REPORT ON CONDITIONS IN GEORGIAN BAY

Prepared for Environment and Climate Change Canada

United Nations Educational, Scientific and Cultural Organization

GEORGIAN BAY BIOSPHERE RESERVE

Table of Contents

Introduction

The 2017-2021 Lake Huron Lakewide Action and Management Plan (LAMP) identifies five priority threats to the waters of Lake Huron: chemical contaminants, nutrients and bacterial pollution, loss of habitat and species, invasive species, and climate change impacts (ECCC & US EPA, 2018). This report provides a summary of conditions in Georgian Bay in relation to each of these five themes. Where information specific to Georgian Bay is not available, conditions in Lake Huron more broadly are discussed. Sources informing the summary of conditions include, but are not limited to:

- Lake Huron LAMP (ECCC & US EPA, 2018)
- Updated State of Knowledge for South-Eastern Georgian Bay (GBBR et al., 2019)
- State of the Bay 2018 Technical Report (GBBR, 2018)
- State of the Great Lakes 2017 Technical Report (ECCC & US EPA, 2017)
- State of the Great Lakes 2019 draft sub-indicator reports

Within each of these documents are references for the original research cited in this summary, where not explicitly referenced.

Chemical Contaminants

Chemical contaminant concentrations in Georgian Bay have generally decreased in all environmental media since the 1970s. Over the last decade the rate of decline has slowed. Legacy contaminants still persist, but new classes of chemicals comprise the majority of the remaining contaminant burden measured in Lake Huron organisms. Chemical contaminant concentrations in Georgian Bay are measured in open water, air, sediments, fish, and herring gull eggs.

Open Water

Lake Huron has one of the lowest levels of chemical contamination in open water as a result of fewer industrial point sources and the fact that it is less subject to atmospheric deposition and retention of persistent compounds due to its geographical location (ECCC & US EPA, 2017; 2018). Mercury and several important legacy organochlorines are showing declining trends in Lake Huron (ECCC & US EPA, 2017). In Georgian Bay, levels of polycyclic aromatic hydrocarbons (PAHs) are low, but there is evidence that they are increasing (driven by napthalene concentrations), possibly due to heavy recreational boat traffic. No guidelines are presently exceeded at the monitored locations (ECCC & US EPA, 2017; 2018).

Air

Long term (1992-2012) air contaminant monitoring data show a slow, but decreasing trend for polychlorinated biphenyls (PCBs) (ECCC & US EPA, 2017). Organochlorine pesticides are also declining, although historical applications of some pesticides are ongoing sources. Atmospheric deposition of chemicals like metals and PAHs is an ongoing source of chemicals.

Sediments

Contaminated sediments represent a pollutant sink and potential source of toxic substances through resuspension and redistribution. In Lake Huron, it is estimated that from 1970 to 2015, sediment contamination declined by 93% for DDT, 64% for mercury, 43% for lead, and 9% for PCBs (ECCC & US EPA, 2017). Researchers at the University of Western Ontario recently conducted a basin-wide analysis of microplastics in nearshore and offshore benthic sediments of Lake Huron. Results from this work are expected to be published within the year.

Whole Fish

Levels of PCBs in Great Lakes fish continue to decline at rates of 3-7% per year since the beginning of monitoring in the late 1970s (McGoldrick & Murphy, 2016). Despite this decline, from 2008 to 2012, the sum of measured PCB congener concentrations (ΣPCBs) exceed all other contaminants in Lake Huron fish by a wide margin (Figure 1) (McGoldrick & Murphy, 2016). Of these PCBs, hexa-chlorinated biphenyls (hexaCB) were the most abundant contaminant group (McGoldrick & Murphy, 2016). Sources are now shifting from external to internal loadings of the large inventory of PCBs that accumulated in biota and sediments over the long period of use of these chemicals before restrictions and bans on use and production were imposed (McGoldrick & Murphy, 2016). Levels of polybrominated diphenyl ethers (PBDEs) appear to have plateaued in Great Lakes fish in the early 2000s and levels are beginning to decline across the basin (McGoldrick & Murphy, 2016). After declines in the 70s and 80s, mercury concentrations in Lake Huron fish have shown variability in recent years. Perfluorooctane sulfonate (PFOS) concentrations also show variability depending on sampling locations, but are generally above Canadian Federal Environmental Quality Guidelines.

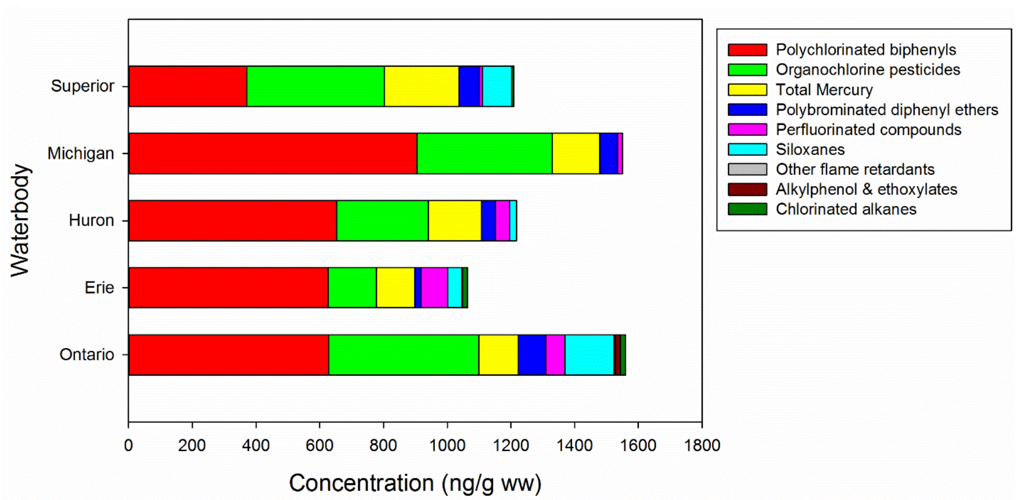

Figure 1. Great Lakes basin chemical contribution to body burden of whole top predator fish (ECCC & US EPA, 2017).

Edible Portions of Fish

Chemical contaminants still trigger consumption advisories in Georgian Bay. However, concentrations of major contaminants of concern, PCBs and mercury, have either declined or remained low over the last three decades (Figure 2). Most advisories for large fish are driven by concentrations of mercury, PCBs, and dioxins/furans. There are no known localized sources of contaminants of human origin identified that trigger fish consumption advisories in Georgian Bay, and there is no evidence that the reproductive health of the fishery is impacted by chemical contaminants (ECCC & US EPA, 2018).

