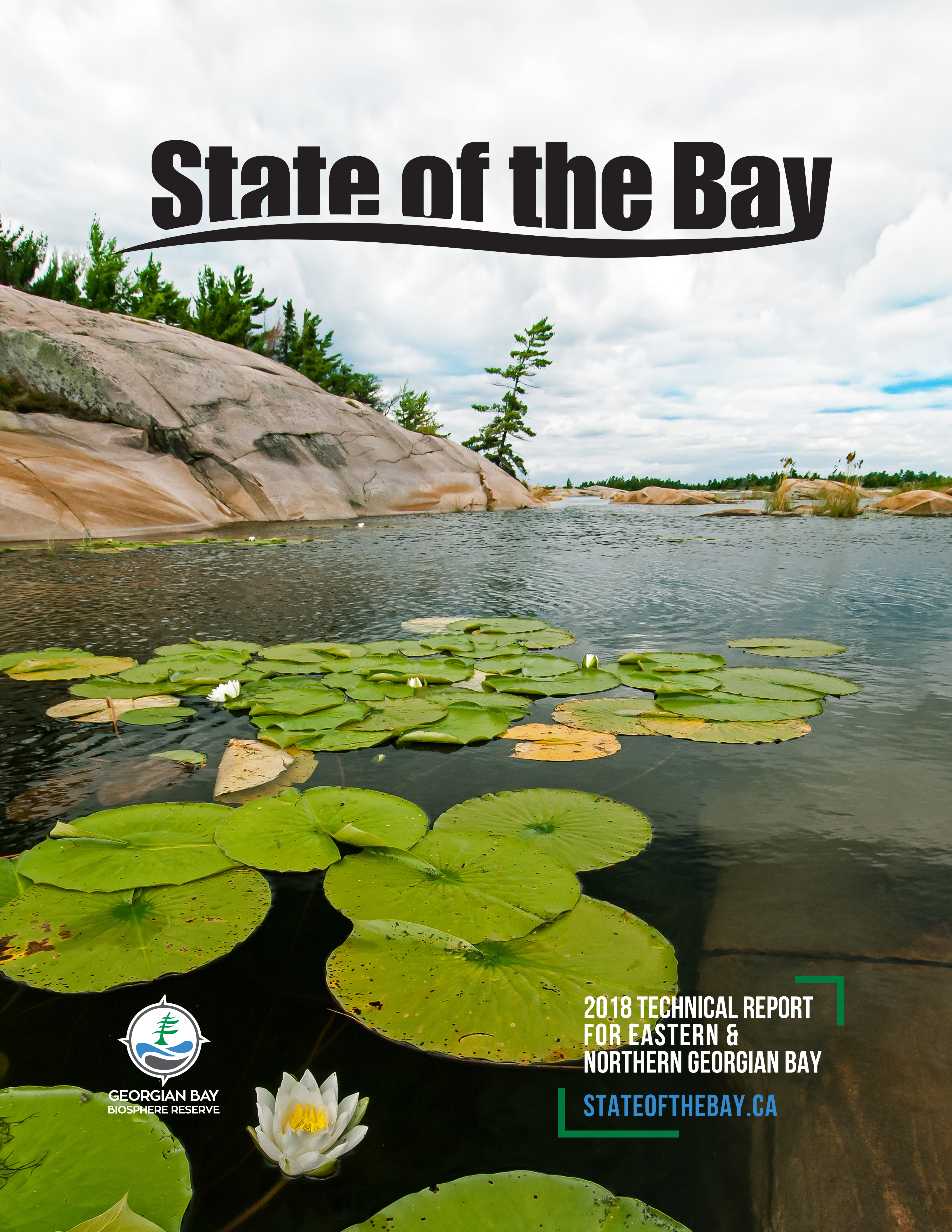
State of the Bay



GEORGIAN BAY
BIOSPHERE RESERVE

2018 TECHNICAL REPORT
FOR EASTERN &
NORTHERN GEORGIAN BAY

STATEOFTHEBAY.CA

Acknowledgements

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We acknowledge that the Georgian Bay Biosphere Reserve is situated in the ancestral and traditional territory of the Anishinabek people, who are the original owners and caretakers of the land. We honour the Huron Robinson Treaty of 1850, and stand in solidarity with those in whose territory we live and work, as friends, neighbours and colleagues.

Compiled by the Georgian Bay Biosphere Reserve.

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1. Introduction

Authors
- David Bywater, Environmental Scientist, Georgian Bay Biosphere Reserve
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When we think about Georgian Bay, images of islands, cobalt blue water, colourful rocks, and windswept pines often come to mind, iconic scenes celebrated through the works of many artists including members of the Group of Seven. It is the same natural beauty of Georgian Bay that draws thousands of visitors each year to fish, swim, boat, and just relax along the shorelines. The quality of their experience is linked to the quality of the natural surroundings. Hence, a healthy environment is essential to our local economy.

How would you respond if asked for your view on the environmental health of Georgian Bay? Your answer is likely influenced by where you live, how long you have been there, and what activities you are involved in. While eastern and northern Georgian Bay are considered to be in good condition compared to the other Great Lakes, they are still subject to pressures from invasive species, water levels, development, and other human impacts. To help monitor these changes the Georgian Bay Biosphere Reserve (GBBR) and its partner organizations initiated the *State of the Bay (SotB)* project.

Project partners came together in 2010 to begin discussions on the need for raising awareness about "the state of Georgian Bay" by selecting key indicators that summarize the ecosystem health of the Bay. In 2013, the first *State of the Bay* report was released reporting on the following six ecosystem health indicators for ten regions in northern and eastern Georgian Bay: phosphorus as an indicator of water quality; fish community health; percentage of natural cover (terrestrial); percentage of large natural areas (water and landscape); percentage of coastal wetland cover; and wetland macrophytes (plants) as an indicator of wetland quality. The report also highlighted three key environmental issues: water levels; invasive species; and species at risk.

Accompanying the 2013 technical report was a 16-page magazine and a *State of the Bay* website. Five years later, the second edition of *State of the Bay* is being released with a brand new 34-page magazine and an updated website (www.stateofthebay.ca). As new information becomes available and our understanding of Georgian Bay's ecosystem health changes, the reporting style will also change. For example, the 2013 and 2018 reports include six (6) and eleven (11) ecosystem health indicators respectively. Other key reporting changes include reporting trends rather than grades, and reporting results at different scales depending on the information available.

The indicators selected and reported on for the 2018 *State of the Bay* report are listed below. Each chapter details the reasons for the selection of these indicators and any changes from the 2013 report.

1. Total phosphorus
2. Lower food web – aquatic ecosystem health
3. Prey fish – aquatic ecosystem health
4. Smallmouth bass – aquatic ecosystem health

5. Northern pike – aquatic ecosystem health
6. Muskellunge – aquatic ecosystem health
7. Walleye – aquatic ecosystem health
8. Lake trout – aquatic ecosystem health
9. Coastal wetlands
10. Landscape biodiversity
11. Climate change

Results for each indicator are reported in terms of trends across different areas of eastern and northern Georgian Bay, whenever possible. Every effort was made to report results at a local scale. Where this was not possible, results were reported for eastern and northern Georgian Bay, at the Georgian Bay scale, or in some cases, at the Lake Huron scale. Table 1 presents a summary of the 2018 *State of the Bay* results.

To help make our measurements consistent with those of federal and provincial research agencies, trends and their definitions have been adopted for the first eight indicators from the *State of the Great Lakes* reports prepared by Environment and Climate Change Canada (ECCC) and the U.S. Environmental Protection Agency (EPA). The trends are as follows:

- 'improving' – metrics show a change toward more acceptable conditions;
- 'deteriorating' – metrics show a change away from acceptable conditions;
- 'unchanging' – metrics show no change; and
- 'undetermined' – metrics indicate a balance of both improving and deteriorating conditions, or data are not available to report on a trend

Outside the established *State of the Great Lakes* reports, we apply a similar trend system to our three remaining *State of the Bay* 2018 indicators:

- Coastal wetlands: Undetermined. As water levels fluctuate, wetlands change. Some species benefit from low water, and other species benefit from high water.
- Landscape biodiversity: Deteriorating. With increasing human impacts and habitat fragmentation, as well as rising numbers of species at risk, biodiversity is declining locally and globally. Future application of this tool will help show more specific trends over time.
- Climate change: Deteriorating. A decrease in maximum annual ice cover from 1973-2016 and an increase in summer surface water temperature of 2.9°C between 1968 and 2002 indicate a rapid environmental change, and one that is consistent with global climate change models.

As with the 2013 report, there is a continued effort to identify and highlight data gaps and research needs in the 2018 *State of the Bay*. By continuing to flag data and research needs, it is hoped that these needs will be strategically filled and will inform future reports. This iteration of *State of the Bay* also features a greater emphasis on letting readers know how they can get involved through citizen science and stewardship activities. For example, readers are encouraged to report invasive species they encounter to the Invading Species Hotline (1-800-563-7711) or using EDDMapS Ontario (http://www.eddmaps.org/Ontario/).

The *State of the Bay* project would not be possible without the continued support of partners and sponsors. Special thanks goes to Environment and Climate Change Canada (ECCC), the Ministry of Natural Resources and Forestry (MNRF) via the Canada-Ontario agreement respecting the Great Lakes Basin Ecosystem (COA), the Lake Huron Framework for Community Action, Iron City Fishing Club via Great Lakes Basin Conservancy, Georgian Bay Forever, and the many businesses, municipalities, and organizations who have become sponsors of the project.

Table 1. Summary of the 2018 *State of the Bay* findings.

Indicator		Sub-indicator/Measure	Data Sources and Partners	Trend	Research and Monitoring Needs
Total phosphorus		Average total phosphorus	ECCC; MOECC; LPP; District of Muskoka; SSEA	Deteriorating	Trophic interactions and lower food web productivity; tributary flow data; shallow nearshore conditions – see section 2.6
Aquatic ecosystem health	Lower food web	Phytoplankton	MOECC; SSEA; U.S. EPA GLNPO; USGS; NOAA	Deteriorating	Seasonal plankton production (e.g., spring bloom conditions); blue-green algae blooms – see section 3.9.1
		Zooplankton	SSEA; U.S. EPA GLNPO; USGS; NOAA	Unchanging	Drivers of recent shifts in community structure; top-down versus bottom-up mechanisms – see section 3.9.1
		Benthic invertebrates	ECCC; MOECC; U.S. EPA GLNPO	Unchanging	Characterization of spatial differences across eastern and northern Georgian Bay – see section 3.9.1
	Prey fish	Offshore and nearshore demersal and pelagic prey fish	USGS GLSC; MNRF UGLMU, U.S. EPA; USGS; NOAA	Undetermined	Linkages between lower and upper food web; round goby biology and importance as prey – see section 3.9.2
	Smallmouth bass	Catch per unit effort	MNRF UGLMU	Unchanging	Enhanced spatial and temporal coverage; predation impacts from round goby – see section 3.9.3
	Northern pike	Catch per unit effort	MNRF UGLMU	Unchanging	Alterations to riverine and deltaic spawning and nursery areas – see section 3.9.4
	Muskellunge	Catch per unit effort, mean and maximum total length	MNRF UGLMU; Muskies Canada Incorporated	Unchanging	Invasive species' impacts on spawning and nursery habitat – see section 3.9.5
	Walleye	Catch per unit effort, spawning stock size, age structure	MNRF UGLMU; AOFRC; EGBSC	Trends for 16 populations presented in section 3.7.4	Estimate of recreational and Indigenous subsistence harvest; evaluate restoration work – see section 3.9.6
	Lake Trout	Age structure, survival/ mortality, spawning stock size, natural reproduction, abundance	MNRF UGLMU	Trends for 5 LTRZs presented in section 3.8.4	Impacts of invasive species; impacts of changes in prey community; updated reviews of LTRZs – see section 3.9.7
Coastal wetlands		Coastal wetland cover	GBF; NASA	Undetermined	A sustainable, reliable source for coastal wetland cover information; new wetland condition data (e.g., WMI); citizen science participation – see section 4.8
Landscape biodiversity		High value biodiversity areas	CWS-ON Biodiversity Atlas	Deteriorating	Revisions to data sources and mapping criteria: birds, boat channels, rock barrens; seasonal 'footprint' better incorporated into analysis – see section 5.5
		Human footprint analysis	CWS-ON Biodiversity Atlas	Deteriorating	
Climate change		Ice cover	GLERL CoastWatch; SSEA	Deteriorating	Increase the intensity of monitoring of Georgian Bay physical data (i.e., meteorological data); data mine GLERL for Georgian Bay specific climate change trends – see section 6.6
		Summer surface water temperature	GLERL CoastWatch; ECCC CIS; SSEA	Deteriorating	

2. Total Phosphorus

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2.1 Introduction

The first *State of the Bay* (2013) report featured total phosphorus (TP) as a measure of water quality that was widely accepted as a surrogate for lake health. At the time, the benchmark of 5 µg/L was used – based on the Great Lakes Water Quality Agreement (GLWQA) substance objective for phosphorus concentrations for the open waters of Lake Huron. Grades were then developed from this benchmark as follows: A < 5.0 µg/L, B 5.0 – 9.99 µg/L, C 10.0 – 14.99 µg/L, D 15.0 – 19.99 µg/L, F > 20 µg/L. Each of the ten regions within the *State of the Bay* reporting area was given a grade, and Georgian Bay itself was given an average grade of B (8.0 µg/L).

New data in 2018 shows offshore phosphorus concentrations have decreased to values that are well below levels required to support a healthy level of lake productivity (i.e., the 5 µg/L target). Accordingly, it was decided that the 2013 grading system would not be replicated in 2018, as it does not communicate local conditions and productivity where total phosphorus is potentially “too low” to sustain the productive aquatic ecosystems of the past. Instead, the 2018 *State of the Bay* reports ecosystem health indicator ‘trends’ (see section 1). For the total phosphorus indicator, the *State of the Great Lakes 2017 Technical Report* (EC & EPA, 2017) lists the trend for nutrients in Lake Huron as ‘deteriorating’. The rationale given for this trend is that offshore phosphorus concentrations are continuing to decrease to values that are well below the objective (current concentrations are approximately 2 µg/L compared to the GLWQA target of 5 µg/L).

2.2 What is measured?

Average total phosphorus concentration (µg/L or ppb) is measured in eastern and northern Georgian Bay (including inland lakes and nearshore and offshore sites). Total phosphorus includes all forms – organic and inorganic, dissolved, and particulate.

2.3 How is it measured?

Sampling water for average total phosphorus concentration is done via many different programs within eastern Georgian Bay, typically as part of a broader water quality monitoring program. These programs are conducted by all levels of government, First Nations, non-governmental organizations (NGOs), and volunteers or "citizen scientists". The scope of these monitoring programs differs in terms of scale, objectives, parameters, and monitoring frequency. A list of these 15 different programs is available in the Georgian Bay Biosphere Reserve's (GBBR) 2014 report titled, *Summary of Water Quality Monitoring Programs along Eastern Georgian Bay*. This report was prepared as part of the Coordinated Nutrient Monitoring Project and is available online at www.stateofthebay.ca. The intent of the report was to inventory water quality monitoring programs within the UNESCO biosphere reserve and then develop and coordinate a common protocol to generate more robust data across a larger portion of the region.

Large and complex bodies of water like Georgian Bay are difficult to monitor due to the great distances between sample sites and the need for large vessels that can withstand considerable waves and inclement weather. These offshore surveys are, therefore, undertaken only by federal or provincial agencies using research vessels outfitted with specialized sampling equipment. Sample visits often occur several years apart due to the need to visit other lakes or areas within the same lake in the intervening years. Volunteer programs such as the Lake Partner Program (LPP) can provide data for enclosed bays or inland lakes that large boats cannot access.

Federal and provincial monitoring programs rarely incorporate data from other programs to help assess spatial or temporal variation in their datasets. Combining the data from multiple agencies at different tiers allows for the assessment of spatial variation in total phosphorus concentrations over wider areas than the data from individual monitoring programs can provide. By combining datasets from several programs, we are able to assess variability on a regional scale. The assessment of total phosphorus for *State of the Bay* reporting relies on partnerships established by the GBBR in an effort to foster inter-agency cooperation and to examine multi-tiered data within the boundaries of the biosphere reserve.

The *State of the Bay* report uses data sets from five sources to report on phosphorus concentrations: (1) Environment and Climate Change Canada (ECCC); (2) Ministry of the Environment and Climate Change (MOECC); (3) MOECC's Lake Partner Program (LPP); (4) District of Muskoka; and (5) Severn Sound Environmental Association (SSEA). Together, these datasets allow for a comparison of TP data that ranges from open water areas in Georgian Bay to inland lakes within the biosphere reserve boundaries (Figure 1). The most recent data available from these sources were used to assess the spatial variation in recent total phosphorus concentrations throughout the biosphere reserve and in open water to the west of the outer islands. Collectively, these datasets provide sufficient spatial and temporal coverage to assess long and short term trends, seasonal variability, and provide a mechanism to encourage public monitoring.

Total phosphorus samples are collected by the aforementioned agencies using various standard and accepted protocols. ECCC samples are analyzed by the National Laboratory for Environmental Testing (NLET) in Burlington, Ontario and both MOECC and LLP TP samples are analyzed at the Dorset Environmental Science Centre (DESC) in Dorset, Ontario. The DESC is the only provincial laboratory that offers low-level concentration detection for precise TP analysis. Volunteers collect water samples across 842 lakes in Ontario as part of the LPP. Samples are coarse-filtered through 80µm Nitex® mesh to eliminate large zooplankton. Samples are collected in the same tubes that are used to digest the samples prior to analysis (reusable 25 x 125 mm, 50 ml borosilicate glass tubes with autoclavable, high-density, polyethylene caps). Tubes are calibrated volumetrically and permanently etched to indicate the final analytical volume (35 ml). With certain precautions, these methods eliminate both container transfer bias and the potential for contamination by large zooplankton. Sulphuric acid and potassium persulphate digestion reagents are added to each tube and samples are digested by autoclave at 121˚C for 60 minutes. The orthophosphate content of the reduced phospho-antimonyl-molybdate complex is determined colorimetrically using ascorbic acid as the reducing agent. Results are precise to a standard deviation (SD) of approximately 0.3 µg/L TP for duplicate samples (Ontario Ministry of Environment and Energy, 1996). Inter-laboratory comparisons have been conducted between the federal (NLET) and provincial (DESC) laboratories and have indicated excellent agreement (A. Dove, pers. comm., 2017).

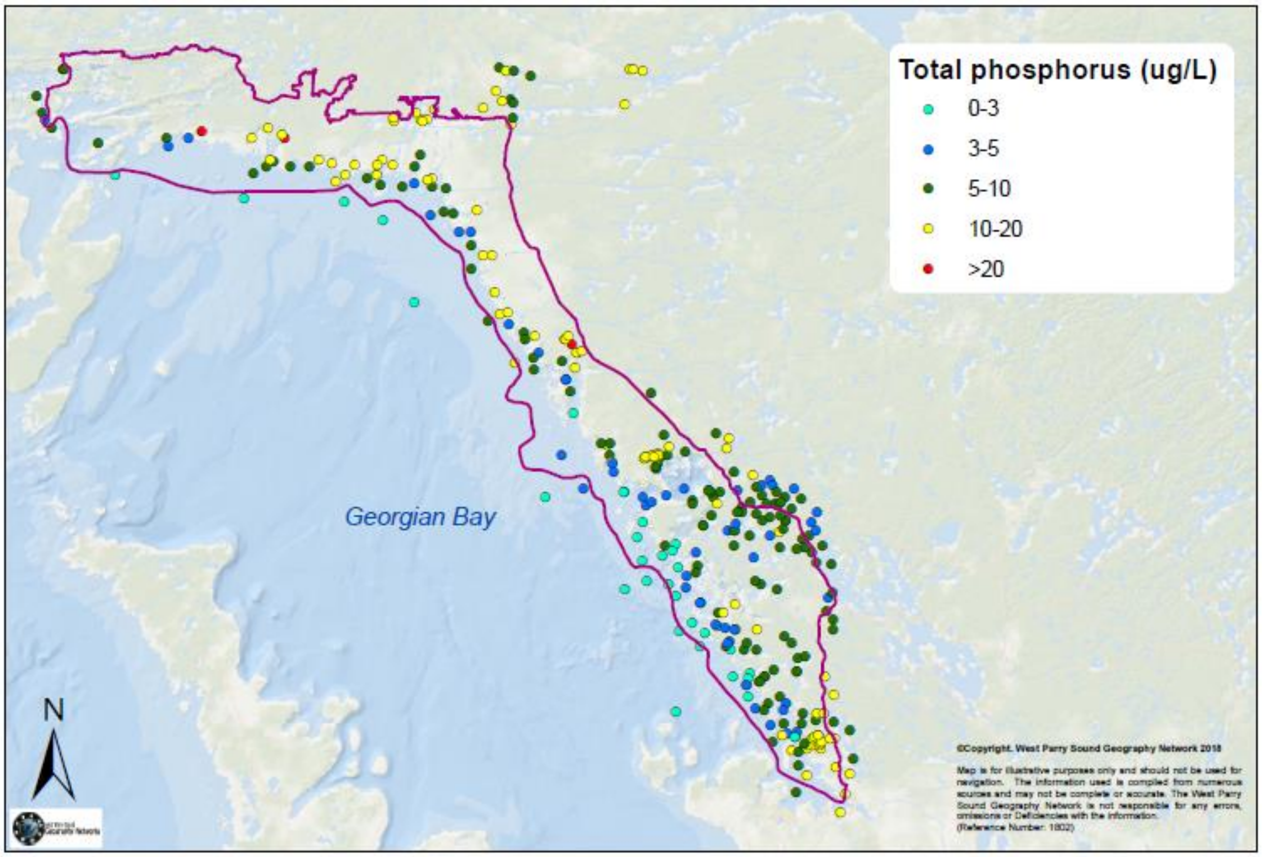

Figure 1. Most recent spring or early summer TP concentrations measured in the mixed layer for areas throughout the *State of the Bay* reporting area (purple line encompassing the Georgian Bay Biosphere Reserve and extending beyond the French River in the North Channel) and adjacent open water. Note: If multiple years of data are available, the most recent data were used. Long term means are shown for LPP data where there is no trend in the data. Examination of the LPP data showed that there is no trend through time observed in 809 of 842 lakes observed. Of these, 21 showed a decline in TP and 12 showed an increase (A. DeSellas, pers. comm., 2017).

2.4 Why is it important?

Phosphorus is an essential nutrient for the plants and animals that make up the aquatic food web. Required by phytoplankton (algae) and aquatic plants, the quantity of phosphorus available is generally a good indicator of the productivity or trophic status of an aquatic system. Phytoplankton, photosynthetic organisms at the base of the food web, require phosphorus for growth and temperate freshwater ecosystems are generally phosphorus limited (Diep et al., 2007). This means that an increase in phosphorus generally results in an increase in phytoplankton biomass.

Phosphorus exists in different forms in water. It can be dissolved, bound to particles of soil and other materials, or contained within living or decaying plants and animals. Dissolved phosphorus is most readily used by plants and algae, and is typically found in low concentrations in unpolluted water bodies (MOE, 2011). Total phosphorus is a measure of all of these forms of phosphorus combined.

TP is also an indirect indicator of recreational water quality, as changes in TP affect water quality in terms of algae growth and water clarity, in turn affecting recreational pursuits such as swimming, boating, fishing, and aesthetic enjoyment. Good water quality and healthy aquatic ecosystems are generally the most important concerns expressed by those living or recreating on lakes and rivers in Ontario. Without clean and safe water, many of our favourite summer recreational activities are jeopardized and our sense of enjoyment from being in a natural and relatively pristine environment is quickly lost (Schiefer, 2009).

2.4.1 The need for nutrient monitoring

In the early 1970s, scientists at the Experimental Lakes Area (ELA) proved that phosphorus (P) was the nutrient controlling algal growth in most temperate lakes. At that time there was evidence that anthropogenic phosphorus additions to surface water were causing increased phosphorus concentrations which in turn led to algal blooms and decreased oxygen concentrations in bottom waters (eutrophication). This was due in part to phosphates in detergents, poor phosphorus removal in sewage treatment facilities, and improper watershed land use practices. Phosphorus reductions were required to mitigate water quality problems that had developed in the Great Lakes (Lake Erie, Severn Sound, Bay of Quinte, and St. Lawrence River) (Beeton, 1965) and in several inland lakes including Lake Simcoe. In Lake Simcoe it was shown that increased productivity due to phosphorus loading had degraded the oxygen climate in bottom waters which resulted in a loss of optimal habitat for cold water stenotherms like lake trout (*Salvelinus namaycush*) and whitefish (*Coregonus clupeaformis*).

Programs to reduce phosphorus loads to surface water have been implemented since the 1970s which has led to improvements in many water bodies, although problems have returned to some areas such as Lake Erie in recent years (IJC, 2014). Generally, the loads from sewage treatment plants have been greatly reduced in more populated areas such as Severn Sound (Sherman, 2002) and there are fewer point sources of phosphorus compared to those noted prior to the 1970s. Diffuse loads from agriculture and stormwater sources remain, but are also improved in many areas compared to the past (Sherman, 2002). While progress has been made to reduce phosphorus inputs to surface water in Ontario, it is important to continue to work towards established targets.

There is some evidence that phosphorus concentrations in inland lakes have decreased in recent years for reasons other than those attributed to reduced anthropogenic loads (Clark, 2010). TP concentrations (spring) began to decline around 1990, abruptly declined around 2000, and are continuing this trend to the present time. TP concentrations in the open water areas of Georgian Bay are also presently very low (T. Howell, pers. comm., 2017) which may provide reason to believe that there have been phosphorus losses from the ecosystem to background levels or lower. In fact, the most recent offshore concentrations are the lowest on record and below the target set to maintain an oligotrophic state (Dove & Chapra, 2015). Offshore productivity in Lake Huron is thought to be negatively impacted by these low phosphorus concentrations (Dove & Chapra, 2015).

The reasons for phosphorus declines are poorly understood and further research is necessary before an informed management direction can be recommended.

2.5 What are the results?

This section provides a summary of spatial and temporal TP conditions and trends along eastern and northern Georgian Bay based on work completed as part of the Coordinated Nutrient Monitoring Project. For further information and discussion pertaining to TP conditions and trends, readers are referred to project reports available online at www.stateofthebay.ca.

2.5.1 Spatial variability in total phosphorus concentrations

Approximately one dozen stations in the Georgian Bay offshore (beyond 50 m lake depth) are used to provide the stable, offshore trend for the Great Lakes Surveillance Program. As demonstrated in Figure 1, there is minimal spatial variability in TP concentrations measured in these open water areas. This has been confirmed statistically in the past by Moll et al. (1985) who noted that the open waters of Georgian Bay are generally one large water mass with two to three nearshore masses in nearshore areas in the east during spring. The most recent (2014) observed average concentration for TP at open water sites near the biosphere reserve was 2.1 µg/L (Figure 1). This represents an unprecedented low level of phosphorus available – a critical nutrient in the open water system.

