtain mercury from their prey and concentrate it in their muscle tissue at levels thousands of times higher than in the surrounding water. In general, mercury accumulation in surface waters and aquatic biota in non-urban areas is highest in low relief landscapes with poor drainage and extensive wetland areas (Dennis et al. 2005, Roue-Legall et al. 2005). The fact that this description characterizes the landscape of much of northern Ontario suggests the release of mercury to aquatic ecosystems may be a common outcome of landscape disturbance in the area.

Clearcutting can lead to the release of mercury from soils into waterbodies, where it bioaccumulates in fish. Consumption of fish with high mercury levels poses a health risk to both people and wildlife.

Researchers have only recently begun to investigate the effects of forest removal on mercury dynamics in aquatic ecosystems, with some important results already emerging. Clear-cutting of boreal lake watersheds in Québec led to a 2 to 9.6 fold increase in methyl mercury in benthic algae, with impacts documented to be strongest in watersheds with an average slope less than 7% (Desrosiers et al. 2006). Garcia and Carignan (1999) found methyl mercury concentrations in zooplankton to be 30% higher in lakes situated in logged landscapes as compared with burned or reference watersheds. At the top of the food chain, logging of boreal watersheds led to a 2 to 3 fold increase in the mercury concentration of pike, walleye, and burbot (Garcia and Carignan 2005). Fish mercury concentrations increased from approximately 1 mg/kg dry weight to 2 to 3 mg/kg dry weight, placing the majority of top predators above the human consumption guideline of 2.5 mg/kg. Similar but slightly lower increases in total mercury were observed for top predators from lakes in partially burned catchments.

It is unclear whether logging and fire differ in their impact on mercury bioaccumulation in aquatic ecosystems. Garcia and Carignan (2005) hypothesized that greater DOC loading associated with logging and the potential for the loss of soil mercury to the air during forest fires would lead to greater impacts from clear-cutting; however, they were unable to demonstrate a statistically significant difference in fish mercury concentrations between logged and burned catchments. Increased mercury concentration in fish appears to be a common outcome of forest disturbance regardless of the agent. Logging differs from for-

est fire in that it is a planned and therefore predictable disturbance (as opposed to most forest fires) that may increase the mercury exposure of human populations that rely on fish for subsistence. Current forestry management practices do not take into account the potential effect of logging on mercury accumulation in fish. In this context, it is important that researchers develop the capacity to predict effects of logging on mercury dynamics and that forestry management plans take human health concerns into account (Roue-Legall et al. 2005).

Nutrient Input

Forestry operations are known to incur direct impacts on the water quality of lakes and streams. Forest removal is commonly followed by an influx of nutrients, minerals, and organic matter to receiving water bodies. In the boreal forest, such effects have been documented for lake ecosystems. In one study area phosphorus and nitrogen concentrations increased by approximately twofold following logging of a lake catchment (Carignan et al. 2000). Logging has also been shown to result in a three-fold or more increase in dissolved organic carbon (DOC) concentrations in lake water (France et al. 2000). In general, impacts on lake water chemistry demonstrate a positive relationship with the ratio of logged area to lake area and an inverse relationship with water residence times (Carignan et al. 2000, Steedman 2000). That is, the larger the area of disturbance the larger the effect. On the other hand, the faster water is exported from the lake the smaller the effect.

Limited research exists on the effects of logging-induced changes in water chemistry on lake ecosystems. In some cases, increased nutrient input results in increased primary production, which may in turn alter food web interactions through changes in the abundance of primary consumers (Planas et al. 2000). In other cases, increased DOC concentrations following logging can reduce light penetration sufficiently to offset nutrient inputs and primary production remains unaltered or declines (McEachern et al. 2000).

The effects on fish of such changes to lake ecosystems are not well studied. Increased DOC concentration results in lower light penetration and a shallower thermocline (the zone of transition from warm to cold water) in lakes. This may in turn alter interactions between coldwater and warm-water fish species. Steedman (2003), however, found no evidence for an effect of logging on littoral (lake edge) fish abundance in boreal lakes, although the measure of fish abundance used in this study may have been unable to detect a difference due to the inefficiency of the fishing gear. Similarly, logging had no discernible effect on fish assemblages of boreal lakes in northern Alberta sampled one to two years post-disturbance (Tonn et al. 2003). Further research is necessary to clarify the effects of changes in water quality due to logging on fish populations in lakes. Current research suggests effects are highly dependent upon the characteristics of the lake and the surrounding landscape; however, given the present state of knowledge it is difficult to build predictive models that could be incorporated into forestry management plans.

The effects of logging and forest fires on water quality can be differentiated by the relative importance of inorganic versus organic elemental runoff. Forest fires generally result in higher inputs of cations and anions, such as calcium,

magnesium, and sulfate, than logging (Carignan et al. 2000). Although total nutrient input appears to be similar for logging and forest fires (Enache and Prairie 2000, McEachern et al. 2000), clear-cutting results in significantly greater increases in DOC (France et al. 2000, McEachern et al. 2000). Furthermore, nutrient inputs following logging tend to have a higher contribution of organic bound nitrogen and phosphorus, a form which is more available to aquatic plants (Lamontagne et al. 2000). These differences in the biogeochemistry of logging versus fire may result in different effects on ecological processes in lakes and rivers, with possible consequences for fish populations. For example, Planas et al. (2000) found differences in the species composition of the open-water algal community between lakes in burned and logged catchments. Changes to water chemistry from logging and forest fire may be short lived. Evidence suggests boreal lakes return to pre-disturbance nutrient levels after 5 to 15 years (Enache and Prairie 2000). The duration of any resulting ecosystem changes is not known; however, a return to pre-disturbance conditions may require a longer period of time.

Runoff and Sedimentation

Logging is known to cause increases in total runoff and changes in the flow regime of forest streams (Sahin and Hall 1996). Changes in flow regime may alter the physical stream habitat, species distributions, and primary production (Poff et al. 1997). In boreal and hardwood forests of northeastern North America, however, increases in water yield following logging are relatively low and effects on physical stream characteristics due to scouring are less likely than in the steep terrain of western North America mountains where effects can be dramatic (Buttle and Metcalfe 2000, Martin and Hornbeck 2000). Increased runoff is, however, associated with increased sediment load due to erosion of surface soils (Platts et al. 1989, Croke and Hairsine 2006); increased levels of sedimentation can in turn alter the stream environment and affect the resident biota. In fact, sedimentation is considered the dominant impact of logging on stream and river ecosystems (Croke and Hairsine 2006). For example, increased loading of fine sediments has been demonstrated to alter invertebrate communities and negatively affect salmonid spawning and nursery habitat (Chapman 1988, Kiffney et al. 2003). Indeed, changes in runoff and sedimentation due to logging were proposed as an explanation for an observed 20% decline in brook trout yield between lakes in unlogged and logged catchments in Québec (Berube and Levesque 1998). Similarly, in a study in northern Michigan, the density and biomass of brook trout was found to be significantly lower in streams located in selectively logged watersheds due to increased fine sediment loading when compared with streams located in unlogged watersheds (VanDusen et al. 2005).

Sedimentation as a result of logging is generally greater than from natural disturbances, largely due to the creation of roads and the disturbance of soils by forestry machinery (Martin and Hornbeck 2000). In fact, roads associated with logging are often a greater source of sedimentation than erosion of forest soils following clear-cutting (Platts et al. 1989, Croke and Hairsine 2006). The persistence of sedimentation impacts following logging depends on the rate of vegetation regrowth, the placement of roads, and the construction of water

crossings, with impacts lasting 3 to 10 years in areas with rapid regrowth or persisting for decades in areas with steep slopes or poor road placement and design (Platts et al. 1989, Martin and Hornbeck 2000). Despite the potential significance of logging-induced sedimentation, the relationship between logging, sediment loading, and fish habitat alteration has not been well studied in the boreal forest of Ontario. Ontario forestry guidelines require the maintenance of an uncut buffer strip around lakes and rivers (OMNR 1988, 1990), which can greatly reduce sedimentation from surface runoff; however, roads placed near water bodies and road water crossings may continue to cause sedimentation despite the presence of buffer zones. Further research is necessary to evaluate current guidelines and practices.

Loss of Riparian Vegetation

Another means by which logging may affect lake and river ecosystems is through the cutting of stream edge (riparian) or lake edge (littoral) vegetation. Clear cutting to the lake shoreline results in increased wind speeds, warmer water temperatures in the littoral zone, and increased sedimentation (Steedman et al. 2001). Increases in wind velocity tend to be greatest for small lakes (surface area < 20 ha) surrounded by flat terrain, and may deepen lake thermoclines or prevent stratification of shallow ponds due to increased water column mixing (Rask et al. 1993). Water temperature and the depth of the warm water por-

tion of a lake are important determinants of fish growth, habitat use, and predator-prey interactions. Warmer water temperatures may increase production of benthic algae and favour survival of warm-water fishes such as bass and sunfish.

Cutting to the water's edge can damage fish habitat and increase sedimentation to lakes and rivers.

SLDF/Wildlands League

Riparian zones are also important to the integrity of flowing waters. Removal of riparian vegetation reduces shading and increases water temperatures and solar irradiance. In the absence of high sedimentation, higher water temperatures and increased light levels cause an increase in algal production that may propagate through the food web leading to increased fish survival and growth (Keith et al. 1998, Kiffney et al. 2003). Alternatively, higher water temperatures may increase mortality of coldwater species such as juvenile trout or salmon. Physical habitat alteration due to the use of logging machinery in the riparian zone or stream bed combined with nutrient loading from runoff may alter primary production in streams resulting in changes to aquatic food webs. For example, changes in algal and insect production in streams following logging of boreal forest in Maine was shown to shift the relative abundance of stream dwelling fish species, potentially altering fish food webs (Garman and Moring 1993).

The effects of logging on physical lake or river habitat can be indistinguishable from that of similar natural processes, such as blow-downs or fire (Schindler et al. 1990, France 1997). However, evidence for adverse effects of clear-cutting to the stream or lake edge is one reason why riparian zones are protected in most jurisdictions across North America. In Ontario, *The Timber*

Management Guidelines for the Protection of Fish Habitat (OMNR 1988) define areas of concern for fish habitat and designate minimum riparian buffer zone widths for lakes and streams (see discussion on the effectiveness of riparian buffers for fish habitat below).

3.1.2 Logging Roads

Forestry operations create an extensive network of roads, the effects of which may persist on the landscape long after logging has ceased. Adverse effects of roads on aquatic ecosystems may arise from poorly constructed water crossings, erosion of the road surface, and increased human access to formerly remote lakes and rivers. The following section reviews the direct effects of roads on aquatic habitat. The effects of increased access and recreational fishing on fish populations are discussed in section 3.4.

