Climate Change and Freshwater Fish in Ontario's Far North

Workshop Summary Report
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Peterborough, ON, Canada

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Executive Summary

Climate change poses significant threats to the health and well-being of human communities and natural ecosystems, such as freshwater ecosystems. Freshwater ecosystems are among the most threatened in the world. The lakes and rivers of northern Ontario are part of the single largest area of high fish biodiversity that has experienced the least amount of human alteration in Canada. For example, five of the 12 remaining undammed and unregulated watersheds in North America occur in northern Ontario. In addition, the largest wetland in North America, the third largest in the world, makes up 25% of Ontario's land surface and receives little or no formal protection from industrial land use. These systems have important cultural and economic values for First Nations that have Constitutional and Treaty rights to harvest freshwater fish and rely on them for food and spiritual values. Natural resource extraction and development including hydro-development, mining, and new infrastructure such as roads and transmission lines are also in growing demand in the region. Even in the absence of land use changes associated with industrial development, climatic changes are affecting freshwater fish and ecosystems in northern Ontario as well as First Nation communities in the region that rely on these resources. Freshwater fish are directly affected by the temperature of their environment and can be grouped into three thermal guilds: 1) warm-water (e.g., smallmouth bass); 2) cool-water (e.g., northern pike, walleye, yellow perch); and, 3) cold-water (e.g., brook trout, lake trout, lake whitefish). Climatic changes such as warming and changes in precipitation can affect freshwater fish within these guilds in numerous and complex ways regardless of human activities, such as industrial development.

In partnership with The Kresge Foundation, Wildlife Conservation Society Canada (WCSC) brought 33 participants from provincial government ministries, First Nations communities, research organizations, and academic institutions (Appendix A) together to share and synthesize information about the potential impacts of climate change on freshwater fish. We also wanted to identify opportunities to include this information in various planning processes in three intact watersheds – Attawapiskat, Winisk, and Ekwan – in Ontario’s Far North (Appendix B). WCSC pre-selected freshwater fish as a focus for this workshop because WCSC has been conducting research on climate change impacts on freshwater fish, particularly lake trout and brook trout, in northern Ontario. WCSC narrowed the focus to three specific watersheds within Ontario’s Far North because of potential land use changes associated with mineral development in the Ring of Fire as well as new hydro-development opportunities. We used a graphic conceptual model to identify and discuss the climate and non-climate drivers affecting freshwater fish and examined a series of spatial climate models to support discussions about how changes from historical baseline (1961-1990) in annual temperature, summer maximum temperature, annual precipitation, and growing season length across the 3 watersheds would potentially impact freshwater fish. We identified a number of limitations in our conceptual and climate models, but were able to make research and monitoring recommendations as well as identify what species (e.g., lake trout), guilds (e.g., coldwater species) and watersheds may be more vulnerable in the future. Participants then discussed how and where this information could inform adaptation options and decision-making about land use and adaptation options to address projected climate change.

This report represents a first step in creating a dialogue on freshwater fish conservation in Ontario's Far North, given land use and climate change. Ultimately, we hope this report, in addition to outreach, will inform future research to fill knowledge gaps, support future vulnerability assessments by First Nations and/or government, and support efforts to identify and evaluate adaptation options for decision-makers in northern Ontario.

Workshop Goal

Share and synthesize scientific information on the vulnerabilities of fish to changing climate in the Attawapiskat, Ekwan, and Winisk watersheds and identify potential adaptation options for reducing those vulnerabilities to support planning and decision-making.

Workshop Objectives

Objective 1. Identify key climate change vulnerabilities for freshwater fish, and how those vulnerabilities vary across the three watersheds.

Objective 2. Identify potential adaptation options for reducing climate change vulnerabilities for freshwater fish and aquatic ecosystems, and how adaptation options vary across the three watersheds.

Introduction: Background Presentations[4]

The first morning started with presentations providing information on the environment, including social and economic context in Ontario's Far North, freshwater fish ecology, and the results of studies on climate change and aquatic systems in Ontario. These presentations were relevant for participant engagement in the subsequent adaptation exercise and discussions.

Introduction to Ontario's Far North and current and potential land uses[5]

Dr. Cheryl Chetkiewicz, *Associate Conservation Scientist, Wildlife Conservation Society Canada*

Key points from this presentation included an introduction to WCS Canada and an overview of the ecological and social context in Ontario's Far North as well as current and potential land use in the three watersheds.

- Wildlife Conservation Society (www.wcs.org) is the oldest environmental non-governmental organization (NGO) in North America, founded in 1897 as the New York Zoological Society. WCS Canada (WCSC) (www.wcscanada.org) was incorporated as an independent Canadian NGO in 2004. In Ontario's Far North, WCSC has focused on scientific research (applied and field-based) on caribou, wolverine, and freshwater fish with applications to policy, legislation, species management and recovery planning, community-based and regional land use planning, and environmental assessment.
- Ontario's Far North is defined by the Government of Ontario in the *Far North Act, 2010* as the region of Ontario north of the Area of Undertaking (~ 51˚N). At 452,000 km^2, the landscape comprises almost half the area of Ontario and is globally, nationally, and locally significant containing the world's largest intact tract of boreal forest, the world's second largest peatland complex, North America's largest wetlands, and six of Canada's largest rivers. The region is highly dynamic, influenced by large-scale processes such as fire, strong winds, and flooding that create diverse habitats.
- These habitats maintain terrestrial biological diversity, some of which have declined provincially and nationally, including caribou, wolverine, and lake sturgeon. The diversity of aquatic ecosystems support a variety of coldwater fish, including lake sturgeon and lake trout, and the wetlands along

[4] All presentations are available upon request. E-mail cchetkiewicz@wcs.org

[5] Note: This is a synthesis of two presentations: one on the Far North in Day 1, and a second on various non-climate stressors and land uses in the watersheds on Day 2.

the James Bay and Hudson Bay coasts provide food and staging areas along a globally significant migratory flyway for waterfowl and shorebirds.

- There are a number of ecosystem services provided by Ontario's Far North that benefit society directly and indirectly at multiple scales. Particularly important are the provisioning of fresh water, food (e.g., fish and wildlife), and First Nation cultural and spiritual values. Ecosystem services provided by peatlands, permafrost, and wetlands, include climate regulation, water quantity and quality control, and erosion controls.
- The area has a long history of human occupancy and is home to a population of about 24,000 First Nations people spread over 36 Cree, Oji-Cree and Ojibway (*Anishnawbe*) communities. Communities face a number of challenges and opportunities in addressing emerging industrial economic opportunities that affect their lands, cultural values, and in some cases treaty and Aboriginal rights while balancing traditional economies and relationships to the land.
- The economic context includes two main types of economies: traditional economies and industrial extractive economies. Traditional economies for First Nations are related to fish and wildlife use and cultural and social values associated with the land and water. There is limited information on subsistence harvest for most fisheries in the three watersheds. First Nations commercial operations for lake sturgeon remain on the upper (inland) portions of the Winisk river and lake sturgeon also are harvested for subsistence purposes in many First Nation communities (Browne 2007).
- Industrial extractive industries in portions of the three watersheds include commercial forestry, mineral exploration and mining, and hydro-development potential sites identified along the Attawapiskat and Winisk Rivers. All-weather infrastructure has become increasingly demanded by remote First Nations that currently depend on deteriorating and unpredictable winter roads for fuel, supplies, and access to services. However, Ontario's focus on all-weather roads and energy infrastructure is being planned for based on industrial development needs and priorities, particularly in the Ring of Fire. Ecotourism e.g., remote fishing, fly-in sport fisheries for walleye, northern pike, and brook trout, as well as provincially-designated protected areas are less prevalent land uses in the Far North.
- The Ring of Fire area is located 535 kilometres northeast of Thunder Bay. The area is remote, wet (on the edge of the James Bay Lowlands), with no power or road access, and is within the Far North Planning area. The Ring of Fire area is one of the most promising mineral development opportunities in Northern Ontario in perhaps a century. Current estimates suggest the potential for more than 100 years of chromite production as well as significant production of nickel, copper and

platinum. There are currently over 32,000 claim units in the area covering 5,120 km^2. There are more than 30 companies exploring in the area with exploration levels exceeding $200 M in 2011. Two companies (Cliffs Chromite Project, Noront's Eagle's Nest Multi-Metal Mine) are currently in federal and provincial environmental assessment processes.

Cheryl Chetkiewicz © WCS Canada/Andrew Male

- Impacts on freshwater fish vary with land uses and non-climate stressors are described in Browne (2007 and references within). Briefly, mining has the potential for much greater acute and chronic environmental impacts when toxic contaminants either as by-products of production (e.g., acid-bearing rock) or spills are released into the aquatic environment. Hydro-development of major waterpower sites involves flooding of peatlands and wetlands, increasing mercury in the aquatic environment, and methane and greenhouse gases in the atmosphere. Damming and fragmentation of rivers is a highly relevant for species at risk such as lake sturgeon. Industrial forestry results in two major changes to the landscape affecting aquatic habitats: altering groundwater flow and surface run-off, which can lead to the release of mercury, nutrients, dissolved organic carbon, and sediment to adjacent water bodies; and, 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. New all-weather infrastructure, particularly roads, can result in increased fishing access and exploitation of lake populations unless access management is explicitly managed and enforced. Single, multiple, and cumulative effects of land use at the watershed scale are poorly understood and assessed in Ontario's Far North.