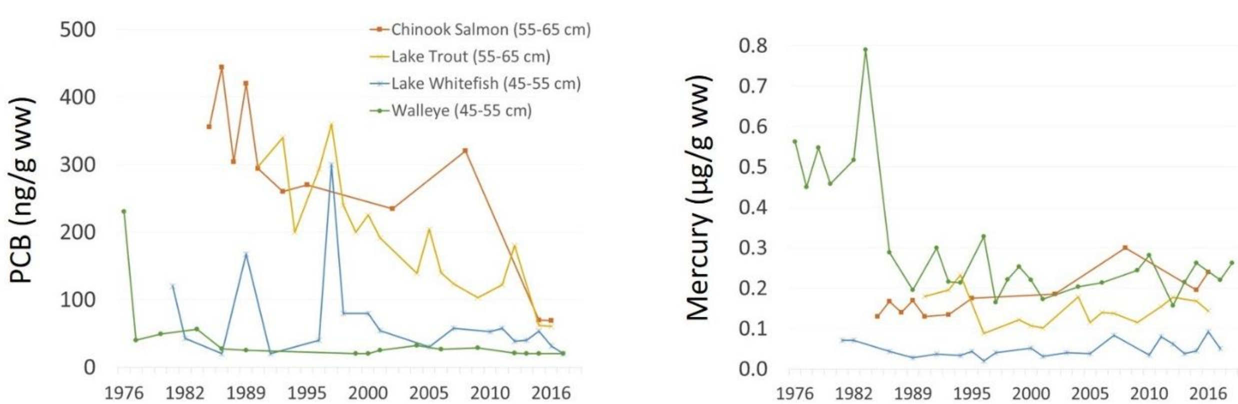

Figure 2. Concentrations of contaminants of concern in edible portions of fish in Georgian Bay (S. Bhavsar, pers. comm., 2019).

Herring Gull Eggs

At all colonies of herring gulls monitored in the Great Lakes Herring Gull Monitoring Program (ECCC), concentrations of PCBs, PCDDs/PCDFs, and organochlorine pesticides have fallen dramatically since the 1970s (de Solla et al., 2016). Legacy contaminant concentrations of PCBs and dioxins (2,3,7,8-TCDD) have stabilized in recent years in Lake Huron (ECCC & US EPA, 2018). Egg concentrations of the flame retardant Dechlorane Plus (Σ2DDC-CO) increased between 2008 and 2012.

Nutrients and Bacterial Pollution

There has been a dramatic decline in total phosphorus (TP) in the offshore waters of Georgian Bay to the point that concentrations are as low in Georgian Bay as they are in Lake Superior (Dove & Chapra, 2015). The extremely nutrient-poor offshore waters result in offshore to nearshore nutrient gradients (Figure 3). In nearshore areas there is greater variability in TP concentrations as a result of interactions between receiving waters and their watersheds. Ministry of Environment, Conservation and Parks (MECP) surveys have shown strong regional relationships between dissolved organic carbon (DOC) and phosphorus which indicates that most, if not all, phosphorus, is associated with watershed/wetland sources (Howell, 2015; SSEA, unpublished). In the few areas where this relationship is decoupled, there are potential additional sources of phosphorus from internal loads.

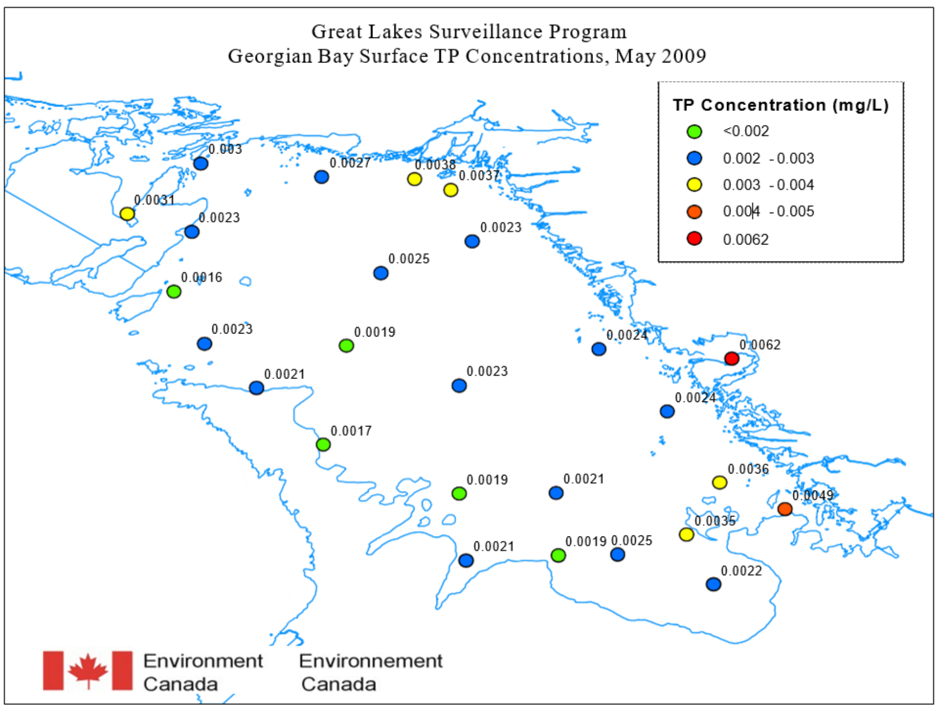

Figure 3. Total phosphorus concentrations at Great Lakes Surveillance Program sites (Charlton & Mayne, 2013).

Several nearshore areas throughout Georgian Bay have relatively high TP concentrations such as the French River, Sturgeon Bay, Deep Bay, South and North Bay, and Nottawasaga Bay. Some of these areas experience periodic reports of cyanobacteria blooms, which sometimes occur as metalimnetic blooms (Chiandet & Sherman, 2014). Areas where anthropogenic inputs of nutrients warrant management efforts include the degraded areas of the Nottawasaga River. Lower and Middle Nottawasaga River reaches and the Innisfil Creek have the lowest stream health ranks with high phosphorus concentrations and turbidity due to agriculture and wastewater inputs from high density residential development (Rutledge et al., 2015). While open water monitoring shows that phosphorus concentrations are the same in the middle of

Nottawasaga Bay when compared to the middle of Georgian Bay, there is still a paucity of water quality data for the nearshore waters of this bay, ranging from water chemistry to biotic components including plankton, fish, and their habitat (GBBR et al., 2019).