Improperly constructed water crossings lead to erosion and fragmentation of aquatic habitat.

Water Crossings and Habitat Fragmentation

Stream crossings in the form of cylindrical corrugated culverts have caused significant fragmentation of aquatic habitats across North America with negative consequences for fish populations (Gibson et al. 2005). Culverts prevent fish passage in two ways. Hanging culverts create a vertical drop in the stream, preventing upstream movement by individuals. Alternatively, if the culvert is well placed but too small for the waterway, it may cause a constriction of the river or stream with consequent increases in water velocities to levels too high for fish to move through.

Concern over the impacts of poorly constructed stream crossings has been particularly high in western North America where culverts have eliminated a significant portion of salmon habitat (Beechie et al. 1994, Gucinski et al. 2001). Much of this habitat loss is due to the presence of poorly installed culverts on thousands of small streams. Small creeks and ephemeral streams can serve as vital habitat for spawning and early life stages of salmonids. For example, 40% of the spawning rainbow trout in a British Columbia creek relied on an ephemeral stream to spawn (Erman and Hawthorne 1976). This stream typically had no water flow by late July but was critical to the maintenance of the population. At the landscape scale, the abundance of rainbow trout in Wyoming streams was found to decline as culvert density increased due to increased sediment load and barriers to migration (Eaglin and Hubert 1993). In the U.S. states of Oregon and Washington, government officials have identified 2,600 culverts that are barriers to migratory fish (Gibson et al. 2005); examination of a single watershed estimated that culverts had caused the loss of 13% of salmon rearing habitat (Beechie et al. 1994). In the boreal forest of Alberta, estimates of the number of culverts acting as barriers (considering only hanging culverts) are as high as 10,700, with fragmentation estimated at 5% to 20% of stream systems (Park 2006). Effects

are also present on the east coast of Canada. High culvert density in the Harry's River watershed of southwestern Newfoundland is thought to be the primary cause of low Atlantic salmon abundance in the river (Gibson et al. 2005). Small non-migratory fish such as minnows and sunfishes also move between habitat patches within streams and are also affected by culverts (Larson et al. 2002). For example, Warren and Pardew (1998) showed that the presence of a 10 m long culvert with water flow of 40 cm/s greatly reduced the movement of several species of minnow and sunfish in an Arkansas stream, and prevented the movement of nine other species.

Improperly installed culverts can make it impossible for fish to move upstream.

FISHERIES AND OCEANS CANADA

In the watersheds of the boreal forest of northern Ontario, species likely to be adversely affected by barriers in small streams include brook trout, white sucker, minnows, and darters. In large streams and rivers, species likely to be affected by poorly constructed water crossings include lake sturgeon, walleye, and brook trout. Brook trout are particularly sensitive to the creation of barriers on small streams. Because lake and river resident populations use tributary streams for spawning, poor culvert installation could remove spawning habitat and decrease brook trout abundance. Shortly after hatching in the spring, juvenile brook trout are known to move up small streams and temporary waterways used as nursery habitat (Curry et al. 1997). Loss of nursery habitat is likely to reduce brook trout abundance in lakes or mainstem rivers, as has occurred on the west coast for other salmonids. Most of the streams used as nursery habitat by juvenile brook trout are not found on the Ontario base maps, making it particularly challenging to incorporate brook trout considerations into forestry management, including the preservation of critical habitat (Borwick et al. 2006). Due to the strong link between brook trout population status and landscape disturbance, the species has been identified as a candidate indicator species for sustainable forestry management in northern Ontario (McGovern and Chang 2004).

The construction of forestry roads in the boreal forest requires a large number of stream crossings. Although no data exist on culvert densities in Ontario, there are tens of thousands of kilometers of forestry roads with tens if not hundreds of thousands of stream crossings (OMNR 2003). In the boreal forest of Québec approximately 10,000 stream crossings are constructed annually in forested areas, and the number is likely similar in Ontario. Given the high abundance of culverts on logged watersheds, the potential for significant loss of stream habitat is high. This problem is exacerbated by the use of cylindrical culverts with no infill. Unlike natural channels that have cobble or debris to provide low current patches, there are no resting places within the culvert. In an attempt to reduce the effects of culverts on fish movement, maximum water velocities for fish passage have been estimated and the Department of Fisheries and Oceans recommends <60 cm/s for passages with coarse substrate, and <34 cm/s for passages without a coarse substrate (Gibson et al. 2005).

Two documents regulate the construction of stream crossings in Ontario: the *Timber Management Guidelines for the Protection of Fish Habitat* (OMNR 1988), and the *Environmental Guidelines for Access Roads and Water*

Crossings (OMNR 1990). In terms of stream crossings, the timber management guidelines state that "road construction within the area of concern should occur only where it can be demonstrated that road design, construction, use and maintenance will ensure protection of fish habitat and water quality" (OMNR 1988: 11). The access road guidelines are slightly more specific on the use and placement of culverts. For engineering reasons, it is recommended that culverts be placed in riffle or rapid areas of streams, although it is acknowledged that if the rapids are used by fish for spawning they should be avoided. In the case where streams are used for fish migration or spawning the guidelines recommend the use of bridges or arch culverts to avoid creating a barrier to migration. They also require that water crossing structures be designed so that flow velocities are not too high to prevent fish migration, although optimal flow velocities are not specified.

Despite the flexibility inherent in the guidelines, non-compliance, as reported by MNR inspectors for fish passage criteria, is common and ranged from 20 to 29% between 1998 and 2001 (OMNR 2002c). Independent assessments of stream crossings in other jurisdictions have found high levels of non-compliance for fish passage to be a common occurrence. In Labrador, 25 of 47 culverts inspected on the trans-Labrador highway posed a barrier to fish passage (Gibson et al. 2005). In forestry areas near Kamloops, British Columbia, 30 of 31 culverts inspected failed to meet Department of Fisheries and Oceans guidelines (Chestnut 2002). In the Swan River basin of northwestern Alberta, 74% of all crossings posed a barrier to fish movement resulting in restricted access to approximately 20% of stream habitat in the basin (Tchir et al. 2004). The major shortcoming of the current regulatory environment is that the Ontario Ministry of Natural Resources does not know, nor could they afford to determine, which areas of which streams are critical fish habitat for spawning, migration, or rearing. This lack of information makes it difficult to assess whether forestry operations are affecting fish populations.

Based on their review of culvert installation in North America and the example of non-compliance on the trans-Labrador highway, Gibson et al. (2005) conclude that a ban on the use of closed bottom culverts is the best option for the protection of fish habitat. New open arch culvert technology which preserves the existing stream bed, is easily installed, and is reusable, has been developed in British Columbia, and may have the potential to reduce impacts from stream crossings if adopted by the forestry industry (Hammerstedt 2004). Alternatively, in the case of roads designated for short-term use (<3 years), closed bottom culverts could be temporarily installed and then removed once the road is abandoned. Although the asscess road guidelines (OMNR 1990) state that culverts should be removed from temporary roads once the road is no longer needed, it has been common practice to leave culverts in place and simply abandon the road (OMNR 2003). Over time, culvert collapse and washout can result in high sediment input to streams and rivers. Due to concern over the impact of unmaintained water crossing on fish habitat, the Department of Fisheries and Oceans has indicated the need for remediation of abandoned water crossings in Ontario (OMNR 2003). Since the location of critical fish habitat, such as spawning areas, is unknown, water crossings of rivers and

streams should be limited to open arch culverts or bridges — structures that are unlikely to pose a barrier to migration. Culvert removal and road decommissioning following logging operations would further reduce impacts on aquatic ecosystems and provisions for requiring road decommissioning are provided in the current Forest Management Planning Manual (OMNR 2004).

3.1.3 Reducing the Effects of Forestry on Aquatic Ecosystems

A wide variety of techniques have been developed to reduce the impacts of logging on aquatic ecosystems. Primary among these is the use of riparian buffer strips, with the existence of specific guidelines for the width of buffer zones in riparian areas (OMNR 1988, 1998). Logging operations are not permitted within 3m of a water body. Recommended buffer width ranges from 30 to 90 m and increases with catchment slope. Actual buffer zone width beyond 3 m is determined on a site by site basis as part of the forestry management plan.

Maintenance of a 30 m buffer strip around streams and rivers has been shown to be effective at reducing sedimentation, erosion, and temperature impacts of clear cut logging on stream ecosystems in western North America (Murphy et al. 1986, Rashin et al. 2006). When riparian buffer zones are used in conjunction with careful planning of road construction, appropriate timing of harvesting, and well-constructed water crossings, sediment loading can be greatly reduced or eliminated in most environments (Rashin et al. 2006). On the other hand, stream buffer zones are less effective at preventing changes in water chemistry due to nutrient loading. The presence of an uncut buffer zone around a lake, for example, has not been shown to reduce the impacts of clear-cutting on lake water chemistry (Norris 1993, Steedman 2000). In general, the benefits to aquatic biota of a riparian buffer zone around lakes with surface area greater than 20 ha are not well established. Clearing of shoreline vegetation does result in increased nearshore water temperatures; however, the ecological implications require further research (Steedman et al. 2001). The impact of sedimentation of nearshore lake habitat on fish communities has likewise received little research attention. In exposed areas prone to blow-down, the resilience of a narrow buffer strip is limited, and in some cases buffer strip width may need to be 2 or 3 times wider to be effective. Following blow down, riparian buffer strips continue to act as sediment traps but no longer provide littoral zone shade or buffering of high winds. Unfortunately, the risk of blow down is highly site-specific, making it difficult to adjust buffer zone width appropriately in forestry management planning.

A second approach to minimizing the effects of logging on aquatic environments is to limit the proportion of watershed area disturbed by forestry. The OMNR is working to establish guidelines for acceptable percent disturbance of second order stream watersheds (OMNR 2002c). Effects on water quality and quantity generally require the disturbance of at least 25% of the watershed, although impacts are highly dependent on the watershed characteristics. Research suggests impacts on fish can occur at lower disturbance levels. For example, declines in bull trout abundance have been shown to occur with the clearcutting of 15% of watershed area, and declines in brook trout abundance

have been noted in selectively logged forests (Ripley et al. 2005, VanDusen et al. 2005). In general, it is thought that limiting the proportion of watershed area disturbed will minimize impacts; however, thresholds for significant impacts on aquatic environments remain to be determined. Forestry has a variety of impacts on aquatic ecosystems. Some of these impacts may be short-lived such as increased nutrient loading to lakes and rivers, or sedimentation from surface runoff; others may persist for decades, such as increased mercury concentrations, barriers to fish movement due to water crossings, and increased human access to the landscape. Likewise, while certain impacts may be mitigated by "best practices" such as reducing sedimentation by leaving vegetated buffer strips around water bodies or minimizing barriers to fish movement by building appropriate water crossings, other impacts pose substantial challenges to mitigate such as the accumulation of mercury in surface waters of logged watersheds or increased human access due to logging road networks. Overall, the consequences of all such changes to aquatic environments for fish habitats and communities vary from minimal to severe and remain poorly understood. Furthermore, the general lack of baseline information for the northern boreal on the importance of aquatic habitats for fish spawning, rearing, or migration, place important handicaps on the ability to avoid or mitigate forestry impacts. Given the variety of effects of forestry on aquatic environments, however, it is clear that logging results in not only a change in the terrestrial landscape but also a change in the streams and rivers and lakes that support abundant and diverse fish communities in northern Ontario.