The role of climate in shaping limnetic environments and their fish communities

Dr. Brian Shuter, *Research Scientist, Department of Ecology and Evolutionary Biology, University of Toronto and Aquatic Research and Development Section, Ontario Ministry of Natural Resources*.

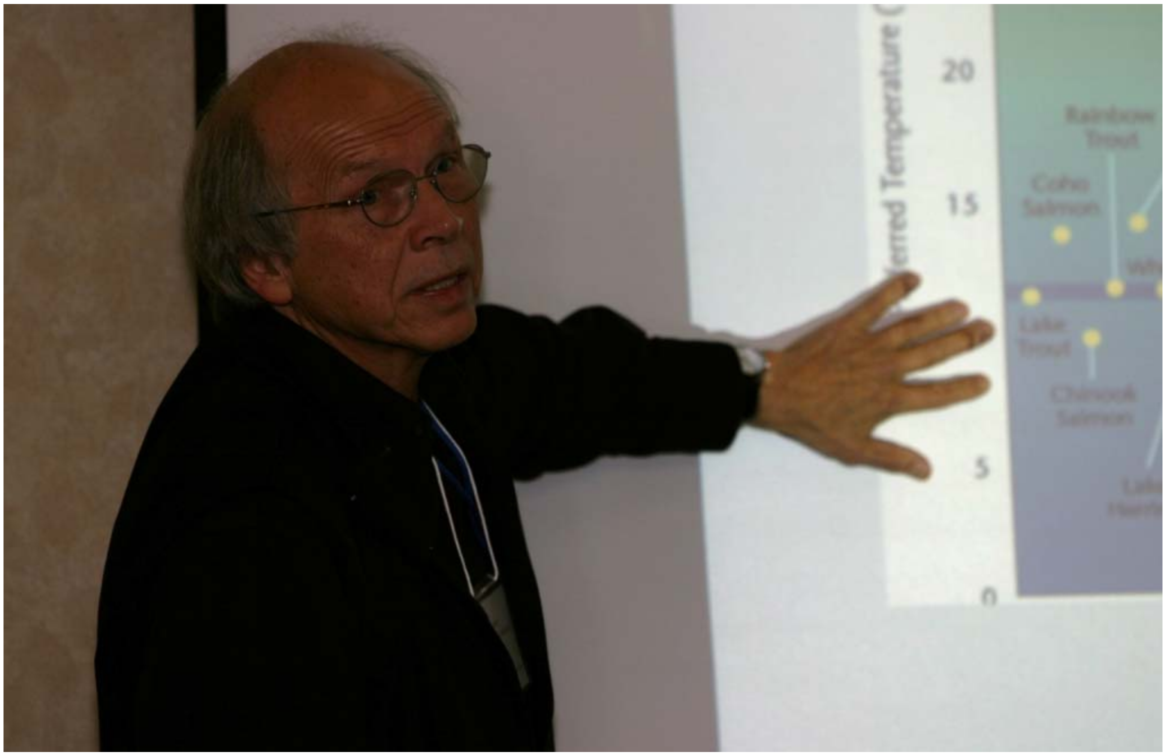
Key points from this presentation included how climate, specifically temperature and ice cover, influence the evolution and ecological adaptation of freshwater fish in North America.

- Fish species that spawn at low temperatures generate larvae that do best at low temperatures, and species that spawn at high temperatures generate larvae that do best at high temperatures.
- Fish species that grow best at low temperatures typically spawn at low temperatures, and species that grow best at high temperatures typically spawn at high temperatures.
- Spring-spawning fish spawn, hatch and grow at progressively higher optimal temperatures (typically cool- or warm-water fish). Fall-spawning fish have low optimal spawning temperatures in the fall, and also low optimal temperatures for hatching and growth in spring and fall, respectively.
- Most fish in North American lakes and rivers are categorized based on their tolerance for specific temperature ranges resulting in three temperature guilds.
    - Coldwater (e.g., lake trout, brook trout)
    - Cool-water (e.g., walleye, northern pike)
    - Warm-water (e.g., smallmouth bass)
- Spawning time in North America is affected by ice cover with the distribution of coldwater to warm-water fish following an approximate north-to-south gradient, respectively.
- Laboratory experiments on water temperature effects on fish growth, spawning, hatching, and preference can be used to identify suitable thermal habitat in lakes throughout the year. Field

research has identified temperature dynamics in different areas of lakes, or in different lakes that can address how fish may change their behavior and life cycle with a changing climate.

Brian presented the likely impacts of climate change on fish ecology and the consequences for fisheries (Shuter et al. 1998).

Climate Change Impacts on Fish Ecology	**Consequences for Fisheries**
Change in overall fish production in a particular aquatic ecosystem.	Change in sustainable harvests for all fish populations in the ecosystem.
Change in relative productivity of individual fish populations in a particular aquatic ecosystem.	Change in sustainable levels of exploitation for fish populations in the ecosystem.
Large-scale shifts in zoogeographic distribution of species.	Change in mixture of species that can be sustainably harvested within a specific region. Change in location of profitable fishing grounds.
Small-scale shifts in the spatial distribution of members of a specific population.	Change in sustainable harvest for the population. Change in efficiency of fishing gear, leading to change in sustainable levels of fishing effort .



Brian Shuter © WCS Canada/Andrew Male

Impacts of climate change and adaptation options for streams, lakes and wetlands in Ontario

Dr. Cindy Chu, *Post-doctoral Fellow, University of Toronto*

Key points from this presentation included how the distribution of freshwater fish species from different thermal guilds may change with climate change and the potential vulnerability of select species in specific Ontario watersheds.

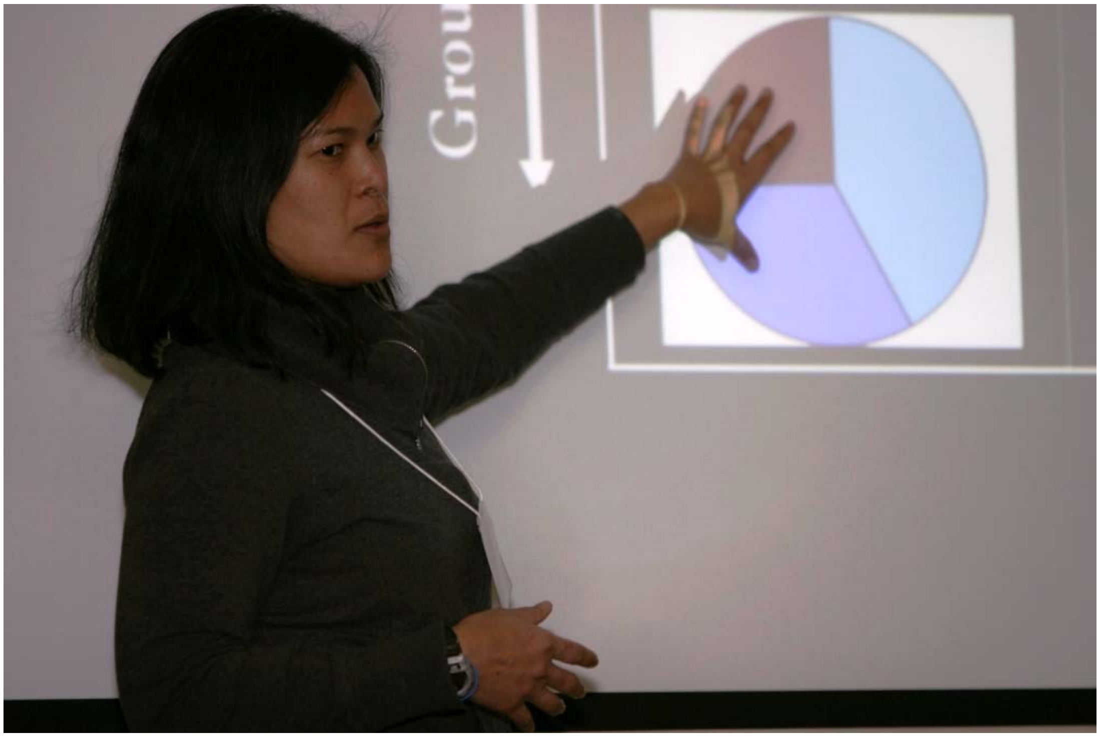
- Under different emissions scenarios (A2- highly industrialized future, B1 – lower rate and intensity of industrialization), coldwater fish across Canada were predicted to decrease, or be restricted to cooler headwaters, especially after 2070. Whereas warm-water fish were predicted to become more prevalent in these areas (Chu et al. 2005).
- In southern Ontario, these scenarios were also used to address changes in fish distribution in streams based on an analysis of air temperature and groundwater discharge, predictors of stream temperatures. Climate change scenarios suggested that watersheds with high groundwater discharge and the associated thermal diversity of fishes within those watersheds are less sensitive to

climate change than watersheds with low groundwater discharge. In southern Ontario, conserving groundwater resources will be required to lessen climate change impacts on the thermal habitat and thermal diversity of stream fishes (Chu et al. 2008).

