Population status, life history and conservation of Mistassini, Albanel and Waconichi Lake brook trout and walleye populations


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For the Cree Nation of Mistissini and Nibiischii Corporation

April 2021

Abstract

Mistassini, Albanel and Waconichi Lakes are situated within the Canadian province of Quebec's largest wildlife reserve. The lakes are home to native brook trout and walleye populations that have been fished by the Cree Nation of Mistissini for many generations. These fishes are important to the local Cree community and regional economy through tourism, subsistence and recreational fishing. The origin of the three lakes during the last deglaciation period ~7000-8000 years ago facilitated the evolution of unique life histories and population divergence in both species, driving home the importance of recognizing and conserving genetically distinct populations within and among the lakes for local conservation initiatives. The regional increase of human activity that exacerbates climate change and habitat quality has the potential to impact Mistassini, Albanel and Waconichi's socio-culturally important fish populations, highlighted by both Indigenous knowledge among local Cree elders/anglers and past empirical scientific studies primarily on Mistassini Lake. This review firstly compiles information on the general biology and threats prominent to brook trout and walleye across their native ranges in North America as well as specifically within Mistassini, Albanel and Waconichi Lakes. The review then summarizes how management/conservation plans and regulations are implemented for brook trout and walleye populations elsewhere. It puts emphasis on how management/conservation is implemented for populations with similar biological characteristics to those inhabiting Mistassini, Albanel and Waconichi Lakes, in order to organize how local community-based management might address the most pertinent threats facing each species. Our review provides a case study for how scientists can help to facilitate Indigenous-led conservation of natural resources at a local level by jointly summarizing the best-available local and scientific knowledge.

Key words: brook trout, walleye, life history, population genetics, Indigenous knowledge, traditional ecological knowledge, conservation,

Table of Contents

BROOK TROUT

Section 1: Socio-economic importance

Brook trout or brook charr (*Salvelinus fontinalis*) are freshwater species from the genus *Salvelinus* in the salmonid family. The species is known for long-distance migrations and the potential to be facultatively ‘sea-run’ (i.e. anadromous) in a permissive environment (Curry et al., 2010; Le François, 2010; Pennell & Barton, 1996).

Figure 1: Cree fishing guide holding a Mistassini Lake brook trout (photo credit: Dylan Fraser)

Salmonids like brook trout have traditionally been popular with commercial fisheries, sport or recreational fishing, and subsistence fishing, especially among various Indigenous communities in eastern North America (Pennell & Barton, 1996). Brook trout were also among the first fish to be cultured in North America (Pennell & Barton, 1996; Schofield, 1993). Anadromous brook trout are increasingly popular in sport fishing in the U.S. and Canada (Naiman et al., 1987) and recreational fishing for the species has been an important primer of tourism development in eastern Canada (Browne & Wildlife Conservation Society Canada, 2007).

Subsistence fishing, the non-commercial capture and consumption of fish, facilitates self-sufficiency in Indigenous communities and allows for the persistence of long-standing fisheries in these communities; the size of these fisheries in the north often rivals the size of commercial fisheries, though little data have been collected on the former (Berkes, 1979). Subsistence fishing contains stocks highly utilized by the community and holds interest as a renewable source of food and income for recreational and sport fishing (Berger, 1977; Berkes, 1979; Fisheries and Oceans Canada [DFO], 2012). DFO (2012) launched the Aboriginal Fisheries Strategy in 1992 so that Indigenous communities have priority over the fishing resources (after conservation) and an opportunity to participate and improve their skills in fisheries management, ensuring self-sufficiency within their community. The program improved monitoring for Indigenous fishing, co-operation on enforcement, selectivity in fishing and led to the creation of up to 1300 seasonal jobs per year since 1993 in the field of commercial fishing activities (DFO, 2012).

Wild brook trout are fit for consumption, and those sampled from the Adirondacks region of New York state are a very lean source of protein, where 42.6 ± 0.94 % of a wild trout's body was edible; wild-caught brook trout has less calories and fat and slightly more protein than its farmed counterpart as well as other species of wild trout, due in part to its diet and living conditions (Tidball et al., 2017). The fat content of the fish could vary up to 10% based on the season it was caught in, such that fish that overwinter will be very hungry and active in the spring, leading to them being leaner when caught (Luzia et al., 2003). Wild trout are also appealing for their pink hued flesh that farmed trout are raised and fed to resemble (Tidball et al., 2017). Brook trout acquire the color by feeding on marine organisms like crayfish and some aquatic and terrestrial insects rich in carotenoids (Czeczuga-Semeniuk & Czeczuga, 1999; Feltwell & Rothschild, 2009; Matsuno et al., 1999). Beta-carotene (vitamin A) confers anti-cancer activity and improved eye function, among other benefits that makes it a dietary staple (Britton et al., 2009; Health Canada, 2011; Matsuno, 2001; Straub, 1987).

Farmed brook trout (along with rainbow trout) are also popular for consumption, as they have the third highest farm-gate value in Canada; 7000 tons worth $40.7 million were produced between 2011 and 2015. Ontario and Quebec are significant in farming, production and export of brook trout, and Quebec officials perform aquaculture activities with the species in the Estrie, Laurentians, Outaouais, and Centre-Quebec regions (DFO, 2017). Brook trout have several benefits that make them fit for farming and consumption over long periods, such as their straightforward egg incubation, quick adaptation and growth and providing a good meat quality and yield relative to its body mass that appeals to a broad range of potential consumers (Le François, 2010).

Section 2: General traits

2.1 Habitat

While brook trout inhabit a range of depths, they are usually found in shallow waters. This is also true for 92% of 'coasters' that occupy waters less than 7 m deep; coasters are brook trout living near the shore of Lake Superior or frequent Lake Superior at some point of their life cycle (Mucha & Mackereth, 2008). Mistassini, Albanel and Waconichi brook trout populations, largely left undisturbed, share similar life histories with coasters from Lake Superior and with other lake-migratory brook trout at similar latitudes. These trout all share philopatric migratory patterns (predominantly returning to their stream of origin), similar age-classes, and similar habitat segregation in nearshore littoral habitats of coldwater lakes (Dutil & Power, 1980; Fraser & Bernatchez, 2008; Newman et al., 2003).

Habitat depth varies diurnally and seasonally, such that lake-migratory brook trout occupy deeper habitats during the day (2.6 m midday), then rise to shallower waters (1.2 m at night or dawn) to forage for food. They occupy deeper habitats during July at 4.2 m and August at 3.6 m, and they spend the remaining months at depths less than 3 m (Mucha & Mackereth, 2008).

Habitat segregation is also affected by the size and age of fish; different sized and aged trout within a population segregate spatially, such that smaller ones and juveniles occupy shallow waters that tend to be more productive. The division of habitat according to depth helps maintain a size-based hierarchy, prevents cannibalism, aggression and ensures enough resource distribution (Hutchings, 1996; Power, 2002). Furthermore, the coaster form in Lake Superior specifically require near shore areas with cover from boulders or aquatic vegetation to avoid predation (Mucha & Mackereth, 2008).

2.2 Reproduction

Brook trout spawn during the daytime and are temperature sensitive, such that those found northwards spawn in cold spring-fed waters during September, while those southwards spawn around December (Groot, 1996; Pennell & Barton, 1996). Lake Superior coasters tend to spawn upstream during September-October (Wisconsin Department of Natural Resources, 2015). According to Raleigh (1982) and others, optimal spawning temperatures range between 4.5-10°C (Mucha & Mackereth, 2008; Naiman et al., 1987). Temperatures above 23°C reduce spawning in trout (Hokanson et al., 1973), and temperatures above 25°C result in trout mortality (Fry et al., 1946). After migrating to lake feeding habitats, lake migratory brook trout return predominantly to their origin river to spawn and complete their life cycle (Fraser et al., 2004, 2013; Fraser & Bernatchez, 2005a).

Other environmental factors impacting spawning are oxygen and sedimentation, such that reduced oxygen availability and increased sedimentation reduce the chances of spawning success (Raleigh, 1982). Gravel is the preferred substrate for spawning, while silt sediment results in higher egg mortality (Webster, 1962). Groundwater upwelling is also a significant determinant of spawning success; nest site selection depends on the occurrence of groundwater upwellings, which replenish oxygen, nutrients and regulate temperature to keep the eggs from freezing during the winter (Power, 2002).

The female trout lays her eggs in redds, the spawning nests of trout, composed primarily of gravel, and the number of eggs is positively correlated with maternal fitness (Hutchings, 1991). The average brook trout egg size is between 3.4-5 mm (Pennell & Barton, 1996). Egg size is inversely correlated with availability of food; larger eggs may be produced to ensure offspring survival in nutritionally poor habitats (Hutchings, 1991). Brook trout eggs are especially sensitive to temperature, as the optimal temperature for development of brook trout embryos ranges between 4.5-11.5°C (MacCrimmon & Campbell, 1969), though closer to the lower end (e.g. Wood & Fraser 2015). The incubating eggs normally hatch between January and April, varying based on their latitude, temperature and number of degree days the incubating egg must reach before hatching (Raleigh, 1982).

2.3 Predation, Diet and Growth

Temperature also regulates brook trout growth, where 13-19°C is the reported optimal range (Dwyer et al., 1983; Pennell & Barton, 1996; Yates et al. 2019). Growth rate decreases as the fish age, such that a growth rate ratio of 1.27 at age 2-3 years drops to 0.35 at 6 years old (Dutil & Power, 1980). Furthermore, growth rate seems to be faster in brackish waters, implying salinity regulated trout growth as well (Dutil & Power, 1980). Oxygen was also found to be a limiting factor on the metabolism and growth rate of salmonids throughout their various life stages (McKenzie & Claireaux, 2010).

Brook trout diet is as flexible as their growth; they are opportunistic carnivores, feeding on smaller fishes, benthic and drifting aquatic macroinvertebrates, terrestrial insects, crustaceans, arthropods, and in rarer cases of small mammals (Dutil & Power, 1980; Le François, 2010; Raleigh, 1982). Diet varies between freshwater and seawater habitats according to food abundance and availability, and it also varies between juveniles and adults, which helps relieve competition (Naiman et al., 1987). Brook trout are plastic in their foraging strategies; when food is widely available and current velocity is high (bringing floating invertebrates to an area faster), brook trout are "sit-and-wait" predators, conserving their energy rather than swimming against the current. They may switch to more aggressive foraging tactics when food availability and current velocity decrease (Grant & Noakes, 1988).

2.4 Population Trends and Distribution

Brook trout are one of the most widely distributed salmonids (Curry et al., 2010), since they are diverse in population life histories shaped by natural habitat barriers and river interconnections that guided fish dispersal after the Laurentide ice sheet retreat (Legendre & Legendre, 1984). Populations differences in life history are shaped by natural selection, which acts on genetic variation within and among populations, and by phenotypic plasticity in relation to local environmental characteristics (Groot, 1996; Pennell & Barton, 1996; Hutchings 1996; Belmar-Lucero et al. 2012).

Northeastern brook trout populations are believed to have evolved slowly in periglacial environments over 0.6 million years ago, making them adapted to cold, ice ridden and highly variable, nutritionally impoverished environments (Le François, 2010). Their native range covers temperate waters of Northeastern North America, ranging from the Maritime provinces to Manitoba and north towards the Arctic Circle, including parts of the US, from the New England states, south to Pennsylvania, the Appalachian mountains and Minnesota and Northwest with the upper Mississippi, upper Great Lakes drainage and Georgia (figure 2) (Groot, 1996; Le François, 2010; MacCrimmon & Campbell, 1969). The species has been introduced and successfully formed self-sustaining populations in Central America, Australasia, Oceania and a few African countries (Le François, 2010; MacCrimmon & Campbell, 1969).

Figure 2: North American distribution of Brook Trout (Maine IF&W) (Seitz, 2014).

Brook trout are often called 'speckles' for being dotted, and 'squaretails' since their tails have only a slight fork relative to other salmonids (Le François, 2010; Naiman et al., 1987). Their morphology differs based on whether they are sea-run or stream residents; trout of 2-4 years old traveling long distances become silvery before migration and move to the seas for a couple months where they gain weight, attain reproductive maturity, and their flesh becomes pinkish-orange. Meanwhile their stream dwelling counterparts keep a greenish-blue hue (Dutil & Power, 1980; Naiman et al., 1987; White, 1940). Anadromy is common among brook trout, since they benefit from temporarily extending their range during the glacial shifts and the cycling of nutrients from the enriched marine environment to the lacking freshwater environment, enhancing their productivity (Kline Jr. et al., 1990; Power, 2002). They also experience greater growth rates, lower mortality, more space and better nutrition (Naiman et al., 1987).

2.5 Threats

Brook trout sensitivity to habitat disruption makes them optimal indicators of coldwater aquatic ecosystem health, since a decrease in their body size is an early warning that their stream or lake is at risk (Browne & Wildlife Conservation Society Canada, 2007; Trout Unlimited, 2006). Table 1 presents the prominent threats to brook trout across its native regions and the consequences at the individual and populations levels.

Table 1: Brook trout population and habitat threats and effects

Threat	Effect	References
Warming	Reduced habitat, fragmentation	Browne & Wildlife Conservation Society Canada, 2007; Schindler et al., 1990

Threat	Effect	References
Eutrophication	Increased adult and egg mortality, reduced habitat	Arend et al., 2011
Logging	Reduced or destroyed habitat, migratory barriers, sedimentation, reduced biomass, residence times and catchments, increased toxicity and mortality	Gibson et al., 2005; Porvari et al., 2003; Planas et al., 2000; Bérubé & Lévesque, 1998; Poff et al., 1997
Dams	habitat alteration and destruction, migratory barriers, flooding, contamination, mercury poisoning	Gosset et al., 2006; Kelly et al., 1997; Ligon et al., 1995
Mining	Contamination, habitat alteration and destruction, impaired reproduction, reduced abundance, mortality	de Rosemond & Liber, 2004; Levings et al., 2004; Schofield, 1993; Spry & Wiener, 1991; Mount et al., 1990
Overharvesting	Population collapse, selection for slower growth and faster maturation	Magnan et al., 2005; Hutchings, 1996
Competition	Reduced resources and productivity, reduced habitat, mortality	Seitz & Olden, 2014; Trout Unlimited, 2006; Shuter et al., 2002
Parasites and Diseases	Mortality	Cipriano et al., 2002

Warming changes seasonal stratification in lakes, impacts fish physiological processes, and raises water levels, destroying wetland surface areas, decreasing river flows and eventually fragmenting brook trout populations (Browne & Wildlife Conservation Society Canada, 2007; Schindler et al., 1990). Furthermore, ice cover and earlier freeze and breakup dates lengthen the growing season and push the native range of periglacial populations northwards (Shuter et al., 2002). Meisner (1990) predicts southern native brook trout populations will be further fragmented, lose their genetic diversity and become extirpated as water temperatures increase by 3.8°C with forecasted climate change (Comte et al., 2013). Land misuse can also contribute to range reduction (MacCrimmon & Campbell, 1969; Trout Unlimited, 2006). Eutrophication is accompanied with an increase in hypoxia, which jeopardizes habitat quality and subsequent growth of brook trout, often leading to sub-lethal effects or direct morality (Arend et al., 2011).