3.2 Hydroelectric Dams

Hydroelectric dams alter river systems in three primary ways:
1) creation of a reservoir above the dam;
2) prevention of upstream and downstream movement of aquatic animals; and
3) alteration of the flow regime below the dam.

Jenni McDermid

Hydroelectric dams change water flows and fragment habitats by blocking fish movement.

Each of these changes to the river can have profound impacts on the aquatic ecosystem. Effects vary with the type of dam, with the magnitude of impact more a function of the engineering of the dam and the characteristics of the watershed, rather than how much power it generates. Storage or peaking dams retain spring runoff in order to produce power year round. Water storage and release requires the creation of large reservoirs and leads to significant alteration of the flow regime below the dam. Run-of-river dams do not store runoff for power production at a later date but instead rely on the natural flow regime of the river. As a result, little change in flow regime generally occurs below the dam. In general, run-of-river dams tend to have smaller reservoirs than storage dams; however, the size of the reservoir will depend on the surrounding landscape and the size of the river. Both types

of dams constitute barriers to the upstream and downstream movements of fish and other aquatic organisms (Poff and Hart 2002). All three types of impacts reviewed below occur with either type of dam; however, impacts from run-of-river dams tend to be of a lower magnitude.

3.2.1 Reservoir Creation

The creation of a reservoir has two main outcomes of relevance to resident fish populations: the loss of river habitat, and the release of mercury from the flooded land into the river ecosystem. Above the dam, a section of river habitat is transformed into lake habitat. This displaces river species such as sturgeon and brook trout, and favours lake-adapted species such as walleye and white sucker. For example, on the Groundhog River near Kapuskasing, Ontario, following construction of the Carmichael Falls dam in 1991, sturgeon were replaced by white sucker and longnose sucker in the 3 km section of river that had been transformed into a reservoir (EIP 1997). On the other hand, the newly created lake habitat may increase the population of some lacustrine species above the dam, for example walleye or northern pike. This positive effect may be counteracted by changing water levels in the reservoir which can result in the loss of spawning habitat and poor recruitment of shallow spawning species such as northern pike, walleye, and many minnow species (Cohen and Radomski 1993).

Following flooding of a reservoir, the concentration of methyl mercury in the water may increase by ten-fold or more (Kelly et al. 1997). High rates of organic matter decomposition within the reservoir result in the methylation of mercury stored in submerged soil and peat and its release into the river. Methyl mercury then makes its way into the river food web and is accumulated in the top predators of the system. Reservoirs in northern Ontario, northern Manitoba, Québec, and Labrador generally exhibit higher mercury levels than those in other provinces (Government of Canada 1996a). Intensive hydroelectric development in the Moose River Basin in northeastern Ontario has led to increased mercury concentrations in northern pike and walleye (Seyler 1997b). Significant increases in the mercury content of pike and walleye have also been observed following hydroelectric development in the Churchill River Basin of northern Manitoba, and the La Grande Complex of northern Quebec (Bodaly et al. 1984, Verdon et al. 1991). Mercury concentrations tend to peak after 3-5 years and levels in fish may persist at slightly elevated levels or return to background levels after 20 to 30 years (Verdon et al. 1991, Rosenberg et al. 1997, St Louis et al. 2004).

The sub-lethal effects of mercury on freshwater fish have received very limited research attention (Beckvar et al. 2005). The main impacts appear to be on reproduction, behaviour, and larval growth. Mercury accumulation and exposure has been shown to incur negative impacts on hatching and larval survival of walleye and fathead minnow (Latif et al. 2001, Hammerschmidt et al. 2002). Juvenile male walleye exposed to a mercury-contaminated diet displayed reduced growth and gonadal development, as well as suppressed cortisol levels (Friedmann et al. 1996). Finally, golden shiner exposed to dietary

mercury at naturally occurring levels, displayed impaired predator avoidance behaviour (Webber and Haines 2003). The implications for population dynamics and food web interactions of such sublethal effects remain unknown.

Of greater concern have been the effects of increased mercury concentrations in fish on human health. Concerns over mercury levels in Cree populations of northern Québec following hydroelectric development led to the initiation of a government program to reduce consumption of walleye and other contaminated fish species. The program was successful at reducing mercury concentrations in the population below levels of concern to human health (Dumont et al. 1998). Van Oostdam and colleagues (2005) point out, however, that a shift away from contaminated country food in Arctic populations may come at the cost of poor nutrition and increased adverse health effects, such as diabetes, as the amount of processed food in the diet increases. Mercury contamination of aquatic resources following dam construction remains a global problem. Future expansion of the hydroelectric system in Ontario will exacerbate existing problems and expose new rivers to contamination. While this impact may be transitory, lasting 20 to 40 years, it poses a significant health concern to humans and animals that rely on fish as a major food source.

3.2.2 Barriers to Migration

A second set of impacts results from the barrier to upstream and downstream migration created by dams. Preventing movement of fish through a river system affects populations in a number of ways: 1) it blocks upstream migration to spawning grounds; 2) it prevents downstream migration of juveniles to rearing areas; 3) it prevents seasonal movement between winter and summer habitats; and 4) it fragments populations. The blocking of migration to spawning grounds has been one of the most extensively studied impacts of dams on fish populations. The most famous example of this is the Columbia River Basin of the northwestern United States where hydroelectric development led to the collapse of the salmon populations (National Research Council 1996, Rosenberg et al. 1997). Barriers to migration due to hydroelectric development have also had major impacts on species such as lake sturgeon, several species of trout, and American eel by preventing upstream movement to spawning or rearing grounds (White and Knights 1997, Neraas and Spruell 2001, COSEWIC 2006, Gosset et al. 2006).

The construction of fish ladders to allow fish to bypass dams has improved the status of some populations. However, only a portion of the adult population is generally successful at migrating through the passage, and even if spawning occurs in upper reaches, a large portion of the resulting juveniles are often unable to successfully migrate back down the system (Kareiva et al. 2000). In some cases, fish populations in the lower reaches of a river where spawning habitat is lacking are supported by juvenile recruitment from upstream populations. Dams reduce recruitment to downstream populations and may eliminate certain species from downstream portions of the river. This may be the case for the lake sturgeon population above the Little Long generating station on the Mattagami River north of Kapukasing. Little Long reservoir contains

an estimated 24,000 lake sturgeon, but no juveniles have been documented and spawning was apparently unsuccessful when last surveyed approximately 10 years ago (Seyler et al. 1996). It is possible that this population was supported by recruitment from populations further upstream on the Kapuskasing, Groundhog, or Mattagami rivers; however, dams on these upper rivers have prevented downstream movement of sturgeon (Seyler 1997a).

In northern latitudes, resident fish move between summer and winter river habitats (Schlosser 1991, McKinley et al. 1998, Jaeger et al. 2005). Winter habitats are often deeper waters or instream lakes. Impediments to seasonal migration may lead to high overwinter mortality and population declines (Cunjak 1996). A further consequence of restricted movement is population fragmentation. It is well documented that genetically isolated sub-populations may be prone to extinction in the face of environmental stress (Jager et al. 2001, Neraas and Spruell 2001). Overall, interrupting fish movement will have negative impacts on most fish populations. These impacts may be temporary for some species, until they locate new suitable spawning grounds or come to a new equilibrium abundance. On the other hand, the impacts can be severe for species or populations that find themselves unable to adapt to a newly fragmented river system.

3.2.3 Flow Regime Changes

A final impact of dam construction and operation is the alteration of the natural flow regime below the dam. Flowing water is a primary structuring force of river ecosystems (Poff et al. 1997). Following dam construction, the magnitude, frequency, duration, timing, and rate of water flow is altered below the dam. This has a wide variety of impacts on downstream biota. For example, reduced peak flows in spring reduces scouring of the riverbed resulting in increased sediment accumulation. Similar to impacts from logging, sedimentation may alter food resources for fish by favouring certain aquatic insect larvae over others (Osmundson et al. 2002). Sedimentation also reduces spawning habitat for species that use gravel and cobble areas for egg deposition, and the accumulation of sediment can reduce oxygen flow to the eggs (Ligon et al. 1995). In northern Ontario, brook trout, and some minnow and darter species may be affected by such a change.

Downstream reaches of dammed rivers are often subject to rapid changes in water level. As a result, fish may become separated from the main channel in isolated pools or river branches. For example, lake sturgeon in the Mattagami River are often stranded in a diversion channel at the Little Long Generating Station when the flow is reduced to zero following the period of spring runoff (Seyler et al., 1996). Rapid reductions in water level shortly after spawning may expose spawning grounds to the air and cause egg mortality. Alternatively, release of high volumes of water during fish spawning may scour deposited eggs from the river bottom. Dams are commonly built on rapid or waterfall sections of a river, the very habitats that serve as spawning grounds for several river species in northern Ontario, such as walleye and lake sturgeon. Following dam construction, the natural habitat is replaced by the dam outflow area. Fish

will continue to spawn at the outflow of the dam; however, water fluctuations, altered substrate, and release of low oxygen waters from reservoirs may reduce spawning success. Many flow-related impacts can be mitigated by altering dam release to mimic natural flows as closely as possible. This often involves a trade-off, however, between maximizing electricity production and minimizing changes to the flow regime (Ligon et al. 1995).

Studies from the Moose River Basin in northeastern Ontario indicate manipulated flow regimes can have positive or negative effects on fish populations, depending on the species. Walleye and northern pike populations were unchanged or increased below dams on the Mattagami, Abitibi, and Groundhog rivers (Hendry and Chang 2001, Griffiths et al. 2004). In contrast, lake sturgeon populations are declining in parts of the basin due to loss or degradation of spawning grounds and other habitats, including lower food resources (EIP 1997, C. Hendry, OMNR pers. comm., Seyler 1997a, b).

