Assessing the Potential Cumulative Impacts of Land Use and Climate Change on Freshwater Fish in Northern Ontario

CHERYL CHETKIEWICZ, MATT CARLSON,
CONSTANCE O'CONNOR, BRIE EDWARDS,
MEG SOUTHEE AND MICHAEL SULLIVAN

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by Dr. Cheryl Chetkiewicz, Matt Carlson, Dr. Constance O'Connor, Dr. Brie Edwards, Meg Southee, and Dr. Michael Sullivan

**Wildlife Conservation Society Canada
344 Bloor Street West, Suite 204
Toronto, Ontario M5S 3A7
www.wcscanada.org**

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Matt and Cheryl would like to extend personal thanks to Dr. Michael Sullivan, Fisheries Scientist with Alberta Parks and Environment. Michael worked with us both over the past two years sharing his knowledge, reports, and expertise on fisheries and cumulative effects. He was instrumental in developing the goals and objectives for the workshop and we benefited from his enthusiastic support for applying tools like Stella and ALCES Online, in an inclusive and participatory way, to encourage better fisheries planning and management. We benefitted immensely from his generosity, good humour, scientific knowledge, and excellent facilitation and storytelling skills.

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ABOUT THE AUTHORS

Dr. Cheryl Chetkiewicz is an ecologist with a passion for nature and conservation. She earned a Ph.D. in Ecology at University of Alberta for her work on landscape connectivity for grizzly bears and mountain lions in the Canadian Rocky Mountains. She is currently a Conservation Scientist at WCS Canada where she leads field and applied research in Ontario's Far North. Her research focuses on community-based and regional-scale issues in the Far North, specifically wildlife (e.g., caribou, wolverine, freshwater fish) research and monitoring, assessing the cumulative impacts of land use and climate change on wildlife, and promoting the need for regional environmental and strategic assessments. She uses her work to inform policy, management and planning decisions in one of the most intact landscapes in the world. When she is not working to conserve wildlife, she can be found exploring nature at home and aboard with her husband, son, and dog.

Matt Carlson is an ecologist interested in applying a systems dynamics approach to develop pragmatic solutions to natural resource management challenges. He is a member of the ALCES Group, a leader in the application of scenario analysis to assess the cumulative effects of land use. His integrative research explores the consequences of forestry, energy, mining, agricultural, and urban development to a diverse suite of environmental and socioeconomic indicators. As a consultant for governments, First Nations, and conservation organizations, Matt's work has informed planning initiatives across Canada, at scales ranging from municipalities to provinces. Recent projects have assessed the cumulative effects of natural resource development in Ontario, British Columbia, Alberta, and the Northwest Territories; evaluated urban development strategies in the Calgary and Edmonton regions; and developed decision support tools for watershed-based planning. Matt lives in Ottawa and, when not at work, can be found running trails or after his kids.

Dr. Constance O'Connor is an ecologist with a lifelong passion for fish and freshwater ecosystems. She earned her B.Sc. in biology and English literature at McGill University and her Ph.D. in biology at Carleton University, and then held a postdoctoral fellowship at McMaster University. She is currently a freshwater conservation scientist with Wildlife Conservation Society Canada, where she leads the freshwater conservation program for northern Ontario boreal landscapes. She is also an adjunct professor of biology at Lakehead University in Thunder Bay. Connie's research uses individual-level data on freshwater fish to understand population- and community-level processes. She then uses this knowledge to develop better tools for monitoring and predictive modelling for policy, management and planning decisions that affect freshwater ecosystems. When she's not solving these scientific puzzles, Connie enjoys exploring the beautiful landscape around her home in northern Ontario by foot and by canoe with her husband and young daughter.

Dr. Brie Edwards is a community ecologist concerned with understanding and protecting aquatic ecosystems. Brie is a Research Scientist with the Ontario Ministry of the Environment and Climate Change, where she leads the Northern Lake and Stream Monitoring programs. Brie completed her Ph.D. at the University of Toronto, where she investigated the conservation status, ecology of and potential threats to freshwater crayfish. Previously with Wildlife Conservation Society Canada, Brie worked on developing innovative tools to monitor effects of climate change and the cumulative effects of multiple stressors on invertebrates. When she is not sampling in northern Ontario, Brie can be found in the waters near her family cottage teaching her young sons that protecting small creatures in the river ensures the integrity of the whole ecosystem.

Meg Southee is the GIS Analyst and Spatial Data Manager for the Ontario Northern Boreal Landscape Program at WCS Canada. She has worked with GIS technology for over 10 years and in 2017, she earned the distinction of Esri Certified ArcGIS Desktop Professional. In 2010, Meg obtained her M.Sc. in Geography from Queen's University, where her research focused on ecological land classification and soil moisture modelling in the boreal forest of Ontario using digital elevation models derived from LiDAR (Light Detection and Ranging) remote sensing data. Meg also holds an Advanced Diploma in Geographic Information Systems (GIS) from the Centre of Geographic Sciences (COGS) in Nova Scotia and a B.Sc. Honours in Environmental Science from the University of Guelph.

Dr. Michael Sullivan continues to nurture a life-long love affair with Canada's wild places, especially in Alberta's mountains and the North. He is paid by the Alberta provincial government as their Fisheries Scientist (Fish and Wildlife Division), but doesn't let that stop him from enjoying the lessons offered by the study of wild lands and the furry and finny residents that live there. His preferred habitat is a snow cave overlooking some lonely valley, but as an adjunct professor, he is usually found near the University of Alberta campus, where he is lucky enough to earn a living (and guide graduate students) to finding ways to make peace between fishermen, developers, and fishes.

EXECUTIVE SUMMARY

The Opportunity

The subarctic boreal landscape of northern Ontario is of global importance thanks to the ecological intactness of terrestrial and freshwater systems spanning an area larger than California. This region also contains some of the largest undammed rivers remaining in the world, thousands of lakes and the largest wetland complex in North America. The region's diverse freshwater ecosystems support at least 50 species of freshwater fish, making this the largest area of high fish biodiversity in Canada.

Healthy aquatic systems in northern Ontario are important for a number of reasons. Freshwater fish are central to First Nation's culture and subsistence in the region and these values are recognized through constitutionally protected Aboriginal and treaty rights. Aquatic systems support recreational and commercial fisheries in some areas and intact and diverse aquatic systems also provide important ecosystem services such as clean water, carbon storage, biogeochemical cycling and flood control.

Northern Ontario is also rich in natural resource potential, including large deposits of chromite and other minerals, and has extensive hydroelectric development potential.

This report seeks to address a gap in current planning efforts, which are largely focused on individual communities and resource development projects such as mines. It looks at the broader picture of what potential development in the region combined with future climate change could mean for freshwater fish. In doing so, it provides an example of the kind of cumulative effects assessment for freshwater fish that is missing in current planning efforts.

As in many other places, the freshwater habitats of northern Ontario face a variety of threats, both natural and as a result of human activities. The largest single threat is climate change, which is occurring more rapidly in the north compared to the rest of Ontario. In fact, this study finds that climate change could have a serious impact on northern populations of walleye, lake sturgeon, lake whitefish, and brook trout over the next half century.

Other aquatic system stressors include fishing, industrial forestry, mining and mineral exploration, hydroelectric development, new infrastructure such as roads and transmission lines, and the introduction of non-native species. Our study finds that when combined with climate change, these stressors can have a serious impact on fish population sustainability.

Despite the importance of Ontario's northern boreal region to fish populations, scientific knowledge of fish distribution in the region is limited. In addition, planning, assessment and monitoring of stressors associated with land use and climate change occurs as if each were acting independently of one another. In reality, freshwater fish and their habitats are experiencing multiple and cumulative effects from human activities, natural disturbance and climate change.

As scientists, we believe it is critical to take a broader and longer-term view of the combined impacts of new mines, roads, transmission corridors, hydroelectric developments, and forestry operations on freshwater fisheries in an area of high ecological significance. That is why we have projected the potential impacts of landscape and climate changes on four culturally and ecologically important fish species 50 years into the future across a large portion of the watersheds in northern Ontario to support environmental planning in northern Ontario.

In 2010, the Government of Ontario made a commitment to work with interested First Nation communities to develop land-use plans in order to protect areas of cultural value and natural importance across *at least* 50% of the Far North as a way of maintaining biological diversity and ecological processes and functions, including storage of carbon. Meeting these ambitious objectives remains an important – and currently unrealized – opportunity to consider the future of Ontario's largely intact Far North ecosystems and the people that depend on them.

However, at the same time, the Government of Ontario has encouraged the development of new mines and all-weather roads and transmission lines, particularly to reach the "Ring of Fire" mineral belt located in the James Bay lowlands approximately 350 kilometres northeast of Thunder Bay. Yet, it has failed to put in place planning processes that can assess and address cumulative impacts of changing land use and climate on freshwater systems, at relevant ecological and social scales, and fish in particular.

Enabling economic growth through resource development while protecting cultural and social values and meeting protection and biodiversity conservation targets will require a planning approach that embraces regional and strategic perspectives. Unfortunately, Ontario's current planning processes remain focused on individual communities (i.e., community-based land-use planning) and individual development projects (i.e., environmental assessment) and do not include any current and future mechanism for considering broader regional objectives or the potential cumulative effects of land use and climate change.

With a rapidly changing climate adding to the existing complexities of understanding cumulative impacts, the government's current approaches are woefully inadequate. In Ontario, neither the industrial proponent nor the government is required to consider cumulative effects during land use or project planning. On the other hand, federal legislation enables cumulative effects assessment, but the process with project-level environmental assessment is largely an *ad hoc* exercise focused on the specific outcomes of industrial developments rather than considering all the combined stressors that affect freshwater fish.

As such, both governments are failing to address the need to assess, monitor, and/or mitigate the potential cumulative impacts of land use and climate change on social and ecological values, including the health and abundance of freshwater fish. The lack of legislative requirement and political will in Ontario to address cumulative effects in regions like the Ring of Fire is exacerbated by the government's siloed approach to managing and regulating issues such as land use, climate change, freshwater resources, and fish. Equally importantly, Ontario's policies, programs, and plans – such as the *Growth Plan for Northern Ontario* – are not subject to assessment despite their potential impact on social and ecological systems.

What is sorely missing in current approaches is the ability to evaluate the potential consequences of land-use activities and climate change at a broad regional scale (i.e., over thousands of kilometres) and across long timeframes (i.e., decades). This report provides an example of how this can be done.

Our Approach

Our study is the first to project the potential impacts of development on freshwater systems in a 440,000 km^2 region of northern Ontario over the next 50 years.

We started by quantifying the current impacts of land use (e.g., forestry, mining, hydroelectric development, infrastructure), natural disturbance (e.g., fire), and climate change on freshwater fish within secondary watersheds that drain toward the Arctic Ocean in the region.

To examine the impact of development and other changes to the region over the next 50 years, we developed a high- and low-growth scenario for each land-use sector (e.g., forestry tenures, mining operations, hydroelectric development) based on available public and industry reports and established government policy and plans. We also determined the current extent of disturbance due to fire and simulated future fire based on data and research from the region. Finally, we applied the most recent climate data and models for the region. Taken together, our scenarios, describe plausible future trajectories for land use, natural disturbance and climate change.

We then used expert-derived models that describe relationships between simulated stressors (e.g., roads, dams, forestry activities, temperature) and species-specific fish sustainability indices (FSI) for walleye, lake sturgeon, lake whitefish, and brook trout. This led to FSI scores for each species under both low- and high-development scenarios based on current conditions and projected conditions, with both scenarios advanced 50 years into the future.

While the course of actual future development in the region is uncertain, these simulations can be used to compare and contrast the implications of various land-use scenarios on each species and to consider the potential risks and benefits of each scenario, both with and without climate change, for each species.

Our Findings

Under the high-growth scenario, the overall development footprint in the study area almost doubled over the 50-year timeframe, with higher disturbance occurring in the portion of the area allocated for industrial forestry (referred to as the Area of the Undertaking - AOU) due to ongoing timber harvest and associated road development.

This scenario also simulated substantial growth in hydroelectric development, particularly in the Far North where reservoirs associated with new dams represented a large part of the expansion of the development footprint, along with new mines and associated road and transmission network expansion.

Development footprint growth, especially roads, was sufficient to cause increased risk of watershed fragmentation and overfishing within the AOU portion of the study area, but not within the Far North. In both areas, the development footprint growth did not cause an elevated risk of non-native species introductions or water quality degradation from phosphorous and sediment runoff.

The projected change in climate was substantial in the Far North. By the end of the 50-year simulation period, almost the entire study area (86%) exhibited mean July temperatures and growing-degree-day values that exceeded the hypothesized optimal levels for walleye, lake sturgeon, lake whitefish, and brook trout.

All four species exhibited increased risk over the simulation period, although lake whitefish were more tolerant of simulated changes in land use and climate change. Risk to walleye was greatest in the southern portion of the region due to the cumulative effect of climate change, road development and dams. By the end of the 50-year high-growth scenario, risk to lake sturgeon and sea-run brook trout was elevated throughout the study area due to the cumulative effect of climate change and dams.

An exception to these findings was the Ekwan watershed, which was identified as being a potential refuge for lake sturgeon and sea-run brook trout due to relatively lower temperatures and the lack of potential hydroelectric development.

Overall, climate change was the most influential driver of risk to freshwater fish, followed by hydroelectric dams. Climate change consistently exacerbated the effects of land use and natural disturbance changes under both scenarios – FSI declined faster or further when land use was combined with climate change.

Our Recommendations

- **Assess cumulative effects in freshwater fish management and conservation:** While we cannot be absolutely certain about future conditions, we can examine plausible scenarios based on current information and informed assumptions about changes due to climate and land use. This allows potential environmental impacts to be understood and evaluated today with a focus on risk management before options for land-use management and conservation have been foreclosed. Such an approach also allows us to examine the potential combined impacts of future land-use activities and climate change in a way that goes beyond the limited and prescriptive federal environmental assessment process or Ontario's siloed decision-making approach. In fact, our proposed approach is vital to developing and implementing strategies intended to deliver on sustainable development and conservation objectives for northern Ontario and the Far North.

- **Continue to gather the information needed to improve decision-making about freshwater fish conservation:** Our study lays the groundwork for continued monitoring and adaptive management of aquatic systems. In fact, the ALCES Online toolkit used for this study can be used to continually improve the models of potential outcomes as more data are gathered or new findings emerge. It can also allow us to further examine the cumulative effects of multiple stressors by embarking on a participatory process involving scientists, First Nations and other interested parties.

- **Prioritize monitoring for freshwater fish conservation:** Our results underscore the need for ongoing monitoring to establish better data baselines and to reduce reliance on fragmented and often narrowly scoped information generated through project environmental assessments. In particular, there is a need to develop community-based monitoring programs focusing on freshwater fish and the processes that they depend on (e.g., connectivity, water flow, water quality). Such efforts would help meet commitments to regional monitoring, such as in the Regional Framework Agreement between Matawa First Nations and the Government of Ontario.

- **Prioritize areas for freshwater fish research and protection:** Our study highlights areas where research should be prioritized as well as areas where protection could be prioritized, such as the Ekwan. It also demonstrates the importance of placing much greater emphasis on the way in which climate change will exacerbate development impacts and other stressors on freshwater fish. In particular, our study illustrates the need for a regional and strategic approach to assessing hydroelectric development in the region.

1.0 INTRODUCTION

1.1 Northern Ontario's Fish Populations and Cumulative Effects

Northern Ontario hosts a subarctic and boreal landscape of international importance due to its ecological intactness and integrity (Abraham et al. 2011:73, Far North Science Advisory Panel 2010:76, Wells et al. 2010). Rivers, lakes, and wetlands dominate the landscape, covering more than half of the total surface area (Marshall and Jones 2011) (Figure 1.1). The region contains some of the largest naturally flowing rivers remaining in the world (Dynesius and Nillson 1994), thousands of lakes, particularly on the Ontario Shield, and the largest wetland complex in North America (Keddy et al. 2009) which is also one of the most productive subarctic coastal wetland habitats in the world (Abraham et al. 2011, Far North Science Advisory Panel 2010).

These abundant and diverse freshwater ecosystems support at least 50 species of freshwater fish and form the largest area of high fish biodiversity with low human impacts within Canada (Marshall and Jones 2011: 24, Browne 2007). Walleye (*Sander vitreus*) are considered to be the most common species along with northern pike (*Esox lucius*), white sucker (*Catostomus commersonii*), and yellow perch (*Perca flavescens*). Lake trout (*Salvelinus namaycush*) populations are glacial relics and important for First Nations cultural values and subsistence fisheries. Brook trout (*Salvelinus fontinalus*) are economically and ecologically important, occurring as both a stream-dwelling and sea-run form. The Sutton Ridges region in the Far North is one of North America's top quality brook trout fishing areas (McGovern and Vukelich 2009). Another important species is lake sturgeon (*Acipenser fulvescens*), which is listed as a species of *special concern* in the study area[1] under Ontario's *Endangered Species Act, 2007*[2] as well as the federal *Species at Risk Act*[3] (Golder Associates Ltd., 2011). The ecological role and habitat requirements of key large-bodied fish species found in northern Ontario are summarized in McDermid et al. 2015a.

First Nations in northern Ontario have long-standing cultural relationships with freshwater fish, in part because of a dependence on fish for food (including for sled dogs), trap bait and trade (Hori et al. 2012, Kerr 2010, Hannibal-Paci 1998, Berkes et al. 1995, Hopper and Power 1991). These relationships remain important today. For example, lake sturgeon (Ojibwe name: *Namay Namaeu*;

[1] Ontario's Southern Hudson Bay/James Bay lake sturgeon population is encompassed by the federal Designatable Unit 7 that also includes the Québec portion of the study area (Golder Associates Ltd. 2011).

[2] E*ndangered Species Act*, 2007, SO 2007, c 6, is available online at: http://www.e-laws.gov.on.ca/html/statutes/english/elaws_statutes_07e06_e.htm.

[3] Canada's *Species at Risk Act* is available online at: http://laws-lois.justice.gc.ca/eng/acts/s-15.3/

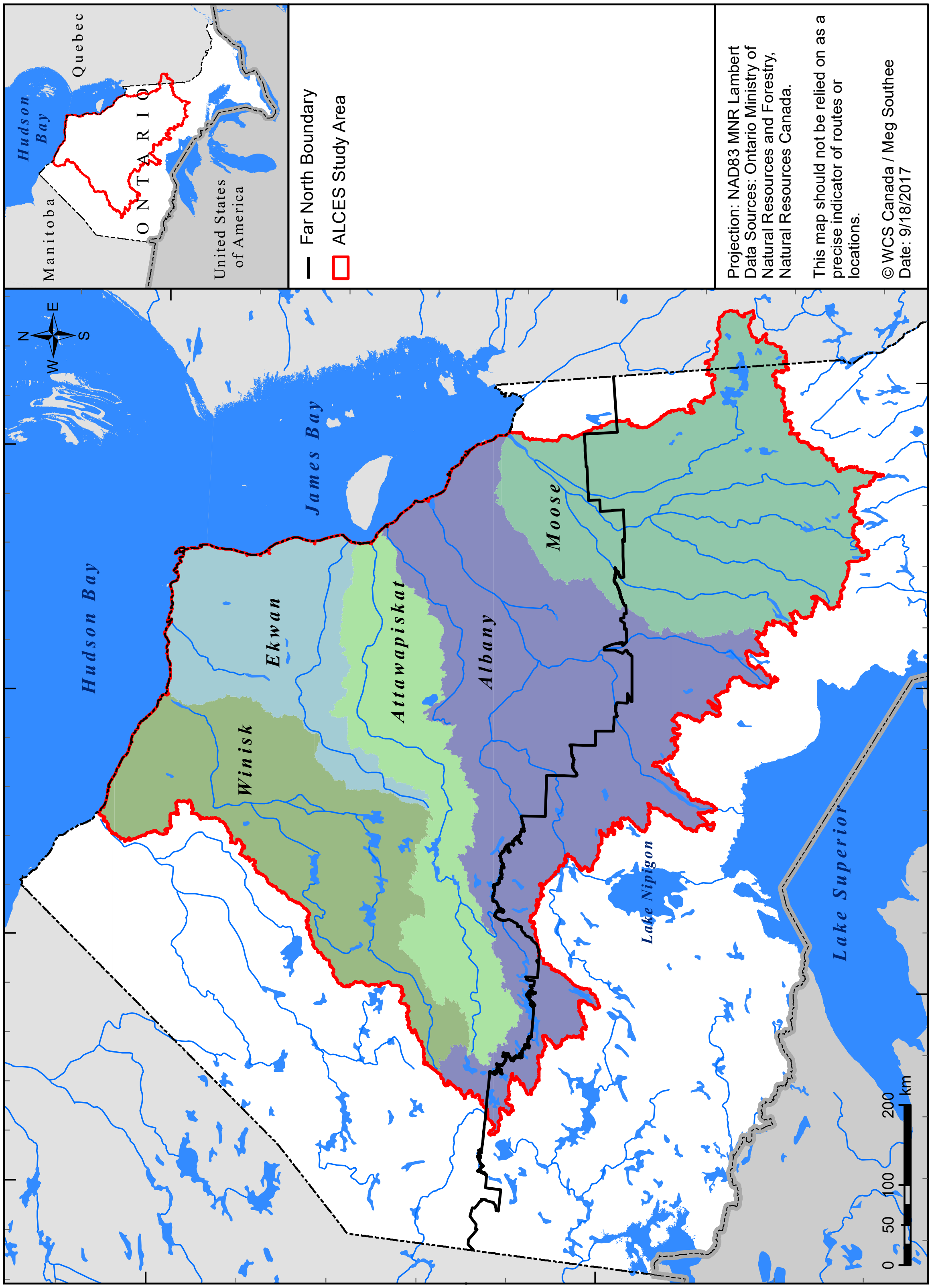


Figure 1.1. The ALCES study area, including the major rivers in Ontario's Far North

Cree: *Nme;* Ojibwe: *Ottawa*), continues to be significant to many First Nations as a source of food and an integral part of their spiritual and cultural identity (Golder Associates Ltd., 2011).

The cultural and spiritual significance of fish and freshwater habitat is also signified through Indigenous family and place names, educational stories and ceremonies (Davidson-Hunt and Berkes 2003) and much of the catch may be distributed to kin and others unable to fish (Hopper and Power 1991). The involvement of youth in fishing activities and ceremonies is one way in which traditional knowledge about fish natural history and fishing techniques is passed on to younger generations (Berkes and Davidson-Hunt 2006, Barnhardt and Kawagley 2005).

Northern Ontario is, of course, of particular importance to its 807,700 residents (in 2011), of which about 97,000 (12%) identify as Indigenous (MTO and MNDM 2016). Many of these residents engage in subsistence, recreational, and commercial fisheries (Cooke and Murchie 2015). Recreational and commercial fisheries are managed by Ontario's Ministry of Natural Resources and Forestry (MNRF) following management direction in Ontario's Provincial Fish Strategy.[4] Marshall and Jones (2011), Abraham et al. (2011), ESTR Secretariat (2014), and McGovern and Vukelich (2009) provide excellent overviews of the historical and recent programs developed to support and document subsistence, commercial and recreational fisheries in Ontario.

We also considered ceremonial and cultural fisheries in our selection of freshwater fish (e.g., Noble et al. 2016). For example, subsistence fishing for lake sturgeon in Ontario is a long-standing tradition for many First Nation communities supporting traditional values, knowledge systems, and taking care of the land and water (Hopper and Power 1991).

Besides providing food and economic benefits in the form of fish, freshwater ecosystems provide many other valuable services (Schindler and Lee 2010). Freshwater biodiversity in northern Ontario provides critical functions in maintaining healthy aquatic ecosystems and related ecosystem services, including production of clean water, carbon storage, nutrient uptake, biogeochemical cycling and flood control (Wells et al. 2010, Woodward 2009).

The connections between freshwater and terrestrial systems are also important for the productivity of terrestrial systems, such as forests (Richardson and Danehy 2007). This connectivity means that the ecological integrity (structure and function) of freshwater ecosystems is affected not only by direct impacts to water bodies, but also by natural and anthropogenic disturbances to the terrestrial components of the watershed.

The relatively simple biological diversity in northern aquatic systems means that freshwater communities are particularly vulnerable to disturbances due to the reduced redundancy among functionally similar species (e.g., Schindler 1998). Any disturbance or impact that reduces or eliminates a specific species or functional group can therefore compromise or eliminate community and/or ecosystem functions as there are few or no similar species to fill their niche (e.g., Vinebrook et al. 2003).

[4] Available online at: https://dr6j45jk9xcmk.cloudfront.net/documents/4538/ontarios-provincial-fish-strategy.pdf

In northern Ontario, as with other boreal regions in Canada, freshwater habitats face a variety of threats from human and natural drivers of change. We developed a broadly defined conceptual model of the central relationships of interest between physical and anthropogenic disturbance (including climate change) and freshwater fish (Figure 1.2). The conceptual model implicitly assumes that the cumulative effects of these stressors on freshwater fish emerge from direct, indirect or interactive effects (e.g., Burton et al. 2016). We used the conceptual model to help clarify assumptions in our modeling, identify key stressors, and consider underlying mechanisms between freshwater fish, land use, natural disturbance and climate change to support our hypotheses and simulations.

Key stressors for the purpose of this work include the following:

- **Fishing**, including recreational, commercial, and subsistence fisheries. The low productivity of cold-water fisheries makes them susceptible to overfishing even at low levels of fishing pressure and localized sport fishing pressure concerns exist in some areas (Gunn and Sein 2000). Human settlement and roads both serve as proxies for fishing pressure (Hunt and Lester 2009, Hunt et al. 2009).

- **Forestry.** By altering forest composition and structure, timber harvest can affect the flow and quality of water as well as other aspects of fish habitat (e.g., coarse woody debris, stream cover) (Brandt et al. 2013, Kreutzweiser et al. 2013). Commercial forestry operations also facilitate access for fishing and non-native species through the construction of a dispersed road network (Cott et al. 2015, Hunt and Lester 2009, Hunt et al. 2009, Post et al. 2002).

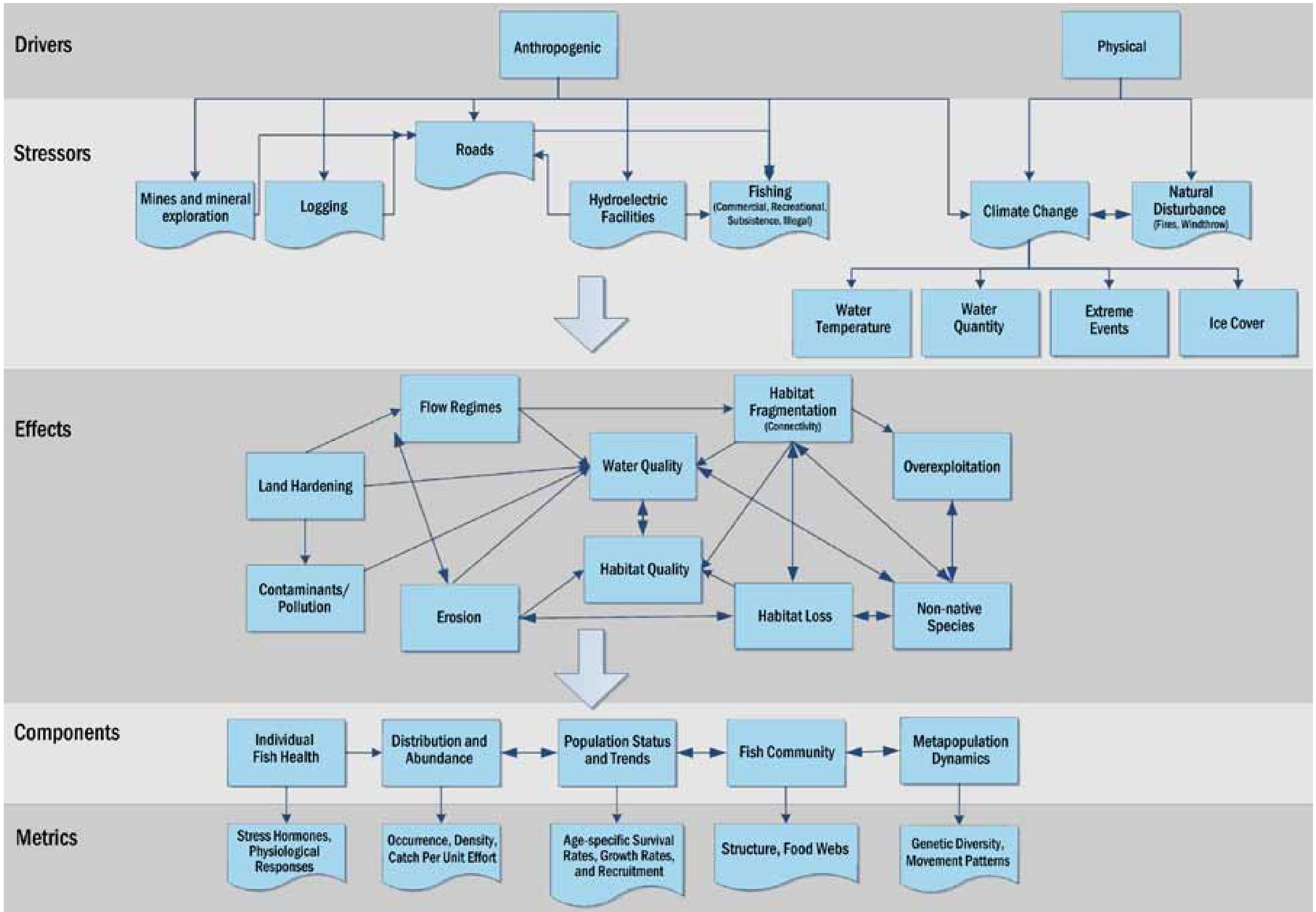
- **Hydroelectric facilities**, including dams and reservoirs can have numerous adverse effects including habitat loss and degradation from changes in flow, as well as act as physical barriers to migratory species (Kreutzweiser et al. 2013). Reservoirs are also associated with increased methylation of natural mercury, leading to human health concerns due to bioaccumulation in large-bodied and predatory fish that people catch and eat, particularly First Nations (Webster et al. 2015, Tang et al. 2013).

- **Mining.** The primary risks to freshwater fish and their habitat due to mining activities are turbidity and potentially toxic compounds that leach or are discharged from tailings and effluent during mining operations (Brandt et al. 2013, Kreutzweiser et al. 2013).

- **Transportation and transmission infrastructure.** Impacts of these linear developments include increased access for fishing, fish passage restriction at culverts (i.e., stream crossings) and water withdrawals (i.e., ice road creation) and sedimentation (Cott et al. 2015, Robertson et al. 2006).

- **Non-native species, including diseases**. Although non-native fish species are virtually absent in Ontario's Far North, the potential range expansion and establishment of non-native fishes (e.g., smallmouth bass (*Micropterus dolomieu*) or rainbow smelt (*Osmerus mordax*) into the region may be facilitated by warmer water temperatures caused by climate change

Figure 1.2. Conceptual model for freshwater fish in northern Ontario. Modified from Kilgour and Associates 2016.



(Edwards et al. 2016, Alofs et al. 2014, Marshall and Jones 2011, Sharma et al. 2009). Non-native species can cause substantial impacts to the native fish community through predation, competition and parasitism (Langor et al. 2014, Sanderson et al. 2012, Ficke et al. 2007).

- **Climate change**, due to the myriad of processes affected by temperature and precipitation including hydrology, biochemistry, fish physiology, fish habitat, and spread of non-native species (Poesch et al. 2016, Dove-Thompson et al. 2011, Heino et al. 2009). Ontario's climate has experienced significant changes over the last 40 years (McDermid et al. 2015b). Since 1970, the province has observed an increase in minimum temperatures, with a 2.6°C rise in northern Ontario and a 1.4°C warming in southern Ontario (Chu and Fischer 2012, Chu et al. 2003, 2005).

Despite the importance of freshwater fish, scientific knowledge of fish distribution in northern Ontario is limited due to the cost of conducting research and monitoring in this remote waterscape. Most of the available data on freshwater fish is based on research and inventories (e.g., Aquatic Habitat Inventory) conducted decades ago. These studies are biased towards portions of northern Ontario that had road access (Marshall and Jones 2011). Studies assessing the response of fish populations to the stressors listed above in northern Ontario are also limited. As a result, planning for fish conservation in the region is constrained by a lack of scientific data.

Another limitation to the management of fish populations in the region is that these stressors are planned for, managed and monitored as if each were acting independently on fish populations. In reality, freshwater fish and their habitats are experiencing multiple and cumulative interacting abiotic and biotic effects resulting from natural and anthropogenic change. Cumulative effects are "changes to the environment that are caused by an action in combination with other past, present and future human actions" (Hegmann et al. 1999:3). Bonar and Matter (2011) suggested that effects on fish populations accumulate as single sources with additive, synergistic, or multiplicative effects or multiple sources with additive or multiplicative effects.

Cumulative effects assessment (CEA) refers to assessment of the accumulation of change on the landscape due to multiple stressors (natural and anthropogenic) over spatial and temporal scales (Dubé 2003). CEA can be triggered during federal and, in some jurisdictions, provincial and territorial environmental impact assessment processes. However, the practice of CEA within project-based impact assessment is largely ineffective (Duinker and Grieg 2006). This is usually because the scope of CEA is narrowly focused on local development projects seeking "one-off" regulatory approval (Duinker et al. 2013). For freshwater fish and their habitats, neither regulating agencies nor proponents focus on relevant ecological scales, such as watersheds, for the purpose of assessing and managing impacts of development or climate change on aquatic systems, despite the benefits of doing so (e.g., Sheelanere et al. 2013, Dubé et al. 2013, Noble et al. 2011; but see Douglas et al. 2014). Without legislative and regulatory requirements, cumulative impacts of human development and climate change on freshwater fish and watersheds are not assessed, planned for or managed holistically (Dubé et al. 2013, Noble et al. 2011).

1.2 Project Objectives

Our overall goal is to improve the capacity to plan for conservation of northern Ontario's fish populations by:

1. Exploring the potential for the freshwater watersheds in northern Ontario to be transformed by the future expansion of industrial development and climate change;
2. Assessing the potential cumulative impacts of these changes on freshwater fish, particularly walleye, lake sturgeon, lake whitefish, and brook trout; and
3. Informing planning and policy to improve freshwater fish conservation in northern Ontario.

In order to do this, our project had the following objectives:

1. Create a freshwater study area that could incorporate the extent of secondary and tertiary watersheds with downstream flow within the Southwestern Hudson Bay watershed.
2. Review the literature concerning drivers of change in the study area and identify current policy and planning pathways to develop a conceptual model for freshwater fish in the study area.
3. Bring together fisheries and aquatic experts to verify the key stressors on native freshwater fishes, particularly walleye, lake sturgeon, lake whitefish, and brook trout, and model their responses to these stressors.
4. Use expert-derived responses to simulate the consequences of current and future land use and climate change scenarios on species-specific fish sustainability indices across the study area using the ALCES Online toolkit.

The report is structured according to the above objectives. Ultimately, our analysis generates a number of hypotheses about how land use and climate change impacts may cumulatively affect freshwater fish in northern Ontario. By providing an integrated assessment of potential impacts of land use and climate change, our analyses are a step towards a more comprehensive assessment of the consequences of land use and climate change on freshwater fish in Ontario's Far North. As such, our results may be used to support a regional and strategic approach to planning and improve community-based land-use planning as well as project-level impact assessment for the purpose of conservation of freshwater fish and their habitats.

2.0 STUDY AREA

Our study area includes secondary watersheds located primarily within northern Ontario, particularly Ontario's Far North,[5] that flow to the Arctic. The 440,436 km^2 study area covers 60% of the Southwestern Hudson Bay primary watershed (Figure 2.1), which forms part of the Hudson Bay Basin, the largest ocean watershed in Canada. There are nine secondary watersheds in the study area and 46 tertiary watersheds (Figure 2.1). Major river systems in the study area include the Winisk, Ekwan, Attawapiskat, Albany, Moose, and Abitibi Rivers and their tributaries. We included extant watersheds whose headwaters were outside Ontario's Far North due to their relevance for freshwater fish conservation in the Far North.

While Ontario's Ecological Land Classification does not adequately represent the diversity of aquatic ecosystems,[6] the study area is comprised of 79% (197,481 km^2) of the Hudson Bay Lowlands ecozone and 36% (242,954 km^2) of the Ontario Shield ecozone (Figure 2.2), as well as portions of seven ecoregions (Figure 2.2). We provide a brief overview of the freshwater systems and climate in each ecozone. More detailed descriptions of the climate, geology, land cover, water features, and flora and fauna for each ecozone and its constituent ecoregions can be found in Crins et al. (2009).

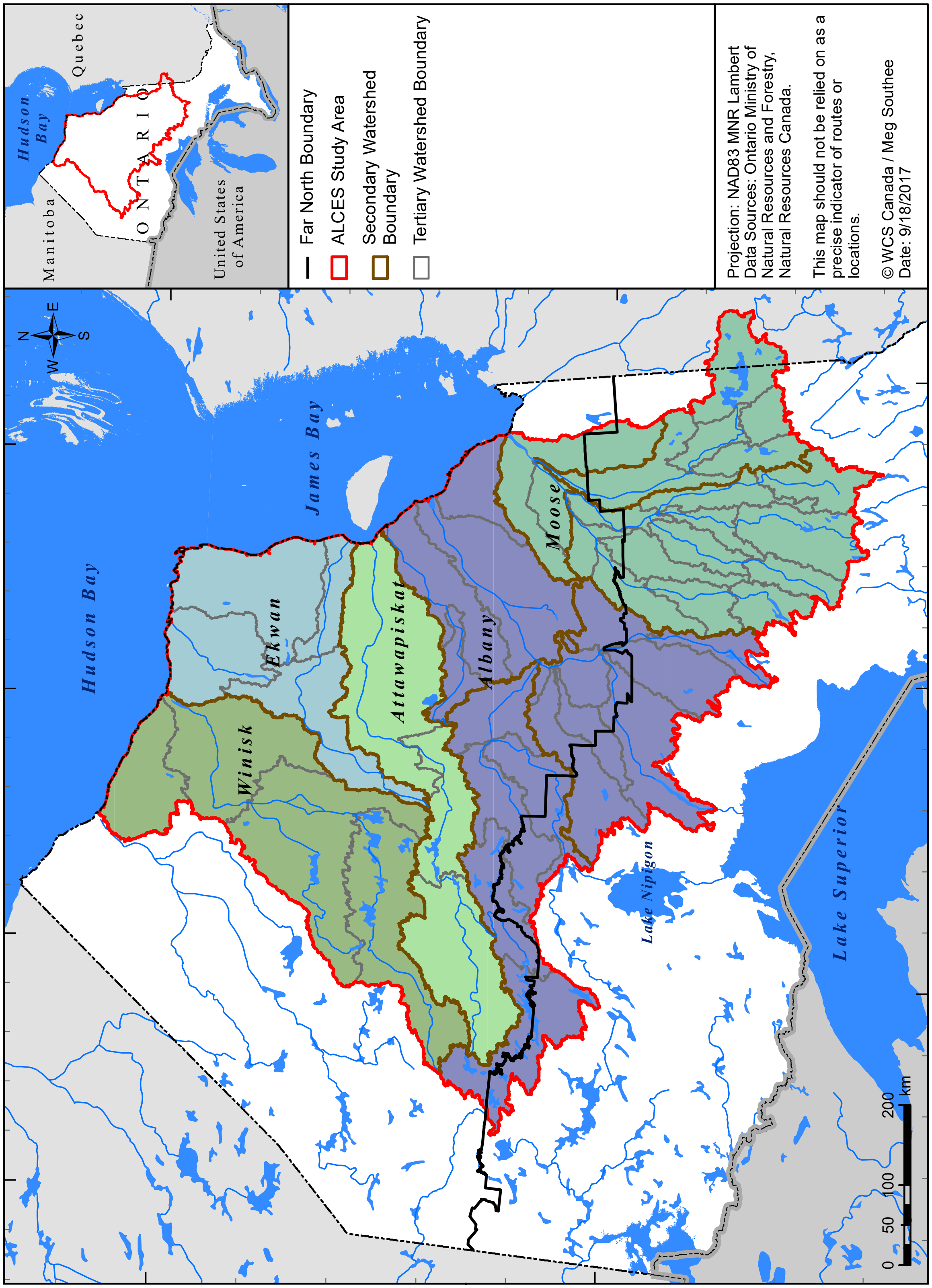
2.1 Lakes and Drainage Systems

There are few large lakes in the Hudson Bay Lowlands portion of the study area. Missisa Lake is the largest lake while Hawley and Sutton Lakes, near bedrock outcrops, are the deepest. In the Ontario Shield portion of the study area, lakes and rivers are frequent and highly variable in size. Marshall and Jones (2011) noted a 2008 inventory of waterbodies indicated that 34% of the province's lakes greater than 20 ha in area were located on the Ontario Shield portion of the Far North. The Albany River is the largest river in the study area while the Attawapiskat and Winisk Rivers are shallow and slow-flowing with highly seasonal flow regimes as they cross relatively flat alluvial valleys and drain into the Hudson and James Bays. Peak flows occur in May to early June with annual lows in August (McGovern and Vukelich 2011). Nutrients and organic material carried by these "tea-coloured" rivers result in productive and diverse coastal estuaries (Abraham et al. 2011).

[5] Ontario's Far North is defined by the *Far North Act, 2010*, SO 2010, c 18, which is available online at https://www.ontario.ca/laws/statute/10f18#s5

[6] There is an ongoing effort to develop an Aquatic Ecosystem Classification system for Ontario (Melles et al. 2013), but currently this classification does not include Ontario's Far North (Nick Jones, MNRF, personal communication).