- Ontario's Ministry of Natural Resources (OMNR) conducted a vulnerability assessment for the Lake Simcoe watershed and the Northeast Clay Belt Ecodistrict (Chu 2011, Chu and Fischer 2012). Aquatic ecosystems (e.g., lakes and streams) and wetlands were assessed. There was a reduction in coldwater stream species distributions.
- Lake indicators including maximum surface temperature increased by 0.5-1.5˚C and 4˚C by 2070 under B1 and A2, respectively. Models also predicted a 10% increase in walleye productivity, a 26% decline in suitable thermal habitat for lake trout, and an increase in the distribution range of small-mouthed bass.

Cindy summarized the impacts of climate change and identified potential adaptation options.

Impact	Adaptation options
Wetlands may be lost or decrease in quality due to drying	• Develop an accurate inventory of current wetland features on the landscape and monitor over time. • Prevent infilling and draining activities in wetlands. • Continue to regulate surface and groundwater withdrawals to ensure wetland water budgets are maintained. • Protect vulnerable wetlands.
Reduction in coldwater fish species distributions in some streams.	• Introduce or extend riparian buffers adjacent to streams to provide shading that reduces stream temperatures. • In regulated streams, consider converting dams and storm water ponds to bottom-draw systems so cooler waters drain into downstream reaches. • Limit or regulate groundwater and surface water withdrawals to maintain flow and temperatures in streams.
Smallmouth bass distribution may increase in lakes throughout the Clay Belt.	• Raise public awareness of species invasions. • Maximize fishing opportunities and socio-economic benefits. • Adjust fishing regulations such as catch limits and season lengths.
Walleye productivity may increase in Clay Belt.	• Maximize fishing opportunities and socio-economic benefits • Adjust fishing regulations such as catch limits and season lengths
Coldwater species productivity may be reduced in some systems.	• Adjust fishing regulations such as catch limits, slot size limits, season lengths, and protected areas.



Cindy Chu © WCS Canada/Andrew Male

Evidence of range shifts in Ontario freshwater fish

Dr. Karen Alofs, *Post-doctoral Fellow, University of Toronto*

Key points from this presentation included evidence for freshwater fish species range shifts, both expansions and retractions, in Ontario.

- Under various emissions scenarios, the northern range boundary of warm-water and cool-water fish are predicted to expand north [invasions] and the southern range boundary of coldwater fish will contract north [extinctions].
- There are four stages of invasion (introduction, establishment, invasion, vulnerability). Determining which sites (e.g., streams, lakes, watersheds) are more vulnerable to invasion requires information on the likelihood of these stages.
- Suitable habitat for smallmouth bass is expanding north due to climate change and predicted to be throughout most of Ontario by 2050. Smallmouth bass could enter new aquatic ecosystems either through naturally connected watersheds, stocking programs, bait bucket transfers, or other means. Their introduction will have impacts on thousands of cyprinid species (e.g., minnows).

- Based on OMNR's species presence data from 10,000 lakes in the 1970s and 1980s, and sampled again in the 2000s, there is evidence that smallmouth bass have expanded northward, but there was no evidence of range contraction by coldwater fish. There was no significant loss of lake trout from lakes invaded by smallmouth bass, however, there was a loss of brook trout (note: sample sizes were small).
- Warm- and cool-water fish have been shifting their ranges northward while coldwater fish have not shifted their range. Many bait fish show signs of contracting their southern ranges northward.
- In general, larger-bodied fish species are moving further north since body length correlates significantly with range expansion. But, species frequently purchased as bait fish are also moving further north compared to other fish. Where smallmouth bass and bait fish are introduced to the same lake, smallmouth bass out compete the bait fish.
- Eleven of 18 fish species surveyed shifted their ranges north by approximately 17.5 km per decade, a rate similar to those recorded for northward shifts by butterflies, birds, and other animals (average of 16.9 km/decade).

Karen Alofs © WCS Canada/Andrew Male

Assessing climate change vulnerabilities of fish in Ontario's Far North

Dr. Molly Cross, *Climate Change Adaptation Coordinator, Wildlife Conservation Society- North America Program*

Key points from this presentation included an introduction to key concepts and terminology. In particular, the vulnerability of a species or ecosystem to climate change is a function of the amount of *exposure* to changes in climate conditions, the level of *sensitivity* to those changes in climate, and the *adaptive capacity* of the species or ecosystem to cope with that exposure and sensitivity.

For the purposes of this workshop, 'adaptation' is defined as adjustments in ecological, social, and/or economic systems in response to observed or expected changes in climate to alleviate adverse impacts or take advantage of new opportunities. 'Adaptation strategies' are actions aimed at reducing vulnerabilities and/or taking advantage of opportunities related to climate change. There were several principles were introduced for framing responses to adaptation (Hansen et al. 2010) including:

- protecting adequate and appropriate space for species, ecosystems, or processes;
- maintaining or enhancing connectivity;
- protecting climate 'refugia';
- enhancing resilience of species and systems to climate change; and
- reducing non-climate stressors; and use adaptive management approaches.

However, understanding which of these concepts may be applicable in the three watersheds in Ontario's Far North depends to a large extent on the specific climate change issues facing the region, and the goals for conservation. It is also necessary to translate these general adaptation approaches into more specific actionable strategies tailored to the local landscape.

To assess vulnerabilities and adaptation options specific to the three focal Far North watersheds, the workshop was structured to follow key steps in two similar and complementary adaptation planning processes – the process presented in the "Practitioner's Guide to Climate Change Adaptation in Ontario's Ecosystems" (Gleeson et al. 2011) and the Adaptation for Conservation Targets (ACT) Framework (Cross et al. 2012) (Figure 1). Both processes include steps that: 1) lay out the key climate- and non-climate-related drivers influencing a target species or system, 2) develop and apply future climate scenarios to estimate future vulnerabilities and responses, and 3) develop potential adaptation options. We specifically decided not to estimate risks associated with climate change because that involves quantifying the consequences related to the occurrence of particular events, and we acknowledge that we did not have the appropriate decision-makers from either First Nations or government to estimate consequences.

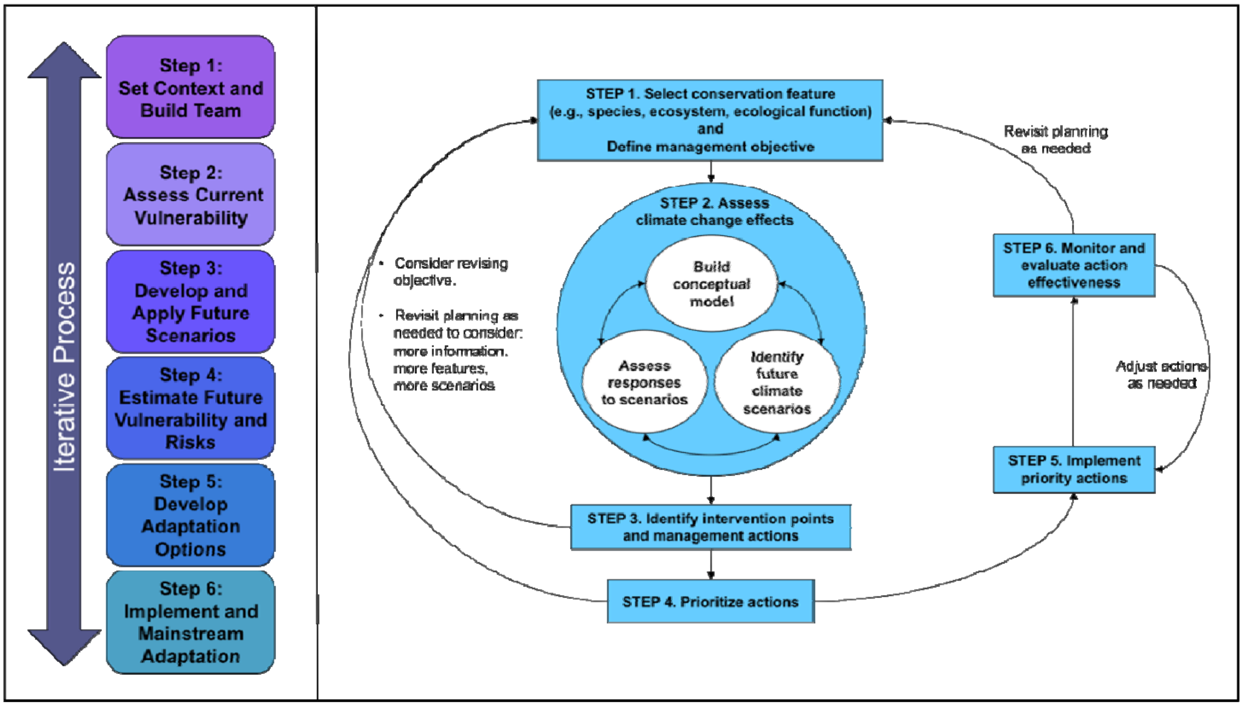


Figure 1. Adaptation planning processes that informed the structure of the workshop. Left: Modified from Gleeson et al. (2011). Right: The Adaptation for Conservation Targets (ACT) Framework (Cross et al. 2012).