3.2.4 Future Hydroelectric Development in Northern Ontario

The northern boreal forest region of Ontario contains three large, unaltered, free-flowing rivers (the Severn, Winisk, and Attawapiskat), one slightly regulated river (the Albany, which is free-flowing but has approximately 17% of its flow diverted from its headwaters) and one highly altered river system (the Moose River drainage basin). Unaltered rivers are globally rare, and particularly rare in the Boreal zone of North America (Dynesius and Nilsson 1994). Eighty-five per cent of the drainage basins contained in whole or in part in the Boreal Shield have been altered by hydroelectric development in one way or another. Seventy-seven per cent of the drainage areas contain major dams, 25% have major reservoirs, and 33% have rivers whose flow has been either augmented or diminished by water transfers (Government of Canada 1996a).

Further hydroelectric development of northern rivers in Ontario is likely, particularly given the pressure to find non-greenhouse gas emitting energy sources for the province at large, and the pressure to find local alternatives to the diesel-powered generators that currently provide most power to remote northern communities. Future hydroelectric potential identified for development by the Ontario Power Authority totals 2,200 MW. Of this, 860 MW are proposed for two sites on the Albany River north of Hearst near the confluence with the Kenogami, and 1,020 MW for sites on the lower reaches of the Mattagami, Moose, and Abitibi rivers (Ontario Power Authority 2006; Figure 3.1). Proposals for hydroelectric development on the other three northern rivers (Severn, Winisk, and Attawapiskat) are currently unlikely; however, if construction of the Northwest Ontario Transmission Line project goes ahead (proposed to carry hydroelectric power from the Conawapa Dam in Manitoba to southern Ontario) and follows a direct route from the Nelson River in Manitoba to Sudbury, some of the potential sites may lie close enough to the transmission line to make them economically viable (SNC-Lavalin 2006). The Attawapiskat River has very little hydroelectric potential with one site identified with a capacity of 105 MW. The Winisk has approximately 400 MW of

capacity located at four sites within 140 km of the river mouth. Most of this is located within Winisk River and Polar Bear Provincial Parks. Finally, the Severn watershed has four sites totalling 550 MW located in the area around Muskrat Dam (Ontario Power Authority 2005). Each of the Severn Basin sites would lie within 50 km of the proposed northwest transmission line, although the cost of connecting them to the transmission grid would be high. Aside from these high capacity sites there are at least ten sites with a capacity less than 25 MW (9 in the Severn watershed and 1 on the Winisk) that could be developed by First Nations communities for local electrical production (Ontario Power Authority 2005). Development of such run-of-river type dams are being seriously considered as a means to reduce reliance on diesel powered generators.

All of the potential future hydroelectric sites on the Albany, Attawapiskat, Winisk, and Severn are subject to the Northern River Commitment between the Government of Ontario and the First Nations communities of the region (Ontario Power Authority 2006). This commitment stipulates that there will be no hydroelectric development greater than 25 MW in the four northern watersheds. In order to develop the two proposed sites on the Albany River, Ontario will have to renegotiate the current policy on northern rivers with First Nations of the region. Additional hydroelectric development in the Moose River Basin is less constrained. The Moose River Basin Commitment states that there will be no new development north of Highway 11 without an agreed upon co-planning process between Ontario and First Nations within the area. In this case development is possible if a co-planning framework can be agreed to (Ontario Power Authority 2006).

Hydroelectric dams result in long term impacts to river ecosystems. In Ontario, lake sturgeon and brook trout are particularly sensitive to the effects of habitat fragmentation and changes in flow caused by dams. River spawning populations of cisco and lake whitefish from Hudson and James Bay may also be affected by hydroelectric development. The effects on walleye and pike appear to be mixed with some populations increasing and others suffering declines. For lake sturgeon, it is unclear whether populations can persist following dam construction. In southern rivers where dam construction occurred 70 to 100 years ago, many lake sturgeon populations have been lost entirely (Figure 2.5). As most of the dam construction in the lower Moose River Basin occurred in the mid 1960s the full effects on the resident lake sturgeon populations may not yet be evident. Beyond significant negative effects on fish populations, a second important effect of hydroelectric development is the associated increase in mercury concentrations of commonly consumed fish such as walleye. For remote northern community residents who rely on fish for a significant portion of their diet, the effects of increased mercury exposure are a serious concern, particularly as evidence mounts that the developing fetus may be affected by mercury concentrations much lower than the level considered harmful to adults.

3.3 Mining

Mining operations can adversely affect the aquatic environment in several ways:

1) Release of mine effluent into lakes and rivers in the form of water pumped from the mine or used for processing the ore;
2) Storage of resulting waste rock and processing waste, referred to as mine tailings, in piles or ponds on the mine site where precipitation and processing waste water leaches metals and other contaminants into adjacent surface water and groundwater.
3) Physical alteration or destruction of aquatic habitat resulting from mine construction and operation;
4) Increased access to surrounding lakes and rivers through the construction of roads to the mining site;

Compared to forestry or hydroelectric development, mining has the potential for much greater acute and chronic environmental impacts when toxic contaminants are released into the environment. On the other hand, mining impacts tend to affect a smaller area unless multiple mines occur in the same watershed such as is currently the case in the Sudbury or Timmins area of Ontario, or mining "opens" the area facilitating other development. Further impacts, such as air and water pollution, may occur if smelters are constructed to process the ore in the vicinity of the mine.

Jamie Kneen /MiningWatch Canada

Acid mine drainage and other contaminated runoff from mine sites can destroy aquatic habitat over large areas.

3.3.1 Mine Effluent and Tailings

The primary impact of mines on aquatic ecosystems is caused by the discharge of mine effluent to surface and ground waters. Effluents are generated in two ways: 1) water used in the mining and milling process is contaminated by metals, acids, salts, fine particles, and synthetic chemicals, and 2) precipitation is contaminated when it falls on waste rock and mine tailings stored on the surface in dumps or ponds. In either case, excess water is ultimately released as mine effluent to lakes and rivers or seeps into the groundwater, and contaminants are diluted or accumulated in the receiving water body or aquifer. Untreated mine effluent is highly toxic to most living organisms. It is often acidic due to the use of hydrochloric or sulphuric acid in ore processing or — more commonly — due to the leaching of sulphate from sulphide waste rock and tailings. The acidic water running through the tailings and waste rock leaches out metals toxic to fish and other aquatic organisms such as arsenic, copper, cadmium, lead, and mercury, which are often present in the rock in high concentrations (see Bell and Donnelly 2006 for a detailed review of the chemistry and impacts of mining effluent). Water

pumped from mine shafts and open pits contains ammonia and ammonium nitrate from blasting compounds. Effluents also contain synthetic chemicals that may be toxic to aquatic organisms (de Rosemond and Liber 2004).

Well-documented impacts of treated and untreated mine effluent include: loss or reduction in the biomass of benthic algae (coal mines in Virginia; Simmons et al. 2005), reduced abundance and diversity of aquatic insects (coal mines in Virginia; Cherry et al. 2001; iron mines in Colorado; Clements 2004), lower fish abundance (a gold mine in Montana; Moore et al. 1991; a copper mine in British Columbia; Barry et al. 2000), impaired reproduction in fish (nickel mines in Ontario; Rickwood et al. 2006), and reduced survival and growth of larval and juvenile fish (a gold mine in Ontario; Leis and Fox 1996). Research has also shown that the mix of toxic metals in mine effluent may result in higher toxicity than that of any single metal (Preston et al. 2000, Clements 2004), often referred to as synergistic effects. Furthermore, cumulative biological effects of mine effluent on multiple species in the receiving waters have been shown to alter food webs and impair ecosystem function (Levings et al. 2004, Kovecses et al. 2005).

Gold mines are the most common type of mine in northern Ontario. Two processes generate most of the toxic mine effluent at these sites: 1) the use of cyanide to remove gold from the ore, and 2) the leaching of acid-generating compounds and heavy metals from waste rock and tailings. At all gold mines in Ontario, the extraction of gold from mined rock is achieved through cyanide leaching. Cyanide is used to dissolve the gold out of finely crushed rock and the gold is subsequently removed from solution most commonly by adsorption to activated carbon. The resulting tailings contain high concentrations of cyanide and heavy metals. Tailings are stored in ponds lined with a membrane and engineered to withstand environmental changes such as flooding and beaver damming of pond outlets. Some of the cyanide is recovered and reused in the extraction process but much remains in the tailings.

Cyanide is highly toxic to most organisms. Over time, cyanide will break down into cyanates, thiocyanates, chlorcyanates, ammonia, and other compounds if exposed to sunlight and air at neutral pH. All such chemicals are also toxic to aquatic life, although less toxic than cyanide (Dzombak et al. 2006). Tailings ponds pose a long term threat to aquatic ecosystems, and require perpetual monitoring and maintenance. Gold mine tailings may bring about negative impacts to aquatic ecosystems if the containment system fails and tailings are released into surface waters. This occurred, for example, in 1990 at an abandoned mine site on the Montreal River near Kirkland Lake, Ontario (Leis and Fox 1996) and also happened in Red Lake, Ontario during mining operations in 2003 (MOE 2005). In both cases fish habitat in general and walleye spawning and growth in particular were negatively affected. An industrial process exists to convert cyanide in tailings to ammonia; however, ammonia is also toxic to aquatic organisms and may reduce oxygen levels in the receiving water body. Such a process is in use at the Musselwhite Mine north of Pickle Lake where the resulting ammonia is released into an artificial wetland in order to reduce effects on the receiving stream and lake. The Government of Canada is researching new technologies for the conversion of cyanide and ammonia to

nitrate and sulphate, two relatively non-toxic forms of nitrogen and sulphur (Kapoor et al. 2004).

Acid mine drainage serves as a second source of mine effluent and can occur at mining sites where metals are extracted from sulphide ore. Since most metals are found in sulphide ore bodies, acid mine drainage is a potential problem common to most types of mines. When metal sulphides in waste rock are brought in contact with oxygen and water, as they are in waste rock dumps or tailings ponds, there is potential for a reaction process that generates sulphuric acid. The sulphuric acid subsequently dissolves metals from the waste rock creating acidic water with high concentrations of heavy metals. This solution — known as acid mine drainage — accumulates and is released into surrounding waters. Whether or not waste rock will produce acid mine drainage depends on the sulphide content of the ore and the buffering capacity of other compounds in the rock. In 1994 there was an estimated 2.6 million tonnes of acid producing or potentially acid-producing waste rock and tailings located at hundreds of sites across Canada. The estimated cost of remediation of these acid-producing sites was $2 to 5 billion (Government of Canada 1996b). Generation of acid mine drainage persists for hundreds to thousands of years depending on the characteristics and volume of waste rock. New technologies for the prevention and remediation of acid-producing mine wastes are currently under research. Existing technologies include submersion of mine wastes under water and capping of waste ponds and dumps with an air impermeable barrier. Both methods attempt to isolate the waste from oxygen to prevent the generation of sulphuric acid.