Figure 2.1. The ALCES study area, including the secondary and tertiary watersheds



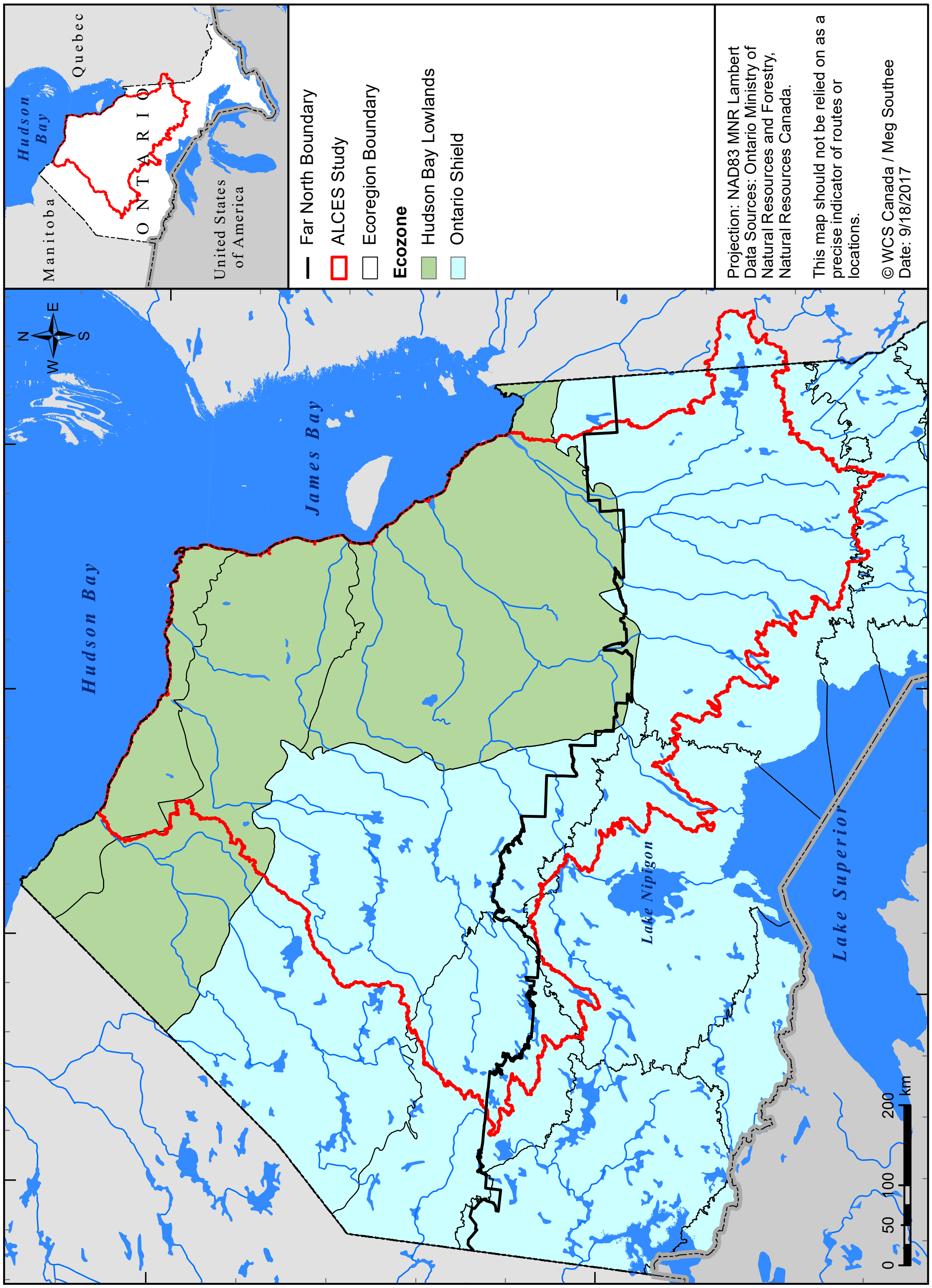


Figure 2.2. The ALCES study area, including the ecozones and ecoregions

2.2 Climate

In the Hudson Bay Lowlands portion of the study area, the climate is relatively cold and semi-arid. The winters are long and cold, with mean daily January air temperatures between -20 and -27.5°C. The summers are short and cool, with mean daily July air temperatures between 12 to 16°C (Crins et al. 2009). Average annual precipitation ranges between 240 and 525 mm (Stewart and Lockhart 2004). Permafrost affects summer climate by preventing moisture penetration into the substrate, keeping air temperatures lower. In the Ontario Shield portion of the study area, the climate is relatively cold and moist, with long, cold winters and short, warm summers. However, there is a wide range of temperature, precipitation and humidity patterns across this ecozone (Crins et al. 2009).

2.3 Wetlands and Peatlands

Drainage in the Hudson Bay Lowlands is poor, with much standing or slowly moving water. The coastal wetlands along Hudson Bay and James Bay contained in the study area are some of the most productive subarctic wetland habitats in the world (Abraham et al. 2011, Far North Science Advisory Panel 2010). Polar Bear Provincial Park and the Southern James Bay Migratory Bird Sanctuaries (Moose River and Hannah Bay) have been designated Wetlands of International Importance (Ramsar sites[7]) because of their significance as staging and breeding grounds for migratory waterfowl and shorebirds (Figure 2.3). In addition, there are 12 Important Bird and Biodiversity Areas (IBAs) along the Hudson Bay and James Bay coastline. While not protected, these areas are now acknowledged as key biodiversity areas (KBAs) which are areas important in terms of animal species, but also extends to areas significant for their plant life or their life-sustaining environment.[8]

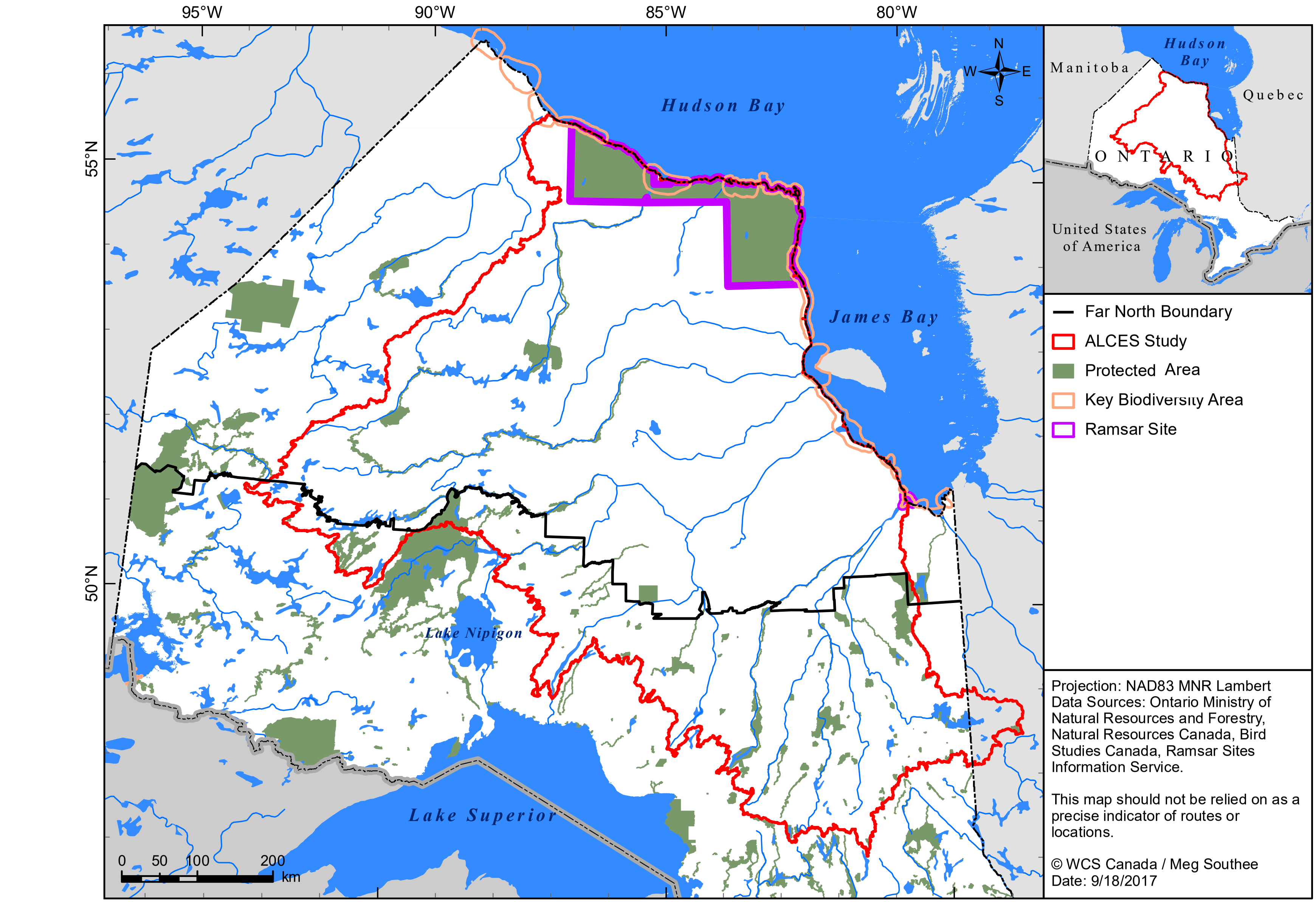
Wetlands with more than 40 cm of peat development are classified as peatlands (National Wetlands Working Group 1997). A large proportion of the wetlands in the Far North are peatlands (bogs and fens), making this ecozone North America's largest peatland complex and the second largest between 40° and 50° latitude (McLaughlin and Webster 2014). Wetlands have important ecological roles (*sensu* ecosystem services) including the cycling of carbon through carbon sequestration in peat, methane production, atmospheric CO_2 exchange, and production and export of dissolved organic carbon (McLaughlin and Webster 2013). Besides providing diverse habitat for plants and animals, wetlands also play important roles in flood control and water filtration (Schindler and Lee 2010). Ontario's northern wetlands and subarctic peatlands are recognized as being globally significant because of their intactness and their role in climate regulation (McLaughlin and Webster 2014, Abraham et al. 2011, Far North Science Advisory Panel 2010).

Hudson Bay, combined with Foxe Basin to the north and James Bay to the south, is considered the world's largest inland sea (Gagnon and Gough 2005). Hudson Bay has a significant advective effect on freshwater and terrestrial biomes along the coast as it produces cold moist atmospheric conditions above its surface, while cold winds reduce air temperatures and suppress evaporation up to 600 km inland (Rouse 1991). Similarly, the discharge of huge volumes of

[7] Ramsar Sites Information Service. Available online at http://www.ramsar.org/sites-countries/the-ramsar-sites

[8] The KBA Standard can be downloaded at: https://www.iucn.org/theme/protected-areas/wcpa/what-we-do/biodiversity-and-protected-areas/key-biodiversity-areas

Figure 2.3. Protected sites and other significant conservation areas within the ALCES study area



sediment and freshwater from major northern rivers disproportionately affects the Bays. For example, the volume of freshwater entering the Hudson Bay reduces salinity by up to a third, helping to make complete freeze-up possible and affecting local and regional climates and environments for freshwater and marine communities (Abraham et al. 2011: 32).

2.4 Fish Communities

Browne (2007) summarized the ecology, distribution and status of fish communities in the Far North portion of the study area based on which top predator species are present. These include: walleye and northern pike communities; lake trout communities, commonly associated with lake whitefish and cisco (*Coregonus artedii*); brook trout communities; and stickleback (Gasterosteidae) and sucker (*Catastomus* spp.) communities. McGovern and Vukelich (2009) provide more recent information on the status of lake sturgeon, lake trout, brook trout, lake whitefish and cisco populations in the Hudson Plains ecozone portion of the study area. The small fish communities within the study area typically include spottail shiner (*Notropis hudsonius*), johnny darter (*Etheostoma nigrum*), ninespine stickleback (*Pungitius pungitius*), and trout perch (*Percopsis omiscomaycus*) (Marshall and Jones 2011, Scott and Crossman 1973).

2.5 Land Use

2.5.1 Industrial Forestry

The majority of the study area is located in the Far North Planning Area. However, 134,380 km^2 (31%) occurs within the Area of the Undertaking (AOU) and includes portions of 20 Forest Management Units (FMUs) in Ontario, specifically: Abitibi River, Caribou, Gordon Cosens, Hearst, Kenogami, Lac Seul, Lake Nipigon, Magpie, Big Pic, Black River, Pic River-Ojibway, Martel, Nagagami, Ogoki, Pineland, Romeo Malette, Spanish, Timiskaming, Trout Lake, and White River. In the Far North portion of the study area, Cat Lake - Slate Falls and the Eabametoong and Mishkeegogamang First Nations have identified forest management areas within their community-based land-use plans.[9] As well, small portions of three forest management units are included in the Québec portion of the study area (Figure 2.4).

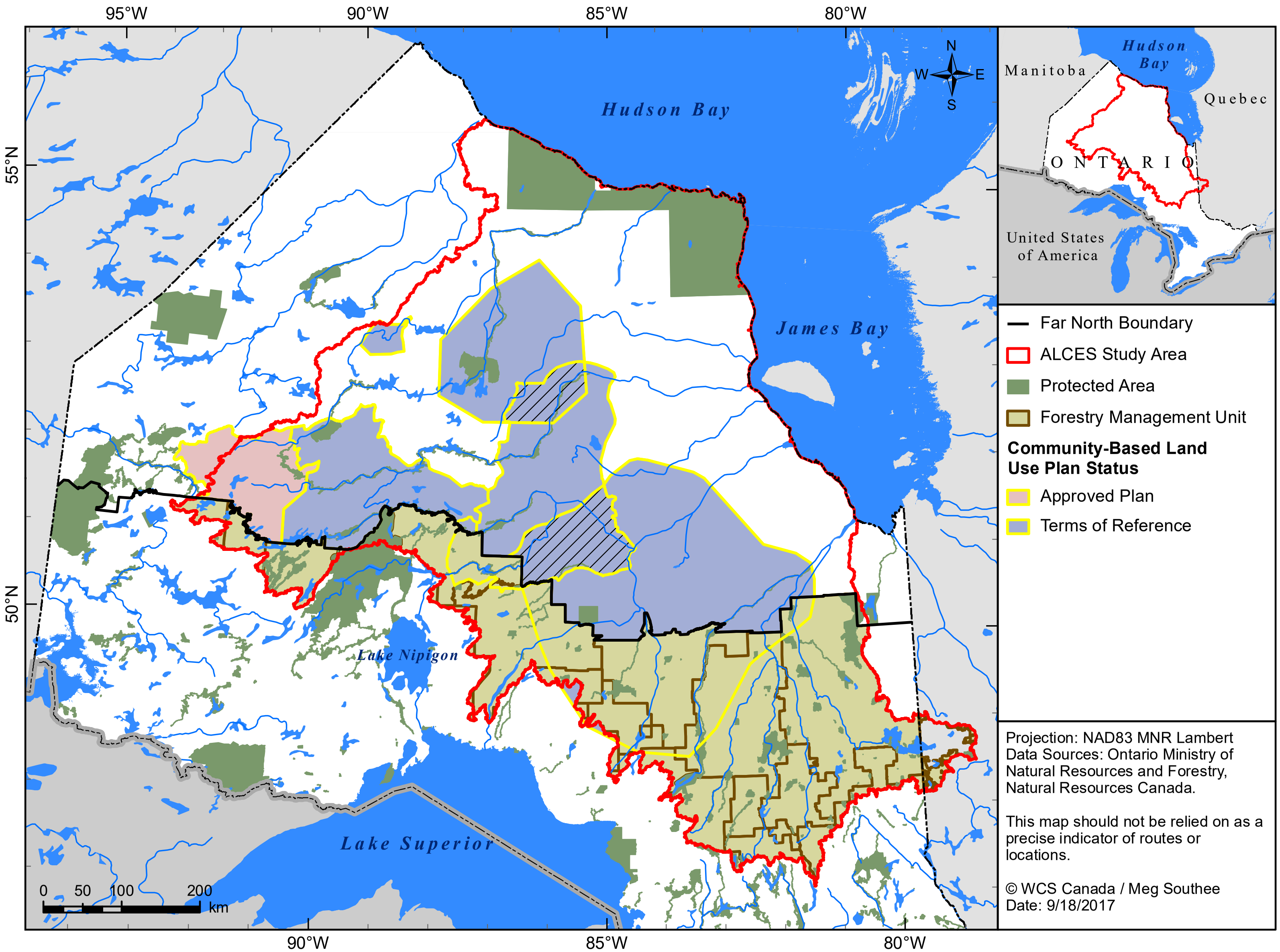
2.5.2 Hydroelectric Development

There are eight generating stations, 25 non-hydro dams, including diversions for flood control and power generation, and 15 run-of-river[10] dams in the study area (Figure 2.5). For example, three large headwater areas in the Albany have been dammed and diverted for hydroelectric developments, reducing the mean annual discharge of the Albany River to James Bay by 17% (Marshall and Jones 2011) (Figure 2.6). The Moose River watershed is one of the most fragmented watersheds in the study area, while the North French watershed remains the only unfragmented watershed in the Moose River system. Most the Far North portion of the study area is under some form of policy regarding future development of new hydroelectric facilities (Figure 2.6). A number of sites along most of the major rivers in the study area have been identified for *potential* future development of hydroelectric power generation (Figure 2.7).

[9] https://www.ontario.ca/page/land-use-planning-process-far-north

[10] Type of dam where hydroelectric generation has little or no water storage (e.g., reservoir).

Figure 2.4. The current status of community-based land-use planning in Ontario's Far North and the forest management units in the Area of Undertaking within the ALCES study area



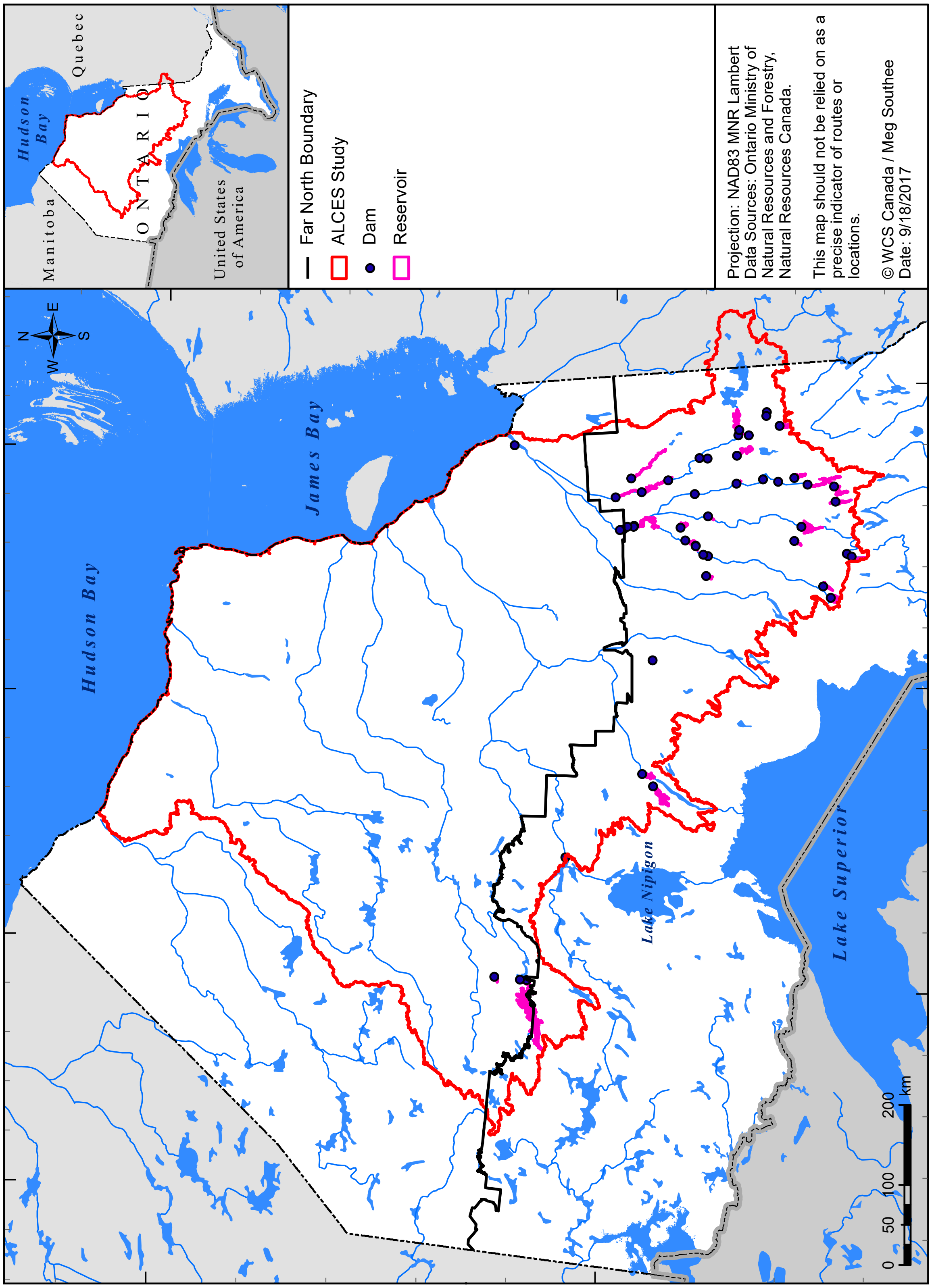


Figure 2.5. The current footprint of hydroelectric power generation sites (dams, reservoirs) within the ALCES study area

Figure 2.6. Major water diversions and water management policy areas within the ALCES study area

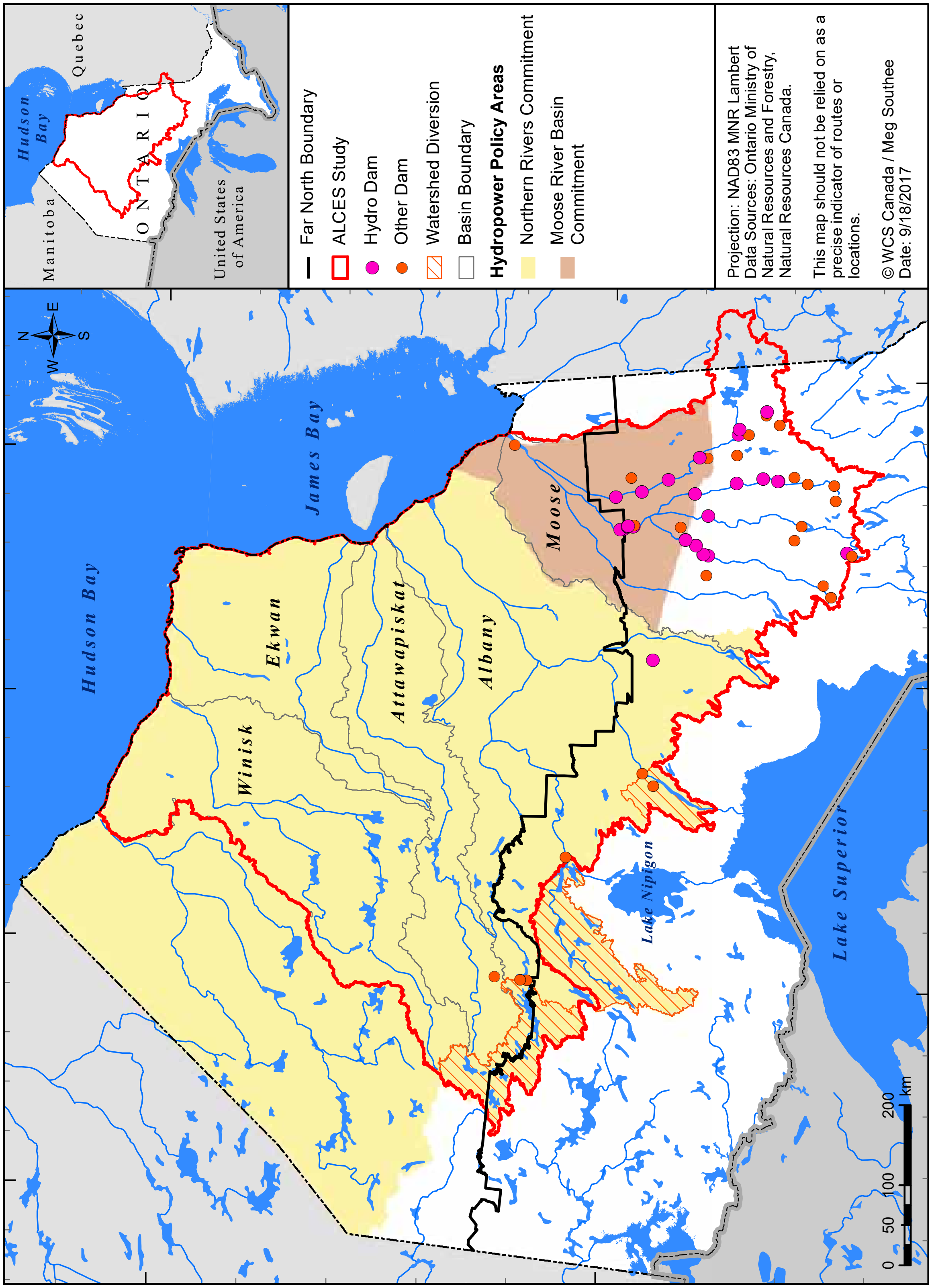
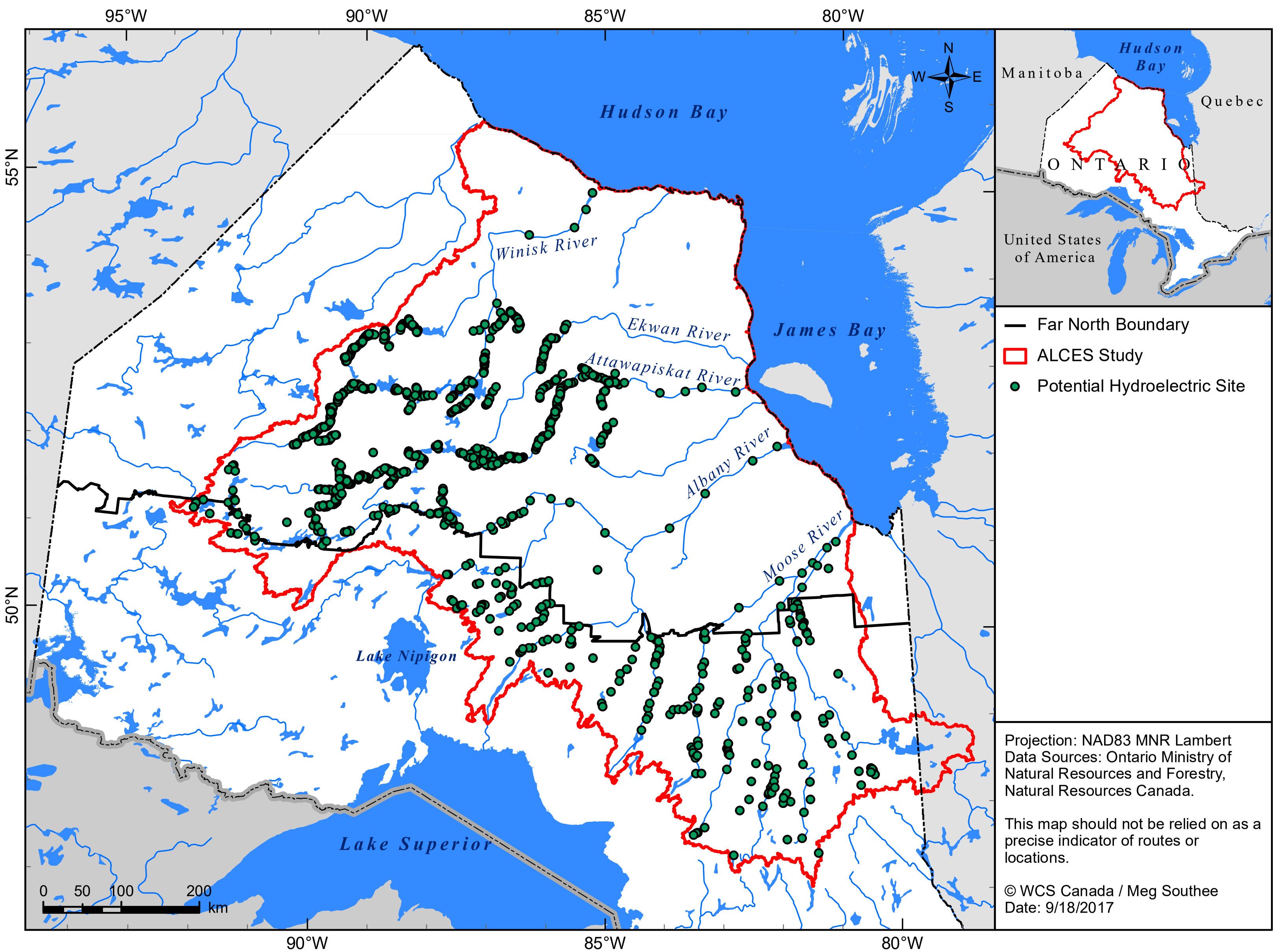


Figure 2.7. Potential hydroelectric power generation sites identified within the ALCES study area



2.5.3 Mining and Mineral Exploration

There are ten producing metal mines and mills including Victor Diamond Mine, Musselwhite Gold Mine, and mines in and around Timmins (Figure 2.8). The study area also contains a diversity of mineral resources identified for *potential* future development including: the Ring of Fire nickel, copper, and chromite deposits and 17,223 km^2 of mineral claims which cover 4% of the study area (Figure 2.9).

2.5.4 Infrastructure

There are approximately 3,158 km of provincial and major roads in the study area, along with 6,817 km of minor roads, including forest access roads and winter roads in the Far North region of the study area (Figure 2.10). In terms of energy infrastructure, there is 4,081 km of transmission lines in the study area, including the 273 km high-voltage transmission line built by Five Nations Energy Inc. along James Bay that connects Attawapiskat, Kashechewan, Fort Albany and Moose Factory to Ontario's power facilities at Moosonee. In the Pickle Lake area, Slate Falls and Cat Lake First Nations are connected to the provincial grid (Figure 2.11). The remaining remote Far North First Nations are currently not connected nor is Mishkeegogamang[11] despite having provincial road access.

2.5.5 Settlements and Human Population

There are nine towns, including Timmins, and 28 First Nation communities within the Ontario portion of the study area, including 26 remote First Nations reserves and two First Nation communities (Moosonee and Mishkegoomagang) that are connected to the provincial road network. Some of these communities are engaged in community-based land-use planning under the *Far North Act, 2010*[12] and have identified areas of interest for planning (Figure 2.12). There is a total registered population of 32,560 indigenous *Anishinaabeg* of which approximately 48% reside in the 28 First Nation communities within the Far North portion of the study area (Indigenous and Northern Affairs Canada 2017).

There are approximately 72,845 people (average global non-response rate[13] = 6.0%) living within major towns and municipalities outside the Far North planning area within the Ontario portion of the study area (Statistics Canada 2016).[14] There are three towns, three villages, 10 hamlets, and 17 municipalities in the Québec portion of the study area (Figure 2.12) containing approximately 20,295 people (average global non response rate = 3.5%) within the 20 census subdivisions in the study area (Statistics Canada 2016).

.

[11] There are two pieces of reserve land associated with the Mishkeegogamang First Nation. The northern reserve land (63B) with the village of New Osnaburg is connected to the grid, whereas the community of Mishkeegogamang on the southern reserve land (63A) is not connected to the grid.

[12] Available online at: https://www.ontario.ca/laws/statute/10f18

[13] The global non-response rate (GNR) is used as an indicator of population census data quality by combining complete non-response (household) and partial non-response (question) into a single rate. A smaller GNR indicates a lower risk of non-response bias and as a result, lower risk of inaccuracy.

[14] Statistics Canada, 2016 Census of Population, Statistics Canada Catalogue no. 98-400-X2016003. Accessed Online (June 5, 2017) Available online at: https://tinyurl.com/y9hgc6t6

Figure 2.8. Active mines and mining footprints within the ALCES study area

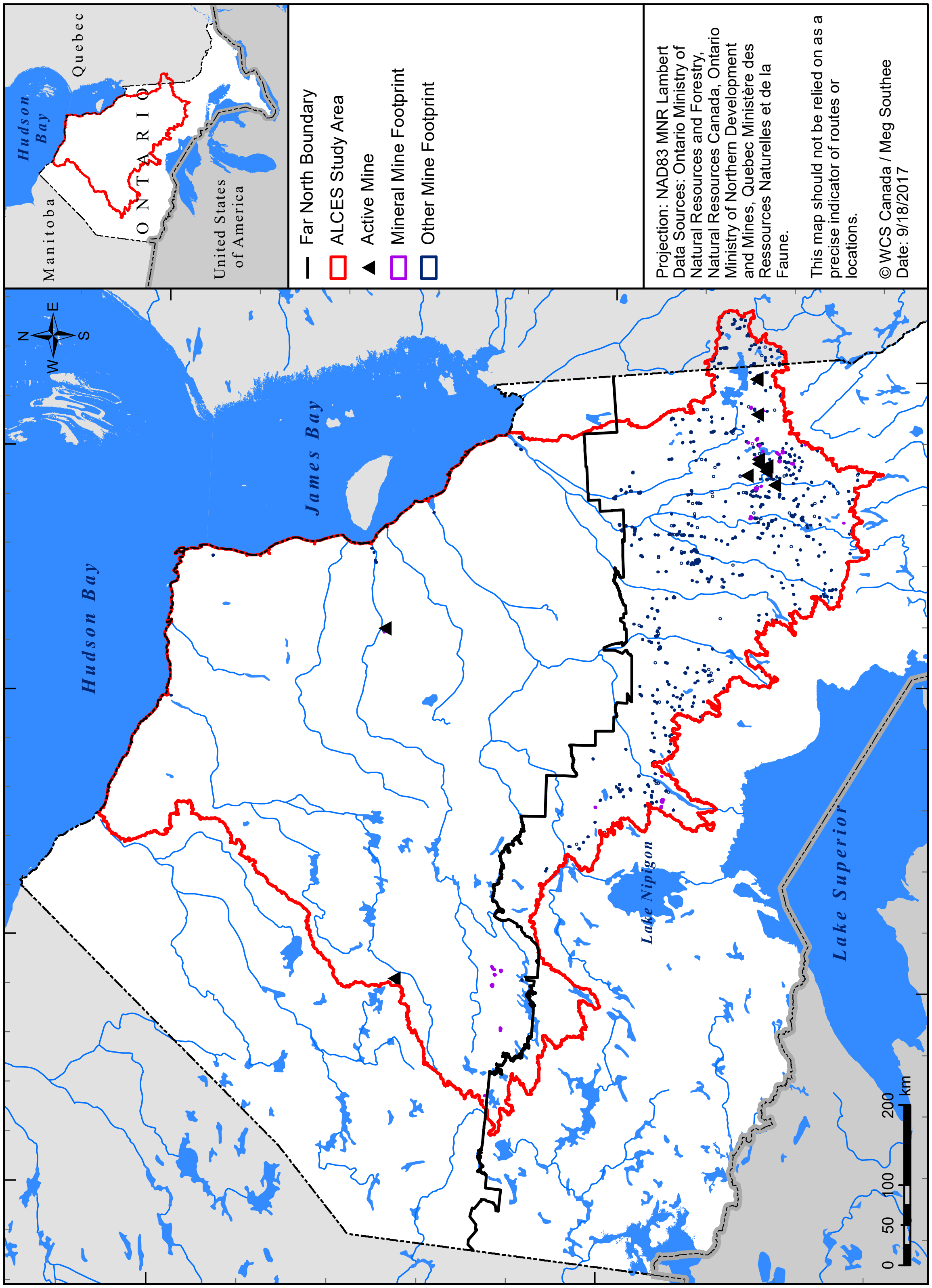
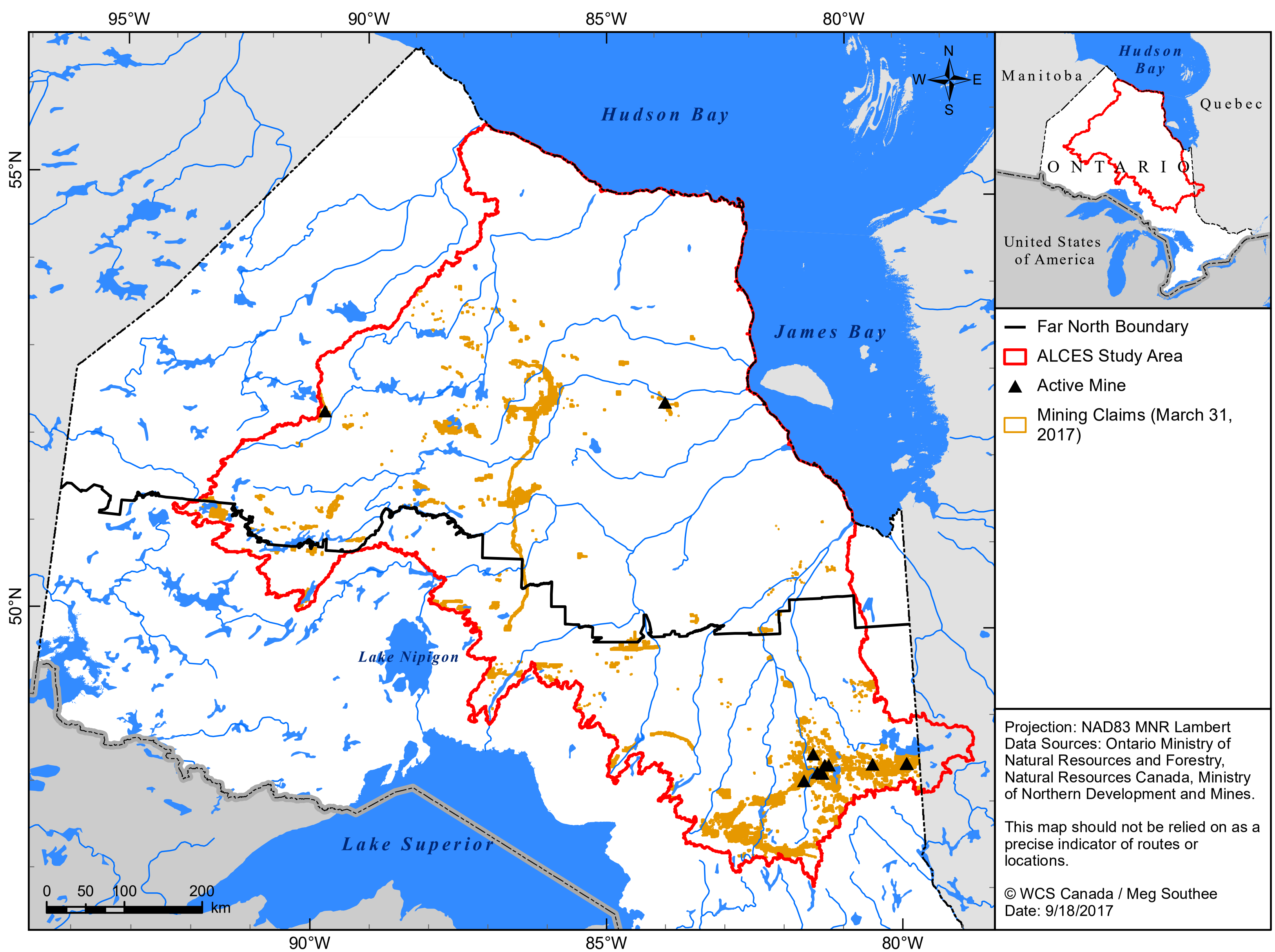


Figure 2.9. Active mines and current (as of March 31, 2017) mineral exploration claims within the ALCES study area



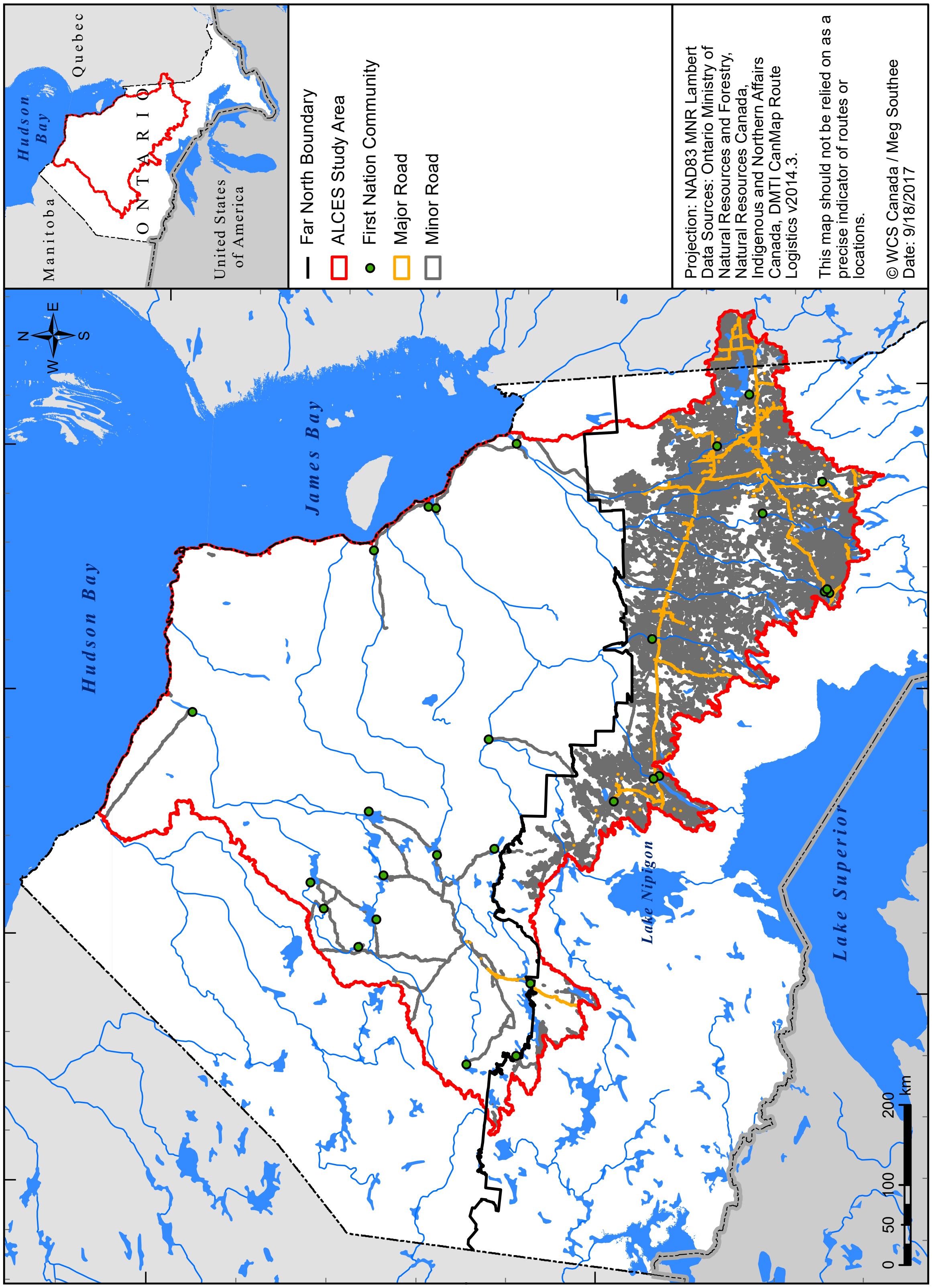


Figure 2.10. Major and minor roads, including winter roads, within the ALCES study area