Greater variability observed in nearshore areas is the result of interactions between receiving waters and their watersheds. This is confirmed by the close relationship between TP and dissolved organic carbon (DOC) in the MOECC 2003-2005 dataset (Figure 2).

Along northern and eastern Georgian Bay (i.e., *State of the Bay* reporting area), phosphorus concentrations in all areas except several locations in the French River and Sturgeon Bay are below the Provincial Water Quality Objective (PWQO) of 20 µg/L to reduce the occurrence of nuisance algal blooms. Figure 1 shows the most recent measured spring or early summer TP concentrations in the mixed layer for areas throughout the *State of the Bay* reporting area and adjacent open water. Data sets used include ECCC (2012-2014), MOECC (2003-2005, 2015), LPP (2002-2016), District of Muskoka (10 year mean), and SSEA (2001-2016).

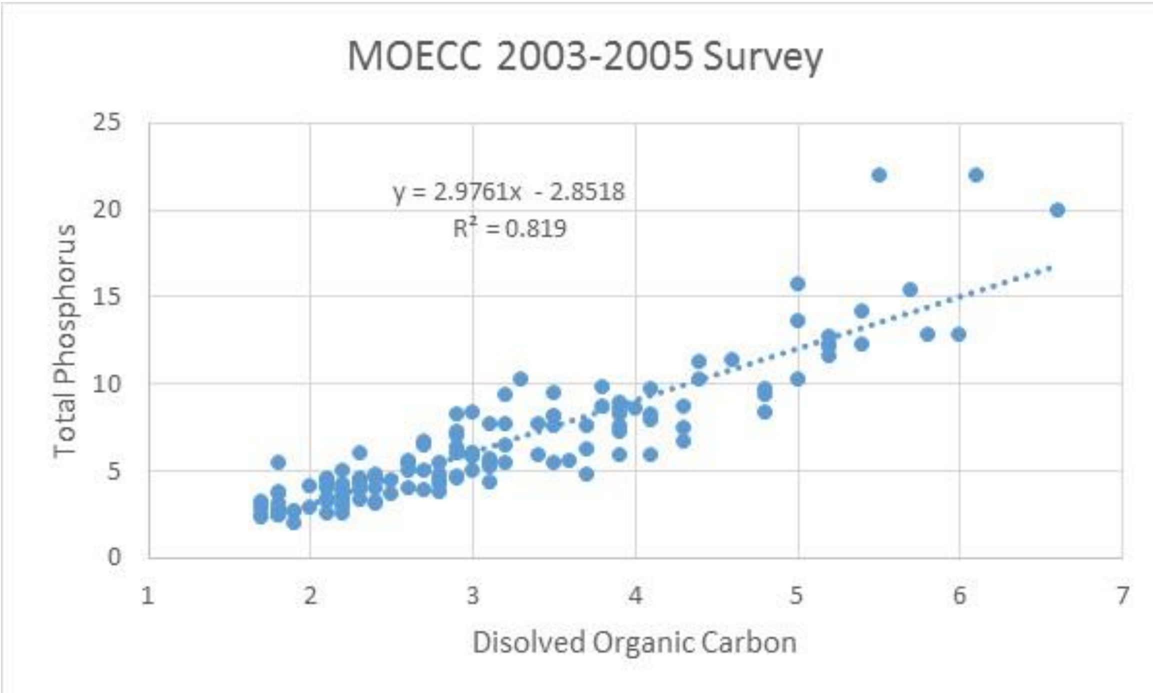

Figure 2. The relationship between TP and dissolved organic carbon (DOC) at 135 sample sites in the MOECC 2003-2005 survey (GBBR, 2015). Most are nearshore sites (TP in µg/L, DOC in mg/L).

2.5.2 Temporal variation in total phosphorus concentrations

The ECCC Great Lakes Surveillance data set demonstrates long term TP trends (Figure 3). Spring surface concentrations at open water stations have continued to decrease since the mid 1990s when concentrations were near 5 µg/L. Since that time, they have declined to approximately 2 µg/L in offshore waters.

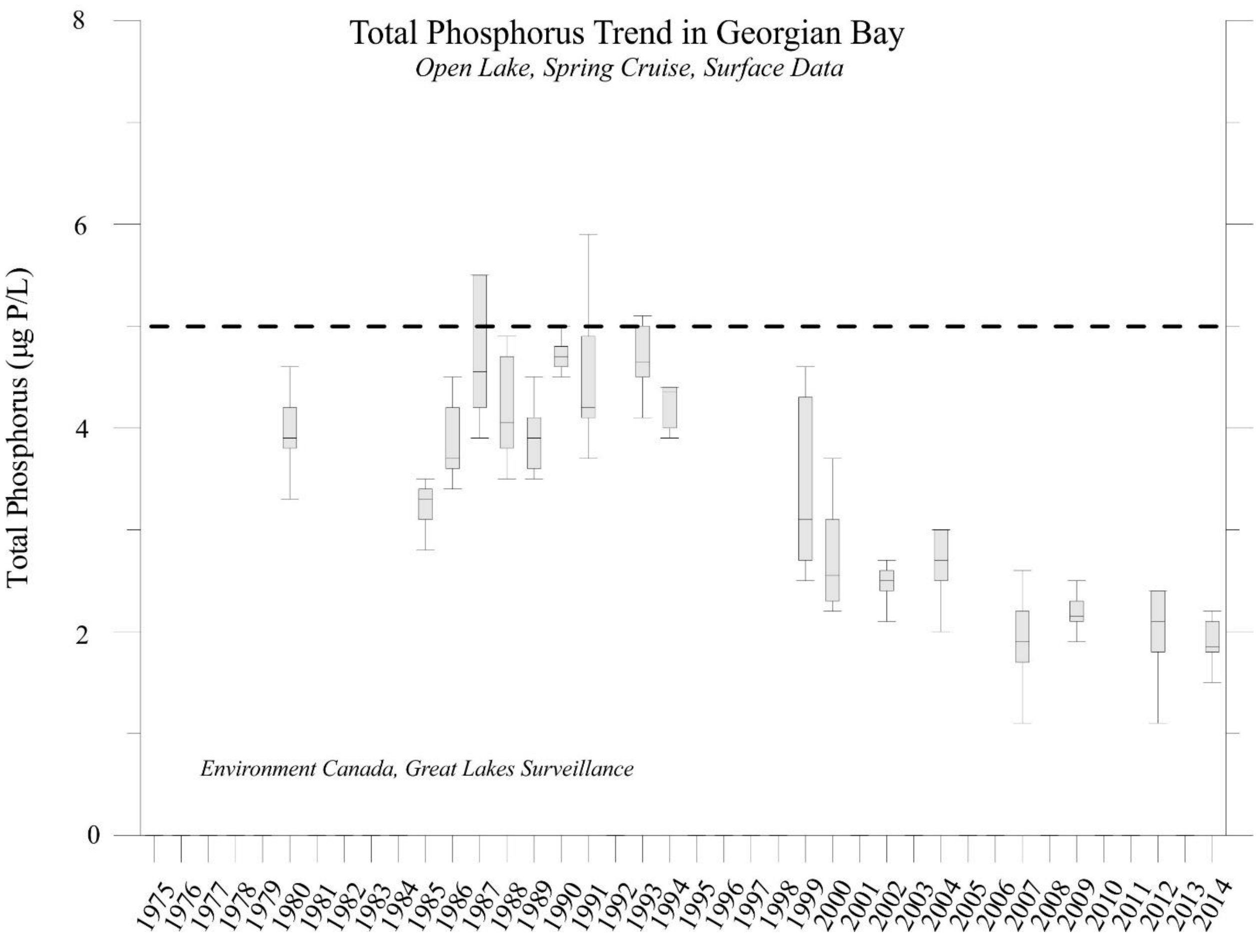

Figure 3. Long term trends in open water total phosphorus concentrations between 1975 and 2014 . The dashed line represents the GLWQA substance objective for phosphorus concentrations for the open waters of Lake Huron (GBBR, 2015).

Declining TP concentrations (oligotrophication) are not limited to the open water areas of Georgian Bay. There have been long term studies at the DESC that indicate losses of TP from shield lakes including lakes with no development in their watersheds (Clark et al., 2010; Palmer et al., 2011; Sivarajah et al., 2016). However, the dramatic decline in TP in the offshore waters of Georgian Bay means that, for the first time in recorded history, concentrations are as low in Georgian Bay as they are in Lake Superior (Dove & Chapra, 2015), and Georgian Bay waters are now classified as ultra-oligotrophic (i.e., < 4 µg/L).

2.5.3 Discussion of potential causes of low phosphorus

Water quality with respect to TP is acceptable in most areas (offshore and nearshore) with reference to Provincial Water Quality Objectives (20 µg/L). Additional guidelines offered by MOECC to limit TP concentrations to less than 50% above the no development background is impossible to assess for large complex water bodies like Georgian Bay. This is due to the fact that background concentrations are difficult to establish and anthropogenic impacts are diluted by large volumes of water. It is possible, however, to state that the current concentrations in many areas are less than 50% of those measured several decades ago and there is presently no guidance for avoiding deleterious effects caused by concentrations that are below background.

There are well documented (physical/limnological) explanations for the maintenance of low TP concentrations in Georgian Bay. Bennett (1988) showed that water exchange between Lake Huron and Georgian Bay through the Main Channel north of the Bruce Peninsula directed nutrient poor Lake Huron surface water into Georgian Bay, which was replaced by more enriched hypolimnetic water from Georgian Bay flowing back into Huron. This process was a result of the tilting of the Georgian Bay thermocline due to wind stress. TP concentrations, however, have continued to decline since that time, and reasons for this dramatic TP decline in Georgian Bay are unclear.

Most likely, there is some interplay between several factors. The invasion and rapid proliferation of *Dreissenid* mussels has resulted in the loss of particulate matter from the lake due to their immense capacity to filter lake water. Changes in the upper and lower food webs may have also exacerbated effects, as they did for the noted zooplankton declines (Barbiero et al., 2009). Meanwhile, declines in total phosphorus have been shown in inland lakes recovering from effects on pH from acid deposition. It is, therefore, unclear whether or not there is a regional driver responsible for these decreases, just as there is no clear understanding of the processes that are driving decreases in inland lakes elsewhere in the province (Eimers et al., 2009; Scott et al., 2015).

2.5.4 Concerns surrounding extremely low open water total phosphorus concentrations

There may be negative effects from low nutrients to the productivity of the lower food web in Georgian Bay. Temporal trends in open water TP concentrations in waters bordering the GBBR boundary have led to current concentrations in many areas that are extremely low (< 2 μg/L). These concentrations indicate reduced potential for productivity compared to those measured in the mid 1980s to the early 1990s.

In the late 1980s, a research synthesis by Munawar et al. (1988) examined trophic interactions in Georgian Bay and the North Channel. This research concluded that the physical limnology of Georgian Bay serves to pump nutrients from Georgian Bay through the Main Channel and into Lake Huron. It also showed that Biomass/Production ratios indicate inhibited primary productivity.

Many of these earlier findings relating to trophic interactions are almost certainly outdated considering that TP concentrations have declined considerably in open water areas since these results were published. The relationship between TP and algal biovolume has changed since the introduction of *Dreissenid* mussels in some areas like the Bay of Quinte, but not in Severn Sound. It should be noted, however, that the trophic relationships determined in the 1970s (Nicholls & Dillon, 1978) still apply to some nearshore waters of Georgian Bay (see for example Sherman, 2002).

More recent science shows that ecosystems in Georgian Bay and in other areas of the Great Lakes are undergoing change. Research presented at a State of Lake Huron Conference (a binational conference on Lake Huron's environment held in Alpena, Michigan in 2016) showed:

- Examples of fish biomass being higher in nearshore areas where nutrients from watersheds are available to fuel production
- Minimal open water production
- Spring bloom of phytoplankton and chlorophyll, a common phenomenon in the past, is gone
- Chlorophyll levels have decreased considerably in all seasons

In an updated mass balance model, Chapra and Dolan (2012) concluded that in order for the model to match recent TP concentrations in the Great Lakes, the particulate settling velocity would need to be increased compared to earlier modeling attempts. In other words, phosphorus is being lost from the water at a rate higher than previously observed. They attributed the need to adjust this model term to the uptake of nutrients by invasive mussels. In Lake Superior, where mussels are not as prolific, there is no such need to adjust the model (Chapra & Dolan, 2012).

Total phosphorus concentrations in open waters have been trending even lower in recent years (Figure 3), which has raised concern about the role this may have had in the decline in primary productivity and the rapid regime shift in the food web noted in Lake Huron waters since the early 2000s (Barbiero et al., 2009; Ridgeway, 2010; Charlton & Mayne, 2012). Continued declines in TP concentrations may contribute to a loss of productivity that could further affect plankton and fish communities, especially in areas strongly influenced by the open waters of Georgian Bay. Nearshore concentrations in many areas are influenced by mixing with open water. It is reasonable to infer that this mixing of ultra low TP water from open water areas with the water in nearshore areas will result in lower TP concentrations in nearshore areas, but the effect this will have on the ecological integrity of nearshore areas is uncertain.

2.5.5 Nutrient trends in Great Lakes reporting

As noted in section 2.1, the 2018 *State of the Bay* is reporting on indicator trends using Great Lakes resources (as opposed to benchmarks and grades used in the 2013 *State of the Bay*).

Provincial objectives for the open waters of Lake Huron are to maintain an oligotrophic state, relative algal biomass, and algal species consistent with healthy aquatic ecosystems; the target is 5 µg/L (Annex 4 of the 2012 GLWQA). However, these objectives reflect a pre-*Dreissenid* lake ecosystem with high open water nutrient concentrations. There may need to be an adjustment of these targets given that offshore phosphorus concentrations continue to decrease to values that are well below levels required to support a healthy level of lake productivity.

The *State of the Great Lakes 2017 Technical Report* (EC & EPA, 2017) lists the trend for nutrients in Lake Huron as ‘deteriorating’. Offshore phosphorus concentrations are continuing to decrease to values that are well below the objective (current concentrations are approximately 2 µg/L compared to the GLWQA target of 5 µg/L).

The *Lake Huron Lakewide Action and Management Plan (LAMP)* (ECCC & EPA, 2018) does not use ‘nutrients’ as an indicator, but summarizes the overall status of nearshore health (<30 m) as determined by the presence of nuisance and harmful algae. Lake Huron's nearshore health is currently described as 'fair' with an 'undetermined' trend.

2.6 Data gaps and research needs

There is a gap in knowledge on conditions in the shallow nearshore (i.e., <3 m depth) in terms of nutrient variability, algae growth (both phytoplankton and periphyton), and benthic invertebrates. Anecdotal evidence exists of increased productivity in this zone, in some areas resulting in heavy growth on rocks and built structures. It is unclear whether this periphyton production is the result of point source nutrient loading like septic runoff and greywater discharge, or a lack of invertebrate grazers. There are indications to suggest a combination of the two factors. Similarly, in the water column, the growth of algae may be due to nutrients or a lack of zooplankton grazers. Qualitative observation has shown an increase in suspended algae in the shallow nearshore over the last 5-10 years across Severn Sound. The shallow nearshore ecosystem is complex and sampling it adequately is outside the scope of large monitoring programs. This type of work could be made more feasible by partnering with university researchers, local cottage associations, and citizen scientists.

There is also a data gap in ECCC's meteorological monitoring network in the southern portion of Georgian Bay. The weather station that was maintained on Beausoleil Island and had been recording hourly data since 1994 was taken offline in 2007, leaving a gap in high resolution temperature, humidity, wind, and pressure data. Currently, there are only stations at Parry Sound, the Western Islands, Collingwood, and Wiarton that provide hourly data in close proximity to the coast. Given the variability in weather conditions, a station should be re-established on Beausoleil Island to capture conditions in the south-eastern corner of the Bay. Meteorological data of this kind informs the modelling and reporting of features (e.g., thermal stratification) and drivers (e.g., exposure, short term water level fluctuation) that contribute to gradients in water quality in eastern Georgian Bay.

Hourly tributary flow data, such as that provided by the Canadian Hydrographic Service's hydrometric station network, is needed for the majority of tributaries along eastern and northern Georgian Bay, from Severn Sound to the French River. This information has numerous applications, such as calculating nutrient loading from watershed sources, and fisheries and watershed management.

The main data gaps and research needs from the lower food web indicator are also applicable to the total phosphorus indicator, as they are centered on establishing regular monitoring programs to measure and help understand lower food web productivity and trophic interactions.

1. Phytoplankton - Assessment of seasonal plankton production, especially spring bloom conditions and possible implications for zooplankton timing and larval fish food supply at locations throughout eastern Georgian Bay. Late summer blue-green algae blooms are also important to track in a variety of locations in order to better understand causes of dominance in some locations and not others.

2. Zooplankton - Studies to identify the drivers of recent shifts in zooplankton community structure (e.g., roles of *Bythotrephes* and *Leptodora*, top-down versus bottom-up mechanisms, and declines in *Diporeia* populations) including a detailed examination of trophic interactions. Food preferences of

the dominant Great Lakes zooplankton need to be investigated, and whether they are able to tolerate shifting diets.

3. Benthic macroinvertebrates - Studies are required to better characterize the spatial differences across eastern Georgian Bay. Programs should include under-sampled species and aquatic habitat types (e.g., rocky substrates and depositional areas). Monitoring would include protocols like that of the Great Lakes National Program Office (GLNPO) and the Canadian Aquatic Biomonitoring Network (CABIN) including nearshore and hard substrates in addition to soft substrates, to identify temporal and spatial trends in the benthic community.

Assuming that many of the identified trends in this report will continue, it will be important to identify the potential future impacts of these trends on the entire aquatic food web. Detailed seasonal sampling of phytoplankton, zooplankton, and benthos is needed to better characterize trophic interactions. With better understanding it may be possible to predict future effects on the higher trophic levels (i.e., coldwater fisheries). In order to complete the sort of sample analysis necessary to better characterize the lower food web, efforts need to be made to train a new generation of taxonomists.

2.7 References

Barbiero, R.P., Balcer, M., Rockwell, D.C., & Tuchman, M.L. (2009). Recent shifts in the crustacean zooplankton community of Lake Huron. *Canadian Journal of Fisheries and Aquatic Sciences, 66*, 818-828.

Beeton, A.M. (1965). Eutrophication of the St. Lawrence Great Lakes. *Limnology and Oceanography, 10*, 240-254.

Bennett, E.B. (1988). On the physical limnology of Georgian Bay. *Hydrobiologia, 163*(1), 21-34.

Chapra, S.C., & Dolan, D.M. (2012). Great Lakes total phosphorus revisited: 2. Mass balance modeling. *Journal of Great Lakes Research, 38*(4), 741-754.

Charleton, M., & Mayne, G. (2012). *Science and monitoring synthesis for south-eastern Georgian Bay*. Report prepared for Environment Canada. Retrieved from https://georgianbay.civicweb.net/document/118759

Clark, B.J., Paterson, A.M., Jeziorski, A., & Kelsey, S. (2010). Assessing variability in total phosphorus measurements in Ontario lakes. *Lake and Reservoir Management, 26*(1), 63-72.

Diep, N., Howell, T., Benoit, N., & Boyd, D. (2007). *Limnological conditions in eastern Georgian Bay: data summary of the 2003-2005 water quality survey*. Water Monitoring and Reporting Section, Environmental Monitoring and Reporting Branch, Ontario Ministry of the Environment.

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.

Eimers, M.C., Watmough, S.A., Paterson, A.M., Dillon, P.J., & Yao, H. (2009). Long-term declines in phosphorus export from forested catchments in south-central Ontario. *Canadian Journal of Fishers and Aquatic Sciences, 66*, 1682-1692.

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/

Environment Canada (EC) 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 http://binational.net

Georgian Bay Biosphere Reserve (GBBR). (2014). *Water quality monitoring along eastern Georgian Bay: a summary of water quality and nutrient monitoring programs along eastern Georgian Bay*. Retrieved from https://gbbr.ca/download/GBBR_Clean-Up-Fund_Nutrient-monitoring-review_Draft.pdf

Georgian Bay Biosphere Reserve (GBBR). (2015). *Nutrient monitoring in the Georgian Bay Biosphere Reserve*. Retrieved from https://gbbr.ca/download/GBBR_Nutrient-monitoring-report_Final_Oct-2015.pdf

International Joint Commission (IJC). (2014). *A balanced diet for Lake Erie: reducing phosphorus loadings and harmful algal blooms*. Report of the Lake Erie Ecosystem Priority. ISBN: 978-1-927336-07-6

Ministry of the Environment (MOE). (2011). *Water quality in Ontario 2010 report*. Retrieved from http://www.ontla.on.ca/library/repository/mon/26004/316712.pdf

Moll, R.A., Rossmann, R., Rockwell, D.C., & Chang, W.Y.B. (1985). *Lake Huron intensive survey, 1980*. Special Report No 110. Ann Arbor, Michigan: Great Lakes Research Division, University of Michigan.

Munawar, M. (Ed.). (1988). *Limnology and fisheries of Georgian Bay and the North Channel ecosystems*. Boston, MA: Kluwer Academic Publishers.

Nicholls, K.H., & Dillon, P.J. (1978). An evaluation of phosphorus-chlorophyll-phytoplankton relationships for lakes. *International Review of Hydrobiology, 63*(2), 141-154.

Ontario Ministry of Environment and Energy. (1996). *1995 performance report: water quality analyses section.* ISSN 1198-3043.

Palmer, M.E., Yan, N.D., Paterson, A.M., & Girard, R.E. (2011). Water quality changes in south-central Ontario lakes and the role of local factors in regulating lake response to regional stressors. *Canadian Journal of Fisheries and Aquatic Sciences, 68*(6),1038-1050.

Ridgway, M.S. (2010). Seasonal and annual patterns in density of double-crested cormorants in two coastal regions of Lake Huron. *Journal of Great Lakes Research, 36*, 411-418.

Schiefer, K. (2009). *Water quality survey of Blackstone, Crane, Healey and Kapikog Lakes, 2008*. Report prepared for the Township of the Archipelago. Retrieved from http://archipelago.municipalwebsites.ca/Editor/images/DOCUMENTS/ENVIRONMENT/Water/2008_Blackstone_Crane_Healey_Kapikog_WaterQuality_Report.pdf

Scott, R.B., Watmough, S.A., & Eimers, M.C. (2015). Phosphorus forms and response to changes in pH in acid-sensitive soils on the Precambrian Shield. *Canadian Journal of Soil Science, 95*(2), 95-108.

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

Sivarajah, B., Rühland, K.M., Labaj, A.L., Paterson, A.M., & Smol, J.P. (2016). Why is the relative abundance of *Asterionella formosa* increasing in a Boreal Shield lake as nutrient levels decline? *Journal of Paleolimnology, 55*(4), 357-367.

3. Aquatic Ecosystem Health

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3.1 Introduction

Georgian Bay, and the Great Lakes more broadly, have undergone significant changes over the past century. Over-harvesting, point source and non-point source pollution, introduction of invasive species, and development are just a few of the many factors contributing to changes to the aquatic ecosystem. Given its interconnected nature, no part of the aquatic ecosystem has been unaffected. From primary producer to top predator, changes have been, and continue to be observed. Various Great Lakes agencies and organizations have been monitoring aquatic populations and communities over time in order to identify trends, inform management decisions, and highlight future research needs.

The 2013 *State of the Bay* reported on fish community health using the following three categories: predators (i.e., walleye, northern pike, muskellunge, smallmouth bass, largemouth bass); panfish (i.e., black crappie, rock bass, pumpkinseed, yellow perch); and benthic fish (i.e., white sucker, northern redhorse sucker, brown bullhead). This division of the fish community reflects fisheries assessment data collected in the Severn Sound area of eastern Georgian Bay from 1975 to present, the most complete and comprehensive nearshore fish community data set available at the time. In recognition of the inconsistencies in the data collection methods used over time and given the lack of appropriate benchmarks against which to assess fisheries data, data were presented in a way that provided broad and descriptive characterizations of the fish community. Moreover, a discussion-oriented approach was adopted to present the assessment of fish community health. It was acknowledged in the 2013 report that the assessment presented was not capable of adequately addressing several identified issues facing the Georgian Bay fishery including low water levels, invasive species, and the changing distribution of nutrients between the nearshore and offshore.

Since the release of the 2013 *State of the Bay* report, a considerable amount of specific research in the Great Lakes and Lake Huron has highlighted the need for a broad perspective when it comes to understanding the health of fish communities. The need for monitoring and reporting on the state of the aquatic ecosystem as a whole, from the lower food web through to top predators, over a larger area, has become apparent. This need is evidenced by the Cooperative Science and Monitoring Initiative (CSMI) priorities coming out of the November 2015 State of Lake Huron Conference and CSMI needs identified in the *Draft Lake Huron Partnership Science and Monitoring Synthesis* report (LimnoTech, 2015a). Similarly, the *Lake Huron Lakewide Action and Management Plan* (*LAMP*) (ECCC & EPA, 2018) features productivity as one of several “hot topics” in response to the notable changes in productivity that Lake Huron has been experiencing and the consequences of those changes at all levels of the food web.

Accordingly, the fish community health indicators used in 2013 have been revised for this report to better reflect current science and identified monitoring and reporting needs. Seven indicators were carefully selected to capture aquatic ecosystem health in eastern Georgian Bay – lower food web (phytoplankton, zooplankton, benthic invertebrates), prey fish, smallmouth bass (*Micropterus dolomieu*), northern pike (*Esox lucius*), muskellunge (*Esox masquinongy*), walleye (*Sander vitreus*), and lake trout (*Salvelinus namaycush*). Indicators were selected based on their ability to shed light on different aspects of the aquatic ecosystem.

The following sections of this chapter describe the seven indicators in terms of how they are monitored, why this monitoring is important, and what the results of the monitoring are. Results are reported in terms of trends across different areas of eastern Georgian Bay, whenever possible. An assessment of inland lakes with regard to these indicators would require reporting on each lake individually and is, therefore, beyond the scope of this report. The trends and their definitions have been adopted from the *State of the Great Lakes* reports prepared by Environment and Climate Change Canada (ECCC) and the U.S. Environmental Protection Agency (EPA). The trends are: ‘improving’ – metrics show a change toward more acceptable conditions; ‘deteriorating’ – metrics show a change away from acceptable conditions; ‘unchanging’ – metrics show no change; and ‘undetermined’ – metrics indicate a balance of both improving and deteriorating conditions, or data are not available to report on a trend (EC & EPA, 2014). Finally, this chapter provides a summary of data gaps and research needs, offers suggestions for how individuals can help, and points readers to where they can learn more about aquatic ecosystem health.