In eastern Georgian Bay, concerns around shoreline development-related nutrient contributions to surface water do not represent a significant threat at this time in most areas, although there may be exceptions in sheltered embayments such as the Honey Harbour area. Due to the extremely dynamic and variable nature of the eastern coastline, it remains difficult to separate the effects of natural onshore-offshore gradients on nutrient conditions and productivity from anthropogenic effects. There is evidence in the paleolimnological record that impacts of recent shoreline development is minimal compared to climate factors in causing increased productivity in some embayments of nearshore waters (Sivarajah, 2016). However, impacts from development (e.g., septic inputs, increased impervious area, shoreline erosion) should not be downplayed as these impacts may play a role in pushing embayments past natural productivity thresholds. Little growth of *Cladophora* is detected on the nearshore lakebed of eastern Georgian Bay (ECCC & US EPA, 2018).

Many townships and organizations in Georgian Bay have shifted from a focus on bacteria monitoring to monitoring TP. The rationale for shifting away from bacteria monitoring is based on research showing that single samples taken at one point in time do not indicate either the spatial or temporal extent of the levels of bacteria observed (HESL, 2011). Should organizations wish to continue with bacteria testing, it should happen in the framework of a scientific investigation focused on testing specific hypotheses on potential sources of contamination through a focused sampling program. For example, recreational sites (e.g., beaches) could be considered for bacteria monitoring as per the province's Beach Management Guidance Document.

Loss of Habitat and Species

Coastal Wetlands

According to research conducted out of the Coastal Wetland Research Group at McMaster University, more than 3,700 coastal wetlands (17,350 ha) are found along the coast of eastern Georgian Bay (ECCC & US EPA, 2018). Eastern and northern Georgian Bay wetlands are considered to be in 'very good' or 'excellent' condition. Wetlands assessed as 'fair' or 'good' condition are found near towns and marinas of southern Georgian Bay. Parry Sound, Severn Sound, and Nottawasaga Bay experience population growth, shoreline development pressure, intense recreational use, and historic and present industrial activities which can have impacts on wetland and island habitat. The spread of phragmites also poses a risk to coastal wetlands of southern and eastern Georgian Bay. The Coastal Wetland Research Group continues to conduct detailed studies on Georgian Bay wetlands.

Open Water

Lower Food Web

Significant changes to the lower food web have been documented in Lake Huron (LHPWG, 2016). In 2003 there was a marked decrease in the magnitude of the spring phytoplankton bloom in Lake Huron, and further reductions were seen through 2008 (EC & EPA, 2017; ECCC & EPA, 2018). By 2005, reductions in summer chlorophyll were also seen and more recently, chlorophyll levels are considered to have decreased appreciably across all seasons (Riley, 2013; LimnoTech, 2015a). Between 1971 and 2013, mean phytoplankton abundance declined 88% (ECCC & EPA, 2018).

Data from Severn Sound Environmental Association's (SSEA) Open Water Monitoring Program shows that in Severn Sound, there has been a steady decline in total annual phytoplankton biovolume since 1969, with a marked drop in 1994 – the year of major dreissenid mussel invasion and substantial reduction in phosphorus loads from local wastewater treatment plants (Figure 4) (Sherman, 2002; SSEA, 2017b). Total phytoplankton biovolume in Penetanguishene Harbour and Midland Bay has not shown any significant trends since 1994, while biovolume in Hogg Bay and at the mouth of the Severn River has increased. Recent results from long term Honey Harbour area monitoring revealed an increasing trend for mean total biovolume of phytoplankton from 1998 to 2016 in South Bay, North Bay, and Honey Harbour (SSEA, 2017a).

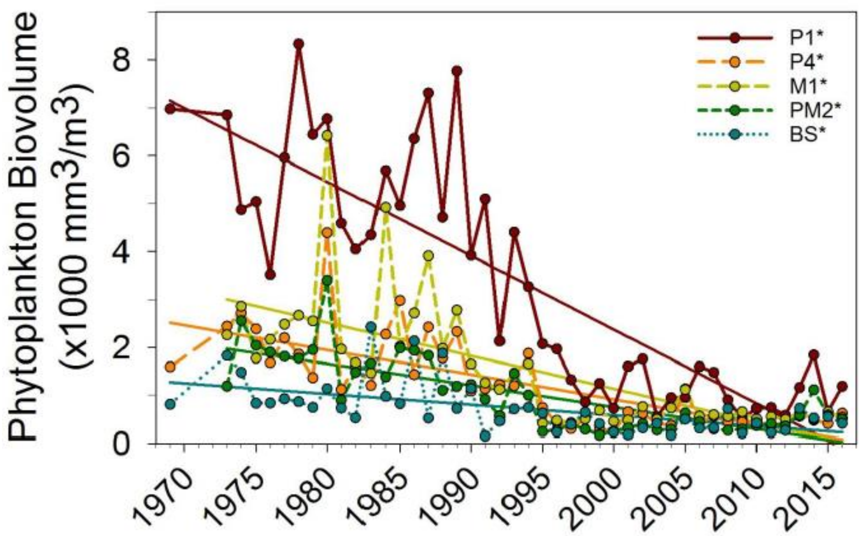

*Figure 4. Annual phytoplankton biovolume at long term stations in Severn Sound from 1969-2016 (SSEA, 2017b). * indicates significant trends over this period. Station locations: P1 – inner Penetanguishene Harbour, P4 – outer Penetanguishene Harbour, M1 – Midland Bay, PM2 – Hogg Bay, BS – Sturgeon Bay.*

Throughout the 15-year period from 1998 to 2012, the composition of the phytoplankton community underwent some changes, particularly in North and South Bay. In North Bay, dominance shifted towards the chrysophyte *Chrysosphaerella* and the dinophyte *Peridinium* during the latter part of the 1998-2012 time period. In South Bay, blue-green algae dominated the phytoplankton community during late summer, with peaks reaching up to 70% of the total biovolume (note that total biovolume in South Bay was still relatively low, so 70% blue-green amounted to approximately 360 mm^3/m^3). The blue-green algae *Anabaena* and *Planktothrix* became more dominant in South Bay, forming metalimnetic blooms (Chiandet & Sherman, 2014).