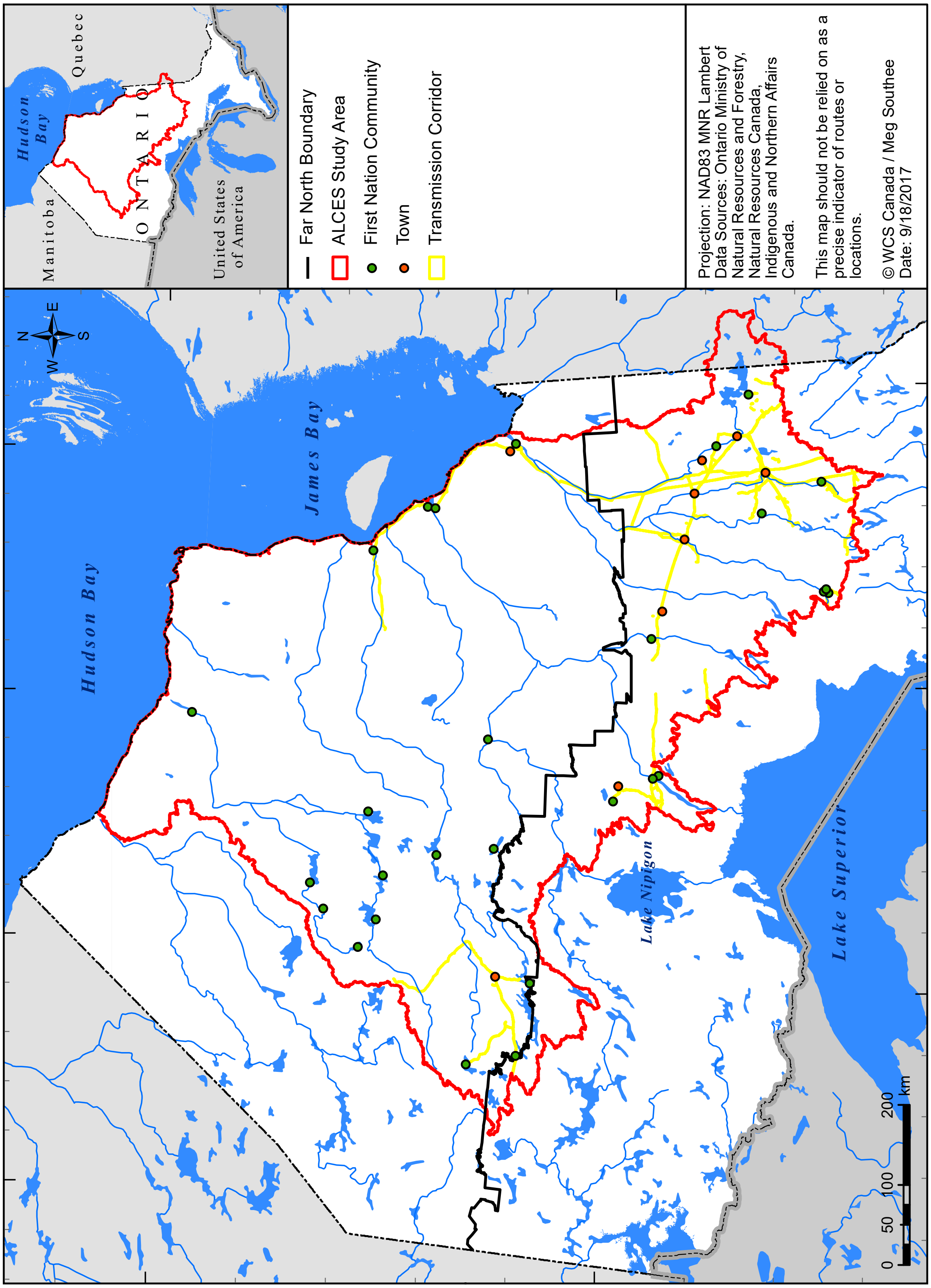
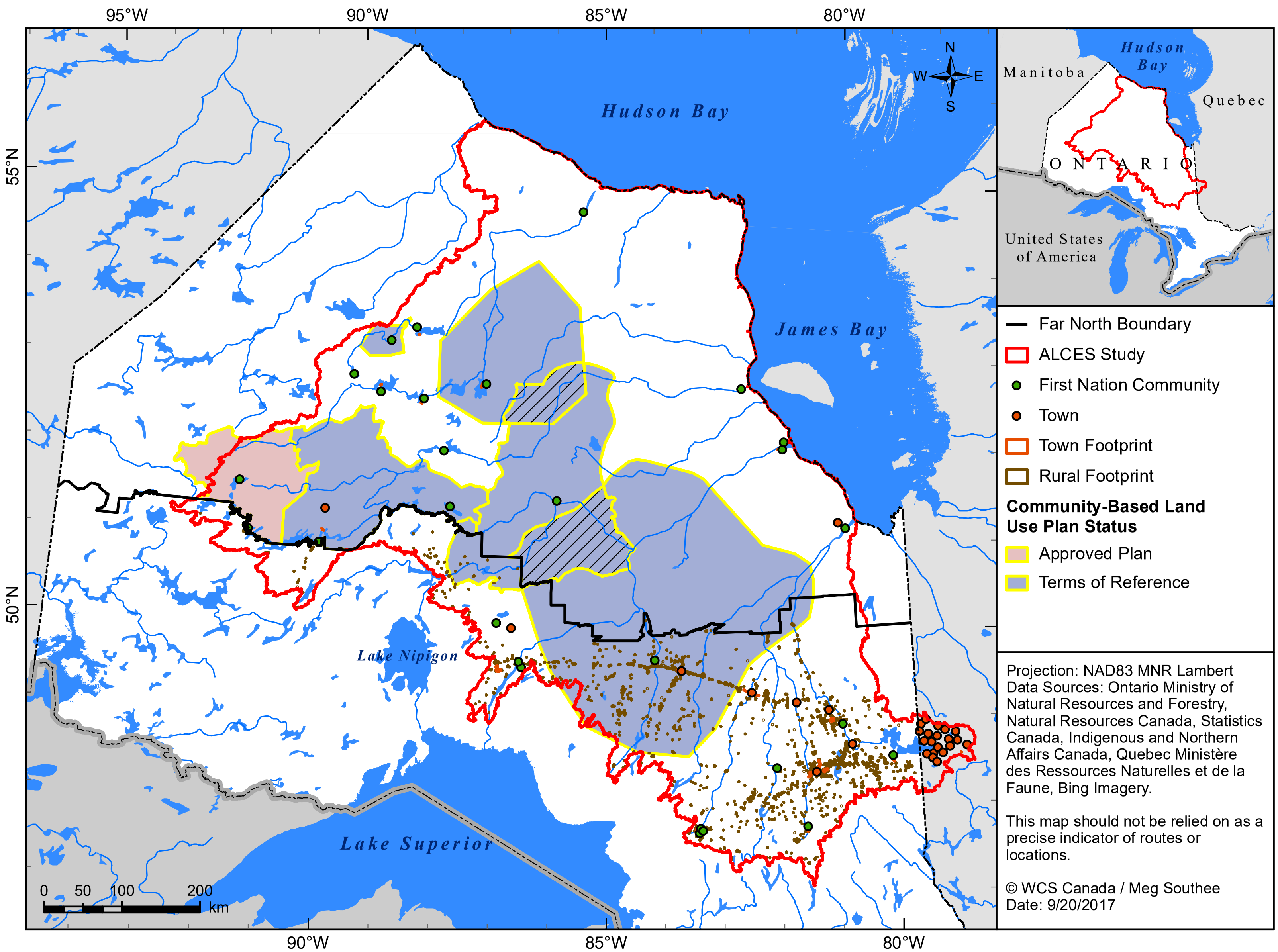


Figure 2.1.1. Transmission corridors within the ALCES study area

Figure 2.12. Towns, communities, and settlements within the ALCES study area, including the status of community-based land use plans in Ontario's Far North



3.0 METHODS

Our project built upon a previous effort that assessed potential cumulative impacts on caribou, moose, and wolverine as well as watershed impacts based on Browne (2007) using ALCES (Carlson and Chetkiewicz 2013). Briefly, ALCES is a simulation model for comprehensive assessment of the cumulative effects of multiple land uses and natural disturbances to ecosystems (Carlson et al. 2014). The model has been applied as a decision-support tool for a variety of land-use planning processes (e.g., Carlson and Browne 2015, Francis and Hamm 2011, Carlson et al. 2011, Schneider et al. 2003). In the context of the present project, ALCES was applied in various ways including:

- An interactive tool to support development of relevant fish models;
- A scenario analysis tool to explore the consequences of development and climate change trajectories on freshwater fish; and
- A decision-support tool for use by WCS Canada and partners to assess and demonstrate the implications of development and climate change to freshwater fisheries.

ALCES works by exposing a cell-based representation of the current landscape to user-defined scenarios that differ with respect to the rate, intensity, and spatial pattern of future land use, natural disturbance, and climate change. Simulated landscape dynamics are combined with indicator relationships to map the response of indicators (e.g., fish sustainability index, fish habitat) to scenarios of land use, natural disturbance, and climate change. To assess cumulative effects, the simulation engine incorporates numerous drivers such as forestry, mining, settlements, energy, transportation networks, natural disturbance, climate change, and reclamation. Scenarios are defined through a flexible set of inputs that control the rate, intensity, spatial pattern, and consequence of each driver of change on the landscape. The model's ability to simulate disturbances and their consequences at a range of spatial extents (e.g., local, regional, provincial) and across long time frames (e.g., decades) allows scenarios to be assessed at scales that are relevant to management and policy development.

For the current study, a newer web-based version of the simulation toolkit, referred to as ALCES Online (Carlson et al. 2014), was used to improve accessibility of the decision-support tool and provide a mechanism to rapidly build and map fish indicator relationships with fishery experts. Exploring the cumulative effects on northern Ontario fish populations required the following steps in ALCES Online:

- assessing the existing composition of the study area;
- defining and simulating scenarios that incorporate plausible future trajectories for land use, natural disturbance, and climate change based on available reports and policy direction; and
- defining dose-response relationships that relate fish population status to simulated changes in land use, natural disturbance, and climate variables.

3.1 Landscape Composition

The current composition of the study area was derived from a variety of land cover, footprint, and hydrological data sources and compiled in ArcGIS 10.3 (ESRI 2014). The data layers were integrated to produce a non-overlapping representation of land cover, human footprints and hydrology. The landscape composition layer was summarized at a resolution of 500 m for use in ALCES Online (Figure 3.1). The composition of each cell was multivariate and expressed as the proportion of the cell covered by each land cover and human footprint type.

The land cover product was created from the Earth Observation for Sustainable Development of Forests (EOSD) land cover remote sensing product,[15] the NASA North American Carbon Program (NACP) Forest Age Maps at 1-km Resolution for Canada (2004),[16] 20 MNRF Forest Resource Inventory (FRI) datasets, and the MNRF forest fire disturbance area dataset.[17] The location of footprint types was derived from a variety of inventories available to WCS Canada through Land Information Ontario as part of the Ontario Geospatial Digital Exchange sharing agreement with MNRF. Footprints took precedence over natural land cover when creating the non-overlapping representation of landscape composition (Figure 3.2). Order of precedence among footprints was based on the permanence of the features. Additional details on land cover classification and footprint data sources are available in Appendix 1, Tables 3.1 and 3.2.

3.2 Landscape Simulation

Spatial simulations were completed to explore changes to the abundance and age of natural and anthropogenic cover types over the next 50 years in response to multiple land-use sectors and natural disturbance. Simulations included the following land uses: forestry, hydroelectric development, mining, and infrastructure, namely transmission and transportation corridors. To address uncertainty surrounding future rates of development, we explored two alternative rates of future development (high and low) as well as a null scenario where there was no new development.[18] Fire was included in all scenarios because of its

[15] http://www.nrcan.gc.ca/forests/measuring-reporting/remote-sensing/13433

[16] https://daac.ornl.gov/NACP/guides/NA_Tree_Age.html

[17] https://www.javacoeapp.lrc.gov.on.ca/geonetwork/srv/en/main.home?uuid=362e7ab7-655e-4c81-bcbd-0f26bc6f8e36

[18] The no development scenario emulates a future where global resource prices remain low and the cost of infrastructure for remote developments remains too high.

Figure 3.1. The composition of landcovers within the ALCES study area

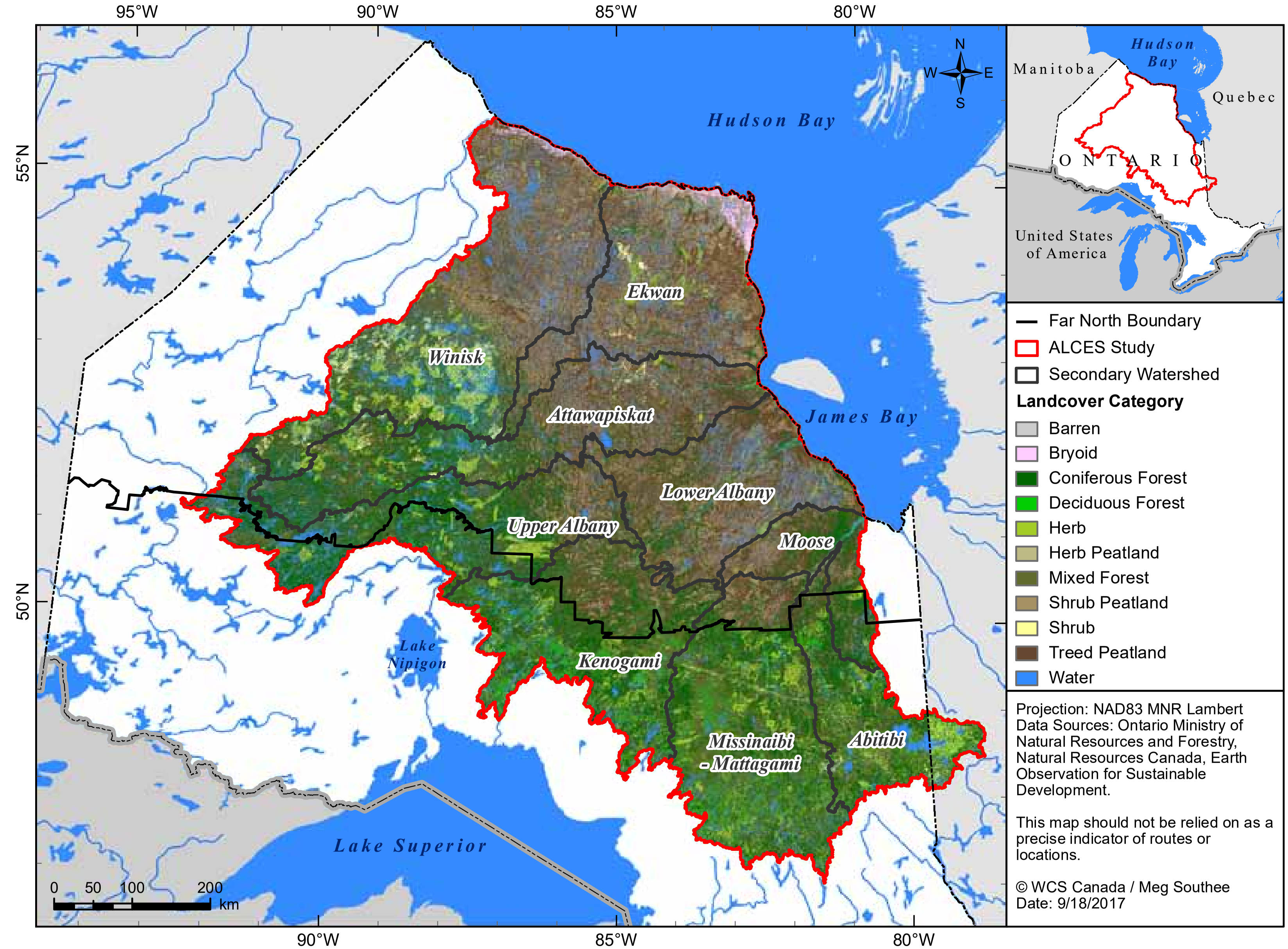
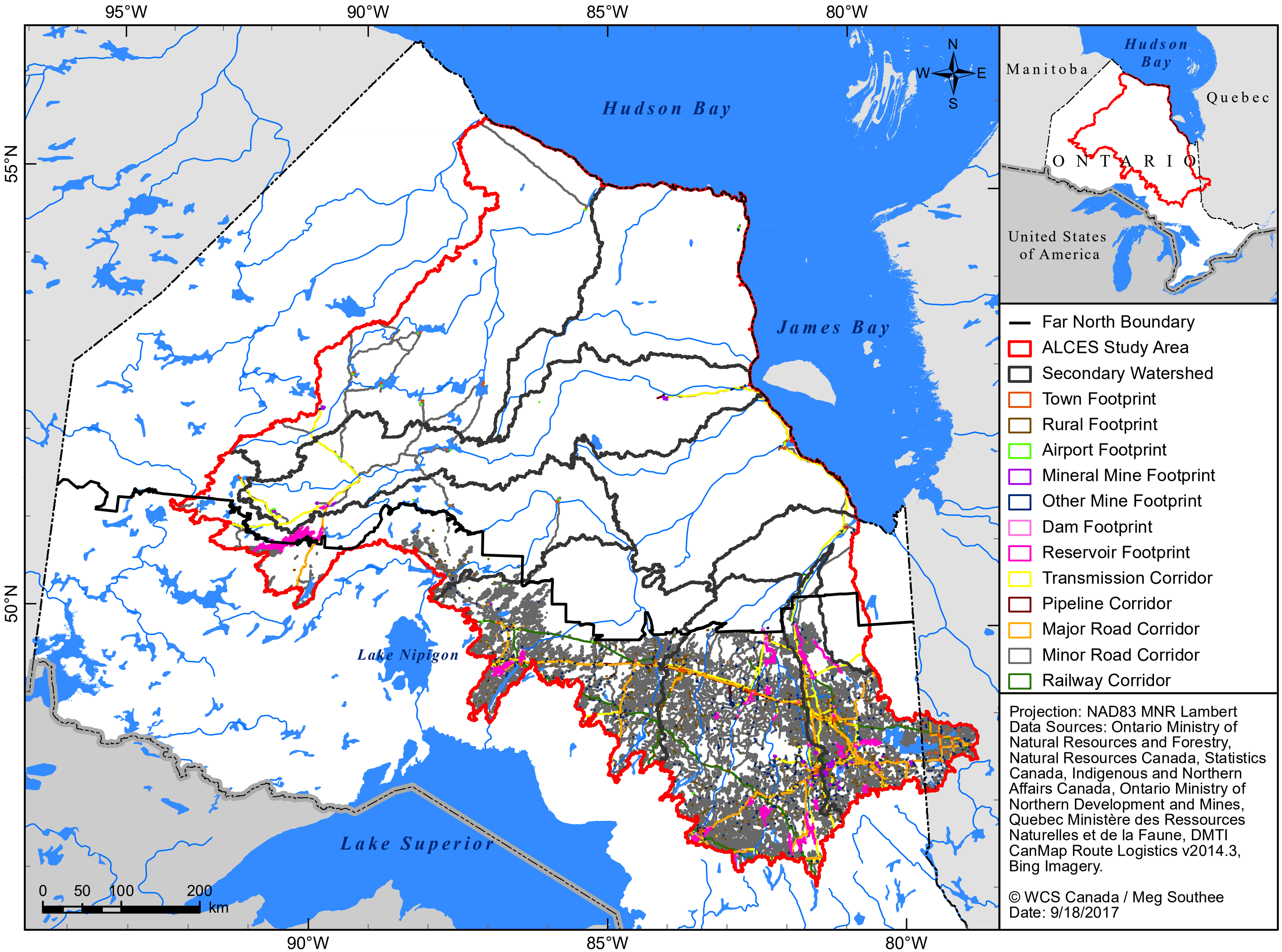


Figure 3.2. All anthropogenic footprints in the ALCES study area



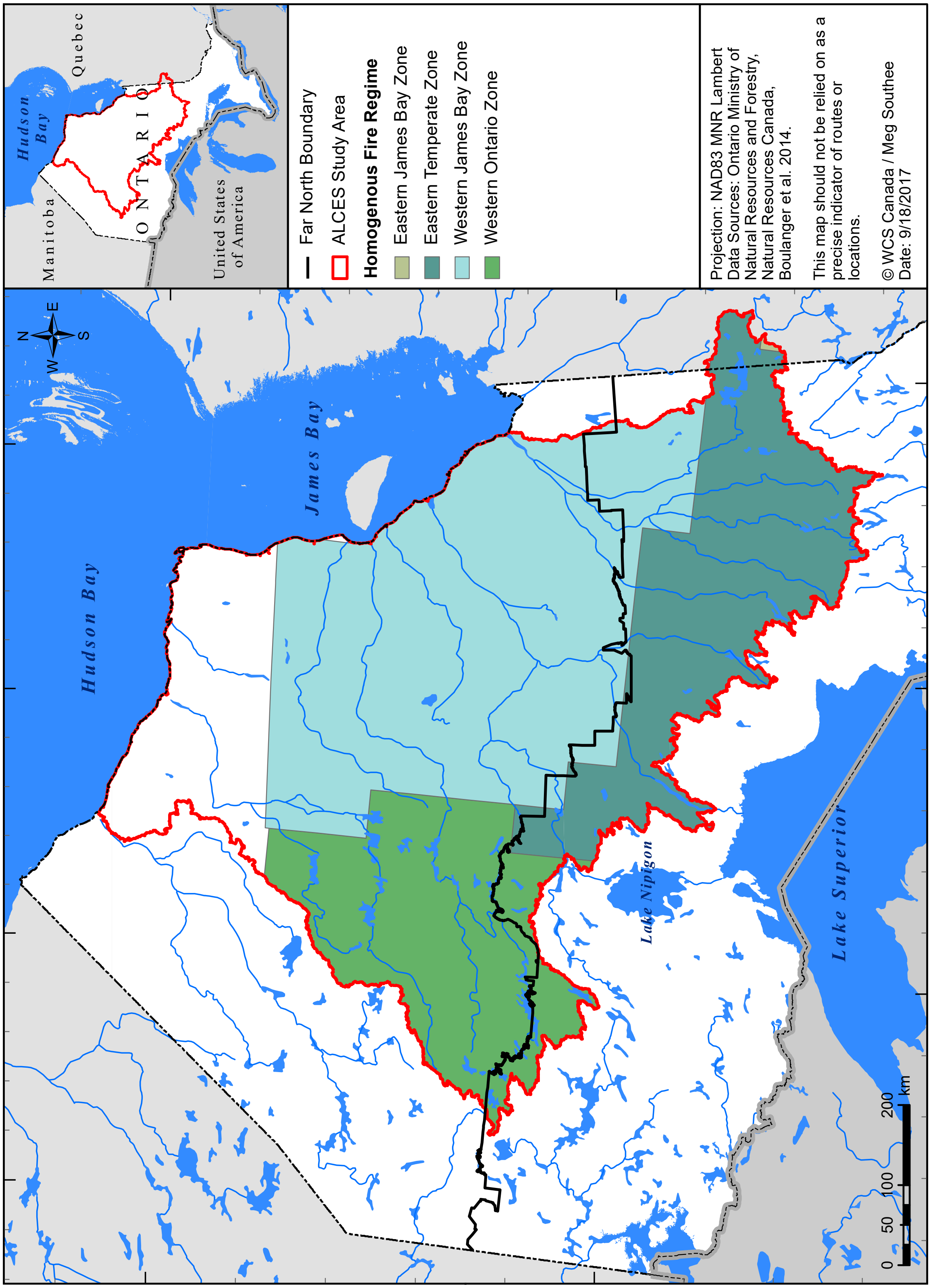


Figure 3.3. Homogenous fire regime zones created for the ALCES study area (from Boulanger et al. 2014)

importance in shaping and structuring boreal forest ecosystems and its effects on freshwater systems (Bixby et al. 2015, Kreutzweiser et al. 2013). We also considered climate change effects in each scenario. In this section, we describe how we developed the scenarios for each stressor.

3.2.1 Fire Scenario

The current (2014) burn rate differs across the study area due to variation in climate, fuels, human impact (e.g., fire suppression), and topography (Figure 3.3). Burn rates in the boreal forest are expected to change in the coming decades in response to a changing climate (Price et al. 2013). To represent spatial and temporal patterns in burn rate, homogenous fire regime (HFR) zones under current and future climate were applied (Boulanger et al. 2014[19]). For the 2011-2040 period, burn rates in HFR zones that overlap with the study area[20] range from 0.03%/year to 1.04%/year. Burn rate increases to the west (e.g., Ontario Shield) due to weather and vegetation, and exhibits a very low rate (0.03%) in the managed forest to the east, likely due to fire suppression (Martell and Sun 2008; but see Bridge et al. 2005). Burn rate approximately doubles for the 2041-2070 period.[21] The burn rates presented by Boulanger et al. (2014) are an average across combustible cover types including trees, shrubs, grasses, herbs, bryoids, and vegetated wetlands.

3.2.2 Climate Change Scenario

We obtained downscaled North America Historical climate data at a resolution of 10 km from the Canadian Forest Service (McKenney et al. 2011). We used Representative Concentration Pathway (RCP) 8.5 to generate our climate change scenarios in this study. RCP 8.5 is based upon the revised and extended storyline of the Intergovernmental Panel on Climate Change (IPCC) A2 scenario (Riahi et al. 2011) and corresponds to a high greenhouse gas emissions pathway, representing the failure of humans to curb current warming trends by 2100 (Fisher et al. 2007). Under this "worst-case" scenario, GHG emissions are up to seven times higher than preindustrial levels (McDermid et al. 2015b). RCPs are designed to address uncertainty and support research on impacts and potential policy responses to climate change.

3.2.3 Forestry Scenario

The simulated timber harvest rate in FMUs in Ontario was based on annual allowable cuts (AACs) for each FMU as reported in respective Forest Management Plans (Figure 2.4). In Québec, the simulated harvest rate was based on AACs of the management units as reported by the Québec government. The AACs were adjusted based on the proportion of each FMU's productive forest area occurring within the study area (Appendix 1, Table 3.3). Expansion of forestry north of the AOU (e.g., under Declaration Order MNR-71) was not simulated due to high uncertainty associated with First Nation applications for commercial or industrial forestry management. In the Abitibi River Management Unit, timber harvest was also excluded from a "no-harvesting zone" (referred to as Zone 3) that is part of an agreement to protect woodland caribou habitat (CBFA 2012)[22] (Figure 3.4).

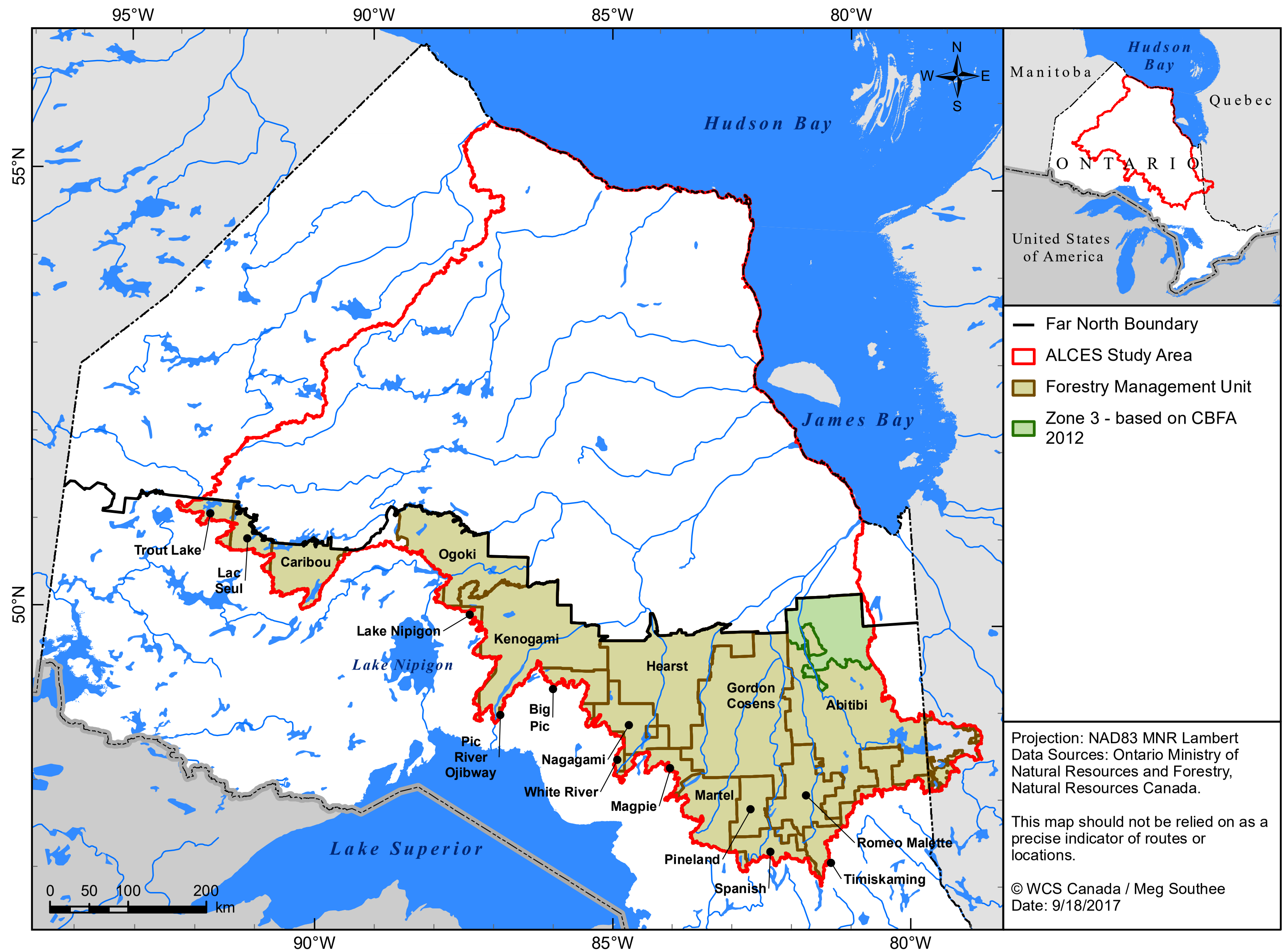
[19] The HFR zone polygons were obtained from the author and used with permission in our analyses.

[20] The northern edge of the study (i.e., north of 54.5 latitude) is beyond the northern extent of the HFR zones, and was assumed to have the same fire rate as the Western James Bay HFR zone with which it shares the largest boundary.

[21] The burn rate was simulated to increase linearly from the 2011-2040 rate to the 2041-2070 rate.

[22] We acknowledge that there is no public information confirming that MNRF has officially approved this zonation.

Figure 3.4. Current forest management units within the ALCES study area, including a caribou management zone within the Abitibi Forest Management Unit (from CBFA 2012)



Primary and branch roads to access cutblocks were simulated at a rate of 0.00008 km per m^3 of timber harvest, based on the area-weighted average planned road construction across the FMUs.[23] Primary and branch forestry roads were created at 20 m width (i.e., minor roads in our simulation) and considered permanent over the length of the simulation.[24] Operational roads, such as those constructed within cut blocks, are more transitory and were assumed to reclaim within cut blocks. This assumption may be optimistic given that Ontario wood supply analyses commonly assume that 2.5-3% of harvest area is lost to operational roads and landings that are not reclaimed (Arborvitae Environmental Services Ltd. 2004).

3.2.4 Hydroelectric Scenario

There are eight generating stations, 25 non-hydroelectric dams, including diversions for flood control, and 15 run-of-river[25] dams in the study area (Figure 2.5). Taken together, hydroelectric generation covers 0.05 km^2 of the Far North Planning Area and 0.37 km^2 of the area south of the Far North Planning Area.

Ontario's Long-Term Energy Plan (LTEP) provides limited information on *potential* hydroelectric facilities (ME 2013). Consequently, we used the more dated Integrated Power System Plan (IPSP) to help develop high- and low-growth hydroelectric scenarios for the study area. The sites identified in the IPSP were compared against reviews of the feasibility of hydroelectric sites made by HATCH (2005, 2013).

The IPSP includes projects that would be subject to policy constraints in the study area. There are 45 sites identified in our hydroelectric scenarios that are subject to either the Moose River Basin Commitment (MRBC) or the Northern Rivers Commitment (NRC) (Figure 2.6). For our project, we assumed these sites would be developed in co-management with First Nations. In addition, six sites are wholly located in protected areas such as provincial parks.

Scenarios explored two levels of hydroelectric development:

- The high-growth scenario implements the IPSP trajectory of 14 planned sites by 2024. Thereafter, potential (as opposed to planned) IPSP sites are developed as well as the most-effective site in proximity to each of the eight First Nation communities north of Pickle Lake (HATCH 2013).
- The low-growth scenario implements the 2025 LTEP target by developing the three planned sites with the earliest projected in-service dates during the first decade of the simulation. The remaining 15 planned sites are then developed over the next four decades, as are the two most cost-effective sites in proximity of First Nation Communities north of Pickle Lake (HATCH 2013). The low-growth scenario develops almost half of the capacity as the high scenario (1935 MW compared to 4658 MW) and about one-third as many dams (18 as opposed to 54 dams).

"New" dam footprints (e.g., reservoirs) were generated using a custom-built modeling tool that estimated the zone of impact based on proposed head heights and surrounding topography measured using a digital elevation model (DEM) for Ontario. Transmission lines and roads were created to link dams with the current provincial transportation network and transmission grid. Core

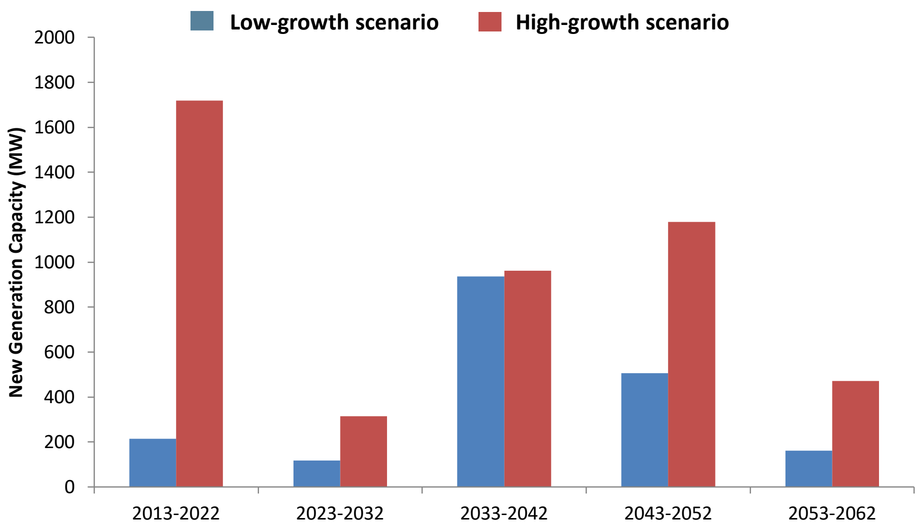
[23] Planned (i.e., 5-year) road construction length for each FMU was obtained from FMPs, and converted to km/m3 by dividing road construction length by the planned rate of harvest.

[24] Although branch roads are not considered permanent in Forest Management Plans, they are also not necessarily reclaimed. For example, the Hearst FMP states that future use management of branch roads is unplanned to maintain flexibility for future operations or use by other parties; if no future access is required, then a road typically becomes the responsibility of MNRF. Some FMPs identify roads for decommissioning, but it is not prevalent.

[25] Type of dam where hydroelectric generation has little or no water storage (e.g., reservoir).

transmission and transportation corridors are described below. The number of dams emerging during each decade under each scenario is summarized in Figure 3.5 and Figure 3.6a, b, c. More detail on the hydroelectric scenarios is provided in Appendix 1, Table 3.4.

Figure 3.5. Hydroelectric generation capacity added each decade according to the low-growth and high-growth scenarios.



3.2.5 Mining Scenario

There are eight gold mines, one copper/zinc mine and one diamond mine currently operating in the study area[26] (Figure 2.8). Several additional mines are in the planning stage. The following sources of information were integrated to generate mining scenarios: an assessment of the mining sector's future in northern Canada (Rhéaume and Caron-Vuotari 2013); a load forecast for new mining development in northwestern Ontario (CVNW Energy Task Force 2013); mine development scenarios for the Ring of Fire (Hjartarson et al. 2014); and a listing of projects undergoing environmental assessment.[27]

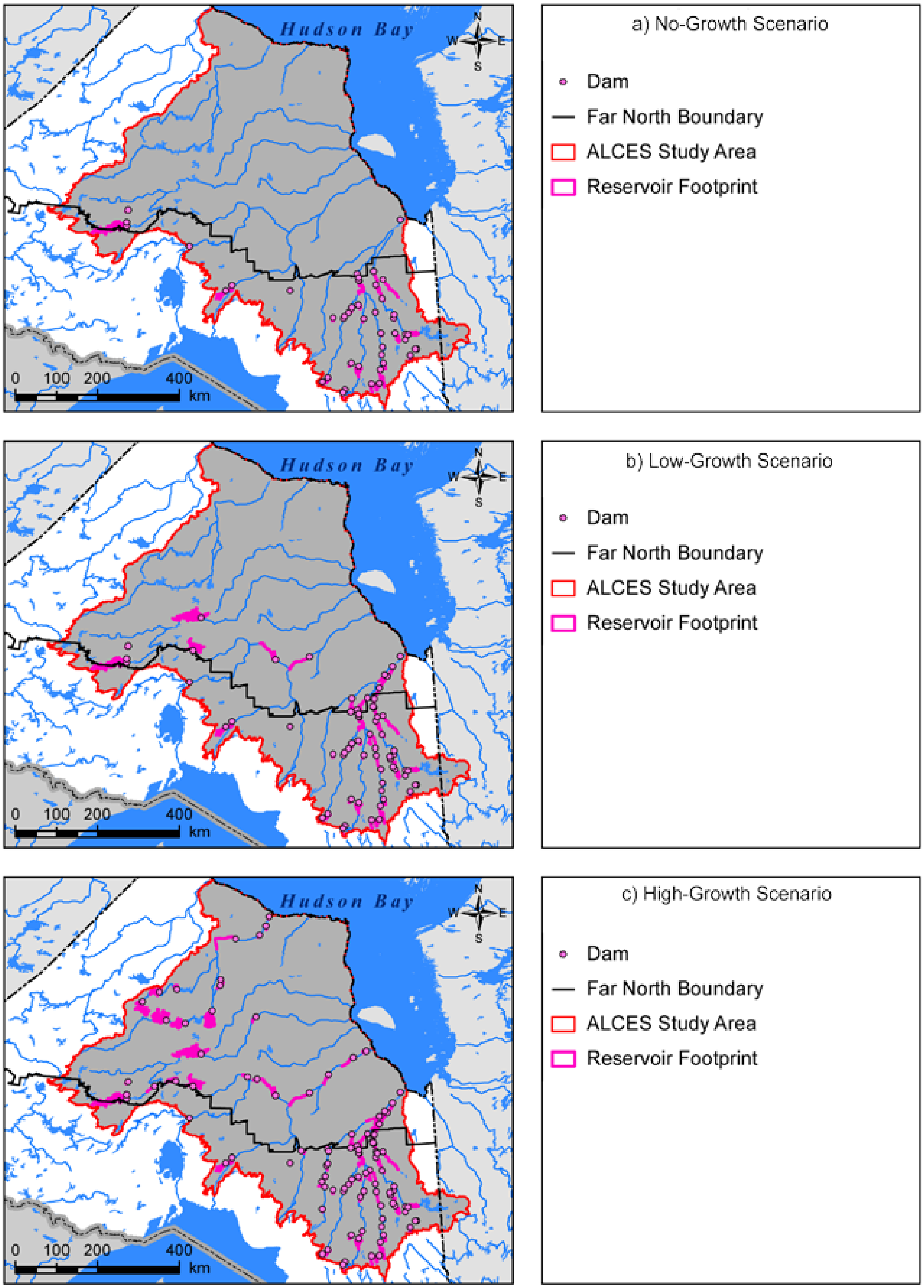
Scenarios explored two levels of mine development:

- The high-growth scenario includes all mines identified by Rhéaume and Caron-Vuotari (2013), CVNW Energy Task Force (2013), Hjartarson et al. (2014), and those undergoing environmental assessment according to their production schedule. Thereafter, the rate of development is extrapolated to maintain a constant number of producing mines during the scenario. Relative to today, the scenario maintains a similar level of gold, diamond, and nickel/copper production and incorporates the emergence of a chromite mining industry. This rate of development is within the bounds of the "business-as-usual" scenario for global resource use developed by the United Nations Environment Program International Resource Panel (2011). Under this scenario, natural resource consumption increases more than three-fold between 2000 and 2050 as per capita natural resource consumption continues to follow the recent trend of "stabilization" in industrial countries and "increasing" in developing countries.

[26] According to the Ontario Prospectors Association (2015), there are eight operating gold mines (Bell Creek, Black Fox, Dome, Hollinger, Holloway-Holt, Hoyle Pond, Musselwhite, and Timmins West), one operating base metal mine (Kidd Creek), and one operating diamond mine (Victor). Dome, Hoyle Pond and Hollinger are managed as a single mine complex called the Porcupine Mine Complex.

[27] Information on projects undergoing environmental assessment was obtained at www.ceaa-acee.gc.ca

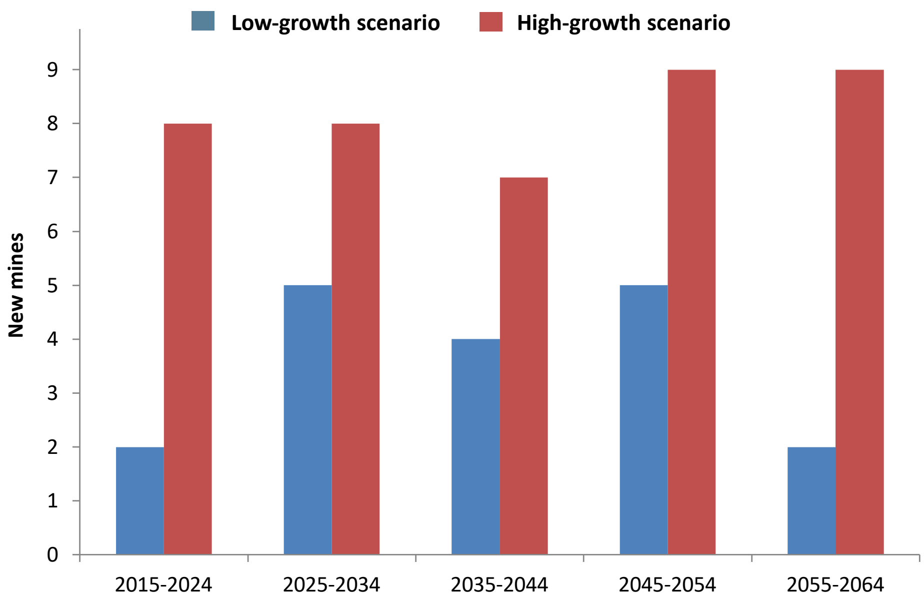
Figure 3.6. The location of hydroelectric power generation sites in the ALCES study area based on: a) current footprint (no-growth scenario); b) low-growth scenario; and, c) high-growth scenario



- Under the low-growth scenario, the number of mines developed is reduced to approximately half of those in the high-growth scenario.

The number of mines emerging in each decade under the high- and low-growth scenarios is summarized in Figure 3.7 and Figure 3.8a, b, c. We provide more detail on each mining sector under the high- and low-growth scenarios in Appendix 1, Tables 3.5 – 3.9. Transmission lines, roads, and a railway were created to link mines and energy sources with the current provincial transportation network and transmission grid. Core transmission and transportation corridors are described in the next section.

Figure 3.7. Number of new mines created per decade according to the low- and high-growth scenarios.