Key Terms

Abundance: a measure (estimate) of the weight or number of a species in a particular stock, segment of a stock (e.g., spawners), or area. Often measured using catch per unit effort (CPUE).

Age/year class: a group of individuals of the same age range in a population. The age-0 group (young-of-the-year) are fish in their first year of life.

Age structure: the age distribution of individuals in a population or sample, typically determined using aging structures such as scales and otoliths.

Catch per unit effort (CPUE): the mean number of individual fish caught per unit of fishing effort, used as an indicator of the species’ abundance.

Clipped: a fish that has had a fin removed prior to stocking to identify it as a stocked fish and to indicate the year that it was stocked.

Cohort: a group of fish born during the same year (a year class).

Community structure: the composition of a community, including the number of species in that community and their relative numbers.

Fingerling: a young, immature fish, roughly the size of a human finger (smaller than juvenile, larger than fry).

Fry: a very young fish no longer in the larval stage, able to eat on their own (smaller than fingerling).

Index gear: fishing gear used to assess fish populations and communities.

Juvenile: a young fish that has not reached sexual maturity.

Mortality: a measure of the rate of death of fish.

Pelagic: inhabiting the water column as opposed to the lake bottom.

Probability of capture (POC): the probability of at least one individual of a species being captured in a net set. Describes how widespread a species is in a survey area.

Productivity: refers to the rate of generation of biomass in an ecosystem, both primary (plants) and secondary (animals).

Pulse stocking: stocking at higher than normal rates for three consecutive years in a location, followed by no stocking for three years. This cycle is repeated three times.

Recruitment: number of fish from a year class reaching a certain age (e.g., fish reaching their third year would be age 3 recruits).

Self-sustaining: a population of fish with sufficient numbers to maintain its levels through time without supplemental stocking.

Spawning stock: mature part of a stock responsible for reproduction.

Stocked: a fish that has been artificially reared and released into a lake or river at a specific life stage.

Survival rate: number of fish alive after a specific time interval, divided by the initial number of fish.

Wild: a fish that has been naturally spawned (i.e., naturally reproduced, not stocked).

3.2 Lower food web

3.2.1 What is measured?

The lower food web is a complex part of the aquatic ecosystem, and for the purpose of this report, will be discussed in terms of phytoplankton (Figure 4), zooplankton (Figure 5), and benthic invertebrates (Figure 6) (please note that aquatic plants are not covered in this report). In an effort to understand the state of, and changes to, the lower food web in the nearshore and offshore of eastern Georgian Bay, a number of measures can be used. With regard to phytoplankton, some of these measures include: biomass (cell mass), cell size and structure (EC & EPA, 2014), total biovolume (cell volume), taxonomic compositions for spring and late summer (IJC, 2014), and trends in chlorophyll *a* concentration in surface waters (EC & EPA, 2017). Zooplankton measures include: species or genus composition and richness, density, biomass, mean length of crustacean zooplankton, and reproductive status (EC & EPA, 2014; EPA, 2017a). Finally, benthic invertebrates are typically measured and described in terms of taxonomic composition, abundance of *Dreissenids* (zebra (*Dreissena polymorpha*) and quagga mussels (*Dreissena bugensis*)), *Diporeia*, *Hexagenia*, *Gammarus*, chironomidae (individuals/m^2), total abundance, taxon richness and evenness, oligochaete diversity, and Oligochaete Trophic Index (OTI) (IJC, 2014; EC & EPA, 2017). Individual studies may use additional or different measures to suit their specific research questions.

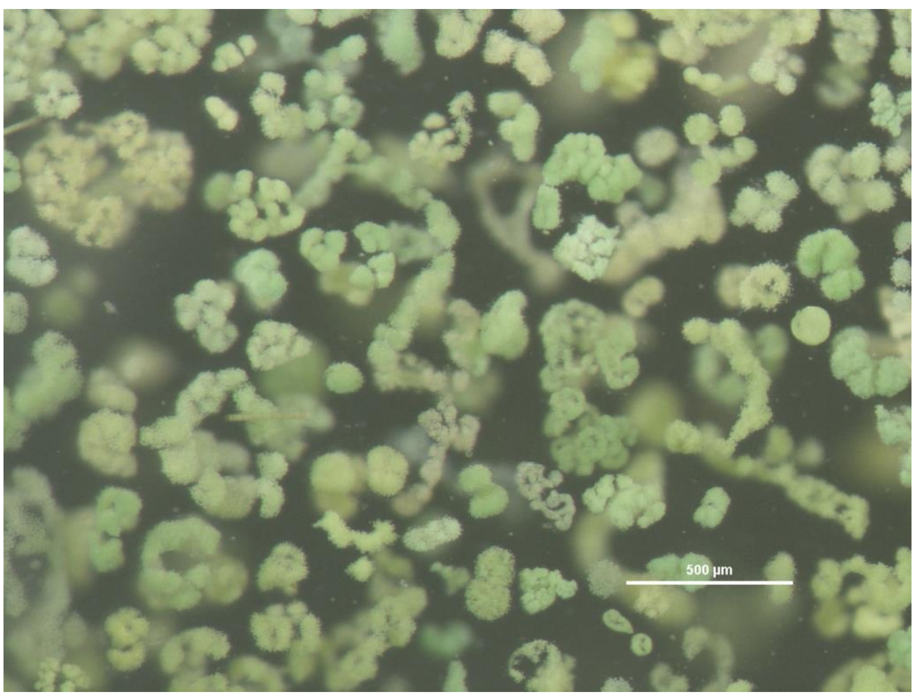


Figure 4. *Microcystis*, a genus of freshwater cyanobacteria (NOAA Great Lakes Environmental Research Laboratory, 2010).

Figure 5. Calanoid copepod (*Diaptomus spp.*), a crustacean zooplankton (NOAA Great Lakes Environmental Research Laboratory, 2000).

Figure 6. *Diporeia* spp., a benthic invertebrate in the order Amphipoda (NOAA Great Lakes Environmental Research Laboratory, 2010).

3.2.2 How is it measured?

Several agencies and organizations are involved in monitoring the lower food web, or parts of it, on a regular basis and over the long-term (see Table 2 for a summary). Others have undertaken short term studies to answer specific research questions or fill particular knowledge voids.

Table 2. Summary of agencies/organizations involved in monitoring Lake Huron's lower food web.

Scale	Agency/Organization	Sampling Locations	Data Collected
National	U.S. EPA GLNPO	Great Lakes including Lake Huron (main basin only)	Biology Monitoring Program - Phytoplankton - Zooplankton - Benthic invertebrates - *Mysis* - Chlorophyll *a*
	U.S. EPA, USGS, NOAA	Lake Huron, including Georgian Bay and the North Channel	CSMI Food Web Study - Nutrients - Plankton - Larval fish
	ECCC	Canadian waters of the Great Lakes including Lake Huron (main basin, Georgian Bay, and North Channel)	Benthic Assessment of Sediment (BEAST model) - Sediment chemistry, grain size, and toxicity - Benthic community structure

Provincial	MOECC	Eastern Georgian Bay (Shawanaga Inlet, outer Parry Sound, Moon Island, Go Home Bay, Severn Sound/Honey Harbour)	Diver-based Benthic Surveys - *Dreissenid* mussel and macroalgae density and species - Round goby assessment - Ponar grab of soft substrate
	MOECC	Canadian waters of the Great Lakes including Lake Huron (main basin and Georgian Bay)	Great Lakes Nearshore Reference and Index Station Network - Indicators of the level of contaminants - Biological indicators of trophic status - Indicators of habitat integrity
Local	SSEA	Severn Sound open water (stations in Severn Sound and Honey Harbour)	Open Water Monitoring Program - Water chemistry and physical parameters - Phytoplankton - Zooplankton

The U.S. Environmental Protection Agency (EPA) Great Lakes National Program Office (GLNPO) Biology Monitoring Program encompasses phytoplankton, zooplankton, benthic invertebrate, *Mysis*, and chlorophyll *a* monitoring across the Great Lakes including the main basin of Lake Huron (Figure 7). These data are utilized in *State of the Great Lakes* reports as well as *Lakewide Action and Management Plans* (*LAMP*s). Prior to 2001, phytoplankton samples were taken but were analyzed by different taxonomists and underwent different quality assessment procedures. GLNPO established phytoplankton sampling and processing standards in 2001. GLNPO's phytoplankton surveys are conducted during the spring isothermal period, as early as possible following ice out, and in the summer during the period of stable thermal stratification (GLSAB, 2016). A Rosette Sampler is lowered through the water column and water samples containing phytoplankton are collected at various depths (each sample bottle contains water collected from a different depth). Water from all depths is mixed to form a combined sample which is preserved for later processing. Processing involves identifying and counting the phytoplankton using a microscope.

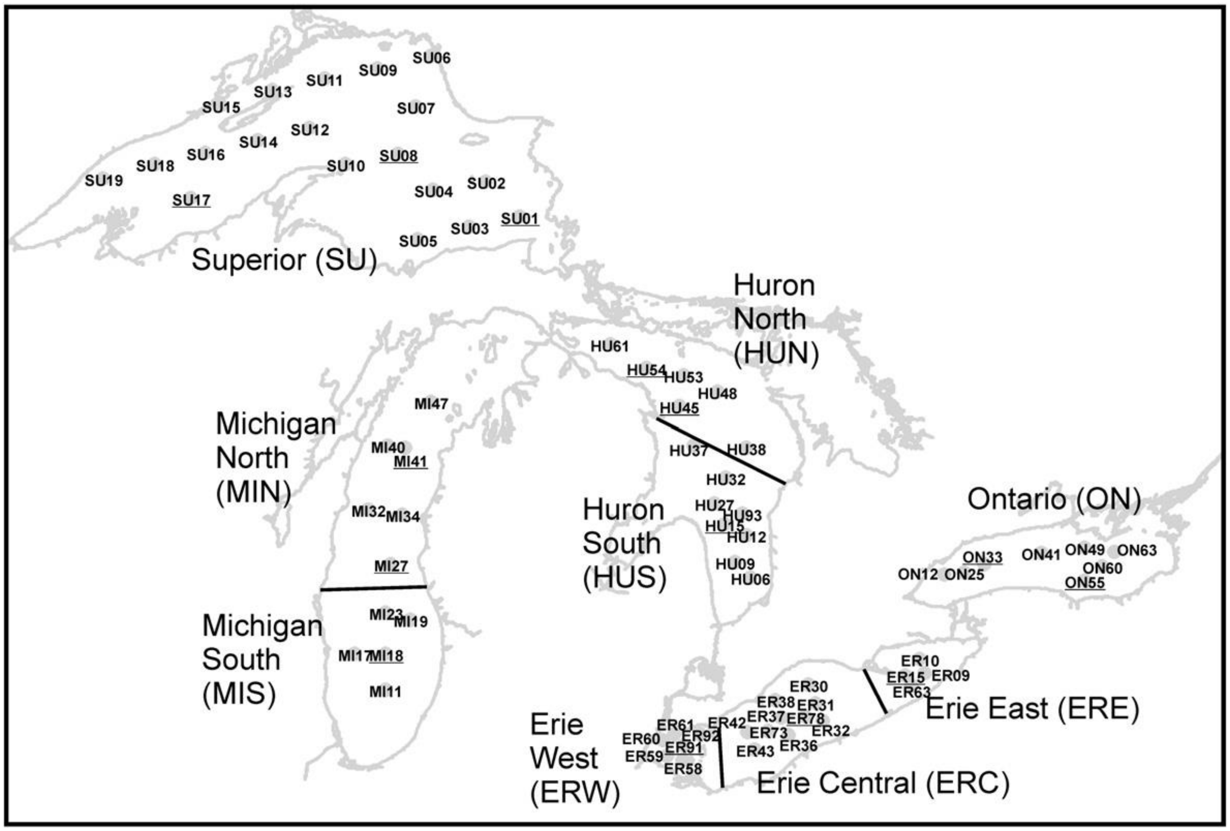


Figure 7. GLNPO Biology Monitoring Program sample stations (Reavie et al., 2014).

Since 1998, the GLNPO has been conducting zooplankton cruises in conjunction with spring and summer phytoplankton sampling. Sampling stations are largely focused in deep, offshore areas. To collect zooplankton, vertical tows are taken from two depths. The first depth of 100 m or 2 m from the bottom (whichever is shallower) is intended to collect the full profile of zooplankton including those that migrate vertically. A 153-µm mesh is used at this depth to avoid issues with clogging. Using a 64-µm mesh net, the second depth of 20 m or 1 m above the bottom at shallower stations, is meant to collect species living in surface water and those too small to be caught with the 153-µm mesh. Zooplankton collected in these vertical tows are preserved in formalin and analyzed under a microscope by taxonomists. Biomass, as well as species diversity and density, are calculated for each Great Lake.

One year earlier in 1997, the GLNPO began a standardized, long-term benthic monitoring program. Sampling occurs during the same periods as phytoplankton and zooplankton sampling, again, mainly in deep offshore areas. A PONAR grab sampler is used to collect sediment and benthic organisms from the lake bottom. Samples are washed to remove fine sediment and organisms are picked from the remaining substrate. Under a microscope, the benthic organisms are identified, counted, and then weighed. The resulting estimates of biomass and density are used to track changes in populations over time. Spring surveys (usually in April) only record the abundance of burrowing mayflies (*Hexagenia*) while summer surveys (usually in August) sample the entire benthic assemblage. The availability of data varies with benthic measure. Lake Huron spring *Hexagenia* samples are available from 2001 on, summer samples from 1997 on, and taxa densities and OTIs from 1997 on.

GLNPO *Mysis* (opossum shrimp) sampling and analysis began in 2006 and involves collecting *Mysis* at night by a full depth net tow using a mysid net. Lights are turned off to ensure a dark environment and to avoid disturbing the *Mysis* during the net tow. Scientists use red lights while conducting the sampling. The samples collected from the net tow are used to evaluate *Mysis* population size, organism size, and reproductive status. An important part of the food web link, *Mysis* feed on algae and zooplankton, competing with fish for food resources, and are also a nutritious food source for fish themselves.

Chlorophyll *a* can be used as a measure of photosynthetic activity and algal biomass in lakes. GLNPO samples and analyzes chlorophyll *a* using two different approaches. The first approach involves using a Rosette Sampler to collect water samples at different depths through the water column. The water samples are filtered and the chlorophyll *a* in the algae caught on the filters is measured. The second approach involves the use of satellite images. The intensity of the colours in the satellite photos is related to the concentration of chlorophyll *a* in the water, providing a broad overview of algal abundance.

While the GLNPO offshore monitoring program focuses on the main basin of Lake Huron, there are other monitoring efforts that hone in on, or at the very least include sites in, Georgian Bay and eastern Georgian Bay, more specifically. The EPA, United States Geological Survey (USGS), and the National Oceanic and Atmospheric Administration (NOAA) collaborated on a Coordinated Science and Monitoring Initiative (CSMI) food web study which included sampling plankton in nearshore to offshore transects around Lake Huron (three transects in Georgian Bay, two in the North Channel, and six in the main basin of Lake Huron) on a monthly basis from April to August 2017. Results from this study were not available at the time of writing.

In 2014 and 2015, diver-based benthic surveys were performed by the Ministry of Environment and Climate Change (MOECC) in five areas on the eastern shores of Georgian Bay: Shawanaga Inlet, outer Parry Sound, Moon Island, Go Home Bay, and Severn Sound/Honey Harbour (Figure 8). The surveys were conducted on hard substrates at 47 sites at depths of 3-18 m. Quadrats were used in the surveys to determine *Dreissenid* mussel and macroalgae density and species. Rock scraping and qualitative round goby assessment were also performed and in 2015, PONAR grab sampling of soft sediment was included as well (LimnoTech, 2015b). Analysis is currently underway and complete results will be available in the near future.

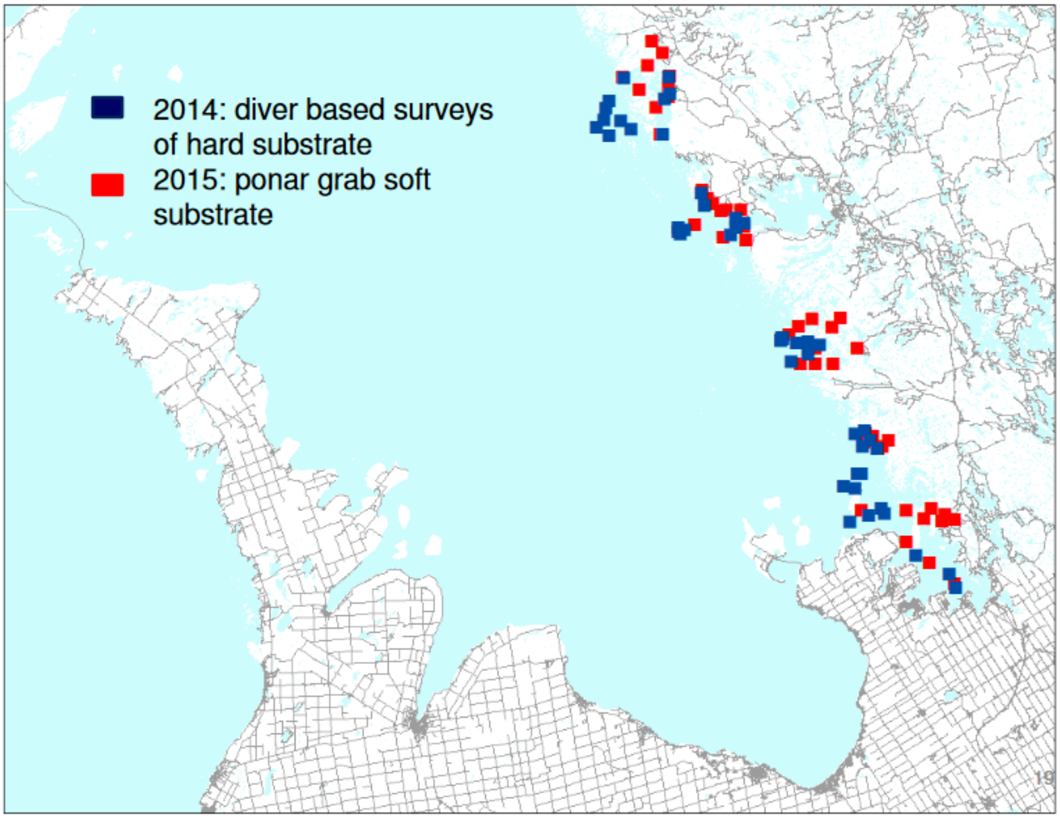


Figure 8. Locations of MOECC's 2014 and 2015 diver-based eastern Georgian Bay benthic surveys (Howell, 2015).

In the early 1990s, the National Water Research Institute of Environment and Climate Change Canada (ECCC) began a program of assessing sediment quality in nearshore areas of the Canadian waters of the Great Lakes as part of ECCC's Great Lakes Action Plan and the Canadian Aquatic Biomonitoring Network (CABIN). The assessment modelling procedures that were established and applied became known as the BEAST model, for Benthic Assessment of Sediment model, and is based on the reference condition approach (RCA). Samples collected as part of this program are analysed for sediment chemistry and grain size, as well as benthic macroinvertebrate community structure. In addition, most sites are also sampled and tested for sediment toxicity. Between 1991-2014, sampling locations included 44 Georgian Bay sites, 28 North Channel sites, and 6 main basin sites (see Figure 9) to be used as potential reference sites for assessments conducted on sediments in Areas of Concern in the Upper Great Lakes (e.g., Severn Sound, Spanish Harbour, St. Mary's River). For example, these assessments are useful for evaluating current benthic conditions in an Area of Concern in Recovery and determining whether they are improving over time, the benthic macroinvertebrate community structure relative to reference sites, and other parameters (e.g., sediment contaminant concentrations). Sampling sites used as reference sites have to be located in nearshore, depositional areas along the shoreline, excluding areas of agricultural and urban shoreline land use. Sites must also be greater than 10 km from known point source industrial and municipal waste water discharges. Samples were collected in late summer or early autumn (September-October) using a box core or mini box core and analyzed using CABIN protocols.

Details on the benthic macroinvertebrate communities at references sites are not reported on their own, only in comparison to those in Areas of Concern, when required.

Figure 9. Upper Great Lakes BEAST reference stations (L. Grapentine, pers. comm., 2017). Map created by Danielle Milani of Environment and Climate Change Canada. Imagery from Environmental Systems Research Institute (ESRI).

As part of their Great Lakes Nearshore Reference and Index Station Network surveys, MOECC samples benthic invertebrates at locations throughout the Canadian waters of Lake Huron Figure 10). This network is intended to provide information on where and how ambient water quality conditions are changing over time by periodically monitoring a suite of indicators at a small network of stations. Three types of indicators are assessed: indicators of the level of contaminants present in the aquatic environment (e.g., concentrations of persistent contaminants in surficial sediment); biological indicators of trophic status and general environmental conditions (e.g., chlorophyll *a*, composition of benthic invertebrates living in bottom sediments); and indicators of habitat integrity (e.g., thermal and optical profiles of the water column, physical characterization of the lake bottom). Approximately 10-18 Great Lakes stations are surveyed annually. Lake Huron stations are sampled every six years (last sampled in 2015). The sampling protocols employ standard MOECC methodology, thereby permitting comparisons with historical and ongoing data collections elsewhere by the Ministry. Benthos samples are collected during the summer survey. Sample sorting, benthic invertebrate identification, and subsequent data tabulation and summarization are completed by an external contractor. The primary use for the information collected is as input to Great Lakes management programs for the purposes of assessing progress in meeting program objectives and to assess the success of programs designed to restore or protect environmental quality in the Great Lakes (e.g., Canadian Areas of Concern). These data are also used in the biannual *Water Quality in Ontario* reports published by MOECC. To the extent that the monitoring identifies adverse changes in environmental conditions, the information may be used to respond to changing conditions, which may include the initiation of cause-effect research or providing supporting information for the development of remedial actions.

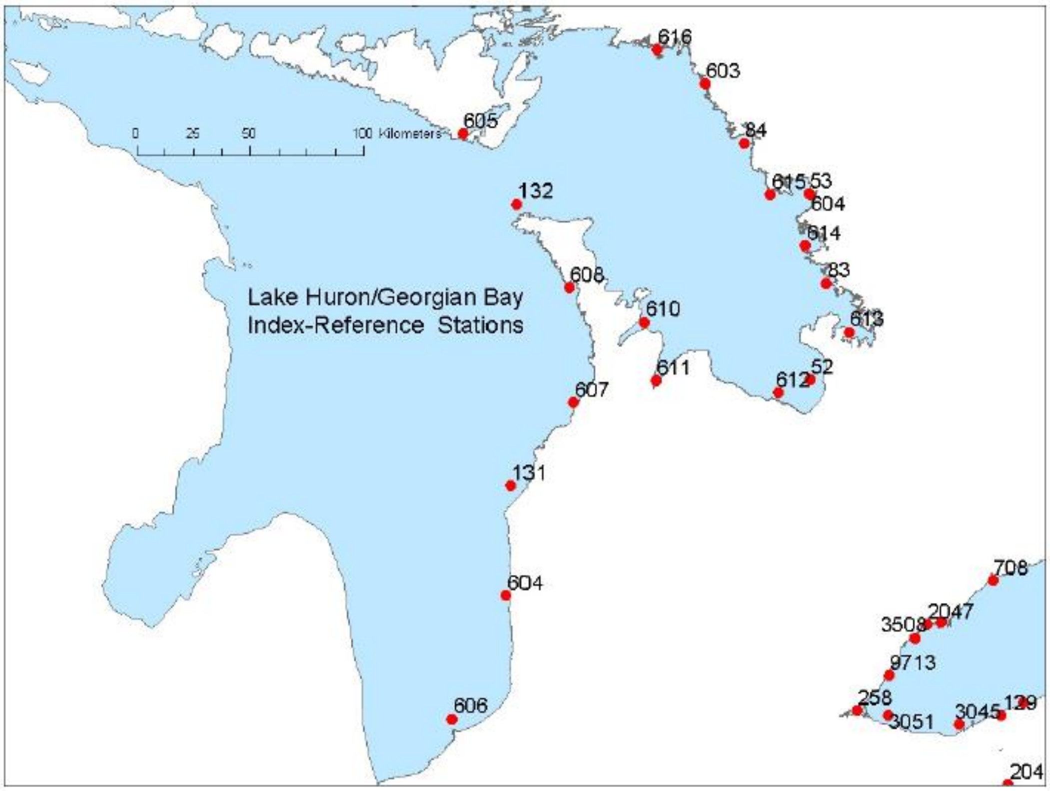


Figure 10. Lake Huron and Georgian Bay Nearshore Reference and Index Station Network sampling locations (Howell, 2015).

Severn Sound was listed by the International Joint Commission (IJC) as an Area of Concern on the Great Lakes, and through support from provincial, federal, and municipal governments and local partners, a Remedial Action Plan was formed, with subsequent delisting in 2003. From 1969 and 1973-1996, MOECC monitored trophic status indicators in Severn Sound. Beginning in 1997, the Severn Sound Environmental Association (SSEA) took over the Open Water Monitoring Program, monitoring the environmental quality of Severn Sound open water for indicators of eutrophication using the same sample collection and analytical methods as the Ministry. Presently, 11 open water stations are sampled biweekly during the ice-free season (May-October). In addition, SSEA has been sampling three stations around Honey Harbour since 1998 (Figure 11). Water clarity is measured along with vertical profiles of temperature, dissolved oxygen, conductivity, and pH. Water samples are taken throughout the sunlit portion of the water column (euphotic zone) and analyzed for a number of parameters (e.g., total phosphorus, total ammonia, total nitrate, heavy metals, ions, chlorophyll *a*). Phytoplankton and zooplankton samples are also taken for counting and identification. Water samples are collected using a depth-integrated, composite sampler deployed to the bottom of the euphotic zone (twice the Secchi depth or 1 m off bottom, whichever is less). At locations that thermally stratify in Honey Harbour, samples are also collected at 1 m off bottom. Beginning in 2001, low level total phosphorus analysis has been provided by the MOECC lab in Dorset. Phytoplankton samples are collected as euphotic zone composites and are identified to genus or species by a private contractor. Biovolume is subsequently calculated for each taxon using standard MOECC methods. Zooplankton samples are collected as vertical tows from 1 m off bottom to the surface using a Wisconsin net with 80-µm mesh. Zooplankton samples are identified by a private contractor, and density and biomass are measured. Data collected through the Open Water Monitoring Program are used to provide updates on the status of Severn Sound and specific embayments, as well as to provide background information for municipal works projects such as upgrades to wastewater treatment plants, Environmental Assessment studies, etc. All available reports can be found at www.severnsound.ca.