Molly Cross © WCS Canada/Andrew Male

Adaptation Planning Exercise

We pre-selected freshwater fish and focused on the Attawapiskat, Ekwan and Winisk watersheds. We did not define management objectives or goals during this workshop because appropriate decision-makers within First Nations and government were not at this workshop.

Conceptual Model: Key Drivers Affecting Freshwater Fish

Graphic conceptual models are used to illustrate and understand physical, ecological, social and climate drivers and how these may change under different climate scenarios. Participants were asked to discuss and assess a conceptual model for freshwater fish describing the key climate and non-climate stressors (Figure 2).

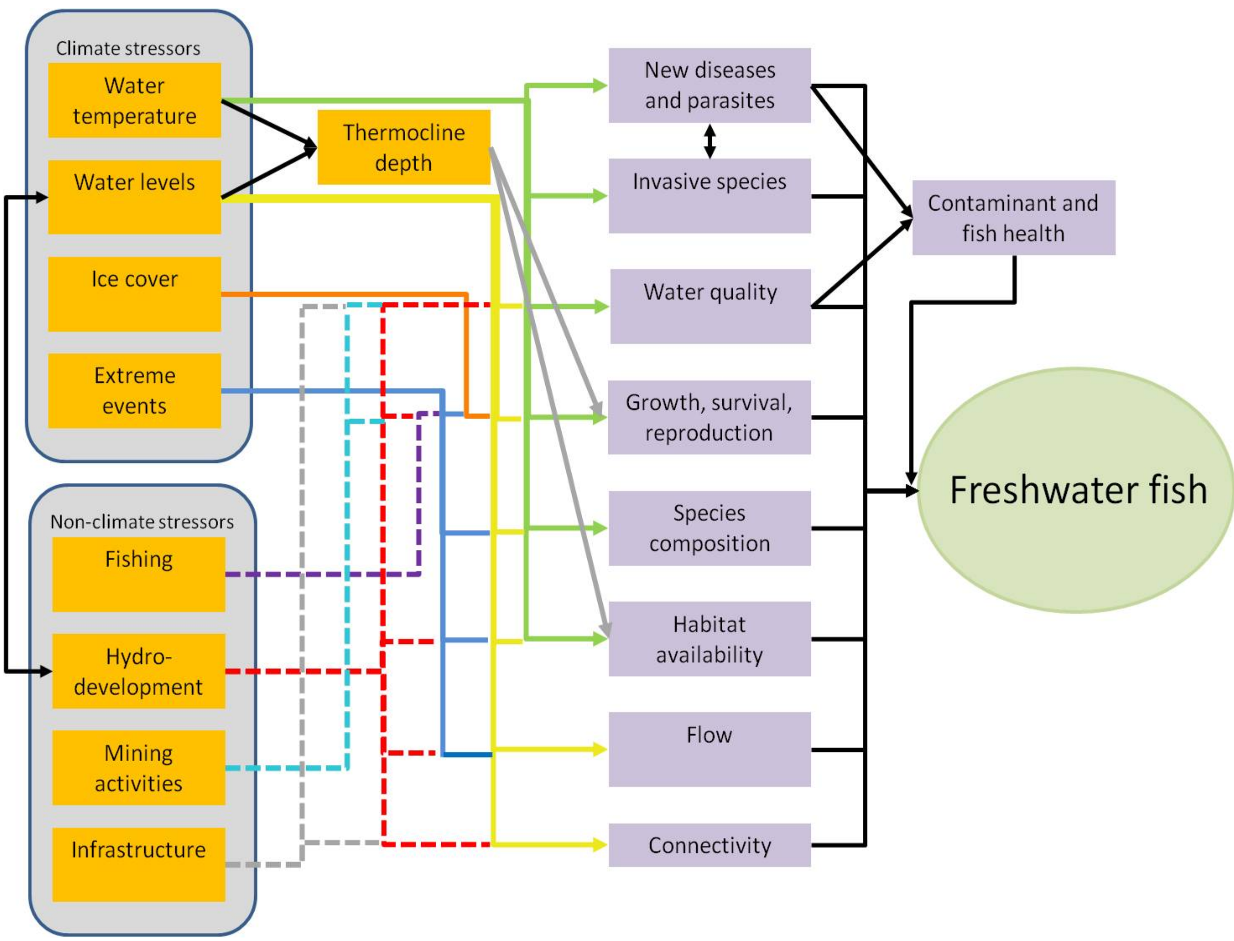


Figure 2. Graphical conceptual model of the key climate and non-climate stressors of potential influence to the Attawapiskat, Ekwan, and Winisk watersheds in Ontario's Far North.

Participants noted several additional climate drivers that could be included in the next iteration of the conceptual model:

- Permafrost
- Watershed chemistry and net water balance (changes in precipitation patterns)
- Temporal variation in temperature and precipitation
- Wind, especially extreme wind events
- Marine environment dynamics such as saltwater intrusion and the effects of sea and bay ice on inland aquatic environments
- Fire regimes (frequency/magnitude/location in Shield vs. Lowlands)

Participants reviewing the conceptual model © WCS Canada/Andrew Male

Impacts to Freshwater Fish from Climate Change

Using the conceptual model as a guide, participants considered the direct and indirect effects of a plausible scenario of future climate (2041-2070) for the three watersheds in northern Ontario.

The scenario considered during the workshop was developed by Drs. Erika Rowland and Molly Cross with data from Natural Resources Canada, Canadian Forest Service (McKenney et al. 2011). The climatic and bioclimatic variables included in the scenario were based on projections from four general circulation models (GCMs) generated using the relatively high IPCC A2 emissions scenario and downscaled to 10 km resolution.

We examined a variety of data in developing the scenario, much of which was presented at the workshop. Variables included annual temperature, annual precipitation, seasonal temperature and precipitation, maximum summer temperature, and growing season length for both the historical baseline (1961-1990) and future (2041-2070) time periods (Table 1). We narrowed the workshop scenario to three variables that captured some of the key sources of climate change exposure for freshwater fish: maximum summer temperature, total annual precipitation, and growing season length (Figure 3). The main scenario considered by participants reflected the projected changes in these variables between the historical baseline and future period, averaged across the watersheds. The changes represented increases for all variables: +3.2°C in summer maximum temperature, a 7-10% increase in total annual precipitation, and an additional 22 days in growing season length (Table 1).

Table 1. Summaries of the projections from four different global circulation models averaged across the three watersheds in Ontario's Far North developed by Dr. Erika Rowland, WCS. Model output is based on the relatively high IPCC A2 greenhouse gas emissions scenario for the period 2041-2070 and downscaled from 50 km to 10 km resolution by the Canadian Forest Service[a].

Climate Models[a,b]	Annual Mean Temperature °C	Annual Total Precipitation mm	Summer Maximum Temperature °C	Growing Season Length (# days)
Historic	*-3.1*	*581*	*18.5*	*147*
CGCM3.1	0.7	645	21	167
CSIRO-MK35	0.6	646	21.7	167
MIROC-32MR	1	613	22.5	168
NCAR-CCSM3	1.1	613	21.8	174
4-Model Average	*0.9*	*629*	*21.7*	*169*
Workshop Scenario		*+7-10%*	*+3.2°C (21.7°C)*	*+22 days*

[a]Data available upon request from the Canadian Forest Service. See McKenney et al. 2011 and http://cfs.nrcan.gc.ca/projects/3/8

[b]CGCM3.1-Canadian Centre for Climate Modelling and Analysis; CSIRO-MK35- *Commonwealth Scientific and Industrial Research Organisation* (CSIRO) Atmospheric Research, Australia; MIROC-32MR- National Institute for Environmental Studies, and Frontier Research Center for Global Change, Japan; NCAR-CCSM3-National Center for Atmospheric Research, USA-Climate System Model, Version 3.0