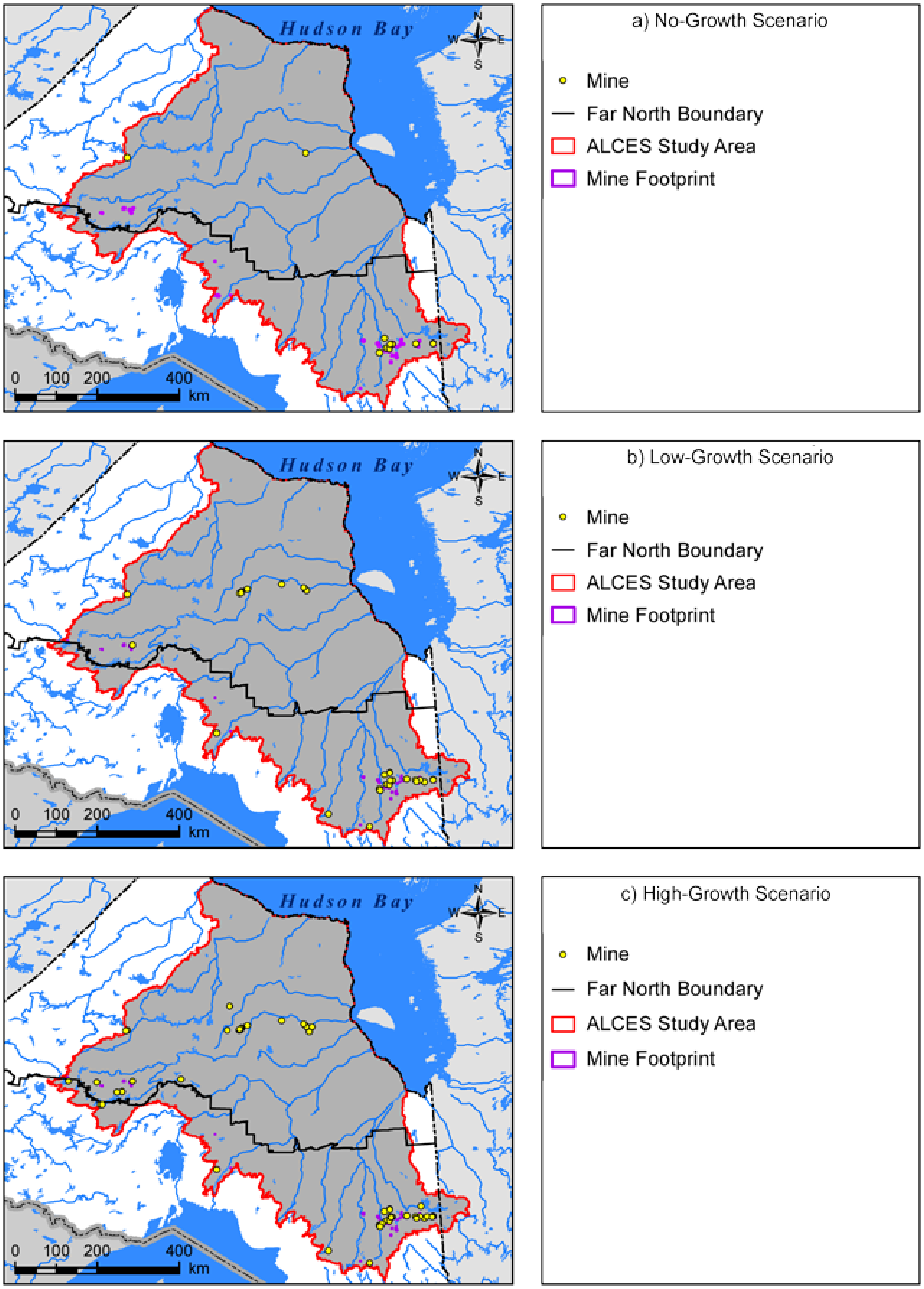


3.2.6 Transmission and Transportation Corridors Scenario

The current density of linear footprint varies across the study area, ranging from 0.01 km/km^2 in the Far North to 0.53 km/km^2 in the region south of the Far North Planning Area (Figure 2.10, Figure 2.11). Overall, linear feature density for the entire study area is 0.18 km/km^2. Linear footprint is dominated by minor roads, followed by transmission lines, major roads, railways and pipelines (Appendix 1, Table 3.10).

The mining and hydroelectric scenarios include several developments in remote Far North locations of the study area that are not currently linked to existing provincial road and transmission networks, including the Ring of Fire mines, mines in the Pickle Lake region, dams along the Upper and Lower Albany River, a dam on the Attawapiskat, and dams along the Winisk River. In addition, there are 25 remote First Nations communities in northwestern Ontario where a new transmission line network is planned (e.g., Wataynikenayap Power) to replace diesel generation (OPA 2014).

Figure 3.8. The location of mines within the ALCES study area based on: a) current footprint (no-growth scenario); b) low-growth scenario; and, c) high-growth scenario



Road and transmission corridors created in the simulations to link remote developments and communities are summarized in Table 1 (Figure 3.9a, b, c). Transmission line corridors were 40 m wide, as were railways and major roads. Other road corridors (e.g., minor roads) were 20 m wide. New mines and dams in the Far North were connected to the nearest corridor. Dams in the Upper Albany basin were linked to the transmission network near Nakina, as was done for previous scenarios in the James Bay ecoregion (see Carlson and Chetkiewicz 2013) and the dam in the vicinity of the Ring of Fire was linked to the transmission network servicing the Ring of Fire. Within the AOU, mine access was linked to the forestry road network.

Table 1. Transportation and transmission corridors developed for the land-use simulations.

Corridor	High-growth Scenario	Low-growth Scenario
East-West corridor to the Ring of Fire from Pickle Lake as well as spurs to remote communities and connection to dams along the Winisk River	✓	✓
Corridor from Dinorwic to Pickle Lake to serve energy demands north of Dryden and connect remote communities north of Pickle Lake	✓	✓
Twinning of the existing transmission corridor from the Moose River basin to Sudbury	✓	✓
North-South corridor from Nakina to the Ring of Fire	✓	
Regional community service corridor between Eabametoong, Neskantaga, Nibinamik, and Webequie First Nations.	✓	

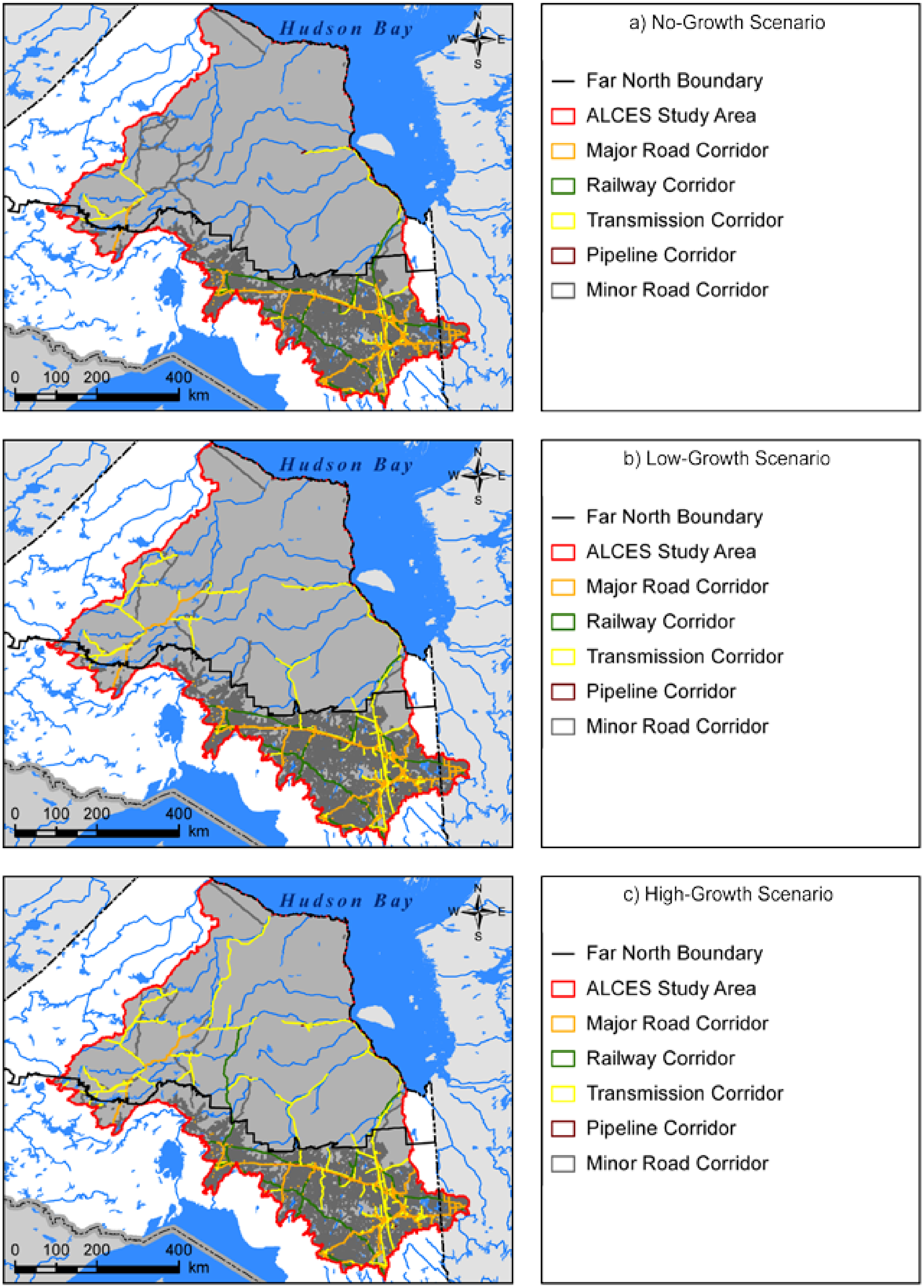
3.3 Impacts to Fish Populations in the Study Area

3.3.1 Drivers of Change

Based on a literature review and conceptual model development (Figure 1.2), together with expert opinion (workshop), the following effects were considered when assessing impacts to freshwater fish populations:

- Fishing;
- Non-native species;
- Stream fragmentation;
- Nutrient and sediment loading;
- Increased temperatures;
- Changes in water quality and flow regimes due to dams; and
- The effect of mercury on fish populations (not on human consumption).

Figure 3.9. The location of linear infrastructure within the ALCES study area based on: a) current footprint (no-growth scenario); b) low-growth scenario; and, c) high-growth scenario



Assessment of stream fragmentation and sediment loading required additional modeling to define how land use affects these stressors. These details are described in Appendix 2 and 3 respectively. The impact of mercury contamination from mines on the viability of fish populations was identified by experts as being negligible and was not considered further in this report. However, we do acknowledge that mercury contamination is an important human health issue since mercury accumulates in freshwater fish, which are important components of First Nations diets, particularly in the Far North region of the study area (e.g., Tang et al. 2013).

3.3.2 Dose-response Relationships

Relationships describing the response of fish populations to simulated land use and climate change stressors were prepared using an approach used by the Government of Alberta to consider cumulative effects of land use and climate change on fish populations (Sullivan 2017). The approach utilizes professional opinion and, where possible, empirical data to derive hypotheses that link fish population sustainability to several effects associated with land use and climate change. The hypotheses inform a strategic-level model that can be used to explore the relative importance of these effects on fish conservation at the watershed-scale and the expected changes in population sustainability in response to changes in the magnitude of stressor impacts. As part of a broader adaptive management framework, the models (i.e., hypotheses) are improved through time, using information acquired through management, research, and monitoring. The response variable is population sustainability as assessed using the fish sustainability index (FSI, MacPherson et al. 2014).

The FSI is a population level metric that conveys risk of extirpation using a scale ranging from 0 (functionally extirpated) to 5 (very low risk of extirpation). The relationship between the index, fishery status, and risk of extirpation is defined in Table 2. The FSI is used in Alberta to assess provincial fish stocks through landscape-level assessment of fish sustainability, temporal comparisons in sustainability, comparisons between sustainability and management actions and development of planning priorities (MacPherson et al. 2014). Lester et al. (2003) proposed a similar set of "stages" as biological reference points for Ontario's fisheries assessment. For example, Stage 1 (= healthy), characterized by low fishing mortality and high biomass; Stage 2 (= overexploited-early), characterized by high fishing mortality and high biomass; Stage 3 (= overexploited-late), characterized by high fishing mortality and low biomass; and, Stage 4 (= degraded, recovering), characterized by low fishing mortality and low biomass).

Table 2. Risk and fishery status associated with fish sustainability index rankings (modified from MacPherson et al. 2014).

FSI rank	Risk Assessment	Fishery status
0	Functionally extirpated	Eliminated
1	Very high risk	Barely detectable
2	High risk	Recruitment overfishing
3	Moderate risk	Growth overfishing that is near the maximum sustainable yield
4	Low risk	Slight growth overfishing that is less than maximum sustainable yield
5	Very low risk	Population is at carrying capacity

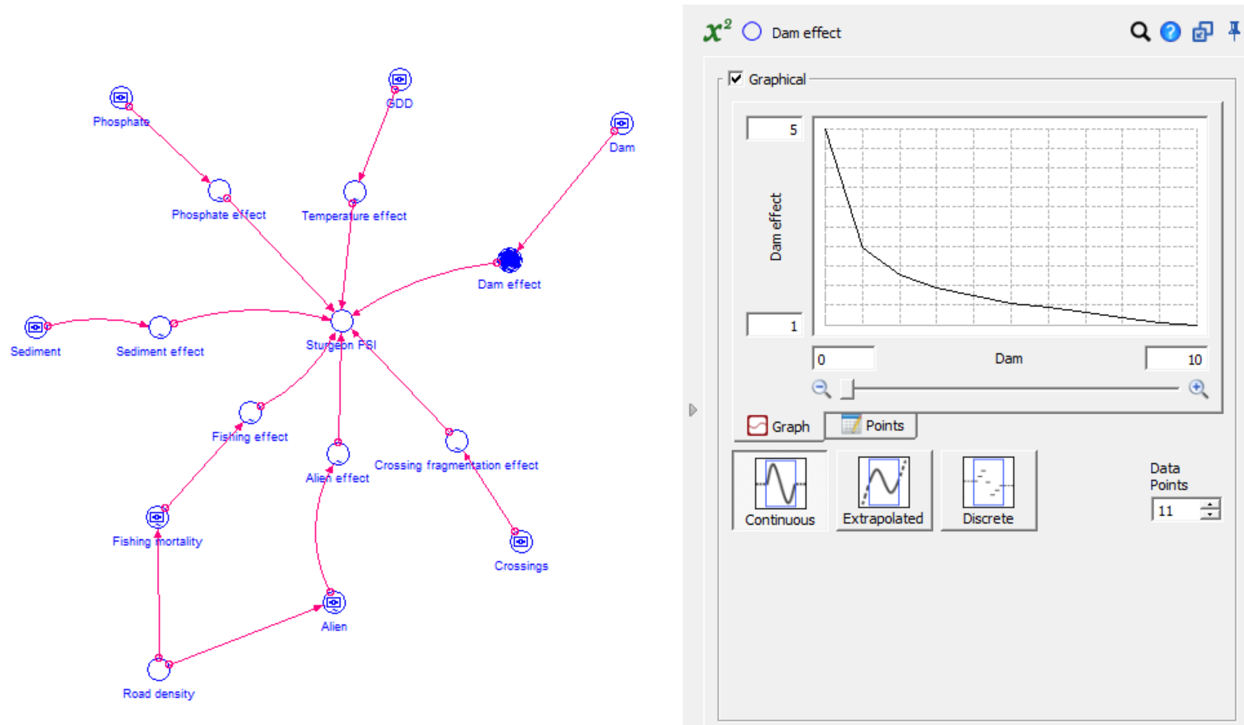
FSI models were prepared for four species in the study area: walleye, lake whitefish, brook trout, and lake sturgeon. For each species, the model is composed of dose-response curves that describe the relationship between effects arising from change in land use and climate and FSI.

Dose-response curves were defined using professional opinion gathered during a workshop attended by northern Ontario fishery experts (Appendix 4). The workshop, held in Thunder Bay in April 2016 (Appendix 5), was facilitated by Government of Alberta fishery scientist Dr. Michael Sullivan and followed a format used in Alberta to gather professional opinion to define FSI (Sullivan 2017).

ALCES Online was initially used to display maps of variation in stressor magnitude across watersheds in the study area. The maps, when combined with the knowledge of regional fishery experts, informed the definition of dose-response curves that were entered into a system diagram using Stella 10.1 (www.iseesystems.com) (Figure 3.10). Stella allows users to create system diagrams and consider hypotheses. To assess the cumulative impacts of land use and climate change on FSI, each species' system diagram model combined the dose-response relationships multiplicatively. Once completed, FSI models for each species were applied in ALCES Online to map the hypothesized response of fish sustainability to current and simulated future magnitude of stressors in the study area. Stressors and FSI response were assessed at the quaternary watershed scale, except where noted.

Our approach utilized both ALCES Online and Stella modelling software to review stressors, build dose-response hypotheses, and visualize their implications. Utilizing both models concurrently allowed the workshop participants to take advantage of ALCES Online's capacity to rapidly map current and future threats (based on the scenarios described above) and their consequences, with the utility of Stella's user-friendly platform to define strategic indicator relationships.

Figure 3.10. Example of a system diagram built using Stella software describing the relationship between key stressors and lake sturgeon FSI. The diagram contains the dose-response relationships between each stressor (e.g., hydroelectric dams) and its effect on FSI.



Hypothesized dose-response curves for each stressor were developed based on the literature, a review of current and predicted footprints, and expert opinion in the workshop. In this section, we summarize the key relationships.

3.3.2.1 Roads

Fishing Mortality

The impact of roads (and other linear features) was described during the workshop by defining curves that relate road density to fishing mortality. Walleye were identified as having relatively high sensitivity to fishing mortality that can be mitigated through access management. Brook trout were identified as having more moderate sensitivity to fishing mortality. Lake sturgeon and lake whitefish were not considered to be affected by fishing mortality due to the closure of the lake sturgeon fishery (to non-Indigenous fishers) and the absence of a significant lake whitefish recreational fishery (Figure 3.11).

We also developed a second set of curves relating fishing mortality to FSI (Figure 3.12).

Figure 3.11. Dose-response curves describing the hypothesized relationship between road density (km/km^2) and fishing mortality (%) for a sport fishery walleye and brook trout), a sport fishery with access management (AM), and a subsistence fishery (lake whitefish).

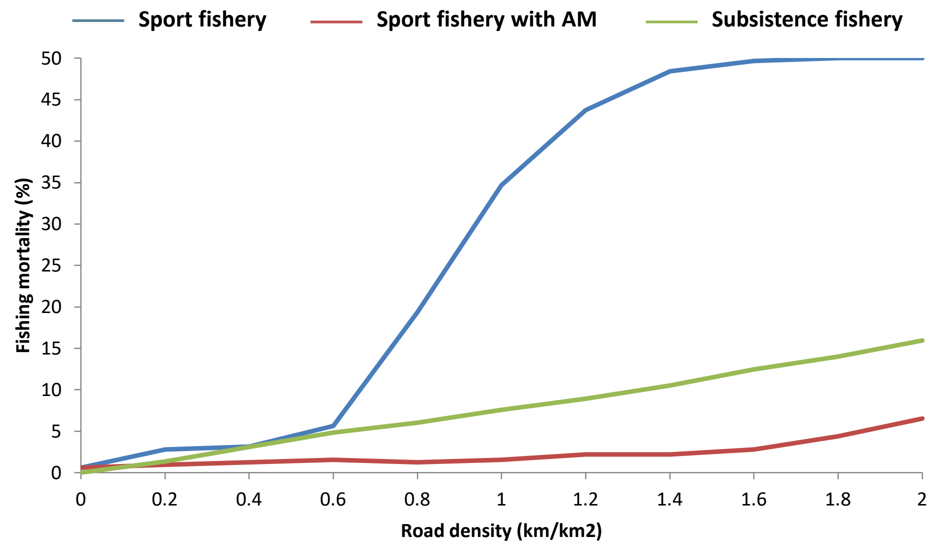
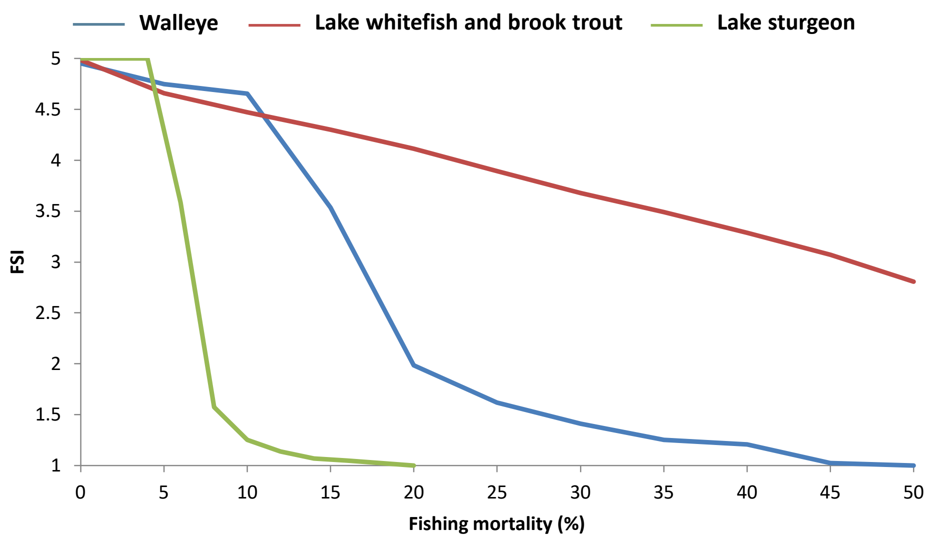


Figure 3.12. Dose-response curves describing the hypothesized relationship between fishing mortality (%) and FSI at the quaternary watershed scale. 5 = Very low risk, population is at carrying capacity, 1 = Very high risk, population is barely detectable.



Non-native Species

The impact of roads was also described by curves that relate road density to non-native species (Figure 3.13).

Brook trout were identified as having the highest sensitivity to non-native species, followed by walleye, lake whitefish, and then lake sturgeon (Figure 3.14). However, the risk of non-native species invading the study area was considered to be low.

Figure 3.13. Dose-response curve describing the hypothesized relationship between road density (km/km^2) and non-native fish species where 1 is absent and 5 is very abundant.

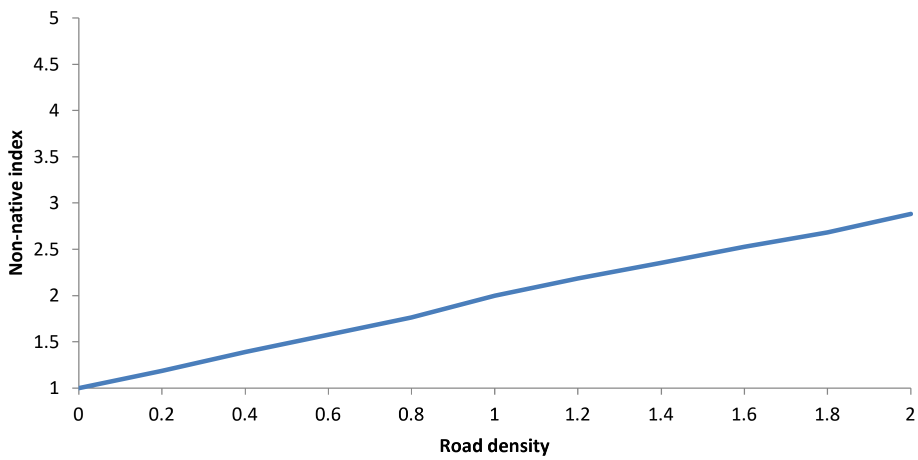
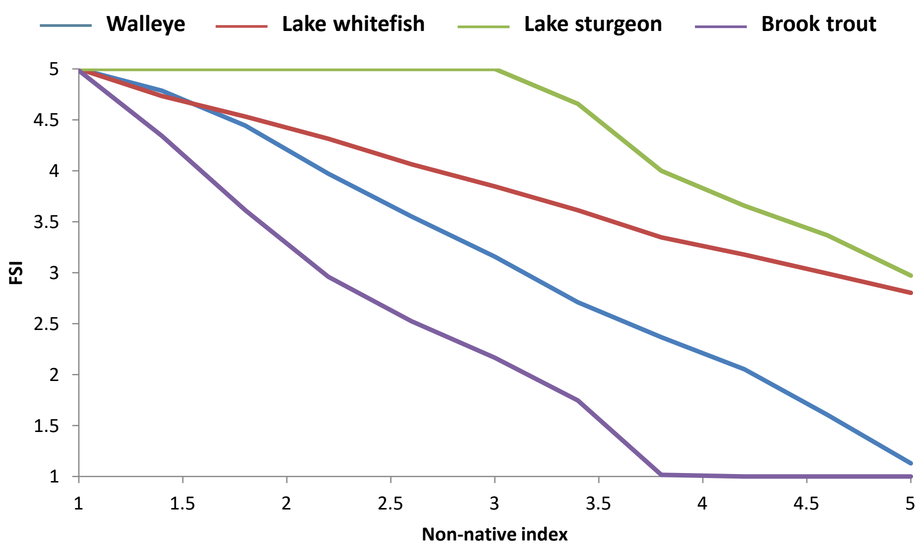


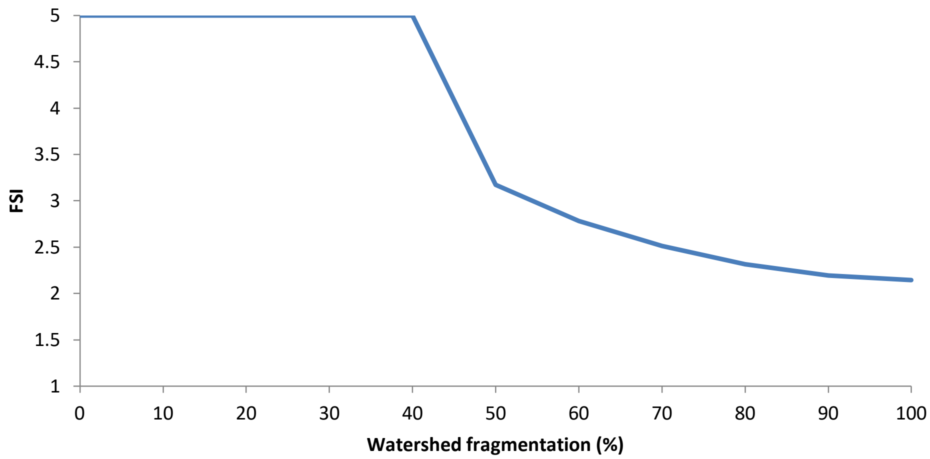
Figure 3.14. Dose-response curves describing the hypothesized relationship between non-native species and FSI at the quaternary watershed scale.



Watershed Fragmentation (Stream Discontinuity)

Stream discontinuity (Appendix 2) was hypothesized by experts to begin having a negative impact on walleye and brook trout when more than half of a quaternary watershed's stream length is made inaccessible (e.g., due to impassable culverts) (Figure 3.15). Lake sturgeon and lake whitefish were identified as being relatively insensitive to stream discontinuity and so a response curve for these species was not prepared. This relationship applies only to smaller streams and not to fragmentation of major rivers.

Figure 3.15. Dose-response curves describing the hypothesized relationship between watershed fragmentation at the tertiary watershed scale and FSI for walleye and brook trout.



Water Quality (Sedimentation)

Experts identified walleye as having the highest sensitivity to sediment (Appendix 3), although even a doubling of sediment load from natural (i.e., water quality index of 0.5) was hypothesized to have only a moderate impact (Figure 3.16). Lake sturgeon was also identified as being detrimentally affected by sediment, although only at very high levels (i.e., more than doubling of sediment load). Brook trout and lake whitefish were identified as relatively less sensitive, particularly in the Far North region. Forestry and permafrost melt may create localized issues depending on timing of activities relative to spawning. The effect of elevated phosphorus loading was identified by experts as being negligible for all species except for lake sturgeon, which was hypothesized to begin to show negative effects when phosphorous loading exceeded natural levels by a factor of two (Figure 3.17).

Figure 3.16. Dose-response curves of the hypothesized relationship between the water quality as measured by sediment water quality index (WQI) at the quaternary watershed scale, and FSI.

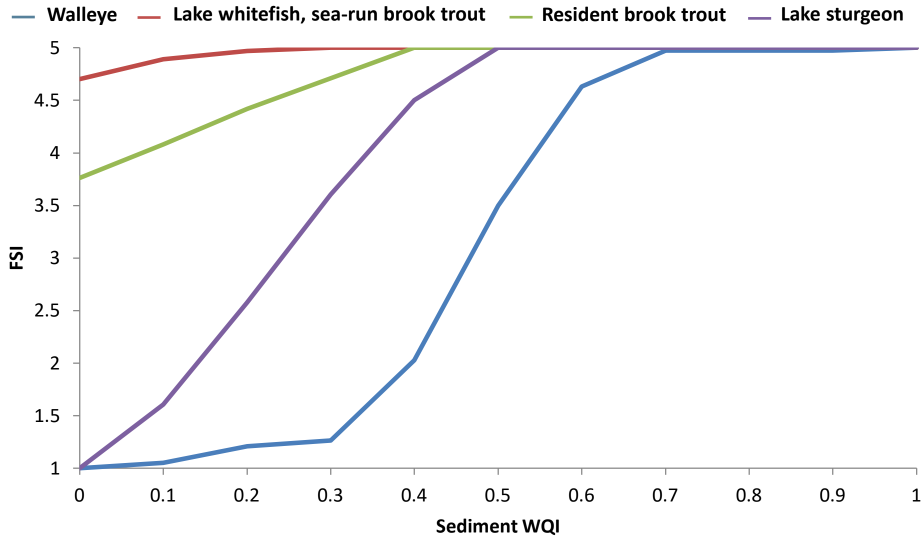
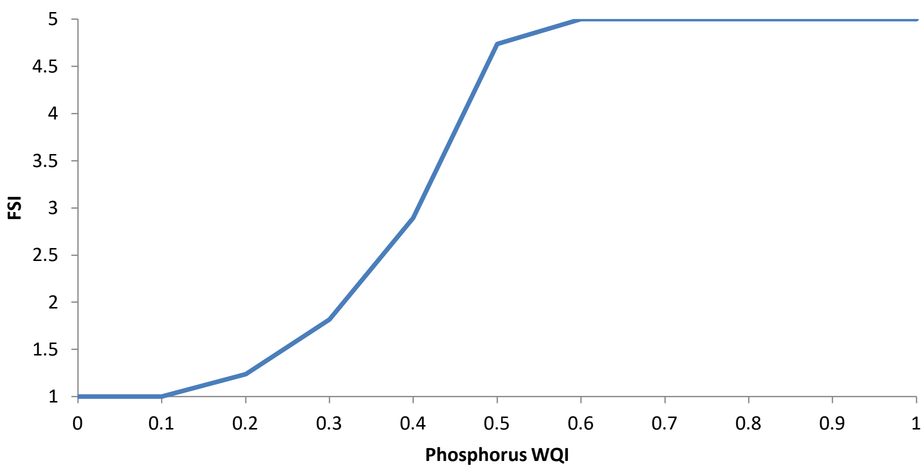


Figure 3.17. The phosphorus effect for lake sturgeon; the effect of phosphorus to other species was judged to be negligible.

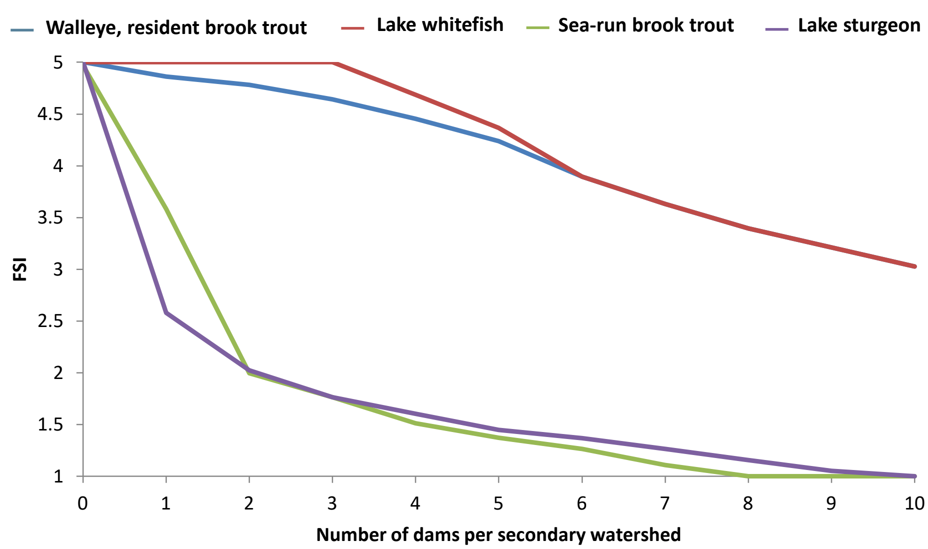


3.3.3.2 Hydroelectric Development

We assumed run-of-river (ROR) schemes have the same impacts on freshwater fish as dams, in part because of the lack of conclusive evidence to the contrary (e.g., Anderson et al. 2015). The effects of hydroelectric development were considered by experts to be more pronounced within the tertiary scale watershed where the project is located. However, we also wanted to capture the potential for impacts of dams and ROR installations at the secondary watershed scale as a result of impacts to movement (e.g., migration) and changes in flow dynamics that can have local as well as downstream impacts that extend along the entire river and watershed. Consequently, FSI was modeled at the secondary watershed scale.

Lake sturgeon and sea-run brook trout were identified by experts as having the greatest sensitivity to hydroelectric development, with two facilities being sufficient to cause high risk to fish populations within a secondary watershed (Figure 3.18). In contrast, walleye, resident brook trout, and non-migratory whitefish populations were considered to be relatively resilient to hydroelectric power installations.

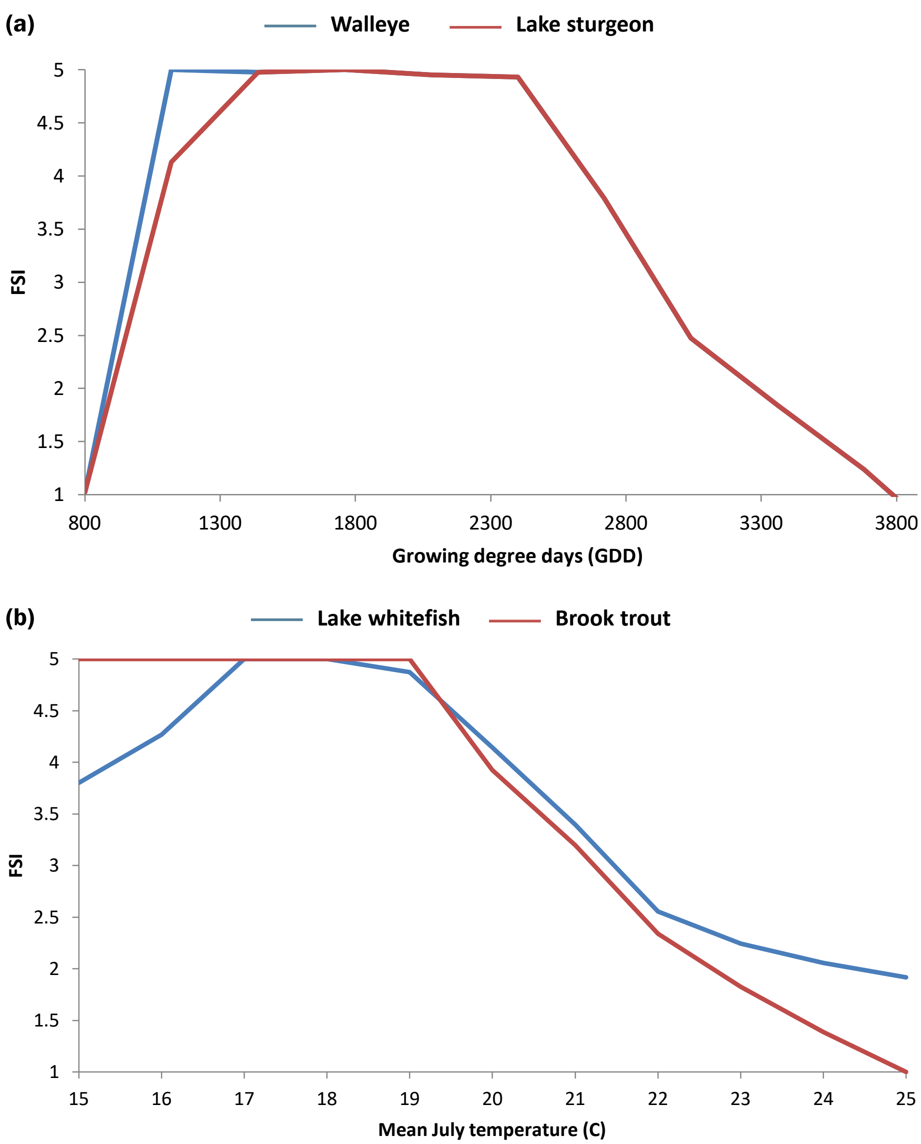
Figure 3.18. Dose-response curves of the hypothesized relationship between the number of hydroelectric facilities (dams, ROR) in a secondary watershed and FSI.



3.3.3.3 Climate Change

Loss of cold-water habitat was identified as the most important climate-related risk to walleye, brook trout, lake sturgeon, and lake whitefish. Increases in GDD and mean July temperature was inferred to cause losses in cold-water fish habitat. Walleye and lake sturgeon were hypothesized to exhibit reduced sustainability when GDD exceeded 2,000 and to be at "very high risk" when GDD exceeded 3,500 (Figure 3.19a). Negative impacts to lake whitefish and brook trout populations were hypothesized to begin when mean July temperature exceeded 20°C (Figure 3.19b). A mean July temperature of 25°C was hypothesized to present a "high risk" to lake whitefish and a "very high risk" to brook trout (Figure 3.19b).

Figure 3.19. Dose-response curves for the hypothesized relationship between (a) GDD and (b) mean July temperature and FSI.



4.0 RESULTS

4.1 Simulated Stressors

Overall anthropogenic footprint almost doubled during the high-growth scenario, increasing from 3,221 km^2 to 6,277 km^2 (Figure 4.1). Footprint intensity remained highest in the southern portion of the study area (e.g., AOU) due to ongoing timber harvest and associated road development, with comparatively smaller increases in mine and dam footprints. In the northern portion of the study area, footprint expansion was dominated by reservoirs associated with new dams as well as mine development and the associated road and transmission network expansion. Anthropogenic footprint expansion during the low-growth scenario was almost 1,500 km^2 lower than the high-growth scenario (Figure 4.1). The majority of the difference (1,220 km^2) in footprint growth was associated with reservoir expansion. It is important to note that reservoir footprint in our scenarios is greater than the area that would be flooded because the tool we used to delineate reservoirs did not discriminate between areas that are terrestrial vs. aquatic habitat prior to dam creation.

Average linear footprint density increased from 0.15 km/km^2 to 0.23 km/km^2 (Figure 4.2). The increase in linear footprint was greatest in the AOU, where quaternary watersheds exceeding 0.6 km/km^2 (the threshold at which walleye and brook trout fishing mortality is hypothesized to rapidly increase in recreational fisheries) increased from 25% to 55% during the high-growth scenario. In the Far North, no quaternary watersheds exceeded 0.6 km/km^2 of linear footprint during the simulations.

Figure 4.1. Current and simulated anthropogenic footprint expansion during the high- and low-growth scenarios. Note: % refers to coverage of each cell by footprint.

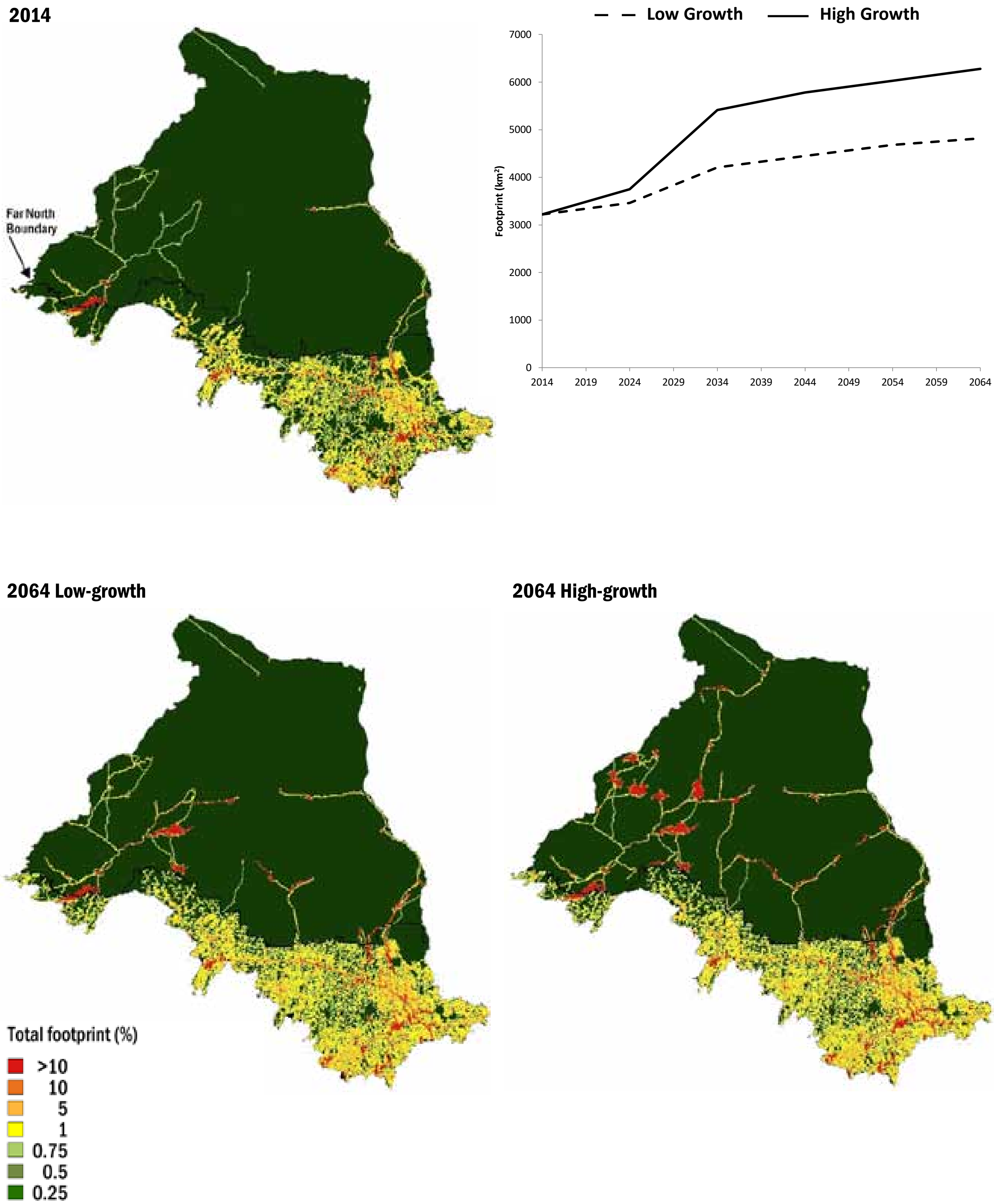


Figure 4.2. Current and simulated future linear edge density in response to high- and low-growth scenarios.