Current regulations on mine closure in Ontario require mine operators to submit a detailed remediation plan. Mine closure and reclamation measures attempt to contain in perpetuity, rather than remove, potential sources of water pollution such as tailings and waste rock. As a result, closed mines often pose a long-term pollution threat that requires perpetual monitoring. There are currently approximately 5,600 abandoned mines in Ontario (OMNDM 2007), a small number of which produce acid mine drainage and have required costly remediation and monitoring by the Province of Ontario in order to reduce long term impacts.

3.3.2 Aquatic Habitat Alteration

Mine construction and operation in areas with abundant surface waters physically destroys aquatic habitat in a prescribed area. Aquatic habitat impacts are dramatic and diverse, including everything from loss of a stream or bog to draining or infilling of an entire lake. Examples of habitat loss in Canada include the draining of a series of lakes and streams in the Northwest Territories during operation of the Ekati diamond mine (BHP Billiton 2007), the conversion of two lakes in Newfoundland into tailings ponds for a copper-lead-zinc mine (Canadian Press 2006), and the potential dewatering of approximately 2600 km^2 of muskeg and the majority of a river basin for the operation of a diamond mine near Attiwapiskat, Ontario (De Beers Canada 2004). In all cases, harmful alteration, disruption and destruction of fish habitat (HADD)

may not occur unless permitted under Section 35(2) of the federal Fisheries Act. Permission to destroy aquatic habitat is contingent upon mitigation measures that are deemed to result in "no net loss" of the productive capacity of fish habitat (Fisheries and Oceans Canada 1986). For example, the Victor diamond mine will be required to pump 22,000 m^3 of water per day from the Attawapiskat River to the upper reaches of the Nayshkootayaow River for most of the duration of mining activities and for 5 to 10 years following mine closure in order to maintain base flow in the river and preserve whitefish and brook trout habitat (De Beers Canada 2004).

Introduction of the no net loss requirement in 1986 has likely reduced the impacts of new mine development on fish production, although no quantitative evaluation has been made (Harper and Quigley 2005). Unfortunately, compliance with no net loss regulations is poor, monitoring is by and large insufficient, and information gaps mean that in over 80% of cases it is not possible to determine if mitigation was successful at achieving no net loss of productive capacity (Quigley and Harper 2006a, b).

3.3.3 Road Access

Similar to forestry or hydroelectric development, road construction for mine access increases access to rivers and lakes of the area, which may in turn lead to increased exploitation of fish populations. Access to mines in remote regions of northern Canada is commonly achieved through construction of winter roads, as is the case for the Victor diamond mine near Attawapiskat. Such temporary roads pose logistical problems and result in high costs for transporting equipment and supplies to the mine site. This may limit development of new mines. If an ore body with a long lifespan is discovered or if a number of deposits are concentrated in an area, government and industry may choose to construct a permanent road in order to encourage further development initiatives. For example, permanent roads to Red Lake and Pickle Lake, both north of 51 degrees, were originally constructed for this reason (Bevers 2007). The winter road from Pickle Lake to the Musselwhite gold mine was upgraded to an all-weather road in order to facilitate development of the mine. As significant gold or base metal deposits are discovered further north in Ontario, incentives to convert winter roads to permanent, all-weather roads will also increase, thereby increasing the attraction for other types of development and settlement.

3.3.4 Regulatory Environment and Future Mine Development

Mine effluent remains one of the most significant sources of pollution to freshwater environments. Prior to 1977 mine effluent in Canada was unregulated and released untreated to receiving waters. This had significant impacts on aquatic ecosystems including fish kills, loss of aquatic insects, and permanent contamination of lake and river sediments leading to food web alteration (Lemly 1994). Subsequent research focused on the acute lethality of mining effluents to fish. The concentration at which metals and other contaminants became lethal to fish was determined in laboratory experiments. This paved the

way for the establishment of water quality regulations and in 1977 the Metal Mining Liquid Effluent Regulations were put in place under the Fisheries Act. Impacts of mining effluent on aquatic ecosystems were subsequently reduced, although they were still significant and persistent (AQUAMIN 1996). This was largely due to combined effects of multiple contaminants, a wide variety of sub-lethal effects on fish populations that occurred at lower concentrations than assessed in lethality testing, and accumulated effects on ecosystem function (AQUAMIN 1996). In an attempt to address these shortcomings, the effluent regulations were reviewed during the 1990s and in 2002 the new Metal Mining Effluent Regulations (MMER) came into effect. Current regulations set limits on the concentration of arsenic, copper, cyanide, lead, nickel, zinc, radium-226, and total suspended solids in mining effluent. They also place limits on the pH range of the effluent. In an effort to address the problem of combined or synergistic effects of contaminants on fish, the regulation also establishes an acute lethality test that exposes rainbow trout to mine effluent for 96 hours and requires that not more than 50% of the trout die.

The MMER regulations place limits on the concentration of contaminants in the mine effluent; however, there is no regulatory limit on total loading to a water body. Thus, a mine may release 10 kilograms or 10 tonnes of copper into a lake as long as the effluent and receiving water quality regulations are met. In an effort to address accumulated ecosystem effects due to total loading, the MMER requires that mines develop and carry out an Environment Effects Monitoring program that evaluates effects on fish and benthic invertebrate populations (Dumaresq et al. 2002). This approach to monitoring mining impacts on aquatic ecosystems is unique in the world and also fraught with questions on how to effectively measure change in fish and aquatic insect populations.

The majority of gold, nickel, copper, and zinc produced in Canada comes from mines located in northern Ontario. There are currently two mines operating or in development north of the managed forest boundary in Ontario. The Musselwhite Mine, operated by Goldcorp and Kinross, is a gold mine located north of Pickle Lake, Ontario on the shores of Opapimiskan Lake, a tributary of the Attawapiskat River. The Victor Diamond Mine, operated by De Beers, is being developed along the Attawapiskat River, 90 km from the mouth of the river in James Bay. There are also several abandoned mines, of which, at least 5 have acid-producing mine tailings. Twenty to thirty percent of the money spent on mineral exploration in Canada is spent in Ontario. By far the greatest amount of exploration is for gold deposits, but there is also significant activity for base metals (copper and zinc), and for diamonds. In spite of this activity, the exploration and development of mineral resources north of the 51st parallel in Ontario is in reality limited due to the high costs of accessing the region, most of which is accessible only by helicopter or floatplane. Where winter roads exist, there is only a short window (2 to 3 months) to move equipment north.

Future mineral exploitation depends on a number of factors, including global commodity prices and the willingness of First Nations communities to accommodate this activity on their traditional use areas. Promising claims north of the 51st parallel as of this writing include several more diamond depos-

its near the community of Attawapiskat, diamonds and precious metals near Kasabonika, precious metals near the shores of Big Trout Lake, base metals in a large sulphide body at McFaulds Lake near the northeastern edge of Otoskwin-Attawapiskat Provincial Park, and further gold deposits at the Musselwhite mine north of Pickle Lake. Mineral exploitation below the 51st parallel has left behind a large number of highly contaminated sites that require expensive remediation and long term monitoring (MNDM 2007). This is partly due to poor practice in the past but also due to the fact that there is no simple solution to the problem of acid mine drainage and tailings disposal.

Mines commonly result in significant permanent destruction and contamination of aquatic ecosystems. Canadian law requires that habitat destruction be mitigated by the creation of equivalent habitat; however, after 20 years of implementation and enforcement there are insufficient data to determine if the law has been effective at preventing negative impacts on fish populations. Likewise, it is too early to determine if the new Metal Mining Effluent Regulations and the addition of Environmental Effects Monitoring will reduce the future impacts of mines on aquatic ecosystems. Certainly, the shift to sub-lethal effects monitoring, if successful, should alert government and mine operators of impacts to aquatic environments and allow for immediate feedback into mine management and effects monitoring procedures (Walker et al. 2003). Regardless of the regulatory environment, mining will always involve a trade-off between economic development and environmental damage and contamination. Northern communities will need to determine what level of long-term risk they are willing to accept in order to benefit from the relatively short-term economic benefits of mine development. The goal will be to avoid the legacy of contaminated sites mining has left in the southern parts of Ontario as mining moves northward.

3.4 Road Access and Recreational Fishing

Three effects follow the creation of new road networks:
1) recreational fishing may lead to overharvesting and declining fish populations;
2) stocking may be used to increase angler success with potential impacts on native populations; and
3) increased access may reduce the variety of fishing experiences offered by the tourism industry.

Bruce Petersen

Lakes accessible by logging or other resource roads may come under intense recreational fishing pressure.

The extension of roads into formerly remote areas is an effect common to all types of resource development with potential impacts on the environment and biological diversity. Forestry, hydroelectricity, and mining, for example, all create permanent roads for transportation of equipment and resources. Forestry is unique in that it also creates a large network of logging roads that extends access to all corners of the harvested area. Although many logging roads are constructed to be temporary in nature, they are often kept open after the completion of forestry operations

to accommodate the needs of recreational user groups (McKercher 1992, Hunt et al. 2000, OMNR 2003). Furthermore, the popularity of all-terrain vehicles and snowmobiles coupled with the use of inexpensive Geographic Positioning Systems means logging roads remain an easy access route long after decommissioning or abandonment. The result is an extension of the human footprint and associated impacts (Sanderson et al. 2002). For aquatic ecosystems, recreational fishing is a major component of this human footprint.

3.4.1 Overharvest Potential

The status of sport fish populations across the province of Ontario ranges from collapsed to pristine (Lester et al. 2003). Although far northern Ontario has a history of commercial fisheries (see "Transition from Commercial to Recreational Fishing in Northern Ontario" on page 71), the predominant mode of fisheries in the region is recreational. Fishing pressure can be exerted on a sport fish population from a variety of types of access, through road access fishing, fly-in fishing, and winter ice fishing. All three types of recreational fishing can exert high pressure on fish populations, capable of causing significant population declines. Three factors play a dominant role in determining the status of sport fisheries across the province: ease of access, distance from human settlement, and regional population density (Post et al. 2002). Consequently, sport fishing quality generally declines from the northwest to the southeast of Ontario. For example, the average number of walleye per monitoring net declines from 10.7 in the northwest, to 6.4 in the northeast, to 2.8 in the southern region of Ontario (OMNR 2005c).