This *State of the Bay* report presents data and summaries from the most recent available reports and presentations at the time of writing. Results from those studies for which analysis is still ongoing may be described in future *State of the Bay* reports as they become available.

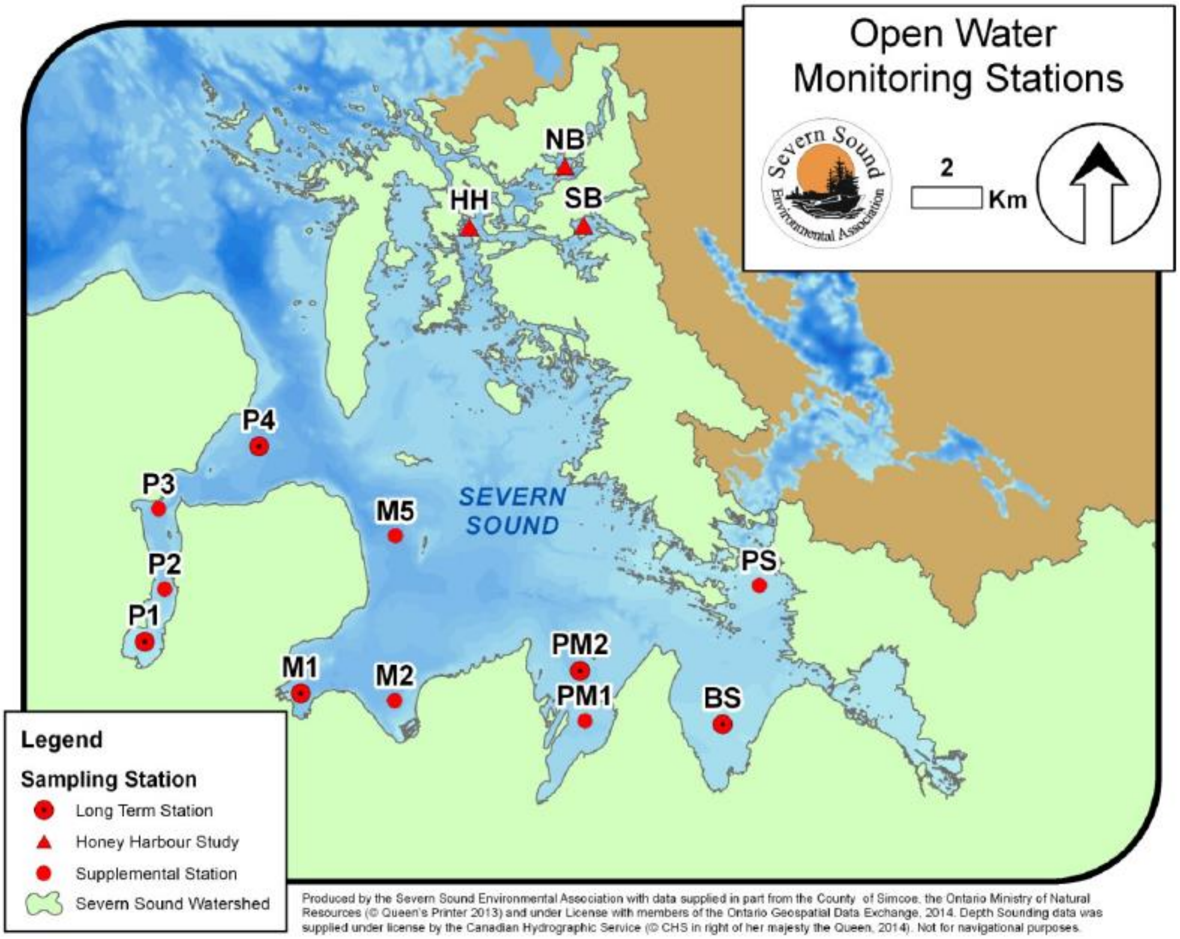


Figure 11. SSEA's Open Water Monitoring Program stations (Chiandet & Sherman, 2014). Long term stations have data going back to 1969 while periods of record for supplemental stations and Honey Harbour stations vary. The newest station is M5, which was added in 2003.

3.2.3 Why is it important?

The lower food web is a valuable indicator of aquatic ecosystem health as it forms the foundation of a healthy food web (see Figure 12). Prey fish and juvenile predatory fish (piscivores) rely on the lower food web as a main source of food for growth, and predators depend on plentiful prey for their growth – if the lower food web is in poor condition, in time higher levels of the food web will respond and reflect that condition. For instance, certain changes in the lower food web can lead to nutritional stress, slower growth rates, and smaller size of some fish, which subsequently results in higher body contaminant levels relative to size (LHPWG, 2016). In this way, changes to the lower food web can serve as a predictor of subsequent change in prey fish and populations of piscivores. A great deal can be surmised from the state of the lower food web. For example, the phytoplankton population can be used to infer impacts of nutrient enrichment or deficiency, contamination, and non-native predators, while zooplankton health can indicate changes in food web dynamics due to changes in vertebrate or invertebrate predation. These are just some examples of trophic interactions and it is important to recognize that there are both bottom-up and top-down interactions.

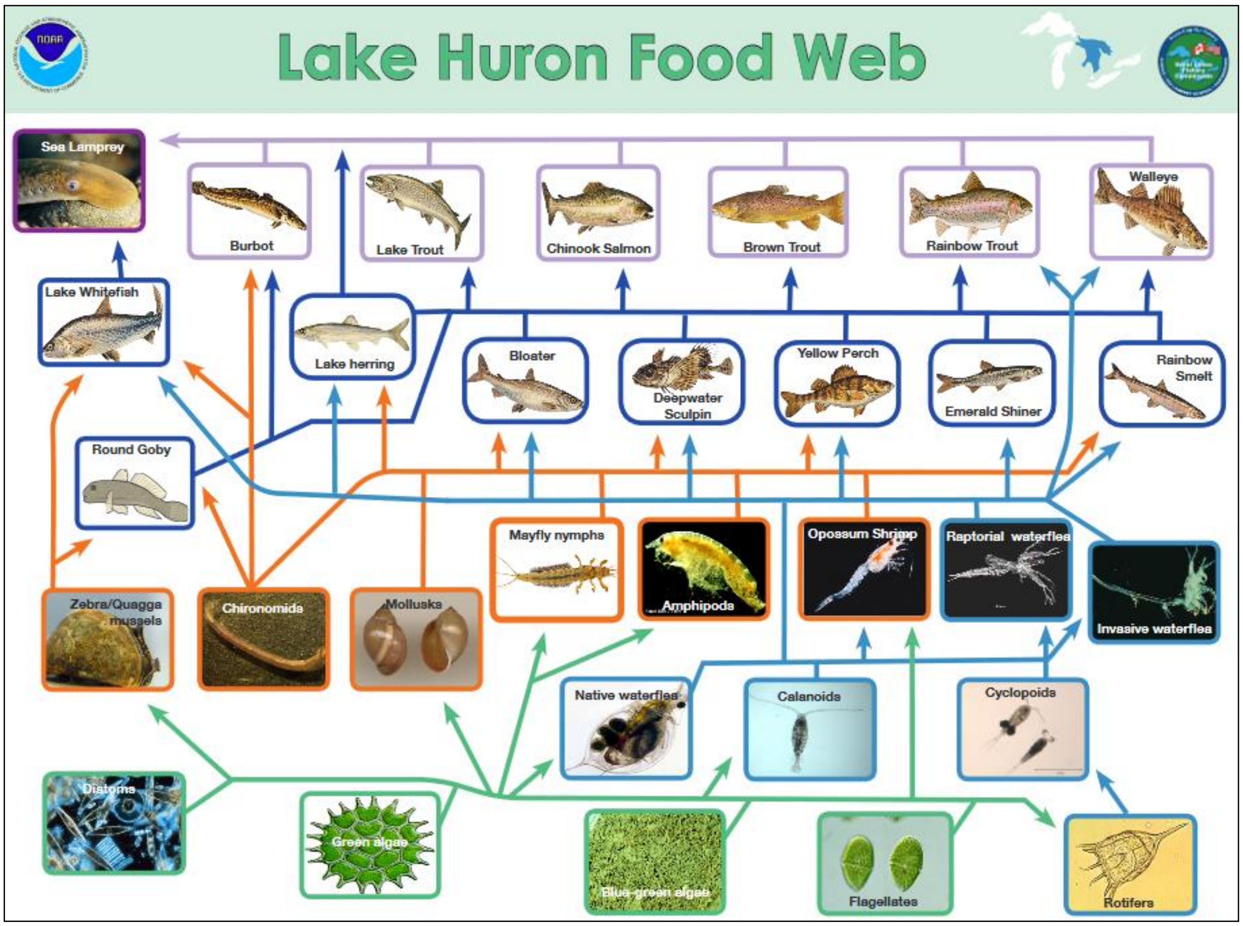


Figure 12. Lake Huron food web including phytoplankton (green outline), zooplankton (light blue outline), benthic invertebrates (orange outline), prey fish (dark blue outline), and top predators (light purple outline) (NOAA Great Lakes Environmental Research Laboratory, 2009).

Significant changes to the lower food web have been documented in Lake Huron. The lake continues to undergo system-wide changes in nutrients, along with changes in phytoplankton, zooplankton, benthic invertebrate, and prey fish community dynamics (LHPWG, 2016). These lower food web changes have prompted further research on this subject. In fact, the lower food web is a reoccurring topic of discussion in the *Lake Huron LAMP* (ECCC & EPA, 2018) given the uncertainty around lake productivity and changes in composition and abundance of phytoplankton, zooplankton, and benthic invertebrates. A particular focus during the 2017 CSMI year was on quantifying the productive capacity of the lake in order to allow governmental agencies, First Nations, and community groups to better implement management programs (LHPWG, 2016).

Phytoplankton

As assessed by remote sensing of chlorophyll, phytoplankton development in Lake Huron has typically exhibited seasonality starting with a spring peak (bloom), the major episode of primary production in the water column, occurring in late April or early May, later in northern parts of the lake (EC & EPA, 2017; ECCC & EPA, 2018). A summer minimum is usually experienced August-September (lower average monthly chlorophyll concentrations), followed by a secondary maximum in October-November (higher average monthly chlorophyll concentrations) once the thermocline disappears and nutrients from the hypolimnion become available in the metalimnion and epilimnion (Riley, 2013). Generally, chlorophyll levels are lower in the north compared to the south.

From the late 1980s through the mid-1990s, the lake-wide phytoplankton community structure in Lake Huron underwent very little change. The majority of phytoplankton abundance and biomass in the lake was comprised of forty common species and varieties and all major groups were similarly abundant over this time period (Dobiesz et al., 2005).

In 2003, there was a marked decrease in the magnitude of the spring phytoplankton bloom and even further reductions seen through 2008 (EC & EPA, 2017; ECCC & EPA, 2018). The large diatoms *Tabellaria flocculosa* and *Aulacoseira islandica* which had contributed a combined total of 60% of the spring phytoplankton biovolume in 2001-2002, were reduced by over 95% in 2003-2004 (Barbiero et al., 2011). 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) (Figure 13). Given that the amount of phytoplankton in a water body is a major determinant of water clarity, it follows logically that offshore areas of Lake Huron are clearer now compared to 30 years ago (EC & EPA, 2014). Moreover, Lake Huron has surpassed Lake Superior as the clearest Great Lake (Yousef et al., 2017).

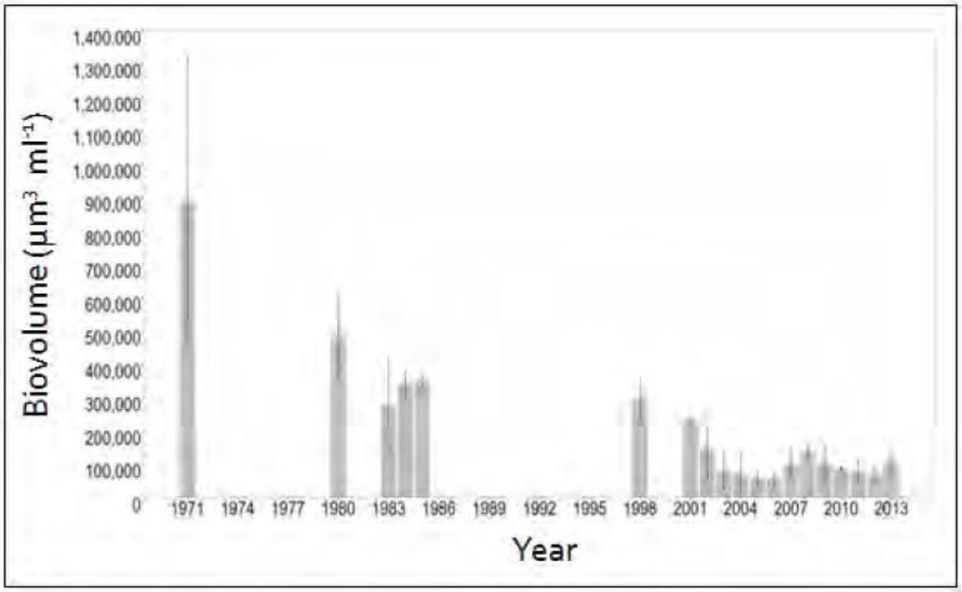


Figure 13. Lake Huron biovolume (±SE) of phytoplankton displayed as the mean of April and August estimates (multiple data sets combined by Reavie et al., 2014) (ECCC & EPA, 2018).

Possible factors contributing to the phytoplankton decline in Lake Huron are nutrient levels below desired concentrations in some offshore areas and invasions by *Dreissenid* mussels. Nutrient concentrations may be too low in some offshore regions resulting in insufficient growth of key phytoplankton species (EC & EPA, 2017). Related to nutrient concentrations, *Dreissenid* mussels have reduced pelagic nutrients and selectively consumed certain phytoplankton taxa, which has likely played a role in spring phytoplankton declines. However, Reavie et al. (2014) point out that the decline in Lake Huron's spring phytoplankton biovolume occurred earlier, and was more severe, than that of Lake Michigan, despite the fact that Lake Michigan experienced a faster and larger *Dreissenid* invasion. From available research, it appears that the dominant processes driving primary production are shifting and are not yet entirely understood. Nevertheless, the two most important future pressures on the phytoplankton community of the Great Lakes as a whole are said to be "changes in nutrient loadings and continued introductions and expansions of non-native species" (EC & EPA, 2014, p. 373).

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 14) (Sherman, 2002; SSEA, 2017b).

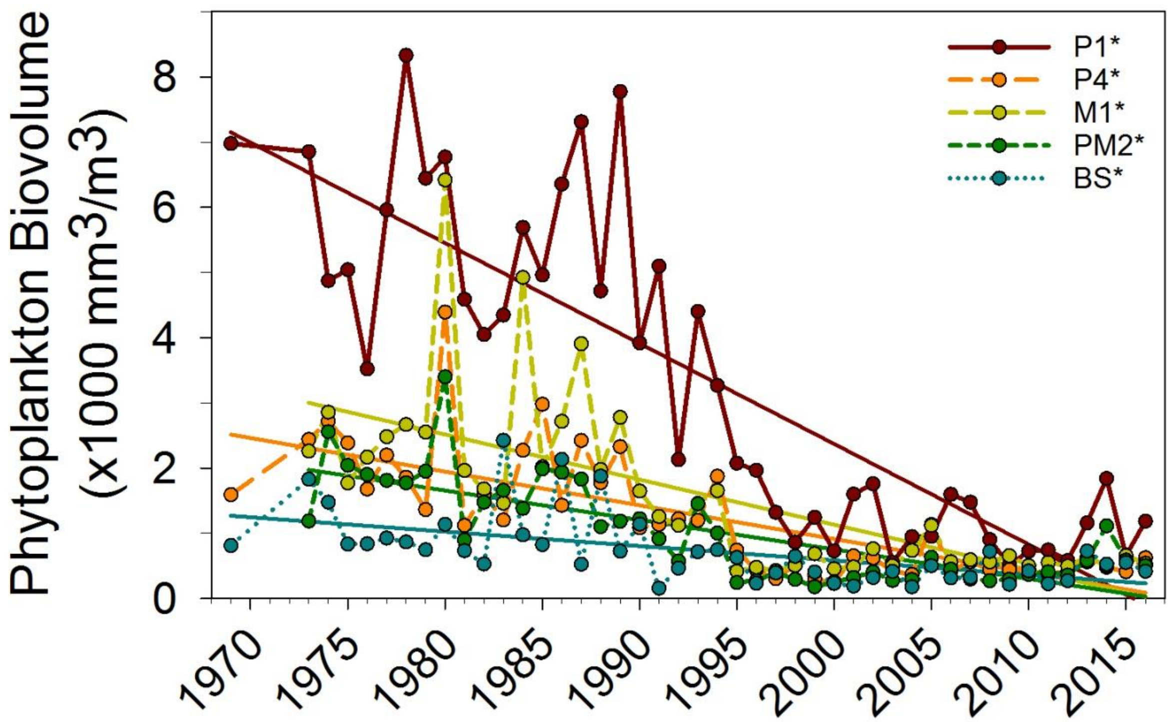


Figure 14. Annual phytoplankton biovolume at long term stations in Severn Sound from 1969-2016 (SSEA, 2017b). * indicates significant trends over this period. Station locations: P1 – inner Penetanguishene Harbour, P4 – outer Penetanguishene Harbour, M1 – Midland Bay, PM2 – Hogg Bay, BS – Sturgeon Bay.

Zooplankton

Nearly every Lake Huron fish species consumes zooplankton during at least one life stage making this an exceptionally important food source. As described in *The State of Lake Huron in 2010*, "the crustacean zooplankton community of Lake Huron has for the most part been limited to a small number of species" (Riley, 2013, p. 13). These species include the cladocerans *Daphnia mendotae*, *Bosmina longirostris*, and the invasive spiny water flea *Bythotrephes longimanus*; the diaptomid calanoid copepods *Leptodiaptomus ashlandi*, *L. minutus*, and *L. sicilis*; the deep-living calanoid *Limnocalanus macrurus*; and smaller numbers of the cyclopoid copepod *Diacyclops thomasi* (Riley, 2013). Taxonomic diversity is higher in Severn Sound due to greater diversity of habitat compared to the open waters of Lake Huron, and includes 45 genera documented between 1987 and 2014 (Chiandet, pers. comm., 2018).

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 (Figure 15) (EC & EPA, 2017; ECCC & EPA, 2018). In 2003, cladocerans had virtually disappeared from the northern region of Lake Huron and had decreased from a 58% average contribution of areal biomass in the southern region during 1998-2002 to 14% during 2003-2006. Over a similar time period, cyclopoid copepod biomass also declined sharply. Cyclopoid copepod biomass in northern Lake Huron in 2005-2006 made up only 13% of levels in 1998-2004. Similarly, biomass for 2005-2006 in southern Lake Huron represented only 7% of 1998-2004 levels (Riley, 2013). Unfortunately, the zooplankton groups that experienced the largest declines were those most often consumed by fish.

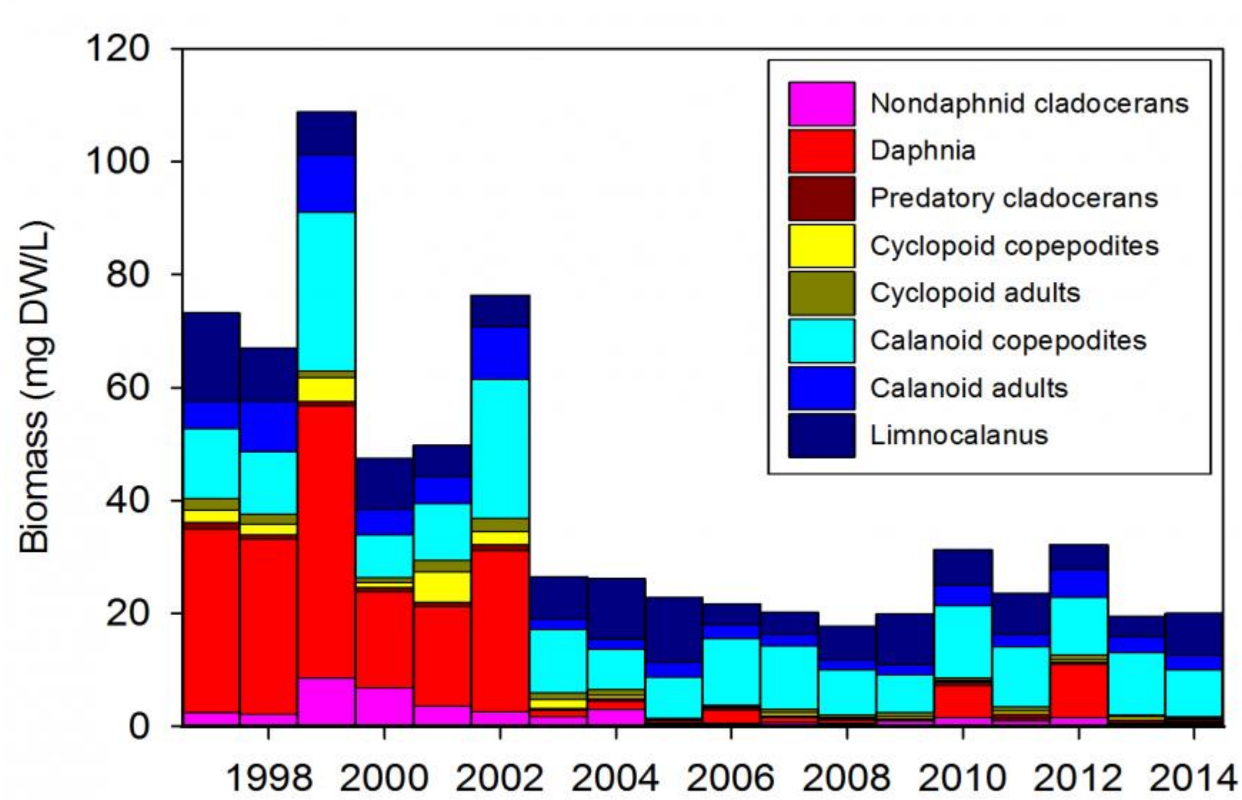


Figure 15. Decline in Lake Huron zooplankton biomass from 1997-2014 (EPA, 2017b).

The drastic decline in cladoceran biomass, particularly *Daphnia*, as well as cyclopoid copepods, resulted in a total zooplankton biomass in Lake Huron (from 4-8 g m^2 to 2 g m^2) falling to less than that of Lake Superior (3 g m^2) and a community dominated by calanoid copepods such as *L. macrurus* (EC & EPA, 2017). The calanoid biomass of Lake Huron is now similar to Lake Superior with biomass deeper in the water column (LimnoTech, 2015b). These changes could have consequences for the lake's prey fish community. Calanoid copepods are more difficult for fish to capture than cladocerans, thus, the shift in zooplankton community structure could "alter competitive outcomes between individual prey fish species if differences in their ability to capture calanoids exist" (Riley, 2013, p. 16). Overall, a decline in zooplankton has ramifications for the food web as whole due to the important link these organisms provide between phytoplankton and healthy fish populations (EC & EPA, 2014).

The zooplankton declines experienced in Lake Huron have been attributed to a number of factors including: changes in primary productivity, specifically the spring diatom bloom; changes in the fish community; introduction of the non-native predatory spiny water flea (*Bythotrephes longimanus*) first discovered in Lake Huron in 1984; and changes in nutrient availability (EC & EPA, 2017; ECCC & EPA, 2018). Invasive species continue to pose a threat to zooplankton communities. For example, the ongoing proliferation of *Dreissenid* mussels is influencing the structure and abundance of the phytoplankton community upon which many zooplankton depend for food (EC & EPA, 2017). As another example, *Bythotrephes longimanus* and *Cercopagis pengoi*, non-native cladocerans, have been shown to have an impact on zooplankton in terms of their abundance and community composition directly through predation and by influencing their vertical distribution (LHPWG, 2016; EC & EPA, 2017). In fact, a study conducted by Bunnell et al. (2011) determined that *Bythotrephes* planktivory was the most dominant factor in structuring zooplankton communities in Lake Huron, with *Bythotrephes* estimated to have eaten 78% of all zooplankton consumed by predators, including fish. Moreover, invertebrates (*Bythotrephes* and *Mysis*) consumed far more zooplankton than fish. Consumption by fish accounted for only 3% of all zooplankton consumed in this study.

In addition to invasive species, climate change may pose a threat to zooplankton. Researchers have observed increasing water temperatures and decreasing ice cover in all of the Great Lakes (Mason et al., 2016). Warmer water can be damaging for some zooplankton species and beneficial for others, but exactly how different species will be affected by a changing climate is uncertain. A species' tolerance to high temperatures is modified by a number of environmental factors including availability of food and calcium concentration in the water. In their 2016 report titled *Planning for Climate Change in Muskoka*, the Muskoka Watershed Council advocated for enhanced, continuous monitoring of zooplankton in lakes in order to be able to "detect deleterious changes quickly, and perhaps act to minimize damage" (Sale et al., 2016, p. 27). Although their report pertains to the Muskoka River Watershed, the message is also relevant to the Great Lakes and eastern Georgian Bay more specifically.

Zooplankton may also be indirectly affected by climate change due to the impact on phytoplankton, the food source of herbivorous zooplankters. A study authored by Winder and Schindler (2004) showed that increasingly warmer springs since 1962 have disrupted the trophic linkages between phytoplankton and zooplankton in Lake Washington, a large temperate lake, because of different sensitivity to warming. The authors state that "the timing of thermal stratification and the spring diatom bloom have advanced by more than 20 days during this time period" as a result of climate change over the latter part of the 20th century (Winder & Schindler, 2004, p. 2100). Consequently, they explain that the long-term decline in *Daphnia* populations, a keystone herbivorous zooplankter, is associated with "an expanding temporal mismatch with the spring diatom bloom" (Winder & Schindler, 2004, p. 2100). This mismatch poses a real threat to the rest of the food web as phytoplankton-zooplankton interactions form the basis for energy flux to higher trophic levels. It is important to note, however, that not all herbivorous zooplankton taxa are experiencing this mismatch. The ability to respond to changes in the timing of phytoplankton blooms has differed among zooplankton species. Winder and Schindler (2004, p. 2103) write that the phenology of the herbivorous rotifer *Keratella*, "paralleled the advance in timing of the phytoplankton peak".

Benthic invertebrates

According to Nalepa et al. (2007, p. 421), benthic macroinvertebrate communities in the Great Lakes have been undergoing broad changes that are "unprecedented in both spatial extent and temporal scale”. 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 was once the most abundant benthic organism in the cold, offshore profundal regions (greater than 30 m) of Lake Huron (EC & EPA, 2017), and a key component of the food web in these regions. It was present but less prominent in the nearshore and naturally absent from shallow, warm bays, basins, and river mouths (EC & EPA, 2017). *Diporeia* live in the upper few centimetres of bottom sediment feeding on settled algal material from the water column, mostly diatoms, and are fed on by most Lake Huron fish (ECCC & EPA, 2018).