Logging reduces riparian or stream-edge vegetation, which increases water temperature and brook trout mortality (Browne & Wildlife Conservation Society Canada, 2007). It also erodes the soil and establishes migratory barriers, which leads to changes in flow rate, run-off, sedimentation, and mercury release (Browne & Wildlife Conservation Society Canada, 2007).

Flow regime changes can alter habitat quality, biotic interactions and primary productivity (Poff et al., 1997). For example, increased sediment input was responsible for up to 22% reduction in brook trout density and biomass per catch rate in the lakes of the Quebec Mastigouche Wildlife Reserve (Bérubé & Lévesque, 1998).

Hydroelectric dams alter flow regimes and habitat, and they establish migratory barriers. They flood and release greenhouse gases and methyl mercury that are toxic and destructive to the ecosystem (Kelly et al., 1997). Cree communities in Quebec and other Northern communities that rely on wild-caught fish as a primary source of nutrition are particularly affected as they lack non-toxic fish (Browne & Wildlife Conservation Society Canada, 2007). Dams also turn rivers into lake habitats, displacing river species like brook trout in favor of lake species like walleye (Browne & Wildlife Conservation Society Canada, 2007). Dams also fragment habitat by preventing trout from reaching spawning and nursery habitats and completing seasonal movements (Gosset et al., 2006).

Mining contaminates, alters and often destroys habitat by draining or infilling lakes and losing streams (Browne & Wildlife Conservation Society Canada, 2007). Mine effluent is brimming with contaminants such as toxic metals, acids, salts, fine particles and synthetic chemicals that prove highly toxic to fish by disrupting their ionic regulation and suffocating them if left untreated (de Rosemond & Liber, 2004). Mining jeopardized 4% of brook trout habitats in Ontario, leaving 65% of water habitats susceptible to acidification effects. Additionally, 18% of lakes are below pH of 5.5, and 5.5% of lakes are below pH of 5.0, and brook trout population densities in highly acidic lakes (pH <5.2) are less than half the density in lakes with pH > 5.5 (Ontario Ministry of Natural Resources, 1988; Wood, 2017). Acidification from mine drainages and precipitation is accompanied by increased brook trout mortality and a reduction in self-sustaining populations (Mount et al., 1990; Schofield, 1993).

New road networks are built to increase access for recreational and sport fishing and allow for overharvesting and the subsequent decline of fish populations and alteration of population structure; selective fishing of older and larger trout will force earlier reproductive maturity times and risk population collapse (Hutchings, 1996). Overfishing selects for slower growing fish that reach maturity at an earlier age, as observed with lacustrine brook trout populations of the Canadian Shield in southern Quebec (Magnan et al., 2005). As the range of species shifts north in latitude and altitude, non-native species escaping warmer southern waters compete with brook trout for resources (Seitz & Olden, 2014). Non-native species like smallmouth bass, rainbow trout and brown trout can outcompete brook trout by eating them or forcing them from high quality stream habitats by virtue of their resilience in bad quality habitats (Trout Unlimited, 2006).

Brook trout are susceptible to parasitic diseases, such as the salmon louse *Lepeophtheirus salmonis* (a copepod ectoparasite) and *Caligus elongatus* (a fish louse), *Salmincola edwardsii* (

freshwater copepod) (Duston & Cusack, 2002; Pennell & Barton, 1996) as well as to Viral and bacterial diseases, such as bacterial kidney disease and tuberculosis, which are prevalent in high stress conditions and spatial densities (Cipriano et al., 2002; Mitchum & Sherman, 1981).

Section 3: Management outside of Mistassini, Albanel and Waconichi

A main goal of brook trout management is to ultimately maintain self-sustaining populations in their original habitats and with varying age-classes (at least 6 age classes) from 0-5 years and with females from at least two spawning years to ensure sufficient population density with a viable gene pool (Newman et al., 2003). The Ontario COA project between 2016-2019 refined the conservation success index and displayed how management intensity is proportional to the severity of habitat damage and population status (figure 3).

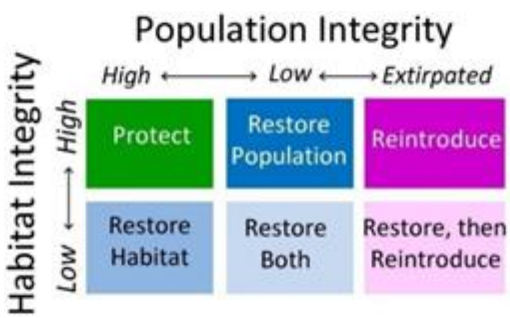

Figure 3: Population management recommendations based on brook trout population status (Wood, 2017)

3.1 Monitoring

Monitoring life history traits and genetic status of brook trout is crucial to assess the impact of management regulations and projects. For example, Goldsworthy et al (2017) recommended conducting Spring and Summer surveys every 3 years to count and assess the spawning of adults and juveniles entering chosen rivers, so they may follow up on the impact of applied regulations, management and sampling protocols. The Maryland Inland Fisheries Division (2006) and the Wisconsin Department of Natural Resources (2005) also regularly assess population abundance and viability as well as the interaction of brook trout with exotic species to determine the degree of competition and threat they pose to native brook trout populations. Newman et al (2003) recommend assessing abundance of adult brook trout with trap netting instead of electrofishing, but if the latter is necessary, using Direct Current (DC), which sends current at a constant direction and speed, would avoid stimulating fish muscle and nerves repeatedly and reduce stress and injury to it. They recommend counting juveniles and young of year brook trout (recruitment) at nearshore areas by electrofishing at low water levels (mid-June to July) and stopping when they start migrating. Creel surveys or angler diary programs can also be used to collect harvest data at stream and coaster sites, and mortality can be assessed by analyzing catch curves.

Habera & Moore (2005) and the Wisconsin Department of Natural Resources (2005) portion of Lake Superior agencies emphasize the importance of identifying the genetic origin of brook trout sampled in the Appalachian waters and building a genetic database for the populations, as some may be mixed with hatchery fish stocked there. These inventories help determine population viability. The high genetic heterozygosity of these populations warrants the use of river sub basins and watersheds that isolated them well enough to manage and conserve genetic variability (Guffey, 1998). The Maryland Inland Fisheries Division (2006) completed a genetic inventory of brook trout populations with secured funding from the Eastern Brook Trout Joint Venture (EBTJV) and the US Fisheries and Wildlife Services (USFWS); the repository incorporates fisheries data and identifies other sources of brook trout data that help develop the genetic inventory. The department would use genetic information to know the extent of population diversity and will use it to evaluate and modify the current guidelines and practices to best preserve brook trout population diversity and habitats.

Monitoring trout habitat is as important as monitoring the trout themselves, therefore the Maryland Inland Fisheries Division (2006) and Goldsworthy et al (2017) from the Minnesota Ministry of Natural Resources thoroughly measure changes in the physical habitat (blockages, presence of riparian buffer zones, groundwater intrusion and woody debris), water chemistry (pH, dissolved oxygen content, sedimentation and channelization) and water flow (hydrology, geomorphology, temperature and connectivity). Water chemistry measurements, such as that of pH or mercury input, helps track acid mine drainage from mining activity (Browne & Wildlife Conservation Society Canada, 2007; Minister of Justice, 2020). Land transformation is also a notable issue, so some departments commonly compile land-use data in a Geographic Information System (GIS) framework for the lake as well as conduct additional surveys where needed to delineate the land-use pattern changes (Wisconsin Department of Natural Resources & U.S. Fish and Wildlife Service, 2005).

3.2 Regulation

Monitoring water quality helped determine thresholds and optimal habitat conditions, which conclude temperatures should not exceed 20°C and oxygen levels must be at least 8.0 mg/L to properly support naturally producing wild brook trout (Tennessee Department of Environment and Conservation, 2015). The Wildlife Conservation Society in Canada set water quality regulations to mitigate the effect of mining, such as the Metal Mining Effluent Regulations (MMER) in 2002 that outlined protocols for defining points of final discharge from mines and research the environmental effects of mines (Browne & Wildlife Conservation Society Canada, 2007). The Canadian Government also set a moratorium for hydroelectric dams over 25 MW north of 51st parallel in Northern Ontario (Browne & Wildlife Conservation Society Canada, 2007).

<u>Overfishing</u>

Regulations regarding catch, possession, size limits and fishing season timings vary across different regions based on brook trout population status and life cycles (Table 2). They are primarily set to prevent overfishing.

Table 2: Recreational fishing regulations for brook trout across Canada and US native ranges

Lake/Zone	State/Province/ Territory, Country	Daily bag and possession limit	Minimum length (cm)	Maximum length (cm)	Timing	Tackle and bait restrictions	Fishing methods	Reference(s)
Superior	Minnesota, US	5	50	NA	NA	NA	NA	Newman et al., 2003; Goldsworthy et al., 2017
Superior (Nipigon bay)	Ontario (zone 9), CAN	5	56	NA	Closed Season from Labour Day to mid-April	Gear: one dip net max 183 cm in diameter or side, one seine net max 10 m long and 2 m high, one spear (for carp or white sucker) within 30 m of water, bow and arrow during zone-wide season from the fourth Saturday in April to Labour Day. Bait maxima: 120 baitfsh, 120 leeches, 36 crayfish, 12 frogs.	Catch-and-Release; Illegal to dump bait in or within 30 m of any of the lake waters	Bobrowski et al., 2011
Superior	Michigan, US	5	NA	17.8 for 5 trout, 50.8 for 1 trout	NA	Gear: maximum length restriction on seines	NA	Goldsworthy et al., 2017
Superior	Wisconsin, US	5 mixed fish, 1 large trout	20.3	NA	NA	NA	NA	Wisconsin Department of Natural Resources & U.S. Fish and Wildlife Service, 2005
Algonquin	Ontario (zones 11, 13 and 15), CN	sport license: 5 and 1 large trout; conservation license: 2 trout, none large	31 (sport license)	NA	Open Season February 15 to September 30 (zone 11), January 1 to September 30 (zone 15), and Fish Sanctuary from December 1 to fourth Saturday of April (zone 13)	Gear: spring gaff, snare, snagger or spear gun is prohibited within 30 meters. use of explosives and artificial lights for fishing any species is prohibited. Non-spring gaff, spear, bow and arrow, dip or seine net or baitfish traps are permitted.	Prohibits fishing endangered and non-bait fish as well as stocking fish without a license; prohibits selling/buying caught fish, crayfish, leeches, frogs or fish eggs without a sport fishing or bait licenses; Illegal to dump bait in or within 30 m of any of the lake waters	Ontario Ministry of Natural Resources, 2006
Zones 1, 2, 8, 11, 16, 17, 35	Ontario, CAN	sport license: 3; conservation license: 2	NA	NA	NA	NA	Illegal to dump bait in or within 30 m of any of the lake waters	Ontario Ministry of Natural Resources, 2006
Zones 3 to 7, 9, 10, 12 to 15, 18 to 22, 24 to 33	Ontario, CAN	sport license: 5; conservation license: 2	Between 28 and 51	NA	NA	NA	Illegal to dump bait in or within 30 m of any of the lake waters	Ontario Ministry of Natural Resources, 2006
Zones 23, 24	Ontario, CAN	sport license: 1; conservation license: 0	NA	NA	NA	NA	Illegal to dump bait in or within 30 m of any of the lake waters	Ontario Ministry of Natural Resources, 2006
Rocky Mountains	Wyoming, US	16	NA	NA	NA	Gear: Hand lines, set lines (between 2 and 6), poles or tips are allowed when fishing through ice; angler name must be attached to each line, pole or tip, and angler should not be further than 300 yards from the line. Underwater spearfishing is only allowed in	NA	Wyoming Game and Fish Commission, 2018

Lake/Zone	State/Province/ Territory, Country	Daily bag and possession limit	Minimum length (cm)	Maximum length (cm)	Timing	Tackle and bait restrictions	Fishing methods	Reference(s)
						lakes. Bait: Any part of a non-sport fish can be used as bait, while only the internal organs, eyes, fins and skin of game fish can serve as bait. Corn can also be used as bait, but fishing and corn bait is prohibited where only artificial flies and lures are used.		
Rocky Mountains	Colorado, US	4 (bag limit); 8 (possession)	NA	20.3	NA	NA	NA	Ficke et al., 2009
NA	New York, US	5 (wild category); 3 (wild-quality category)	NA	30.5 (2 if wild, 1 if wild-quality)	Open Season from April 1 to October 15, Catch-and-Release with artificial lures from October 16 to March 31	NA	NA	New York State Department of Environmental Conservation, 2020
NA	Vermont, US	12	NA	NA	NA	NA	NA	Kirn, 2017
NA	Nebraska, US	5 (bag limit), 14 (possession)	NA	NA	NA	Gear: archery fishing (with bow and arrow or crossbow) permitted from July 1 through December 31 and spearfishing of nongame fish permitted from sunrise to sunset from September 1 through March 31 and unrestricted April 1 through August 31.	snagging is only permitted with paddlefish or nongame fish	Ficke et al., 2009
NA	South Dakota, US	5 (bag limit), 10 (possession)	NA	NA	NA	NA	NA	Ficke et al., 2009
Savage River	Maryland, US	5	30.5 (22.9 if downstream of Piedmont dam)	NA	NA	Gear: single hook point use on artificial lures and flies since 2004; Bait: prohibited	NA	Hudy et al., 2005
North Branch Potomac River	Maryland, US	NA	NA	NA	NA	Bait: artificial lures are permitted	catch-and-release 0.8 miles in length downstream; stocking prohibited	Hudy et al., 2005
Big Hunting Creek	Maryland, US	NA	NA	NA	NA	Bait: artificial lures are permitted	catch-and-release; stocked trout	Hudy et al., 2005
Little Hunting Creek	Maryland, US	NA	NA	NA	NA	Bait: artificial lures are permitted	put and take, then catch-and-release	Hudy et al., 2005
Zones 1, 2	Quebec, CAN	10	NA	36	NA	NA	NA	Gouvernement du Québec, 2020
Zone 13 East, West	Quebec, CAN	3 in West, 2 in lac Wetetnagami	NA	NA	NA	NA	NA	Gouvernement du Québec, 2020
Zone 17	Quebec, CAN	15 trout or 4 kg + 1 trout (whichever is reached first)	NA	NA	NA	NA	NA	Gouvernement du Québec, 2020
Zone 22 (Mistassini)	Quebec, CAN	15 trout or 2.5 kg + 1 trout	NA	NA	Open Season June 1 to September 7, 2020	Gear: 5 lines at a time are authorized between December 1 to April 30. Circular hooks are required	NA	Gouvernement du Québec, 2020

Lake/Zone	State/Province/ Territory, Country	Daily bag and possession limit	Minimum length (cm)	Maximum length (cm)	Timing	Tackle and bait restrictions	Fishing methods	Reference(s)
		(whichever is reached first)				when using natural lures. Prohibited bait fish (including fish, mollusks, crustaceans (e.g. shrimp, crayfish), marine animals and the parts (eggs, sperm, roe, spawn, larvae, spat or offspring); Bait: dead bait fish permitted, artificial lures or flies count as hooks and are permitted for baited and unbaited use.		