Restricted access is the only management tool known to be successful at maintaining high quality sport fisheries, defined as fish populations with large mean size and high catch per unit effort (Cox and Walters 2002). By limiting recreational fishing to certain times of the year and restricting the number of fish allowed per person per day, the Ontario Ministry of Natural Resources attempts to indirectly limit the total harvest from any particular lake or river. Because there are no restrictions on the total number of anglers per water body, however, fish population status is primarily determined by the number of anglers rather than the regulatory regime (Lester et al. 2003, Sullivan 2003). Consequently, the vast majority of high-quality fishing opportunities in Ontario are a direct result of the difficulty in accessing the water body. Only three lakes in Ontario have government-regulated, restricted-access fisheries (Lester et al. 2003). As road networks expand and human populations increase, the extent to which remoteness will serve to maintain quality fishing opportunities will decline and limited-access fisheries will likely become a necessary management tool.

The impacts of increased recreational fishing on fish populations and aquatic ecosystems are diverse and dependant upon the intensity of exploitation (Lewin et al. 2006). The initial impact is commonly a truncation of the age or size range as the larger, older fish are removed from the system. This level of exploitation is referred to as *growth overfishing* and commonly results in a population dominated by a large number of small individuals. This occurs as reductions

in the density of adult fish reduce competition and/or predation between large and small individuals, resulting in increased survival and growth of juveniles, while continued fishing pressure prevents the survival of juvenile fish to large sizes. A well-documented example of this phenomenon is the lake trout sport fishery in Squeers Lake, near Thunder Bay, Ontario. Since 1985 this fishery has been managed as a limited access, 10 day winter fishery. Exploitation during the first 10 years was maintained at or below the estimated sustainable yield of 2 kg per ha per year. Catch rate remained relatively constant over the 10 years; however, mean size of harvested lake trout declined and the fishery resulted in a 66% decline in the number of large bodied (> 35.9 cm) lake trout (from ~11000 to ~3700 fish) (Fruetel 1998). Similar patterns have been documented for walleye in northern Alberta where fishing pressure has severely reduced the mean age and length of fish in 80% of walleye populations (Sullivan 2003). Ice-fishing appears to have particularly strong effects due to the use of multiple lines and the high catch rates of species such as walleye, lake trout and brook trout during winter. Gunn and Sein (2000) documented a 75% decline in lake trout biomass following construction of a logging road to within a few kilometers of a lake. The majority of the lake trout were removed by ice-fishing over a period of two months.

At higher exploitation levels, removal of the majority of large, mature fish can have negative consequences for the long-term persistence of a population. Because many reproductive traits correlate with fish size (e.g., large females tend to have more and larger eggs), loss of large adults can lead to reduced reproductive capacity of the population over time (Aday et al. 2002). Populations can also be compromised if the number of spawning fish is reduced below the level necessary for successful juvenile recruitment and population growth. This level of exploitation is referred to as *recruitment overfishing* and may result in the collapse of the population to a very low density.

Finally, the removal of a significant portion of the biomass of one fish species may lead to changes in the abundance of other aquatic organisms, thereby altering the aquatic food web and favouring the dominance of alternative species. Termed *ecosystem overfishing* (Pauly 1988), this phenomenon has not been well-documented for freshwater fisheries; however, there is some evidence that severe overfishing of walleye in northern Alberta has led to the dominance of minnow species that prey on walleye eggs, thereby preventing recovery of walleye stocks (Post et al. 2002).

If high fishing pressure persists, evolutionary changes may also occur (Conover et al. 2005). Over time, angling selects for slower growth and earlier age at maturity by increasing mortality of fast growing individuals. Evidence for evolutionary change in sport fishes has been found in exploited populations of northern pike, brook trout, and bluegill sunfish (Diana 1983, Drake et al. 1997, Magnan et al. 2005).

Without careful measurements, the changes described above can take place unbeknownst to anglers or other users of a water body. Fishing quality, therefore, may be perceived to be unchanged over time because changes in quantity or body size occur at a rate that escapes detection. In particular, the initial effect of a change in average body size can occur without changes in quantity,

the latter of which is likely to be more obvious to anglers (Sullivan 2003). Change over time in the human perception of what is good fishing quality is referred to as the "shifting baseline syndrome." This phenomenon — coined by Pauly (1995) in reference to ocean fisheries — refers to the loss of a historical sense of change whereby each generation tends to redefine the pre-harvest natural conditions. Lake populations are at particular risk of this when baseline conditions (i.e., before human exploitation) are not known or no longer present on the landscape. In such situations, efforts to rehabilitate collapsed populations may be hindered by public perception of full recovery long before a self-sustaining population size has been attained (Sullivan 2003).

3.4.2 Stocking

Fisheries management response to declining fish abundance often exacerbates population and genetic changes by resorting to stocking of hatchery-reared fish in order to maintain fishing quality (Evans and Willox 1991, Ryman et al. 1995). In Ontario 60% of lake trout populations in the southeast of the province are maintained through stocking (Evans and Willox 1991). The number of lake trout, brook trout, and walleye stocked annually in Ontario waters by the Ministry of Natural Resources is 4.5 million, 1.3 million, and 75,000 respectively (Kerr 2006). A large number of walleye are also stocked by local fish and wildlife clubs across the province. Fish stocking can foster unrealistic expectations by anglers of potential fish yields from inland waters. This in turn may promote high harvest rates and increase fishing pressure on native and introduced stocks. Intensive stocking of hatchery-reared fish can dilute native stocks which are often locally adapted to specific lake conditions, leading to decreased fitness and potential loss of the native population (Evans and Willox 1991). Stocking on top of native populations, while discouraged by the Ontario government, still occurs across the province (Kerr 2006). On the other hand, stocking of lakes that did not previously support sport fish populations, can be used to reduce pressure on native populations. The Government of Ontario stocks brook trout in hundreds of lakes across the province that lack native populations in order to provide alternative fishing opportunities for anglers, with the goal of preserving the quality of sport fisheries as the number of anglers increases.

3.4.3 Access and Fishing Quality

There is an inherent trade-off between expansion of road networks and the loss of high quality fishing opportunities. This is particularly evident in Ontario, where some remote outfitters explain how they have moved or attempted to move their operations further north to less populated areas with fewer access roads to maintain the experience their guests have come to expect (T. Eastman, Nature & Outdoor Tourism Ontario, pers. comm.). The construction of new roads for resource extraction in the north has the potential to severely compromise remote (not road or train accessible) tourism operations while creating new opportunities for road-based tourism (McKercher 1992, Hunt et al. 2000). The resource-based tourism industry is a major component of the northern economy, providing 3.3% of jobs in the region, slightly less than forestry at 5.7% and mining at 4.2%. Total economic

Box 2: Transition from Commercial to Recreational Fishing in Northern Ontario

Despite the remoteness of lakes in northern Ontario, commercial fisheries were common on most large lakes between 1950 and 1980. Walleye, whitefish, and to a much lesser extent northern pike, were exploited commercially at over 300 locations during the 1950s and 60s; however, this number declined to approximately 70 lakes during the 1970s. Between 1973 and 1978, average yearly harvest was 415,676 kg with an average value of $312,305 (Carlson 1979). The harvest was made up of approximately equal portions of walleye and whitefish with northern pike making up less than 10% of the total. Walleye accounted for over 70% of the total value of the harvest. Annual harvest rates were generally below estimated maximum sustainable yields and averaged approximately 0.55 kg/ha for walleye. This fishery was not economically sustainable due to the high costs of flying the fish to market, restrictions due to mercury levels in the fish, and the decline in fish abundance in some lakes following several years of exploitation (Thompson 1981). Exploitation ended in the 1980s in most lakes.

Currently, walleye and pike are commercially exploited in approximately 8 lakes in Ontario outside the Great Lakes and Lake Nipigon, although commercial licenses are still held for over 100 lakes in the region (J. Johnson, OMNR, pers. comm.). The total landings of walleye from small inland lakes in Ontario were 23,000 kg in 2005, with 82% of the catch coming from Lake St. Joseph and Cat Lake. Thus commercial exploitation currently affects a small number of lakes in the region. With the potential for increased road access to northern watersheds, the number of commercially exploited lakes may increase; however, economic considerations will continue to limit commercial fisheries in remote lakes.

Following the initial decline in commercial fisheries in the late '60s and early '70s, there was a major expansion of the recreational fishing industry in northern Ontario. The majority of tourism facilities were established between 1970 and 1985 (Hunt et al. 2002). The high concentration of lakes containing walleye and northern pike has made northern Ontario a top destination for fly-in sport fishing. The walleye and pike recreational fishery of Ontario is unique in that approximately 66% of the catch is by anglers from outside of Canada, the majority of whom fish from the many tourism outposts operating in northern Ontario. Catch rates for walleye and pike in lakes accessible solely by floatplane are more than double that of lakes with road access, and fishermen are willing to pay over $1000 per week to access these lakes (Hunt et al. 2002). Currently most lakes large enough to land a float plane on are fished for sport.

activity is about 306 million dollars. The industry contributes $202 million in wages and $185 million in taxes to the province (Lawson and Burkhardt 2005). Approximately 25% of the resource based tourism businesses in northern Ontario are remote.

Because forestry operations in particular negatively impact the resource-based tourism industry, conflict is common between the two industries (Hinch and Butler 1993). The Ontario Ministry of Natural Resources has made an effort to address concerns by developing Management Guidelines for Forestry and Resource-Based Tourism (OMNR 2001b). This guide outlines a process and a set of tools for reducing forestry impacts on tourism operators. Access control is the primary conflict, followed by noise and visibility of forestry operations. While the guide suggests access control tools such as road decommissioning and removal of water crossings, the most common access control is a sign indicating public use of the road is prohibited. Unfortunately, compliance with posted signs is low (Henschel 2003). If remote tourism operators and pristine fish populations are to persist in Ontario, a provincial road network plan that manages for remoteness and is developed in coordination with fish and wildlife conservation objectives will need to be developed.

Increased access in an open-access fishery ultimately leads to a flattening of fishing quality characterized by smaller fish, lower catch rates, or both (Cox and Walters 2002). This transition can take anywhere from three months to decades depending on fish population size, fishing intensity, and the reproductive capacity of the species (Gunn and Sein 2000, Post et al. 2002). The outcome of increased access to lakes and rivers in northern Ontario can be surmised from the status of sport fisheries in the south. In general, increased fishing pressure will lead to declines in the abundance and mean size of walleye, northern pike, lake trout, brook trout, and lake sturgeon. Hence, development in previously roadless areas may indirectly result in a loss of abundant fish populations and high quality sport fisheries. Construction of new road networks, therefore, should take into account the provincial objectives for fish conservation and sport fisheries management. This could be achieved by designating specific lake districts to be set aside as remote access areas. The extension of road networks north of 51 degrees in Ontario will result in an expansion of human resource use into currently minimally exploited terrestrial and aquatic ecosystems. In many parts of Canada this has led to declines in wildlife populations and poses a growing challenge to resource management agencies across the country. Applying a conservation first approach to development planning in northern Ontario could greatly reduce the impacts of human resource use and allow for the persistence of biodiversity and remote recreational values on the landscape.