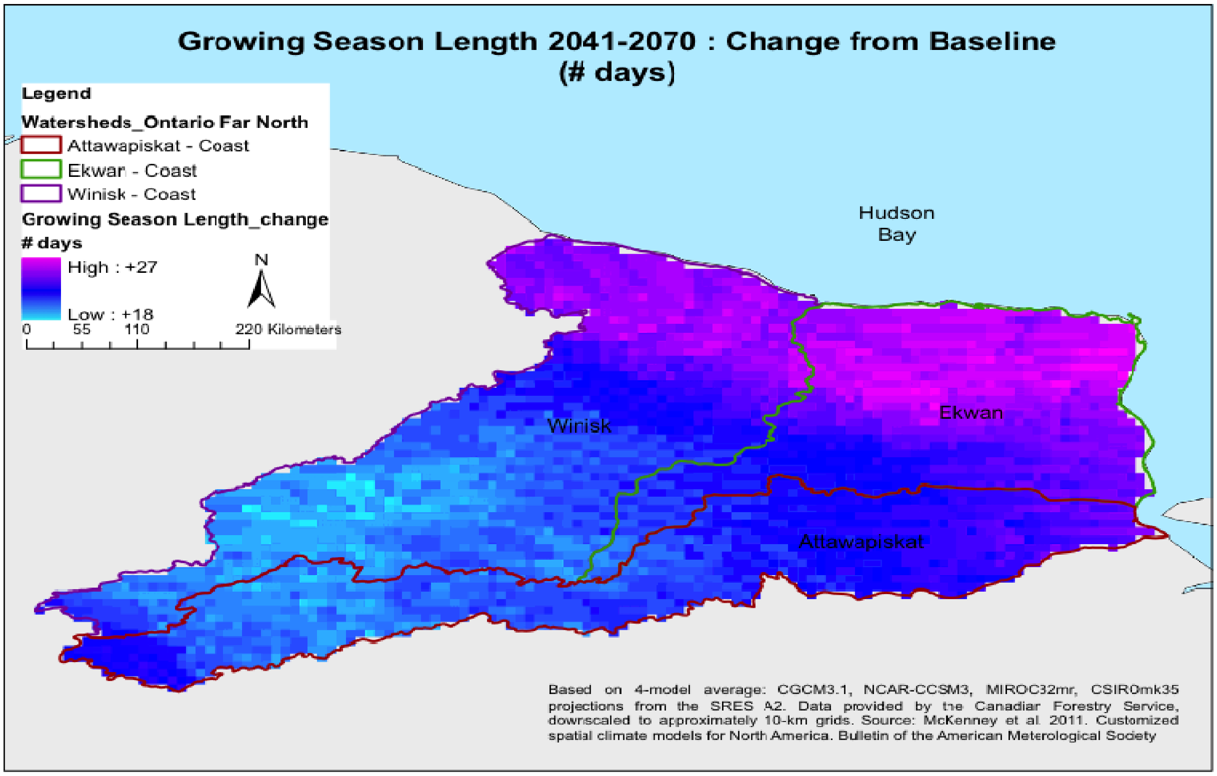


Figure 3. Map depicting the spatial heterogeneity across the watersheds of the change in growing season length between the baseline (1961-1990) and future (2041-2070).

Participants indicated that there were two general, but important limitations to what the climate change models address:

1. There are significant unknowns for important hydrological processes affected by climate in the region, such as:
   - Feedback mechanisms between freshwater and marine ecosystems in the lowlands, particularly ice dynamics. Consequently, the magnitude of future temperature change in particular is likely greater than the amount described in our scenario.
   - Dynamics in hydrological cycles between surface and groundwater.
   - Effects of slow and long-term changes associated with isostatic rebound (e.g., the Ekwan watershed is currently rising over a metre/century) on hydrological cycles and aquatic ecosystems, particularly in the lowland portion of the watersheds.
2. Seasonal variation may be more important than annual means in northern systems:
   - 80% of river flow comes from spring melt that is in turn affected by storage of water in ice during winter.

- Four calendar seasons may not be the appropriate timing for aquatics. For example, local observations suggest that six seasons [Spring: May-June; Summer: July-Aug; Fall: Sept-Oct; Freeze: Nov-Dec; Winter: Jan-Feb; Thaw: March-April] may be more appropriate.
- Seasonal or annual extremes in northern systems may be critical drivers in adaptation that are generally not captured in overall projected trends. Extremes in temperatures during winter incubation may impact egg survival and hatching success, while extreme summer temperatures may exceed physiological limits of coldwater species. Meanwhile extreme precipitation events may be more critical due to flooding, erosion, sediment mobilization, and possible mixing between watersheds.

While the intent was to develop an alternate climate scenario for the exercise, there was little variation between the four GCM model projections in the climate variables examined for the watersheds. It is widely acknowledged that the sea ice dynamics in Hudson Bay are not well accounted for in the current GCMs and, as a result, the magnitude of future temperature change may likely be greater than described in our scenario. We noted this in the workshop presentation and in subsequent discussions, but did not attempt to build an alternate scenario around it.

Potential Impacts - Climate stressors

Using the conceptual model as a guide, participants considered the direct and indirect effects of the scenario on freshwater fish guilds in the three watersheds. A summary of the discussion around anticipated impacts on freshwater fish in the three watersheds as a result of climate change under the future scenario (2041-2070) is presented in Appendix C.

Below is a summary of the potential impacts and knowledge gaps around climate stressors arising from the group discussion for the scenario:

- Coldwater fish will generally experience losses in habitat and certain coldwater species (e.g., lake trout) will be more vulnerable than other coldwater fish species.
    a. Within coldwater fish guilds, research has shown that lake trout have a more fixed physiological limit and cannot tolerate warmer temperatures whereas brook trout may have greater adaptive capacity.
    b. Coldwater species will be more vulnerable in shallow lakes and rivers and areas without groundwater input and less vulnerable in aquatic ecosystems that are deeper and have groundwater input.

    c. Cool-water species may benefit either way with limitations affected by competition and predation with warm-water species as they expand their range.
    d. Warm-water fish will benefit from increased thermal habitats in the north.

- All guilds will be equally susceptible to certain impacts due to climate change. All thermal guilds could experience salt incursion, increased mobilization of sediment, and the loss of flow and droughts.
- Vulnerability (and knowledge) varies between aquatic ecosystems on the Boreal Shield and the Hudson Bay Lowlands.
    - Our knowledge is better about freshwater fish in Shield environments since most of the previous work in these watersheds has focused on the Boreal Shield.
    - The Lowlands, given little groundwater input, are vulnerable to climate-related changes affecting water due to the shallow nature of these systems. The Lowlands are generally home to cool water species such as migratory brook trout, that may be more at risk as a result of climate change impacts on the Hudson Bay Lowlands ecozone. In the Boreal Shield ecozone, cold water species (e.g., lake trout, burbot, lake whitefish) in smaller, shallower lakes would be most vulnerable.
- The availability of thermal refugia in the lowlands e.g., Sutton River, could be moderated by groundwater and connectivity. Participants indicated that groundwater dynamics are poorly understood in the lowlands. Populations in the lowlands may be more homogenous genetically because of seasonal flooding (e.g., mixing) compared to discrete populations in lake habitats.
- The Ekwan watershed is most vulnerable to climate change. Participants suggested that the Hudson Bay Lowland ecozone will experience greater relative impacts from climate change (due to proximity to James and Hudson Bay, isostatic rebound, permafrost, etc). Since the Ekwan watershed is largely contained within the Hudson Bay Lowland ecozone, it was highlighted as being most vulnerable of the three watersheds considered.
- "Ecohydrological Zones" and watersheds may be appropriate scales for conservation and planning for freshwater fish. From the perspective of climate stressors and impacts, the variation between boreal shield and lowland aquatic systems should be considered in adaptation planning and vulnerability assessment e.g., ecohydrological zones. Inter- and intra-specific population dynamics e.g., competition, invasion and thermal niches also require a watershed scale assessment. Watersheds are also the relevant scale to assess contaminants associated with climate related stressors.

Participants discuss impacts of climate stressors on fish (from left: Brian Shuter, Nigel Lester, Lindsey Jupp, Bertha Sutherland, Michael Gatt) © WCS Canada/Andrew Male

Potential Impacts – Non-Climate stressors

Participants next considered the direct and indirect effects of the scenario on freshwater fish guilds in the three watersheds due to non-climate stressors drawing on a previous presentation on the various stressors indentified in the conceptual model (see Chetkiewicz above). A summary of the discussion around anticipated impacts on freshwater fish in the three watersheds as a result of climate change under the future scenario (2041-2070) is presented in Appendix D.

Below is a summary the group discussion for the scenario given non-climate stressors on the three watersheds:

- Generally, land uses exacerbate climate change impacts on freshwater fish.
- Participants suggested it was important to set goals/visions/objectives for the desired conditions in watersheds or ecohydrological zones.
- Pathway of effect diagrams would also be useful for helping understand and communicate how various land use scenarios and plans could affect freshwater fish guilds.

- Cumulative effects assessment needs to be better developed and applied in Ontario. Participants indicated that multiple land uses and climate change impacts warranted more proactive and effective approaches for addressing cumulative effects than currently practiced.
- The transition zone between the boreal shield and lowland ecozone is a critical area for further investigation and should be addressed in environmental assessment for the Ring of Fire. The elevation drop in the ecotone makes it important for animal migrations, lake sturgeon habitat, and has implications for potential hydro-development.
- Each land use has varying degrees of impact on the aquatic ecosystems that should be considered as single, multiple, and cumulative effects.
- Attawapiskat[6] watershed may be the most affected by land use changes given planned infrastructure and access roads associated with Ring of Fire mines, De Beers, etc. Monitoring needs to be proactive to address these upcoming developments.

