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Large lakes of northern Canada: Emerging research in a globally-important fresh water resource

The large lakes of northern Canada have long been the focus of amazement and fascination. Early explorers, such as Samuel Hearne (1795), provided some of the first published information on freshwater resources and species present in Canada's northern most lakes and rivers (e.g., Great Slave Lake and Coppermine River; see Fuller, 1955). However, it was not until the end of the Second World War that research on northern lakes and rivers truly took off. In 1944, the Fisheries Research Board of Canada launched the North Pacific Planning Project, in part aimed at surveying the fishery potential in northern freshwaters, specifically Great Slave Lake and the Mackenzie River (Hachey, 1965). During that time, substantial efforts were made to better understand two of Canada's largest lakes, Great Slave Lake and Great Bear Lake, and exploratory research was conducted under the guidance of D.S. Rawson and R.B. Miller, and later published in several seminal papers (Rawson, 1949, 1950, 1951; Miller, 1947). The early impression was that most of these northern lakes were unproductive depressions filled with cold, clear water (Hachey, 1965). As a result, research on Canada's northern lakes substantially declined following these early fishery survey efforts of the 1940s and 50s, and this lack of interest is reflected in the literature.

This decline in national awareness of our northern aquatic ecosystems did not escape notice by researchers. In a paper by limnologist David Schindler, the state of research on the northern great lakes was bluntly referred to as “a national disgrace” and the paucity of information on Great Bear Lake in particular, was described as “tragic” (Schindler, 2001). Since then, scientific investigation on the northern lakes has been steadily increasing. For example, there have been approximately 29 peer-reviewed studies conducted on Great Bear Lake since the turn of the new millennium, more than was published over the previous 100 years. Nonetheless, the relative emphasis on our large northern lakes is still small compared to that in the south. There have only been 168 peer-reviewed studies involving four of the most-studied large northern lakes (Great Slave Lake, Great Bear Lake, Lake Winnipeg, and Lake Athabasca) since Schindler's scathing paper was written 15 years ago, as compared to almost 6000 publications on the five Laurentian Great Lakes alone (Table 1).

The relative paucity of research conducted on the large lakes of northern Canada is surprising considering that they are of global significance. Although 71% of the Earth's surface is water-covered, freshwater resources remain scarce. Only 2.5% of the planet's water is fresh (Shiklomanov, 1993), and only a small fraction of this is considered renewable (Sprague, 2007). At just over 6% of the world's landmass, Canada contains over 20% of the world's freshwater resources, and nearly 50% of the world's lakes (UNEP 2008). Approximately 60% of the freshwater in Canada is in northern watersheds and much of it is considered to be non-renewable (Sprague, 2007), so it is imperative that we better understand these northern watersheds in order to use and manage them wisely.

The Canadian Conference for Fisheries Research held jointly with the annual meeting of the Society of Canadian Limnologists (collectively CCFFR-SCL), is a gathering of like-minded researchers and resource managers to discuss ideas and advancements in the field. In 2014, CCFFR-SCL was held in Yellowknife, Northwest Territories (NWT) marking the first time in its 67-year history that it was held above the 60th parallel. In line with this milestone, the editors of the Journal of Great Lakes Research (JGLR), acknowledging that the focus of large lakes research has traditionally been on the Laurentian Great Lakes, suggested that a special issue showcasing Canada's large northern lakes was in order. For this special issue “northern” is considered to be all lakes including and north of Lake Superior, and “large” defined as freshwater bodies that have a mean surface area of >500 km^2 as proposed by Herdendorf (1982). The scope of papers would include research conducted within the watersheds of large northern lakes. Aligning with the multidisciplinary scope of JGLR, this special issue presents a range of research projects spanning paleolimnology to fisheries management, and a range of lake types, from some of the world's largest and deepest freshwater lakes to tundra ponds within the watersheds of large subarctic lakes. A common thread that joins these studies together is that they were all conducted in a landscape bound much of the year by winter, and often in remote locations. Long periods of ice cover drastically change the physical and chemical characteristics of these remote northern lakes and rivers. Faithful (2016–in this issue), illustrates this through documenting the seasonal limnological transformation from isolated ice-bound small lakes into a watershed system of interconnected lakes.

Northern lakes were the last to be de-glaciated, and so their relative pristine nature provide a glimpse into the past and serve as a facsimile of what southern lakes may have looked like before they were heavily impacted or altered (Reist et al., 2016–in this issue). Was the Great Bear Lake ecosystem, with its several forms of lake trout (discussed by Chavarie et al. (2016–in this issue)), closer to the natural state of the Laurentian Great Lakes than what is present today in those lakes? Following fisheries collapses in the lower Laurentian Great Lakes, the current diversity of the coldwater ichthyofauna of our large northern lakes may give us an idea of what the fish composition in these lakes once was. Understanding the ecosystems of our northern great lakes is even more pressing as even the most “pristine” of the Laurentian Great Lakes – Lake Superior – is showing signs of excess fisheries

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Table 1
Number of peer-reviewed limnological studies (biological, chemical, or physical) conducted up to and since the year 2000 on large northern lakes, compared to those on the Laurentian Great Lakes. Data is generated from ISI Web of Science (August 2015).