Diporeia abundance has drastically declined and now comprises only a small portion of the Lake Huron benthos. Between 1972 and 2000, mean *Diporeia* abundances in the main basin at 18-30 m, 31-50 m, and 51-90 m declined 99.8%, 90.0%, and 52.1%, respectively (Riley, 2013). By 2003, *Diporeia* populations fell to less than half their 2000 abundance (Figure 16) and biomass fell below levels in Lake Superior (EC & EPA, 2017). Between 2002 and 2007, *Diporeia* had also declined throughout Georgian Bay and the North Channel, even with fewer *Dreissenid* mussels present in these regions. In Georgian Bay, mean *Diporeia* densities across depth intervals ranged from 40-100 m^2 in 2007 whereas in 2002, the same range had been 1400-1700 m^2. The change in the North Channel was less striking but still noteworthy. In 2007, the range in mean densities was 250-890 m^2 compared to 900-3300 m^2 in 2002 (Riley, 2013). 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 other large invertebrate found in the offshore region, *Mysis* 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.

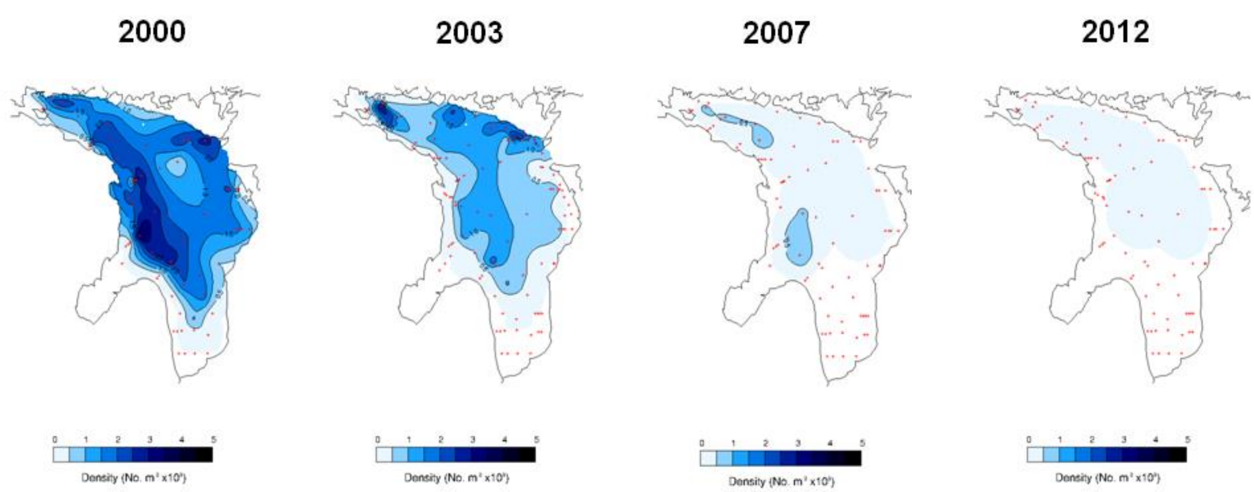


Figure 16. Decline of the amphipod *Diporeia* in Lake Huron from 2000-2007, density in thousands per m^2 (EC & EPA, 2009).

The crash of *Diporeia* in Lake Huron coincided with the proliferation of *Dreissenids*, however, the nature of these interactions is not yet well understood (EC & EPA, 2017). A commonly referenced hypothesis is that *Dreissenids* are shunting energy and nutrients into a benthic pathway, thus reducing their availability for *Diporeia* and pelagic zooplankton and fish (EC & EPA, 2014; LimnoTech, 2015b). Other theories include that waste products from *Dreissenids* are toxic to *Diporeia* (Hinderer et al., 2011) and that diseases, pathogens, and parasites have played a role in the decline (Messick et al., 2004). A reduction in available food has been disregarded as a potential main cause for the *Diporeia* decline given their complete disappearance from areas where food is still settling to the bottom and also where no local populations of *Dreissenids* were present (EC & EPA, 2014). Abundances can also be influenced by shifts in predation pressure resulting from changes in fish populations (EC & EPA, 2017). Ultimately, the cause or causes behind the *Diporeia* decline are not entirely clear but it is apparent that the loss of *Diporeia* represents the loss of a major food source for many Lake Huron fish species. Consequently, fish populations have responded with changes in diet, movement to areas with more food, and reductions in weight and/or energy content. These changes have implications for fish populations which include changes in distribution, abundance, growth, recruitment, and condition (EC & EPA, 2017).

While not as severe as *Diporeia*, declines in oligochaetes and sphaeriids were also observed from the early 1970s to 2000 across all depth intervals. Conversely, consistent changes in chironomids were not apparent over the same time period (Riley, 2013). During the 2000s, trends in oligochaetes varied according to depth interval with mean densities increasing at shallow depths (<50 m) and decreasing at greater depths (>50 m). Since 2007, oligochaete abundance has been up particularly at 30-90 m depths and in southeast Lake Huron, abundance increased rapidly in the nearshore (<50 m) from 2007-2012, presumably due to a combination of factors including higher sedimentation rates, nutrient inputs, and growth in algal biomass (LimnoTech, 2015b; LHPWG, 2016). Overall, oligochaete worms have become more dominant and biomass has increased. In terms of sphaeriids and chironomids, during the 2000s, densities were inconsistent with no clear temporal trends within depth intervals (Riley, 2013). More recently, sphaeriids have generally trended downward while chironomids have shown little change.

The abundance of zebra and quagga mussels can have a dramatic impact on the structure and abundance of aquatic communities. These filter feeders affect nutrient availability by removing detritus, algae, and small zooplankton from the water column, resulting in less available food for young fish, zooplankton and other native species (Riley, 2013). Zebra mussels became established in Lake Huron in the early 1990s and their abundances peaked in 2000-2003 in the main basin and in 2007 in Georgian Bay. Within the same general time period, mean density of zebra mussels was $<1/m^2$ in the North Channel. Quagga mussels became established in the lake 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). Peak biomass reported in 2015 was at 31-50 m, populations had stabilized at <90 m but were still climbing at >90 m (LimnoTech, 2015a). Overall, Lake Huron has a low abundance of *Dreissenids* relative to Lake Michigan and Lake Ontario, but mussels from Lake Huron are healthier on an individual basis (LimnoTech, 2015a).

3.2.4 What are the results?

The following results from this body of research are presented first at the Lake Huron scale and then at the Georgian Bay, eastern Georgian Bay, and finer scales. Where possible, results are discussed in terms of trends and focus on abundance and/or biomass and community composition.

Lake Huron

Phytoplankton abundance and community composition in the open waters of Lake Huron are described in the *Lake Huron LAMP* as being in fair condition with a 'deteriorating' trend (ECCC & EPA, 2018). This status and trend are echoed in the 2017 *State of the Great Lakes* report which goes on to explain that Lake Huron has a phytoplankton assemblage reflecting oligotrophic conditions. If trophic status was the only factor being considered, Lake Huron's low phytoplankton abundance would seemingly reflect good conditions. However, the report clarifies that the "periodic, mussel-driven depletion of phytoplankton" (EC & EPA 2017, p. 225) represents not only food web stress, but also likely an overall reduction in the carrying capacity of the lake. Since the notable decrease in the magnitude of the spring phytoplankton bloom observed in 2003, this major episode of primary production has remained almost entirely absent to present (EC & EPA, 2017; ECCC & EPA, 2018).

The status of Lake Huron zooplankton was assessed in the *Lake Huron LAMP* as poor with an 'unchanging' trend (ECCC & EPA, 2018). Biomass has remained low since declines in 2003 and no further change in community composition has been seen (EC & EPA, 2017). Despite the similarity of Lake Huron's current zooplankton status to that of Lake Superior, the abruptness with which the zooplankton community changed in 2003 has had ecosystem implications (EC & EPA, 2017). The composition of summer zooplankton communities in Lake Huron is now characteristic of cold, oligotrophic systems with an increasing proportion of calanoid copepods, largely the result of substantial declines in cladoceran and cyclopoid copepod populations. These declines, coupled with continued reductions in *Diporeia* populations, may represent a decreasing food base for prey fish. The 2017 *State of the Great Lakes* report points out that the changes in Lake Huron's zooplankton community are "consistent with reductions in nutrient levels … and could represent a consequence of nutrient reduction activities, perhaps compounded by effects of dreissenid mussels" (EC & EPA, 2017, p. 232). However, the authors note that the exact mechanisms of zooplankton declines have yet to be fully determined (EC & EPA, 2017) and even the mechanisms of nutrient reductions are poorly understood.

As a whole, the Lake Huron benthic invertebrate community is characterized as being in good condition with an 'unchanging' trend (EC & EPA, 2017). Conversely, looking specifically at *Diporeia*, the status is considered to be poor with a 'deteriorating' trend, reflecting the continued decline in *Diporeia* abundance (EC & EPA, 2017; ECCC & EPA, 2018). Lake wide *Diporeia* surveys were conducted in 2000, 2007, and 2012. Abundances in 2007 were lower by 93% compared to 2000, and 2012 abundances were even lower than those in 2007 (EC & EPA, 2014). Abundances at depths 31-90 m are now <100/m^2 and <300/m^2 at depths >90 m (EC & EPA, 2017). *Dreissenid* mussels are also listed as poor with a 'deteriorating' trend but differ from *Diporei*a in that this description is based on their continued expansion in Lake Huron, rather than a reduction in abundance (ECCC & EPA, 2018). With regard to the

OTI, as of 2014, most sites in Lake Huron had been below 0.6 over the past decade, indicating oligotrophic conditions (EC & EPA, 2014).

According to the *Lake Huron LAMP*, future lower food web trends in Lake Huron may be dependent upon *Dreissenid* mussel density, as well as nutrients (ECCC & EPA, 2018).

Table 3. Summary of lower food web trends at the Lake Huron scale.

Component of Lower Food Web	Trend
Phytoplankton	Deteriorating
Zooplankton	Unchanging
Benthic invertebrates	Unchanging
- *Diporeia*	Deteriorating
- *Dreissenid* mussels	Deteriorating

Georgian Bay

At the time of writing, the most recent results from SSEA's Open Water Monitoring Program indicated that all Severn Sound bays had shown a decrease in the total biovolume of phytoplankton since 1973, particularly after 1994/5 when wastewater treatment plants in Penetanguishene were upgraded and zebra mussels also became widespread across Severn Sound. During the same time period, zooplankton diversity had fluctuated but remained healthy (SSEA, 2017b). Recent analysis indicates that since 1994, total biovolume in Penetanguishene Harbour and Midland Bay has not shown any significant trends, while biovolume in Hogg Bay and at the mouth of the Severn River has increased.

A 2014 Honey Harbour water quality report indicated that between 1998 and 2012, total phytoplankton biovolume fluctuated from year to year but had not increased significantly at the three Honey Harbour stations (Chiandet & Sherman, 2014). However, 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).

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.

With regard to zooplankton in Honey Harbour, 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.

Nalepa et al. (2007) noted that Lake Huron was the least studied of all the Great Lakes in terms of assessing long-term trends in the benthic invertebrate community. Further, the authors reported that while recent trends had been documented in Saginaw Bay, South Bay (Manitoulin Island), and in the shallow, nearshore zone (<2 m), trends in the open water of the main basin, Georgian Bay, and the North Channel remained largely unknown (Nalepa et al., 2007). In response to this acknowledged gap, Nalepa et al.'s 2007 paper presents results of surveys conducted in the main basin, North Channel, and, of particular interest for this report, Georgian Bay (Figure 17). Results from surveys conducted in Georgian Bay in 2002 were compared to results from a 1973 survey by Loveridge and Cook (1976) in order to assess long-term trends. Sampling in 2002 involved PONAR grabs at 15 sites in Georgian Bay. Sampling sites in 2002 were matched by depth and location to the 1973 sites. In Georgian Bay, Nalepa et al. (2007) found that differences between years (1973 and 2002) were non-significant for the four taxa considered – *Diporeia spp.*, oligochaeta, sphaeriidae, chironomidae – and mean total densities were remarkably similar (2,736 ± 436/m^2 in 1973 and 2,962 ± 474/m^2 in 2002). The authors state that the lack of density difference suggests that increased productivity resulting from nutrient enrichment was not an issue or alternatively, that productivity increased but then declined to 1973 levels by 2002. Sampling done off Cape Rich (southern end of Georgian Bay, north of Meaford) in the same general time period showed declines in *Diporeia* and sphaeriidae which may be related to greater densities of *Dreissenid* mussels at Cape Rich sites compared to the other Georgian Bay sites (mean density of 1,700/m^2 at 20 m off Cape Rich compared to 86/m^2 at the <30 m interval). Between 1973 and 2002, the oligochaete community in Georgian Bay shifted from oligotrophic-indicator taxa to more eutrophic taxa. The mean OTI value was 1.00 in 1973 and 1.09 in 2002 (Nalepa et al., 2007).

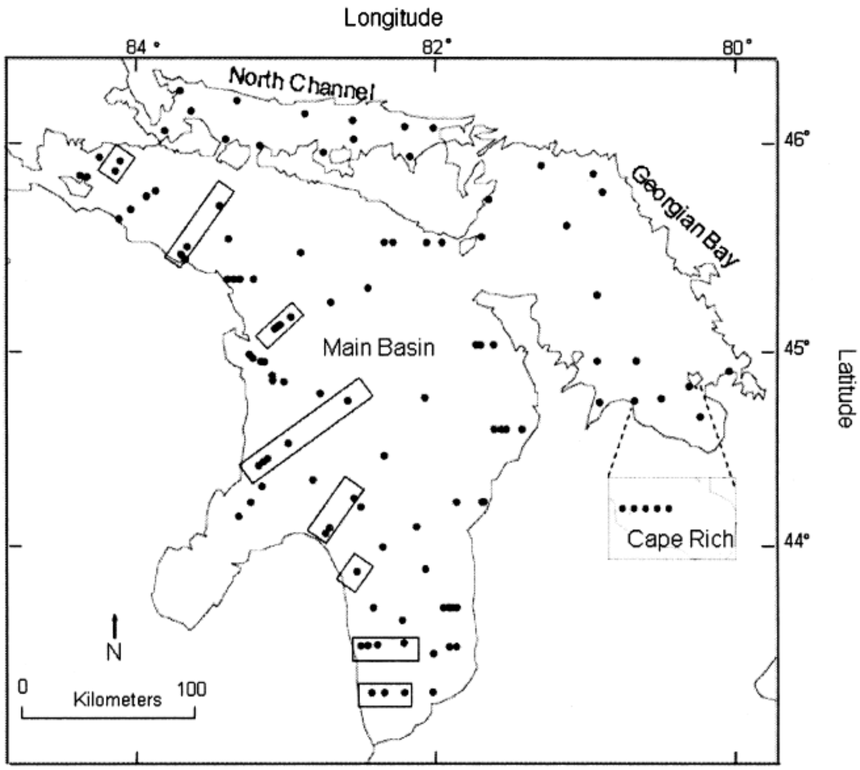


Figure 17. Sites sampled in the main basin of Lake Huron in 2000 and 2003, and sites sampled in the North Channel and Georgian Bay in 2002 (Nalepa et al., 2007).

As previously stated, analysis of data gathered during MOECC's diver-based benthic surveys is still underway and complete results will be available in the near future. However, some high level observations regarding *Dreissenid* mussels have been presented. For instance, 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 (Howell, pers. comm., 2017). Mussel abundance is broadly correlated with trophic state. Honing in on 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) (see Figure 18) (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).

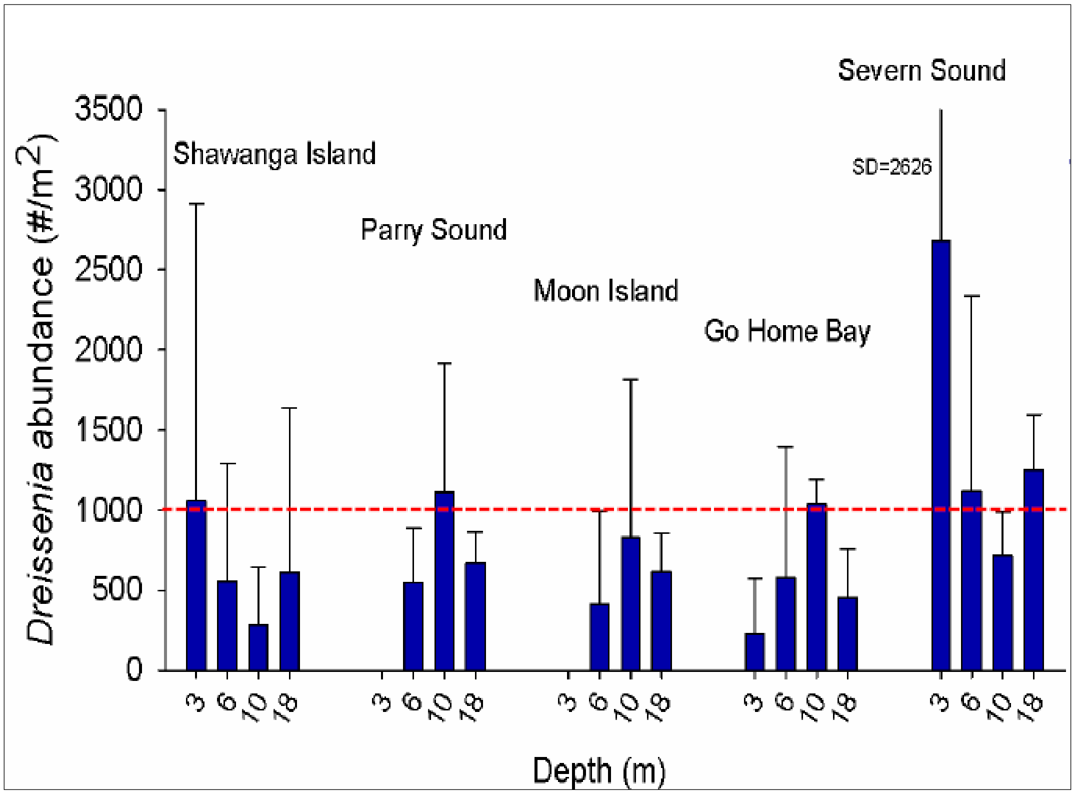


Figure 18. *Dreissenid* mussel abundance at various eastern Georgian Bay locations in 2014 (Howell, 2015).

3.3 Prey fish

3.3.1 What is measured?

As described in *State of the Great Lakes 2011* prepared by Environment Canada and the United States Environmental Protection Agency (EPA) (2014), the 'prey fish' component of the fish community refers to species that prey on invertebrates for their entire life history including pelagic, benthopelagic, and benthic species. Monitoring of prey fish takes place in both nearshore and offshore areas (demersal and pelagic zones) of Lake Huron. These surveys are often carried out with the aim of understanding broadscale changes in the prey fish community. For this purpose, measures such as species composition, abundance and relative abundance, age, biomass, density, and recruitment are typically considered. Projects with more specific goals may also consider measures such as body condition and energetic condition along with others.

3.3.2 How is it measured?

Several organizations are involved in monitoring prey fish communities. The United States Geological Survey (USGS) Great Lakes Science Center (GLSC) has been conducting annual fall bottom trawl surveys to assess changes in the offshore demersal fish community of Lake Huron since 1973. These surveys are carried out only in the main basin of Lake Huron. The surveys involve bottom trawls (using 21 m headrope since 1992 and 12 m headrope from 1973-1991) at fixed transects at up to eleven depths (9, 18, 27, 36, 46, 55, 64, 73, 82, 92, and 110 m). Of the six sampling locations, five transects are located in the Michigan waters of Lake Huron and one transect, added in 1998, is located in Ontario waters. Ten minute trawl tows are conducted during daylight hours at each transect. Catches are sorted by species and each species is counted and weighed in aggregate (large catches are subsampled). Catches of alewife (*Alosa pseudoharengus*), rainbow smelt (*Osmerus mordax*), and bloater (*Coregonus hoyi*) are separated into size-based age classes for analysis. Each year, the GLSC reports estimates of density (fish/ha), biomass (kg/ha), relative abundance (catch per 10 minutes on bottom), size and age structure, and species composition.

In recognition of the fact that a substantial proportion of the prey fish biomass is distributed in the pelagic zone, integrated acoustic and mid-water trawl surveys have been conducted by the GLSC annually since 2004 (the first survey was conducted in 1997) in each of the three distinct basins of Lake Huron – main basin, the North Channel, and Georgian Bay. These surveys utilize a stratified-random design with acoustic transects and accompanying mid-water trawl tows in five geographic strata including Georgian Bay. Trawling depths (10-250 m), durations, and locations vary and are chosen to target fish aggregations. Fish are collected using a 16.5 m headrope mid-water trawl or a 19.8 m headrope mid-water trawl depending on the research vessel. Fish captured in the mid-water trawl tows are identified to species, counted, and weighed in aggregate by species. A subsample from each species is measured for total length and fish are assigned to age categories based on length cutoffs. The density (fish/ha) and biomass (kg/ha) of individual species are estimated. As with the offshore demersal fish bottom trawl surveys, results from the integrated surveys of offshore pelagic prey fish are reported by the GLSC each year. These reports present abundance and biomass estimates for major pelagic prey fish species and compares them to estimates from previous years.

With regard to the nearshore, the Ministry of Natural Resources and Forestry's (MNRF) Upper Great Lakes Management Unit (UGLMU) has been monitoring the nearshore fish community in different locations throughout the Ontario waters of Lake Huron annually since 2003. In the 2013 *State of the Bay* report, the need to track nearshore fish community abundance trends over time, specifically in eastern Georgian Bay, was identified. UGLMU subsequently sought and received funding from ECCC to supplement the traditional UGLMU Smallfish Community Assessment Program for three years, from 2014-2016. The purpose of this funding was to describe differences between 'degraded' and 'less degraded' locations to establish linkages between nearshore fish communities and water quality. This was done, in part, by gathering relative abundance and species composition data for the nearshore fish community. The Smallfish Community Assessment Program was carried out during summer months using Fyke nets and Ontario Small Mesh Index nets. Sites from three habitat types – consolidated, coarse, fine – were chosen randomly and fishing gear was set less than 150 m from shore and fished for approximately 24 hours. Captured individuals were identified to species and counted. Total length and fork length, and round weight for exotic and sport fish, were recorded for the first 20 individuals of each species from each mesh size. Biodiversity was measured and reported using probability of interspecific encounter (PIE). Catch per unit effort (CPUE) and biomass per unit effort were calculated for several key subpopulations – invasive species, preybase, and sport fish. Since 2014, the following locations have been included in the program: Britt; Deep Bay (Parry Sound); French River; Severn Sound; Shawanaga

River; Shebeshekong River; and Sturgeon Bay. Analysis is underway and complete results will be available in the near future.

From 2014-2016, MNRF conducted hydro-acoustic surveys in Parry Sound and the northern Severn Sound area to assess the fish community, with a focus on pelagic prey fish, and evaluate the importance of Great Lakes embayments to fish productivity. Pelagic trawls and pelagic gill netting surveys were run concurrently with the acoustic surveys. The addition of netting aids in the interpretation of acoustic trends. Preliminary results indicate that the Parry Sound pelagic community is dominated by rainbow smelt, alewife, and cisco or lake herring (*Coregonus artedi*). Analysis is currently underway and complete results will be available in the near future.

The EPA, USGS, and National Oceanic and Atmospheric Administration (NOAA) collaborated on a Coordinated Science and Monitoring Initiative (CSMI) food web study. The study involved sampling 11 nearshore to offshore transects around Lake Huron on a monthly basis from April to August 2017. The transects were split across Lake Huron – three in Georgian Bay, two in the North Channel, and six in the main basin (Figure 19). All three agencies sampled nutrients, plankton, and larval fish in an effort to determine how well larval fish are growing and whether or not there is enough food to eat. While the USGS was out sampling as part of this study, they were also sampling prey fish and measuring their energetic condition. Results of this study will be available in the near future.

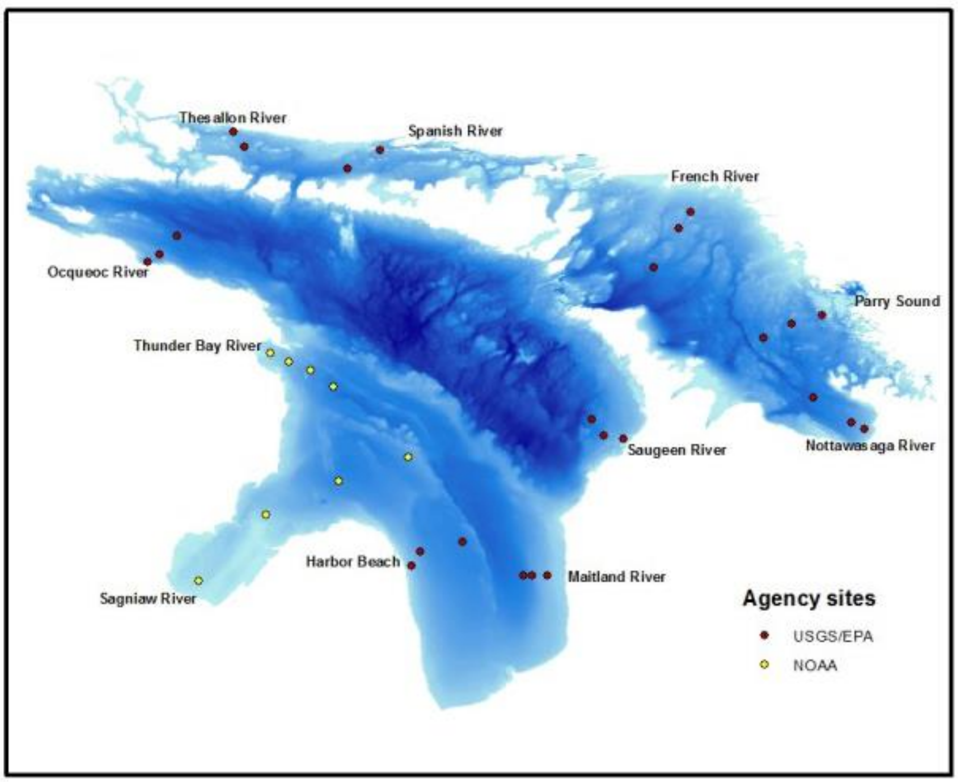


Figure 19. CSMI food web study nearshore to offshore transects.