With regards to on-site management, it is recommended to plan roads with limited access to watersheds and to newly logged areas with single entry and exit points, ultimately limiting fishing activity (Browne & Wildlife Conservation Society Canada, 2007).

With regards to fishing methods, catch-and-release proved effective at Lake Superior, where catch rates increased and harvest rates were reduced, as between 15 and 33% of tagged trout were caught twice (Bobrowski et al., 2011). Furthermore, OMNR (2006) prohibits fishing within 25 m of a culturing site or 23 m downstream from the lower entrance to any fishway, obstruction, or leap (OMNR, 2006).

The impact of size regulations (Table 2) is positive on population abundance; the OMNR reduced the daily possession limit to one trout of at least 56 cm in 2005 and monitored the amendment for 5 years, observing an increase of spawning populations in the Nipigon Bay portion of Lake Superior. South Bay witnessed its spawning population increase from 29% to 88% and the same occurred in West Bay with an increase of 28% to 71% (Bobrowski et al., 2011). Brook trout are often tagged and marked with PIT (passive integrated transporter) tags, visual implant tags, or sonic tags, as well as electrofishing, weirs, stationary or mobile hand-held PIT-tag antennas to count and follow brook trout movements to map population ranges and structure (Wood, 2017).

Gear and bait restrictions (Table 2) mitigate overfishing, increase post-release survival and can prevent invasive species spread (Newman et al., 2003). Since non-native species like yellow perch, smallmouth bass and white sucker jeopardize brook trout fisheries in Ontario, the OMNR recommends anglers avoid dumping empty bait buckets and restricting the use of live baitfish to avoid introducing non-native species.

Newman et al. (2003) at Lake Superior recommend year-round closed seasons at streams and lakes undergoing rehabilitation and reintroduction. They also recommend seasonal closures during spawning and fry emergence periods at key lake waters and tributaries, as is done at the Nipigon River, established by OMNR (Bobrowski et al., 2011). They advise establishing seasonal fish sanctuaries, where all fishing would be prohibited, by protecting pre-spawning areas fish gather at after a cold period and areas below migratory barriers. The OMNR (2006) recommends setting season closure dates to match spawning times in order to protect them.

Regulations also limit fishing-induced mortality to the fish. An angler should avoid touching the eyes and gills of the fish to avoid even minor injuries, and the fish should be returned to the water within 15 s in the air and should be allowed to recover in the palm of the hand in the water before being released, as being in the air longer than 60s may irreversibly reduce the trout's swimming performance (Schreer et al. 2005; Ministère des Forêts, de la Faune et des Parcs de Québec [MFFP], 2016; Gouvernement du Québec, 2020). Circular hooks and barbless hooks will avoid hooking the gills or stomach, while barbed hooks lead to more deaths and should be avoided (Taylor & White, 1992; MFFP, 2016). Dipping nets makes fish struggle and tire and should be avoided, but if necessary, small mesh nets without a knot in rubber or cotton if a dip net are allowed (Gouvernement du Québec, 2020). Finally, salmonids should not be fished at water temperatures around 21°C or at deeper ends of the lake, so that they do not suffer from heat stress or from decompression when pulled to the surface respectively (MFFP, 2016).

Educating the public, members, advocates and anglers encourages them to enforce regulations. Information can be delivered through posters, pamphlets, videos and consultations to popularize brook trout as anadromous members as well as their habitat requirements (Newman et al. 2003). It is especially important to educate anglers on the impact of introduced non-native species that jeopardize brook trout as a result of bait bucket dumping and unauthorized introductions of non-native species that pose a risk to brook trout (OMNR, 2006).

3.3 On-site management projects

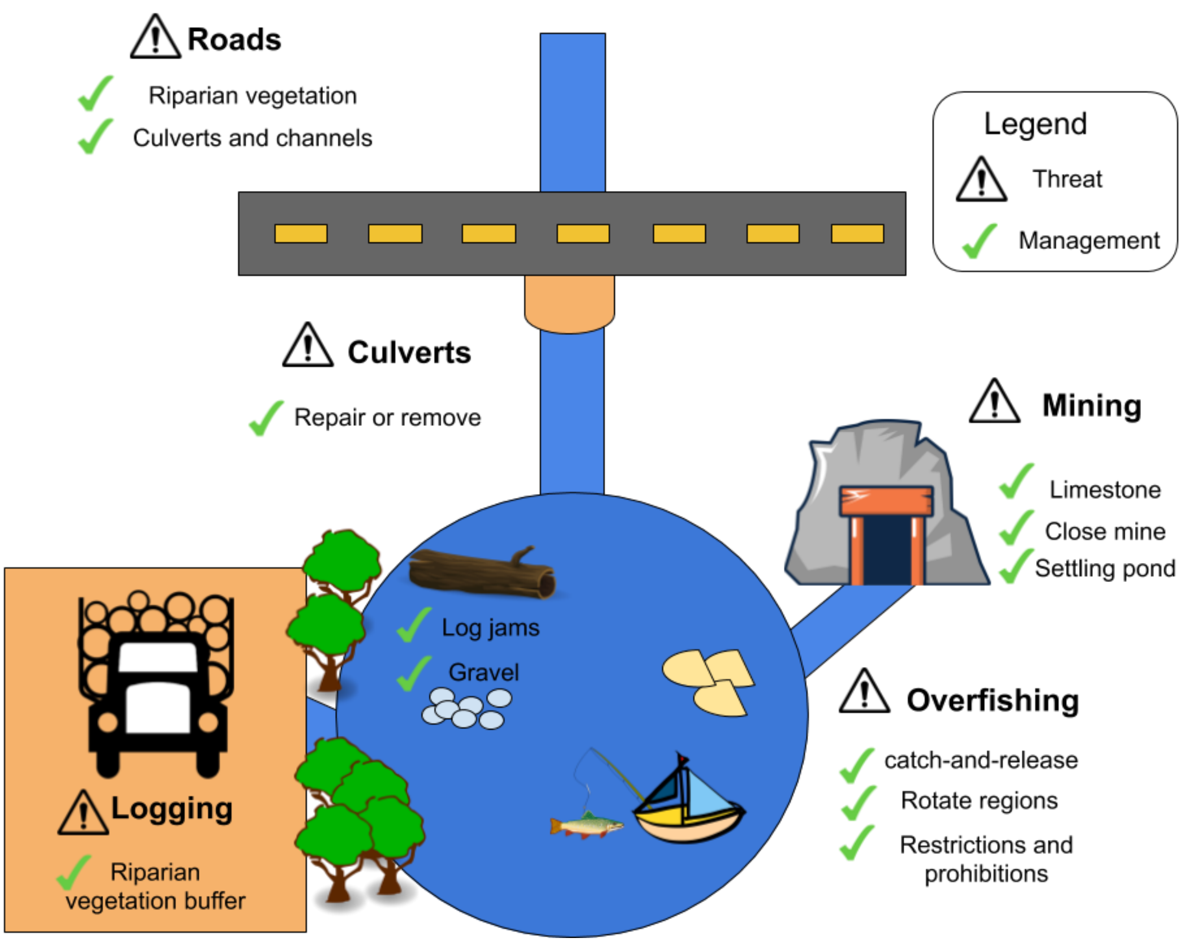

Figure 4: Summary of management applied for different habitat and population threats

Logging and land exploitation

Riparian (stream side) vegetation buffers are sustainable solutions against logging, as they control the supply of sediment and woody debris reaching streams and providing shade. Shade prevents drastic increases in water temperature and regulates water flow (Petty & Merriam, 2012; Rashin et al., 2007). A buffer should be at least 3 m wide nearest to the bodies of water and can range between 30 m and 90 m according to the catchment slope (Timber Management Guidelines for the Protection of Fish Habitat (OMNR 1988); Newman et al., 2003; Rashin et al., 2007). Riparian buffers are also beneficial for managing land misuse, and EBTJV recommends working with farmers and landowners to replant shrubs and trees alongside streams and set up cattle fences to keep livestock away (Roni et al. 2002; EBTJV, 2006). The planting of riparian buffers was followed by increased colonization of brook trout habitats, as well as increased density, biomass and reproductive potential (Carline and Walsh 2007; Summers et al. 2008).

Mining

Mine tailings (mine-like ore wastes from mines) should be removed, and the mine should preferably be closed after it is no longer in use to avoid acid drainages. Water must also be continuously pumped in a region to prevent drops in brook trout habitat productivity, like with the Victor diamond mine that must pump water from the Attaqapiskat River to Nayshkootayaow River up to a decade after mining before closing. Area rehabilitation will involve landscape repair by foresting with spruce, poplar, and possibly Jack pine to restore forest habitat for wildlife (De Beers Canada 2004). Settling ponds or basins are also a common way to treat mine water as they remove undissolved suspended solids or turbidity from the water. They promote passive flow through a linear fen system to remove residual clay-sized particles before discharge to the Nayshkootayaow River (De Beers Canada 2004). Limestone sand is also a common acid abatement technique are also a common solution that EBTJV (2006) recommends; the sand prevents pH reduction and alkalinity related problems that kill fish, and its application proved successfully in the Appalachians where stream acidification is a notable problem (McClurg et al., 2007; Petty & Merriam, 2012). Treating interconnected drainage networks would impact a larger range than treating individual streams (Petty & Thorne, 2005; Petty & Merriam, 2012).

Dams, culverts and other physical barriers

The Government of Canada (2017) removed the barrier and replanted a riparian buffer zone of 500 m to restore habitat in Kama Bay, Ontario after a dam destroyed a 300 m stretch of brook trout habitat and prevented their migration. Lake Narraguagus River in Maine was restored using several techniques: dam and culvert removal, riparian vegetation, and log jams, all of which reduced habitat fragmentation and regulated current, sediment transport and warming (Koenig, 2017). The log jams dispersed along the stream act as cover structures or seeding structures that create hydraulic heterogeneity. They can withstand higher than average spring floods and are cheap tactics for watershed and stream restoration with immediate effects despite thinning some of the canopy over the stream (Camp, 2015; Koenig, 2017; Wheaton et al., 2011). Wisconsin also implemented log jams to create new habitat and regulate sediment input and water flow, and the department also added gravel at Brule river and Graveyard Creek to increase spawning habitats (Wisconsin Department of Natural Resources & U.S. Fish and Wildlife Service, 2005).


Figure 5: Installation of post-assisted log structures and log jams along the Upper Narraguagus River, Maine U.S. (Koenig, 2017)

<u>Competition with non-native species</u>

While barriers often form obstacles to brook trout migration, they may be beneficial to prevent competition between exotic and native species for control over native habitat. One successful barrier establishment was done upstream of cutthroat trout habitat, preventing brook trout invasion (Petty & Merriam, 2012; Shepard et al., 2002). This approach's long-term effects are unknown, and the approach comes at the risk of isolating the trout and reducing their productivity; down the line it could even risk a bottleneck in case of catastrophic flood or drought (Kruse et al., 2001; Petty & Merriam, 2012). Goldsworthy et al. (2017) prohibit the transport of live Rainbow Smelt to prevent their introduction into inland lakes where brook trout reside.

<u>Stocking Precautions</u>

While sometimes successful, reintroduction can negatively affect population genetics and population persistence through outbreeding depression or genetic contamination to a native population considering hatchery fry are not under natural selection and lack the ability to adapt to their environment (Gharrett et al., 1999; Hudy et al., 2000; Marsden et al., 1993; Petty & Merriam, 2012). Newman et al. (2003) recommend selecting and collecting gametes that limit the risk of weakening the donor population with enough finding individuals at different hatcheries to avoid bottlenecks.

Section 4: Lake Mistassini/Albanel/Waconichi Brook Trout Life History

The history of Mistassini Lake brook trout populations, along with divergent natural selection, played a major role in population divergence following the postglacial formation of the lake 7000-8000 year ago that changed the direction of its discharges (Fraser & Bernatchez, 2005a). Mistassini Lake may have been colonized by populations from the separate Atlantic and Mississippian glacial refugia (Fraser & Bernatchez, 2005a). The ancestral populations were hypothesized to have pre-existing features that allowed them to be physiologically suited to occupy different habitats and were further shaped to fit in those habitats through the selective pressures of their environments as habitats changed post glaciation (Fraser & Bernatchez, 2005a; Schluter, 1996). Three rivers stood out as the main spawning grounds for brook trout: Cheno and Pepeshquasati rivers (Inflows) and the Rupert river (outflow). The inflow populations, by virtue of having similar habitats and geographic proximity to each other, share a different ancestry than the outflow population (Fraser & Bernatchez, 2005a). They also preceded the outflow population as they colonized the outflow river briefly and were then pushed back, since incoming outflow populations apparently had pre-existing features to fare better in that environment (Fraser & Bernatchez, 2005a). Furthermore, the Pepeshquasati population had the most productive and abundant trout population (having several thousand breeding trout, relative to the several hundred in Cheno), and its dispersal shaped much of the demographic and genetic structure of other inflows (Fraser et al., 2004, 2006). The Pepesquasati also contributes the most to harvest rates with 55%, followed by Rupert with 30% and Cheno with 15%, based on data collected in 2000 and 2001 (Fraser & Bernatchez, 2005b).