Box 3: Climate Change (by Jenni McDermid, WCS Research Associate)

Numerous studies have been conducted to assess and predict the consequences of climate change on freshwater habitats (lakes, rivers, streams, and wetlands) and the fish that inhabit them. Climate change has been predicted to affect freshwater bodies and fish in numerous, complex ways.

Climate change will influence (i) ice cover, (ii) water temperature profiles, (iii) total water volumes, and (iv) water quality of freshwater bodies (Schindler et al.1990, Lofgren 2002). The magnitude of these responses can differ depending on characteristics of the waterbody, such as area, depth, latitude, and stratification (Lofgren 2002). A warming of 1.8°C has taken place over the last 150 years and lake and river ice patterns have demonstrated significant trends over this time frame towards later freeze, earlier breakup and shorter duration of ice cover in the northern hemisphere (Magnuson et al. 2000), and specifically in the North American Boreal Forests (Benson et al. 2001).

Lakes in temperate climates generally undergo a process called thermal stratification as summer approaches. As air temperature increases, the surface waters warm whereas the bottom layer of water remains relatively cool. These two layers are separated by the thermocline — the transition layer between the mixed water layer near the surface and the deeper colder water layer. During the summer the surface waters reach their maximum depth and stratification is maintained for the remainder of the summer. Surface water temperatures are generally predicted to increase with increasing air temperature (Lofgren 2002); however, the temperature response of the lake as a whole is dependent on its depth and the characteristic of thermal stratification (Gerten and Adrian 2001). Climate change may result in changes in length of seasonal stratification of lakes and the depth of thermoclines (i.e. the thickness of the surface water layer). Shallower thermocline depths have been predicted because of rapid onset of spring stratification (Robertson and Ragotzkic 1990, Snucins and Gunn 2000), whereas deepening of thermoclines has also been predicted as a consequence of warmer water and longer ice-free seasons (Schindler 2001).

Total water volumes are also expected to be affected by climate change. Warming is predicted to cause greater evaporation which is expected to exceed the increase in precipitation (Schindler 2001, Lofgren 2002). Mortsch et al (2000) estimated a drying out of watersheds leading to an approximately 1 m drop in water levels. Such a drop could result in the disappearance of wetland surface area (Schindler 2001), decreases in river flow (Schindler 2001), and ultimately decreased connectivity among waterbodies. Decreases in nutrient input and increases in water transparency are also expected to accompany climate change (Schindler et al. 1990). Such changes in nutrient input will lead to lower phytoplankton abundances (Lofgren 2002), which can have cascading effects throughout the food web.

How can these changes in the freshwater environment affect freshwater fish in boreal lake environments? Fish are directly influenced by the temperature of their environment, as it plays a role in the regulation of all physiological processes (Fry 1971). Unfortunately, the effects of climate change are less well understood for freshwater fish than for marine fishes (Casselman 2002). Freshwater fish can be grouped into 3 thermal guilds: (i) warm-water (e.g. bass, sunfish); (ii) coolwater (e.g. pike, walleye, perch); and (iii) coldwater (e.g. brook trout, whitefish, lake trout), with responses to climate change differing among them. Changes in ice cover patterns result in a lengthening of the growing season and will increase growth and productivity of all guilds if suitable thermal habitat and nutrients are available. Shuter et al. (2002) predicted an increase in yield and productivity

of walleye north of 51° as air temperature increases, yet if increases in air temperature are accompanied by changes in water quality (30% decrease in dissolved organic carbon, DOC) and a drop in water levels of 1 m, this would be sufficient to cause a small decrease in productivity. Decreases in DOC may also lead to increased UV penetration (Schindler 2001) that may negatively affect survival of eggs, fry, and photosensitive fish species (Hunter et al. 1979, Williamson et al. 1997, Huff et al. 2004). Changes in water temperature profiles will alter the availability of habitat that is near the optimal or preferred temperature of each fish species. In freshwater fishes, for example, warm-water fish prefer temperatures greater than 25°C, cool-water fish prefer temperatures of 15-25°C, and coldwater fish prefer temperatures below 15°C. Thus as climate warms the amount of thermal habitat available for warm-water species will increase, whereas for coldwater species thermal habitat will decrease. For cool-water fish the response is more difficult to predict. Magnusson et al. (1990) suggests that climate change may expand thermal habitat for cool-water fish by extending the growing season. This idea is further supported by Casselman (2002) who found that cool-water species were more negatively affected by colder than warmer temperatures.

Coldwater fish such as lake trout and brook trout will be most adversely affected by climate change, with a range recession of the native range for such species expected as water temperatures increase (Snucins and Gunn 1995 – lake trout, Meisner 1990 – brook trout, Shuter et al. 2002). In addition, with increased evaporation and decreases in thermocline depth (i.e. distance from the surface to the thermocline), subthermocline habitat available for coldwater species will decrease (Schindler 2001), leading to an overall decrease in productivity in lakes where coldwater species persist. For example, increased water temperature during spawning of lake trout resulted in decreases in survival of young (Casselman 2002). Furthermore, unstratified and shallow northern lakes may warm to greater than the optimum for coldwater species (lake trout, Schindler 2001). Coldwater species are also adversely affected by increases in both native and non-native warm-water species through competition for resources (Shuter and Meisner 1992, Vander Zanden et al. 1999). Warm-water fish species such as smallmouth bass and rockbass will benefit most by the warming of shallow waters. Productivity of warm-water species will increase as water temperatures increase by extending the growing season (Shuter et al. 2002).

Warm-water species are expected to exhibit a northward range expansion as climate warms, with invasion of warm-water species that has already taken place correlated with warm temperatures in the Great Lakes (Casselman 2002). Climate warming may accelerate the rate of spread of non-native species. A number of species are currently at the northern limit of their zoogeographic range south of 51° latitude, such as smallmouth bass, rockbass, fathead minnow, river and Iowa darters, and various *Notropis* species. These species have the potential for range expansion with climate warming. Smallmouth bass are currently held at their northern zoogeographic limit (south of 51° latitude) by climate (Shuter and Post 1990); however, it is predicted that the northern limit for this species will advance 120 km north for every degree Celsius of air warming that occurs (Shuter and Post 1990). Such northward expansion of bass not only adversely affects coldwater species through competition for food resources (Vander Zanden et al. 1999) but could also lead to the extirpation of over 20,000 cyprinid populations in Ontario (Jackson and Mandrak 2002). Climate change may also interact with overexploitation, dams, habitat destruction, and non-native species to destroy native species (Schindler 2001)

4. RECOMMENDATIONS AND INFORMATION NEEDS

This report has highlighted a growing body of research that documents a number of important negative impacts to fish populations from the principal agents of change in Ontario's northern boreal forests. Regulatory guidelines designed to reduce these potential effects have been subjected to limited testing. As a result, their effectiveness in preventing or mitigating impacts remains unclear. Therefore, as plans for the northward march of natural resource development activities continue, we cannot be secure in the knowledge that the regulatory systems will be adequate to safeguard the integrity of these intact and globally significant aquatic systems. Basic research is necessary to establish impact thresholds for potential development activities. For example, we are currently unable to determine the risk of mercury accumulation in aquatic ecosystems due to clearcutting or to establish whether lake sturgeon populations can persist following habitat fragmentation due to dams. We are likewise ill-prepared to forecast the cumulative effects that might impact fish populations and their habitats as new development projects follow others. To compound this further, the lack of baseline information on distributions and population status of many fish species across the region will make it challenging to monitor change in the face of future development projects. Finally, while some key attributes necessary for fish community conservation are known, much more site and species-specific work needs to be undertaken in order to incorporate aquatic ecosystem services into landscape planning for the region.

The following section contains recommendations for research and policy in the interest of freshwater fish conservation based on the preceding literature review. The audience for the recommendations are all those concerned about freshwater fish in northern Ontario including government, conservation organizations, academic institutions, First Nations, tourism operators, and other interested citizens.

4.1 Fish Ecology and Population Status

Incorporating fish and aquatic considerations into conservation-based planning requires knowledge of the distribution and status of fish in the region, particularly those exhibiting demonstrated vulnerability to development. Presently, a lack of baseline information hinders our ability to incorporate freshwater fish into land use planning exercises in the province and/or to consider fish in advance of development initiatives. Responsibility for population assessment in the roadless portion of Ontario is spread across four Ministry of Natural Resources Districts. District offices have very limited funds for research in remote areas and activities are focused on management of fisheries in populated areas. We make the following recommendations to improve our knowledge of fish ecology and conserve freshwater fish resources in Northern Ontario.

Gregor Beck

There is a pressing need for better information on fish populations in the northern boreal.

Research and Assessment Capacity

Establish a fisheries research and assessment unit for the roadless portion of northern Ontario. This should be a cooperative initiative that brings together federal, provincial, private, and First Nations funding and personnel. The fisheries research unit should provide training to survey, assess and enforce fishery programs. Research undertaken under the umbrella of this unit would yield fisheries and aquatic habitat information necessary for land-use planning and resource management in the unallocated portion of Ontario. Research priorities of the unit would be mapping fish distributions, collecting information on fish biology in Northern Ontario, and assessing population status as outlined in the recommendations that follow. Funding for this unit should come from a fund established to support land-use planning in Ontario's northern boreal region. Revenue could emanate from both general government revenues and diverted royalties from resource extraction. Additional monies may become available from carbon trading programs.

Lake Sturgeon

Lake sturgeon populations are declining across much of their range in Canada due to overharvesting and habitat fragmentation. There is little to no knowledge of their current status and/or distribution in the Hudson Bay drainage of northern Ontario. Because road network planning in particular takes place with little or no information on sturgeon spawning grounds or habitat use, there is a need for baseline information on the status of this species in the north.

Research Recommendations:
- Survey and map the distribution of lake sturgeon across northern Ontario. Combine local and traditional knowledge with a focused sampling program on the major rivers and their main tributaries.

- Assess the status of representative northern populations. Determine abundance, age structure, and juvenile recruitment of selected exploited and unexploited northern populations.

- Determine the degree of connectivity between sturgeon populations within large, unfragmented river systems by quantifying gene flow between river reaches isolated by natural barriers.

We have too little information on tolerable disturbance thresholds for species like sturgeon (juvenile pictured above).

Policy Recommendations:
- Incorporate lake sturgeon values into land use planning by identifying intact, unaltered (undammed) watersheds with healthy sturgeon populations and protecting these watersheds from future hydrological development.