Prey fish are captured, incidentally or otherwise, in other surveys conducted by these and other agencies (e.g., Broadscale Monitoring, Offshore Index Assessment Program, End of Spring Trap Netting). However, these surveys are not discussed here because the data are not collected and analysed with the intent of assessing the prey fish community and thus, the resulting reports based on these surveys do not describe the state of the prey fish community.

This report utilizes the most recent available data and summaries from the following sources: the GLSC *Status and Trends of the Lake Huron Offshore Demersal Fish Community, 1976-2016* report (Riley et al., 2017); the GLSC *Status and Trends of Pelagic Prey Fish in Lake Huron, 2016* report (O'Brien et al., 2017); and UGLMU (2016b) *Smallfish Community Assessment Program* summary report. These sources are used to report on some of the measures listed in section 3.3.1.

3.3.3 Why is it important?

Prey fish constitute the majority of fish production in the Great Lakes and support key ecosystem functions by connecting the aquatic food web. Prey populations rely on the availability of phytoplankton and zooplankton food sources and are in turn, a necessary food source for predatory fish. The role of prey fish populations in supporting healthy, productive populations of predator fish is recognized in the *Fish Community Objectives for Lake Huron* with the following prey objective, "maintain a diversity of prey species at population levels matched to primary production and to predator demands" (DesJardine et al., 1995, p. 21).

Prey fish populations make a great indicator of aquatic ecosystem health given their ability to bring attention to top-down and bottom-up changes to, and/or issues within, the food web. Healthy, functional fish communities incorporate healthy populations at all levels of the food web.

The Lake Huron fish community has undergone dramatic changes over the past century (see Figure 20). Historically, Lake Huron prey fish available in colder regions of the lake consisted of a mixture of native species such as deepwater ciscoes (including bloater, cisco/lake herring), sculpins (*Cottus spp.*), ninespine stickleback (*Pungitius pungitius*), and trout-perch (*Percopsis omiscomaycus*) (DesJardine et al., 1995; EC & EPA, 2014). In addition, gizzard shad (*Dorosoma cepedianum*), spottail shiners (*Notropis hudsonius*), emerald shiners (*Notropis atherinoides*), young whitefish (*Coregonus spp.*), and yellow perch (*Perca flavescens*) were also seasonally important in the diet of nearshore predators (DesJardine et al., 1995).

From the 1970s to the early 2000s, the 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.

These changes in the prey fish community are believed to be largely due to changes in the food web resulting from a combination of top-down and bottom-up pressures. Top-down pressure in the form of excessive piscivory (i.e., alewives being consumed by salmonines) is believed to have played a particularly important role in the alewife decline. Reduced primary and secondary production which are hypothesized to be associated with decreased phosphorus availability in the offshore (LimnoTech, 2015b), and reduced energy transfer from benthic to pelagic regions (EC & EPA, 2014), present a bottom-up limitation that could be negatively influencing growth and survival of fish or their larvae (LHPWG, 2016). Adding to this bottom-up limitation is the changing composition of the crustacean zooplankton community, including the introduction of predatory zooplankters (e.g., spiny water flea (*Bythotrephes longimanus*)) (EC & EPA, 2014; LHPWG, 2016). Given this combination of top-down and bottom-up pressures, prey fish may be 'squeezed' by adjacent trophic levels (LHPWG, 2016).

Changes to the composition and abundance of prey fish in Lake Huron presents new challenges for fisheries managers. Ecological changes that used to occur over decades are now happening in just a few years (MNRF, 2014). Accordingly, these changes have received considerable attention in recent years and a great deal of research is now being conducted concerning potential causes and repercussions of these changes at all levels of the aquatic food web. This research is reflected in documents such as *State of the Great Lakes* reports, the *Lake Huron Partnership Cooperative Science and Monitoring Synthesis* report (LimnoTech, 2015a), and the *Feast and Famine in the Great Lakes* report (Hinderer et al., 2011), among others.

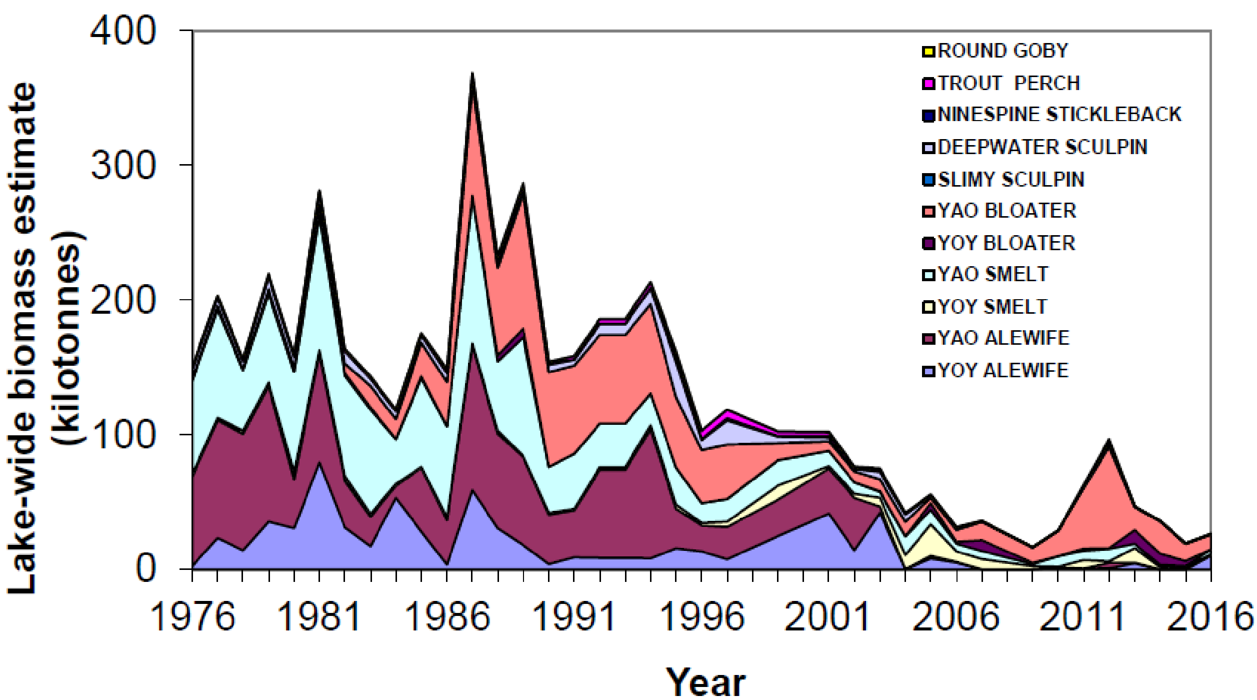


Figure 20. Lake Huron biomass of major pelagic fish species from 1976-2016 (Riley et al., 2017).

3.3.4 What are the results?

The results that follow are presented in order from general to specific starting with Lake Huron results, followed by Georgian Bay results, and then eastern Georgian Bay results. Finally, an overall summary is provided in relation to trends.

Offshore demersal prey fish – Lake Huron

In Lake Huron, the peak estimated prey fish biomass occurred in the late 1980s and has since declined steadily. While data from 2016 show an increase in estimated prey biomass of roughly 37% over the 2015 estimate, the 2016 figure is still the fourth-lowest observed in the time series and represents only 7% of the maximum biomass estimate observed in 1987. Of the total 2016 biomass estimate, yearling and older (YAO) bloater represent approximately 42% while young-of-the-year (YOY) alewife contributed 40%. This is the first time since 2006 that either YOY or YAO alewife have made a considerable contribution (>10%) to prey fish biomass estimates. In terms of general abundance, since the collapse of the offshore demersal fish community in 2004, prey fish abundance levels have remained low. The following paragraphs provide more detailed information for several notable species.

Alewife abundance remained relatively low in 2016. YAO biomass and abundance estimates were the second lowest in the history of this survey. Conversely, YOY alewife made a substantial contribution to the 2016 biomass estimate. In fact, age-0 alewife biomass and density were the highest estimated since 2003, before the alewife crash. Nevertheless, these figures remained low compared to historic estimates.

Rainbow smelt abundance and biomass estimates showed a pattern opposite to that of alewife. In 2016, YOY rainbow smelt abundance and biomass were among the lowest observed in the time series while YAO estimates for both abundance and biomass increased from 2015. Despite the increase, YAO abundance and biomass estimates remained low relative to historical estimates.

In general, bloater abundance is currently considered to be at a moderate level while biomass is described as being at low levels, comparable to estimates from 2001-2006. Poor bloater biomass estimates are believed to be linked to decreases in body condition associated with declines in the abundance of prey for bloater, including *Diporeia*. By age class, YOY bloater abundance and biomass were the second lowest estimates in the time series. YAO abundance and biomass estimates decreased from 2015 to 2016 but still contributed roughly 42% to total prey fish biomass.

Despite remaining relatively low compared to historical estimates, 2016 biomass estimates for deepwater sculpin (*Myoxocephalus thompsonii*), slimy sculpin (*Cottus cognatus*), ninespine stickleback, and trout-perch were greater than in recent years. The report authors note that Lake Huron benthic offshore conditions may have undergone changes over the years resulting in conditions that are no longer favourable for, and/or able to support, previous population levels of these species.

The invasive round goby (*Neogobius melanostomus*), first caught in a Lake Huron trawl survey in 1997, has become a significant part of lake trout (*Salvelinus namaycush*) diets in some areas of the Great

Lakes. Round goby reached peak abundance in Lake Huron in 2003, after which it declined in abundance until increasing again in 2011-2012. A decrease in round goby abundance and biomass estimates was seen in 2016, these levels are among the lowest estimates in the time series. Although round goby abundance estimates are currently considered to be at a moderate to low level in the offshore waters of Lake Huron, considerable fluctuations throughout the time series suggest that estimating abundance for this species using this survey method may be difficult. For instance, round gobies most commonly inhabit nearshore areas and are primarily found over rocky substrates. Estimates of consumption of round goby by whitefish, lake trout, and walleye (*Sander vitreus*) (He et al., 2015) suggest that prey fish assessments greatly underestimate round goby abundance and biomass in Lake Huron (LimnoTech, 2015b).

Offshore pelagic prey fish – Georgian Bay

Although still lower than in 1997 when surveys first started, pelagic prey fish biomass in Georgian Bay increased from 2015 to 2016 showing a two-fold increase to 76% of the long term mean. In contrast, the Lake Huron-wide mean pelagic fish density decreased from 1,313 fish/ha in 2015 to 824 fish/ha in 2016, a decrease of 15% representing roughly 60% of the long-term mean. The increase in biomass observed in Georgian Bay is primarily due to changes in YOY and YAO rainbow smelt and bloater, the two most dominant prey fish species in Georgian Bay.

In 2016, no alewives were captured. Despite large fluctuations in density during 2004-2013, due largely to differences in size and age structure, acoustic estimates of alewife biomass have remained low for the last decade. In fact, since 2004 alewives have not comprised more than 2% of the pelagic fish biomass. Alewife recruitment continues to be limited and the population has not shown signs of returning to higher levels of abundance seen in the past.

Compared to the main basin, rainbow smelt are more abundant in Georgian Bay but are less abundant than in the North Channel. YOY rainbow smelt density for 2016 decreased from 2015 estimates by nearly a factor of 3 to 24% of the long term mean. This figure is considerably less than the high observed in 1997. No clear trend in abundance has been observed since 2004. Conversely, YAO rainbow smelt biomass is up from 2015 to approximately 60% of the long term mean of 4.3 kg/ha, still substantially less than in 1997.

Estimated bloater density had been increasing from 2004-2015 but showed a decrease in 2016. The 2016 bloater density estimate was 33% of the estimated density for 2015. Bloater biomass estimates for 2016 were reported to have low precision and are not included here.

Emerald shiner biomass remained unchanged in 2016 relative to 2015 at 24% of the long term mean of 0.10kg/ha. In 2016, mean biomass of emerald shiner was estimated to be 0.27% of total pelagic fish biomass. With the exception of 2006, emerald shiner biomass has rarely exceeded 1% of total fish biomass between 2004 and 2014.

The 2016 GLSC pelagic prey fish report predicted that pelagic prey fish available to piscivores in 2017 would likely be similar to that seen in recent years.

Nearshore prey fish – eastern Georgian Bay

A comprehensive report capturing results from, and describing the prey fish community in, all seven locations sampled in the UGLMU's Smallfish Community Assessment Program is not yet available. However, the 2016 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. In all locations, round goby remained a minor component of the catch. In fact, round goby 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.

A more thorough assessment of nearshore prey fish populations in eastern Georgian Bay will be possible in the future using results from UGLMU's Broadscale Smallfish Community Assessment Program.

Summary

The *Lake Huron LAMP* (ECCC & EPA, 2018) summarizes the state of the Lake Huron prey fish community as being lower in abundance and diversity than in the past. Moreover, the *LAMP* reports that the status of Lake Huron prey fish is fair with an 'undetermined' trend. Similarly, the Georgian Bay results presented in the 2016 GLSC pelagic prey fish report (O'Brien et al., 2017) suggest an 'undetermined' trend. The eastern Georgian Bay nearshore prey fish trend is also best described as 'undetermined' given the need for more information, over a longer period of time.

3.4 Smallmouth bass

3.4.1 What is measured?

Smallmouth bass (*Micropterus dolomieu*) are sampled for fork and total length, round weight, sex, maturity, and age when they are captured in survey nets. Information regarding relative abundance, age structure, mortality, and maturity can be determined from these measures. Additional measures specific to a particular research study may also be included. Smallmouth bass relative abundance in terms of catch per unit effort (CPUE) is the primary measure reported. This focus is in line with the Lake Huron Fish Community Objective for smallmouth bass which refers to sustaining populations at recreationally attractive levels (DesJardine et al., 1995). As such, CPUE is the primary measure of focus in this section.

3.4.2 How is it measured?

No surveys are routinely carried out specifically targeted at documenting smallmouth bass populations. However, several surveys capture smallmouth bass (e.g., End of Spring Trap Netting, Spring Muskellunge Index Netting, Spring Walleye Index Netting, Fall Walleye Index Netting, Broadscale Monitoring, creel surveys). This section utilizes data presented in End of Spring Trap Netting (ESTN) reports as they are the most readily available and numerous (see section 3.7.2 for a detailed description of ESTN).

3.4.3 Why is it important?

Smallmouth bass are a useful indicator of aquatic ecosystem health as they are an important native predator of the nearshore warmwater fish community. The diet of smallmouth bass begins at the bottom of the food web and through maturity, expands to include almost all aquatic organisms. As a result, thriving smallmouth bass populations suggest productivity and health of the lower food web and can also provide insights on nearshore habitat quality. Smallmouth bass are targeted recreationally and support the sport fish industry in Georgian Bay along with other important species.

In eastern Georgian Bay, smallmouth bass are one of the more abundant species in terms of both numbers and biomass. Nevertheless, smallmouth bass populations are impacted by human activities including harvesting, disturbed nearshore habitat, and by summer temperatures and lake levels. The *Fish Community Objectives for Lake Huron* (DesJardine, 1995) and *Biodiversity Conservation Strategy for Lake Huron* (Franks Taylor et al., 2010) both acknowledge the importance of sustaining smallmouth bass populations at or near their recent abundance. In line with this thinking, the Eastern Georgian Bay Stewardship Council undertook a proactive Smallmouth Bass Nest Creation project in 2006-2007 in partnership with cottage associations to increase bass productivity where spawning habitat may be limited.

3.4.4 What are the results?

Table 4 details smallmouth bass relative abundance calculated from individual ESTN surveys for 10 populations within the *State of the Bay* reporting area. Table 5 provides an average smallmouth bass CPUE for each survey area.

The smallmouth bass population in the Shawanaga River area is described in more detail in the 2016 Shawanaga River area ESTN report. During the 2016 ESTN, smallmouth bass were caught in every valid net lift and were the most abundant fish sampled during the survey. In 2009, the average age of captured smallmouth bass was 5.4 years with ages ranging from 3 to 12 years. In 2015, average age was 6.1 years with ages ranging from 3 to 11 years and in 2016, average age was 5.6 years with ages ranging from 3 to 12 years. These results indicate that smallmouth bass continue to be a prominent species in the Shawanaga River area fish community with strong recruitment evidenced by several year classes being well represented. This trend of successful recruitment is consistent with smallmouth bass populations in Georgian Bay and the North Channel more broadly since the mid-1990s.

Table 4. Smallmouth bass CPUE for eastern Georgian Bay ESTN surveys from 1998 to 2016 by individual survey (UGLMU, 2016a).

Survey Area	Year	CPUE
Byng Inlet	2005	3.4
	2011	5.7
French River	2014	1.4
	2015	1.5
Key River	1998	1.8
McGregor Bay	2007	3.0
	2008	2.0
	2013	0.8
	2014	1.8
Moon River	2004	7.5
	2005	12.7
	2008	5.7
	2012	8.9
	2013	10.8
Parry Island Area	2010	1.2
Severn Sound	1999	7.5
	2000	14.0
	2001	4.7
	2002	6.8
	2003	13.2
	2004	11.4
	2005	9.5
	2007	12.8
	2010	14.3
	2012	8.5
	2013	8.3
Shawanaga River	2009	7.6
	2015	17.1
	2016	9.9
Twelve Mile Bay	2008	4.2
Wah-Wah-Taysee	2010	14.4

Table 5. Average smallmouth bass CPUE for eastern Georgian Bay ESTN surveys from 1998 to 2016 by survey area.

Survey Area	Year	CPUE
Byng Inlet	2005, 2011	4.6
French River	2014, 2015	1.4
Key River	1998	1.8
McGregor Bay	2007-2014	1.9
Moon River	2004-2013	9.1
Parry Island Area	2010	1.2
Severn Sound	1999-2013	10.1
Shawanaga River	2009-2016	11.5
Twelve Mile Bay	2008	4.2
Wah-Wah-Taysee	2010	14.4

Summary

Recent documents suggest eastern Georgian Bay smallmouth bass populations are maintaining their status as one of, if not the most, abundant nearshore predators despite the increased presence of the invasive round goby (*Neogobius melanostomus*). In fact, some sources imply that smallmouth bass have benefited from feeding on round goby (see for example LimnoTech, 2015b). Most recently, the *Lake Huron LAMP* (ECCC & EPA, 2018) states that eastern Georgian Bay shows an increase in smallmouth bass.

The available smallmouth bass relative abundance data as presented in ESTN reports suggests that there are no definitive trends. Accordingly, the smallmouth bass populations across eastern Georgian Bay can be described as 'unchanging', although future reports may reveal an 'improving' trend as suggested in the 2010 *State of Lake Huron* report (Riley, 2013) and *Lake Huron LAMP* (ECCC & EPA, 2018).

3.5 Northern pike

3.5.1 What is measured?

When captured during various netting surveys, northern pike (*Esox lucius*) are sampled for fork and total length, round weight, sex, maturity, and age. These measures provide information on relative abundance, age structure, mortality, and maturity with regard to the population being assessed. Research studies may incorporate additional measures specific to the objectives of the research. Northern pike relative abundance is the primary measure that is reported on. Accordingly, northern pike catch per unit effort (CPUE) is considered in this section.

3.5.2 How is it measured?

There are no surveys routinely carried out specifically targeted at understanding northern pike populations. Nevertheless, several surveys capture northern pike (e.g., End of Spring Trap Netting, Spring Muskellunge Index Netting, Spring Walleye Index Netting, Fall Walleye Index Netting, Broadscale Monitoring, creel surveys). This report utilizes data presented in End of Spring Trap Netting (ESTN), Fall Walleye Index Netting (FWIN), and Spring Muskellunge Index Netting (SMIN) reports (for a detailed description of ESTN and FWIN, see section 3.7.2 and for a description of SMIN, see section 3.6.2).

3.5.3 Why is it important?

Northern pike are a native top predator in nearshore waters and embayments. As such, they are a species that reflects ecosystem health through their role in the aquatic food web. Based on the status of northern pike populations, insights can be drawn regarding the productivity and health of the nearshore food web. Similar to muskellunge (*Esox masquinongy*), northern pike are reliant on functional coastal wetlands for successful spawning and nursery habitat. Consequently, reproductive success of northern pike reflects changes in habitat availability and quality. In addition to their significance as a useful indicator of fish and ecosystem health, northern pike are also an important sport fish, facing substantial fishing pressure in Georgian Bay and Lake Huron more generally.

Although northern pike are not considered threatened anywhere in Canada, they are as vulnerable to habitat loss as any other freshwater species. From a high of 1.6 million kg/year at the turn of the century, the Great Lakes northern pike fishery declined to less than 0.05 million kg/year by the late 1960s with the loss of nearshore spawning and nursery habitat as a result of development (Harvey, 2009). More recently, sustained low water levels, along with continued cottage development, have impacted the important coastal wetlands upon which northern pike rely. Figure 21 illustrates the decrease in northern pike abundance in the Severn Sound area, correlated with low Georgian Bay water levels.

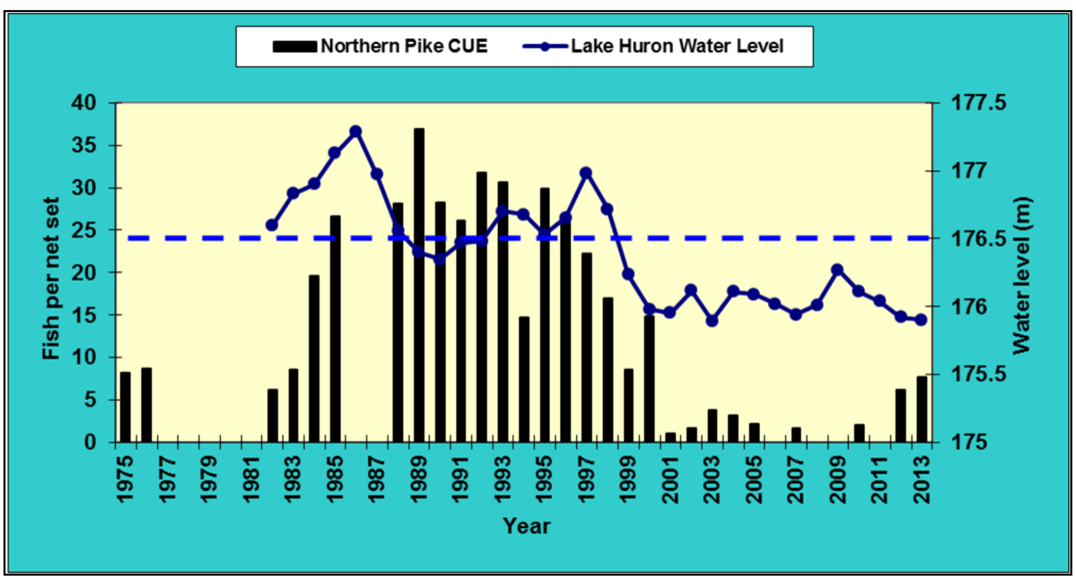


Figure 21. Severn Sound northern pike CPUE correlated with Georgian Bay water levels (1982-2013). The dashed blue line represents average Georgian Bay water level over the entire time period (Liskauskas, 2015a).

3.5.4 What are the results?

Table 6 lists relative abundance, as measured by CPUE, of 10 northern pike populations within the *State of the Bay* reporting area. This includes CPUE calculated from ESTN, FWIN, and SMIN surveys. Table 7 provides an average northern pike CPUE for each survey area based on ESTN surveys.

The 2016 Shawanaga River area ESTN report provides some additional details regarding the Shawanaga River northern pike population. In 2009, the average age of captured northern pike was 3.1 years with ages ranging from 1 to 9 years. In 2015, average age was 5.5 years with ages ranging from 2 to 10 years and in 2016, average age was 4.5 years with ages ranging from 1 to 10 years. This information suggests that some degree of successful reproduction and recruitment continued to take place in the Shawanaga River area despite a prolonged period of low water levels in Georgian Bay.

Table 6. Northern pike CPUE for eastern Georgian Bay ESTN surveys from 1998 to 2016 and FWIN and SMIN surveys since 2013 by individual survey (UGLMU, 2016a).

Survey Area	Year	CPUE (ESTN)	CPUE (FWIN)	CPUE (SMIN)	Mean Total Length (mm)
Byng Inlet	2005	0.4			775
	2011	0.5			637
French River	2014	0.5	1.04		631
	2015	0.7			582
Key River	1998	1.4			633
McGregor Bay	2007	1.0			1000
	2008	0.9			705
	2013	2.6			529
	2014	1.1			534
Moon River	2004	2.4			639
	2005	2.0			672
	2008	3.4			591
	2012	1.5			607
	2013	1.3			660
Parry Island / Wasauksing Area	2010	0.6			677
Severn Sound	1999	2.4			671
	2000	14.8			622
	2001	1.0			592
	2002	1.6			650
	2003	3.8			650
	2004	3.2			655
	2005	2.2			631
	2007	1.6			694
	2010	2.0			724
	2012	6.2			666

Survey Area	Year	CPUE (ESTN)	CPUE (FWIN)	CPUE (SMIN)	Mean Total Length (mm)
	2013	7.7			646
Shawanaga River	2009	1.3			597
	2015	1.1	1.07	3.32* 1.42**	755
	2016	1.1	1.39	1.76* 1.85**	650
Twelve Mile Bay	2008	1.0			658
Wah-Wah-Taysee	2010	1.4			717

*trap net CPUE, **hoop net CPUE

Table 7. Average northern pike CPUE for eastern Georgian Bay ESTN surveys from 1998 to 2016 by survey area (UGLMU, 2016a).

Survey Area	Year	CPUE
Byng Inlet	2005, 2011	0.4
French River	2014, 2015	0.6
Key River	1998	1.4
McGregor Bay	2007-2014	1.4
Moon River	2004-2013	2.1
Parry Island Area	2010	0.6
Severn Sound	1999-2013	4.2
Shawanaga River	2009-2016	1.2
Twelve Mile Bay	2008	1.0
Wah-Wah-Taysee	2010	1.4

Summary

Similar levels of northern pike abundance are seen across the 10 eastern and northern Georgian Bay northern pike populations examined. These levels of abundance do not show any definitive trends, therefore, the populations can be considered to be 'unchanging'. Although current levels of abundance in Severn Sound are well below the highs observed in the 1980s and 1990s, the abundance of the population appears to be increasing more recently. However, additional years of data are required before it can be stated that this population is in fact exhibiting an 'improving' trend.

3.6 Muskellunge

3.6.1 What is measured?

The Ministry of Natural Resources and Forestry's (MNRF) Upper Great Lakes Management Unit (UGLMU) has been assessing muskellunge (*Esox masquinongy*) populations in eastern Georgian Bay and the North Channel since 1996. A range of information is collected to describe these populations in various ways. Collecting data related to spawning stocks facilitates the management of self-sustaining muskellunge populations which is the primary management goal in Ontario with regard to muskellunge. Relative abundance in terms of muskellunge catch per unit effort (CPUE) is commonly measured and compared across regions. A secondary goal in Ontario is the provision of quality trophy angling opportunities. As such, mean and maximum total length are typically measured and reported in addition to relative abundance of the spawning population. These two measures are considered in this report, as abundance and size are indicators of the species' overall health.