Lake Huron's zooplankton biomass has remained low since declines in 2003. Between 1998 and 2006, a 95% reduction in the abundance of herbivorous crustaceans like cladocerans, and considerable decreases in cyclopoid copepod biomass, drove a significant overall decline in Lake Huron zooplankton (EC & EPA, 2017; ECCC & EPA, 2018). Unfortunately, the zooplankton groups that experienced the largest declines were those most often consumed by fish.

SSEA reports that in Honey Harbour, zooplankton density, biomass, and taxa richness were all much lower at North and South Bay from 2009-2012 compared to earlier years. *Daphnia*, *Bosmina* (a non-daphnid cladoceran), and *Tropocyclops* (a cyclopoid copepod) populations dropped over the 2009-2012 period. The cause of these reductions is not known (Chiandet & Sherman, 2014). Analysis of zooplankton communities in Severn Sound's Sturgeon Bay showed that there was a shift in community composition between the period of 1988-1994 and 1995-2008. This was presumably driven by the arrival of dreissenids and the subsequent change in the phytoplankton community. The herbivorous non-daphnid cladoceran group has decreased since the arrival of dreissenids, presumably due to food competition, while calanoid copepods, whose feeding habits range from herbivores to carnivores, have increased (Sherman et al., 2011). More recent zooplankton data across all Severn Sound monitoring sites show declines in all zooplankton groups (SSEA, unpublished).

From the early 1970s to 2000, all major, non-dreissenid benthic invertebrate groups (*Diporeia*, oligochaeta, sphaeriidae, chironomidae) declined in abundance in Lake Huron. Nearshore areas saw a decline in benthic invertebrates of approximately 75% while offshore, deep water areas experienced a decline of roughly 50% over this period (EPA, 2008; LHPWG, 2016). *Diporeia* abundance has drastically declined and now comprises only a small portion of the Georgian Bay benthos. Between 2002 and 2007, *Diporeia* abundance declined throughout Georgian Bay, mean densities across depth intervals ranged from 40-100 m^2 in 2007 whereas in 2002, the same range had been 1400-1700 m^2. In 2015, *Diporeia* were reported as absent in Lake Huron at <50 m. Conversely, their presence was confirmed in deeper water as a result of their appearance in bloater (*Coregonus hoyi*) stomach contents (LimnoTech, 2015b). Although some prey fish appear to be eating *Mysis*, the population does not appear to be increasing in abundance in conjunction with the *Diporeia* decline and is thus not likely able to replace *Diporeia* as a food source.

Prey Fish

From the 1970s to the early 2000s, the Lake Huron prey fish community became dominated by introduced, non-native alewife and rainbow smelt (ECCC & EPA, 2018). Coinciding with a collapse of alewife in 2003, significant declines in prey fish were observed from time series, this includes record low abundances of rainbow smelt and native sculpin species over the last two decades (ECCC & EPA, 2018). While no single species has filled the niche left by alewife, several native species including bloater, yellow perch, cisco, and emerald shiner have experienced population increases (MNRF, 2014). Nevertheless, overall prey fish biomass has declined creating a potential food web imbalance.

With regard to offshore pelagic prey fish, the main basin west and Georgian Bay regions had the lowest biomass out of the five regions sampled in 2018. In Georgian Bay, large cisco accounted for 34% of the biomass. Large rainbow smelt (32.3%), small rainbow smelt (20.5%), large bloater (11.7%), small bloater (1.5%), and ninespine stickleback (0.006%) made up the remaining biomass (Figure 5) (O'Brien et al., 2019). Between 2007 and 2018, cisco catches were variable in Georgian Bay, but biomass and density of large cisco appears to be trending upwards. Increased biomass of cisco during 2015-2018 was due in part to increased numbers of larger fish (> 300 mm) caught in mid-water trawls (O'Brien et al., 2019).

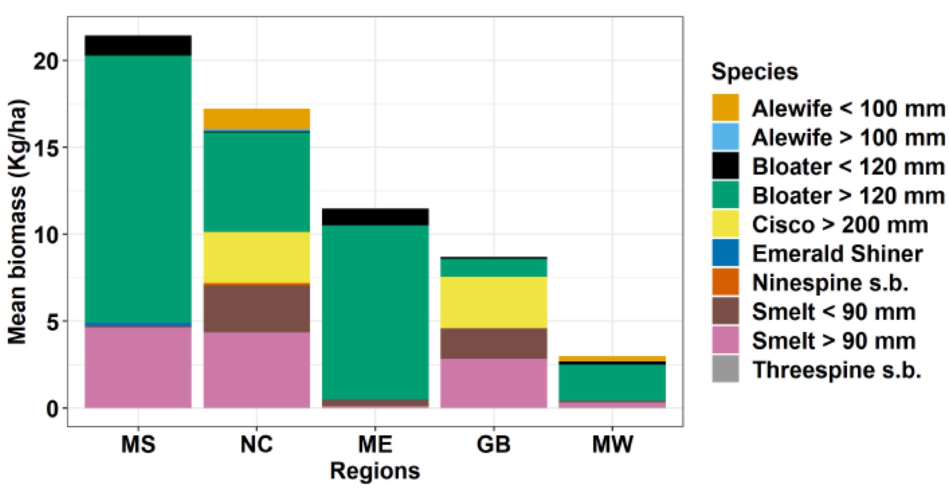

Figure 5. Regional acoustic and mid-water trawl estimates of mean biomass (kg/ha) of pelagic prey fish species in Lake Huron during 2018 (O'Brien et al., 2019). MS – main-basin south; NC – North Channel; ME – main-basin east; GB – Georgian Bay; MW – main-basin west.

The Upper Great Lakes Management Unit (UGLMU) of the Ministry of Natural Resources and Forestry (MNRF) has been conducting a smallfish community assessment program in the Georgian Bay nearshore since 2003. A 2016 program summary report discusses some high-level results for the four locations sampled that year – Deep Bay (Parry Sound), Sturgeon Bay, Shawanaga River, and Shebeshekong River. In 2016, prey fish biomass was found to be relatively low in three of the four locations sampled. High catches of Cyprinids made Shawanaga River the exception with a high prey fish biomass. Prey fish were abundant in Deep Bay catches but were small in size and thus, they did not contribute a great deal to overall biomass.

Lake Trout
Less progress toward lake trout rehabilitation has been observed in Georgian Bay compared to other Lake Huron basins, populations remain largely dependent on stocking to maintain current levels. The Parry Sound population represents the only lake trout population to be considered fully rehabilitated outside of Lake Superior.