	1900–2000	Since 2000
Great Bear Lake	25	29
Four major northern lakes[a]	156	168
Laurentian Great Lakes[b]	6169	5779

[a] Lakes: Great Bear, Great Slave, Winnipeg, Athabasca.
[b] Lakes: Erie, Huron, Michigan, Ontario, Superior.

exploitation. Baillie et al. (2016–in this issue) demonstrated that the remnant lake trout are displaying increased genetic introgression of ecomorphs, and therefore a loss of diversity. Such insights from large northern lakes can help us rehabilitate and restore our southern lakes. Alternative morphotypes of lake trout are now being stocked into Lakes Michigan, Erie, and Ontario, where initially only lean, nearshore varieties were reintroduced (Bronte et al., 2008; Markham et al., 2008; Lantry et al., 2014). Further, specialized techniques in paleolimnology can look into the past conditions and reconstruct missing historical data of aquatic ecosystems through investigating sub-fossil remains as proxies of ecosystem condition through time. Stewart et al. (2016–in this issue) used chironomid and diatom assemblages to show that unstable walleye (*Sander vitreus*) populations in a northern lake since the 1940s are likely the result of climate warming and associated winter hypoxia.

Unfortunately, the remoteness of our northern lakes is not necessarily enough to make them immune to pollutants from anthropogenic (Cott et al., 2016–in this issue), atmospheric, or upstream sources (Evans and Muir, 2016–in this issue). In fact, some northern ecosystems are at greater risk of contamination from atmospherically-deposited contaminants from distant pollutant sources because of the strong prevailing winds in the north that can carry contaminants across continents (Marx and McGowan, 2011). There is still a lot to learn about the biogeochemical impacts of many of these pollutants in the north, and the remoteness of some northern areas can make research and monitoring expensive and logistically challenging. Infrastructure to gain access to the north is limited, and much of the land transportation is via ice-roads constructed over lakes and rivers (Cott et al., 2015). Such activity can transmit noise into the under-ice environment, potentially disturbing fish, impeding their hearing, or masking their communication (Martin and Cott, 2016–in this issue). Even with these unique challenges in living and conducting research in the north, we are progressing towards a better understanding of our impacts on these important systems.

The extreme environmental conditions of these large, and often remote, northern lakes and watersheds are fascinating and challenging in their own right. From a researcher's perspective, northern lakes are full of possibilities of adventure and discovery as many areas have not been adequately studied, if at all. For example, Roux et al. (2016–in this issue) investigated how freshwater and marine fish communities occurred with saline gradients in the sparsely studied Husky Lakes, an estuary lake system draining into the Beaufort Sea. Kissinger et al. (2016–in this issue) used otolith microchemistry to determine the existence of an anadromous lake trout (*Salvelinus namaycush*) population within the Husky Lakes, confirming that this life history type first described by Swanson et al. (2010) in a different system was not an isolated occurrence. Further, Kissinger et al. (2016–in this issue) also discovered a lake trout population that spends its entire life in brackish estuarine water — a life history never before observed for this species. New technologies are allowing for studies in these remote northern lakes that were not possible before. Guzzo et al. (2016–in this issue) used a state-of-the-art acoustic telemetry system to document the seasonal movements, inter-specific, and habitat interactions of lake trout, northern pike (*Esox lucius*), and burbot (*Lota lota*) at a spatial and temporal resolution that was not previously possible with conventional radio telemetry techniques. By embracing creative approaches and new technologies and challenging conventional wisdom, we are beginning to facilitate research in these understudied northern lakes, and this is imperative to our ability to manage these resources adequately in a changing environment.

As we begin to further our understanding of these remote northern lakes and we start to challenge conceptual models of northern ecosystems, we must revisit our practices and state of knowledge to make sure that they are still relevant and applicable. For example, the toxicity and water quality information we use for setting water quality benchmarks stems from ambient-temperature laboratory studies. However, toxicity in northern species may actually be delayed due to cold water, which would not be observed in a test conducted in warmer water conditions (Chapman, 2016–in this issue). We now also know that northern lakes are more productive, allowing for greater biomass and trophic exchange rates than previously thought (Samarasin et al., 2014). Few would have guessed that tundra lakes as small as 3 ha would be able to support lake trout populations, but Hulsman et al. (2016–in this issue) show this to be the case within the Lac de Gras watershed. We have begun to build a better understanding of the uniqueness of these northern ecosystems, but our knowledge is limited and we still have a lot to learn (for additional challenges and data gaps see review by Reist et al., 2016–in this issue).

In the absence of specific information, management decisions for northern lakes are often based on studies conducted on southern lakes that are often used as surrogates to inform northern management. We now understand that the differences between these systems can be great, and in many cases using information derived from southern lakes is not always appropriate. For instance, Callaghan et al. (2016–in this issue) found that lake trout in a northern boreal lake select spawning sites based on wind induced water currents, rather than direction of the seasonal prevailing winds as was the conventional thought based on studies from populations in the south. Additionally, Zhu et al. (2016–in this issue) found that due to the slow growth in the cold waters of Great Slave Lake, the ages of lake whitefish (*Coregonus clupeaformis*) were being underestimated and potentially misleading fisheries managers as a result. This type of information specific to large northern lakes is becoming increasingly important for proper management decisions and conservation of this important freshwater resource, as both human expansion and climate change accelerate in these regions (Reist et al., 2016–in this issue).

With a steady increase in awareness and interest in Canada's northern sovereignty, including military operations, resource development, and scientific investigations, our understanding of Canada's northern lakes is dramatically improving; and it is imperative that it continue in order to ensure their conservation and management into the future. As part of Canada's heritage and legacy, northern lakes are important to our national identity and reputation, as well as a globally important freshwater resource. These lakes and watersheds offer unique opportunities to advance our understanding of freshwater ecosystems and resources and to train the next generation of scientists and resource managers while engaging and finding common ground with Canada's aboriginal population who have their own ecological heritage. With a growing worldwide recognition of the importance of freshwater resources, it is time for Canada to once again be recognized as a world leader in research, and our northern lakes offer that opportunity.

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