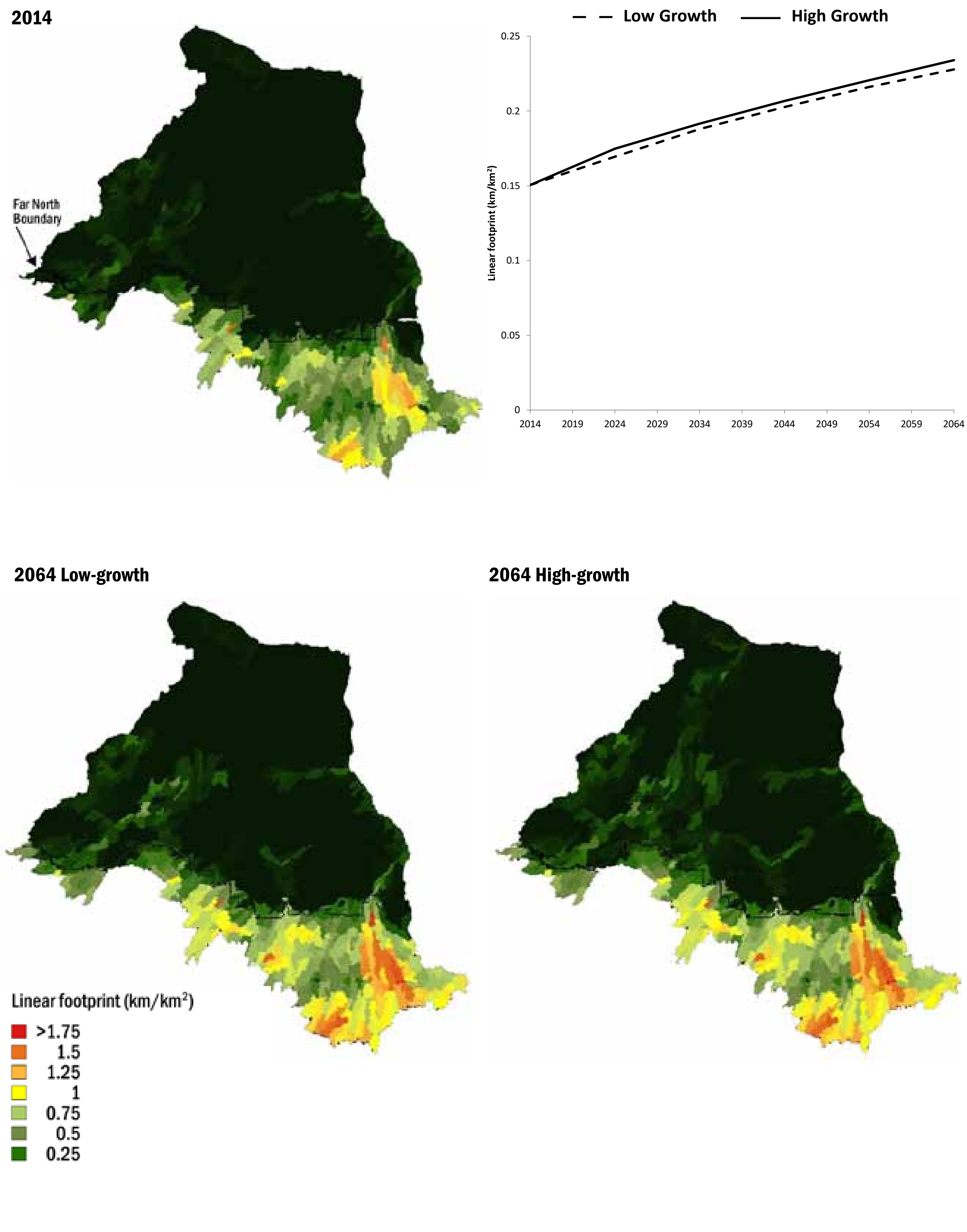


Figure 4.3. Current and simulated future watershed fragmentation in response to high- and low-growth scenarios. Note: % refers to the percent of a tertiary watershed's stream network that is upstream of impassable culverts.

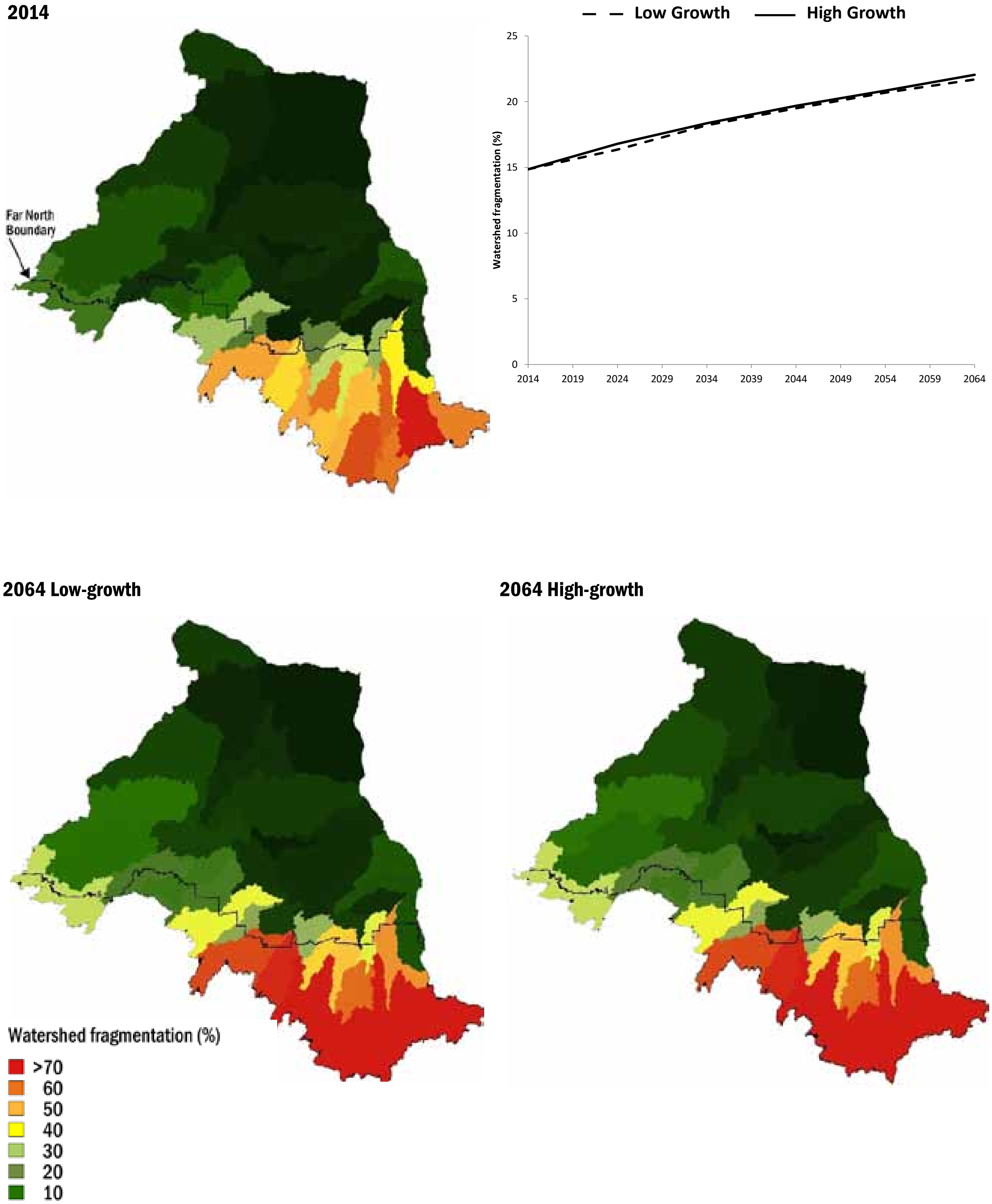


Figure 4.4. Current and simulated future sediment water quality index (WQI) in response to high-growth scenarios. Note: Only the high-growth output is displayed since simulated development was insufficient to cause levels of sediment that may be detrimental to fish population sustainability (< 0.7).

2014 **2064**

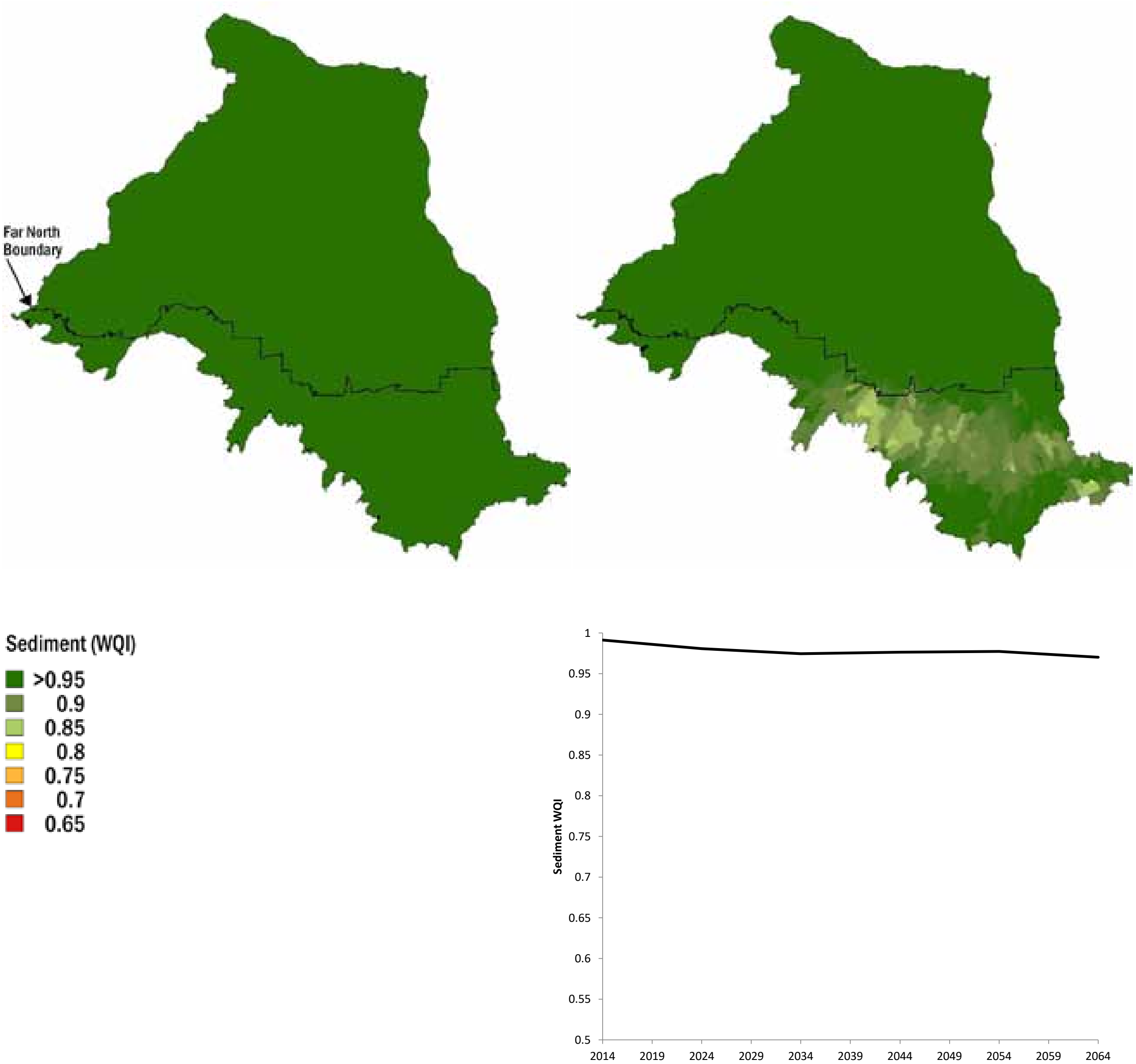
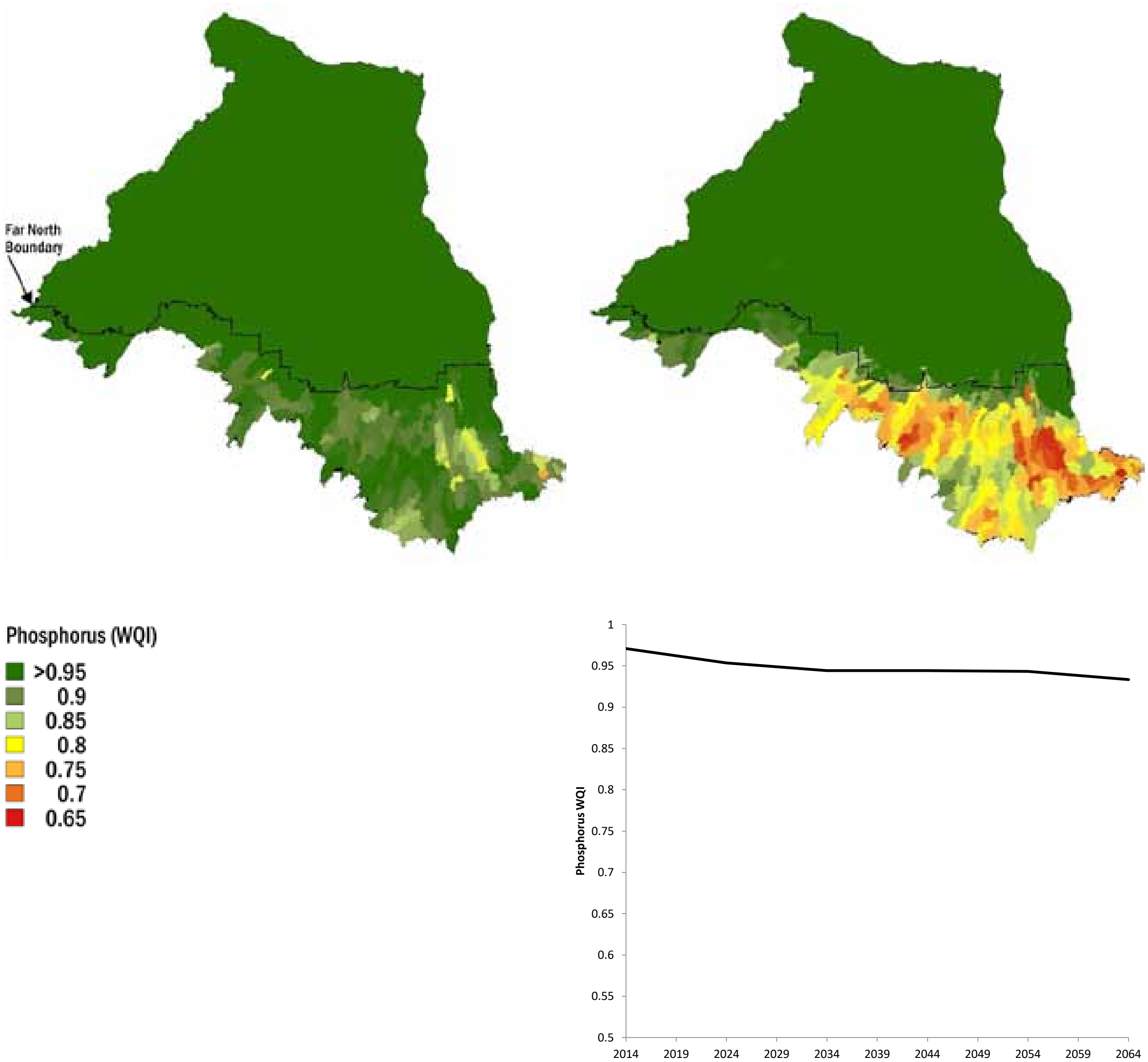


Figure 4.5. Current and simulated future phosphorus water quality index (WQI) in response to high-growth scenarios. Note: Only the high-growth output is displayed since simulated development was insufficient to cause levels of phosphorus that may be detrimental to fish population sustainability (< 0.7).

2014 **2064**



The simulated expansion of the road network increased watershed fragmentation from 15% to 22% during the high-growth scenario (Figure 4.3). As was the case with linear footprint growth, the increase in watershed fragmentation was concentrated in the AOU due to growth in the forestry road network. Watershed fragmentation increased from 39% to 56% in the AOU and from 4% to 6% in the Far North.

Growth in linear footprint was generally insufficient to cause non-native species to reach levels affecting fish population sustainability according to the hypothesized dose-response relationship (Figure 3.14). Simulated development was also insufficient to cause levels of sediment (Figure 4.4) and phosphorus loading (Figure 4.5) that may be detrimental to fish population sustainability. Sediment and phosphorus water quality indices did not decline below 0.7, the minimum value hypothesized to cause impacts to fish (Figure 3.16, Figure 3.17).

One land use exhibiting substantial growth in the Far North region of the study area was the number of hydroelectric facilities (dams, ROR) per secondary watershed (Figure 4.6). The area-weighted average number of dams per watershed in the Far North region of the study area increased from less than one to almost six during the high-growth scenario, and from eight to 16 in the AOU. Overall, the average number of dams per secondary watershed increased from almost three to more than nine. These effects are likely to impact migratory species such as lake sturgeon and lake whitefish in particular.

The RCP 8.5 climate scenario resulted in a substantial increase in mean July temperature (Figure 4.7) and GDD (Figure 4.8). By the end of the simulation period, almost the entire study area (86%) exhibited mean July temperatures and GDD that exceeded the hypothesized optimal levels for the fish species (i.e., 19°C and 2,400 GDD, Figure 3.19a, b).

Figure 4.6. Current and simulated future abundance of dams in secondary watersheds in response to high- and low-growth scenarios.

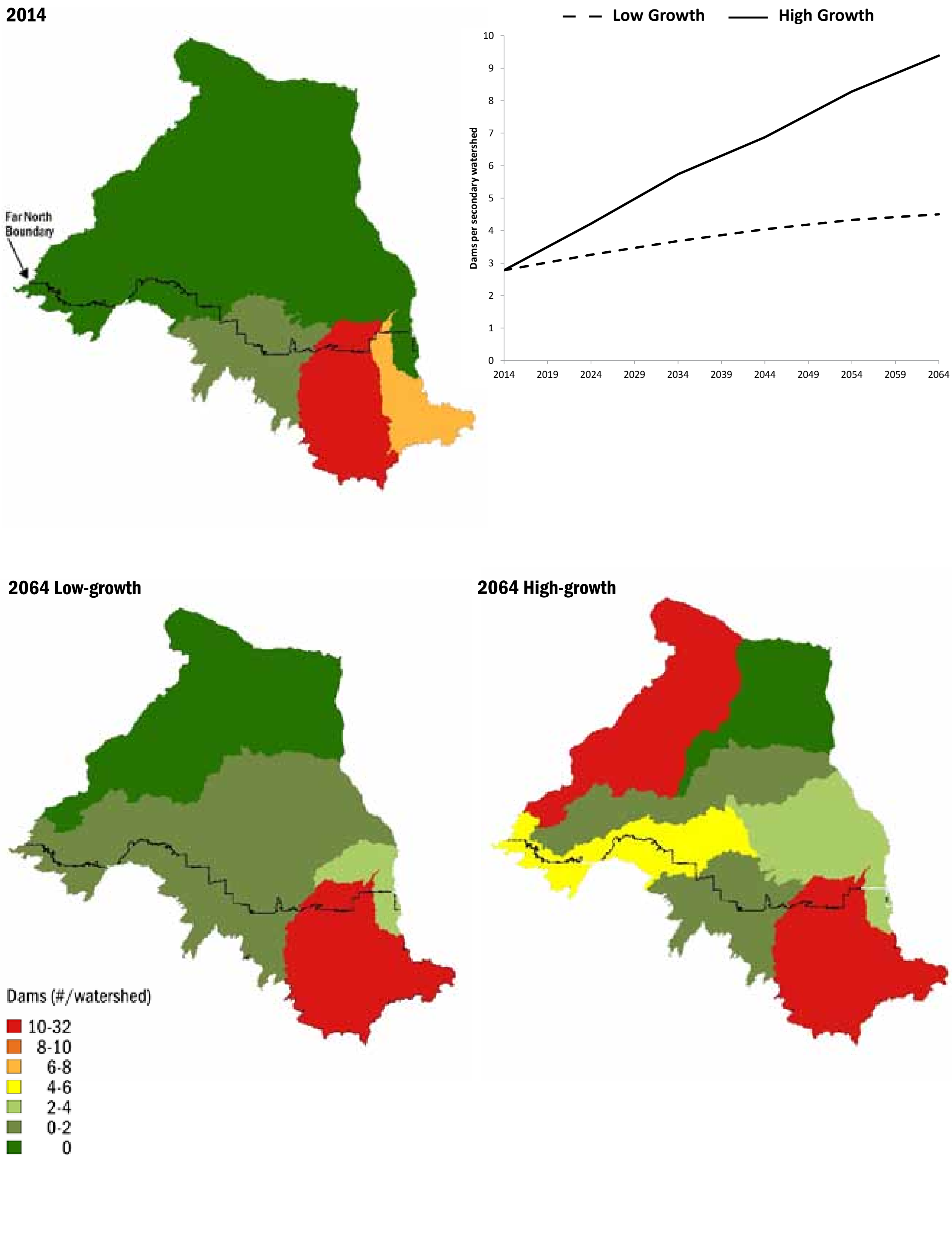


Figure 4.7. Simulated increase in mean July temperature based on RCP 8.5.

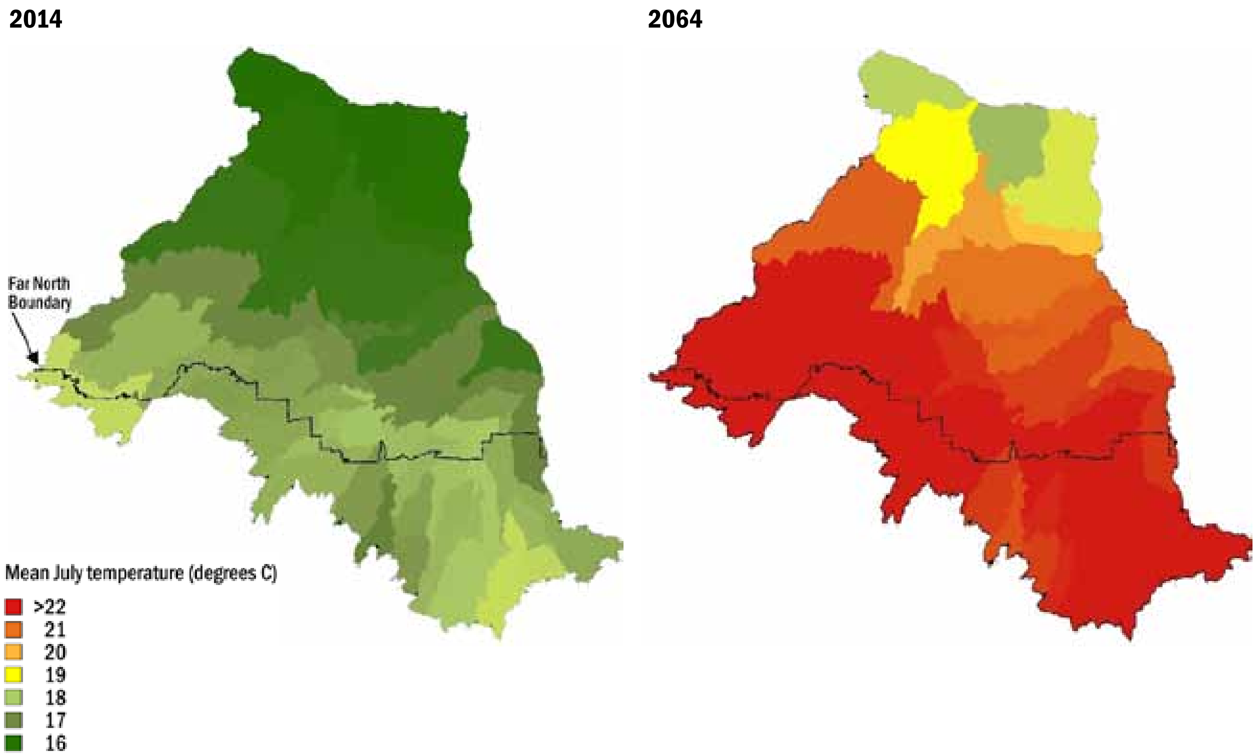
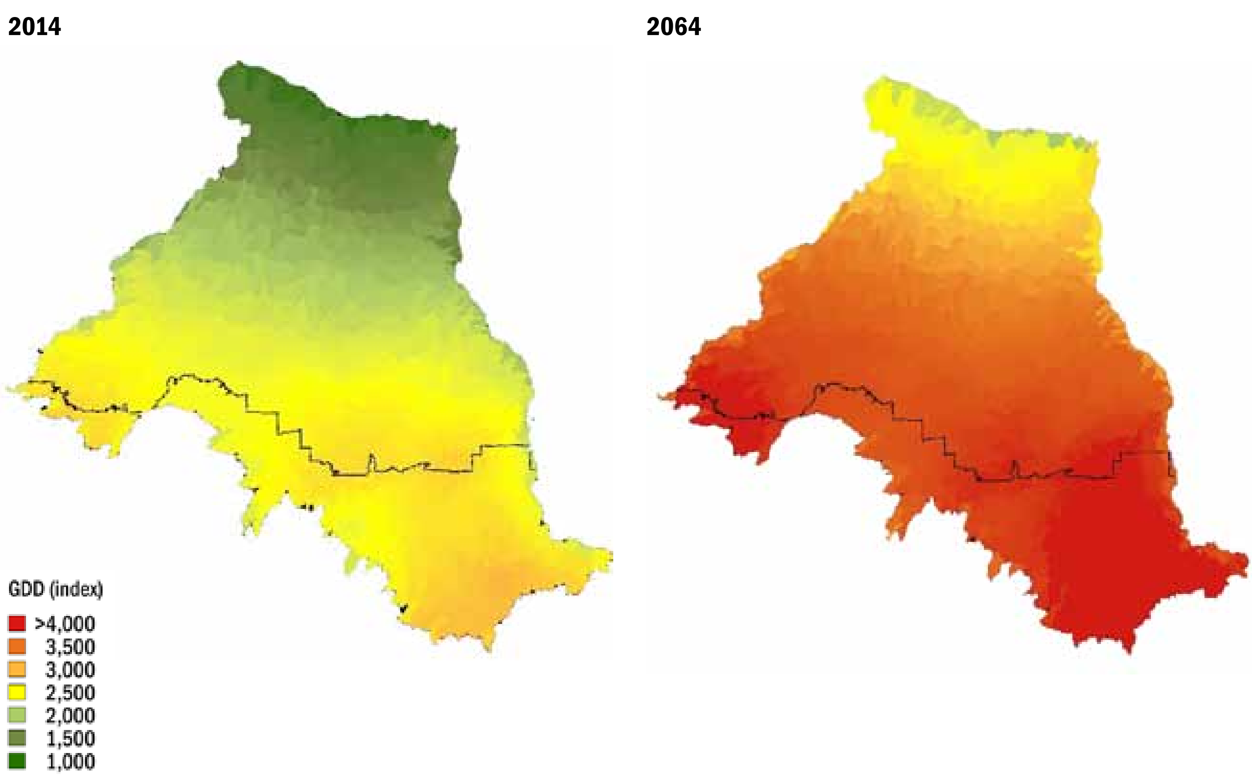


Figure 4.8. Simulated increase in growing-degree days (GDD) based on RCP 8.5.



4.2 Fish Responses

In this section, we describe the response of each species' FSI to the simulated scenarios. The FSI trajectories integrated simulated changes in stressors (Section 4.1) with the hypothesized relationship between fish and the stressors (Figures 3.11 – 3.19a, b).

4.2.1 Walleye

Risk to walleye increased from low (FSI = 4) to high (FSI < 2) (Figure 4.9). Climate change was the most influential driver of change in walleye FSI, and risk declined substantially when climate change was removed from the simulations (Figure 4.10). Dams and hydroelectric developments were the second most influential effect, followed by road development and associated fishing pressure and watershed fragmentation (Figure 4.10). Risk was highest in the AOU outside of the Far North Planning Area where land use intensity was greater and temperatures were higher.

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Figure 4.9. Current and simulated future performance of the walleye fish sustainability index (FSI) in response to high- and low-growth scenarios. Maps of estimated future (i.e., 2064) performance include climate change, whereas the graph demonstrates the influence of removing climate change (CC) from the scenarios.

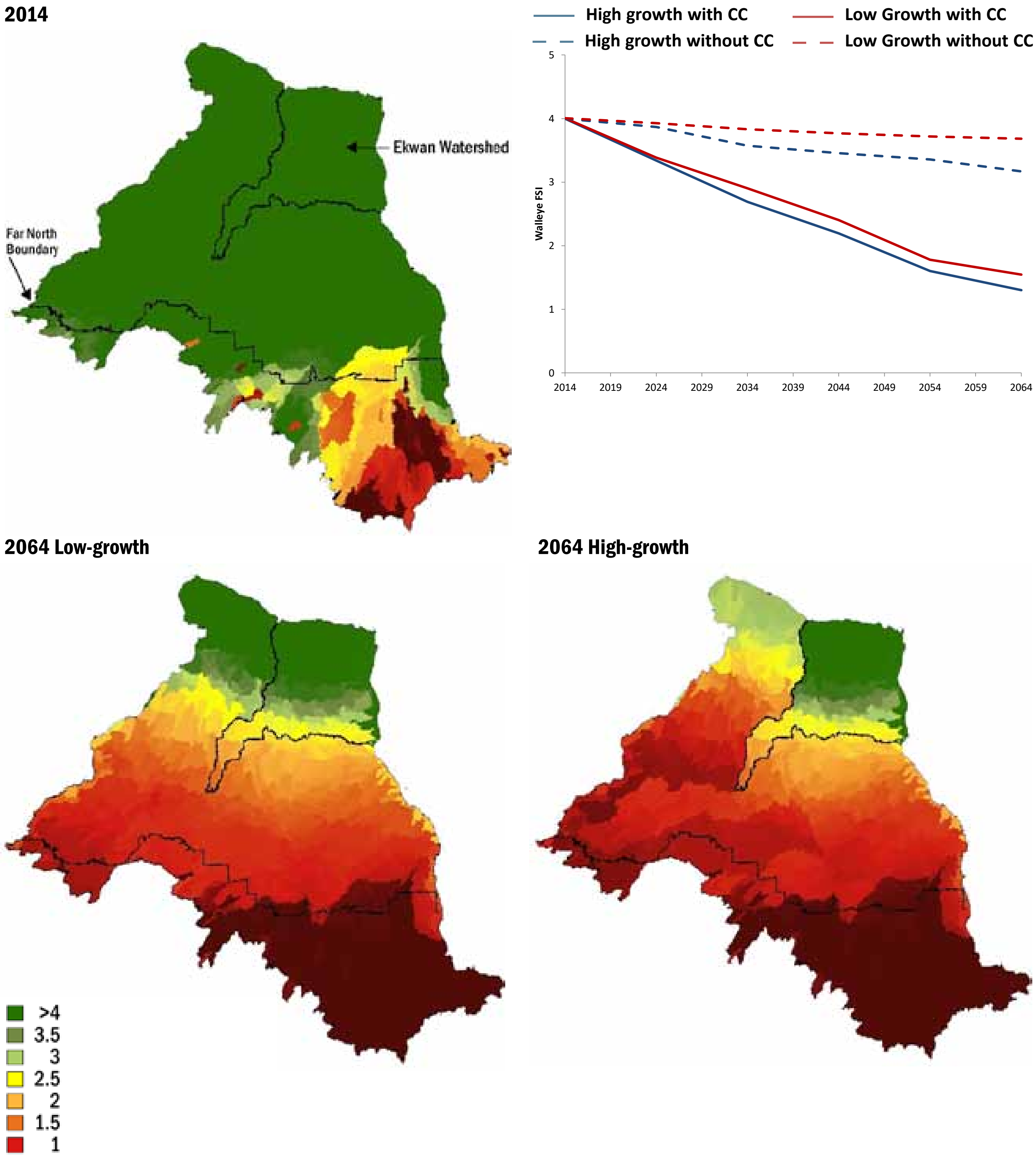
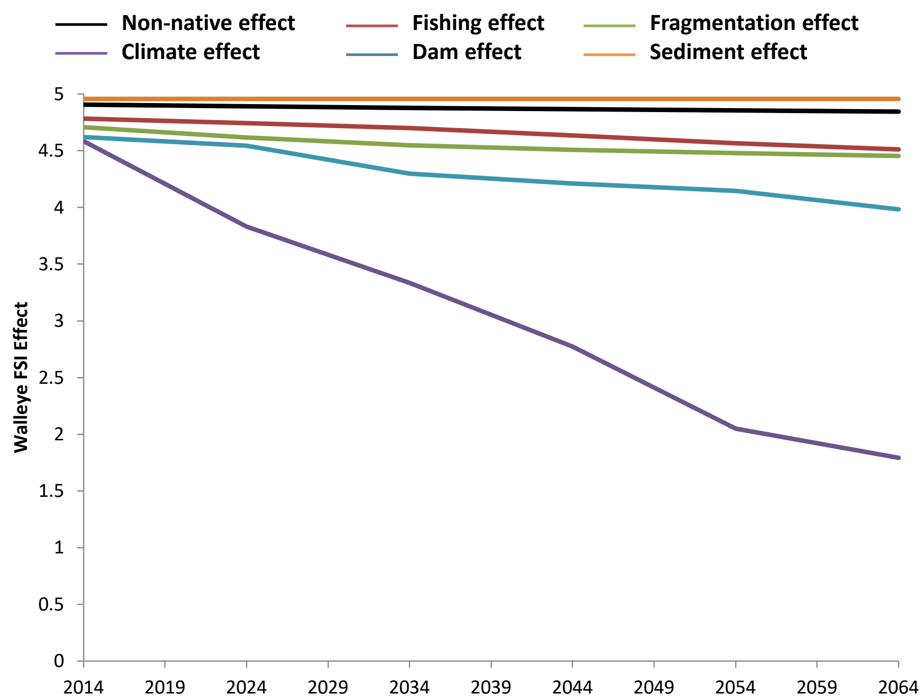


Figure 4.10. Response of the walleye fish sustainability index (FSI) to simulated threats according to the high-growth scenario with climate change.



4.2.2 Lake Sturgeon

Risk to lake sturgeon increased from low (FSI = ~ 4) to high (FSI = ~ 1) during simulations, with risk being most pronounced in the high-growth scenario due to the larger footprint and number of hydroelectric developments (Figure 4.11). Lake sturgeon was sensitive to climate change and dams, but resilient to other stressors (Figure 4.12). By the end of the 50-year simulation, risk to lake sturgeon was high throughout the study area with the exception of the Ekwan watershed due mainly to the lack of hydroelectric development predicted in the watershed and its lower temperature regime. In the absence of climate change, risk to lake sturgeon was reduced.

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Figure 4.11. Current and simulated future performance of the lake sturgeon fish sustainability index (FSI) in response to high- and low-growth scenarios. Maps of estimated future (i.e., 2064) performance include climate change, whereas the graph demonstrates the influence of removing climate change (CC) from the scenarios.

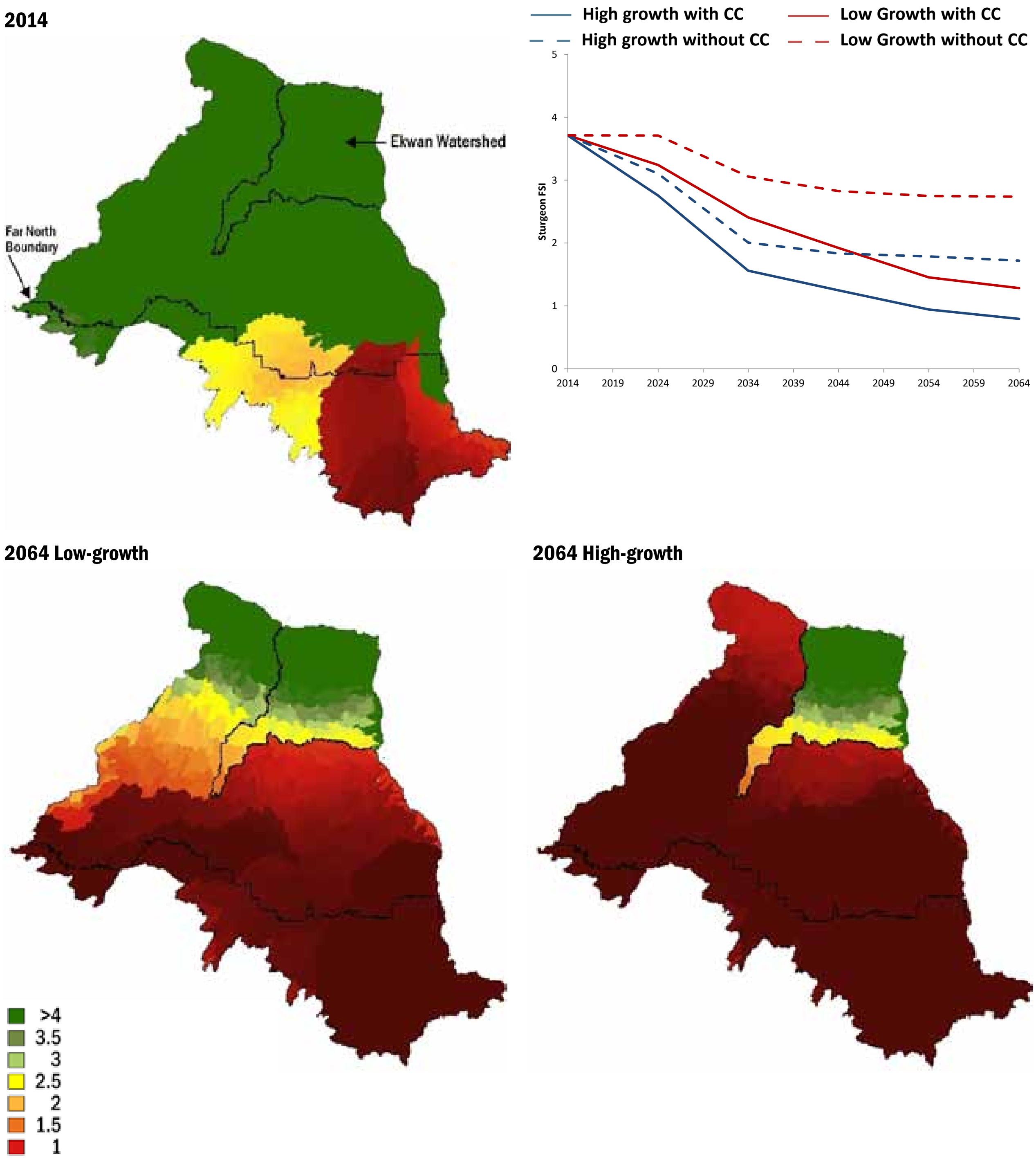
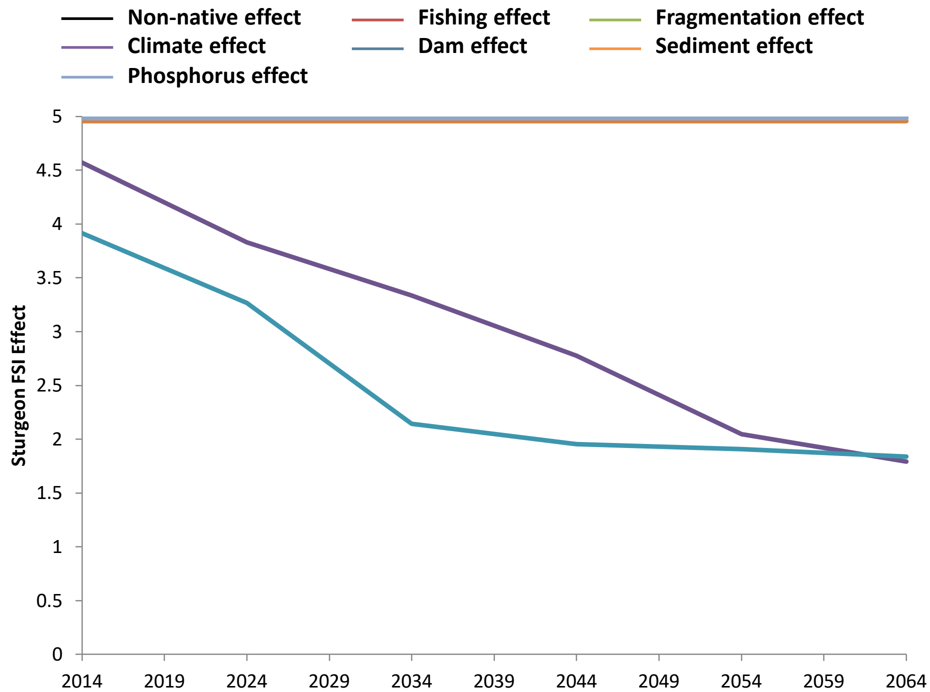


Figure 4.12. Response of the lake sturgeon fish sustainability index (FSI) to simulated threats according to the high-growth development scenario with climate change.



4.2.3 Lake Whitefish

Compared to other species, the lake whitefish FSI was relatively tolerant of changes in the climate and land-use scenarios (Figure 4.13). By the end of the simulation, overall risk had increased from low (FSI = ~ 4) to moderate (FSI = ~ 3). Climate was the most important stressor, and watersheds to the south were at higher risk due to warmer temperatures (Figure 4.14). Removing climate change from the simulations eliminated most of the increase in risk that otherwise occurred. Hydroelectric facilities were somewhat influential. Their impact on lake whitefish accounts for the lower FSI values occurring during the high-growth scenario as opposed to low-growth scenario.

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Figure 4.13. Current and simulated future performance of the lake whitefish fish sustainability index (FSI) in response to high- and low-growth scenarios. Maps of estimated future (i.e., 2064) performance includes climate change, whereas the graph demonstrates the influence of removing climate change (CC) from the scenarios.

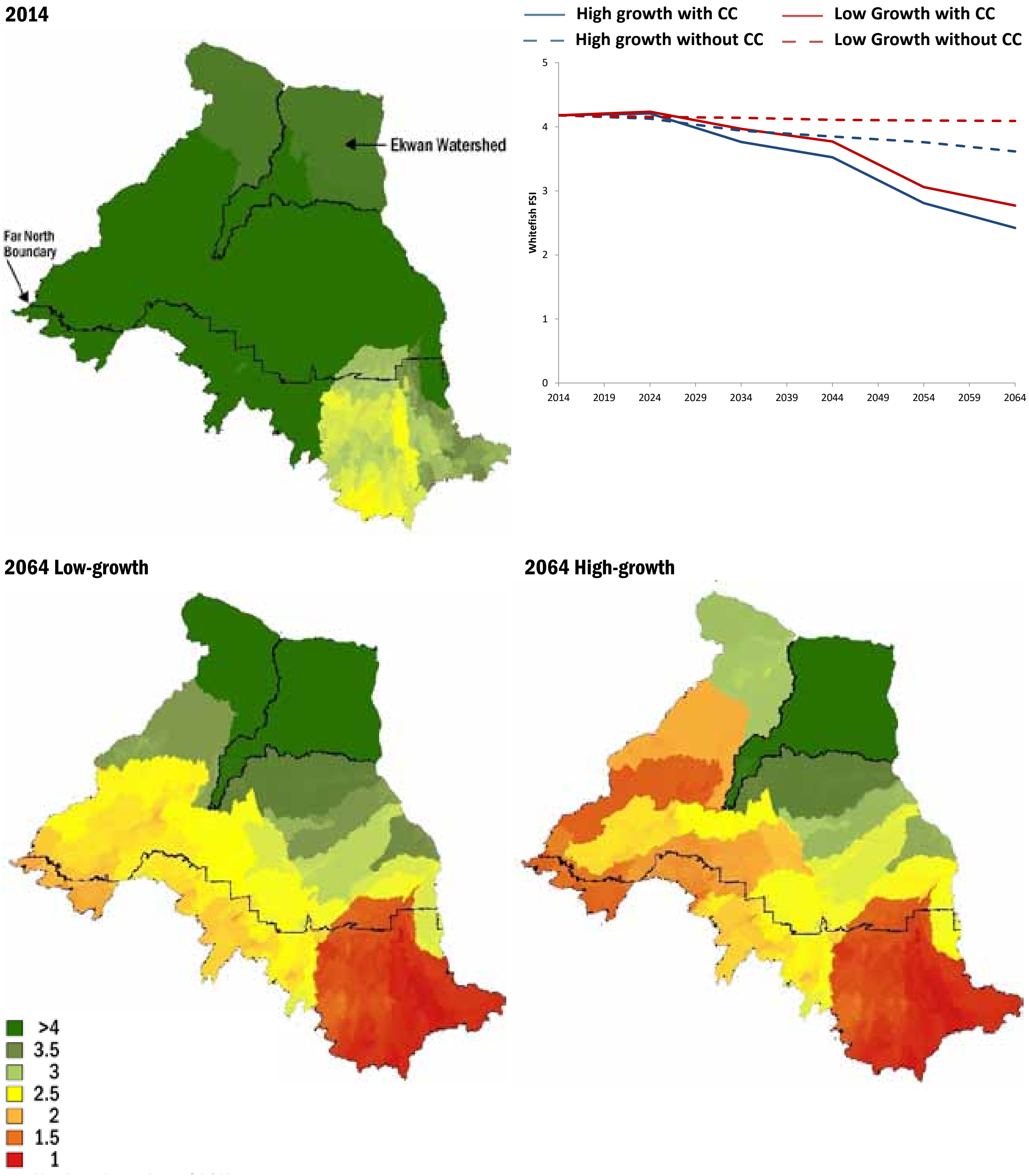
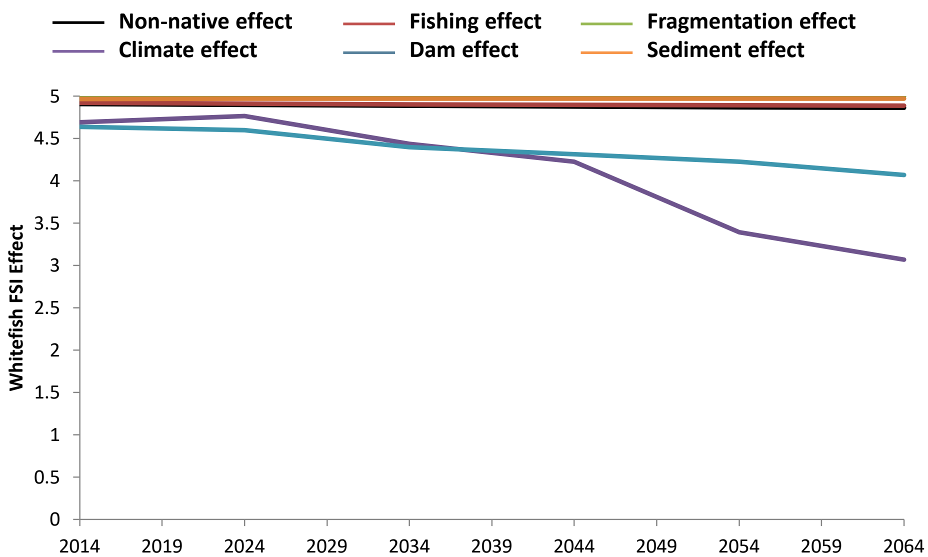


Figure 4.14. Response of the lake whitefish fish sustainability index (FSI) to simulated threats according to the high-growth scenario with climate change.