Salmonid populations are characterized by varying degrees of genetic differentiation and migration distances between different environments (marine vs. freshwater, lakes vs. streams, rivers vs. streams: Hendry et al., 2004), with Mistassini brook trout being no different. They are composed of philopatric migratory populations that exist in small numbers in isolated habitats, and their life history provides a new understanding to dispersal dynamics and population structure that can further our understanding of intraspecific diversity and evolutionary ecology (Fraser et al., 2004) and help with conservation planning and management (Newman et al., 2003). Brook trout life history is particularly plastic, since each river or set of rivers developed unique habitats and environmental pressures during postglacial dispersal ~7000-8000 years ago that facilitate the formation of genetically distinct populations (Fraser et al., 2004). Adaptations were shared among several rivers with similar habitats rather than being unique to a single river, such as how northeast tributary inflow rivers' populations share traits that differ from outflow population (Fraser et al., 2004).

Figure 6: Cree fishing guide holding Pepeshquasati brook trout, a tributary of Mistassini Lake (Fraser et al., 2017; photo credit: Dylan Fraser)

The three genetically distinct populations are characterized by seasonal migrations between lake areas for feeding and river areas for breeding (Fraser et al., 2004; Fraser & Bernatchez, 2005b). Juveniles spend most commonly 1-2 years in natal rivers before migrating to lakes to mature as adults for another 1-4 years, and once sexually mature, they migrate back to their natal river breeding areas (as they are philopatric) to complete the life cycle; their geographic separation by returning to their respective natal areas reduces gene flow, which helps populations be genetically distinct and develop local adaptations, emphasizing the role of biogeography in differential evolution (Castric & Bernatchez, 2003; Fraser et al., 2005). The breeding system in Mistassini is a polygynous one, where males' reproductive success is based on the availability of females whom they compete over as males often outnumber females during spawning seasons, and females' reproductive success is based on the number of eggs they produce (Blanchfield & Ridgway, 1997). Usually, male biased dispersal for as far as 2.5 times as much as females occurs commonly in response to and to reduce competition amongst males (Hutchings & Gerber, 2002). Nevertheless, for Mistassini Lake, many females were noted to migrate further than males from inflow populations to outflow populations, thus females have less pronounced physical features so they may be adapted to both habitats (Fraser et al., 2004). Since migrations have lower post breeding adult survival changes, long-distance migratory fish have delayed reproduction to first grow to efficiently migrate upstream and have better chances at reproductive success (Fraser & Bernatchez, 2005b).

Since inflow and outflow populations migrate separately from each other and are philopatric, they do not intermix, resulting in a lack of gene flow, increased phenotypic differentiation and intraspecific diversity (Castric & Bernatchez, 2003; Fraser et al., 2006). Inflow migrants travel longer distances and greater elevations to breed and feed (35-75 km vs. 0-15 km; 50-150m vs. 210-0 m). Hence, inflow populations are characterized by having more fusiform bodies with silvery coloration and longer posterior regions that enable sustained swimming and longer migrations between their feeding and breeding areas than outflow trout (Fraser et al., 2006; Fraser & Bernatchez, 2005b; Taylor & Foote, 1991). Inflow and outflow populations also differ with age-at-maturity, breeding times and feeding habitats, where outflow trout are observed to breed later and feed in lake areas east and west of the outflow mouth (Fraser et al., 2006). Indigenous knowledge revealed trends both Inflow and outflow populations share, where between 1970-2000, the time to capture a brook trout increased, accompanied by a slight reduction in the number and size of the trout. Furthermore, the results of a baseline study comparing habitat use, life history, genetic diversity and effective population sizes between 2000-2002 and 2011 shows the measures remain stable in Cheno and Pepshquasati populations, while the Rupert population witnesses a decline in catch per unit efforts, effective population size, and in length-at-age (the latter is also declining in Cheno and Pepeshquasati populations).

Figure 7: Local angler holding Cheno brook trout, a tributary of Mistassini Lake (Fraser et al., 2017) (photo credit: Matthew Yates)

Besides migration, salmonid population structure is also impacted by kin associations that occur during and are affected by the hatching of salmonid eggs or fish migration to ocean or lake feeding areas (Carlsson et al., 2004). Small streams are less turbulent than larger rivers and hence facilitate kin associations (Fraser & Bernatchez, 2005a). Some schools of fish among brook trout (between 3 - 12 individuals) were observed foraging in lake feeding areas. Fraser & Bernatchez (2005a) found that schools tend to be composed of individuals from the same population and have more kin (half and full siblings) than random chance. Nevertheless, they reveal that kin associations within schools were principally determined by whether fish were raised together over biological relatedness, such that fish raised in a tank together recognize their tankmate regardless of genetic relatedness and would recognize each other through olfactory cues (Quinn & Hara, 1986). Nevertheless, Rajakaruna & Brown (2006) did report the combined effect of being tankmates (having the same diet and sharing dietary cues) and having genetic relatedness allows for the most recognition, and that once again if no biological kin-ship is present, they would favor fish receptive to similar cues as them.

Kin-structured groups that share similar migration times or maturation dates can accrue a survival advantage, since as a school, the fish have an increased chance of finding feeding and breeding areas that are a long migration away, and they additionally would respond to similar environmental cues and olfactory ones especially, enabling them to better evade prey and operate as a cohesive unit, as is the case in Atlantic salmon that are also migratory (Bentzen, 2001; Fraser & Bernatchez, 2005a; Olsén et al., 2004). The knowledge of school structures within trout populations is important with regards to management decisions, since what is now known about trout schools implies each has a certain degree of genetic distinctness from another school, making it so overfishing or fully fishing one school may be more harmful than expected for genetic diversity within a trout population (Fraser et al., 2005).

Albanel Lake is home to brook trout populations that share a similar size distribution to Mistassini Lake populations. Both lakes' brook trout populations are not numerically abundant.

Figure 8: Local angler holding Rupert River brook trout, the outlet of Mistassini Lake (Fraser et al., 2017) (photo credit: Matthew Yates)

Furthermore, Albanel brook trout age, size and age at maturity, which is between 4 and 6 years of age, resembles the life history of brook trout in Lake Mistassini (Flick 1977, Fraser et al. 2004, 2013). Albanel Lake brook trout are harvested by local and visiting anglers (Flick, 1977); harvest monitoring and management is now the responsibility of the Nibiischii Corporation.

The Nibiischii Corporation (Nibiischii), along with guidance from the Ministère des Forêts, de la Faune et des Parcs de Québec (MFFP), oversees maintaining populations in Mistassini, Albanel and Waconichi Lakes. Nibiischii reduced their brook trout catch quota for non-local fishers by 70 % (from 1302 in 2017 to 389 brook trout in 2018) in Albanel to reduce fishing pressure, since northern lakes have lower productivity compared to southern lakes (pers. comm., M. Gravel, Sept 9, 2020). Following recent fishing trends and concerns from the MFFP, Nibiischii also took a more active stance on controlling fishing number and size quotas; in 2018 they implemented a new reservation system to follow catch quotas with an integrated alarm that warns of the bag limit being reached (Nibiischii, 2018a; pers. comm., M. Gravel, Sept 9, 2020). Nibiischii also suggested implementing the following conservation measures:

- Rotating lake access (derived from Indigenous knowledge).
- Implementing catch and release fishing.
- Regulating the minimum and maximum sizes per species.
- Restricting lake access to the clientele at the Rupert reception, Waconichi chalets, Baie Pénicouane and Albanel Lake camps.
- Periodically closing sectors like the north-west sector in Albanel lake (Nibiischii, 2018a).
- Installing the first boat washing station for the summer of 2019 to further hinder invasive species from being introduced (Nibiischii, 2018a).
- Installing a tipi in the spring of 2019 to hold cultural tools to increase sensibilization for the clientele visiting their outfitting camps on the subject of Indigenous fishing practices, aquatic and terrestrial invasive species, catch and release practices to optimize survival rate (Nibiischii, 2018a).

The following population trends represent non-indigenous anglers and are not representative of subsistence harvesting. In 1999, the rate of growth of brook trout in Albanel at 4, 5 and 6 years old was an average of 457, 504 and 547 mm respectively (Larose and Belles-Isles, 2003). Compared to walleye, pike and lake trout populations, the brook trout is the species with the most ‘memorable’ and ‘trophy’ size fish within their population for the region, whereas the former species are considered as being smaller yet ‘quality’ fish sizes. Nevertheless, brook trout is not a dominant species in Albanel in terms of biomass and catch abundance. It has a similarly low catch success rate as the pike, and its yield has steadily been decreasing since 1987 (Larose and Belles-Isles, 2003). It is not the dominant species in Waconichi Lake either, where lake trout are a more abundant species (pers. comm., M. Gravel, Sept 9, 2020).

Brook trout fishing pressure at Albanel Lake increased by 40% from 1996 to 2014 while catch success witnessed a 77% decrease from 1987 to 2018 (Sépaq, 2016; Nibiischii, 2018b). The total harvest of brook trout in Albanel declined between 2009 and 2018 (Table 3; Nibiischii, 2018b).

Table 3: Annual brook trout harvest by non-indigenous anglers in Albanel Lake

Year	Brook trout harvested	Fishing days
2009	691	3770
2010	512	4108
2011	482	3612
2012	422	3218
2013	534	3081
2014	610	2832
2015	586	-
2016	483	2659
2017	395	4013
2018	307	3770

In Waconichi Lake, lake trout is the dominant sportfish fished by non-indigenous anglers, while brook trout is the second most popular (Nibiischii, 2018c). Since 1987, an average of 450 brook trout are harvested annually by non-indigenous fishers (Table 4), a trend that has remained fairly stable, similar to the average mass (Nibiischii, 2018c). Catch success declined by 30% between 1987 and 2018, with the lowest reported catch success in 2018 (Nibiischii, 2018c). The fishing quota remained at 1169 brook trout in 2018, while the Albanel fishing quota was 1302 brook trout in 2018 (Sépaq, 2016).

Table 4: Annual brook trout harvest by non-indigenous anglers in Waconichi Lake

Year	Brook trout harvested	Fishing days
2009	407	1155
2010	321	1152
2011	371	974
2012	293	954
2013	449	644
2014	630	624

2015	518	625
2016	369	1517
2017	446	1291
2018	327	2233

Brook trout is the least harvested sportfish by non-indigenous anglers in Mistassini compared to walleye and lake trout. Since 1987 the number of brook trout harvested has declined, where between 1987 and 1990 over 3000 brook trout were captured annually. More specifically, since 1996 less than 1500 brook trout have been harvested and have even shown a decreasing trend since 2013 despite a stable number of fishing days (3395 days in 2013, 4436 days in 2018; Table 5; Nibiischii, 2018d). Notwithstanding, the average mass of brook trout in Mistassini has remained stable since 1987 (900g; Nibiischii, 2018d).

Table 5: Annual brook trout harvest by non-indigenous anglers in Mistassini Lake

Year	**Brook trout harvested**	**Fishing days**
2009	782	4736
2010	901	4411
2011	656	5049
2012	1309	5456
2013	1482	3395
2014	1167	4042
2015	789	4309
2016	756	-
2017	484	2661
2018	488	4436

There is a lack of catch data collected on brook trout during the winter seasons between 1987 and 2018 on all three lakes by non-indigenous anglers (pers. comm., M. Gravel, Sept 9, 2020).

Indigenous knowledge surrounding brook trout at Mistassini, Albanel and Waconichi Lakes:

Indigenous knowledge (IK; also known as Traditional Ecological Knowledge) is the "cumulative body of knowledge, practice and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment" (Berkes et al., 2000).

With regards to conservation, IK emphasizes the importance of monitoring, such as the continuous monitoring of the environment to avoid diminishing fish, and these limits are enforced by the Tallymen (senior hunters from each territory). IK complements Western scientific methods (WSM) in conservation and management work; IK operates at a finer spatial scale and longer temporal scale than WSM, so it provides a major advantage in remote areas and improves resolution on the spatial distribution, catch trends and local conservation concerns of brook trout (Fraser et al., 2013).

There is a wealth of IK surrounding brook trout in these three lakes that has highlighted not only seasonal movements and temporal trends, but as well knowledge about spawning grounds in Mistassini, namely the Rupert Cheno and Pepeshquasati rivers (Fraser et al., 2013). The following trends were noted through IK:

- Population distribution and movement: Cree fishers noted a late arrival of all populations to spawning grounds in the fall. Changes in spatial distribution were noted especially in the Rupert river, as well as a slight decrease in trout numbers there. Cheno and Pepeshquasati did not witness a change in population distribution nor a change in capture success (Fraser et al., 2006).
- Concerns: Cheno and Pepeshquasati witnessed intense fishing pressure, and Rupert suffers from climate change effects (increased temperature and water level variation) and from increased boating activity that could be scaring the brook trout. (Fraser et al., 2013). Fishers also noted a decline in brook trout abundance in Mistassini over 30-40 years through less efficient fishing captures, and some also noted a reduction in trout size (Fraser et al., 2006).
- Catch time: between 1970 and 2000, Cree fishers anecdotally reported an increase in the average time required to catch a trout and a decrease in the number of trout captured (Fraser et al. 2006).
- Inflow vs outflow trout: breeding times are distinct between inflow and outflow populations. Furthermore, Cheno and Pepeshquasati brook trout had a distinct morphological appearance than those in Rupert, where Rupert trout had deeper bodies with shorter tail regions, and Cheno and Pepeshquasati trout had long, sometimes silvery, body forms (Fraser et al., 2006).
- Conservation planning: harvest trends across multiple populations and schooling behavior in feeding areas and fishing practices are investigated with the goal of discerning population abundance trends 40 years ago to now, and to maintain genetic diversity at the population level at small geographic scales (Fraser et al., 2006).