Adaptation Options for Freshwater Fish

Participants brainstormed adaptation options for reducing vulnerabilities and taking advantage of opportunities related to climate change. Referring to the conceptual model, we discussed intervention points (where we may be able to influence outcomes) for climate and non-climate stressors.

Intervention Points for Climate Stressors

Before assessing intervention points, participants noted that species composition changes are inevitable. They emphasized the need to be clear about what we want to promote and prevent in the face of climate change. Because we did not establish a specific goal for these species and watersheds, participants emphasized the importance of defining whether one goal could be to try and conserve current aquatic communities and ecosystem services while also maintaining the native species at least in some places. We acknowledged that different adaptation options may be needed in different places. We also discussed the limits to addressing these options. For example, it takes time to understand what is causing species declines and identifying and attributing factors to the decline. Finally, aquatic systems may be changing faster than our adaptation options.

[6] Katawapiska is the local pronunciation of Attawapiskat and translates to "where we are going" the river between the tree lines that may become the route of access for new developments, including ocean going vessels.

A number of intervention points were suggested. We have categorized them below including:

Climate refuges

- Climate refuges are generally defined as places where suitable climate/habitat conditions for a given species, ecosystem, or process will be found in the future. They can be in-situ refugia (places that are currently suitable and that will likely remain suitable in the future) or ex-situ refugia (places that are not currently suitable but may become so in the future).
- If these kinds of refugia can be identified, we may need to consider:
  - Movement of species to access refugia
  - Creation and maintenance by rerouting groundwater
  - Decision-criteria to decide if and when to move species
- May need to accept that traditionally used native species may only occur in certain parts of the north.
- May need to consider approaches such as triage and focus on species and areas of greatest conservation concern or potential. For example, ignoring populations that aren't expected to survive as well as the ones that are currently sustainable and focus efforts on species and places that offer greater conservation gains.

Climate change mitigation

- Need to address the causes of climate change more explicitly. Attention should focus on sources of greenhouse gas emissions (natural and man-made) and include local planned or existing sources of CO_2 emissions.

Stewardship and education

- Solutions are often found at the local level (hunters, fishers, farmers). There must be attention to locally focused/community-based adaptation and determining what is important to local communities within watersheds.
- Understanding how to incorporate traditional ecological knowledge and how to increase capacity and empowerment of people within communities to address changes and impacts.
- Understanding local people's attitudes to invasive species specifically the costs and impacts of introducing water-water species into the Far North. Consider a ban on the transport of live bait into those fish camps.

- Provide information i.e., ecology, contaminant loads, etc. about new species to inform consumption and/or other uses of potential opportunities e.g., fishing.
- Educate southern Ontario decision makers and population about the north and the local perspective to also avoid imposing southern ideas of protection within First Nation territories.

Intervention Points for Land Use Stressors

Participants suggested that minimizing non-climate stressors is an important action in the face of climate change. In general, it is assumed that adaptability is more likely if there are fewer additional stressors. The discussion for this section of the workshop focused on two main areas: 1) adaptation strategies in land use planning by First Nations communities; and 2) integrating climate change more explicitly in land use sectors and various regulatory processes. Participants suggested that it was important to get all northern peoples to work together on protection of waterways, development of urban centres, and infrastructure. Ultimately, approaches that support economic development with the conservation of First Nations traditional values are needed. A list of points raised in the discussion is found in Table 2.

Table 2. Intervention points for land use stressors.

First Nations Infrastructure planning in communities • Plan urban development in advance considering an additional 100,000 people. Consider food, resource needs, waste treatment, fuel. • Expansion of transmission lines to reduce the need for diesel e.g., Attawapiskat. Infrastructure associated with industry • Access infrastructure (including for industrial users e.g., mines) needs to consider communities. Could offer benefits for other services such as education, health, electricity e.g., get off diesel. Industrial development • There is often conflict (internal, external) and tension between industrial development and the negative impacts on local communities with the benefits e.g., jobs, training. Challenge is how to balance this. • Sense that industry ultimately holds the decision-making power. Need to shift decision-making to communities. North vs. South • Cannot tell a community what they need. • Need for southern science to assist communities with mapping/monitoring to identify areas to protect for incorporation in land use plans.
Ontario processes and regulations Environmental Assessment (EA) • Integrate climate change more explicitly into EA. • Address climate change in a strategic EA. • Include climate change in cumulative effects assessment. Fish and harvest regulations • Focus regulations around species that are most vulnerable/stressed by climate change and reduce fishing pressure as an added stressor. Hydro-development • Potential opportunity for dams to act as barriers to movement of invasive species however, the threat of invasive species originates in the headwaters so there may not be potential to block downstream spread if invasives are already in the headwaters. Mining • Tailings ponds are not mitigation options for freshwater fish. There needs to be a plan before they are proposed and we should not wait for eventual engineering solutions. Agencies and processes for managing freshwater fish • Need to consider if we *can* adapt, as agencies, NGOs etc. Do we have the internal/institutional capacity to adapt? Philosophy, leadership, cross-agency/organization collaboration? Protected areas • Be proactive in addressing refugia and planned infrastructure to prioritize actions.

Baseline research

In Ontario's Far North, there is a dearth of scientific information to address changes and impacts due to climate change and land uses which supports the need for baseline research and monitoring (Far North Science Advisory Panel Report 2011[7], Marshall and Jones 2011, McGovern and Vukelich 2009). Throughout the workshop, participants identified a number of research needs (Table 3).

Table 3. Preliminary research needs.

Hydrology • What are the feedback mechanisms between freshwater and marine ecosystems in the lowlands, particularly the effects of ice dynamics on the Bays? • What are the dynamics of groundwater cycles in the lowland systems in particular? • Dynamics of flows in terms of timing, magnitude, and relationships with temperature • Dynamics of spatial and temporal changes in water temperature
Freshwater fish and habitats • What fish communities currently occur in wetland and spring bogs? • What is the adaptive capacity of species in these thermal guilds? • How will changes in connectivity with the marine environment affect anadromous fish? • How does change in scouring and ice activity in streams and rivers affect eggs and spawning habitat? • How will ice cover affect winter-kill, especially in shallow lakes? How will this dynamic be balanced with increased productivity that may decrease winter kill?
Permafrost • How does permafrost melt affect mercury levels and dissolved organic carbon?
Mapping • Mapping of permafrost needed as national dataset and maps are no longer relevant • Mapping the spatial and temporal changes in water temperature
Terrestrial habitats • Will the boreal forest expand in the Far North and how will that impact evapotranspiration?
Fish health and disease • How might increased temperatures affect health of fish from a disease perspective e.g., increase diseases and parasites? • How do other stresses affect fish health and immunity?
Extreme events • How do these impacts vary based on boreal shield vs. lowland • Alternatives for removing ice dams (engineering solutions) to prevent flooding • Will more extreme precipitation events translate to more extreme runoff events because of increased storage (more=increased frequency)?
Climate model • Net water balance (change in precipitation patterns, snow:rain). • What will temporal variation in temperature and precipitation be?

[7] http://www.mnr.gov.on.ca/en/Business/FarNorth/2ColumnSubPage/266512.html

Monitoring

Many participants supported and advocated for the need for multi-scale monitoring of numerous system components to understand impacts on freshwater fish in the three watersheds for change (Table 4). At present, there are two scales of scientific monitoring occurring in the Far North: baseline studies and monitoring programs that may be associated with current or new development projects under Ontario's environmental assessment processes; and, lakes being sampled under OMNR's broad-scale monitoring program for freshwater fish and aquatic ecosystems (Marshall and Jones 2011).

Table 4. Preliminary monitoring recommendations.

Monitoring for baseline
• Review existing systems of monitoring and protocols e.g., BSM, Alberta's Biodiveristy Monitoring Index.
• Monitoring for aquatics should include:
    o Temperature, precipitation, stream flow, water quality
    o Fish health e.g., parasites
    o Fish contaminant loads e.g., mercury
    o A diversity of fish, not just game species
• Attention to multiple scales for monitoring
    o Regional scales are most relevant for cumulative effects.

Monitoring for Industrial land uses. • Develop before and after control impact (BACI) monitoring systems for new developments. • Review Point source contamination in watersheds e.g., PCB sites. • Share information from other contaminated sites e.g., military sites, to support better monitoring programs. • Review guidelines for freshwater fish consumption with respect to mercury and other contaminants.

Next Steps

Participants were asked to share their thoughts about the workshop and possible next steps. One activity identified was the need for a centralized hub or resource gateway for Far North data and research activities with someone to periodically synthesize it. WCS will take the lead in looking at various approaches/ models for such a database.

Participants shared a number of perspectives including:

- Importance of including and focusing on indigenous knowledge and the experience of change and historical trends since communities have an historical perspective and are also seeing changes on the land.

- Importance of baseline information for planning and monitoring change.
- Sharing existing information and new information within the group and more broadly, including First Nations.
- The scientific information is necessary, but it is a challenge to bring this kind of information home to First Nation and local communities.
- Host these kinds of meetings in the community to share the information directly.
- Support for monitoring for both climate and land use stressors and impacts.
- Support for a working group.
- Need cooperation from other organizations, NGOs, and communities to help to develop solutions.