3.6.2 How is it measured?

UGLMU's assessment of muskellunge populations in Georgian Bay and the North Channel has primarily involved Spring Muskellunge Index Netting (SMIN) (UGLMU, 2008). The SMIN protocol was designed by UGLMU specifically to assess muskellunge populations during the spawning run. SMIN surveys utilize live capture trap net gear in known or presumed muskellunge habitat. Captured muskellunge are biologically sampled for length, weight, girth, sex, and may be affixed with an external floy tag to monitor future movements and survival. The protocol uses a roving design which involves moving nets regularly depending on muskellunge catches. This approach allows for a large number of sites and areas to be surveyed in a relatively short period of time, which is important given the relatively low abundance of adult muskellunge and their accessibility to nearshore assessment gear for a limited period of time during the spring spawning run (UGLMU, 2008).

From 1996-2015, 26 targeted muskellunge spawning surveys (SMINs) have been conducted in eastern Georgian Bay and the North Channel. SMIN surveys accounted for 80% of the 925 muskellunge captured and tagged between 1996 and 2015. Muskellunge are also occasionally captured incidentally during several other types of netting. This includes Spring Walleye Index Netting, End of Spring Trap Netting, Fall Walleye Index Netting, and Fall Lake Trout Index Netting surveys.

In addition to netting, various types of creel surveys and voluntary angler diary programs provide important information about muskellunge populations. Angler diaries are considered useful for specialized fisheries such as muskellunge where angling effort is sporadic and catches are typically low. Two main angler diary programs exist in Ontario, MNRF-sponsored programs and the Muskies Canada Incorporated (MCI) angler diary program. MNRF-sponsored programs require cooperation from anglers and/or tourist lodge operators. Information is submitted by participants at the end of the fishing season. The MCI program was initiated in 1979 and has been maintained by its members since. MCI members provide information on fishing activity (e.g., number of active anglers, length of time fishing, catch (whether successful or not)) and biological information for any muskellunge caught (e.g., length, girth, sex, incidence of lymphosarcoma). For both programs, participants are specialist anglers who target muskellunge.

Data from available SMIN reports are drawn on here. Wherever possible, these sources are used to report on relative abundance as measured by CPUE and mean and maximum total length. Information from MNRF-sponsored and MCI angler diaries is also used to provide a broad overview of the state of muskellunge populations in Georgian Bay and province-wide.

3.6.3 Why is it important?

Muskellunge are a native predator of nearshore environments in Georgian Bay and a highly sought after trophy fish. The nearshore waters of eastern Georgian Bay and the North Channel reportedly support the largest contiguous distribution of muskellunge populations in the Great Lakes (Liskauskas, in press). Assessing muskellunge populations can help in drawing conclusions about the productivity and health of nearshore fish communities and the lower food web. In addition, muskellunge require functional coastal wetlands to spawn and changes in habitat quality are often reflected in their reproductive success. Accordingly, muskellunge are valuable indicators of the health of nearshore environments in Georgian Bay and the aquatic ecosystem more broadly.

Muskellunge fisheries in Ontario are managed solely on the basis of self-sustaining stocks and at present, Georgian Bay supports a “world class”, naturally reproducing muskellunge fishery. However, muskellunge have a low reproductive rate, grow rather slowly, and in the past, have had their spawning and nursery habitat in Georgian Bay adversely affected by sustained low water levels, creating concern over some populations. Several agencies have recognized that if the muskellunge population is to remain self-sustaining, the preservation and enhancement of spawning and nursery habitat will be critical to the well being of the species.

3.6.4 What are the results?

The 2008 Moon River Delta Muskellunge Population Assessment Survey involved four live-capture trap nets and the use of four hoop nets on an experimental basis. Additionally, muskellunge captured in an ESTN survey in the same area were included in the biological assessment of the SMIN captured muskellunge. A total of 43 muskellunge were captured, 18 females, 20 males, and the remaining 5 unknown. Of these 43 fish, 5% were recaptures with one individual having been tagged in 2000 and the other in 2005. The number of muskellunge captured at each netting location varied from 0 to 10 fish. Muskellunge were captured at 6 of 13 (46%) of the trap net locations and 6 of 14 (43%) of the hoop net locations. The muskellunge CPUE for trap nets, hoop nets, and ESTN were 0.23, 0.21, and 0.39, respectively. These catch rates are similar to those found at other locations sampled in Georgian Bay and the North Channel. In terms of size, female muskellunge averaged a total length of 1231 mm (range 1095 mm-1375 mm) while male muskellunge averaged 1005 mm (range 709 mm-1180 mm). Overall, the comparable catch rates, coupled with the wide range in size classes of mature muskellunge captured, and the widespread distribution of potential spawning habitat suggests that the muskellunge populations in the Moon River delta are well established.

In 2013 a SMIN survey was conducted in Severn Sound with 37 valid trap net sets and 22 hoop net sets. As with the 2008 Moon River Delta Muskellunge Population Assessment, muskellunge captured during the ESTN in the same area were also incorporated in the Severn Sound SMIN results. A total of 22 muskellunge were captured in trap nets, 2 in hoop nets, and 10 in ESTN nets (13 females, 19 males, 2 unknown). The muskellunge CPUE was 0.6. Female muskellunge average total length was 1196 mm and male average total length was 985 mm.

SMIN surveys were conducted in 2015 and 2016 in the Shawanaga River area. In 2015, 38 trap net sets captured 22 muskellunge for a CPUE of 0.58 (muskellunge captured at 7 of 11 sites) and 12 hoop net sets captured 2 muskellunge for a CPUE of 0.17 (muskellunge captured at 2 of 4 sites). Of the captured muskellunge, one was a recapture from 2006 and three were recaptures from 2009. Female average total length was 1175 mm (range 975 mm-1338 mm) while male average total length was 1083 mm (range 918 mm-1262 mm). In 2016 the netting effort in the Shawanaga River area was increased. A total of 105 trap net sets captured 18 muskellunge for a CPUE of 0.17 (captures at 35% of the sites) and 28 hoop net sets captured 1 muskellunge for a CPUE of 0.04 (captures at 11% of the sites). Six females and 13 males were captured. Three recaptures were all from 2015. As shown in Figure 22, average total length of both females and males was slightly below 2015 values but still comparable to previous years (2015, 2009, 2006). CPUE and average total length results from other SMIN efforts are summarized in Figure 23 and Figure 24. As illustrated in Figure 23, muskellunge populations in eastern Georgian Bay and the North Channel show no consistent trends in CPUE.

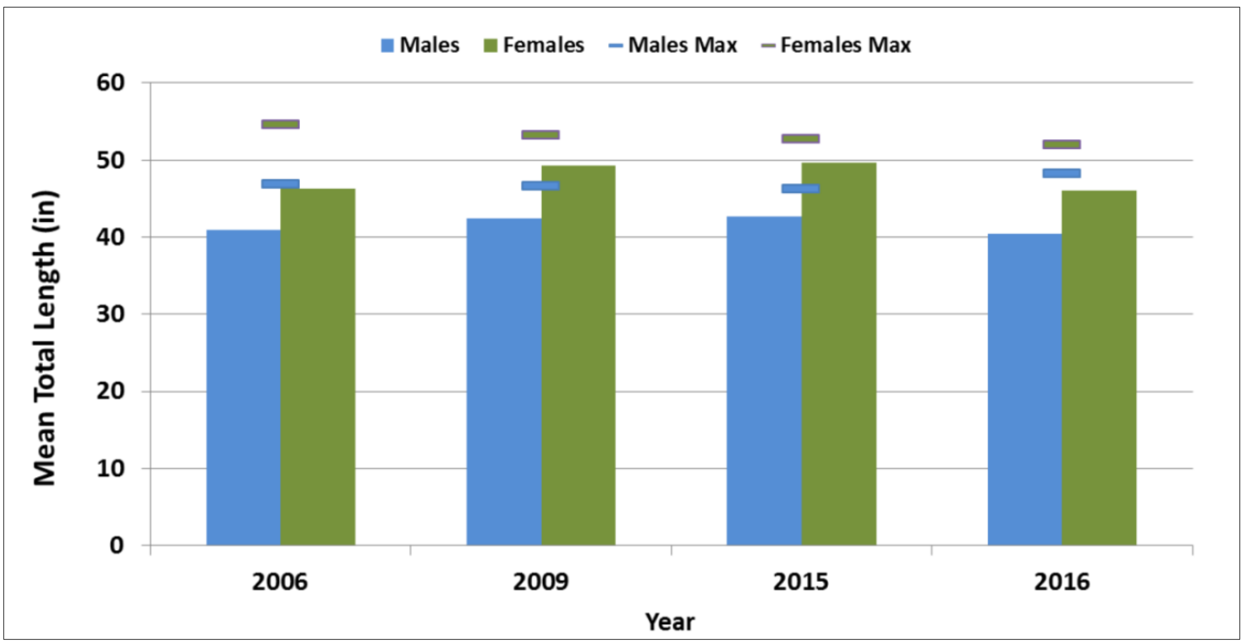


Figure 22. Muskellunge mean and maximum total lengths in 2006, 2009, 2015, and 2016 (UGLMU, 2016a).

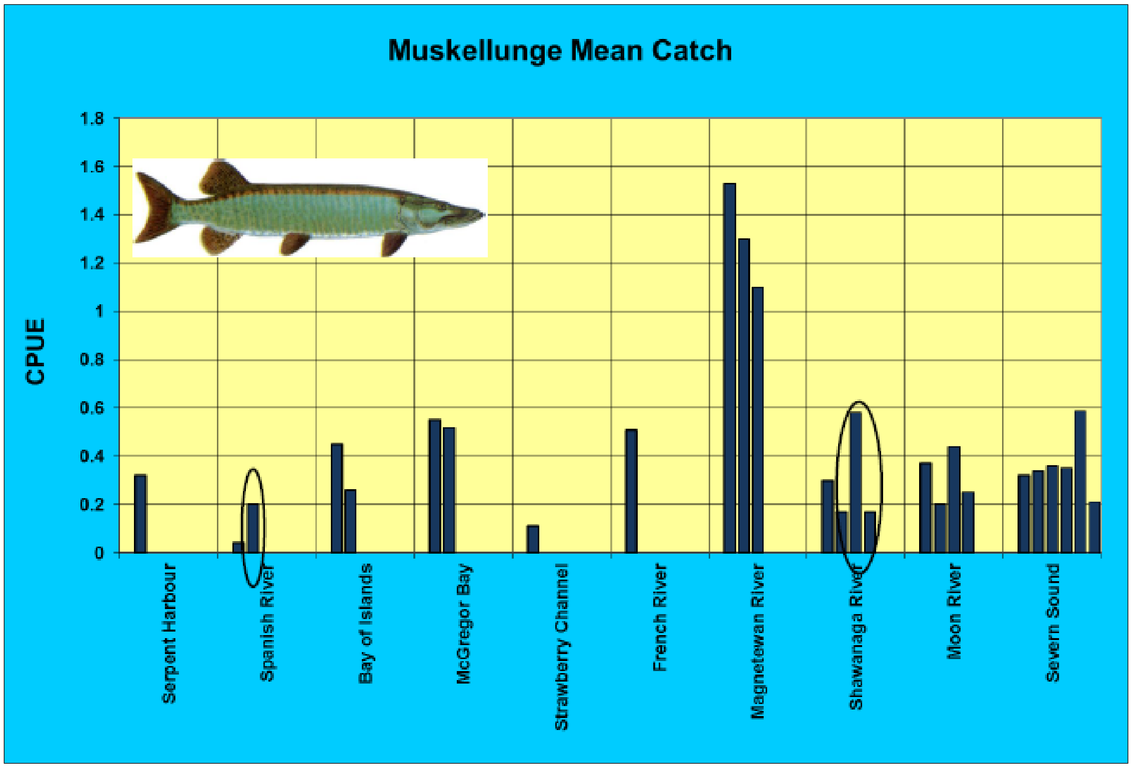


Figure 23. Muskellunge mean catch for various populations and across years (UGLMU, 2016a).

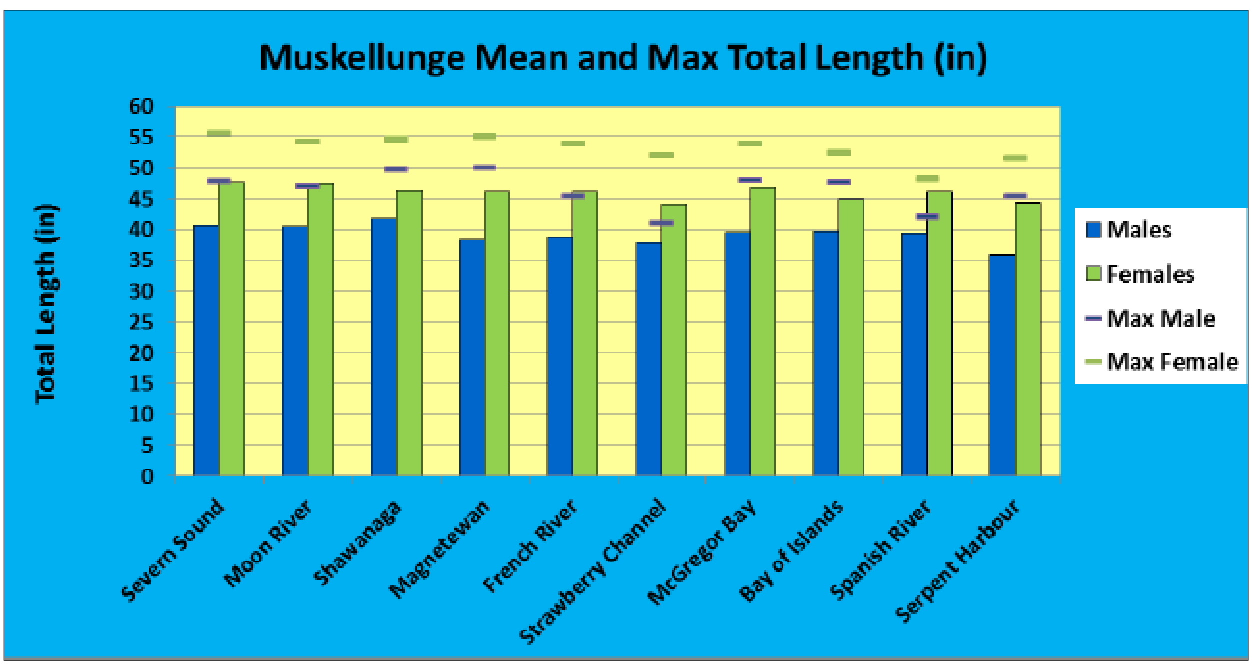


Figure 24. Muskellunge mean and max total length for various populations (UGLMU, 2016a).

Angler diary records collected from 1979 to 2004 were compiled and summarized in an MNRF report (Kerr, 2004) and published in a peer-reviewed journal (Kerr, 2007). The MNRF-sponsored and MCI angler diary programs provide information on Ontario muskellunge sport fisheries from experienced, specialized anglers targeting muskellunge. Over the entire 26 year period considered, Georgian Bay muskellunge CPUE, as expressed in terms of the number of fish caught per rod hour of angling effort, was 0.024 compared to the long term provincial CPUE of 0.069. Provincially, release rates averaged 94% for those anglers targeting muskellunge. The mean size of angled muskellunge in Georgian Bay over this period was 1001 mm while the provincial mean was 940 mm. Overall, the provincial mean size of catch remained relatively consistent over the 1979-2004 time period. Provincial improvements in angling quality over the last few decades have been attributed to new minimum size limit regulations and increased catch-and-release angling practices (presently, release rates are up to 99%). Based on the analysis of angler diary information, the report concludes that Ontario's muskellunge fisheries appear to be stable and sustainable.

More recently, the 2008 angler diary report listed the Georgian Bay muskellunge CPUE at 0.020 (provincial CPUE of 0.052), mean size of angled fish at 970 mm, and reported harvest of 0. In 2011, the Georgian Bay muskellunge CPUE was 0.020 (provincial CPUE of 0.059), mean size of angled fish was 1107 mm, and reported harvest was again 0. Taillon and Heinbuck (in press) report on Georgian Bay angler diary data from 1995 up to 2015. The authors state that CPUE remained below 0.05 until a high of 0.08 in 2013. Muskellunge mean length reportedly ranged from 890 mm to 1180 mm and exceeded the long term average since 2013, remaining stable near 1040 mm (Taillon & Heinbuck, in press). Moreover, the authors explain that Georgian Bay has seen an increase in the representation of fish 1140 mm and larger from 16.9% of the catch in 1996-2000 to 30% of the catch in 2011-2015.

A study published in 2014 provides another perspective on the state of muskellunge populations, specifically in southeastern Georgian Bay. Although trophy sized adults continue to be captured in Georgian Bay, Leblanc et al. (2014) assert that, at the time the study was published, young-of-the-year (YOY) muskellunge had not been found at historically confirmed muskellunge nursery habitat in the Severn Sound area for at least the last decade. The authors hypothesize that sustained low water levels and increased shoreline modifications in southeastern Georgian Bay played a role in altering historic nursery habitat in coastal wetlands making these sites unsuitable for YOY muskellunge despite the fact that spawning adults were observed in the area during the spawning season. Given that Georgian Bay muskellunge exhibit spawning site fidelity, it is possible that they may be unable to adapt to changing habitat conditions, even if it means using degraded spawning habitat (Weller et al., 2016). Despite the apparent health of the Georgian Bay population as a whole, Leblanc et al. (2014, p. 870) concluded from their study that a Georgian Bay specific muskellunge strategy should be developed to "identify and ultimately protect suitable muskellunge breeding habitat by accounting for the unique geomorphology, current physical stressors affecting Georgian Bay, and the biological links between suitable spawning and nursery habitats".

Summary

UGLMU has been assessing muskellunge populations in eastern Georgian Bay and the North Channel since 1996; these surveys have confirmed the widespread distribution and presence of mature muskellunge throughout this area (Figure 25). Nevertheless, there is continued concern over the potential for high quality spawning and nursery habitat to become degraded and subsequently impact reproduction and recruitment.

While YOY muskellunge were absent during a study in southeastern Georgian Bay (Leblanc et al., 2014), seining efforts in northern Georgian Bay have been successful in catching YOY. Accordingly, muskellunge populations in eastern Georgian Bay and the North Channel appear to be ‘unchanging’ and sustainable whereas populations in southeastern Georgian Bay may potentially be ‘deteriorating’ but could be classified as ‘undetermined’ until further studies can confirm a continued lack of recruitment.

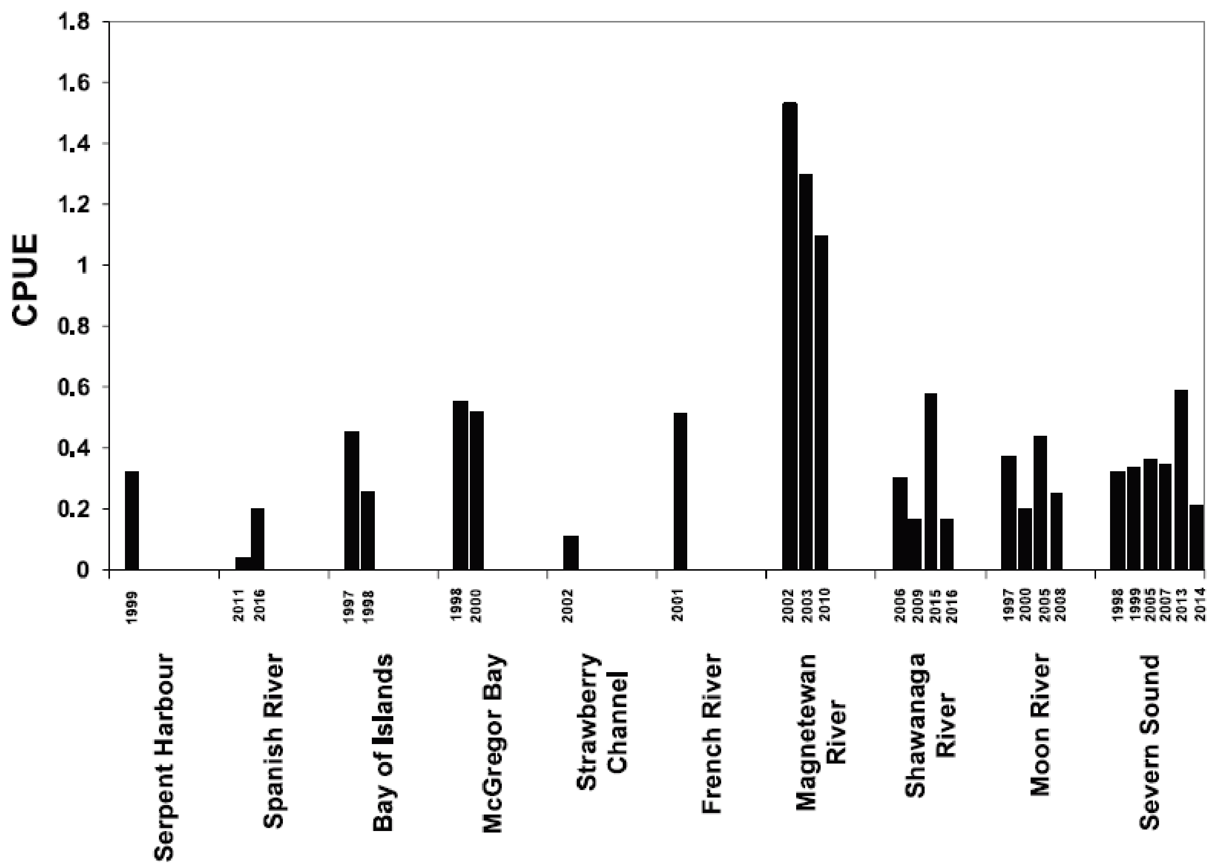


Figure 25. CPUE and survey year for spawning muskellunge using the SMIN protocol in eastern Georgian Bay and the North Channel (Liskauskas, in press).

3.7 Walleye

3.7.1 What is measured?

Walleye (*Sander vitreus*) spawning populations (i.e., populations associated with a specific spawning area, usually a river) exist in multiple locations around Lake Huron. Of these locations, 37 have walleye populations that are considered “more important” and are assessed with greater frequency (Fielder et al., 2010). Sixteen of those populations fall within the focal area of this report (eastern and northern Georgian Bay). Individual walleye in these populations, and populations as a whole, can be assessed in many ways based on the type of information sought. For the purpose of describing an entire walleye population, relative abundance, spawning stock size, and age structure are most commonly assessed and reported, although many other measures exist.

3.7.2 How is it measured?

Several types of netting methods are used to gather information on walleye, including Spring Walleye Index Netting (SWIN), End of Spring Trap Netting (ESTN), Fall Walleye Index Netting (FWIN), and Broadscale Monitoring (BSM). These types of surveys are routinely done in eastern Georgian Bay by the Upper Great Lakes Management Unit (UGLMU) and intermittently by the Anishinabek/Ontario Fisheries Resource Centre (AOFRC), the Eastern Georgian Bay Stewardship Council (EGBSC), and the French River Stewardship Council (FRSC).

SWIN is a live release spawning survey intended to monitor the status of spawning populations of walleye, namely abundance and biological characteristics (e.g., age, sex, size). Walleye are captured in 6' live capture trap nets during their spring spawning run and sampled for length, weight, sex, maturity, lymphocystis, lamprey marks, and aging structures (e.g., scales, dorsal spine). Species other than walleye are counted and released with minimal biological sampling. During a SWIN survey, walleye may also be marked for future population abundance estimation.

ESTN, an adaptation of the Nearshore Community Index Netting (NSCIN) program, is a live release trap netting program, making it particularly useful where gill netting is not acceptable. ESTN is designed to estimate the relative abundance of a fish stock and provide biological measures to assess the status of walleye populations. Trap netting begins in late spring when surface waters reach 12°C and can take place up until surface water temperature reaches 18°C, typically in early summer. This timing best reflects the population density of walleye as it occurs after walleye have spawned and are beginning their post-spawning recovery and feeding movements. Age structure, growth, condition, recruitment, and other attribute data are collected from the sampled fish.

FWIN uses overnight sets of multi-mesh gill nets in various habitats to collect biological information for the management of percid fisheries dominated by walleye. Where lethal sampling is acceptable, netting is carried out in the fall when surface water temperatures drop to between 10°C-15°C. Lethal sampling offers many advantages including access to better aging structures, internal examination of stomach contents, sex, and gonad maturity, and generally, a more representative catch per unit effort (CPUE) to true population density and size. Walleye and other sport fish captured during FWIN surveys have a scale sample taken along with at least one other ageing structure. All sport fish are also sampled for species, length, weight, sex, and maturity. Species not classified as sport fish are sampled for length. Like SWIN and ESTN, FWIN assesses the relative abundance of a fish stock and provides biological measures to help determine stock status. CPUE is used to evaluate trends in walleye population size.

Recently, UGLMU has also started using the BSM survey type to describe walleye and the broader fish community. This survey is a critical part of a five year strategic assessment strategy begun in 2015.

The objectives of the BSM survey are to develop fish community indicators, measure nearshore biodiversity, examine ecosystem health indicators, measure water quality and habitat, and to develop linkages between the nearshore fish communities and water quality. A modified provincially standardized monitoring protocol is used for this survey type. The netting gear utilized in this survey includes both large- and small-mesh gill nets. Sampling of fish is similar to the FWIN protocol.

EGBSC undertook a Fish Habitat Assessment project with a goal of assessing whether there is sufficient accessible habitat (spawning, nursery, rearing, foraging) to support walleye, lake sturgeon (*Acipenser fulvescens*), and Sucker species (Catostomidae family) in eight tributaries of eastern Georgian Bay. The specific tributaries assessed were the Seguin, Shebeshekong, Shawanaga, Naiscoot, Magnetawan, Key, and Pickerel Rivers, and Sucker Creek. As part of the broad habitat assessments undertaken in each of the tributaries, egg mats placed in the channel along with visual day and night spawning surveys were used to evaluate the presence/absence and spawning activity of walleye, as well as, the other target species.

There are several other surveys undertaken in eastern Georgian Bay by agencies and organizations, including UGLMU, the Ministry of Environment and Climate Change (MOECC), AOFRC, FRSC, and EGBSC, that periodically capture walleye but are not focused specifically on describing their populations.

Data from UGLMU and AOFRC SWIN, ESTN, and FWIN reports and data from EGBSC's Fish Habitat Assessment project specifically related to the 16 walleye populations that fall within the focus area of this report are discussed below. Wherever possible, these sources are used to report on relative abundance as measured by CPUE, spawning stock size, and age structure.