In the past, IK was compiled through analytical workshops (meetings and presentation that brought together aboriginal informants, fishers from the local community and researchers to consolidate information), semi-directive interviews (general series of questions to cover important topics), and collaborative fieldwork (exchange of information between scientists and local community over the long term. Although some IK has been documented through various fish studies in the area, this report does not present them all; there is still a need to consult local

Cree fishers, elders and tallymen further to better develop a framework that can be used for scientific research and conservation planning.

For Albanel and Waconichi, IK of brook trout has not yet been documented. At the time of writing, the Témiscamie River is the only known important spawning ground for Albanel brook trout; one spawning ground is also known locally in Lake Waconichi but owing to the small size of this spawning ground and proximity to human settlements its location is not disclosed here (Flick, 1977; pers. comm. P. MacLeod, Sept 9, 2020). Currently, consultation is underway to determine if IK identifies additional spawning rivers in both lakes.

WALLEYE

Section 1: Socio-economic importance

Walleye (*Sander vitreus*), also known as pickerel in some areas, is a cold-water species whose importance spans across the social and economic spheres of North America (see Figure 9). In 2015, walleye was the most popular sportfish caught across Canada, with over 50 million walleye caught, representing 26% of total catch (DFO, 2015). In Quebec, walleye are the second most popular sportfish species (after brook trout), and generates $359 million annually (MFFP 2017).

Figure 9: Cree fisherman with his caught walleye on Mistassini Lake (Mistassini Outfitting Camps, 2020)

Commercial walleye fisheries are only found in Canada, and are centered primarily in Ontario, Manitoba, and Saskatchewan. Between these three provinces, a total of 11,217,000 kg of walleye were harvested in 2018, which represents $38,841,000 (DFO, 2018). Quebec used to have a greater stake in commercial walleye fishing, however due to high mercury concentrations, commercial fishing is only allowed in the St. Lawrence River between the 'Pont Laviolette' near Trois-Rivières and the eastern tip of Ile d'Orléans (MFFP, 2017). In 2018, only 4000 kg of walleye were commercially harvested in Quebec (DFO, 2018).

Despite these active commercial fisheries, walleye stocks have crashed throughout Canada, but since then have rebounded to a certain extent. This instability stems from pollution, increased fishing pressures, spawning habitat reductions, invasive species and other threats.

Management programs have been implemented throughout the Great Lakes and other areas to curb the declining walleye stocks (Hartman, 2009) and to promote recreational fisheries (VanDeHey et al. 2014). Stocking of juvenile walleye (Rutherford et al., 2016) and their prey to enhance the prey base (VanDeHey et al., 2014), have been also implemented in many southern parts of Canada and in the USA.

Walleye also have socio-economic importance for Indigenous peoples. Walleye, which are a traditional food to many communities, contribute to cultural continuity, autonomy, and are an important component of socio-cultural practices (Fieldhouse and Thompson, 2012). Walleye are a preferred subsistence food in the Cree town of Mistissini due to its proximity to the southern tributaries of Mistassini Lake which hold important walleye spawning grounds (Bowles et al., 2020). Walleye provide an important source of vitamin D and B12 (Neff et al., 2014), protein, and omega-3 polyunsaturated fatty acids which promote neurocognitive development and cardiovascular health (Laird et al., 2018). Traditional foods are also important economically due to the high cost of market foods in northern communities (Donaldson et al., 2010), therefore a continuous source of walleye protein can reduce the cost of food.

Section 2: General traits

2.1 Habitat

Walleye are known as a cold-water species (Hokanson, 1977; Kitchell et al., 1977a) and their habitat use is dictated by lake size, bottom type, depth, temperature, oxygen concentration, pH, light and turbidity (Colby et al., 1979; Scherer, 1976).

Larger lakes, like Mistassini, tend to always have optimal oxygen, and temperature levels than smaller systems which may impair overall walleye growth, development and maturation of eggs (Bozek et al., 2011). Walleye are typically found above the thermocline (Wang et al., 2007), which is a thin layer of a lake that establishes in the summer where temperature changes more rapidly than depth. They reside mainly in rocky areas (Bozek et al., 2011), which have boulders and other rocky structures for shelter during the day (Ryder, 1977).

Water chemistry of lakes and rivers is vital across all walleye life stages. It has been reported that the optimal water temperature for walleye growth is around 22ºC (Hokanson, 1977; Kitchell et al., 1977b). In spring, during the spawning season, laboratory tests show that the optimal temperature range for egg fertilization is 6-12ºC (Koenst and Smith, 1976). Walleye generally prefer dissolved oxygen (DO) levels above 5mg/L but can survive in 3mg/L (Bozek et al., 2011; Barton and Taylor, 1997). Optimal pH levels for successful development and maturation of walleye eggs lies slightly above pH 6 (Hulsman et al., 1983).

Walleye have a strong affinity to turbid waters because they have specialized eyes which allow them to feed in low light environments (Ryder, 1977). As a result, in clear lakes, walleye will only feed at dawn or dusk (Ali et al., 1977) while they retreat to deeper waters to avoid warmer temperatures, lower dissolved oxygen (DO) levels and the high amount of light penetration throughout the day (Colby et al., 1977). In turbid lakes, like Mistassini Lake, walleye are more inclined to feed throughout the day (Ali et al., 1977).

2.2 Reproduction

Walleye spawning season ranges from February (in the extreme southern populations) to June (in the extreme northern populations) (Johnston and Leggett, 2002). Male walleye generally mature between 2-4 years, while females mature between 3-6 years (Scott and Crossman, 1973), but have been reported to mature as early as two years (Johnston and Leggett, 2002). Walleye are iteroparous fish, meaning that they spawn more than once in their life. However, they may skip spawning in a specific year if they had a poor growth season (Forney, 1965) and do not have enough lipid reserves (Henderson et al., 1996). This may be the case for walleye in Mistassini, Albanel and Waconichi lakes, however no studies have studied this phenomenon for walleye in northern latitudes. In lakes, spawning typically begins when the ice begins to break and when water temperatures are between 6-11^{o}C and lasts 1-2 weeks (Johnston and Leggett, 2002).

Walleye will spawn in shallow waters on exposed rocky shorelines and shoals of lakes (Johnston and Leggett, 2002; Strange and Stepien, 2007). Walleye will also spawn in lake tributaries where rapids and riffles are present to ensure sufficient oxygen for egg development (Bozek et al. 2011). Although walleye prefer gravel and cobble substrate for their eggs to adhere to (Collette et al., 1977; Colby et al., 1979), they will use mud and sand as well despite them being less favourable (Johnson, 1961). Males arrive at the spawning areas first and leave last as they can spawn multiple times in a given season, increasing their odds of encountering a reproductive female (Fagerström and Wiklund, 1982). Walleye do not use redds (spawning nests) like brook trout, rather they are broadcast spawners and release their eggs onto the substrate to then be fertilized (Collette et al., 1977; Colby et al ,1979). Eggs will generally hatch between 10-20 days after fertilization (Johnston and Leggett, 2002).

2.3 Predation, Diet, and Growth

Walleye undergo several diet shifts as they grow (Pratt and Fox, 2001; Galarowicz et al., 2006). These shifts occur due to changes in food availability, competition between other fishes, and increase in body size of the fish itself (Galarowicz et al., 2006). Walleye larvae will feed on their yolk sac for several days before they swim to a pelagic environment and consume zooplankton (microscopic crustaceans) (Johnston and Leggett, 2002). They then switch to benthic freshwater invertebrates (Maloney and Johnson, 1957; WDNR, 1970; Galarowicz et al., 2006), which consists of mayflies (similar to dragonflies), chironomids (fly larvae), amphipods (‘small freshwater shrimp’) and leeches (Colby et al., 1979). They eventually predate almost exclusively on fish once they reach 50mm in length (Johnson et al., 1988).

Prey densities will change throughout the year, whereby walleye will consume more invertebrates throughout late spring and early summer and shift to a more piscivorous diet later in the summer when prey fish are more abundant (Colby et al., 1979). This may alter the timing of dietary shifts (Stein et al., 2017; Hoxmeier et al., 2006; Jackson et al., 1992).

Adult walleye have been reported to predate on a variety of fish. They tend to prefer soft-rayed fish such as: emerald shiner, cisco (Arvisais et al., 2012) and gizzard shad (Sheppard et al., 2015). They will also predate upon spiny rayed fish such as: yellow perch (Arvisais et al., 2012), freshwater drum (Arvisais et al., 2012) and black crappie (Mittlebach and Persson, 1998). Cannibalism upon small walleye has also been reported (Chevalier, 1973).

Feeding typically occurs in shallow waters where light conditions are favourable (Ali and Antcil, 1968; Gorman et al., 2019). Furthermore, feeding primarily occurs at the bottom of the water column (Colby et al., 1979).

Walleye's large geographic distribution subjects them to a wide climatic gradient of about 4000 growing degrees (GD) within a given year (Bozek et al., 2011). GD is calculated by subtracting all daily mean temperatures within a year by a base temperature at which development/growth of the organism does not occur (i.e. 5^{o}C) (negative values are assigned a value of zero). Warmer water temperatures stimulate prey productivity (Wetzel, 1975), but also increase metabolic processes and energetic costs, forcing walleye to consume more prey (Rieger and Summerfelt, 1997, Trometer and Busch, 1999). Prolonged warm temperatures allow young-of-year (YOY) walleye to grow faster, decreasing the risk of predation decreases (Chevalier, 1973; Madenjian and Carpenter, 1991; Hoxmeier et al. ,2004). In higher latitudes, like in Mistassini Lake, slower growth is exhibited by walleye, resulting in a longer time to reach maturity (Scott and Crossman, 1973).

2.4 Population Trends and Distribution

Walleye are primarily found in freshwater systems which span across Canada and the USA. In Canada, walleye's native distribution includes Quebec and spans westward into the Northwest Territories. In the USA, walleye's native range consists of most northern states and spans southward into Alabama (Colby et al., 1979; Hartman, 2009) (see Figure 10).

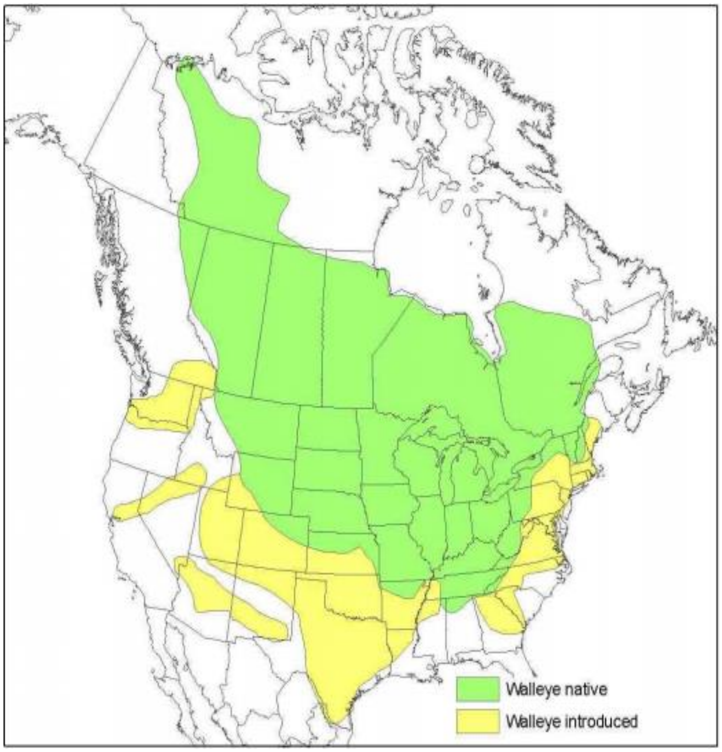

Figure 10. Walleye native and introduced range from Bradford et al. (2008)

Declines in the walleye stocks across the Great Lakes from 1800-2000 were linked to a combination of stressors such as: overharvesting, nutrient loading, alteration of walleye spawning grounds, introduction of exotic species and introduction of toxic chemicals (Leach and Schneider, 1979; Pothoven et al., 2017). The commercial catch dropped by 88-100% from its peak in 1929 to 1975 (Leach and Schneider, 1979). Management efforts such as stocking and restorative activities have been implemented to restore walleye populations across the Great Lakes. Other important fisheries have also declined from overharvest including the decline in Albertan walleye (Sullivan, 2003; McGregor et al., 2015) (Sullivan, 2003), Minnesota (MNDNR 2018) and Manitoba (Klein and Galbraith, 2016).

In large lakes, including the Great Lakes and Mistassini Lake, divergent walleye populations exist which have their own life histories. This is vital for fisheries managers to consider when creating a management plan. For example, molecular evidence shows that there are at least two different spawning groups of walleye in western Lake Erie (Merker and Woodruff, 1996) and two in the central basin (Stepien et al., 2018). Walleye belonging to their respective breeding groups display natal philopatry and spawning in their respective spawning grounds (Merker and Woodruff, 1996). Analyses done in Lake Erie's eastern basin also shows high site fidelity during the spawning season (Stepien et al., 2010). Similar patterns have been observed in Mistassini Lake (Dupont et al., 2007)

As scientists better understand population characteristics for walleye, developing tailored management plans for populations is advised (Hayden et al., 2017; Stepien et al., 2018). Genetic analyses shed light on the ecological and anthropological factors that influence populations and can provide important biological traits of said population that might be critical for management (Scribner et al., 2016; Page et al. 2017). Maintaining high genetic diversity across and within populations allows a species as a whole to better cope with stressors (Scribner et al. 2016) (i.e. climate change) as there are more unique individuals, therefore increasing the odds of survival.

Populations with low genetic diversity are most sensitive to extirpation due inbreeding, stunted growth, and reduced reproductive success (Lacy, 1997) and should be targeted for conservation.

2.5 Threats

There are many factors that have contributed to historical declines of walleye stocks across North America, but there are also others which are contemporary issues that must be highlighted as well (see Figure 11).