Lake Whitefish
Recruitment, growth, biomass, and catch of lake whitefish has declined throughout large areas of Lake Huron (GLFT & GLFC, 2018). Nottawasaga Bay is an epicentre of the lake whitefish spawn in Georgian Bay, supporting some of the highest catch rates for whitefish across the lake fishery. Since the early 2000s, there have been drastic declines in recruitment of young fish which has led to an ageing population and significant reductions in overall abundance of lake whitefish in Nottawasaga Bay (Wood, 2019). In an effort to sustain the fishery into the future and protect spawning fish, the MNRF has imposed a prohibition of commercial fishing in the fall in anticipation of igniting strong recruitment (Wood, 2019).

Native Migratory Fish

Lake Sturgeon
Georgian Bay lake sturgeon are a threatened species (COSEWIC, 2017). Spawning lake sturgeon have last been confirmed in assessments in the Moon and Musquash Rivers in 2019 (E. Timusk, pers. comm., 2019), Nottawasaga River in 2014 (UGLMU, 2014), Magnetawan River in 2009 (A/OFRC, 2014), and the Pickerel River in 2000 (A/OFRC, 2000). The status of spawning populations in a number of tributaries where lake sturgeon historically spawned is unknown. Shawanaga First Nation and the Georgian Bay Biosphere Reserve are undertaking a three-year project to gather traditional ecological knowledge on lake sturgeon in eastern Georgian Bay, monitor select rivers for presence/absence, and develop a lake sturgeon conservation plan for eastern Georgian Bay.

Walleye
Until population declines in the 1940s and 1950s, walleye were the dominant coolwater predator in Georgian Bay. Despite exploitation management and restoration and stocking efforts, the majority of walleye stocks in Georgian Bay remain far below historic levels and are considered to be in poor condition overall (UGLMU, 2019). As outlined in the draft *Report on the Status of Walleye in the Ontario Waters of Lake Huron* (UGLMU, 2019, p. 12), "The main areas of issue relate to low densities of adults and the subsequent low rates of recruitment." The MNRF is currently drafting a walleye management plan for the Ontario waters of Lake Huron.

Aerial Migrants
As indicated in the Lake Huron LAMP (ECCC & US EPA, 2018) and Lake Huron Biodiversity Conservation Strategy report (Franks Taylor et al., 2010), the status of colonial nesting water birds in Lake Huron is considered 'fair'. Since 1976, populations of double-crested cormorants, great egrets, and black-crowned

night herons have increased, while populations of great blue herons, herring gulls, ring-billed gulls, common terns, and Caspian terns have declined (ECCC & US EPA, 2018).

Through a four-year Community Nominated Priority Places project funded by Environment and Climate Change Canada, several automated radio telemetry arrays will be added to the Motus Wildlife Tracking System network on the coast of Georgian Bay. Strengthening this network along the coast will greatly increase opportunities for aerial migrant (including birds, bats, and insects) research in Georgian Bay to answer large and small scale questions related to migration corridors, habitat connectivity, and habitat use.

Invasive Species

More than 75 aquatic invasive species have been detected within Lake Huron (ECCC & US EPA, 2018). While recent introductions have slowed in the Great Lakes basin, the impacts of established invaders persist and their ranges within the lakes are expanding (ECCC & US EPA, 2017). For example, phragmites, considered to be the most aggressive invasive species of marsh ecosystems in North America (Bains et al., 2009), has spread to coastal wetlands and river mouths of southern and eastern Georgian Bay (ECCC & US EPA, 2018). Georgian Bay Forever has been active in the removal of phragmites around Georgian Bay for seven years and with partners, have removed more than 103,000 kg of phragmites from shorelines (GBF, 2019). In 2017, SSEA launched a dedicated Invasive Species Program to address the ecological, economic, and social impacts of invasive species within the Severn Sound watershed. SSEA provides invasive species identification, detection, management planning, and training services to local municipalities, community groups, and residents. Invasive species under active management include: Japanese Knotweed, Giant Hogweed, Spotted Knapweed, and Eurasian Watermilfoil.

Several invasive species are discussed in greater detail in this section – dreissenid mussels, round goby, sea lamprey, and Asian carp.

Dreissenid Mussels

Zebra mussels became established in Lake Huron in the early 1990s and their abundances peaked in 2007 in Georgian Bay (GBBR, 2018). Quagga mussels became established in the late 1990s (except in the North Channel) and over the period 2000-2007, underwent major expansion ultimately replacing zebra mussels at shallow depths (<50 m). Through 2012, quagga mussels increased offshore at depths >50 m where zebra mussels had rarely been found (Riley, 2013; LimnoTech, 2015a). In Georgian Bay, quagga mussel densities at 31-90 m decreased two-fold between 2007-2012 (ECCC & US EPA, 2018).

In 2014 and 2015, diver-based benthic surveys were performed by MECP on the eastern shores of Georgian Bay. Surveys were conducted on hard substrates at 47 sites at depths of 3-18 m. Quadrats were used to determine dreissenid mussel density. When compared to Lakes Erie and Ontario, zebra and quagga mussels were found to be less abundant in Lake Huron and least abundant in Georgian Bay (T. Howell, pers. comm., 2017). Mussel abundance was determined to be broadly correlated with trophic state. In eastern Georgian Bay, abundance of zebra and quagga mussels is relatively low, but with a wide distribution (mostly $<1000/m^2$; maximum $<3000/m^2$) (Howell, 2015). Interestingly, there is a gradient of abundance across the coastal fringe. Loading of low alkalinity water (low calcium and pH) to the shoreline from the Canadian Shield limits distribution of zebra and quagga mussels (T. Howell, pers. comm., 2017).

Round Goby

The invasive round goby was first detected at regular UGLMU smallfish assessment monitoring locations in the following years: Owen Sound 2003, Severn Locks/Sound 2003, Midland Bay 2007, Britt 2009, and Fathom Five Park 2011 (Ritchie, 2019). Round goby has not been detected at Blackstone Harbour or

Colpoys Bay, although the latter has not been sampled since 2004 (Ritchie, 2019). Considerable fluctuations in estimated round goby abundance throughout time series suggest that estimating abundance for this species using current survey methods may be difficult. Furthermore, estimates of consumption of round goby by lake whitefish, lake trout, and walleye (He et al., 2015) suggest that prey fish assessments greatly underestimate round goby abundance and biomass in Lake Huron (LimnoTech, 2015b). The Great Lakes Fishery Commission is currently developing methodologies to adequately measure gobies.