- Incorporate lake sturgeon values in forestry planning. For example, require the use of open arch or bridge crossings to span rivers containing lake sturgeon and establish road buffer zones around sturgeon spawning sites that effectively limit access.

- Phase out commercial fishing licences for lake sturgeon in northern Ontario.

Lake Trout and Brook Trout
Lake trout and brook trout are sensitive to fishing pressure and habitat alteration. There is limited knowledge of the distribution of the two species north of the managed forest boundary. Special regulations apply to forestry operations around lake trout lakes; however, the distribution of lake trout is poorly sampled north of the 51st parallel. Forestry operations can affect brook trout populations by altering spawning and nursery habitat in small streams. Current knowledge of brook trout occurrence and habitat use in the region is poor.

Research Recommendations:
- Improve the state of knowledge of lake trout distribution north of the 51st parallel. Particular attention should be placed on sampling lakes under 200 ha which were overlooked by previous surveys.

- Map brook trout occurrence north of the 51st parallel. Combine local knowledge with targeted sampling program to establish presence or absence of brook trout in the primary streams and rivers of each tertiary watershed.

- Undertake research to quantify the effects of forestry on brook trout habitat in the northern boreal of Ontario. Determine whether stream crossings and sedimentation from road erosion affect brook trout survival and growth under current forestry practices.

Policy Recommendations:
- Plan for the retention of high quality brook trout habitat in areas reserved from development.

- Incorporate brook trout values in forestry road network planning.

- Plan road networks for the continued existence of remote lake trout lakes on the landscape in order to preserve old growth populations.

Engbretson Underwater Photography

Better life-history information for species like Walleye should be a research priority.

Walleye and Northern Pike

Walleye and northern pike exhibit marked changes in life history characteristics with changes in the length of the growing season. Such changes tend to render walleye and pike more susceptible to overfishing in northern latitudes. Latitudinal trends in life history are not well documented for Ontario north of the 51st parallel. Data are needed to validate yield estimates for northern lakes and rivers and assess the potential impacts of increased fishing pressure in lakes that are accessed by road and by air (fly-in fishing) alike.

Research Recommendation:
- Collect baseline data on the life history variation of walleye and northern pike in lakes and rivers north of the 51st parallel.

Policy Recommendation:
- Incorporate knowledge about high-quality walleye fisheries into landscape-scale land use planning, road access, and tourism development opportunities and include monitoring within an adaptive management framework following the introduction of new development projects in the area.

- Plan road networks and logging operations to maintain a variety of walleye and pike fishing opportunities, including remote, semi-remote, and drive-in.

4.2 Reducing the Impacts of Resource Extraction

Forestry, hydroelectric development, and mining may negatively affect aquatic ecosystems. Some of the possible effects require further research in order to make informed policy and planning decisions, while other effects are well established and action can be taken to reduce or prevent the impacts of development based on this knowledge.

Mercury

Mercury is a toxic chemical that accumulates in commonly consumed fish such as walleye, pike, lake trout, and sturgeon. There is strong evidence that forestry and hydroelectric development result in increased mercury concentrations in fish. As detailed in this report, the threshold for an effect of clearcutting on mercury accumulation in aquatic ecosystems of boreal forest regions remains poorly understood. Despite this lack of understanding, some methods in forestry planning assume clearing less than 25% of second order stream catchments will minimize effects on mercury concentrations in fish. In the absence of studies demonstrating otherwise, it is assumed that intensive forestry around water bodies used for subsistence fisheries may increase mercury concentrations in fish and pose a health risk to pregnant women and infants in particular.

Research Recommendation:
- Evaluate the relationship between clearcut area and mercury accumulation in lakes and rivers of northern Ontario. Current logging operations provide an opportunity for on-going research. Establishment of a monitoring program for mercury concentrations in fish before and after logging in control and logged areas would provide the information necessary to manage forestry operations for minimal impact on mercury contamination.

Policy Recommendations:
- Retain selected watersheds in an unlogged and undammed state to ensure that there are aquatic habitats that do not have mercury concentrations above the regional baseline.

- Restrict logging in the watersheds of lakes and rivers used for subsistence fisheries by northern communities until impact thresholds are well established.

Hydroelectricity

Development of small and large scale hydroelectricity is a future possibility in several rivers north of the 51st parallel. Lake sturgeon and brook trout are two species that may be negatively affected by habitat fragmentation and flow regime alteration caused by dams. Further research is needed to determine if lake sturgeon can persist in dammed rivers, and if so, the threshold of disturbance populations can tolerate. Hydroelectric development in the Moose River Basin provides an opportunity to study long term effects of river alteration on sturgeon populations. To date, data collection has been sporadic and few reports have been published in peer reviewed journals. Current capacity to predict the impacts of hydroelectric development on sturgeon populations is limited.

Research Recommendation:
- Carry out a long term, comprehensive study of lake sturgeon populations in fragmented and unfragmented rivers of the James Bay drainage.

Policy Recommendations:

- Maintain and enforce the current moratorium on hydroelectric development over 25 MW north of the 51st parallel.

- Avoid piecemeal decisions on hydroelectric development projects by undertaking a comprehensive landscape-level assessment of lake sturgeon values north of the managed forest boundaries and conferring adequate protection measures before development projects are initiated

Mining

Mining and mine tailings have long-term impacts on aquatic ecosystems due to habitat destruction and water pollution. There is a high potential for new mine development north of the 51st parallel in Ontario. Two questions relevant to fish conservation remain unanswered regarding new mine development: Are mitigation measures effective at compensating for lost fish habitat? Can acid mine drainage be prevented or controlled at remote northern mine sites?

Policy Recommendations:

- Prevent cumulative effects of mining in northern Ontario by considering new mine development in the context of comprehensive land-use planning and incorporating consideration of cumulative effects in the environmental assessment process

- Improve the methods used for the collection of fish production data prior to mine development to allow for assessment of habitat compensation measures. Assessment of fish habitat compensation is currently made difficult by poor experimental design.

- Require permanent containment of mine tailings or removal of tailings from the site prior to mine closure in order to prevent long term contaminant risk in remote locations.

Road Access and Recreational Fisheries

Increased road access leads to increased exploitation of sport fish. However, the role that distance from human settlement, degree of road access to water body, and pressure to fisheries from fly-in recreational fishing play in determining the level of exploitation is not well understood. In order to carry out integrated planning of road networks to protect recreational fishing values, an improved understanding of how roads affect resource exploitation is necessary. Increased access eliminates remote fishing opportunities and tends to homogenize fishing quality across the landscape when operating under an open access system. Restricted access fisheries have been successful at maintaining high quality fishing opportunities in Ontario and provide a tool for maintaining a diversity of fishing experiences in the face of increasing development of road networks and fishing pressure.

Research Recommendation:

- Investigate the relationship between logging road development and human resource extraction with an aim toward answering the following questions: How does increased access interact with distance from human settlement to affect fishing pressure? What distance is necessary between a road and a water body in order to prevent increased exploitation? This can be accomplished by combining research on recreational fishing with on-going logging operations. Fishing effort surveys conducted before and after logging operations would provide the data necessary to establish recreational fishing guidelines for road network planning.

Strategies to limit increased access due to resource road building must be considered to protect fisheries.

Policy Recommendations:

- Incorporate knowledge about high-quality fisheries into landscape-scale land use planning maintaining selected areas as roadless and access-free

- Establish restricted access fisheries in newly logged areas in partnership with anglers, local communities, and tourism operators.

- Plan road networks to allow for restricted watershed access by constructing single entry and exit points.

APPENDIX I: METHODS FOR MAPPING WATERSHED IMPACTS (BOX 1)

Two scores were developed to evaluate a predicted impacts assessment for each tertiary watershed. For the provincial map, 4 criteria were evaluated; population density, % of transformed land, road density and number of hydro and flood retention dams (see final thresholds below). For the northern map, 3 additional criteria were evaluated; number of pulp and paper mills, number of acid mine drainage sites, and tourism outpost density (see final thresholds below). Provincial scores ranged from 0 to 46, northern scores also ranged from 0 to 46, providing evidence that the "northern" criteria developed was in fact most relevant to the northern watersheds where scores were low on the provincial scale. Data were classified and displayed using the Natural Breaks method in ArcGIS, because it tends to reveal groupings and patterns inherent in the data. This method identifies breakpoints between classes using Jenk's optimization. Jenk's method minimizes the sum of the variance within each of the classes. The lowest score class was then manually adjusted to emphasize watersheds that are most intact (e.g. scores below 2 for the northern map, scores below 3 for the provincial map).

1. Population density
A score from 0 to 10 where every watershed with a population density >10/km^2 receives a 10. Watersheds with a population density less than 10 receive their population density value. Density is calculated on total watershed area.

2. Land Transformation
Land transformation score is the sum of the scores for recent cut, cropland, and settlement area (see table). The total surface area of water was subtracted from the watershed area to give total land area. Percent transformation was then calculated based on the total land area of the watershed.

3. Road density.
Calculated as kilometres of primary and secondary road per square kilometre of land area for each watershed (see table for scores).

4. Dams.
Number of dams per watershed. Hydroelectric dams were scored as higher impact than flood control dams (see table for scores).

Northern Ontario rankings

5. Acid mine drainage sites.
Scores based on the number of acid mine drainage (AMD) sites per watershed (see table for scores).

6. Pulp and paper mills.
Mills located directly on the Great Lakes, St. Lawrence River, or Ottawa River were excluded from the analysis. Watersheds with a pulp and paper mill present were assigned a score of 10. The next watershed immediately downstream of a watershed containing a mill was assigned a score of 5.

7. Tourism Outposts.
Outpost density was calculated based on the total surface area of water in the watershed. Watersheds with an outpost density greater than or equal to 1 outpost per km^2 of water were assigned a score of 10. Scores were linear from 0 to 1 outpost per km^2, such that a watershed with 0.5 outposts per km^2 of water are received a score of 5.

Recent Cut		Cropland		Settlement		Hydrodams		Control Dams		AMD Sites	
%	Score	%	Score	%	Score	Number	Score	Number	Score	Number	Score
0-0.9	0	0-0.9	0	0	0	0	0	0	0	0	0
1-5.9	1	1-5.9	2	0.1-2	2	1	3	1-3	1	1	2
6-10.9	2	6-15.9	4	2.1-5	4	2	5	4-6	2	2	4
11-15.9	3	16-24.9	6	5.1-10	6	3	7	7-9	3	3	6
16-19.9	4	25-49.9	8	10.1-15	8	>3	10	>9	4	4	8
>=20	5	>=50	10	>15	10					5	10

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