Acknowledgements

WCS, both North America and Canada Programs, is very grateful to the participants in the Climate Change and Freshwater Fish Adaptation Workshop for their thoughtful and respectful participation and time commitment. We were impressed by the interest and level of engagement for this topic and look forward to continuing to work together. We recognized that this group reflected a variety of expertise, however, we also acknowledge that a number of First Nation participants could not attend. We are hopeful that outreach associated with the report and other networks will encourage sharing and application of this information in Ontario's Far North.

We were grateful and honoured to have Rick Beaver open and close our workshop. Together with Dan Longboat, they brought clear, strong words and perspectives on change and the need to work together. Many thanks also to the First Nations participants who traveled a long way from their homes in the north to attend the meeting in Peterborough (*Miigwetch*). Our presenters shared their time and expertise during the workshop for which we are grateful and we want to thank Jerry Jenkins, Michael Sullivan, and John Magnuson who came from other parts of North America to share their expertise and lessons learned with us. A special thanks to our advisory committee: Al Douglas with OCCIAR, Brian Shuter with MNR/University of Toronto, Ken Minns emeritus Fisheries and Oceans/University of Toronto, David Pearson with Laurentian University, and Nigel Roulet with the University of Guelph, for helping create the framework and focus for the workshop and for suggesting participants to invite to the workshop. Many thanks to WCS Canada's Kaia Tombak for her help in organizing the logistics for the workshop and taking notes during the workshop along with Sarah Nienhuis. We are also grateful to Andrew Male for attending the workshop and taking photographs. We thank all the participants for attending and for your help in addressing climate change in Ontario's Far North; we are grateful for your commitment and appreciate all you do in the region. Finally, we are grateful to the W. Garfield Weston Foundation (C. Chetkiewicz, J. McDermid) and The Kresge Foundation for generously funding WCS' climate change work in North America and supporting both this workshop and WCS Canada's efforts with First Nations involved in climate change adaptation planning.

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APPENDIX A. Workshop Participants

Organization	Name
Mushkegowuk Environmental Research Centre (MERC)	Alex Litvinov
Alberta Environment and Sustainable Resource Development	Michael Sullivan
Alderville First Nation	Rick Beaver (Elder)
Aroland First Nation	Louie Mendowegan
Constance Lake First Nation	Bertha Sutherland
Eabametoong First Nation	Xavier Sagutch
Fort Albany First Nation	Michael Sutherland
Laurentian University	David Pearson Bill Keller Josef MacLeod John Gunn
Marten Falls First Nation	Jack Moonias
Matawa First Nations Management	Lindsey Jupp
Nibinamik First Nation	Tommy Yellowhead
Ontario Centre for Climate Impacts and Adaptation Resources (OCCIAR)	Allan Douglas
Ontario's Ministry of Environment	Ed Snucins
Ontario's Ministry of Natural Resources	Michael Gatt Nick Jones Nigel Lester Paul Gray Paul Sampson Bob Metcalfe Scott MacRitchie Steve McGovern
Trent University	Dan Longboat Mohammed Alshamlih
University of Madison-Wisconsin	John Magnuson
University of Toronto	Cindy Chu Brian Shuter Don Jackson Karen Alofs
WCS Canada	Cheryl Chetkiewicz Jenni McDermid Kaia Tombak Andrew Male Sarah Nienhuis
WCS North America Program (Climate Change)	Molly Cross
WCS North America Program (Adirondacks)	Jerry Jenkins

APPENDIX B. Workshop Agenda

Agenda

Climate Change and Freshwater Fish in Ontario's Far North

December 12-13, 2012

Holiday Inn Peterborough, Ontario

Workshop Goal:

Sharing and synthesizing scientific information on the vulnerabilities of fish to changing climate in the Attawapiskat, Ekwan, and Winisk watersheds and identifying potential **adaptation*** options for reducing those vulnerabilities to support decision-making.

Workshop Objectives:

Objective 1. Identify key climate change vulnerabilities for freshwater fish, and how those vulnerabilities vary across the 3 watersheds.

Objective 2. Identify potential adaptation options for reducing climate change vulnerabilities for freshwater fish and aquatic ecosystems, and how adaptation options vary across the 3 watersheds.

***Adaptation** to climate change is defined here as adjustments in ecological, social, and/or economic systems in response to observed or expected changes in climate to alleviate adverse impacts or take advantage of new opportunities.

Wednesday December 12

8:00—9:00 Continental Breakfast *(provided)*

9:00–9:15 Blessing and Opening Ceremony

9:15—9:30 Welcome and Introductions

- Jenni McDermid, *Wildlife Conservation Society-Canada*

9:30–10:00 The Role of Climate in Shaping Limnetic Environments and Their Fish Communities

- Brian Shuter, *Research Scientist, Department of Ecology and Evolutionary Biology, University of Toronto, & Aquatic Research and Development Section, Ontario Ministry of Natural Resources*

10:00–10:30 Impacts of climate change and adaptation options for streams, lakes and wetlands in Ontario

- Cindy Chu, *Post-doctoral Fellow, University of Toronto*

10:30–11:00 Break

11:00—11:30 Evidence of range shifts in Ontario freshwater fish

- Karen Alofs, *Post-doctoral Fellow, University of Toronto*

11:30—12:00 Introduction to Far North

- Cheryl Chetkiewicz, *Wildlife Conservation Society-Canada*

12:00–1:00 Lunch *(provided)*

1:00—1:30 Introduction to Afternoon Activities and Future Climate Scenarios

- Molly Cross and Erika Rowland, *Wildlife Conservation Society—North America Program*

1:30-2:00 Conceptual model presentation and discussion – Jenni McDermid, *Wildlife Conservation Society-Canada*

2:00–3:15 Facilitated Adaptation Exercise – Molly Cross and Erika Rowland, *Wildlife Conservation Society—North America Program*

- Climate impacts on fish given future climate scenarios

3:15-3:30 Break

3:30-5:00 Facilitated Adaptation Exercise cont.

Thursday December 13

8:00—9:00	Continental Breakfast *(provided)*
9:00–10:30	Facilitated Adaptation Exercise – Molly Cross and Erika Rowland, *Wildlife Conservation Society – North America Program* • Identifying adaptation strategies for reducing climate change vulnerabilities of fish in the Far North [in the absence of changes in land use]
10:30 – 10:45	Break
10:45 – 11:30	Facilitated Adaptation Exercise cont.
11:30 – 12:00	Current and potential industrial land use in the Far North – Cheryl Chetkiewicz, *Wildlife Conservation Society-Canada*
12:00 – 1:00	Lunch *(provided)*
1:00 –2:00	Complete Adaptation Exercise • Discuss whether/how future land use changes might affect adaptation options for reducing climate change vulnerabilities. • Summarize research and monitoring needs to inform understanding of vulnerabilities and adaptation options
2:00 – 2:15	Break
2:15 - 3:30	Identify next steps and processes this exercise can inform - Cheryl Chetkiewicz and Jenni McDermid, *Wildlife Conservation Society-Canada*
3:30	Closing Ceremony

APPENDIX C. Climate Change Impacts due to Climate Stressors on freshwater fish in Ontario's Far North (Attawapiskat-Coast watershed).

Key Climate-Influenced Drivers/Effects	Observed & Predicted Climate Change Impact
Water levels	• Complicated because there are drivers that may increase water levels and others that may decrease water levels. • Increased precipitation but also increased temperatures (and evaporative loss) → net drying and lower water levels. • Could be some increases in lake effect snow (localized to areas closest to the Bay?) resulting in increase moisture inputs. • Melting permafrost could lead to increased water inputs to lakes and rivers. • May be affected by isostatic rebound. • Increased rain-to-snow ratio.
Ice cover	• Later ice-on in the Fall and earlier ice-off in the spring, therefore shorter duration of ice cover. • Thinner ice cover. • Changes in frequency of ice jams?
Extreme events	• More frequent drought. • More frequent heavy rainfall events (even if total amount of precipitation is not very different). • Drought periods mixed with heavy rainfall events.
Growth/survival/reproduction	• Fish kills due to thermal stress (brook trout, suckers in Sutton River plus other coastal rivers) • Delayed spawning due to warm temperatures (brook trout in Sutton and Attawapiskat Rivers). • Low flows reduce spawning habitat for sturgeon. • Fall shoal spawning negatively affected by freezing and drying of eggs as water levels decrease. • RESEARCH: how will changes in connectivity with the Bay affect anadromous fish? Decreased connectivity may decrease growth, decrease reproduction, but increase survival? Will having less access to oceans affect their overall fitness? • RESEARCH: Winter-kill more likely in shallow lakes? Decreased ice cover may increase winter-kill but increased productivity may decrease winter-kill? How will snow affect over winter survival? • Increased productivity (warmer, longer growing season) may lead to higher survival and growth of forage fish.