Smallfish assessment work done by UGLMU was expanded in 2017 to find out more about round goby (Ritchie, 2019). Analysis is still ongoing, however, UGLMU's Smallfish Community Assessment Program 2016 summary report discusses some high-level results for four locations sampled that year – Deep Bay (Parry Sound), Sturgeon Bay (Pointe au Baril), Shawanaga River, and Shebeshekong River. In 2016, in all locations, round goby remained a minor component of the catch, they were only found at half of the sampled locations both in 2015 and 2016. Round goby represented less than 2% and less than 1% of the catch in 2015 and 2016, respectively. However, these results must be considered in light of the challenges associated with sampling gobies. The Aquatic Research and Monitoring Section of MNRF is presently doing in-depth analysis on small fish data to examine the association between the round goby invasion and changes in the nearshore fish community. Analysis is still ongoing (Ritchie, 2019).

Sea Lamprey

Sea lamprey abundance has been reduced significantly in the Great Lakes. Nevertheless, native fish are still subject to sea lamprey predation which remains an impediment to achieving fish community and ecosystem objectives (ECCC & US EPA, 2017). The adult index target for Lake Huron is 36,000 sea lamprey, the marking rate target is less than 5 marks per 100 large lake trout (>532 mm) (Barber & Steeves, 2019). In 2015 the adult index target was achieved for the first time in 30 years. The following year the marking rate target was met for the first time (4.0 marks per 100 lake trout) and in 2017, the marking rate was 3.0 marks per 100 lake trout, the lowest marking rate in the times series (1984-2017). More recently, in 2018, the adult index target was not met (39,178), nor was the marking rate target (8.6 marks per 100 lake trout) (Barber & Steeves, 2019).

Asian Carp

The Asian Carp Program of Fisheries and Oceans Canada (DFO) identified the need for a binational ecological risk assessment of grass carp to the Great Lakes basin (DFO, 2017). The resulting report assessed the likelihood of arrival, survival, establishment, and spread of triploid (sterile) and diploid (fertile) grass carp, as well as the magnitude of the ecological consequences. Under current conditions, the overall risk for triploid grass carp is assessed as low for Lake Huron for the time periods of 5, 10, 20, and 50 years from the baseline year of 2014. For diploid grass carp, the overall risk is considered to be low within 5 years from the baseline, but increases to extreme at 50 years (DFO, 2017).

Researchers at McMaster University are presently evaluating potential impacts of grass carp specifically for Georgian Bay.

Climate Change Impacts

At the scale of Lake Huron, there is evidence for a warming trend over the past several decades. The first evidence of biological change in the Great Lakes shows that the diatom taxa in the group *Cyclotella sensu lato* are increasing in abundance in correlation with recent and rapid atmospheric warming (Reavie et al., 2016).

Based on linear regression of data from 1980-2014, the summer surface water temperature in Lake Huron has increased at a rate of approximately 0.7±0.3°C per decade over this time period (warming rates measured at two separate buoys are statistically consistent with each other) (ECCC & EPA, 2017). Similarly, the Lake Huron LAMP (ECCC & EPA, 2018) reports a 2.9°C increase in summer surface water temperatures in Lake Huron between 1968 and 2002. These figures, based on a paper by Dobiesz and Lester (2009), represent an annual increase in surface water temperature of 0.084°C or an increase of 0.84°C per decade. In Severn Sound, the mean ice-free season (May-October) surface water temperature at five locations increased significantly (n=48 years, 1969-2017). Seasonal mean surface water temperature has risen by an average of 2.0°C over the last 48 years, with the temperature in early October increasing at double the rate for mean temperature. Over the same time period, air temperature has increased by 1.9°C (Chiandet et al., 2017).

When the maximum annual ice cover data for Lake Huron from 1973-2016 are run through a Generalized Linear Model (with 95% C.I.) there is an apparent decreasing trend in ice cover (with a considerable amount of variation from year to year), although, it is not statistically significant (P<0.05) (S. Parker, pers. comm., 2018; see Figure 6). However, a significant decline in ice cover duration of -0.67 days/year is reported by Mason et al. (2016) for Lake Huron.

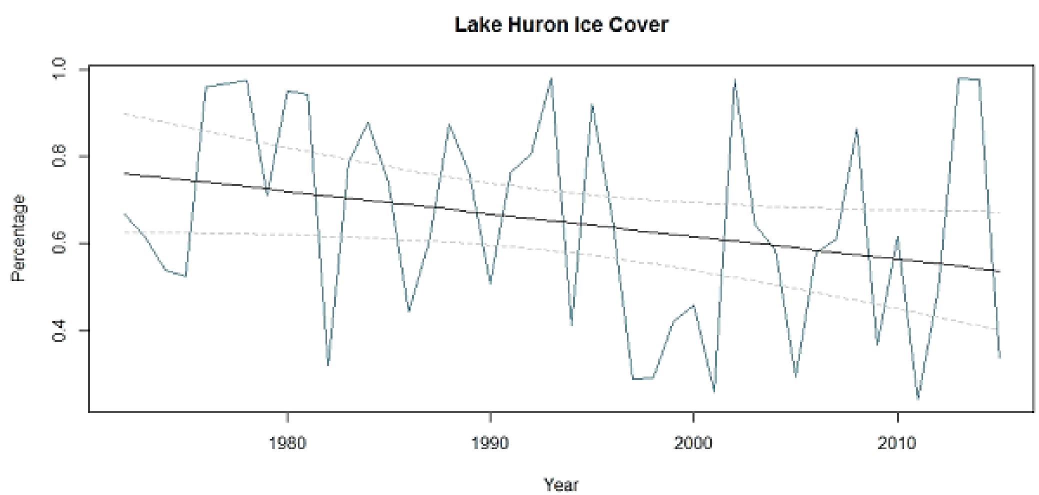

Figure 6. Generalized Linear Model (with 95% C.I.) of annual maximum ice cover for Lake Huron from 1973 to 2016 (S. Parker, pers. comm., 2018)

Ice phenology for Severn Sound embayments and local inland lakes show no statistically significant monotonic trends (based on Canadian Ice Service ice charts, IceWatch data, and citizen ice cover observations) (Chiandet et al., 2017). However, trends were nearly significant for Lake Couchiching, which had the longest data record. The time series for these datasets ranged from 13 to 111 years, with most being less than 40 years. It is likely that in many cases, the data record is not long enough to detect trends in ice phenology. Ice cover was not considered in terms of maximum annual ice coverage or long term average ice concentration for SSEA's study as these data are not available at a fine scale.