4.2.4 Brook Trout

Risk to brook trout increased during the scenarios, with sea-run brook trout (Figure 4.15) exhibiting higher risk than resident brook trout (Figure 4.16) due to their sensitivity to hydroelectric development. The effect of these facilities also accounts for the lower FSI values during the high-growth scenario as compared to the low-growth scenario. Climate change was also influential (Figure 4.17). As was the case for lake sturgeon, the Ekwan appeared to be a potentially important refuge for brook trout due to lower temperatures and simulated lack of future hydroelectric development.

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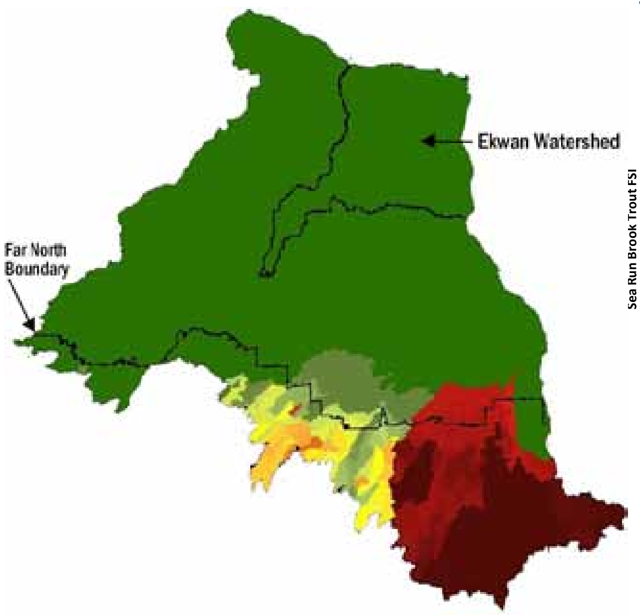
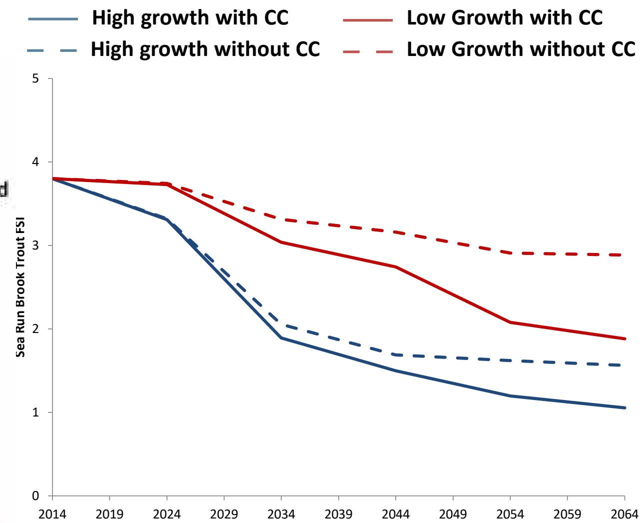
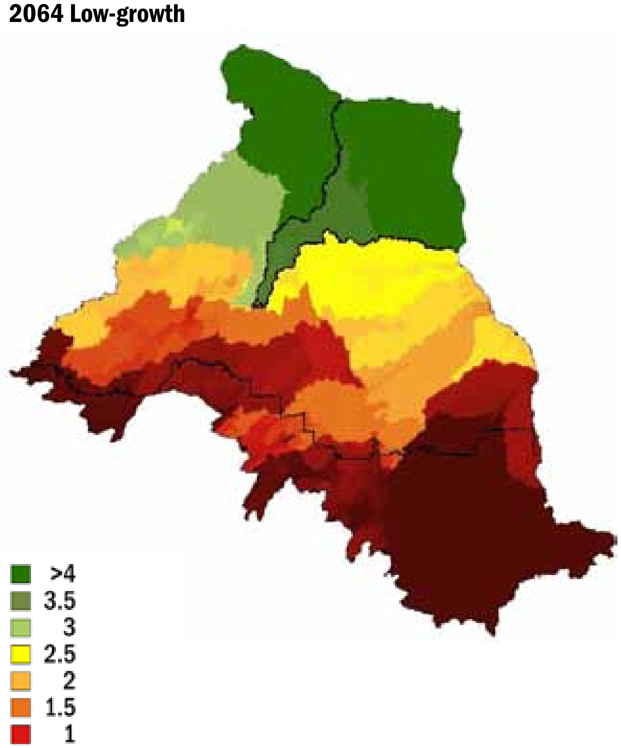
Figure 4.15. Current and simulated future performance of the sea-run brook trout fish sustainability index (FSI) in response to high- and low-growth scenarios. Maps of estimated future (i.e., 2064) performance include climate change, whereas the graph demonstrates the influence of removing climate change (CC) from the scenarios.

2014





2064 Low-growth



2064 High-growth

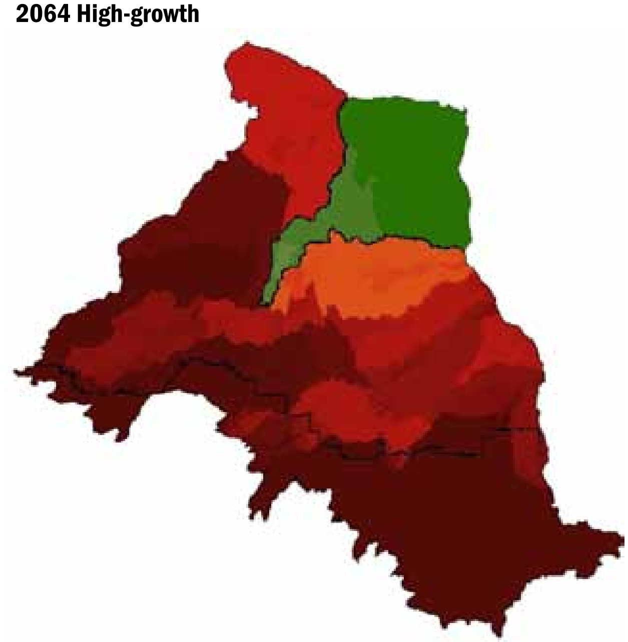


Figure 4.16. Current and simulated future performance of resident brook trout fish sustainability index (FSI) in response to high- and low-growth scenarios. Maps of estimated future (i.e., 2064) performance include climate change, whereas the graph demonstrates the influence of removing climate change (CC) from the scenarios.

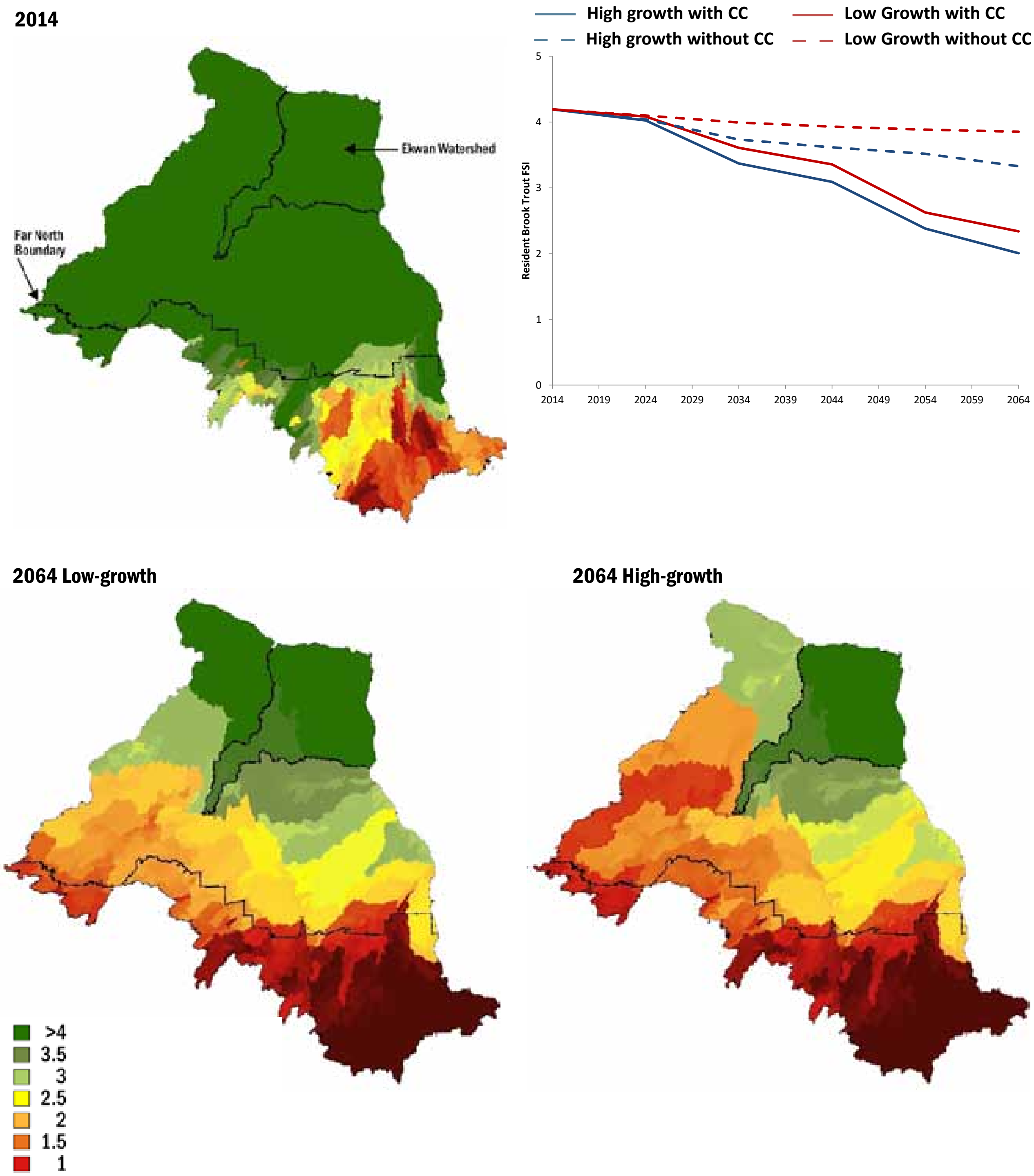
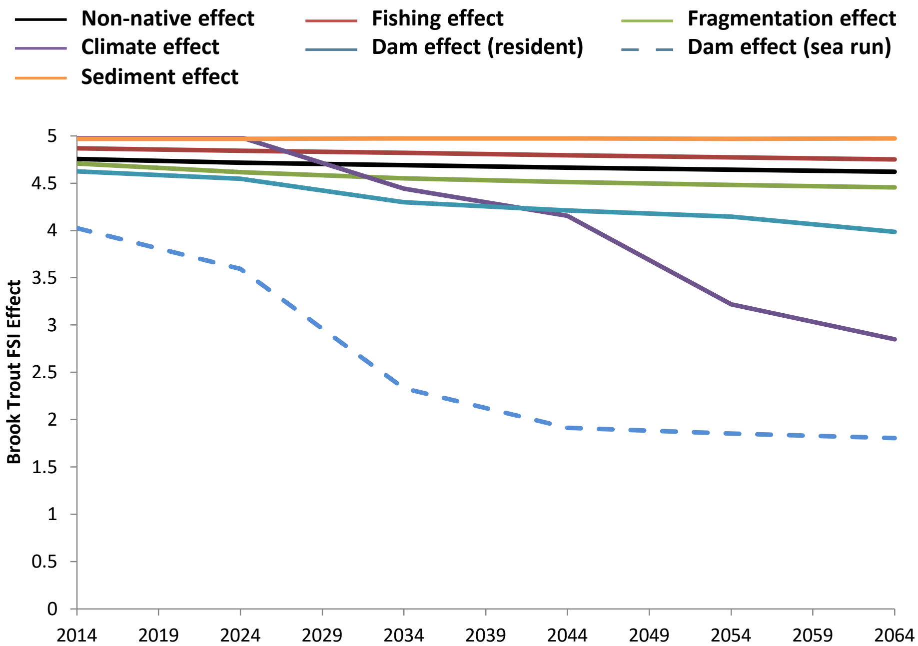


Figure 4.17. Response of the brook trout fish sustainability index (FSI) to simulated threats according to the high-growth development scenario with climate change.



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5.0 DISCUSSION

Introducing economic developments such as mining in the "Ring of Fire" and new all-weather roads and transmission lines into the relatively intact Far North landscape demands a strategic planning approach, particularly if the overriding objective is to maintain biological functions such as freshwater quality and fish populations and carbon storage and sequestration.

However, developing such an approach is hindered in Ontario on a number of fronts. First, current planning processes focus on individual projects and sectors such as mining, forestry, and hydroelectric development are managed separately within siloed government ministries. Second, project-level impact assessment in Ontario does not address cumulative effects, with the majority of projects processed through approved Class EA processes rather than individual project assessments (Lindgren and Dunn 2010). While Ontario's Ministry of the Environment and Climate Change (MOECC) Statement of Environmental Values (SEV) commits the Ministry to a number of important principles, including consideration of cumulative environmental effects, it remains unclear *how* they actually do this when making decisions about project approvals.

In addition, Ontario is engaged in land-use planning in the Far North. Community-based land-use planning between interested First Nations and the Government of Ontario is likely the appropriate governance structure to address Aboriginal and treaty rights and issues of jurisdiction. But while Ontario's Far North Land Use Strategy does address the need to address "big-picture, broad-scale land use interests to support community-based land-use planning" (MNR 2013:14), the current advice provides no guidance on *how* to consider cumulative effects in community-based land-use planning.

Our study illustrates the key elements that need to be considered in order to address cumulative effects and support positive conservation outcomes in the Far North for fish species and the societies that depend on them, including:

- defining what cumulative effects are;
- generating and assessing alternative future scenarios for key values such as freshwater fish; and,
- applying decision-support tools (e.g., ALCES Online) to consider the location, rate and intensity of change on the landscape.

Building on recommendations from Carlson and Chetkiewicz (2013), our study integrates information for assessment of cumulative effects of anticipated industrial land use and climate change on four freshwater fish species. We integrate a diversity of information including land cover, human footprint inventories, and climate data, as well as information on various land-use sectors and government policy and plans, to develop and apply a high- and low-growth scenario that varies the rate and spatial dispersion of land-use development within watersheds. We include the latest generation of climate change models and use a species focus based on their ecological, social, and economic importance in the study area.

Due to the lack of species-specific models for the study area, we drew on expert opinion and the literature to develop species-specific responses to different stressors before considering them cumulatively in each scenario. The reliance on expert opinion implies that a relatively high degree of uncertainty surrounds the response relationships used to assess fish response to stressors. As such, we consider these responses to be hypotheses that warrant testing with empirical data. However, the outcomes of the analyses at a minimum suggest priorities for research, provide the basis for a cumulative effects framework for freshwater fish in northern Ontario, and highlight gaps in current government planning and policy around freshwater fish conservation in this important region.

5.1 Impacts of Land Use and Climate Change on Freshwater Fish in Northern Ontario

5.1.1 Land Use

The level of disturbance created by industrial development in the simulations was sufficient to increase risk to all four species of fish. Dams were the most influential land use in our simulations, particularly for lake sturgeon, sea-run brook trout, and migratory populations of lake whitefish. In the AOU portion of the study area, our results highlighted an increased risk to walleye due to the relationships between roads, fishing pressure and stream fragmentation.

In Ontario, research has focused on the response of lake sturgeon to dams outside the Far North (Golder Associates Ltd. 2011). Lake sturgeon are particularly sensitive to the effects of habitat fragmentation and changes in water flow caused by dams. Habitat alteration due to existing dams, future dam construction and operating regimes associated with these facilities represent significant risks to lake sturgeon recovery in Ontario (Haxton and Cano 2016, Haxton et al. 2014, Golder Associates Ltd. 2011). The actual cumulative impacts on the region's lake sturgeon sub-populations are unknown (Seyler 1997a in Golder Associates Ltd. 2011), but impacts have been observed in discrete sections of rivers that have been impounded (Golder Associates Ltd. 2011). Dam construction as well as overfishing have contributed to localized declines in abundance of lake sturgeon and eventual recruitment failure in the Moose River basin, where16 hydroelectric dams make it one of the most fragmented river systems in North America.

On the Mattagami River, adult lake sturgeon are entrained each spring within a diversion channel of the river (e.g., Adam Creek). The number of individuals entrained is dependent on the timing and duration of spills relative to post-spawning movement (Seyler et al. 1996 in Golder Associates Ltd. 2011). In addition, river-spawning populations of lake whitefish around Hudson Bay and James Bay may also be affected by hydroelectric development.

Due to the lack of potential hydroelectric development in the Ekwan, our results highlight the potential importance of this watershed as a refugia[28] for species most impacted by hydroelectric impacts. However, it is unclear whether the Ekwan is good habitat for freshwater fish. For example, lake sturgeon spawn near waterfalls which may not be present on the Ekwan. It is important to confirm the quality of fish habitat in the Ekwan to help determine its potential as refugia.

In Ontario, more fisheries research has been focused on the effects of roads, particularly forest access roads, on walleye and/or lake trout lakes. The relationships between road access and recreational fisheries for these species are reasonably well documented (e.g., Gunn and Sein 2000, Hunt and Lester 2009). The annual exploitation rates of walleye by angling are considerable, for example ranging from 7–32% of the population in Minnesota lakes (Radomski 2003) and reaching 43% in boreal lakes in Ontario (Mosindy et al. 1987). Potential management responses to over-exploitation include access management of anglers and application of other well-established fisheries regulations such as catch and size limits.

Our relatively simplistic assessment of potential fishing mortality focused on the effect of roads in increasing angler access. Other factors include angling effort, opening time and duration, angler party size, angler type, and travel distance among others (see review in Lewin et al. 2007). The impacts of recreational fishing are increasingly being considered within a framework of linked social-ecological systems (*sensu* resilience) that brings the ecology of fish and their habitats together with a better understanding of the behaviour and motivation of anglers to improve management and conservation of recreational fisheries in Ontario (e.g., Arlinghaus et al. 2017).

5.1.2 Climate Change

Climate change was a significant driver of risk to FSI for all four species, although lake whitefish were considered to be more tolerant in our study area compared to the other species examined. Edwards et al. (2016) found lake whitefish were vulnerable to climate change in most of their current range and identified potential refugia in the Far North region of the study area.

Fish are powerful indicators of changes in climate and highlight the fact that large-scale regional and global climate change can have local impacts on fish populations (Heino et al. 2009, Tonn 1990). At a regional scale in Ontario, freshwater fish distributions are influenced by postglacial life history and environmental (climate) factors (Mandrak and Crossman 1992). At local scales, freshwater fish distributions are influenced by abiotic (e.g. water chemistry) and biotic (e.g., species interactions) factors (e.g., Minns 1989).

In Ontario, warm-, cool-, and cold-water types of freshwater fish also have preferred temperature conditions, meaning the effects of climate change are likely to be species- and ecosystem-specific (Dove-Thompson et al. 2011, Prowse et al. 2009, Reist et al. 2006). Research examining the effects of climate

[28] Refugia have been defined in freshwater systems as areas where spatial and temporal conditions are more favourable for fishes and convey resistance or resilience of the population to natural and anthropogenic disturbances. These areas can be sources for recolonization when conditions improve and/or act as sources to repopulate other areas (Hermoso et al. 2013, Sedell et al. 1990).

change on freshwater fish species distribution includes examining the response of species distributions to present-day climate conditions and using correlations to predict shifts given projected future climate scenarios (e.g., Edwards et al. 2016, Alofs et al. 2014, Chu et al. 2005). This work, together with vulnerability assessments for freshwater fish for some regions in Ontario (e.g., Chu 2015, Chu and Fischer 2012, Chu 2011), has produced a number of important findings for freshwater fish conservation in Ontario given climate change including:

- **Many cold-water species will be threatened in the next 50 years**. Isolated populations of cold-water fishes may, however, remain in deep, dimictic lakes within their original range even after climate change (Chu et al. 2014). Priorities for conservation of cold-water fishes include identifying and monitoring deep, dimictic lakes or other water bodies (e.g., Sutton River) and reducing other stressors, including human use, through regulations and access management, as well as limiting land use within the watershed where these water bodies are contained. Ontario's Far North in particular remains an important opportunity to proactively identify and conserve these cold-water refugia through community-based land-use planning (e.g., Edwards et al. 2016).
- **Cool-water and warm-water species will become established further north**. Better growth habitats and shorter winters can reduce the incidence of winter starvation (Shuter and Post 1990). While the expansion of the walleye fishery is generally considered a positive result for recreational fishers, they are top predators in freshwater systems and their effect on native populations will depend on competition and predation by warm-water species.
- **Warm-water species such as smallmouth bass will affect many native fish species and communities as they move north.** However, these expansions will only take place if fish are able to disperse naturally or are deliberately introduced for recreational fisheries (Sharma et al. 2007, Jackson and Mandrak 2002).

The lack of detailed bioclimatic models for lake sturgeon, brook trout, lake whitefish, and walleye across our study area hinders predictions about their *population* responses to future climate change. Research on rapidly changing climates in Alaska show swift population-level responses in northern Pacific salmon (*Oncorhynchus spp.*) (Kovach et. al. 2015, Taylor 2008, Schindler et al. 2008). These effects are anticipated to be similar for some northern boreal species (Lynch et al. 2016).

In general, the ability of freshwater fish to survive this climatic transition may depend on the availability of suitable habitats within their future ranges and the ability for freshwater fish to reach these new areas (*sensu* connectivity) and adapt. The availability of these habitats depends on changes in land use, particularly dams, crossing structures, and roads that are well-known to reduce connectivity in freshwater systems, even with mitigation (Maitland et al. 2015, Park et al. 2008). Some species and habitats may be more susceptible to climate change as described above and these should be prioritized in planning for conservation (e.g., cold-water fish species). Addressing the vulnerability of freshwater fish to both climate change and land use in our study area will require proactive freshwater conservation strategies at different scales including:

- **Reducing or removing non-climate stressors.** Reducing existing direct threats associated with human activities including fishing, forestry, mining, hydroelectric development and infrastructure is an important climate change adaptation strategy. It is well established that these land uses result in habitat degradation and fragmentation, introduction of invasive species and pollution, and can lead to overexploitation in freshwater systems (Lawler 2009). In general, reducing these impacts or limiting development in watersheds can help species, ecosystems and landscapes cope with additional stresses caused by a changing climate.

- **Create networks of protected areas for freshwater biodiversity.** Protected areas can act as refuges from non-climate stressors, potential refugia (e.g., deep, dimictic waterbodies), and sources to recover freshwater fish populations. Existing protected area networks in Ontario are designed to protect static (rather than dynamic) patterns of biodiversity and tend to be biased towards terrestrial species and a low number of taxonomic groups (e.g. vascular plants, terrestrial vertebrates). While the goal of protected areas in Ontario under the *Provincial Park and Conservation Reserves Act, 2006*[29] (PPCRA) is to ensure ecological integrity is maintained, this objective seems more focused on terrestrial species than freshwater fish and biodiversity in general. While the PPCRA enables the establishment of aquatic-class parks to protect freshwater ecosystems, we are not aware of any that were established to protect freshwater biodiversity.[30] We are also not aware of any assessment of Ontario's current protected area network to support freshwater biodiversity at present or in the future given range shifts anticipated due to climate change. There are significant opportunities for proactive assessment and planning for freshwater fish biodiversity given Government of Ontario commitments to conservation targets including at least 50% (e.g., 225, 000 km^2) under *Ontario's Far North Act, 2010* as well as an overall target of 17% for Ontario under Ontario's Biodiversity Strategy.[31] The former offers significant opportunities to consider freshwater biodiversity more systematically in protected area planning being led by the MNRF and to consider First Nations values and Treaty and aboriginal rights to freshwater fish more explicitly. To be useful for freshwater fish, freshwater protected areas must be based on the characteristics of freshwater ecosystems and the requirements of freshwater fish (Suski and Cooke 2007, Abell et al. 2007). Planning should include future climate scenarios and connectivity (Scott and Lemieux 2005). Further, large and heterogeneous areas are more likely to incorporate a wider array of different types of lentic and lotic ecosystems thereby supporting comprehensive preservation of regional freshwater biodiversity (Heino et al. 2009). These various requirements for protection of freshwater biodiversity demand a catchment approach during freshwater conservation planning (Dudgeon et al. 2006) and explicit consideration of climate change (e.g., Douglas et al. 2014). Prioritization of watersheds for protection using tools such as Marxan coupled with species

[29] Available online at: https://www.ontario.ca/laws/statute/06p12

[30] There are a number of fish sanctuaries that prohibit fishing within provincial parks (e.g., Killarney Provincial Park)

[31] Available online at: http://ontariobiodiversitycouncil.ca/homepage_banners/ontarios-biodiversity-strategy/

distribution models provides an opportunity to consider freshwater protected area design more systematically (e.g., Hermoso et al. 2016, Hermoso et al. 2015, Bush et al. 2014, Hermoso et al. 2011).

- **Commit to long-term monitoring networks.** The absence of comprehensive species distribution data in our study area hinders assessment of current and predicted impacts of climate change and land use on freshwater species and their distribution (O'Connor et al. in preparation). There are a limited number of monitoring programs focused on freshwater fish and there are a number of gaps in the current approach, including the lack of government commitment to systematic monitoring for streams and rivers as well as climate change indicators (e.g., Table 3, Furrer et al. 2014), particularly in the Far North. Also needed are reference control sites (e.g., Kilgour et al. 2016) and pilot studies to consider the effects of climate change and land use. Finally, we also support community-based approaches to monitoring that can address recommendations by the Far North Science Advisory Panel and the Environmental Commissioner of Ontario that the Government of Ontario develop a program to monitor the state of the environment and First Nations health in a way that integrates Traditional Ecological Knowledge (TEK) in monitoring and planning processes.

Table 3. The relationship between aquatic long-term monitoring programs sponsored by the MNRF and climate change monitoring needs (response indicators) for aquatic ecosystem components (from Furrer et al. 2014).

Lakes and streams	Wetlands	Fish*
Disease, parasite, and pest distribution x	Coastal wetlands x	Disease, parasite, and pest distribution x
Ecosystem productivity ✓✓	Distribution of ecosystems x	Habitat quality x
Ice Cover x	Ecosystem productivity x	Phenological events x
Phenological events x	Permafrost x	Species abundance ✓✓
Species abundance* ✓✓	Species distribution and composition x	Species distribution ✓✓
Species distribution* ✓✓	Water quantity x	Species composition x
Species composition* ✓	Wildfires x	
Water quality* ✓		
Water quantity ✓✓		

*Lakes only
x MNRF monitoring programs do not support measurement variables of the indicator
✓ MNRF monitoring programs support some measurement variables of the indicator
✓ ✓ MNRF monitoring programs support all measurement variables of the indicator

- **Assess vulnerability and adaptive capacity of freshwater systems in the Hudson Bay Lowland.** The Hudson Bay Lowland ecozone is predicted to experience greater relative impacts from climate change due to proximity to James and Hudson Bay, isostatic rebound, and permafrost degradation among other factors (e.g., Abraham et al. 2011, Far North Science Advisory Panel 2010). Since the Ekwan watershed is largely contained within the Hudson Bay Lowland ecozone, it is potentially more vulnerable to climate change than other secondary watersheds that straddle the Ontario Shield in our study area. Despite its sensitivity to climate change, simulations point to the importance of the Ekwan watershed as a climate refugia for boreal fish populations. Its northerly location means that the watershed is likely to remain one of the coldest in Ontario, despite the substantial increase in temperature that is expected. Contributing to its importance as a climate refugia in the simulations is the absence of future development, in part due its remote location. The intactness of the Ekwan combined with its colder climate suggests that this watershed is likely to play an important role in the persistence of boreal fish populations in the future. However, as mentioned previously, research is needed to assess habitat quality and availability for freshwater fish in the Ekwan.

5.1.3 Limitations and Assumptions

In the absence of empirical data and models, our exploration of fish response to stressors relied on expert opinion. As described previously, the expert opinion was gathered over a two-day period from over 20 scientists with a background in northern Ontario fisheries and ecology (Appendix 4). Workshop participants felt that the resulting fish models, while approximate, performed well at assessing fish response to stressors. As such, the integration of expert opinion and scenario analysis successfully facilitated proactive consideration of management priorities. However, there is a high level of uncertainty surrounding the hypothesized relationships and empirical research is needed to test and improve the models. In addition, the gathering of expert opinion could be improved in the future through the use of a more standardized approach that ranks the certainty surrounding each hypothesized relationship.

Our land-use scenarios focused on key stressors shown to influence freshwater fish either in the literature or based on the expertise of aquatic scientists in Ontario. However, some notable stressors that were not included or that were assumed to have negligible impact were as follows:

- Although a fairly detailed mining scenario was developed, experts considered impacts to fish viability (i.e., through water contamination) to be minimal relative to other stressors such as dams, climate change, and fishing.

- Our forestry scenario focused on forest management (harvesting, roads) and did not consider the effects of pesticide and herbicides also used in forest management or the effects of effluents associated with pulp mills. Potential stresses on freshwater fish include persistent chemicals and water quality due to insecticides, herbicides mainly glyphosate, pesticides, pulp mill effluents as well as temperature effects (Kreutzweiser et al. 2013).

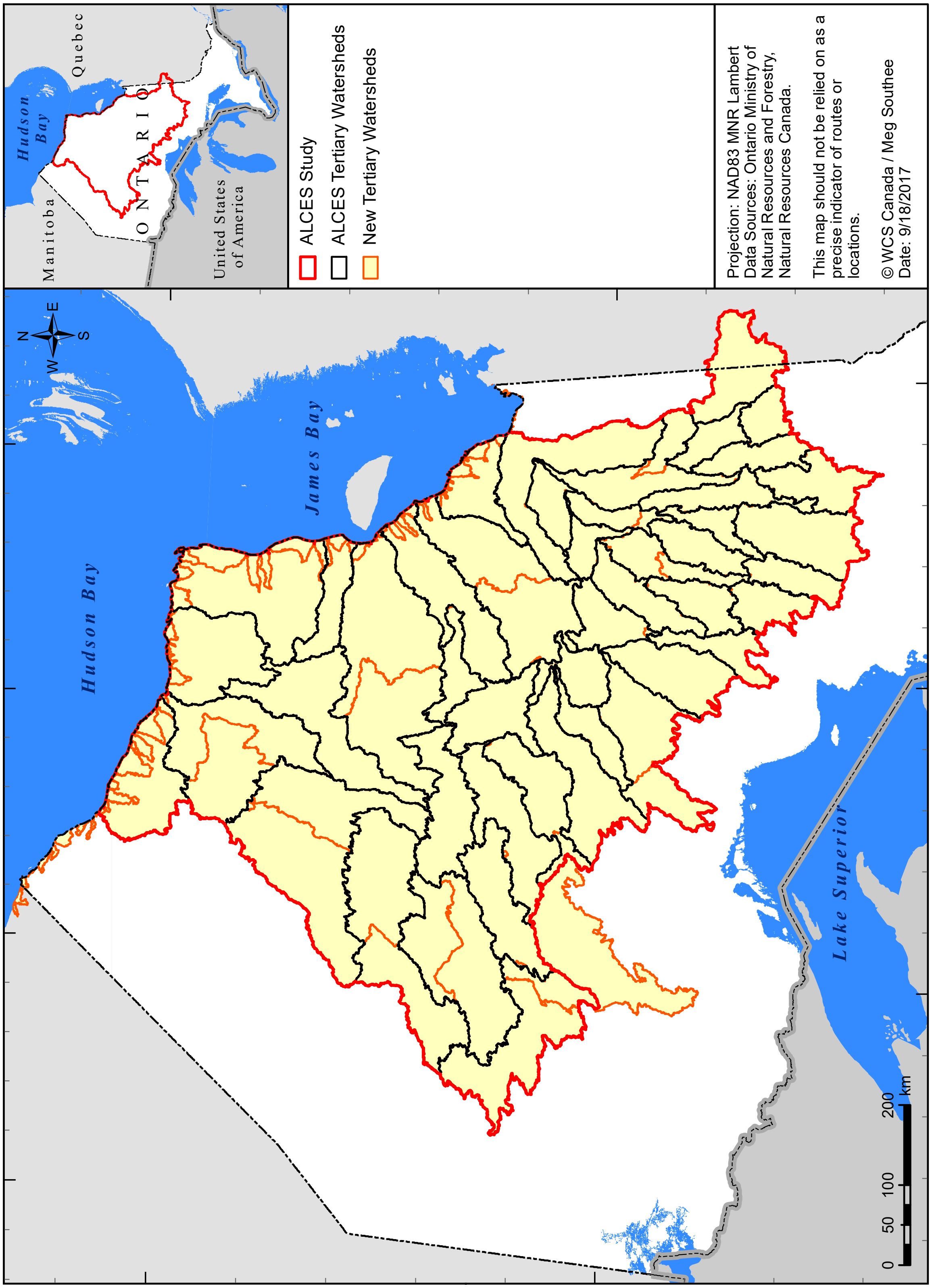
- While a first start to addressing multiple impacts from land use and climate change, our analyses do not explicitly consider the *interactive effects* between climate change and other stressors (e.g., acidification, eutrophication, non-native species and diseases) on freshwater fish (e.g., Heino et al. 2009). Given the large negative impact of climate change suggested by our modeling, future research should more thoroughly explore climate change impacts including the implications of northward shifts in land use (e.g., forestry) and changes in the biochemistry and biodiversity of waterbodies.

While we obtained the best geospatial data available to assess the region's landscape composition and hydrology, limitations exist. Land cover products used in our analyses are a compromise between coverage and classification accuracy at the scale of interest for planning. Although the Far North Land Cover product is more recent, it has not been assessed for classification accuracy and does not provide complete coverage for our study area. As such we used the EOSD land cover product.

It is worth noting, however, that the choice of land cover product had limited influence on the outcome of our study because, in the absence of species-specific habitat models, the relationships between land cover and fish populations is unknown. More influential are hydrology layers, especially watershed delineation due to the role of watersheds as analytical units in our study. The quaternary watershed layer, used as the unit of analysis for most stressors, became available for the Far North in 2015. In a *post-hoc* review, we identified discrepancies between the quaternary layer and the publicly available tertiary watershed layer. These were most obvious along the coast where quaternary watersheds are identified as being hydrologically isolated from adjacent inland watersheds (Figure 5.1). Because we used higher order (i.e., tertiary or secondary) watersheds as units of analysis for dams and watershed fragmentation, future changes to higher order watershed boundaries (i.e., in response to the discrepancies that we noted) could influence the outcomes of our analysis including:

- The impact of dams was assessed at the secondary watershed scale, such that inland dams in watersheds such as the Attawapiskat and Albany were assumed to cause risk to species such as lake sturgeon in coastal areas. While this assumption requires further assessment, given that quaternary watersheds along the coast are hydrologically isolated, impacts from inland dams may still occur given the ability of lake sturgeon and other species to migrate large distances (Wishingrad et al. 2014, Auer 1996).

Figure 5.1. Locations of new tertiary watersheds created as a result of more recent quarternary watershed layer that became available after the analyses



- Watershed fragmentation was assessed at the tertiary watershed scale (see Appendix 2). Many of the watersheds used to approximate the relationship between stream crossing density and watershed fragmentation are likely to have revised boundaries based on comparison of the quaternary and tertiary watershed products. Changes to tertiary watershed boundaries may therefore alter the simulated relationship between road network expansion and watershed fragmentation. However, given that watershed fragmentation did not emerge as a key driver of fish sustainability (see Figures 4.10, 4.12, 4.14, 4.17), boundary changes are unlikely to cause substantive changes to our conclusions.

Our assessment of climate change utilized RCP 8.5 because it provides a "business-as-usual" assessment. If atmospheric greenhouse gas emissions are lower than those projected by the RCP 8.5 scenario, managers could anticipate a modification of effects due to climate and adjust adaptation approaches. Re-running our models with both RCP 2.6 and RCP 4.5 could provide a sensitivity analysis to climate change for freshwater fish. However, we suspect this current scenario (i.e., RCP 8.5) is more useful for policy makers and decision makers that must consider integrated management of land uses given that many of the future impacts of climate change are outside of local, municipal, regional, and national control.

6.0 RECOMMENDATIONS

We make the following recommendations regarding planning for freshwater fish conservation in northern Ontario, particularly Ontario's Far North.

1. Assess cumulative effects in freshwater fish management and conservation.

Our study highlights the importance of considering cumulative effects and helps identify and illustrate the potential unintended consequences of land use and climate change on freshwater fish. As such, it lends support to proactive and precautionary management approaches and the need for greater research attention on cumulative effects. This call to action has been around for freshwater systems since at least 2001 (Schindler 2001). In natural systems, lake sturgeon, for example, may be capable of adapting to changing environmental conditions, just as they have done for millions of years. However, in developed systems decreasing water levels may require more deliberate action to address impacts, such as reversing diversions (e.g., the Albany) or reducing the flows in existing dams (e.g., in the Moose River basin) in order to maximize river species' resilience in the face of multiple stressors (e.g., Healey 2009). In fact, maximizing species resilience while supporting the subsistence needs of Indigenous peoples may require forgoing or limiting development and fishing opportunities in the face of impacts from other land use and climate changes. Such decisions are best made within the context of a regional or strategic plan that is informed by assessment of cumulative effects and the values we place on freshwater fish, their habitats and aquatic ecosystem services.

2. Gather the information needed to improve decision-making about freshwater fish conservation.

Our results represent a set of testable hypotheses for a set of plausible scenarios that can be refined as data on the responses of fish to stressors over large areas in the region and across variable timeframes is improved. As such, the results provide a basis for informed discussion and debate on the desired futures for these species and ultimately the societies that depend upon them. Ideally, future research is prioritized to improve our understanding of stressors that appear to be of greatest concern in our models, particularly climate change, hydroelectric developments, and roads. As such, our work also helps address a key action in

Ontario's lake sturgeon recovery strategy, namely developing tools to evaluate and address the cumulative impacts of instream development and other anthropogenic stressors on lake sturgeon populations and sub-populations (Golder Associates Ltd. 2011). Modeling and testing cumulative effects on lake sturgeon through an iterative process similar to the one we followed can also consider the value of best management practices for lake sturgeon given hydroelectric development (OWA 2009). In addition, the ALCES Online toolkit enables us to update our models and re-run the simulations in a participatory process with scientists, First Nations, and other interested parties.

3. Prioritize monitoring for freshwater fish conservation.

Long-term systematic monitoring by scientists and communities is needed to establish baselines of undisturbed systems, detect and understand past and current changes, and to avoid management practices that lead to shifting or declining baselines (Pinnegar and Engelhard 2008). Given commitments to protection under the *Far North Act, 2010*, along with ongoing interest in development and all-weather infrastructure in the Far North, government and First Nations should commit to proactive regional freshwater monitoring in the Ring of Fire (e.g., Attawapiskat and Albany watersheds). We suggest this program's overarching objective should be to provide information to Ontario's fishery and biodiversity managers, First Nations, and stakeholders about the status of key freshwater species and ecosystem components and services. Which species, ecosystems, and functions to monitor needs to be decided in a transparent manner with First Nations while incorporating existing monitoring requirements (e.g., under environmental assessment). These processes should also be subject to Elder and independent science review.

Working with communities in the Far North also provides opportunities to collect and apply historical perspectives from traditional knowledge, assuming processes between managers and First Nations are based on trust and sharing of information. Without the perspectives provided by historical baseline data, it is difficult to develop monitoring and management programs that can assess the impacts of human development, measure the efficiency of management decisions, engage in adaptive management, and identify the extent to which freshwater fish should be protected given other impacts such as climate change.

Going forward, we anticipate northern communities will be the main agents for monitoring freshwater fish and systems rather than government. This conclusion draws on a growing body of evidence and practice around community-based monitoring (Raygorodetsky and Chetkiewicz in preparation, McKay and Johnson 2017, Kouril et al. 2016, Johnson et al. 2015, Lawe et al. 2005). The Regional Framework Agreement between Matawa First Nations and the Government of Ontario may provide a useful mechanism for establishing this approach in the Ring of Fire.[32]

[32] The Regional Framework Agreement can be downloaded at: https://www.mndm.gov.on.ca/sites/default/files/rof_regional_framework_agreement_2014.pdf

4. Prioritize areas for freshwater fish research and protection.

Our study highlights areas where research should be prioritized, such as the Ekwan watershed, as well as areas for potential protection in environmental planning. Our study shows, qualitatively, how climate change exacerbates impacts on freshwater fish, particularly cold-water species, which should be considered explicitly in environmental planning and protection processes. Finally, our study illustrates the need for a regional and strategic approach to hydroelectric development in the region given the impacts on the species examined in our study.

Our scenario analysis represents a clear and straightforward approach to informing land-use planning decisions based on impacts to freshwater fish. This is particularly important for Ontario's Far North, where government commitments to protect at least 50% of the region need to proactively consider cumulative impacts on freshwater fish and First Nations rights to fish along with other wildlife and freshwater ecosystem services. The long-term regional outcomes of land-use decisions on freshwater fish need to be considered and managed accordingly, for example with thresholds or limitations on land use changes in watersheds in order to maintain healthy and productive fisheries in the presence of a changing climate.