	• Higher growth of game species with more abundant forage and longer growing season. • Increased methylated mercury with higher productivity? Higher organic matter may increase the bioaccumulation of mercury, but greater growth might dilute mercury concentrations. Not sure what will be the net effect. • Increased water temperature may lead to increased overwinter survival of small mouth bass due to increased resources and increased growth [except where winter kill events lead to mortality]. • Phenological changes – egg maturation geared toward photoperiod is mismatched to temperature (e.g., white suckers). Changes in flow rates and water/snow levels can also affect phenology.
Water quality	• Warmer temperatures increase biogeochemical cycling (high possibility) • Increased rain/drought events lead to more dynamic water quality (likely) • Increase dissolved organic carbon (DOC) particularly in areas where loss of permafrost, also in the Shield (likely). • Increase biological oxygen demand (BOD) and lower DO with increased temperatures (likely). • RESEARCH: As permafrost melts, it will physically release mercury, but not clear if will get methylated. • Increased sedimentation, possibly stored in lakes. • Permafrost melt along the lake shorelines could lead to more turbid systems. • Observed trend: increased DOC, lakes getting darker due to increased decomposition. • Data needs: grab samples for all three watersheds, continuous monitoring (temp, DO, pH, etc.) where possible. • Increased productivity, lower transparency, DO depletion, increased phytoplankton, and other issues associated with increased phytoplankton. • Increased salinity due to increased evaporation in inland lakes and increased tidal intrusion in coastal systems. • Stagnation in rivers with lower flows.
Habitat availability	• Generally increases in warm and cool water habitat as temperatures warm. • Some loss of cold water habitat as temperatures warm, but in some places that are temperature-constrained might see increases in availability of cold water habitat and growth of cold water species could be improved in shoulder seasons. • Changes in competition for habitat resulting from changing species composition (e.g., cool water habitat may increase but those species may be outcompeted by warm water species). • Potential for thermal refugia in lakes (at greater depths), and streams and potholes (e.g., those with significant groundwater inputs and connectivity to colder water tributaries). • Spawning habitat in streams – shifts in sediments and changes in scouring may affect nesting and

	smother eggs. • Decreased water levels may result in perched tributaries. • Changes in flows can lead to physical changes (e.g., watersheds redesign and destruction). • Less wetted perimeter • Changes in riparian connectivity (not sure if less or more).
Species composition	• Increase of 3.6C is huge for water temperatures, which will greatly influence the distribution of thermal habitat types (e.g., cold, wool, warm). • Likely to see warm water species invading Shield lakes • Deep lakes on the Shields provide thermal refugia for cold water guild which can persist there and possibly even expand. • But lowlands is isothermal, shallow, brown water with less opportunities for cold water refugia (although it is unknown how much groundwater inputs may buffer those effects) • Species composition in lowland lakes like the change the most – some losses of species but also some gains (so perhaps not much change in total diversity). • Need to account for temperature variability (i.e., mean of 3.6C but some years may have summer temperatures 6-8C greater). • Rate at which we lose species may be greater than the rate at which we gain species via natural connectivity (although varies by species). • Floods in the lowlands could potentially move species across watersheds.
Connectivity	• Coldwater fish move to deeper water if possible • Possibly other impacts of changing connectivity e.g., flow of contaminants from lake to lake (or Musselwhite mine contaminants going from Pipestone to Winisk). • Spring events – runoff from South to North • Ground water may buffer changes in connectivity • May affect local adaptation of fish populations by changing the gene pool and changing metapopulation connections • Changes in seasonal accessibility of areas for spawning, thermal refugia, anadromy • Affects ability to re-establish populations after extreme weather events (if no connections with source populations) • Facilitate movement of invasive species • Some areas may become less connected, some more connected, depends on: -Permafrost (loss, reshaping of drainages) -Extreme precipitation

	-Isostatic rebound (changes drainage) • Important over many time scales (seasonal, annual, decadal, geological) • Changing cues for migration
Disease/Parasites/Invasives	• Possibly seeing some changes in parasites now (e.g., on whitefish) • Temperature increases may lead to increased rate of proliferation by parasites and disease vectors (many do better in warmer temperatures) and this higher abundance in lakes that harbour them may in turn increase the probability of the spread of these parasites to other lakes (because any fish or other parasite carriers, such as some birds, that transfer between lakes are more likely to carry them if they are higher in abundance). (high confidence) • Temperature increases may also lead to increased suitability of lakes to invasive species, particularly coming from the South, that are better adapted to warmer temperatures than native species. • Increased precipitation may cause flooding, which may increase spread (likely). • Environmental stress may reduce immune capacity of many species to fight off diseases and parasites (high confidence). • Habitat may become more suitable for the establishment of warm water invasives • Asynchrony in native phenologies may provide opportunities for invasive species establishment • Changes in human access (e.g., less ice cover may allow more ships from the sea to come in to the bay and may bring invasive species, parasites and diseases).
River flows	• Less water volume (high confidence). Variable water levels. Not enough flow in summer, ice jams, and flooding in spring. • Reversal of ice formation (bottom up –permafrost transfers cold up and water freezes from the bottom, and top down – ice freezing from the top down in absence of permafrost)→Observation from Meshan Sutherland, traditional knowledge • Lower summer baseflow (high confidence) • Channel-forming flows may happen less frequently and with shorter duration • More alteration (storage) on smaller tributaries due to beavers (observation). (possible in the future) • Earlier freshet (=spring runoff), later freeze-up (timing of critical flood events) • RESEARCH: Will boreal forest expand in the Far North and how will that impact evapotranspiration? Potentially a huge effect • RESEARCH: What is the net impact of extreme storm events? Different impact in boreal versus lowlands? Water quality impact? • RESEARCH: impact of major flood events, ice events, thunderstorms on fish populations/distribution? • RESEARCH: impact/influence of ground water (melting permafrost, hydrology + soil links)

APPENDIX D. Climate Change Impacts due to Non-Climate Stressors on freshwater fish in Ontario's Far North (Attawapiskat-Coast watershed).

Key Climate-Influenced Drivers/Effects	**Observed & Predicted Climate Change Impact**
Water quantity	• Water withdrawals for mining will affect water quantity and quality • Open pit mines can under-drain adjacent water bodies and re-route groundwater • Hydro-development tends to affect flow regimes
Growth/survival/reproduction	• Overharvest of species with increased access (e.g., roads)
Water quality	• Roads, changing land use and more people mean more nutrients entering aquatic systems, especially nitrogen and phosphorus. Eutrophication and oxygen stress decreases resistance to parasites/invasive species and other stressors. • Dewatering associated with mines can increase salinity in lakes e.g., diamond mines in AB. • Release of contaminants, toxics, spills
Habitat availability	• Infrastructure with mining affects thermal regime via runoff, clearing, etc. • Reservoir types (top or bottom draw) will affect thermal regime
Disease/Parasites/Invasives	• Eutrophication and oxygen stress due to land use and inputs like nitrogen and phosphorus decreases resistance to parasites/invasive species and other stressors. • POTENTIAL OPPORTUNITY. Dams may act as barriers to movement of invasive species

For more information about this project, please contact the Wildlife Conservation Society Canada in Thunder Bay at (807) 472-1440 or cchetkiewicz@wcs.org or Peterborough at (705) 760-9500 or jmcdermid@wcs.org.

About Wildlife Conservation Society (WCS)

WCS has over a century of experience developing and implementing wildlife-focused strategies to protect and conserve globally significant wild places and the biodiversity and ecosystem processes they support. Founded in 1895 as the New York Zoological Society, WCS has played a central role in North American conservation including the first-ever survey of Alaskan wildlife in 1897 leading to laws to control overhunting. In 1905, WCS General Director William Hornaday formed the American Bison Society to protect bison from extinction. WCS also led captive breeding programs and successful reintroductions of bison across the West. In 1912, Hornaday was a principal architect of the Alaskan Fur Seal Treaty and the Migratory Bird Treaty between Canada, U.S., and England (later joined by Mexico). During its history in North America, WCS has supported pioneering field studies on species including bighorn sheep, black-footed ferrets, grizzlies, mountain lions, and bald eagles, and helped create more than 30 U.S. parks and reserves, including the Arctic National Wildlife Refuge, and Olympic and Wind Cave National Parks.

Today, WCS's work includes efforts to help ecosystems adapt to climate change, which is arguably one of the most significant challenges facing the conservation of wildlife and wild places. The WCS North America Climate Change Program is working with partners to identify management strategies for conserving landscapes and species in North America that are under threat by climate change. WCS conducts research to detect and understand the projected and observed vulnerability of particular habitats, ecosystems and wildlife species to climate change. Additionally, WCS scientists help assess the capacity of these species and systems to cope with climate-driven impacts. By working with decision-makers, WCS helps develop and implement wildlife conservation and management strategies to mitigate the consequences of climate change.

About Wildlife Conservation Society (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. Since 2004, WCS Canada has been an independently registered and managed non-government organization, while retaining a strong collaborative working relationship with sister WCS programs in more than 55 countries around the world.