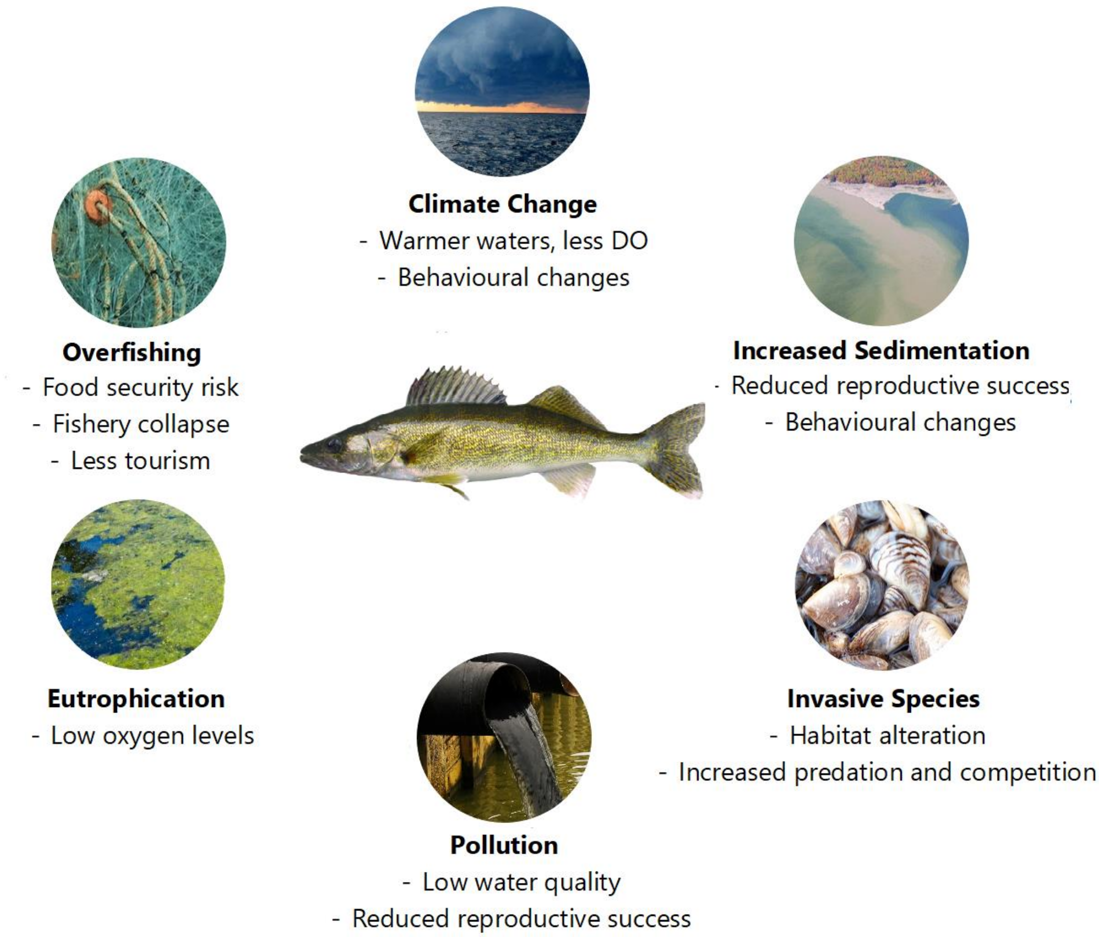

Figure 11. Summarized walleye threats

Climate change may be the biggest threat for walleye as it impacts many aspects of its life. Since walleye cannot regulate their own body temperature, their body's metabolic processes will increase in response to climate warming, resulting in higher energetic costs. Increased water temperature also lowers the amount of dissolved oxygen in water, which can also reduce the survival rate of larval walleye (Siefert and Spoor, 1974) , increase the chance for viral diseases (Snieszko, 1974), and eventually lead to an elevated risk of death (Peat et al., 2015).

Warmer waters may impact walleye movements as there may be less optimal habitat, forcing walleye to expend more energy to find more suitable (colder) areas to lower their metabolic costs (Peat et al., 2015). Hansen et al. (2017a) examined young-of-year walleye survival success in 359 Wisconsin lakes and found a heterogeneous response of walleye recruitment success in relation to warming water temperatures. Some walleye populations responded negatively, while walleye populations had more recruitment success, therefore other factors like the fish community and other lake-specific characteristics must be considered (Hansen et al., 2017b).

Overfishing is a prevalent threat in slow growing, more northerly distributed walleye populations like in Mistassini Lake, because there is a slower maturation rate within the population. Such is the case in Alberta, whose walleye fisheries are mainly found between the 54th and 60th parallel and have growing degree days ranging from 900 to 1400 (Sullivan, 2003). Due to the few lakes in Alberta, there is a disproportionately high recreational fishing pressure per lake compared to other provinces. Coupled with lax fishing regulations, and slow maturing walleye fisheries around Alberta collapsed in the 1980s (Sullivan, 2003).

The human-assisted introduction of exotic species has led to ecosystem changes in myriad freshwater systems. Direct competition and predation are classic impacts stemming from exotic species (i.e. alewife in the Great Lakes were competing and predating upon young walleye life stages [Fielder et al., 2007; Madenjian et al., 2008]). Indirect effects such as habitat alteration have also been reported (i.e. increased water clarity, reducing viable walleye spawning grounds in the Great Lake basin due to zebra mussels [Johannsson et al., 1998; Chu et al., 2004]).

Deforestation (Jones III et al., 1999), agricultural run-off (Mardsen and Langdon, 2012), large storms (Gatch et al., 2019), and dredging (Suedel et al., 2012) are drivers of increasing sediment in the water column (turbidity). Increased turbidity decreases light penetration and can impact a walleye's ability to identify prey (Nieman and Grey, 2019). Sediment may deposit on crucial nursery areas disturbing the spawning season, burying walleye eggs, increasing in egg mortality rates (Gatch et al., 2019). Furthermore, deposited sediment may prevent eggs to adhere to spawning grounds, increasing the chance of eggs being swept away by storm conditions to sub-optimal areas for egg incubation and protection (Madenjian et al., 1996; Crane and Farrell ,2013).

Eutrophication is another stressor brought upon by nutrient loading, typically from agricultural run-off. Harmful algal blooms are created when limiting nutrients such as nitrogen and phosphorus are added in high quantities into a system, typically from agricultural run-off, and reduces the amount of usable oxygen in the system (Watson et al., 2016). This can create sub-optimal habitats for growth due to the extra energetic cost to cope with lowered oxygen levels.

Industrial pollutants such as mercury, organochlorides (a group of persistent pollutants), and heavy metals are also deleterious to walleye populations. These pollutants are all responsible for birth defects, growth impairment and survival of larval walleye (see Palace et al., 2003; Marentette et al., 2017). This adverse risk stems from female walleye potential transferring pollutants to the eggs (McKim et al., 1976)

In many cases, stressors often act synergistically together. Climate change can impact the severity and frequency of storms, and therefore increase the entrainment of sediments in the water column. Eutrophication coupled with warmer waters may lead to unusable habitats for walleye due to oxygen-poor waters. Less refuge for walleye means more stress and less opportunities for growth, which can ultimately lead to female walleye skipping spawning seasons (Forney, 1965), since they were not able to acquire enough lipid reserves (Henderson et al., 1996).

Section 3: Management outside of Mistassini, Albanel and Waconichi

Management strategies targeted towards an almost pristine fishery should strive to achieve a balance between maintaining a healthy and sustainable fishery, while still providing excellent recreational fishing opportunities. The Ontario Ministry of Natural Resources (OMNR) recognizes four broad management issues and challenges when creating a management plan: education, exploitation, habitat and invasive species (OMNR, 2014).

3.1 Monitoring

An essential part of proposing, implementing and assessing conservation strategies is to routinely monitor the status of the fishery. For example, Lake Erie is managed by the Lake Erie Committee, which is a bi-national committee of state and provincial fisheries agencies (Kayle et al., 2015). Currently, walleye in Lake Erie are being managed as a single population, despite studies showing divergent populations (Stepien et al., 2018). Lake Erie is divided into five management zones, where annual walleye surveys are conducted to estimate population abundance and ultimately create a recommended allowable catch for the upcoming year (Kayle et al., 2015). Surveys take the form of fall and spring gillnet assessments, sportfishing surveys, young-of-year trawling survey and commercial gillnet monitoring (Kayle et al., 2015) (see figure 12). These surveys provide population characteristics (i.e. age structure, average fish size, and relative abundance), ensure regulations are being followed and evaluates the overall health of the fishery. Annual population assessments occur elsewhere as well, such as Wisconsin, where a variety of gear is used. Non-lethal electrofishing and fyke netting are commonly used to assess the long-term trends of walleye populations in many lakes including Lake Michigan (Roberts, 2019; Hogler and Surendock, 2018; Cole, 2014). The Nipissing First Nation (NFN) collaborates with the OMNR to conduct their fall walleye index gillnetting, creel surveys and spawning assessments (Smith, 2017). NFN also oversees commercial fisheries and provide statistical information to the OMNR (OMNR 2014b).

Figure 12: A biologist conducting a gillnet survey (Steelhead Voices, 2017) (photo credit: DFO)

Similarly, Alberta uses a 'Fish Sustainability Index' (FSI) to inform managers about the sustainability of a fishery (ABGOV, 2018). This index is based on scientific information and Indigenous knowledge to create historical population baselines (ABGOV, 2018). This index ranges from 0 (extirpated) to 5 (very low risk) and depends on adult netting catch rates (ABGOV, 2018). A high FSI score (i.e. 4+) is attributed to a population which is lightly exploited, with low mortality rates and has a wide variety of fish sizes. Meanwhile a low score (i.e. 1) describes a population at low abundance in which fishing harvest cannot continue. Appropriate measures are then taken depending on the score and status of the fishery to reach a specific goal.

Figure 13: A creel clerk recording data from a fisherman returning from a day of fishing (Michigan DNR, 2015)

Creel surveys, otherwise known as angler surveys, are a complimentary strategy to population assessments that provide valuable information about the use of the fishery by recreational fishermen and their habits (Roberts, 2019) (see figure 13). Information like angling effort, targeted species, catch success, and harvest can be combined with population estimates from monitoring efforts to create angler exploitation estimations for a given waterbody (Roberts, 2019). These estimations are important in understanding whether current fishing regulations are sufficient to prevent overfishing.

Fish tagging is another monitoring measure to better understand fish ecology and inform managers fish are being captured by fishermen (see figure 14). Knowing where fish aggregate at different life stages may shed light on population characteristics, seasonal movements and may highlight key spatial areas for conservation. These types of efforts are used throughout the Great Lakes (see Lake Michigan [Hogler et al., 2018], Lake Ontario [OMNR, 2019a], Lake Erie [Wills et al., 2020]). This practice involves surgically implanting acoustic transmitters to capture their movements (OMNR, 2019a). Anglers who catch these tagged fish can call a hotline to report a capture and/or can physically return the tags to management offices. In combination with harvest management, this can be a useful tool for managers to ensure the protection of key spawning grounds/areas of concern.

Figure 14: An example of a fish tag, which provides vital information about fish movement (Fishing Booker, 2020) (photo credit: Wikimedia, Des Colhoun)

Water quality monitoring is vital for the sustainability of walleye populations (see figure 15). Baseline levels of the water chemistry provides managers the ability to detect potentially deleterious changes in the waterbody from industrial processes or from climate change. The Great Lake Indian Fish and Wildlife Commission (GLIFWC) have been monitoring water quality in the Lake Superior Ojibwe Treaty-ceded Territories for the past 10 years (Coleman et al., 2019). Water samples are assessed for the quantity and type of suspended solids and metals within the water, while instruments such as YSIs are used to measure dissolved oxygen, water temperature, conductivity and pH. Proposed industrial projects could have negative effects on the water quality, therefore these monitoring efforts are essential to observe potential changes and potentially serve as protection to further impairment if legal actions need to be pursued. Alberta has created an 'Indigenous Lake Monitoring Program', where Indigenous communities aid scientists conduct water sample surveys (ABGOV, 2019).

Figure 15: A scientist assessing water quality using a YSI instrument (Geotech Environmental Equipment 2020)

3.2 Regulations

Aside from monitoring, restricting recreational fishing through seasonal closures is a method used throughout Canada and the USA to actively manage walleye fisheries. Closures are typically enforced in the spring when walleye are spawning and are most vulnerable. Walleye fishing is generally closed between the months of March and April and reopens in early May (see Manitoba [MBGOV, 2020]; see Ontario [OMNR, 2020]; see Wisconsin [WDNR, 2019]).

Harvest regulations are another common strategy for recreational fisheries. Daily bag limits will vary depending on the status of the walleye fishery. However, size limits are a common strategy to protect large female walleye (See figure 16). In Quebec, an allowed harvest range for slow-growing (32cm-42/47cm) and fast-growing walleye (37cm-47/53cm) was implemented in 2011 to allow walleye to reach maturity, whilst also protecting large walleye (Arvisais et al., 2012). In 2016, their initial plan's effectiveness was reviewed, and positive trends were observed for the abundance of mature females walleye and for the species as a whole, therefore minimal regulatory changes were applied for their 2016-2026 plan (MFFP, 2017). Other states and provinces have similar approaches; Lake Winnipeg, Manitoba's largest walleye recreational fishery, has prohibited the harvest of walleye under 35cm (MBGOV, 2020); A harvest minimum of 46cm in Lake Nipissing, Ontario (OMNR, 2020); and a harvestable range of 38-51cm in the Ceded territories in Wisconsin (WDNR, 2019).

Figure 16: A walleye being measured to verify if it can be kept of not (Master Angler – Travel Manitoba, n.d.)

In extreme cases where the walleye fishery is suffering due to increased fishing pressure, emergency regulations may be implemented to prevent overharvest. Due to an extremely productive ice fishing season, the Minnesota Department of Natural Resources (MNDNR) has set strict catch and release measures in Mille Lacs Lake for the 2020 fishing season. Furthermore, night closures, and a one-month walleye moratorium in July were also implemented to allow walleye to mature and become reproductively viable (MNDNR, 2019).

Catch and release related deaths do become an inevitable consequence because of such measures. However, one method to reduce the risk of death is by regulating the hook type for fishermen. In Manitoba, it is strictly forbidden to use barbed hooks, therefore barbless hooks are used ubiquitously among fishermen (MBGOV, 2020) (see figure 17). This strategy minimizes injury, reduces handling time and air exposure to the fish, and can ultimately increase their chance of survival (Cooke et al., 2001).