Observed and predicted impacts of climate change on terrestrial and aquatic biodiversity include: shifts in species distribution (Alofs et al., 2014); changes in phenology (Collingsworth et al., 2017); reductions in population size (Franks Taylor et al., 2010); species extinction and extirpation (Nituch & Bowman, 2013); habitat loss (Dove-Thompson et al., 2011); increased disease and spread of invasive species (FOCA, 2016); and change to ecosystem services (Nituch & Bowman, 2013).

Acknowledgements

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- Rebecca Willison, Muskoka Watershed Council
- Jennifer Winter, Ministry of Environment, Conservation and Parks

References

Alofs, K.M., Jackson, D.A., & Lester, N.P. (2014). Ontario freshwater fishes demonstrate differing range-boundary shifts in a warming climate. *Diversity and Distributions, 20*, 123-136.

Anishinabek/Ontario Fisheries Resource Centre (A/OFRC). (2000). *Henvey Inlet First Nation: Pickerel River lake sturgeon spawning assessment.* Draft report.

Anishinabek/Ontario Fisheries Resource Centre (A/OFRC). (2014). *Magnetawan First Nation: Magnetawan River lake sturgeon spawning assessment.*

Bains, G., Kumar, A.S., Rudruppa, T., Alff, E., Hanson, T.E., & Bais, H.P. (2009). Native plant and microbial contributions to a negative plant-plant interaction. *Plant Physiology, 151*(4), 2145-2151.

Barber, J., & Steeves, M. (2019). *Sea lamprey control in the Great Lakes 2018: annual report to the Great Lakes Fishery Commission.* Paper presented at the Great Lakes Fishery Commission Annual Meeting, Detriot, MI.

Charlton, M., & Mayne, G. (2013). *Science and monitoring synthesis for south-eastern Georgian Bay*. Report prepared for Environment Canada. Retrieved from https://georgianbay.civicweb.net/document/118759

Chiandet, A.S., & Sherman, R.K. (2014). *Report on water quality from 2010-2012 in the Honey Harbour area of Georgian Bay.* Retrieved from http://www.severnsound.ca/resources/reports-publications

Chiandet, A.S., Sherman, R.K., Lesperance, C.T., McPhail, A.K., & Madill, P.M. (2017). *How and why do local climate signals vary in different ways? A case study in Severn Sound, Georgian Bay.* Severn Sound Environmental Association. IAGLR conference poster.

Collingsworth, P.D., Bunnell, D.B., Murray, M.W., Kao, Y-C., Feiner, Z.S., Claramunt, R.M., et al. (2017). Climate change as a long-term stressor for the fisheries of the Laurentian Great Lakes of North America. *Reviews in Fish Biology and Fisheries, 27*(2), 363-391.

Committee on the Status of Endangered Wildlife in Canada (COSEWIC). (2017). *COSEWIC assessment and status report on the Lake Sturgeon Acipenser fulvescens, Western Hudson Bay populations, Saskatchewan-Nelson River populations, Southern Hudson Bay-James Bay populations and Great Lakes-Upper St. Lawrence populations in Canada.* Retrieved from http://www.registrelepsararegistry.gc.ca/default.asp?lang=en&n=24F7211B-1

de Solla, S., de Silva, A., Crump, D., Williams, K., Hebert, C., Letcher, R., et al. (2019). *State of the Great Lakes 2019 – DRAFT. Sub-indicator: toxic chemicals in herring gull eggs.*

Dobiesz, N.E., & Lester, N.P. (2009). Changes in mid-summer water temperature and clarity across the Great Lakes between 1968 and 2002. *Journal of Great Lakes Research, 35*, 371-384.

Dove, A., & Chapra, S.C. (2015). Long-term trends of nutrients and trophic response variables for the Great Lakes. *Limnology and Oceanography, 60*(2), 696-721.

Dove-Thompson, D., Lewis, C., Gray, P.A., Chu, C., & Dunlop, W. (2011). *A summary of the effects of climate change on Ontario's aquatic ecosystems.* Retrieved from http://files.ontario.ca/environment-and-energy/aquatics-climate/stdprod_088243.pdf

Environment and Climate Change Canada (ECCC) and the U.S. Environmental Protection Agency (EPA). (2017). *State of the Great Lakes 2017 technical report.* Cat. No. En161-3/1E-PDF. EPA 905-R-17-001. Retrieved from https://binational.net

Environment and Climate Change Canada (ECCC) and the U.S. Environmental Protection Agency (EPA). (2018). *Lake Huron lakewide action and management plan, 2017-2021.* Cat. No. En164-56/2018E-PDF. Retrieved from https://binational.net/2018/04/09/lhlamp-pddplh-2/

Federation of Ontario Cottagers' Associations (FOCA). (2016). *Managing your waterfront property in a changing climate*. Retrieved from https://foca.on.ca/resources/

Fisheries and Oceans Canada (DFO). (2017). *Ecological risk assessment of grass carp (*Ctenopharyngodon idella*) for the Great Lakes basin.* Science Advisory Report 2016/057. Retrieved from http://waves-vagues.dfo-mpo.gc.ca/Library/40596679.pdf

Franks Taylor, R., Derosier, A., Dinse, K., Doran, P., Ewert, D., Hall, K., et al. (2010). *The sweetwater sea: an international biodiversity conservation strategy for Lake Huron – technical report.* A joint publication of The Nature Conservancy, Environment Canada, Ontario Ministry of Natural Resources, Michigan Department of Natural Resources and Environment, Michigan Natural Features Inventory, Michigan Sea Grant, and The Nature Conservancy of Canada.

Georgian Bay Biosphere Reserve (GBBR). (2018). *State of the Bay: 2018 technical report for eastern and northern Georgian Bay*. Retrieved from https://www.stateofthebay.ca/wp-content/uploads/2018/07/2018-State-of-the-Bay-Technical-report.pdf

Georgian Bay Biosphere Reserve (GBBR), Environment and Climate Change Canada, Severn Sound Environmental Association, Nottawasaga Valley Conservation Authority, Georgian Bay Forever, & Clark, B. (2019). *Updated state of knowledge for south-eastern Georgian Bay.* Retrieved from https://www.stateofthebay.ca/wp-content/uploads/2019/09/GBBR_updated-state-of-knowledge-for-SEGB_final.pdf

Georgian Bay Forever (GBF). (2019). *Invasive phragmites.* Retrieved from https://georgianbayforever.org/invasive-phragmites/

Great Lakes Fishery Trust (GLFT), & Great Lakes Fishery Commission (GLFC). (2018). *Developing research priorities for lake whitefish in the upper Great Lakes: results of a workshop sponsored by the Great Lakes Fishery Trust and Great Lakes Fishery Commission.* Retrieved from http://www.glfc.org/pubs/clc/whitefish/2018%20Whitefish%20Workshop%20Proceedings.pdf

He, J.X., Bence, J.R., Madenjian, C.P., Pothoven, S.A., Dobiesz, N.E., Fielder, D.G., et al. (2015). Coupling age-structured stock assessment and fish bioenergetics models: a system of time-varying models for quantifying piscivory patterns during the rapid trophic shift in the main basin of Lake Huron. *Canadian Journal of Fisheries and Aquatic Sciences, 72*, 7-23.