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APPENDICES

APPENDIX 1 – SCENARIO ANALYSIS METHODS DETAILS

Landscape Composition

The land cover product was created from the Earth Observation for Sustainable Development of Forests (EOSD) land cover remote sensing product,[33] the NASA North American Carbon Program (NACP) Forest Age Maps at 1-km Resolution for Canada (2004),[34] twenty MNRF Forest Resource Inventory (FRI) datasets and the MNRF forest fire disturbance area dataset.[35]

The EOSD land cover was used because it provided full coverage of our landscape compared to newer land cover products focused on the Far North portion (i.e., Far North Land Cover product[36]). The EOSD dataset has a resolution of 25 m, was current to the year 2000 based on Landsat imagery, and the classification was completed in 2009 with an 86% classification accuracy (Wulder et al. 2008). The EOSD land cover was used to estimate current land cover composition, with the exception of 134,380 km^2 of managed forest within Forest Management Units in Ontario where FRI was used to update the land cover information because FRI includes age, identifies areas for harvest, and is more current (2007-2013) than EOSD. For areas not covered by FRI, forest age values were added directly into the EOSD product using the NASA 1 km Canada-wide 2004 Forest Age dataset. The MNRF Fire Disturbance Area dataset, current to 2013, was used to update the forest age values in the FRI where the fires were more recent than the latest harvest data, and to update forest age values in the area outside of the FRI where fires were more recent than 2004. The FRI and EOSD inventories were used to create a single land cover data set by adopting reclassification rules described in Table 3.1. Separate land cover types were created for productive forest (e.g., merchantable) to constrain forestry activity properly based on a previous project (Carlson and Chetkiewicz 2013) and the herbaceous category in Québec was reclassified to cropland to harmonize land cover data between the provinces. Water bodies were added to the EOSD using the MNRF Ontario Hydro Network (OHN) - Waterbody dataset[37] that also included waterbodies in the Québec portion of the study area.

[33] http://www.nrcan.gc.ca/forests/measuring-reporting/remote-sensing/13433

[34] https://daac.ornl.gov/NACP/guides/NA_Tree_Age.html

[35] https://www.javacoeapp.lrc.gov.on.ca/geonetwork/srv/en/main.home?uuid=362e7ab7-655e-4c81-bcbd-0f26bc6f8e36

[36] https://www.javacoeapp.lrc.gov.on.ca/geonetwork/srv/en/main.home?uuid=ab1da0f2-7bba-430b-af11-d503865ff130

[37] https://www.javacoeapp.lrc.gov.on.ca/geonetwork/srv/en/metadata.show?uuid=3ebaf6b2-6dd6-4ebb-a6bb-c778426709&currTab=simple

Appendix 1. Table 3.1. Reclassification scheme for EOSD, FRI and ALCES

EOSD Value	EOSD Landcover Class	ALCES Land-cover Type	FRI Category	FRI Provincial Forest Type
10	Unclassified	Unclassified		
11	Cloud			
12	Shadow			
20	Water*	Water	water	
30	Non-vegetated Land	Barren	rock	
31	Snow/Ice			
32	Rock/Rubble			
33	Exposed/Barren Land			
34	Developed	Unclassified		
40	Bryoids	Bryoids		
50	Shrubland	shrubs	brush and alder	
51	Shrub Tall			
52	Shrub Low			
80	Wetland	treedpeatland	treed wetland	
81	Wetland - Treed			
82	Wetland - Shrub	shrubpeatland		
83	Wetland - Herb	herbpeatland	open wetland	
100	Herb	herbs		
110	Grassland	grassland		
120	Agriculture	cropland	developed agriculture	
121	Cropland			
122	Pasture / Forage	pasture	grass and meadow	
210	Coniferous Forest	conif	forest (U)***	Conifer Lowland, Conifer Upland, Red and White Pine, Jack Pine
211	Coniferous Dense			
212	Coniferous Open			
213	Coniferous Sparse			
220	Deciduous Forest	decid	forest (U)***	Poplar, White Birch, Tolerant Hardwood
221	Broadleaf Dense			
222	Broadleaf Open			
223	Broadleaf Sparse			
230	Mixed Forest	mixed	forest (U)***	Mixedwood
231	Mixedwood Dense			
232	Mixedwood Open			
233	Mixedwood Sparse			

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EOSD Value	EOSD Landcover Class	ALCES Land-cover Type	FRI Category	FRI Provincial Forest Type
upconifmerch** decidmerch** mixedmerch**		lowconifmerch**	forest (A)***	Conifer Lowland
		forest (A)***	Conifer Upland, Red and White Pine, Jack Pine	
		forest (A)***	Poplar, White Birch, Tolerant Hardwood	
		forest (A)***	Mixedwood	

* Replaced EOSD water polygons with MNRF Ontario Hydro Network waterbodies
** Merchantable forest classes created from FRI data
*** U = unavailable (non-productive); A = available (productive)

The location of footprint types were derived from a variety of footprint inventories that were available to WCS Canada through Land Information Ontario (LIO) as part of the Ontario Geospatial Digital Exchange sharing agreement with the MNRF (Table 3.2). Footprints took precedence over natural land cover when creating the non-overlapping representation of landscape composition. Order of precedence among footprints was based on the permanence of the features. We further subdivided dams and mineral mines into 3 distinct features based on impacts to fish and freshwater that are associated with each subtype. Buffering widths were based on Carlson and Chetkiewicz (2013). We buffered linear features so that transmission line corridors, active railways, and major roads were 40 m wide. Other road corridors (e.g., minor roads), abandoned railways and linear dam features were buffered to a total width of 20 m. Pipelines were buffered to a total width of 60 m. Current mines, aggregate pits, towns, airports and generating stations were digitized from Bing satellite imagery when no polygon shapefiles existed in LIO for these features. Reservoirs were created using an in-house dam footprint tool to calculate the total amount of upstream area that is likely to be affected based on the hydraulic head of the current or proposed dam.

Appendix 1. Table 3.2. Footprint types and data sources used in ALCES Online for scenario analysis.

Order of precedence	Footprint Dataset	ALCES Footprint Type	Buffer width (m)	Source and link
1	Town	town		Statistics Canada 2011 Census Population Centres (boundaries adjusted using Bing Imagery and Ontario Forest Resource Inventory where Category == UNCLASSIFIED); Government of Quebec Urban Perimeters (boundaries adjusted using Bing Imagery); Natural Resources Canada Aboriginal Lands CAD Data (boundaries adjusted using Bing Imagery)
2	Major Roads	majorroad	20 m	Ontario MNRF Road Segment where SURF_TYPE == 'Paved'; DMTI CanMap Route Logistics Quebec Major Roads (hwy.zip)
3	Railways	rail	20 m	Ontario MNRF Railway; DMTI CanMap Route Logistics Quebec Railways (rll.zip)
4	Transmission Lines	transmission	20 m	Ontario MNRF Utility Line where CLASS_SUBTYPE NOT LIKE '%Pipeline%'
5	Pipeline	pipeline	30 m	Ontario MNRF Utility Line where CLASS_SUBTYPE LIKE '%Pipeline%'
6	Airport	airport		Ontario MNRF Airports Official; Ontario MNRF Airports Other; DMTI CanMap Quebec Aerodromes (aer.zip)
7	Diamond Mine	diamond		Ontario MNDM Mineral Deposit Inventory 2014 (boundaries digitized using Bing Imagery)
7	Gold/Silver Mine	gold		Ontario MNDM Mineral Deposit Inventory 2014 (boundaries digitized using Bing Imagery)
7	Copper/Nickel Mine	copper		Ontario MNDM Mineral Deposit Inventory 2014 (boundaries digitized using Bing Imagery)
8	Hydroelectric Generating Dam	largedam		Atlas of Canada 1,000,000 National Frameworks Data - Hydrology Dams; Ontario MNRF Wpower Generation Station; Ontario MNRF Ontario Hydro Network (OHN) - Dam Lines, Ontario MNRF OHN - Dam Poly; Ontario MNRF OHN - Hydrographic Line; Ontario MNRF OHN - Hydrographic Poly; Ontario MNRF Dam Inventory (ODI); Ontario MNRF Dam and Barrier (retired); EA Reports; Additional features digitized using Bing Imagery
8	Run-of-River Dam	rrdam		Atlas of Canada 1,000,000 National Frameworks Data - Hydrology Dams; Ontario MNRF Wpower Generation Station; Ontario MNRF OHN - Dam Lines, Ontario MNRF OHN - Dam Poly; Ontario MNRF OHN - Hydrographic Line; Ontario MNRF OHN - Hydrographic Poly; Ontario MNRF Dam Inventory (ODI); Ontario MNRF Dam and Barrier (retired); EA Reports; HATCH Study (2013); Additional features digitized using Bing Imagery
8	Other Dam	nonhydrodam		Atlas of Canada 1,000,000 National Frameworks Data - Hydrology Dams; Ontario MNRF OHN - Dam Lines, Ontario MNRF OHN - Dam Poly; Ontario MNRF OHN - Hydrographic Line; Ontario MNRF OHN - Hydrographic Poly; Ontario MNRF Dam Inventory (ODI); Ontario MNRF Dam and Barrier (retired); EA Reports; HATCH Study (2013); Additional features digitized using Bing Imagery

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Order of precedence	Footprint Dataset	ALCES Footprint Type	Buffer width (m)	Source and link
9	Reservoir	reservoir		Generated using the custom-built model INFI Reservoirs Tool developed by Meg Southee using ArcGIS Model Builder and dam data sources listed above
10	Minor Road	minorroad	10 m	Ontario MNRF Road Segment where SURF_TYPE <> 'Paved'; DMTI CanMap Route Logistics Ontario All Roads (rte.zip); DMTI CanMap Route Logistics Quebec All Roads (rte.zip)
11	Aggregate Mine	gravelpit		Ontario MNRF Aggsite Authorized Active; Ontario MNRF Aggsite Authorized Inactive; Ontario MNDM Mineral Deposit Inventory 2014 (boundaries digitized using Bing Imagery); Quebec Mining Rights Surface Mine Sites
12	Rural Residential Area	rural		Ontario Forest Resource Inventory where Category == UNCLASSIFIED (boundaries modified using Bing Imagery)

Forestry Scenario

Appendix 1. Table 3.3. Simulated harvest levels are based on the AACs of the FMUs within the study area (including Québec), adjusted to account for the proportion of each FMU that is within the study area's boundary.

Forest Management Units (FMUs)	Adjusted AAC (m3/year)	
	Softwood	Hardwood
Abitibi River	1071207	408423
Caribou	283612	66318
Gordon Cosens	1038502	365054
Hearst	631202	259746
Kenogami	869200	170296
Lac Seul	103103	7084
Lake Nipigon	47499	10295
Magpie	78524	53505
Marathon[38]	105910	84270
Martel	324902	149482
Nagagami	241143	193901
Ogoki	421084	120227
Pineland	219931	159735
Romeo Malette	337438	156849
Spanish	88541	39170
Timiskaming	202258	188517
Trout Lake	128267	14571
White River	21295	11518
082-51 (Québec)	51803	38932
085-51 (Québec)	12678	2142
086-51 (Québec)	8168	2882
Total	**6286268**	**2502917**

[38] The Marathon Block is made up of multiple FMUs. Harvest intensity (i.e., m3/ha) was based on values for Big Pic, the FMU which dominates the portion of the Marathon Block occurring within the study area.

Climate Change Scenario

We obtained downscaled North America Historical climate data at a resolution of 10 km from the Canadian Forest Service (McKenney et al. 2011). The climate data is interpolated using a thin-plate smoothing algorithm (ANUSPLIN) to develop spatially continuous climate models that reduce the predictive residual error across the surface (McKenney et al. 2011). A baseline average model average for 2014 was calculated using the average of bioclimatic and growing season parameters from 2004-2013. Climatic projection grids were developed for 2024, 2034, 2044, 2054, and 2064 using the CanESM2 Climate Model (The Fourth Generation Global Climate Model).[39] Future grids were developed based on representative concentration pathways (RCPs) used by the Intergovernmental Panel on Climate Change (IPCC) in their 5th Assessment Report (e.g., IPCC 2013, 2014a,b). The RCPs are an improvement on previous scenarios because they include other forces such as aerosols and land cover as well as greenhouse gas emissions. The RCP provide quantitative information concerning the radiative forcing, ranging between 2.6 and 8.5$W{\cdot}m^{-2}$, in the year 2100 resulting in an increase in the global temperature from below 1 °C in RCP 2.6 to about 7 °C for RCP 8.5 above pre-industrial levels (Rogelj et al. 2012). We used RCP 8.5 to generate our climate change scenarios in this study. RCP 8.5 is based upon the revised and extended storyline of the IPCC A2 scenario (Riahi et al. 2011) and corresponds to a high greenhouse gas emissions pathway, representing the failure of humans to curb current warming trends by 2100 (Fisher et al. 2007). Under this "worst-case" scenario, GHG emissions are up to seven times higher than preindustrial levels (McDermid et al. 2015b).

We obtained current (2014) climate grids and future climate grids for the following variables based on the literature relating freshwater fish occurrence and distribution (primarily in lakes) including:

- **Growing Degree-Days (GDD).** Growing season was determined using temperature-based rules, starting when the mean daily temperature was greater than or equal to 5°C for 5 consecutive days beginning March 1. GDD is an index of ambient thermal energy is directly related to the cumulative metabolism of fish with warmer temperatures resulting in faster growth and earlier maturity (Alofs et al. 2014, Venturelli et al. 2010). GDD ≥ 5°C has been shown to be a significant predictor of freshwater fish biodiversity given climate change across Canada (e.g., Chu et al. 2003, 2005, 2014).

- **Precipitation seasonality and temperature seasonality (e.g., coefficient of variation (CoV)).** CoV is the standard deviation of the monthly mean temperatures expressed as a percentage of the mean of those temperatures (i.e. the annual mean). Extreme weather events (*sensu* "flashiness") result in increased winter flows into rivers (Beauchamp et al. 2015), increased permafrost melt that affects the access and quality of freshwater habitat for freshwater fish at critical times such as spawning and migration (Poesch et al. 2016). Heat waves and droughts also cause loss of habitat and reduced flows.

[39] http://ec.gc.ca/ccmac-cccma/default.asp?lang=En&n=3701CEFE-1

- **Min, Max and Mean Temperature and Maximum July Temperature.** Increased air temperature, particularly in the winter, can affect ice break-up and timing as well as freshet (Poesch et al. 2016, Alofs et al. 2014, Shuter et al. 2013). Air temperatures are related to near-surface lake water temperatures and ice duration (Sharma et al. 2008). Maximum July temperature can reduce available fish habitat, particularly for cold and cool-water species (Shuter et al. 2013).
- **Total and Mean Precipitation.** Timing, intensity and volume of precipitation can affect water quantity and quality of freshwater habitats including higher winter flows, changes in spring peak flows, lower summer flows, and drying of wetlands, such as bogs (Dove-Thompson et al. 2011).

Hydroelectric Scenario

Ontario's Long-Term Energy Plan (LTEP) provides limited information on potential hydroelectric facilities (ME 2013). Consequently, we used the more dated Integrated Power System Plan (IPSP) to help develop high- and low-growth hydroelectric scenarios for the study area. The IPSP, originally released in 2007 and updated in 2008, identifies projects that could contribute to targeted increases in hydroelectric generation capacity. The Ontario Power Authority (OPA) was directed by the Ministry of Energy to develop a revised IPSP in 2011, but development of this plan is not proceeding. The IPSP identified 2921 MW of planned projects to be added by 2025 to the province's hydroelectric capacity of 7850 MW as of 2007, for a targeted capacity of 10771 MW (OPA 2008a,b). As such, the IPSP identified substantially larger growth in hydroelectric capacity than targeted by the more recent LTEP.

The sites identified in the IPSP were compared against reviews of the feasibility of hydroelectric sites by HATCH (2005, 2013) for the Ontario Waterpower Association (OWA). HATCH (2013) used a GIS screening model to assess potential hydroelectric sites greater than 20 MW in the Far North region of the study area. Some sites from the IPSP are identified as having infeasible head heights by HATCH (2013), and revised head heights are provided. HATCH (2005) categorized hydroelectric sites as "practical" or "not practical" based on technical and economic factors. We used the Wpower Potential Site GIS layer developed by MNRF and the HatchAllPotentialDamSites KML layer from HATCH to locate these sites in the study area and assign capacities and the MNRF site ID, locations, and site names were cross-referenced with data in the HATCH reports.

The IPSP includes projects that would be subject to policy constraints in the study area. There are 45 sites identified in our hydroelectric scenarios that are subject to either the Moose River Basin Commitment (MRBC) or the Northern Rivers Commitment (NRC) (Figure 2.6). The MRBC pertains to new development (greenfield or redevelopment) within the Moose River basin, north of Highway 11 (OPA 2008a:95). Ontario committed that there would be no hydroelectric development, other than the "extension" to the generating capacity of four existing Ontario Power Generation and Moose Cree First Nation partnership dams along the Mattagami River. The only way future hydroelectric development can occur in the Moose River Basin is through co-planning processes with affected First Nations. The NRC sets out that there will be no development > 25 MW in the basins of the Albany, Attawapiskat and Winisk Rivers; and development < 25 MW can proceed only if it is proposed by the local Aboriginal community or communities and/or their partner(s) (OPA 2008a:95). These commitments arose due to extensive flooding of First Nations traditional territories associated with hydroelectric development in the past (Far North Sciences Advisory Panel Report 2010). For our project, we assumed these sites would be developed in co-management with First Nations. In addition, 6 sites are wholly located in protected areas such as provincial parks. Some of these park designations may be subject to revision through community-based land planning with First Nations under the Far North Act, 2010 as well as new emerging protected areas in this process that may affect future hydroelectric development.

Scenarios explored two levels of hydroelectric development:

- The **high-growth scenario** implements the IPSP trajectory of 14 planned sites by 2024, as well as one potential site (Yellow Falls) that was expected to be developed by 2016.[40] During the second decade, two IPSP sites and the most cost-effective site in proximity to the eight First Nation Communities north of Pickle Lake as well as the Ring of Fire dam, as identified by HATCH (2013), are developed. To extend the high growth scenario beyond the second decade, potential (as opposed to planned) IPSP sites are developed resulting in an increase in generation capacity that is slightly less than average annual rate occurring during the first two decades of the simulation (87 MW vs. 102 MW per year).

- The **low-growth scenario** implements the 2025 LTEP target by developing the three planned sites with the earliest projected in-service dates, as well as Yellow Falls, during the first decade of the simulation. The remaining 15 planned sites are then developed over the next four decades, again prioritizing sites with earlier projected in-service dates. In addition, the study area's two most cost-effective sites in proximity of First Nation Communities north of Pickle Lake, as identified by HATCH (2013), are developed during the second decade of the simulation. The low-growth scenario develops almost half of the capacity as the high scenario (1935 MW compared to 4658 MW) and about one-third as many dams (18 as opposed to 54 dams).

40 http://www.powerauthority.on.ca/hydroelectric/island-falls-generating-station-20-mw-smooth-rock-falls-mattagami-river

More detail on the hydroelectric scenarios is provided in the table below.

Appendix 1. Table 3.4. Hydroelectric generation sites added to the study area under low and high growth development scenarios (based on MNR Waterpower Potential database, OPA 2008, 2008a, 2007, HATCH 2005, 2013).

Future Hydro ID	Site Name	Capacity (MW)	MNRF ID	Secondary Watershed	Low Growth Scenario	High Growth Scenario	Policy Constraints[1]
H01	Newpost Creek	25		Abitibi	2015-2024	2015-2024	MRBC; Provincial Park
H02	Yellow Falls	12.87	4LB32	Missinaibi - Mattagami	2015-2024	2015-2024	
H03	Grand Rapids	174	4LG7	Missinaibi - Mattagami	2015-2024	2015-2024	MRBC
H04	Opasatika Rapids	2.56	4LL5	Missinaibi - Mattagami	2015-2024	2015-2024	MRBC; Provincial Park
H05	Breakneck Falls	3.77	4LL11	Missinaibi - Mattagami	2025-2034	2015-2024	MRBC
H06	Sand and Adjacent Rapids	64.64	4ME56	Abitibi	2025-2034	2015-2024	MRBC
H07	Nine Mile Rapids	295.5	4ME11	Abitibi	2035-2044	2015-2024	MRBC
H08	Hat Island	490	4HA4	Lower Albany	2035-2044	2015-2024	NRC
H09	Eabametoong	26.19	4GD50	Upper Albany	2025-2034	2025-2034	NRC; Provincial Park
H10	Neskantaga	23.16	4FB32	Attawapiskat	2025-2034	2025-2034	NRC; Provincial Park
H11	Nibinamik	17.38	4DA387	Winisk		2025-2034	NRC
H12	Webequie	23.2	4DB309	Winisk		2025-2034	NRC; Provincial Park
H13	Wunnumin Lake	13.55	4DA386	Winisk		2025-2034	NRC
H14	Kingfisher Lake	2.38	4DB306	Winisk		2025-2034	NRC
H15	Wawakapewin	4.31	4DB307	Winisk		2025-2034	NRC
H16	Kasabonika Lake	6.94	4DB308	Winisk		2025-2034	NRC
H17	Ring of Fire	30.98	4FC117	Attawapiskat		2025-2034	NRC
H18	Poplar Rapids	10.2	4LB6	Missinaibi - Mattagami	2035-2044	2015-2024	MRBC
H19	Blacksmith	140	4ME55	Abitibi	2035-2044	2015-2024	MRBC
H20	Allan Rapids	131	4ME57	Abitibi	2045-2054	2015-2024	MRBC
H21	Chard	370	4GF1	Upper Albany	2045-2054	2015-2024	NRC
H22	Neelands Rapids	2.51	4MD3	Abitibi	2045-2054	2015-2024	
H23	Wanatango Falls	3.21	4MD2	Abitibi	2045-2054	2015-2024	
H24	Sankey Rapids	9.67	4MD4	Abitibi	2055-2064	2015-2024	MRBC
H25	Sextent Rapids	16.14	4ME9	Abitibi	2055-2064	2015-2024	MRBC; Provincial Park
H26	Renison	135	4LG9	Moose	2055-2064	2025-2034	MRBC
H27	Mawhinney	6.4	4ME58	Abitibi		2035-2044	MRBC
H28	Ten Mile Rapids[3]	28.4	4LD3	Missinaibi - Mattagami		2035-2044	Provincial Park

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Future Hydro ID	Site Name	Capacity (MW)	MNRF ID	Secondary Watershed	Low Growth Scenario	High Growth Scenario	Policy Constraints[1]
H29	Achapi Lake	6.95	4GC12	Upper Albany		2035-2044	NRC; Provincial Park
H30	Lower Limestone Rapids	10.37	4JB7	Upper Albany		2035-2044	NRC
H31	Miminiska Falls	5.06	4GC8	Upper Albany		2035-2044	NRC; Provincial Park
H32	Coral Rapids	192	4ME10	Abitibi		2035-2044	MRBC; Provincial Park
H33	Grey Goose	140.4	4LG8	Moose		2035-2044	MRBC; Provincial Park
H34	Blackbear Island	490	4HA3	Lower Albany		2035-2044	NRC
H35	Buffaloskin	76	4GD13	Upper Albany		2035-2044	NRC
H36	Camus Rapids near middle of Reeves TWP	4.81	4LC2	Missinaibi - Mattagami		2035-2044	
H38	Black Feather Rapids	4.8	4LJ7	Missinaibi - Mattagami		2035-2044	MRBC; Provincial Park
H39	Whist Falls	12.5	4LD4	Missinaibi - Mattagami		2045-2054	MRBC; Provincial Park
H40	Albany Rapids	6.59	4LJ10	Missinaibi - Mattagami		2045-2054	Provincial Park
H41	Split Rock Rapids	7.4	4LH7	Missinaibi - Mattagami		2045-2054	Provincial Park
H42	Devil Rapids	7.78	4LJ11	Missinaibi - Mattagami		2045-2054	Provincial Park
H43	Kettle Falls	9.5	4LJ9	Missinaibi - Mattagami		2045-2054	MRBC; Provincial Park
H44	Glass Falls	10.4	4LJ5	Missinaibi - Mattagami		2045-2054	Provincial Park
H45	Thunder House Falls & Chute	42	4LK3	Missinaibi - Mattagami		2045-2054	MRBC; Provincial Park
H46	Long Rapids	126	4LK6	Missinaibi - Mattagami		2045-2054	MRBC; Provincial Park
H47	Biglow	480	4HA2	Lower Albany		2045-2054	NRC
H48	Stooping	285	4HA1	Lower Albany		2045-2054	NRC
H49	Wabimeig Creek	185	4GF2	Upper Albany		2045-2054	NRC
H50	Gneiss Rapids	32.88	4DB6	Winisk		2055-2064	NRC; Provincial Park
H51	Seashell Rapids	37	4DB7	Winisk		2055-2064	NRC; Provincial Park
H52	Atik Island	64.3	4DC1	Winisk		2055-2064	NRC; Provincial Park
H53	Winisk P.O.	94.7	4DC4	Winisk		2055-2064	NRC; Provincial Park
H54	Shamattawa River	112	4DC3	Winisk		2055-2064	NRC; Provincial Park
H55	Maminiska River	130	4DC2	Winisk		2055-2064	NRC; Provincial Park

[1] MRBC = Moose River Basin Commitment; NRC = Northern Rivers Commitment (see Section 3.2.4 for description)

Mining Scenario

The following sources of information were used to estimate when new mines could open during the next five decades.

1. As part of an assessment of the mining sector's future in northern Canada, the Conference Board of Canada (Rhéaume and Caron-Vuotari, 2013) identified mining projects that are likely to occur in northern Ontario by 2020 to achieve a projected compound growth rate of 5.8%/year. The projection includes three new gold mines (Detour Lake Project, Cochenour, Hammond Reef), one expanded gold mine (Young-Davidson), and two nickel/copper mines (Totten, Eagle's Nest). Of these, only Eagle's Nest Multi-Metal Mine is located within the study area.

2. The North of Dryden Integrated Regional Resource Plan (IRRP) indicated that future energy demands in the northwest will be driven primarily by the mining sector (IESO 2015: 39). Their high demand scenario assumes an extensive, near- to medium-term build out of the Ring of Fire area with multiple mines will be operating in the region by 2020. Their low demand scenario assumes the Ring of Fire will not be developed before 2034. They do not identify which mines will be developed or included in their scenarios. However, the Common Voice Northwest (CVNW) Energy Task Force's (2013) response to draft energy plan development in northwestern Ontario identified a number of projects. The CVNW Energy Task Force (2013) suggested that OPA's load forecasts for northwestern Ontario were too low and identified eight mining projects that CVNW expects to be developed by 2020, four of which occur within the study area (e.g., Noront (nickel and chromite), Rockex, PC Gold (CVNW 2013: 51)).

3. In the Ring of Fire, the Ontario Chamber of Commerce assessed conservative and optimistic mine development scenarios (Hjartarson et al. 2014). Their conservative scenario assumed that two mines would be developed over the next 32 years (e.g., 2046), specifically the Black Thor chromite mine and the Eagle's Nest nickel/copper mine. Their optimistic scenario assumed that five mines would be developed over the next 32 years: Black Thor and Eagle's Nest mines as well as the McFaulds nickel/copper mine and the Black Creek and Big Daddy chromite mines.

4. Rhéaume and Caron-Vuotari (2013), CVNW Energy Task Force (2013), and Hjartarson et al. (2014) projections do not include the Timmins region in the southeastern portion of the study area, which is an active gold mining district. Two projects within the region are sufficiently advanced to be undergoing environmental assessment (Hardrock and Côté gold mines[41]) and were included in our scenarios. The Hardrock project is located at an historic mine site, whereas the Côté project is a new mine site. An additional project within the study area that is undergoing environmental assessment is an extension of the Victor diamond mine.[42]

[41] www.ceaa-acee.gc.ca
[42] www.ceaa-acee.gc.ca

We generated the following scenarios:

- Under the **high-growth scenario**, all mines identified by Rhéaume and Caron-Vuotari (2013), CVNW Energy Task Force (2013), Hjartarson et al. (2014) and undergoing environmental assessment are developed on schedule. Thereafter, the rate of development is extrapolated to maintain a relatively constant number of producing mines during the scenario. Relative to today, the scenario maintains a similar level of gold, diamond, and nickel/copper production and incorporates the emergence of a chromite mining industry. This rate of development is likely within the bounds of the "business-as-usual" scenario for global resource use developed by the United Nations Environment Programme International Resource Panel (2011). Under this scenario, natural resource consumption increases more than 3-fold between 2000 and 2050 as per capita natural resource consumption continues to follow the recent trend of stabilizing in industrial countries and increasing in developing countries.

- Under the **low-growth scenario**, the number of mines that are developed is reduced by approximately half compared to the high-growth scenario

Ontario Ministry of Northern Development and Mines (MNDM) Mineral Deposit Inventory (MDI)[43] was used to locate the current and potential "future mines" and examine prospect status, ownership, and exploration history where available.[44] The size of some future mine footprints could be digitized from publically available project site descriptions contained in environmental assessment documents (e.g., Eagle's Nest (nickel/copper), Hardrock (gold), Côté (gold), Tango Extension (diamonds)) or other technical project reports (e.g., Pickle Crow [gold], Eagle Island [iron], Black Thor [chromite][45]). The size of other simulated mines was based on the average size of gold mines (11.72 km^2), nickel/copper mines (2.68 km^2), chromite mines (19.94 km^2), iron mines (6.03 km^2), and diamond mines (13.65 km^2 for new remote diamond mines and 3.28 km^2 for "extensions" associated with Victor Diamond Mine). The MDI location was used as the centre of the new "mine" footprint.

More details for each mining sector under the high- and low-growth scenarios is provided in Tables 3.5 – 3.9 (below).

[43] http://www.ontario.ca/data/mineral-deposit-inventory-ontario http://www.geologyontario.mndmf.gov.on.ca/mndmaccess/mndm_dir.asp?type=pub&id=mdi

[44] http://www.mndm.gov.on.ca/en/mines-and-minerals/applications/ogsearth/mining-claims

[45] http://www.ontario.ca/page/cliffs-chromite-project

Appendix 1. Table 3.5. The scheduling of new gold mines under described high and low growth scenarios.

Future Mine ID	Mine Name	MDI ID	High Scenario Open	High Scenario Close	Low Scenario Open	Low Scenario Close
G01	Côté Lake Deposit[46]	MDI41P12SW00036	2017	2031	2028	2042
G02	Hardrock Project[47]	MDI42E10NW00009	2018	2032	2018	2032
G03	Pickle Crow No. 3 Shaft[48]	MDI52O08NE00126	2018	2025	2028	2037
G04	Taylor Mine / Shoot Zone	MDI42A10SE00066, MDI42A10SE00065	2022	2036	2033	2047
G05	Borden Lake Gold Property	MDI000000000908	2026	2040	2036	2050
G06	Southwest Zone/ Windjammer South / Moneta 55 Zone	MDI42A08NE00038, MDI42A08NE00158, MDI42A08NE00030	2028	2042	2038	2052
G07	Fenn-Gib	MDI42A08SE00121	2028	2042	2043	2057
G08	Gold River Trend Project / South Zone	MDI42A05SE00065, MDI42A05SE00066	2032	2046	2048	2062
G09	Frankfield East Deposit	MDI42A11NE00007	2033	2047	2051	2065
G10	Timmins North Deposit	MDI42A11NE00034	2037	2051	2053	2067
G11	Contact / 147 Zone	MDI000000001430, MDI000000001431	2038	2052	2058	2072
G12	Springpole Lake Property	MDI52N08NW00008	2041	2055		
G13	TPW Property	MDI42A06NW00200	2043	2057		
G14	Vogel-Schumacher Property	MDI000000000248	2043	2057		
G15	Jonpol	MDI32D12SW00044	2047	2061		
G16	Kerrs	MDI000000001443	2048	2062		
G17	Stroud	MDI42A08NW00142	2052	2066		
G18	Kasagiminnis Lake	MDI52O08SW00007	2053	2067		
G19	Goss Lake	MDI52P09SW00002	2056	2070		
G20	West Anticline Zone	MDI53B09SW00008	2058	2072		
G21	Tousignant	MDI32D12SW00176	2058	2072		
G22	Koval-Ohman	MDI52O07SE00002	2062	2076		
G23	Umex-Dorothy Lake	MDI52O06NW00003	2063			

[46] The Côté mine is expected to begin production in 2017 and have a mine life of 15 years (AMEC 2013). Indicated and inferred resources are 289.6 million tonnes of ore and 8 million ounces of gold, for an average grade of 0.0276243 ounces per tonne (http://www.iamgold.com/English/Operations/Development-Projects/Cote-Lake-Ontario/default.aspx). Ore production is expected to be 60,000 tonnes per day (21.9 million tonnes per year). Based on the average grade, annual gold production should be 604,972 ounces. We digitized the Côté Lake mine footprint using figures in the project description (AMEC 2013).

[47] The Hardrock mine is expected to begin production in 2018 and have a mine life of 15 years (Stantec Consulting Ltd. 2014). The projected annual gold production is 202,700 ounces

[48] The start date for the Pickle Crow mine is from CVNW (2013). A projected mine life and annual rate of production is not available. In the absence of better information, annual production is assumed to be approximately equal to that projected for the Hardrock mine (200,000 ounces). The estimated proven, probable and possible geological reserves for the entire property are estimated at 1.2 million ounces (Hennessey et al. 2011), which would support a mine life of 6 years at a production rate of 200,000 ounces per year. We digitized the Pickle Crow mine footprint using figures in Hennessey et al. 2011.

Appendix 1. Table 3.6. The scheduling of new nickel/copper mines under described high and low growth scenarios.

Future Mine ID	Mine Name	MDI ID	High Scenario Open	High Scenario Close	Low Scenario Open	Low Scenario Close
N01	Eagle's Nest Project	MDI000000000695	2018	2028	2025	2035
N02	McFaulds Lake #1 / McFaulds Lake #3 Deposits	MDI43D16SE00001, MDI43D16SE00002	2029	2039	2045	2055
N03	Eagle Two Prospect	MDI000000000697	2040	2050		
N04	Mcnugget (MN07-40)	MDI000000000896	2051	2061		
N05	5.01	MDI000000000912	2062			

Appendix 1. Table 3.7. The scheduling of diamond mines under the high and low development scenarios.

Future Mine ID	Mine Name	MDI ID	High Scenario Open	High Scenario Close	Low Scenario Open	Low Scenario Close
D01	Tango Extension[49]	MDI43B13SW00004	2018	2024	2023	2033
D02	X-Ray	MDI43B13SW00007	2025	2034	2038	2048
D03	U2 Kimberlite	MDI000000000251	2035	2044	2053	2063
D04	Delta 1	MDI43B13SE00002	2045	2054		
D05	Alpha-1 North[50]	MDI43B12NW00005	2055	2064		

Appendix 1. Table 3.8. The scheduling of new chromite mines under the high and low development scenarios.

Future Mine ID	Mine Name	MDI ID	High Scenario Open	High Scenario Close	Low Scenario Open	Low Scenario Close
C01	Black Thor Deposit[51]	MDI000000000704	2020	2049	2030	2059
C02	Big Daddy Chromite Deposit[52]	MDI000000000700	2030	2044	2060	2074
C03	Black Creek Chrome Deposit	MDI000000000956	2045	2059		
C04	Koper Lake Project (Black Horse)	MDI000000001644	2050	2064		
C05	Blackbird One Deposit	MDI000000000693	2060	2074		
C05	Blackbird Two Deposit	MDI000000000694	2060	2074		

[49] The Tango Extension to the Victor diamond mine is projected to begin production in 2018 and have a mine life of 7 years (http://www.ceaa-acee.gc.ca/050/details-eng.cfm?evaluation=80043).

[50] We assumed Alpha-1 North would be the last prospect developed based on the layout of the prospects and the De Beers claims around Victor diamond mine.

[51] The Black Thor chromium mine was projected to begin production in 2016 (CVNW 2013) and have a lifespan of 30 years or greater (http://www.ontario.ca/environment-and-energy/cliffs-chromite-project).

[52] Chromite mines subsequent to Black Thor are all located within the Ring of Fire. Identified mineral resources include: Big Daddy (32.5 Mt resource estimate), Black Creek (10.3 Mt resource estimate), Black Horse (or Koper Lake Project) (77.2 Mt resource estimate), and Blackbird (44 Mt resource estimate). Big Daddy and Black Horse (or Koper Lake Project) will be developed first due to their inclusion in the "optimistic scenario" developed by Hjartarson et al. (2014)

Appendix 1. Table 3.9. The scheduling of new iron mines under the high and low development scenarios.

Future Mine ID	Mine Name	MDI ID	High Scenario Open	High Scenario Close	Low Scenario Open	Low Scenario Close
I01	Eagle Island	MDI52J14NE00004	2018	2047		
I02	Fish Island	MDI52J14NE00007	2048	2077		

Transmission and Transportation Corridor Scenario

Appendix 1. Table 3.10. Current linear feature footprints in the study area.

Type of Linear Feature	Region of the study area	Length (km)	% of length (of respective linear feature in the region)
Major Roads	Far North	84.41	2.67
Major Roads	South of the Far North Planning Area	3073.29	97.33
Minor Roads	Far North	2831.1	4.15
Minor Roads	South of the Far North Planning Area	65333.75	95.85
Active Railway	Far North	125.78	5.25
Active Railway	South of the Far North Planning Area	1901.22	79.38
Abandoned Railway	South of the Far North Planning Area	367.95	15.36
Transmission Lines	Far North	1037.81	25.43
Transmission Lines	South of the Far North Planning Area	3043.21	74.57
Pipelines	Far North	11.14	1.54
Pipelines	South of the Far North Planning Area	713.43	98.46

APPENDIX 2 – DETERMINING WATERSHED FRAGMENTATION

Roads and linear features have the potential to temporarily or permanently affect habitat quality and quantity for fishes, including access to specific habitats at different times of year for feeding, spawning, overwintering, etc. Various types of watercourse crossings can be constructed including ice bridges, shallow areas where vehicles are able to cross (e.g., ford crossings, road beds with culverts, and bridges, see Cott et al. 2015). Culverts come in a variety of shapes and sizes and are required for most all-weather road crossings and some winter road crossings. If they are improperly installed or maintained, they can become impassable (upstream or downstream movements) to fish. Culverts that are undersized can also be a barrier because they can increase the flow velocity to rates too great for fish to move through (MacPherson et al. 2014). Culverts can also settle, be dammed by beavers, and fill with debris and material, all of which can obstruct fish passage. Waterway restrictions and crossing structures, including bridges, also alter the physical habitat above and below the area, with pooling above, reduced flow and or channelization below, changes in temperature, alterations in substrate and sediment composition, etc. (Maitland et al. 2015).

There is great concern about the impacts of poorly constructed crossing structures in western North America where culverts have eliminated access to significant amounts of salmonid habitats (Gucinski et al. 2001). A study of culverts in northeastern Alberta found 30% of culverts to be impassable to fish (Park et al. 2008). In the Great Lakes basin, only 36% of stream crossings are estimated to be fully passable to fish (Januchowski-Hartley et al. 2013). In northern Ontario, species likely adversely affected by barriers in both small and large streams include brook trout, white sucker, minnows and darters (Browne 2007). In larger streams and rivers, poorly constructed or maintained bridges or other structures will affect lake sturgeon, walleye, and brook trout (Browne 2007). Even though commercial forestry in the southern portion of the study area requires the construction of thousands of kilometers of forestry roads that cross tens of thousands of streams, no public data exist on culvert status or densities.

Based on analyses of stream crossings in northern Alberta watersheds (Park et al. 2008), we assumed that stream crossings occurred at intersections between roads and streams of Strahler order 4 or less (but not rivers or virtual flows/connectors). If a stream crossing is impassable, the proportion of a watershed's upstream habitat that becomes inaccessible depends on the location of the culvert. As impassable culverts become more abundant, more of the watershed's upstream habitat is likely to become inaccessible. To estimate the relationship between the density of impassable culverts (# per stream km) and watershed discontinuity (proportion of upstream habitat that is inaccessible), a portion of stream crossings were assumed to be impassable and consequences to the proportion of stream length made inaccessible were calculated. The analysis was completed for eight tertiary watersheds: Upper Abitibi, Upper Groundhog, Upper Kenogami, Upper Winisk, Otoskwin, Upper Albany-Cat, Kinosheo, and Opasatika[53] (Figure 1).

[53] Upper Abitibi, Upper Groundhog, Upper Kenogami, Upper Winisk, Otoskwin, Upper Albany-Cat, Kinosheo, and Opasatika were selected for the analysis because they are tertiary watersheds with the greatest number of crossings within their respective secondary watershed (i.e., Abitibi, Missinaibi-Mattagami, Kenogami, Winisk-Coast, Attawapiskat-Coast, Upper Albany, and Lower Albany Coast, respectively). A tertiary watershed from the Ekwan secondary watershed was not included because low road density in this remote basin did not provide enough crossings for the analysis. A tertiary watershed from the Moose secondary watershed was not included because of low overlap with the study area and low road density. Opasatika (watershed 04LL) was selected because it is "average" with respect to the density of stream crossings (e.g., Opasatika has 0.11 crossings per km of stream).

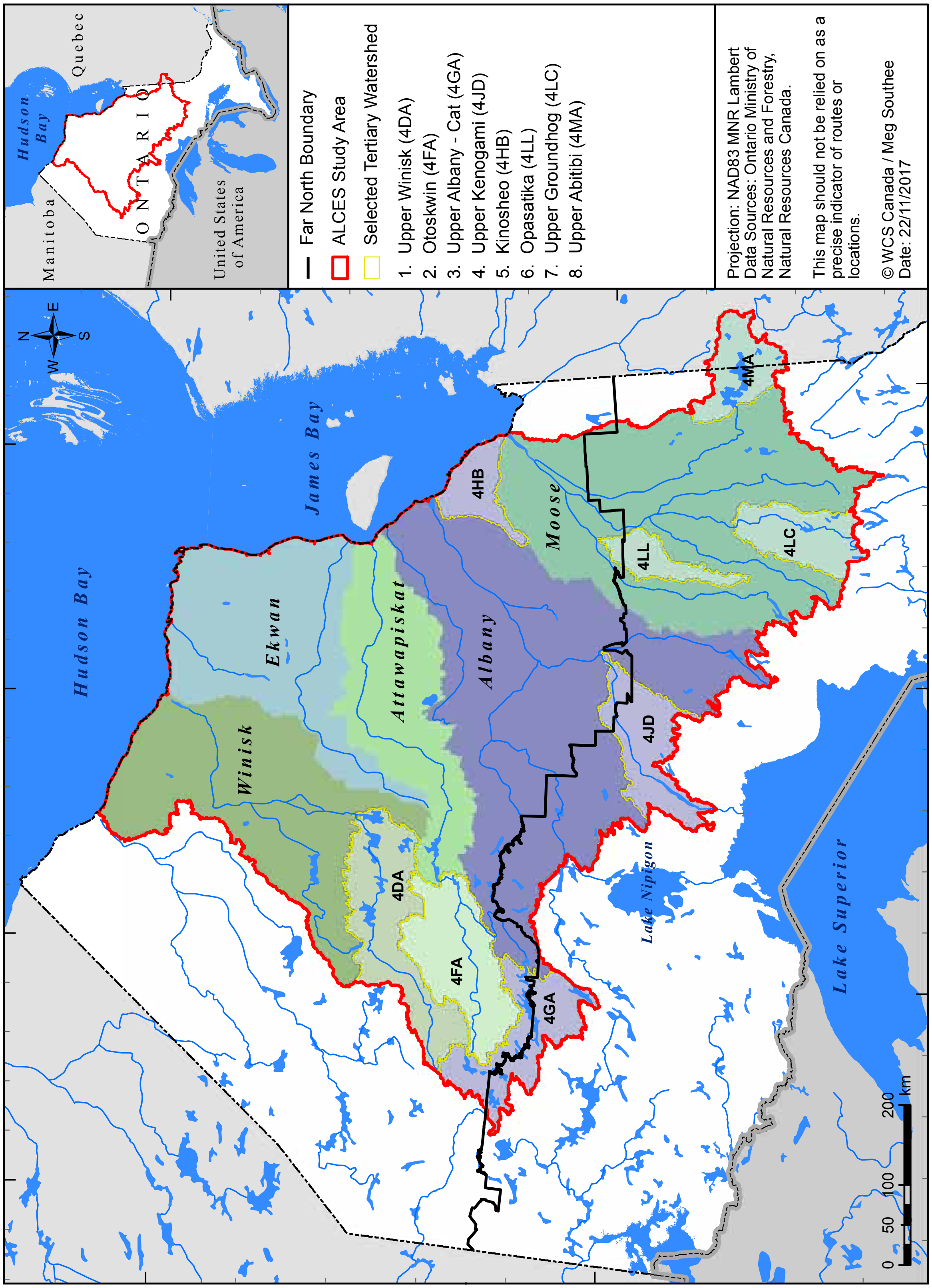

Figure 1. Tertiary watersheds used in the watershed discontinuity assessment.