Figure 17: A comparison between barbed and barbless hooks (Fly Fishing Shop 2020)

Although the catch-and-release movement is growing (Bartholomew and Bohnsack, 2005), fishermen do enjoy keeping fish, and in some cases, 'trophy-sized fish'. Special walleye license draws are a method to regulate the harvest of large trophy-sized fish. Alberta currently holds annual special walleye license draws for specific lakes. These allow holders to keep 2 or 3 Walleye >43cm depending on the lake (ABGOV, 2020). Similarly, in Lake Winnipeg, Manitoba, license holders can keep one walleye over 70cm per year and must record the details on their license (MBGOV, 2020).

Night fishing is typically ignored in management plans despite it being the optimal time to catch walleye (Cooke et al., 2017). Handling times and air exposure may increase due to reduced visibility in the dark, thus increasing the risk of catch and release-related deaths. Furthermore, the fishing industry has created baits and lures to be used specifically at night to increase fishing success. Managers should at least consider this as a viable strategy in unison with the more 'standard management techniques' (Cooke et al., 2017).

Commercial fisheries have also been regulated to prevent overfishing. In Ontario, commercial fishing is culturally and economically important, therefore the OMNR wants to create sustainable commercial walleye fisheries. Seasonal closures are also applied for commercial fishing, typically during spawning season (OMNR, 2007). Quotas are also set for fisheries to prevent overharvest and are reviewed every year to ensure its efficacy (OMNR, 2014). In addition, commercial sampling programs have been created when current harvest levels may pose a threat upon a species well-being (OMNR, 2014). Manitoba is the only province to achieve a Marine Stewardship Council eco-certification in Canada for its sustainable fisheries. A buy-back quota system has been implemented in Lake Winnipeg, whereby commercial fishes will not be forced to reach their quota and can sell the remainder back to the state, therefore reducing walleye harvest (MBGOV, 2019). Furthermore, commercial fishers need to keep a logbook of their harvest to ensure the credibility of the physical haul (Klein and Galbraith, 2016). Lastly, Manitoba has a strict minimum gillnet mesh size ranging from 96mm (3.75 inches) to 108mm (4.25 inches) to allow immature fish to escape and reach maturity and successfully spawn (Klein and Galbraith, 2016; MBGOV, 2019). Previous regulations of 76mm minimum mesh size gillnets caused several walleye collapses around the province (Klein and Galbraith 2016).

3.3 On-site management projects

Aside from actively managing fishermen, habitat restoration projects have been carried out to improve walleye stocks (see figure 18). In 2015, walleye stocks in Georgian Bay, Lake Huron were believed to be severely stressed based on monitoring. Significantly fewer eggs were deposited in their spawning river (Key River) due to railways and pollution. Spawning sites were located, and river rocks were deposited to create optimal spawning habitat (EGBSC, 2015). The spawning habitats were monitored for three years and although it is too early to make conclusions, an increase in deposited eggs was generally recorded (EGBSC, 2018). In Minnesota, the St. Louis River estuary, which flows into Lake Superior, has degraded significantly throughout several decades from industrial discharges, forestry and many other human activities (NOAA, 2016). This has impacted the health of several fish species including walleye. In collaboration with the National Oceanic and Atmospheric Administration (NOAA), the existing hardened shoreline was reverted to its natural conditions (rocky bottom with woody vegetation) in several parts of the river (NOAA, 2016). Water quality management projects are also underway. Due to the nature of this large ongoing project, walleye population reports have not been conducted.

Figure 18: Habitat restoration projects conducted in Ontario; monitoring deposition of river rocks to create walleye spawning habitat (EGBSC, 2015)

Despite lakes being separated from one another, boats, fishing gear and ultimately roads are one of many factors that aid the spread of aquatic invasive species (AIS). Ontario created an AIS strategic plan which is guided by four goals: 1) preventing harmful introductions, 2) detecting and identifying AIS once they have been spotted, 3) responding rapidly to AIS before they spread, and 4) implementing sound management actions to minimize the impacts of AIS (OMNR, 2012; OMNR, 2014). AIS awareness and education programs have been carried out in Ontario to prevent their introduction. Some of these efforts include creating simple action plan documents targeted towards anglers (OMNR, 2019b) and boaters (OMNR, 2019c), and AIS identification keys for the general public (Lui et al., 2010). Monitoring actions include conducting broadscale monitoring efforts in waterbodies to monitor AIS spread, creating an AIS hotline to report sightings (OMNR, 2014) and investigating sightings based on sightings (OMNR, 2014). Quebec's MFFP (2016) does not appear to have a rigorous AIS plan. Once an exotic species is introduced, managers must monitor if it will establish a self-sustaining population, because heavy economic costs may occur to either reduce its population to minimize impact or to eradicate it, normally with pesticides (Meronek et al., 1996).

Educational and public awareness programs are vital to not only ensure that the regulations and rules are understood by fishermen, but also for the overall acceptance of new regulations. The Ontario Ministry of Natural Resources (OMNR) has set up public education materials to inform anglers on a variety of topics ranging from the correct catch and release techniques to the importance of large female walleye and why they are being protected (OMNR, 2014). Wisconsin created detailed decontamination protocols for boats, gear and equipment. This involves washing boats before entering new bodies of water, dedicating certain gear for specific waterbodies, and minimizing the amount of plants and other organisms attached to boats and sampling gear (WDNR, 2020). Quebec also has a similar guide to protect their aquatic environments (MFFP, 2018). First Nations elders monitored walleye harvest in Dauphin Lake, Manitoba during the spawning season and talk to the First Nations fishers about protecting these important fisheries. Furthermore, they have added signage advising people to to voluntarily restrain their harvest of pre-spawn walleye (MBGOV, 2010).

Although not a relevant conservation method for this report, it is still important to mention that walleye stocking is a commonly used strategy in Canada and the USA to maintain, restore and/or supplement walleye populations (see annual stocking reports for Saskatchewan [SKGOV, 2019]; Wisconsin [WDNR, 2018a]; Minnesota [MNDNR, 2019]. Despite its wide use, its overall benefit is questionable in the short and long-term.

Section 4: Lake Mistassini/Albanel/Waconichi Walleye Life History

In contrast to the Laurentian Great Lakes and other more southern bodies of water, Mistassini Lake walleye populations only have a few peer-reviewed scientific papers covering some aspects of their life history. Meanwhile, to our knowledge, there are no peer reviewed scientific publications in Albanel and Waconichi Lakes, which becomes a challenge for fisheries managers when trying to implement strategies to sustain and protect these fish.

Mistassini Lake is a large lake (2335km^2) located in central Quebec between the 50th and 52nd parallel, that remains a largely pristine habitat for walleye (Dupont et al., 2007) (see Figure. 19). The open waters of the lake remain cold throughout summer, whereby some of the deep-water areas would never exceed 15^{o}C, which is below the optimal temperature for walleye (Dupont et al., 2007). Furthermore, due to its long length of 161km, Mistassini is subjected to a longitudinal atmospheric temperature gradient, whereby its north end experiences 816-979 growing degree days and 979-1141 growing degree days in the south end throughout the year. This may explain why northern walleye are smaller in size than walleye in the southern tributaries (Bowles et al., 2020). Mistassini walleye will leave their spawning rivers and feed in the adjacent bays and in the lake near their spawning grounds during the summer (Bowles et al., 2020). Walleye movements may strongly influence pike movements due to sharing similar spawning ground requirements, and because walleye are a crucial prey species for pike (Bowles et al., 2020). Furthermore, walleye are characterized as returning to their natal birth grounds to reproduce. Only a fraction of the walleye populations (7.6%) were reported as dispersers (Dupont et al., 2007).

Figure 19. Cree fishers with their caught walleye at Mistassini Lake (Mistissini Tourism, n.d., Mistassini Outfitting Camps, 2020).

Dupont et al. (2007) documented the patterns of genetic population structure in Mistassini Lake and found a minimum of four genetically distinct walleye populations: Takwa (north), Rupert (west), Perch-Icon (south) and Chalifour (~south) (see figure 20). The Rupert population appears to be the most genetically distinct population and to be the only population that did not disperse towards the other populations within the lake. Rather, they remained in the vicinity of their spawning grounds and only migrated small distances in comparison to the other populations. This may be in part due to it being the only outflow population whose ancestry may have originated near the James Bay watershed compared to the other three inflow populations (Billington et al., 1992; Dupont et al., 2007).

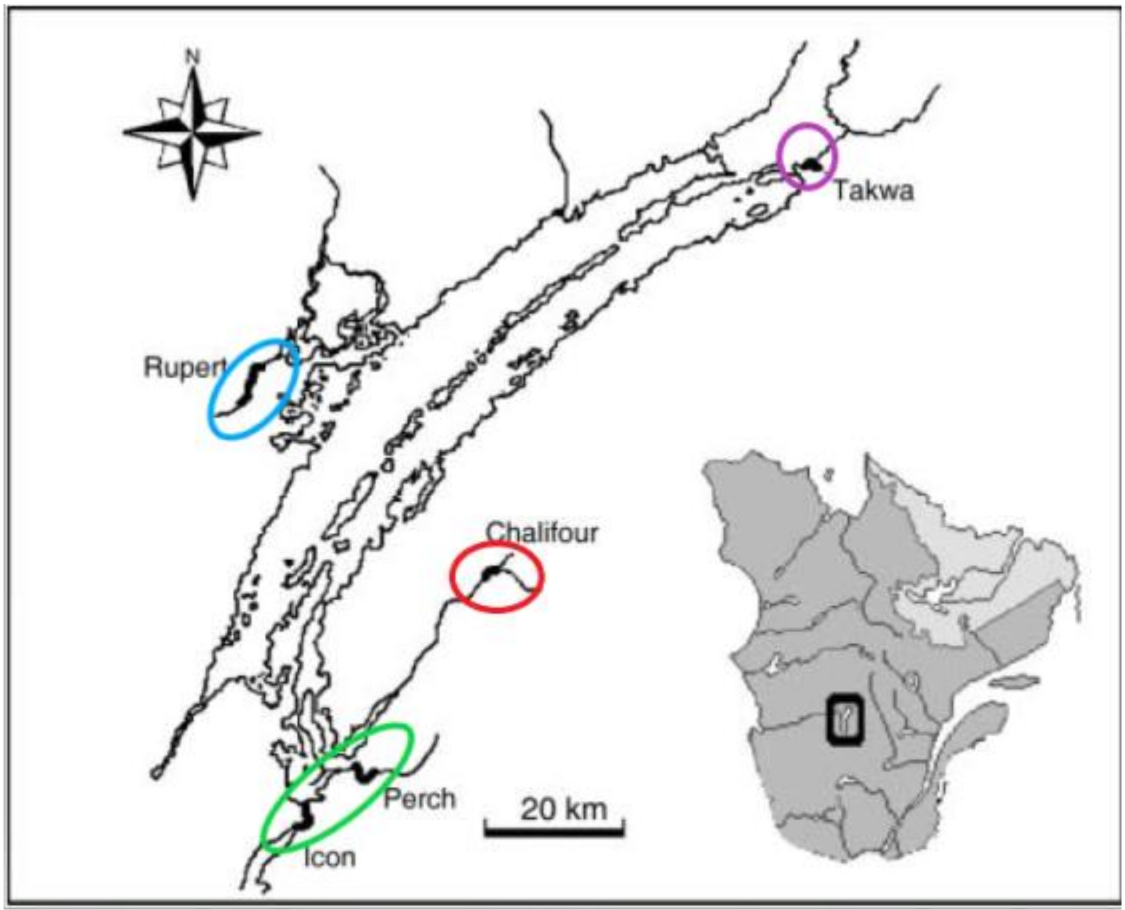

Figure 20. Four distinct walleye populations in Mistassini Lake (Adapted from Dupont et al. 2007)

Although some individuals from the Takwa, Perch-Icon and Chalifour populations will disperse between each other, habitat heterogeneity and environmental stresses appear to spatially separate them. The temperature gradient across the lake has affected walleye behaviour, whereby anglers were most successful in the warmer and shallower back bays, compared to the cool open water areas in the northern part of the lake (Takwa population) (Dupont et al., 2007). Furthermore, analyses revealed that Takwa walleye are found widely across the open water areas of the lake, insomuch that some individuals were found in the southern reaches of the lake. This may be due to Takwa walleye searching for more optimal habitat. The three other observed populations were found to remain closer to their spawning grounds (Dupont et al., 2007).

There is evidence for a tendency of male-based dispersal in walleye, but it is not statistically significant (Dupont et al., 2007). Interestingly, Perch-Icon displayed female-based dispersal. Their analyses also revealed that larger individuals would migrate larger distances within the lake.

An increase in fishing pressure in the southern areas of Mistassini Lake may be leading to the early stages of fisheries-induced evolution (Bowles et al., 2020, 2021a). Such effects may be most apparent for female walleye, as they are generally bigger than males and more desirable for anglers alike (Bowles et al., 2020). These anthropogenic selective pressures have been documented to induce the evolution of smaller sized fish (Heino et al., 2015; Hutchings, 2005; Swain et al., 2007; Hutchings & Fraser 2008).

Bowles et al. (2020) examined the Chalifour, Perch, Icon, and Takwa rivers in Mistassini Lake to observe whether increased fishing pressure noted by local Cree anglers and tallymen affected overall walleye size and population structure. A significant decrease in mass, and total length between 2002/3-2017 was reported for walleye in the southern tributaries except for Perch River males and Chalifour females (Bowles et al., 2020). Takwa walleye appeared to be unaffected across all the years examined. A male-biased catch of walleye was reported for all rivers and for all sampling years (Bowles et al., 2020). Genetic diversity for all four rivers was maintained between 2002-2015, however genetic changes due to harvesting were observed within a 1-2.5 generation period in the southern rivers. Walleye from all southern rivers were consistently smaller, albeit a small reduction, across all age classes for the years examined.

It is vital to highlight that there is no clear association with the increased fishing pressure and body size changes as habitat or environment shifts may have played a factor throughout the years of comparison (Bowles et al., 2020, 2021a). In any case, if these size reductions are related to increased harvest in a relatively short time span, then further (and potentially more severe) impairment upon the southern populations is likely to arise without conservation strategies.