Howell, T. (2015). *Monitoring of water quality in the nearshore of eastern Georgian Bay by the Great Lakes group of MOECC* [Presentation slides]. Retrieved from http://www.stateofthebay.ca/download/GBBR_CUF_MOECC-nearshore-monitoring_Todd-Howell.pdf

Hutchinson Environmental Sciences Ltd (HESL). (2011). *Georgian Bay Forever coastal monitoring program review.* Retrieved from https://georgianbayforever.org/wp-content/uploads/2016/10/Township-of-Georgian-Bay-Water-Quality-Monitoring-Program-SynopsisV2.pdf

Lake Huron Partnership Working Group (LHPWG). (2016). *Research and monitoring priorities CSMI field year on Lake Huron 2017.*

LimnoTech. (2015a). *DRAFT Lake Huron Partnership science and monitoring synthesis.* Report prepared for Environment Canada. Retrieved from https://www.lakehuroncommunityaction.ca/wpcontent/uploads/2016/03/DRAFT-Lake_Huron_Science_Synthesis_Report_28-Oct-2015.pdf

LimnoTech. (2015b). *State of Lake Huron workshop proceedings*. Report prepared for Environment and Climate Change Canada. Retrieved from https://www.lakehuroncommunityaction.ca/resourceslinks/

Mason, L.A., Riseng, C.M., Gronewold, A.D., Rutherford, E.S., Wang, J., Clites, A., et al. (2016). Fine-scale spatial variation in ice cover and surface temperature trends across the surface of the Laurentian Great Lakes. *Climatic Change, 138*(1), 71-83.

McGoldrick, D.J., & Murphy, E.W. (2016). Concentration and distribution of contaminants in lake trout and walleye from the Laurentian Great Lakes (2008-2012). *Environmental Pollution, 217*, 85-96.

Ministry of Natural Resources and Forestry (MNRF). (2014). *State of the Lake Huron food web.* Retrieved from http://docs.files.ontario.ca/documents/3801/lake-huron-report-october-24.pdf

Nituch, L.A., & Bowman, J. (2013). *Community-level effects of climate change on Ontario's terrestrial biodiversity*. Retrieved from http://www.climateontario.ca/MNR_Publications/CCRR-36.pdf

O'Brien, T.P., Farha, S., Warner, D.M., & Esselman, P.C. (2019). *Status and trends of pelagic prey fish in Lake Huron, 2018*. Paper presented at the Great Lakes Fishery Commission Lake Huron Committee Meeting, Ypsilanti, MI.

Reavie, E.D., Barbiero, R.P., Allinger, L.E., & Warren, G.J. (2014). Phytoplankton trends in the Laurentian Great Lakes: 2001-2011. *Journal of Great Lakes Research, 40*, 618-639.

Riley, S.C. (Ed). (2013). *The state of Lake Huron in 2010.* Great Lakes Fishery Commission Special Publications 13-01. Ann Arbor, MI: Great Lakes Fishery Commission. Retrieved from http://www.glfc.org/pubs/SpecialPubs/Sp13_01.pdf

Ritchie, J. (2019). *Lake Huron CSMI nearshore biodiversity and AIS monitoring.* Presentation in Lake Huron Engagement Webinar.

Rutledge, J., Narini, M., Kirkwood, A., Duval, T., & Chow-Fraser, P. (2015). *Land-use effects on nutrient and algae in the Middle and Lower Nottawasaga River and the Minesing Wetlands.* Report submitted to Environment Canada.

Severn Sound Environmental Association (SSEA). (2017a). *Honey Harbour area monitoring.*

Severn Sound Environmental Association (SSEA). (2017b). *Severn Sound water quality.*

Sherman, R.K. (2002). *Severn Sound Remedial Action Plan stage 3 report: the status of restoration and delisting of Severn Sound as an Area of Concern*. Environment Canada-Ontario Ministry of the Environment Report. Retrieved from https://www.severnsound.ca/Shared%20Documents/Reports/SSRAP_Stage_3_Report_2002.pdf

Sherman, R.K., Ciborowski, J., Barker, N., Milne, J., Chiandet, A., & Madill, P. (2011). Sediment quality, benthos community structure and water quality of Sturgeon Bay, Severn Sound, in relation to the proposed upgrade of the Victoria Harbour wastewater treatment plant. Severn Sound Environmental Association. Retrieved from https://www.severnsound.ca/Shared%20Documents/Reports/SSEA_Sturgeon_Bay_Sediment_Qual_Benthos_2011.pdf

Sivarajah, B. (2016). Assessing diatom shifts in embayments and lakes in and around Georgian Bay (Lake Huron) using paleolimnology (Unpublished master's thesis). Queen's University, Kingston, Ontario.

Upper Great Lakes Management Unit (UGLMU). (2014). *Lake Sturgeon Program 2014 – Nottawasaga River.* Upper Great Lakes Management Unit, Lake Huron Office.

Upper Great Lakes Management Unit (UGLMU). (2016). *Smallfish community assessment program summary report 2016.* Upper Great Lakes Management Unit, Lake Huron Office.

Upper Great Lakes Management Unit (UGLMU). (2019). *DRAFT report of the status of walleye in the Ontario waters of Lake Huron.* Owen Sound: Ministry of Natural Resources and Forestry.

U.S. Environmental Protection Agency (EPA). (2008). *Lake Huron binational partnership 2008-2010 action plan*. Retrieved from https://www.epa.gov/sites/production/files/2015-11/documents/lake-huron-lamp-2008-81pp.pdf

Wood, J. (2019, October 7). Nobel fishery business scrambling after province takes catch away. *My Muskoka Now.* Retrieved from https://www.mymuskokanow.com/95337/nobel-fishery-business-scrambling-after-province-takes-catch-away/