For a given watershed, stream crossings were randomly selected one at a time and assumed to be impassable. After a given stream crossing was added to the set and assumed to be impassable, the total upstream length made inaccessible by impassable culverts was calculated and applied to estimate a relationship between the density of impassable culverts and watershed discontinuity. The analysis took into account crossing location and routing (based on Ontario Hydro Network) so that the calculation of watershed discontinuity considered the location of crossings in the stream network relative to other crossings. The analysis was completed 100 times, each time using a different sequence of randomly selected impassable crossings. The average across the 100 iterations was used to estimate the watershed discontinuity associated with different densities of impassable stream crossings. A power regression model was fit to the combined results for the watersheds (with the exception of Upper Albany-Cat and Kinosheo[54]) to estimate an average relationship between the density of impassable stream crossings and watershed discontinuity that was subsequently used in simulations when calculating watershed discontinuity. The derived relationship between impassable culverts and discontinuity was y = 3.3627 x 0.8504, where x is impassable culverts per stream km and y is proportion of stream network that is inaccessible.

This relationship is somewhat steeper than that reported for watersheds in northern Alberta (Park et al. 2008). For example, a northern Alberta watershed with a hanging culvert density of 0.011/km of stream exhibited 5.4% watershed discontinuity. In contrast, based on the power regression model fit from northern Ontario data, a hanging culvert density of 0.011/km of stream corresponds with 7.3% watershed discontinuity.

[54] Results from the Upper Albany-Cat and Kinosheo watersheds were excluded because the relationship between hanging culverts and watershed discontinuity was very steep relative to the other watersheds that were assessed. The reason for the steep relationship for these two watersheds is the existence of crossings that are downstream of almost the entire stream network. Because this situation seemed atypical, we excluded the watersheds from the analysis to avoid exaggerating the relationship between hanging culvert density and watershed discontinuity.

APPENDIX 3 – DETERMINING SEDIMENT AND PHOSPHORUS LOAD

The clearing of vegetation during natural resource development exposes soil to erosion, which in turn contributes not only sediment to the aquatic system but also phosphorus that is attached to soil particles. Adverse effects of sediment include degradation of habitat, harm to gills, and impediment of feeding. High levels of phosphorus can cause oxygen depletion through eutrophication.

To assess the effect of simulated changes in landscape composition and climate change on water quality, chemical load factors (CLF) from Table 6 in Donahue (2013, Table 1 below)[55] were applied to natural and anthropogenic cover types and multiplied by annual precipitation to calculate sediment and phosphorus load (kg/ha). The load estimates were then applied to calculate water quality indices for sediment and phosphorus with values ranging from 0 to 1, with lower values indicating compromised water quality. This was done by dividing the load expected from undisturbed forest by the load calculated for the simulated landscape.

[55] Donahue, W.F. 2013. Determining Appropriate Nutrient and Sediment Loading Coefficients for Modeling Effects of Changes in Landuse and Landcover in Alberta Watersheds. Water Maters Society of Alberta, Canmore, AB.

Table 1. Chemical load factors (Table 6 of Donahue 2013) used to calculate sediment and phosphorus load.

Cover type	Chemical load factor (kg/mm*ha)	
	Phosphorus	Sediment
Forest and shrubs	0.00061	0.55350
Herbaceous	0.00013	0.07153
Agriculture	0.00096	0.27041
Roads	0.00314	0.41330
Mines	0.00068	0.42273
Industrial plants (i.e., dams)	0.00184	1.08731
Settlements	0.00178	0.62382
Rural residential	0.00026	0.06309
Transmission lines	0.00134	0.36043
Pipelines	0.00201	0.54065

APPENDIX 4 – WORKSHOP PARTICIPANTS

Name	Title	Contact
Alex Litvinov	Fisheries Biologist, Moose Cree First Nation	alex.litvinov@moosecree.com
Brie Edwards	Post-Doctoral Student, WCS Canada	bedwards@wcs.org
Cheryl Chetkiewicz	Conservation Scientist, WCS Canada	cchetkiewicz@wcs.org
Chris Jones	Research Scientist, Benthic Biomonitoring, MOECC	f.chris.jones@ontario.ca
Cindy Chu	Research Scientist, Inland Lakes, Aquatic Research and Monitoring Section, MNRF	cindy.chu@ontario.ca
Constance O'Connor	Fisheries Conservation Scientist, WCS Canada	coconnor@wcs.org
Erika Rowland	North America Program, WCS	erowland@wcs.org
Geoff Klein	Sustainable Fisheries Planning Manager, Manitoba Water and Stewardship	geoff.klein@gov.mb.ca
Jason Dietrich	Aquatic Ecologist, AMEC	jason.dietrich@amecfw.com
Kim Armstrong	Senior Aquatic Specialist, River & Stream, MNRF	kim.armstrong@ontario.ca
Len Hunt	Human Dimensions Research Scientist, Centre for Northern Forest Ecosystem Research, MNRF	len.hunt@ontario.ca
Matt Carlson	Landscape Ecologist, ALCES Group, ALCES Landscape & Land-Use Ltd.	mcarlson@alces.ca
Meg Southee	GIS Spatial Analyst and Data Manager, WCS Canada	msouthee@wcs.org
Michael Sullivan	Fisheries Scientist, Alberta Environment and Parks, Fish and Wildlife Policy Branch	Michael.G.Sullivan@gov.ab.ca
Mike Friday	Assessment Biologist, MNRF	mike.friday@ontario.ca
Nick Jones	Research Scientist, River and Stream Ecology Lab, MNRF	nicholas.jones@ontario.ca
Nigel Lester	MNRF (retired)	nigel.lester@ontario.ca
Paul Sampson	Senior Science Advisor, MNRF	paul.sampson@ontario.ca
Peter Colby	MNRF (retired)	pjcolby@tbaytel.net
Rob MacKereth	Research Scientist, Fish Habitat, Centre for Northern Forest Ecosystem Research, MNRF	rob.mackereth@ontario.ca
Steve McGovern	MNRF (retired)	mes.steve@gmail.com
Terry Marshall	Principal, Marshall Consulting	tmarshall@tbaytel.net
Tim Cano	Renewable Energy Science Specialist, MNRF	tim.cano@ontario.ca
Tim Haxton	Fisheries Specialist, MNRF	tim.haxton@ontario.ca

APPENDIX 5 – WORKSHOP NOTES AND SYNTHESIS BASED ON NOTES COMPILED BY JASON RAE

Introductions and Overview

In this workshop, we will use ALCES Online, a web-based GIS simulation tool, for land-use planning support within Ontario's portion of the Arctic watershed. This tool has been used in Western Canada, Australia and other parts of the world to inform land-use planning, primarily where cumulative effects of multiple stressors are a concern. The combined effect of stressors on freshwater fish, especially across regional scales and relatively long planning times is the primary focus of this workshop.

Agriculture, hydroelectric dams, mining activities (exploration, mines, infrastructure), human settlements, and infrastructure (e.g., energy, transportation) have footprints that may or may not be permanent depending on their location and societal values. We gathered 24 experts, including 3 freshwater ecologists with WCS Canada, to discuss their perceptions of these impacts with relation to fish populations in northern Ontario. These representations are not intended to be detailed or exact, but are probabilities that represent the opinions of the experts at the workshop. In addition to examining individual rivers, our cumulative effects discussions focused on impacts at large scales, like watersheds.

Natural land cover data were gathered from FRI or EOSD when no FRI available, footprint inventories were drawn from publically available MNRF data sources, and climate data were downloaded from CFS.

Michael Sullivan – Presentation and Introduction to the Approach

Perspectives of natural populations of fish tend to be skewed by low abundance, particularly during the last century. Baselines have already shifted, making monitoring more essential than ever. Northern lakes have few people, limited all-weather access, and no industrial development creating favourable fishing conditions. While industrial development typically increases access to rivers and lakes, the tendency is for fishing quality to decline, often within two winters. Natural limitations, exploitation (from other groups of people), agriculture (phosphates/pesticides/round-up algae blooms), oil and gas (pipeline/train spills), forestry, mining, roads, and stream and watershed fragmentation are typically given as reasons for poor catch/quality of fish when we ask the public.

The commonly used Fish Sustainability Index, FSI, provides a conceptual model to explain why fish species disappear given that declines are already underway by the time reports are developed. Forming committees to write recovery plans that provide a laundry list of issues and threats does not spur management change. Ideally, we should be acting before negative effects accumulate. For example, precautionary fishing regulations on certain lakes right may reduce the rush to overharvest. Mitigation like this can help compensate for other stressors like climate change, but they are crude measures that are not targeted at the problem. Alberta has seen positive results with closures based on the current year's climatic conditions, such as emergency closures when the rainfall and temperature is particularly unfavorable for fish populations in specific watersheds. Enforcement of regulations is difficult, so we must expect a minimum level of non-compliance and poaching. When fish stocks are low, any poaching is a big problem. If stocks are high, however, the same poaching pressure has minimal effect, relative to the system's capacity to adjust to it. Stock vs. recruitment curves are useful to rank the "health" of system (i.e., 1 – 5) and these curves can be validated through various methods such as electrofishing.

The first step in our model is to figure out and decide what factors are important. Next, we use ALCES Online to conduct a large-scale experiment based on our model. The final cumulative effects model represents our best guess (*sensu* hypothesis) of what might happen to freshwater fish. This is an hypothesis that we test in the field with natural and policy or management experiments. For example, a large chromite mine may be developed in the headwaters of the Attawapiskat River.

1. Walter's Adaptive management cycle:
2. Assume cumulative effects (CE) and declines will happen
3. Build a simple model of CE (= best hypothesis)
4. Identify most-likely critical stressor
5. Act NOW to avoid/reduce/mitigate stressor

Monitor Effects

In this process, first we create dose-response curves to represent our hypotheses, and provide a rough estimate of all the likely variables. Real datasets will never have information on these variables in isolation of all other confounding variables. For example, real world experiments typically can't alter fishing pressure without increasing roads. However, studies from the Experimental Lakes Area may generate good information about other variables such as phosphorus and sedimentation. Incorporating Traditional Ecological Knowledge (TEK) can be easily done through participation and including knowledgeable persons to consider the information for a dose response curve. There is a large degree of uncertainty around these models, but robust management recommendations can be made while acknowledging the uncertainty of the model. Overall, these models/processes are intended to be simple, with no need for presence and absence modeling, including catchment variables. Complex or categorical variables like point source pollution should be broken down to specific details like individual type of pollution when possible, but general categories may be used occasionally.

We will draw the response curve suitability from 1 to 5 for each variable and the set range of doses to fill the whole range of suitability, even if it has an unrealistic maximum (e.g., exhaust from 100,000 motorboats per hectare creating unsuitable habitat). This means the models are also self-weighting and multiplicative.

We will also consider the management units, or the scale of the management.[56] Once we have discussed the issues and factors that matter, we then need to determine an appropriate scale for the factor (e.g. fishing mortality across HUC 12). Factors will vary by location, and you can consider smaller HUCs if it is necessary. Typically, we start by creating one model, with different values for each watershed. I notes that the MNRF management zones (e.g., Fisheries Management Zones) in the Far North at least may not match the watershed scale we're modeling. MNRF sampling units are usually small (e.g., lakes), resulting in spotty productivity data, chemical data, etc. It will be a challenge to scale that information up to watersheds. It may also be necessary to develop two models if we think that important factors may differ between two types of freshwater systems (e.g., lakes vs. rivers).

Two levels of regulation can be used to manage fishing pressure: catch and release (easy to implement) or complete closure (more difficult to implement). The models we generate allow management officials to say, "If you put a road here, I'll have to close fisheries, and you will need to explain to the public and First Nations users in the area why this will affect them."[57] The only time, managers should consider stocking as a management option is when all the other habitat parameters are good. All Alberta watersheds are genetically distinct, so stocking policy is heavily weighted towards maintaining genetic integrity. To maintain this integrity, Alberta has actively transported adults from one part of the watershed to another rather than stocking with hatchery individuals who may have different genes. Stocking should also only be considered when fish are completely extirpated.

There is a need to ensure the management plan is robust to all factors associated with species and population health. Managing fish populations in this way means a lot of work that ultimately results in a predicted change of habitat suitability from 1.7 to 1.9, extreme risk to very high risk. While a small change, it is very positive. Also keep in mind that some areas are just not good fish habitat e.g., the region is generally cold and low in terms of productivity. Not all areas will have a habitat suitability of 5 even when considered "pristine" in terms of environmental conditions. In fact, many northern communities will say most of the fish stocks managed in cooler, less productive regions are typically low (3) to very low (1) habitat suitability.

In many cases, there is no recorded baseline pre-development for some factors like hydroelectric dams, but we can ask for stories about fishing quality before and after the development. Large changes (e.g., from 5 to 3 habitat suitability) would be very noticeable to the local experts/respondents, and would be mentioned frequently. I recommend letting people tell their the stories but sometimes the effects are too small to make any difference. For example, a 5% water diversion is important to us, but ecologically, 5% does not generally affect fish much. When creating response curves, always ask the experts why they think each response curve has each specific shape, and record their reasoning.

It would be beneficial to define a process or criteria to determine what factors are added to or excluded from the model. Some factors could have five converters, but ultimately only one is added to the model after the discussion. An implicit mechanism is included in the process we use during these workshops.

[56] Alberta has switched to HUC – usually 8s, sometimes 12. 12 is far more specific (each stream is one basically). HUC 6 is secondary watersheds in Ontario, HUC 10 is Quaternary in Ontario.

[57] Alberta populations are treated with a 2x2 factorial of solutions. Recovery rest periods and habitat best management practices (managing fishing pressure and reducing sedimentation after development).

Generally, if there is consensus that factor x is important, it is included in the model. We also discuss whether there is an effect of that factor and how strong it could be. If there are divergent opinions, we create two curves. This process is intended to capture expert information as well as stories in the dose response curves instead of an exact image. Writing this response out as a formalized procedure can help structure the process.

Overall, the "Joe" model lets us quickly identify the key parameters, then design an experiment to explore, measure and improve upon them in the regions we care about.

1. Benefits of "Joe" models:
2. Simple, just based on expert knowledge.
3. Quick and cheap to generate
4. Functional
5. Suitable for multiple taxa (i.e., wolverines, trumpeter swans, trout)

Supports allocation of responsibility. For example, departments or people can be delegated responsibility for determining specific variables or factors that are the most important such as forestry management section is responsible for addressing sedimentation in the models.

1. Challenges of "Joe" models:
2. All models are wrong, some models are useful
3. Not data driven, but the qualitative expertise of experts and knowledge holders

Walleye Model Discussion

- Mortality – Once total annual mortality passes 30% of the popuation, the walleye FSI (Fish Suitability Index) drops dramatically.
- Growing Degree Days – In general, 1,000 to 2,500 is good for walleye. GDD would more accurately capture temperature effect on walleye than other metrics like mean July temperature.
- Fishing pressure – Use a mortality response curve.
- Water discharge – For example, dewatering of pits to access kimberlite pipes may dump water into other waterbodies. In general, you can reduce water discharge by ~85% before you see effects in walleye habitat suitability. Beyond this, the dip is heavier creating a sigmoidal relationship. The experts agreed that suitability remains high between 100% flow, up to 200%. Some opinions were that when some rivers increase volume, they can spill over into the entire basin and cover valuable well oxygenated habitat resulting in a potential decrease in suitability. In general, context is important, with wetlands acting as sponges for flow when the watershed is large. While mean annual discharge can have a large range of effects, it was not considered that important in the model and was dropped in favor of spring melt or seasonal precipitation metrics.

- Sedimentation – Can be a problem. In our discussion, 1 is normal, 0.5 is a doubling of sediment, and 0.1 is 10 times as much sediment as normal. Experts agreed that walleye are tolerant of dirty water/sediment loads.

- Water clarity/secchi depth – Experts agreed that clear water make is difficult for predatory fish like walleye to hide and hunt prey.

- Mercury – Mercury needs to be very high to affect fish populations. But, it is relevant for human who consume fish and bioaccumulate the mercury in their tissues. This in terms affects fishing mortality. Cultural values are also affected. No objection from experts that there is no real effect of mercury on fish populations within current ranges.

- Fragmentation – Hanging culverts are difficult to prevent and extremely common (50% of a total 50,000 culverts) leading to fragmentation. They are part of any landscape when you develop a road. Fourth-order streams or lower, require culverts, while larger orders generally require a bridge for any road construction. Established rules and regulations.

- Short term effects of irrigation reservoirs and dams – Reservoirs could create more habitat, but strong draw down negatively affects eggs and survivorship.

- Precipitation (annual) – If rainfall doubles, and rivers warm up – likely more rain in spring, less in the summer and more evapotranspiration. GDD increase should be beneficial for walleye (a cool-water fish). High rain improves the stream connectivity, but lowers water clarity. Summer droughts possible with increasing temperatures.

- Compensatory factors are anticipated to not be particularly impactful. With greater warming of waters, we may see more productivity of walleye in northern regions, but not enough to counteract the impacts of fishing.

- Walleye abundance likely driven by water clarity and GDD – natural limiting in our study area due to these two factors mean walleye populations are quite sensitive and we cannot add much more fishing. If we see only see 5 walleye per net, stochasticity may lead to extirpations. An FSI of 3 generally leads to about 15 walleye per net.

- May also need to separate lentic from lotic populations and create another model.

- It is often difficult to estimate effects of development on fishing mortality. Fishing mortality is related to the density of roads. We created a second variable in a road density vs. fishing mortality response curve. A linear response, at 0 km/km^2 with 50% fishing mortality at 5 km/km^2. This variable is not so simple though, as experts agreed it will vary based on the population density around the region, the mobility of the fishers, and the number of available fishing spots.

Detailed Discussion of the Effects of Roads

- Most of the experts were not concerned about the construction of roads into the NW, because it's simply too isolated (far from Thunder Bay) and population density is low. There is an exponential decay in the distance that people will drive from population centers. A 3-hour drive time is likely an important threshold; it's the point where fishermen can reach the site and return in one day.

- In Alberta, at 0.2 km/km^2 (mean length of roads per square km) fishing mortality is barely detectable. Most anglers would call it good fishing. At 0.6 km/km^2, there is about 5% fishing mortality, light growth over fishing in good habitat areas. As high as 1 km/km^2, we see 30% fishing mortality and potential for collapsed fisheries. 50 years in the future, because of road corridors alone we're expecting to see ~0.5 km/km^2 in ~50% of the currently undisturbed landscape including ring of fire, resulting in a situation with no detectable growth over fishing mortality and the experts in the room seemed OK with that. We created a positive dose response curve between roads and lakes, which represents the chance that each road will cross a lake: More roads, higher chance that one connects to a lake. Based on the predicted road density in ALCES, the model is not expecting fishing mortality to exceed 5% in walleye in the far north. There are no motorists attempting to travel past Lac Seul anyway because there are higher quality lakes elsewhere.

- Timmins and Cochrane areas may be a bigger issue, as road density is expected to increase and cause extremely high >35% mortality surrounding those two cities, and the regions of high mortality are expanding toward each other. The fisheries in the southern extent are quite different than those in the northern extent though. There are more lakes in the NW, few lakes immediately north of Hearst, more again as you go farther north. We also see low catch per unit effort around Timmins, where there is high access, but fly in areas like Kesagami still have to regulate their fishermen to keep stocks high. Note that commercial fisheries allocations are still in place up in the Far North, but not being fished. Many of those populations are above mercury guidelines for consumption so the commercial fisheries aspect is not worth modeling.

- Road density can also introduce invasive species. The risk in these areas is that some people may take long trips and introduce invasive species, as opposed to our earlier discussion of fishing mortality increases following road construction. Need to consider management to address this – no translocation of live bait laws, etc. Few potentially positive invasive species do exist for walleye, rusty crayfish possibly. Since there are nearly always few cases where invasives improve habitat suitability, in a general sense, aliens are negative. Should acknowledge the occasional positive effects elsewhere, not in model here.

- Note that spills from transportation and trains may be important to consider too. Oil can cause devastating effects, especially in northern environments where it persists longer. Grain spills can cause low DO in water, or other behavioural effects.

Mitigation Suggestions for Fishing Mortality

- Just putting a season on harvest can significantly decrease fishing pressure. For example, seasonal regulations on Constance Lake reduced fishing pressure from 20 people to 5-10. Consider seasonal closures, but experts suggested it was deemed likely more trouble than it's worth to regulate fishing with catch and release in those areas.
- May also be useful to try canoe access only or restricting motors on lakes. Reasonable success restricting motorized access in Alberta, and Quetico or Algonquin have good success with no motorized fishing. But not many motorists traveling that far anyway. For moose hunting in NE Ontario, a deactivation of a road from a network drops 70% of traffic on the road, seasonal 90%, and permanent closure only 50%. Compliance with road closures and regulations is also related to the relative abundance of fish in the closed areas and those in the open areas.
- On the other hand, if you close or restrict access to a frequently used lake, this can push the people harvesting from that lake to all the nearby lakes. In addition, instituting a catch and release zone can create an expectation for greater size of "trophy" fish in that lake, which can spur high rates of fishing and incidental mortality for that area.

Sturgeon Model Discussion

- We can separate the effect of large dams into the detrimental effects of fragmentation and life history/recruitment problems. Dams can cause mortality indirectly through loss of recruitment. This may be due to stress, but needs more studies. Experts provided examples of sturgeon at the base of a dam with high cortisol that resulted in no spawning.
- We basically doubled the negative effect of the dam by adding an identical dose response curve for the negative effects of fragmentation and life history effects. We get the sense this is a good variable because no-one in the room is speaking up about the benefits of dams at all. Results suggest dams will be a big problem for sturgeon with no mitigation.
- In 30 years, with predicted hydroelectric dam developments, nearly all watersheds are red in ALCES. Given the high growth dam scenarios, we are concerned about the effects of dams in the Far North on sturgeon. Visible population effects will be delayed due to the longevity of the species though and it could be years before the problems of current (and new) developments are detected.

- There is already a closed season in spring for lake sturgeon. But First Nations are generally the only ones in the Far North harvesting sturgeon anyway. Caviar sturgeon poaching is an issue that led to the closing of sturgeon season previously.

Discussion of Mitigation of Effects of Dams

- Run-of-river (RoR) dams have similar effects as other types of dams. Fish ladders on RoR dams are also pretty significant barriers. There is only one example where they are not a significant barrier and that is Deer Lake. It consists of a channel through a rock outcropping with the turbine placed in the outcropping. Water flows through the channel as it would have prior to the dam. Furthermore, RoR dams are often shut down at night to store water up for the day, so the fragmentation effects are not actually mitigated. This is also a problem for walleye.

- New dams in Ontario are likely going to be RoR, but they're going to go into critical spawning habitats for the sturgeon. Prior to development, it was thought that Carmichael Falls was an impassable barrier. But after building a dam there, they found a 10m crevasse that the sturgeon were using to get up the river. This also depends on the year too as discharge conditions will vary, etc. Some years, a waterfall may look like a complete barrier, other years it may be far better.

- Drawdowns in spring and fall can have major negative impacts for spring and fall spawners. But too often dam operators don't include consideration for impacts on fish written in their operating manuals. As such, more dams results in more spawning and recruitment failures per year.

- Regional strategies are useful here to identify the best spots for these dams. If we put a dam on a 60-foot falls, we can expect low impact, but if we put one in limestone riffles where the feeding takes place pre-spawning, it will have a huge impact. A proper regional land use strategy would incorporate cumulate effects considering things like whether there is one dam and what the system is, other fault lines and hydraulics, benefit of the dam, feeding habitat, where the resources that we know about are.

- Look at areas of protection in community-based land use plans. There is another lens that helps in dialogue of where to put development and some cases this advice is highlighted in the Far North Land Use Strategy.

- On a positive note, literature and studies suggest that the fish recover when we remove the dams.

Brook Trout Model Discussion

- Brook trout are generally anadromous.

- Question: Would a dark river accumulate more heat than a clear river?

- Temperature: It's 17 C mean July temp in SE of far north region right now, in 30 years it will be around 21 C, which is starting to get hot for brook trout. Brook trout are doing fine in Cochrane/Timmins area right now because it's a headwater. But generally most water bodies, seeps, etc., increase to whatever the average temperature is. Thus, risk gets higher, and with more stress the population can fail. Groundwater seeps may be refuges of low temperature water and there may be a moderating effect as trees start to grow and shade waters. In general though, after 10 C, suitability linearly decreases until it reaches FSI = 1 at 25 C for brook trout. Our climate data shows 6 degree increases in mean July temperature in many spots. This will mean the lower reaches of Far North to St. James warm up to the same temperatures as the regions of St Lawrence near Ottawa are currently – an area that is much poorer brook trout habitat, primarily as a result of the temperature. The current climate scenario also predicts the end of discontinuous permafrost in Far North, which leads to sediment and silted water. [58]

- Sediment: Examples in the Yukon with muskeg drained but clear water and salmon are gone, replaced by pike. Aside from this, there are not many situations in Ontario currently where we would have high amounts of sediment near sources of groundwater. At Loon Lake, people are worried about new forestry developments increasing sediment and upsetting the spring spawning brook trout. Sediment changes due to forestry are hard to predict and could be positive or negative for brook trout because of changes in infiltration, evapotranspiration, shading, and temperature. The road crossings associated with development are generally the major sources of sediment that we would be concerned about.

- Dams – Because dams primarily impact brook trout through the associated water temperature increase, somewhere up to 3 dams should prove no real problems for brook trout, but quality then linearly declines to 2.5 at 10 dams or so. What's happening in southern Ontario is lots of the smaller streams have small dams, and the water warms up with each dam and after the 3rd one brook trout are pretty much gone. There are a number of examples in Southern Ontario where dam creation changed the relationship of the incoming tributary and the mainstem – and river is now inundated. Dams control the river and there are a number of tributaries that have brook trout, but none are found in the mainstem where the dams are. This change in the river system starts to push it more to smallmouth bass habitat instead of brook trout.

- Fragmentation by Dams – Sea run brook trout will be stopped and fragmented by dams, but in the south there may be more tributaries they can go to. Dams are a big problem for sturgeon and anadromous brook trout, but not as large a problem for walleye or resident brook trout. Should create two models, one for anadromous and another for resident brook trout.

[58] A study was done in Russia on development of eggs of whitefish and lake trout. In a hatchery they increased temp by 2C and development was time reduced by almost 60 days. Deformities increased by 20%. If we have an environment with increased temp, we could see shorter number of days (same GDD) to hatching, but higher deformities (credit Alex Litvinov).

- It may be better to combine both effects of dams together because it's hard for experts to separate those effects mentally, especially because they're multiplicative in the model. If we called it the dam effect then that leaves the door open to saying "well it's more than just fragmentation." On the other hand, having the two effects does help when working with industry, because they will say that they can mitigate some of those effects. No clear conclusion to this concern.
- Fishing mortality – Due to the relatively low maximum age, fishing mortality isn't a huge detriment to brook trout populations, relative to the longer lived species. The room had no objections to this point.
- Climate – match-mismatch hypothesis – hatching time may become earlier in the year with warmer temperatures, and young fish may miss important peaks in food availability. Evidence in many types of species interactions around the world, could be a possibility. Some Lake Trout are spawning earlier than before and using up their egg sac before food is available, but photoperiod is driving their spawning, not temperature. Certain strains of lake trout had plasticity that allowed them to adjust. We also see earlier hatching in fish along thermal blooms from power plants, and they can often miss the timing of their food blooms. Warmer temperatures in the past, we can see all the fall spawners declining with increases in temperature – speculated that it may be due to asynchrony. We ultimately have no idea how this variable will affect the populations, similar to hydrology. We can say it will increase, but not much beyond that. In this case we would make two scenarios, a low risk synchronicity effect and a high risk synchronicity effect that offer the full range of possibilities. The room is somewhat divided on this variable, many suggest it's not worth separating out asynchrony at all because it's too uncertain that it's even happening in many species and it's already incorporated into the estimates of the temperature effect.

Walleye

- Fishing pressure
- GDD – Too cool is a bad thing, there is a wide range of good July GDD, and suitability drops off when it gets too high
- Spring freshet
- Sediment
- Secchi – water clarity, high clarity impacts walleye negatively, they're more of a murky water species. Too murky water may be bad
- Mercury – May cause minor birth defects at high doses, generally more of a food contaminants issue for fishers. Also important to keep it in for public opinion, they perceive it as a big issue

- Invasive species – centrarchids – Are invasives displacing the walleye, or replacing them when they are gone? Experts agree this is hard to determine. May suggest make multiple response curve scenarios depending on the species. Invasive species will interact with other factors in here. So may need to make multiple scenarios based on these interactions. For example, if temperature increases, centrarchids will probably find the habitat more favorable, so may be a bigger effect then.
- Small stream Fragmentation – hanging culverts – At 100% hanging culverts, walleye will still spawn in their native lakes, so worst effect would be ~2, up to 5 at ~35% fragmentation
- Large stream fragmentation – Dams
- Annual Precipitation – generally this seems like it would be good for walleye even up to ridiculous levels. What about drought frequency? These two would affect too many variables including surrounding vegetation to give a clear impact on walleye.

Lake Sturgeon Model

- Use similar variables as walleye model, but change the response.
- Diversions of rivers with % of water flow should be considered, as it will impact lake sturgeon
- Large dam fragments – lake sturgeon can live in fragments, but putting a dam in does other things that wipe out the populations. One dam has severe effects potentially. Lake sturgeon are very long-lived, key spawners today are individuals born in the 1920s. It takes a long time to see effects since they are so long lived. There are also no real before and after comparisons, but sturgeon likely have severe mortality due to dams.
- Experts agreed that RoR dams for sturgeon would be important. They are likely far more impactful than they are "supposed" to be.
- Because sturgeon are so long lived, anywhere past 5% fishing mortality results in near 1 habitat suitability for Alberta. Fishing pressures have been far higher than this in great lakes during the turn of the century, leading to observed declines.[59]
- Non-native species – Not likely a huge effect for sturgeon unless very high densities like 50%, then drop in suitability starts slowly. Effect is unclear and experts don't provide much of a clear opinion here. Sturgeon feed on zebra mussels and gobies. Prussian carp may be a competitor.
- Growing degree days – there is a temperature effect. Slower growing in Winisk and Atawapiskat systems. Similar to walleye, a bit more narrow optimal range.
- Secchi/clarity – no effect on sturgeon, high throughout the range.

[59] Most of this information is from Dr. Tim Haxton, with no objections raised from the rest of the room.

- Sediment – low sediment is OK generally. High sediment is still bad as it was for walleye, but linear increase to 5 FSI around 50%. Likely will not see much sediment increase in sturgeon habitat anyway. They're a wetland species.
- Sturgeon don't care about small streams, so fragmentation from culverts stays at 5 all across to 100%.
- Mercury – effect negligible also
- Phosphates – sigmoidal curve down from 50% to 1 at 0% phosphates
- Spring freshet – higher water flow is better
- Phosphates can cause fish kills due to Biological Oxygen Demand (BOD) but not likely in Far North.

Brook Trout Model

- Dams – Quality declines to poor around 3 dams per river
- Fishing Pressure – not much of a concern for brook trout, short lifespans
- Temperature – expected to be a large factor, but temperatures in the northern region of Ontario's Far North may actually increase to be more favorable, while the southern parts of the Far North could be too hot.
- Water clarity – Brook trout are pretty good even in very stained water, but for BsM lakes, secchi and mean depth explain 85% of brook trout habitat suitability. Clearer water, more brook trout suitability is Cindy's assertion. Divided opinion in the room.
- Spring freshet – Removed. Flow effect or variance in the fall is more important. They often can't get into the rivers until that fall flow goes up. The system in Ontario is unlikely to get flashier – you would expect with climate change elsewhere. The system is full of sphagnum moss, etc. It's heavily buffered. Conversely, you may not get lots of total volume snow or spring rain, so drought intensity might increase. Seasonality of precipitation is getting more uniform across the landscape in the future. Experts unclear on direction, so variable removed.
- Sediment – Double sediment and you will start to see some brook trout problems. What about sediment from melting permafrost – may cause problems.[60] Experts are not too worried about sediment in Far North because we don't have the conditions for sheets of sediment and already use guidelines for construction to mitigate sediment. Sea run should see a very low effect, resident may see a higher effect. Sediment is not a concern for sea run, resident maybe.
- Fragmentation by crossings – % of stream lost to continuity. All streams have some hanging culverts, broken stick model of habitat. Worry more about reverse culverts more as a source of fragmentation than sediment.

[60] Matt noted that one of the problems with the sediment metric is that it's compared to natural for that region. Some regions may have 0 sediment, where any change from a road would make multiple times more sediment without making it too high. So this metric may overestimate the effect of sediment in some spots.

- Non-native species – Brook trout are more sensitive to non-native species than walleye. Brook trout generally disappear first from a system, and very sensitive to disturbances from non-natives.

Lake Whitefish

- Dams – may be a moderate problem, but not a severe problem. Fish quality may go down (according to commercial fisheries research) because dam draw downs are in winter because of hydroelectric.
- Fragmentation – No small stream fragmentation concern.
- Non-natives – Smelt can cause a problem, but won't wipe them out. We have rules against moving smelt around, but they can cause an impact.
- Fishing mortality – Some first nation food harvest and some sport fishing on some inland lakes. Can have something like 30% fishing mortality on lake whitefish and still have a sustainable fishery. They spawn younger for example.
- Road density relation to fishing mortality – Even at high road densities, not worried about over exploitation on lake whitefish by angling. Mostly First Nations that harvest for lake whitefish, roads would make their access easier.
- Sediment effect – Not an issue for lake whitefish.
- Clarity – They like dirty water, they like clear water. No effect.
- Temperature effect – They die at warm temperatures, above 26 C is lethal. They're a cold water species, caught between the low DO lake bottom and the high temp surface. May be too cold for lake whitefish up north right now. Suitability decreases for lake whitefish at 15 C
- Phosphates – not a concern in Far North.
- Alberta has significant problems due to eutrophication and resulting low DO. This happens in Ontario too, mostly southern Ontario though. Anoxic rivers, but these rivers have many other problems too.
- Productivity is important, dimictic lakes have more habitat and stratification may buffer them from temperature increases somewhat.

Discussion of Improvements for Footprints in ALCES

- Consider including forestry roads and spur roads on the map of the NW, as they don't seem to be included currently. The first road, then the small roads coming off of it may have more of an impact because it opens up completely inaccessible locations.
- Forestry development leads to oil and gas. They use the roads that forestry put down to truck oil, cheaper without building their own.
- Also consider population growth in the region. Non-aboriginal populations not expected to grow, but aboriginal populations are.

- Annual allowable cut in FMUs should be closer to 60%, instead of the 100% we used initially.
- Consider adding two different scenarios for two planned major roads with different effects – one if the east-west road comes in, the other if the Keene road comes in.
- There's a layer developed by Steve Colombo called the climate change index and uses precipitation and temperature. Indicates that areas around Wawa to the Sault will experience massive changes.

Discussion about the Index of Native Fish Integrity (INFI)

- As more and more negative effects accumulate in a river, the fish communities change and predators decline. This change can be measured through INFI = # species, % Predators, % omnivores. If INFI = 0.58, that corresponds to a 42% decline. In Alberta, many spots north of fort mac are becoming severely omnivore heavy, few predators. Resulting in a low INFI.
- Ontario uses something slightly different namely size spectra. Ideas today are shifting to a community approach, push for ecological integrity and considering the community effects, fisheries act and community is really important.
- It may be beneficial to use biodiversity as the metric for these discussions with academics, individual species may be a better metric for public though. Use the one that works for your audience. We have some traction with biodiversity, but it's hard to model. We could combine the species we have models of from this workshop, and call it a Valued Fisheries Index. Mean VEC (valued ecosystem component) of these is likely what Mike will use.
- As much as possible we survey for biodiversity indexes in random locations, stratified by stream order. This is still biased in practice though, by the type of water, researcher access, and their safety. Also need to define success of conservation efforts in terms of biodiversity. If biodiversity doesn't increase after conservation efforts does that mean we've failed or if it doesn't increase does it mean we've succeeded because we've prevented new species from coming in or loss of current species?
    - The goal is now to figure out how to prevent these species from disappearing. We can't prevent climate change, but we can mitigate through strategies like:
    - Provide refuges for species to persist in for longer
    - Based on the workshop results, we know we need to protect deep lakes, higher pieces of land, or boreal water. Zones of changing ecotones seem to be important too because they can be used by species in both ecotones.
    - The only thing we can do for climate change is make protected freshwater areas that keep industrial development off some patches for a time. It's a losing battle, but you can delay the development in critical areas.

Discussion of the Plans for the Far North (with Paul Sampson, MNRF)

- Far North Science Advisory Panel Report is important to read, it does identify climate change as an important driver. It also includes asking communities what's important. We need to be mindful of lifecycle requirements of species at local and large scales. Consider what kinds of protection are required, local or bigger. Recommend using/reading the FNLUS because it highlights the types of decisions and information being used by the MNRF. The ministry is working closely with First Nations at the community level and also keeping in mind the larger picture.
- The *Far North Act* indicates a joint process to establish where protected area are going to be. There is a target to have a certain level of areas of protection too. Provincial interests include species of interest, areas of natural and scientific interest. These protected areas help inform those choices by identifying the interesting/sensitive areas. They are recognizing there are some tools that would be helpful to inform that discussion too, including ALCES. The aim is that discussions and consultations are done before development occurs. Together, the MNRF is working with 6 communities in planning. Consideration is also given to the fact that there are shared areas, where communities all want to have interest in that area.
- Community-based land-use planning recognizes there is need for determining appropriate metrics.
- How about the industry, do they discuss how much they can mitigate without losing profit? As it is now, development can proceed if there is a land use plan that allows for that type of development, then that falls to the environmental assessments.
- Matt has had very good success using ALCES as a tool to communicate holistic development in First Nation communities. They usually are far more on board with this type of discussion at the beginning though.

Summary and General Comments on Far North Development

- The models we generated are very rough, but they perform remarkably well. A model can be as simple as positive/neutral/negative and still fit, but we are able to gather much more detailed information with the aid of the experts at the workshop.
- Solid data on fish, and in particular lake whitefish and lake sturgeon, are limited in the Far North so finding enough data is a challenge for these kinds of conclusions, but through this process experts may provide useful insight. We can use the information

generated today to show what areas are important. This allows us to prevent situations where protected areas are created only in areas unimportant for development as opposed to important habitat for any species. We need to protect these areas even if they are useful for development.

- A regional framework is useful to deal with these dimensions in order to create a conservation plan that incorporates cumulate effects. Companies coming in may balk at first, but modeling provides a powerful negotiation tool.
- Cultural values must also be considered. Some of that information is being derived from the community, but some of it needs to come from careful planning to ensure we preserve the regions and areas that are ecologically important. In the history of environmental assessment, considering impacts individually has very often led to difficulty controlling the negative impacts of development.
    - In particular, our workshop has indicated that climate change in the South and West will be important, along with fragmentation of large rivers (from Dams and roads or otherwise). We need to start taking steps including:
    - Create refuges in the boreal forest
    - Engage with the local communities
    - Create adaptation plans
- Reduce small stream fragmentation – no culverts, no riparian losses, reduced fishing for cold-water species (want stronger age classes)
- It should be noted that climate change has many unknown effects and could have many ramifications, including some beneficial. Because of these unknown effects, we can't model many aspects of climate change e.g., storm surges, turbidity, salinity changes due to permafrost melt etc. just include as text. Climate change may also be a bigger problem for rivers, if lakes stratify without increases in nutrients they may still have an oxygenated hypolimnion and not pose a huge problem, but rivers would be mixed and therefore be hotter throughout.
- We should mitigate climate change by focusing on the factors that are most vulnerable to change, regardless of development scenarios. In the high development scenarios, these factors are likely going to be affected by development too, so we need to plan to mitigate those effects.
- This workshop has identified that the cumulative effect of dams could be very serious. People should consider the cumulative effect of multiple dams because the expert group at our workshop indicated multiple dams could cause significant negative effects on these valued stocks. Further, the effects of these dams must be considered for entire regions, not just individual rivers. Identifying the desires of the local communities is also critical, as supported by the *Far North Act*.

- Alternatively, mines were not prominent in the fears of these experts. The potential for negative effects with their development was discussed early on, but not frequently described for any particular species. After some debate, the experts also decided that roads in the far north were not expected to have a major impact on northern fish populations.
- Ultimately, trade-offs will be made with development. Money or power will be traded for the likelihood of lost species. But we need to be explicit about this cost. Northern communities have a strong desire to eliminate their dependence on diesel, but it must be noted that this will place local species at higher risk. We should ask local communities and First Nations what their expectations are. The overall report should also allude to this potential for loss of species and any subsequent cultural effects in First Nations communities. Include specific species like lake whitefish, lake sturgeon, the loss of country food, fish camps, fish integrity, and potentially even the sharing economy that ties communities together.
- We should push to consider developing the rivers that are already disturbed and avoid the ones that are not so long as this allows them to provide power to the people who need it. On a large enough scale (regional), we can go to these communities and figure out what they value most – natural resources relative to potential development sites. If there are some areas they frequently use that could be impacted or species that are critical for their subsistence or culture and you are planning development on a regional scale, then there are options to move the developments to less harmful locations.
- Taking into account the larger temporal and spatial scale you have time and options to make decisions, but planning developments individually on a smaller scale (as has been done in the past) leaves fewer options. Optimize the impending development within the geography of the province, consider what we need and what it will cost in terms of environmental impact to get it to the GTA or the Far North communities.
- On process, we should share a draft to all members of the workshop to get input from the experts on the report. Also make the document public for First Nations, government, NGOs and others to use. Make recommendations based on species in these public documents, save the biodiversity discussion for scientific community.

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Wildlife Conservation Society Canada
344 Bloor Street West, Suite 204
Toronto, Ontario. M5S 3A7   CANADA
Telephone: (416) 850-9038

WCSCanada.org