Sportfishing within the Albanel-Mistassini-Waconichi Wildlife Reserve primarily targets brook trout, lake trout, northern pike and walleye. Among these species, walleye is the most popular sportfish among non-indigenous anglers in Albanel Lake with an average of 6892 walleye caught yearly between 2009 and 2015, while an average of 542 brook trout, 851 lake trout, 815 northern pike were caught annually (Sépaq, 2016). Despite this popularity, since 2011, walleye harvest has declined every year (Table 6) (Nibiischii, 2018b). Fishing days (one fishing day represents a day of fishing regardless of the amount of time spent on a body of water) spent on Albanel Lake have also shown similar declines with 4108 days in 2011 dropping to 2659 in 2017, with a spike in 2018 with 4013 days (Table 6). Témiscamie River, a known spawning ground for Albanel Lake walleye (pers. comm., P. McLeod, Sept. 9, 2020), has experienced an increase in harvest since 2007, with an average of 1504 walleye harvested annually (Nibiischii, 2018b). The mean weight (650g) has stayed consistent throughout the same timeframe as well (Nibiischii, 2018b).

Table 6: Annual walleye harvest by non-indigenous anglers in Albanel Lake

Year	Walleye harvested	Fishing days
2011	8241	4108
2012	7207	3612

2013	6496	3218
2014	5849	3081
2015	5256	2832
2016	4946	-
2017	4871	2659
2018	4831	4013

Walleye are rarely caught in Waconichi Lake (pers. comm., M. Gravel, Sept. 9, 2020). Between 2009-2015, an average of 12 walleye were caught compared to an average of 412 brook trout, 1081 lake trout and 44 northern pike (Sépaq, 2016). Furthermore, walleye captures have been so sporadic that no catches were reported in certain years (i.e. 2013-2014) (Sépaq, 2016). Walleye fishing days have also dropped whereby in 2009, 1155 fishing days were reported and only 58 days were reported in 2015 (Sépaq, 2016). Walleye were mainly caught in the northern parts of the lake close to the Waconichi/Icon River (pers. comm., M. Gravel, P. MacLeod Sept. 9, 2020). Based on IK, the Waconichi/Icon River are the known spawning grounds for walleye in Waconichi Lake (pers. comm., M. Gravel, P. MacLeod Sept. 9, 2020).

Walleye are the most harvested sportfish by non-indigenous anglers in Mistassini Lake. Brook trout, lake trout and walleye have been fished for extensively, whereby between 1987-2018, 4814 walleye fishing days were recorded, while brook trout (4317 days) and lake trout (4814 days) show similar results (Nibiischii, 2018d). Despite the extensive effort fishing walleye, walleye mass has remained stable (879g) since 1987 (Nibiischii, 2018d).

Indigenous knowledge surrounding walleye at Mistassini, Albanel and Waconichi Lakes:

It is important to recognize that there is rich IK on walleye, but not all has been presented in this report. Despite this, it is important to note that IK on walleye has been collected throughout various fish studies since 2002 (Dupont et al. 2007). Through IK, Mistassini Lake walleye spawning regions and timing, and distinct morphotypes have been noted (Bowles et al., 2021b). The following trends were noted through IK:

- Spawning: Cree fishers described the three major regions (south, north & west) and timing (after ice off in the spring) of walleye spawning consistently (Bowles et al., 2021b).
- Morphology: regional differences in walleye colour were reported, where lighter walleye are captured in the south and brighter/gold/blue walleye are captured in the west and north (Bowles et al., 2021b).
- Fishing pressure: Concerns towards increased fishing pressure near walleye spawning grounds, fishing techniques, walleye body size and harvest trends, garbage/pollution have been raised by tallymen near Mistassini's southern rivers. Specifically, fewer and smaller walleye were observed between 5 and 25 years ago (Marin and Fraser, 2016; Bowles et al., 2021b).

Spawning grounds, temporal changes, and changes to harvest techniques in Albanel and Waconichi Lake are known by local tallymen and families around these lakes (pers. comm., M. Gravel, P. MacLeod Sept. 9, 2020), but have not yet been presented in the primary literature.

SECTION 5: Management Recommendations for brook trout and walleye populations in Mistassini, Albanel and Waconichi Lakes

Currently, aquatic and terrestrial habitats encompassing Mistassini, Albanel and Waconichi Lakes remain largely intact. Human-associated development remains minimal when compared to lakes where walleye and brook trout reside in the southern parts of their ranges. Nonetheless, it is important to be aware of the sensitivities that each species has in relation to a variety of human activities, especially those noted in this report that may become more important in northern regions in the coming decades (e.g. mining, increased road development, human population expansion). Currently, overfishing appears to be the most prevalent threat that could jeopardize the sustainability of brook trout and walleye populations across Mistassini, Albanel and Waconichi Lakes. In part, this is because (i) these lakes are oligotrophic meaning that on a per-area basis they do not produce much biomass of harvestable fish and can be easily overfished, and because (ii) the fish are slow growing and take several years or more to reach maturation, meaning that their populations will take time to rebound if they are depleted. This is especially true for walleye, though it should also be noted that brook trout are not known to be numerically abundant in large lake habitats in general. As communities in the surrounding region grow and non-local fishers are attracted to fish in these lakes for their quality-sized brook trout and walleye, fishing pressure may increase further. It is important to emphasize that, in Mistassini Lake, Cree knowledge gathered from tallymen, elders and fishers has already pointed to a reduction in the body size and numbers of brook trout and walleye caught over several decades in response to fishing pressure (Fraser et al., 2006; Fraser et al., 2013; Bowles et al., 2021b).

Herein we list a series of recommendations that the Cree Nation of Mistissini and Nibiischii Corporation can consider for local management decision-making to ensure the long-term continuation of healthy walleye and brook trout populations in Mistassini, Albanel and Waconichi Lakes:

- Reduce the overall harvest of both species, and/or the number of brook trout and walleye removed from spawning grounds and rivers via:
    - Setting a daily bag limit in the known spawning grounds; current brook trout harvest rates are 2.5 kg + 1 brook trout of any size in Mistassini and 5 kg + 1 brook trout in Albanel and Waconichi (Gouvernement du Québec, 2020). The average size of brook trout there ranges between 2-3 lbs (0.9-1.4 kg), making a 5

kg limit on brook trout equivalent to about 5 trout. Local managers may consider reducing the limit to 2.5 kg + 1 trout at Albanel and Waconichi.
    - Creating daily closures (i.e. fishing only allowed from sunrise to sunset).
    - Enforcing a moratorium on brook trout and walleye fishing on spawning grounds and fry-emergence sites, or within spawning rivers.
    - Enforcing catch-and-release in habitats undergoing population restoration to maintain open season and reduce harvest rates.
    - Rotating fishing sectors to periodically rest non-fished sectors (Fraser et al., 2006).
    - Avoiding the harvest of entire schools of fish to conserve school genetic diversity (Fraser et al., 2006).
    - Suggesting that the Cree community distribute the number of active fishers across designated areas to avoid concentrating fishing pressure on a single area (new data from the ongoing FISHES project could aid in determining lake sectors experiencing over- or under-exploitation of different, genetically distinct populations within each lake).
- Limit the type of fishing gear allowed in lakes (i.e. enforcing the use of barbless hooks, no gillnetting, or only permit gillnetting in specified areas to allow the continuation of Cree culturally practices).
- Enforce an allowable harvest size range to ensure the walleye and brook trout reach maturity, while also preventing the harvest of large walleye, primarily females.
    - If there is demand to harvest large 40-45cm+ fish of either species, creating annual license raffles may be another avenue worth exploring.

Monitoring is another important step to ensure the regulations applied to prevent overfishing are effective, but also to gather critical baseline data about population characteristics (i.e. population size, age structure and genetic diversity) and fisher's habits such as catch rates and fishing effort across the three lakes. Furthermore, obtaining a better understanding of the water chemistry of lakes would be useful for better understanding ecosystem health and determining the overall production of fish these each lake sustains. In addition, this strategy can detect heavy metals (potentially stemming from industrial logging and/or mining) which can accumulate in brook trout and walleye, negatively impacting their health (or human health via consumption). Routine water level and temperature recordings will be very important for scientists and local managers/officials to better understand how climate warming is impacting these large boreal lake ecosystems. A series of recommendations has been created to address monitoring strategies:

- Monitoring that involves recording life history traits (i.e. total length, mass, and preferably size-at-age via otolith extraction and aging) in tributaries of Mistassini Lake for walleye (Rupert, Perch, Icon, Takwa and Chalifour) and brook trout (Rupert, Pepeshquasati, Cheno) to continue gathering data in a standardized manner; the same could be applied to Albanel and Waconichi as more is learned of key spawning tributaries from local Cree in each of these lakes.

- Obtaining water chemistry baselines (i.e temperature, DO, pH) across Mistassini, Albanel and Waconichi to better understand lake characteristics and how they might influence fish production and harvestable biomass.
- Set-up a creel clerk position to document the harvest, angling effort, location and size fish caught and targeted species for local Cree, local non-Cree and non-local fishers; this could apply to all three lakes.
- Encourage collecting scales and otoliths of fish when they are harvested for food in order to record the age of the fish (Fraser et al., 2013).
- Enforce a mandatory boat wash at boat launches before entering a new body of water to prevent the potential spread of aquatic invasive species.
- Follow the Cree Nation Government's recently developed best practices for operating sustainable fishing derbies on any of these three lakes
- Create an aquatic invasive species lake monitoring plan to avoid/mitigate aquatic invasive species impacts.
    - Create an aquatic invasive species hotline for fishermen to report any suspicious organism.

Education and public outreach is an essential strategy to ensure that information is disseminated to local people and tourists. It is recommended that education programs/strategies/information be communicated in Cree, English and French to ensure a wide variety of people are reached. A series of recommendations have been created addressing educational strategies:

- Radio advertisements, posters and informational pamphlets are important to ensure people are aware of regulatory changes, AIS and recommended fishing practices. They should also be easily accessible for the public to find, such as in corner stores, Tim Hortons, etc., but also creating a website devoted to educational information is also vital.
    - For example, the pamphlet could feature information that advises the angler on some of the sensitivities that each fish species has, their life history characteristics, the unique population characteristics of walleye and brook trout found within Mistassini, Albanel and Waconichi Lakes, etc.
- Signage at popular fishing locations as a constant reminder of important rules is important.
- Creating a platform for tallymen to pass down their information at public information sessions prior to the spawning period.
- Holding public meetings and presentations to educate various audience types on the reasoning and importance of enforcing management regulation.

Mining, while useful for extracting prized resources, results in acid drainage and the release of contaminants like mercury that reduce nearby habitat quality, harming their aquatic inhabitants and risking human health, such as the Waconichi mine that resulted in an input of copper (9 mg/kg) and arsenic (4 mg/kg) (Laliberté, 2004). Mines must be managed properly during a project and after its completion to ensure environmental rehabilitation. A series of recommendations have been created to address the issue:

- Close a mine no longer harvesting resources efficiently.
- Apply limestone sand in streams or lakes to offset the pH reduction from acid mine drainages.
- sample and quantify the level of mercury and other contaminants in fish muscle and tissue as a proxy for contaminant levels fish habitat.
- Establish a moratorium on mines with the potential to harm human health and habitat population, as was done with the Matoush project Uranium mine by the Cree Nation of Mistassini (Edwards, 2016; Cree Nation of Mistissini, 2012).
- Manage run-off, mine drainage and wastewater and develop pits to divert mineral input from nearby lakes or streams (Renaud diamond mining project; Agence canadienne d'évaluation environnementale, 2013).
- Following mine closure, flood pits and establish a vegetative buffer zone spanning at least 30 m (Renaud diamond mining project; Agence canadienne d'évaluation environnementale, 2013).
- Plan and cooperate with the Indigenous community running the land (Daugherty, 2018)
- Monitor surface and groundwater, air, soil quality and water regime (hydrology and hydrogeology), as well as boating activity and explosive manufacturing and use (Dougherty, 2018).

Roads are among the numerous barriers that fragment fish habitats and limit their migration, such as Route 167 that crosses into Mistassini and Albanel brook trout and walleye habitats; it risks opening access to fisheries and compromising rich habitat (Canadian Environmental Assessment Agency, 2012). A series of recommendations have been created to address the issue:

- Increase riparian vegetation, log jams and other structures to provide shade and regulate water temperatures where needed (Fraser et al., 2013).
- Replace culverts and build temporary diversion channels to keep fish passages clear of obstructions (Canadian Environmental Assessment Agency, 2012).
    - Install culverts in the dry to avoid downstream and sediment accumulation
- Prohibit queries, sand pits and waste disposal sites within 20 m of high mark of watercourses (Canadian Environmental Assessment Agency, 2012).
- Construct ditches along temporary roads to direct and capture sediment from soil erosion (Canadian Environmental Assessment Agency, 2012).

Acknowledgements

This review is part of the initiative of the FISHES project (Fosterings Indigenous Small-scale fisheries for Health, Economy and food Security (http://fishes-project.ibis.ulaval.ca/). We would like to thank Pamela MacLeod (Cree Nation of Mistissini) and Mireille Gravel (Nibiischii Corporation) for their input and sharing of information associated with fish harvest in the Reserve Faunique Albanel-Mistassini-Waconichi. Funding for this study was provided by Genome Canada, Genome Quebec, MITACS, Niskamoon Corporation and the Cree Nation Government.

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Glossary

- **acid mine drainage**: outflow of acidified water from mines.
- **catch-and-release**: fishing method where the fish are unhooked and returned to the water.
- **tackle**: equipment anglers use when fishing (hooks, lines, bait etc.).
- **creel survey**: also called angler survey, is a method of monitoring different fish and fishing measurements.
- **catch per unit effort**: measure used indirectly in conservation biology and fisheries to assess species abundance in a certain area.
- **seining**: fishing method where a fishing line (usually a net) hangs down in the water as weights are attached to the bottom and is held at the top by floaters.
- **weirs**: also called low-head dams; they act as a barrier and alter water flow characteristics, change the river level height.
- **snagging**: fishing method that involves catching fish with a hook without them taking bait from the hook in their mouths.
- **mine tailings**: leftover fractions from the undesired part of the ore during separation.
- **setting ponds**: concrete basin that use sedimentation to remove turbid matter from wastewater.