3.7.3 Why is it important?

Native to Lake Huron, walleye are a valuable indicator of fish health as they are a top predator of the coolwater, nearshore community. Walleye support key ecosystem functions and healthy walleye populations suggest productivity and health of the nearshore food webs. Furthermore, because walleye live in nearshore habitats, they tend to be directly and indirectly exposed to human activities and their impacts. As such, changes to the health of walleye populations can offer insights on the extent of those impacts. Given that many walleye populations spawn in rivers, they are also good indicators of tributary connectivity. Walleye are targeted recreationally and commercially in Lake Huron, and receive significant interest from the public and scientific community. Moreover, walleye are also an important species culturally for Indigenous and non-Indigenous communities.

Historically, Georgian Bay was renowned for its abundant walleye populations and the considerable size of many fish (Figure 26). However, since the early 1900s, most Georgian Bay walleye stocks have declined in abundance compared to historical levels due to a combination of over-exploitation, water flow manipulation in spawning rivers, spawning habitat alteration, and the introduction of invasive species (Reckahn & Thurston, 1991). In the Moon River, for example, where walleye spawning runs used to number over 30,000 fish, these numbers have dropped more recently to several hundred (EGBSC, 2015).

Efforts to rehabilitate declining walleye populations have been ongoing in parts of Lake Huron since the early 1980s and focus on rehabilitative stocking, habitat restoration, and regulations that restrict harvest. These efforts have been met with variable degrees of success. A comprehensive walleye management plan for Lake Huron is presently being developed by UGLMU. The desire for healthy walleye populations over their traditional range in Georgian Bay and Lake Huron is evidenced by their mention in the *Fish Community Objectives for Lake Huron* (DesJardine et al., 1995), the *Environmental Objectives for Lake Huron* (Liskauskas et al., 2007), the *International Biodiversity Conservation Strategy for Lake Huron* (Franks Taylor et al., 2010), and by their continued use as an indicator in the *State of the Great Lakes* reports.

Figure 26. Notable historic walleye populations and fisheries in Lake Huron (orange dots indicate locations and relative size of spawning populations – i.e., smaller dots represent smaller spawning populations) (Reckahn & Thurstan, 1991; Fielder & Liskauskas, 2014).

3.7.4 What are the results?

The results regarding relative abundance as measured by CPUE, spawning stock size, and age structure are presented by population using the most recent information available and subsequently summarized in terms of trends. Where this specific information is not available, a discussion-oriented approach is taken. For populations without any recent data, only the trend is reported in the summary section.

McGregor Bay

During the 1950s and 1960s, the McGregor Bay area was a popular destination for anglers pursuing walleye. However, during the 1970s, substantial declines in both shoal and river spawning walleye became apparent. These declines were likely due to the impairment of water quality as a result of acid rain originating from the nearby Sudbury Basin as well as the increase in abundance of exotic prey fish species such as alewife (*Alosa pseudoharengus*) and rainbow smelt (*Osmerus mordax*) (Reckahn & Thurston, 1991). Walleye, like many other sport fish, are sensitive to changes in pH. Increasingly acidic water can have a negative impact on walleye recruitment. Walleye may also be affected by increased abundance of exotic prey fish species through competition and predation.

Since the mid 1980s, efforts to rehabilitate walleye populations in the McGregor Bay area have been ongoing. These efforts include stocking of walleye fry and fingerlings in the mid 1980s by local community groups, spawning habitat enhancements, and stocking of fingerlings on a biannual basis since 1999. Furthermore, the recreational fishery in McGregor Bay was formally closed to walleye angling in 2002. This closure was intended to reduce adult mortality and enhance survival prospects for recently stocked walleye.

UGLMU conducted a SWIN survey in McGregor Bay in 2007. Combined, 158 walleye were caught in 23 trap net sets and 8 hoop net sets. Of those, 100 males, 23 females, and 28 walleye of unknown sex were size sampled. Walleye were the third most abundant species caught in the trap nets with a CPUE of 5.0 (probability of capture (POC) of 0.87), much higher than in 1998 when SWIN CPUE was calculated to be 0.8. Walleye were the second most abundant species caught in hoop nets with a CPUE of 6.1 and POC of 0.88. The mean age of all male walleye caught was 8 years (range of 2-13 years). For female walleye, the mean age was 10 years (range of 6-13 years) and for walleye of unknown sex, the mean age was 9 years (range of 3-12 years). Overall, the most abundant year classes were the 8 and 9 year olds which represented 46% of the total walleye caught. While the age class structure is weighted towards older fish, the 2007 SWIN results also showed that compared to 1998 SWIN results, most age classes had some representation. These results suggest more consistent evidence of natural reproduction than in 1998. Further to this point, it is important to note that the most abundant year class (9 year olds) was generated from a non-stocking year (1998) indicating successful natural reproduction. Evidence of fin clips was found for 8 walleye (5% of the total sampled walleye) with representation from each of the stocking years since 1999. Accordingly, stocked walleye appear to be surviving and may contribute to spawning runs in the future. Despite some seemingly positive signs from the 2007 SWIN survey, AOFRC sampling later in 2007 and in 2008 (described below) resulted in very low catch rates and anecdotally, anglers in the area were still indicating that walleye were rarely encountered.

A 2007 ESTN conducted by AOFRC in partnership with the Whitefish River First Nation resulted in the capture of only three walleye from 30 net sets for a CPUE of 0.11. Two of the walleye were 8 years of age and the other was 11 years of age. The following year, one 10 year old walleye was captured in 28 net sets for a CPUE of 0.03.

Six years later in 2013, AOFRC carried out a survey combining SWIN and ESTN methods to capture walleye during and after the spawning run. A total of 31 walleye (16 males, 13 females, 2 unknown) were captured in 45 trap net sets for a CPUE of 0.69. Of the 31 walleye captured, 21 (68%) were clipped and 10 (32%) were recruited from the natural population. Eight year classes were captured with the mean age being 8.6 years and the range being 5 to 15 years. These studies suggested that the spawning walleye population in McGregor Bay had decreased in size and age since 1998 and that the population consisted mostly of stocked walleye with limited natural recruitment.

In 2014, another ESTN was conducted by AOFRC in partnership with Whitefish River First Nation. Ten walleye were captured in 31 trap nets throughout the duration of the survey for a CPUE of 0.32, 40% were clipped. Given the low number of walleye captured in 2014, captures from 2013 and 2014 were combined to provide a larger sample size for analysis. Over these two years, a total of 41 walleye (18 males, 13 females, 9 unknown) were captured representing 12 year classes with a mean age of 9 years and a range of 5 to 16 years. Based on these results, AOFRC reported that the McGregor Bay walleye population remains relatively low and largely consists of stocked walleye from the mid-2000s.

French River Delta

The French River supports a historically important recreational walleye fishery which is presumed to be one of the most stable Georgian Bay walleye fisheries due to its remoteness (Fielder & Liskauskas, 2014). Although intermittent monitoring since the mid 1990s has indicated a broad size range and evidence of ongoing successful reproduction, there has also been a long-term declining trend in abundance.

In 2014, UGLMU conducted a SWIN but due to persistent ice cover and high flows, the netting period was delayed and it is believed that part of the spawning run may have been missed. Walleye was the fifth most dominant species making up 5.50% of the total catch. Walleye catch rates averaged 1.06 walleye per net lift and the POC was 0.52. Also in 2014, a FWIN survey had Walleye as the third most abundant species captured with 8.16% of the total catch being walleye. The FWIN walleye catch rates averaged 1.93 walleye per net lift and the POC was 0.70 (Figure 27).

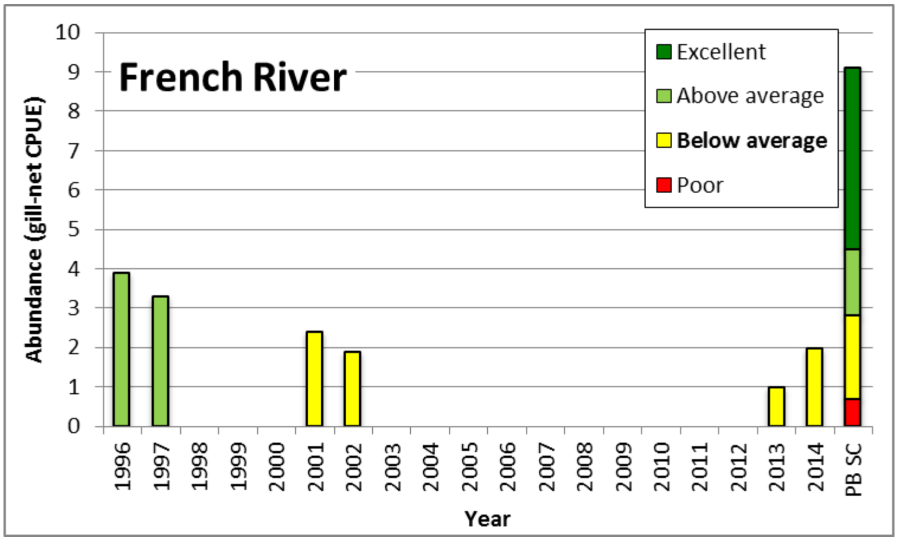


Figure 27. French River FWIN walleye CPUE compared to the South-Central provincial benchmarks (PB SC) for relative abundance (Liskauskas, 2015b).

ESTN surveys were carried out in 2014 and 2015 by UGLMU. In 2014, walleye were the fourth most abundant species making up 10.87% of the total catch and in 2015 they were the fifth most abundant species comprising 10.20% of the total catch. CPUE was 1.48 with a POC of 0.50 in 2014 and 1.31 with a POC of 0.36 in 2015.

Moving inland from Georgian Bay, a considerable amount of monitoring has been done on the French River walleye fishery between Recollet Falls and the delta at Georgian Bay (central and eastern sections of the French River have also been extensively studied). Figure 28 shows FWIN walleye relative abundance for this western section of the river from 1994 to 2013 while Figure 29 illustrates the FWIN walleye stock status.

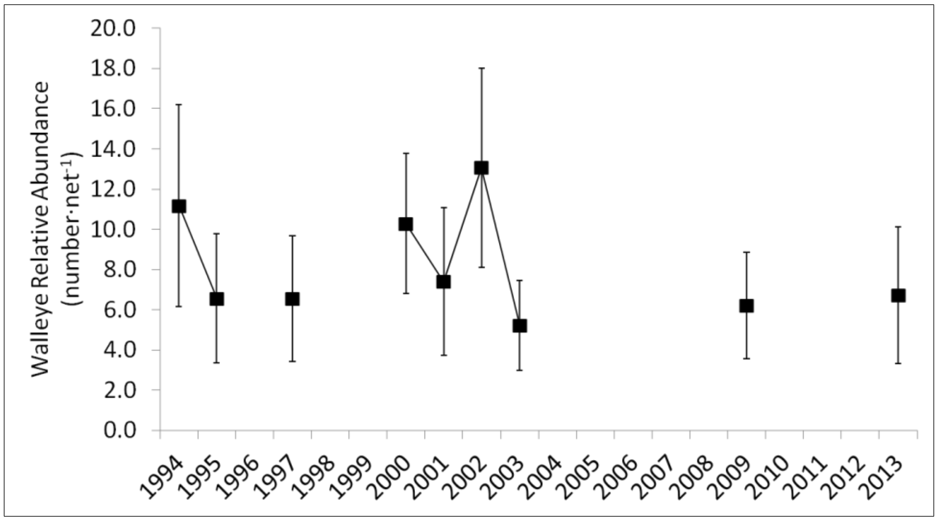


Figure 28. Western French River FWIN walleye relative abundance from 1994-2013 (±95% confidence interval) (G. Morgan, pers. comm., 2017).

Figure 29. Western French River FWIN walleye stock status (G. Morgan, pers. comm., 2017).

Key River

Historical monitoring data is lacking for the Key River. Walleye population assessments carried out by UGLMU in 1985 and 1998 clearly showed that the Key River stock was severely stressed despite rehabilitation efforts undertaken by the Key River Area Association. This description was echoed in EGBSC's 2015 document, *Walleye Woes.*

In the fall of 2015, EGBSC, with project partners, enhanced two walleye spawning sites on the Key River in an effort to promote a healthy and naturally sustainable walleye population over time. Preliminary monitoring at these sites in the spring of 2016 and 2017 suggested that there continues to be a low number of walleye spawning at these sites. The full impact of these enhancements will take several years to be realized and as such, continued monitoring in future years will be critical.

Magnetawan River

The Magnetawan River walleye population is described as a 'stressed population' in EGBSC's (2015) *Walleye Woes* document. Recent efforts to monitor the population have been met with challenges due to the nature of the river near its outlet into Georgian Bay. In 2010, AOFRC in partnership with Magnetawan First Nation undertook spotlighting during the spawning run to confirm walleye coming up the river and then used short set gill nets. No walleye were observed during spotlighting. In total, 19 walleye were captured for a CPUE of 0.61 compared to walleye CPUEs of 0.63, 0.54, and 0.0 in 2002, 2005, and 2008, respectively. Thirteen of the 19 walleye captured in the 2010 study were small, mature males while the remaining 6 were too small to determine sex. Similar observations (low numbers of small, mature males) were reported by an UGLMU crew looking for Muskellunge in the Magnetawan River during the same time period. Average walleye age was 3.2 years with ages ranging from 2 to 6 years. Two and three year old walleye made up 21% and 42% of the walleye observed, respectively. These results suggest that some degree of recruitment is still occurring.

The following year, EGBSC set out to undertake an ESTN survey but had to deviate from the survey design due to exceptionally high winds. The modified ESTN resulted in the capture of 18 walleye making up 3.3% of the total catch. Walleye CPUE was 0.7 suggesting low abundance with a POC of 0.46. Notwithstanding low walleye abundance, the small spawning population was displaying some measure of successful reproduction and recruitment.

In 2014, AOFRC, again in partnership with Magnetawan First Nation, conducted a spawning survey consisting of short-set gill nets and trap nets, and an ESTN survey. A total of 25 walleye were captured and tagged during the spawning survey (gill net walleye CPUE of 0.45 and trap net walleye CPUE of 0.0) while only 3 walleye were captured during the ESTN (walleye CPUE of 0.1). Accordingly, walleye abundance remains low compared to historical abundances and compared to other tributaries throughout Georgian Bay. Of the 28 walleye captured during both surveys, full biological sampling occurred for 27 walleye (14 were females, 9 were males, and 4 were unknown). A total of 7 year classes were captured during the study, the mean age was 4.8 years with a range from 1 to 9 years.

Most recently, during the spring of 2016, EGBSC monitored Deadman's Rapids, one of several potential spawning areas on the Magnetawan River. Given the gorge-like nature of the site with deep and fast flowing water, visual surveys were very difficult and at most, three walleye were observed during a single visual survey. In total, 561 walleye eggs were counted on two egg mats placed along the few shallow areas at the site. Overall, an exceptionally small spawning population was observed at the site. However, it is possible that a larger number of walleye were moving upstream to other spawning sites and could not be seen due to the nature of the site.

Naiscoot River

Spawning assessments were carried out in 2017 by EGBSC at two locations – the Naiscoot River downstream of the Naiscoot Lake Dam and the Harris branch of the Naiscoot River near Highway 69. No signs of a walleye spawning population were observed downstream of the Naiscoot Lake Dam. Conversely, six walleye were spotted at the Harris branch of the Naiscoot River during a night survey. In addition, walleye eggs were found on egg mats placed at the Harris spawning site on several occasions throughout the monitoring period although in very low numbers (highest count of five eggs on a single mat, at one time). These observations suggest that there is a very small walleye spawning population remaining at the Harris branch of the Naiscoot River. No historical data are readily available for comparison.

Sucker Creek

During spawning assessments carried out by EGBSC in 2016, the highest number of walleye observed in one night survey at the Sucker Creek spawning bed was seven. No walleye were observed during the day. A total of 217 walleye eggs were counted on three egg mats placed in areas at the downstream end of the spawning bed. The number of eggs found at the Sucker Creek spawning bed confirmed that some walleye spawning had occurred but in comparison with other sites along eastern Georgian Bay, the number of walleye eggs counted was low.

The spawning bed at Sucker Creek was identified as a potential SWIN location for 2016 following the completion of the nearby UGLMU Shawanaga River SWIN. However, Sucker Creek was unable to be fished by UGLMU due to: large catches of walleye in the Shawanaga River that required significant time to sample; the difficulties associated with setting a net due to the characteristics of the Sucker Creek site; and the fact that the spawning run appeared to be small and finished when catches at Shawanaga River allowed for consideration of a secondary SWIN site.

Shawanaga River

The Shawanaga River walleye population is an important resource to the area supporting recreational, commercial, and Indigenous fisheries. In the 1950s and 1960s, declines in the size of the walleye spawning population were first documented. Speculation around the causes of this decline ranged from overfishing to acidification inhibiting recruitment. During the 1970s and 1980s, efforts such as spawning habitat improvement and stocking occurred in an attempt to rehabilitate the walleye population. Since the late 1980s, increased spawner abundance has been noted and the relative abundance of spawning walleye in the Shawanaga River has remained high. Following the 2006 symposium on the Status of Walleye in the Great Lakes, the proceedings listed Shawanaga River's walleye population as 'depressed but increasing' indicating that although the population is not back to historical levels, it is improving. It is not known exactly what caused this notable turnaround.

UGLMU's 2015 and 2016 SWIN surveys provided an update on the status and characteristics of the spawning population of walleye at Shawanaga. In 8 trap net lifts in 2015, 4,018 fish were captured representing 9 species. Numerically, walleye was the most abundant species making up 95% of the total catch with a ratio of 1.5 males to 1 female. In 2016, 12 trap net lifts captured 4,125 fish representing 9 species. Again, walleye was the most dominant species comprising 93% of the total catch with an almost 2:1 ratio of males to females. The walleye CPUE in 2015 was 477.13, higher than the 2016 CPUE of 321.75 and the 1998 CPUE of 196.6 (Figure 30). Both years, the Walleye POC was 100%. Multiple year and size classes were present for both males and females in 2016 indicating a level of ongoing natural recruitment despite supporting several intensive fisheries (Figure 31). Average age for males was 7.7 years and 8.0 years for females with ages ranging from 4-15 years. The most abundant year class was from 2008 (8 year olds) representing 23% of the walleye subsample that was aged. Four other age classes (6-9 years) had at least 10% representation. These SWIN results suggest that the Shawanaga walleye spawning population remains at high levels of abundance particularly when compared to historical netting data; however, uncertainty remains with regard to how the current population compares to pre-war and pre-settlement eras.

ESTN surveys were also conducted in 2015 and 2016 by UGLMU. In 50 trap net lifts in 2015, 2,117 fish were captured representing 18 species. Numerically, walleye was the third most dominant species making up 12.5% of the total catch. In 2016, 54 trap net lifts captured 1,947 fish representing 17 species. Walleye was the fourth most abundant species comprising 9.6% of the total catch. The walleye CPUE was 5.30 in 2015 and 3.44 in 2016, both higher than the 2009 CPUE of 3.2. Walleye POC was 0.86 in 2015 and 0.57 in 2016. In 2016, the mean age of walleye was 5.2 years, ranging from age 1 to 15 with the most abundant age class being 2 year olds (2014 year class) representing 30% of the walleye that were aged. The dominance of the 2014 year class is a sign of recent successful reproduction. Five, six, and seven year olds comprised 14%, 16%, and 18% of the aged walleye, respectively.

As with the SWIN and ESTN surveys, FWIN surveys were carried out in Shawanaga River in 2015 and 2016 as well. In 2015, 2,025 fish were captured with representation from 25 species. Numerically, walleye was the second most dominant species making up 10.1% of the total catch. In 2016, 1,733 fish were captured representing 24 species. Walleye was the fourth most dominant species comprising 7.4% of the total catch. The walleye CPUE was 3.00 in 2015 and POC was 0.74. In 2016, the walleye CPUE was lower at 1.93 as was POC at 0.67.

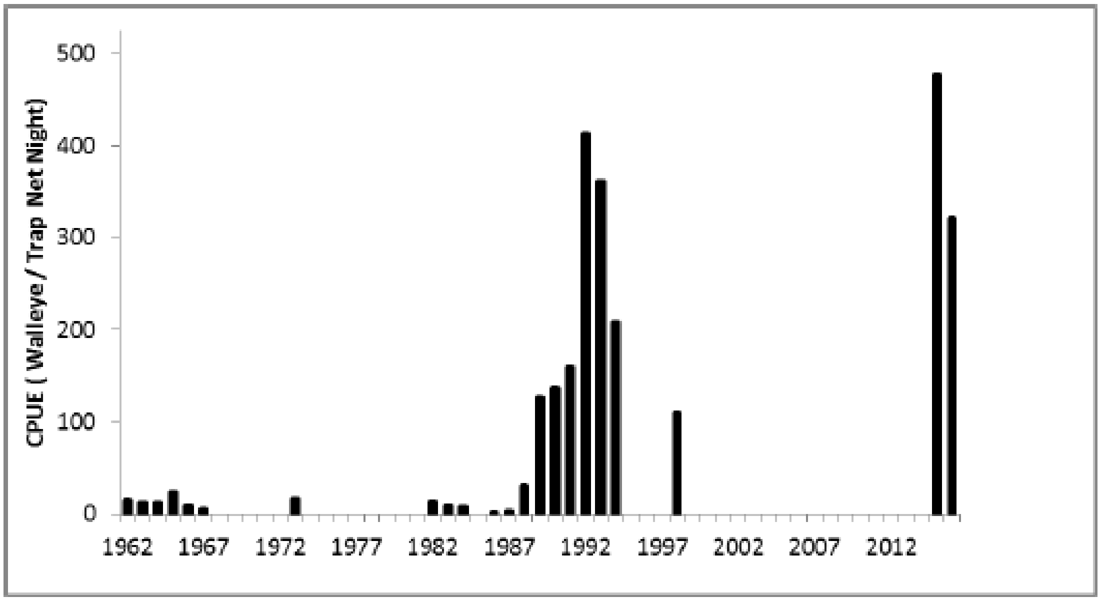
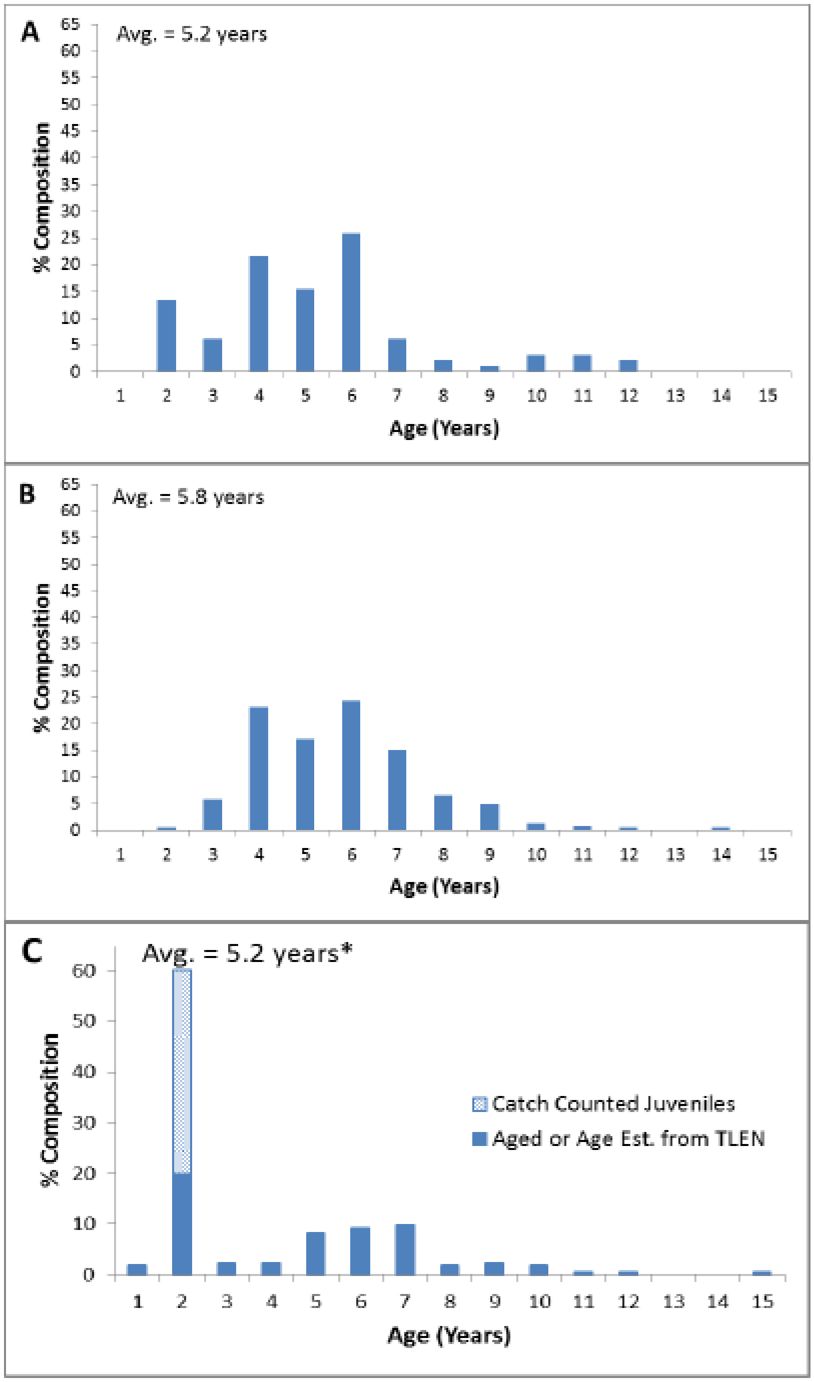


Figure 30. Relative abundance of walleye captured during spring trap netting at the Shawanaga River index site expressed as CPUE (UGLMU, 2016b). Zero catches indicate no netting effort conducted in that year.



* the average of fish aged successfully (n=92; includes 3 aged from 2016 SWIN)

Figure 31. Comparison of walleye age distribution (in years) between Shawanaga ESTN surveys in 2009 (A), 2015 (B), and 2016 (C) (UGLMU, 2016a).

Shebeshekong River

The Shebeshekong River walleye population is considered by UGLMU to be a notable historic population that has been overfished and has crashed. EGBSC (2015) lists this population as 'severely stressed' in their *Walleye Woes* document. Walleye CPUE for SWIN surveys conducted in the 1990s is displayed in Figure 32. EGBSC field observations in 2016 and 2017 indicate the number of spawning walleye in the Shebeshekong River is exceedingly low. In 2016, the highest number of Walleye observed during a night survey was 11 and in 2017 this number was 8. Only 28 walleye eggs were counted on the one egg mat that was not removed from the spawning bed in 2016.

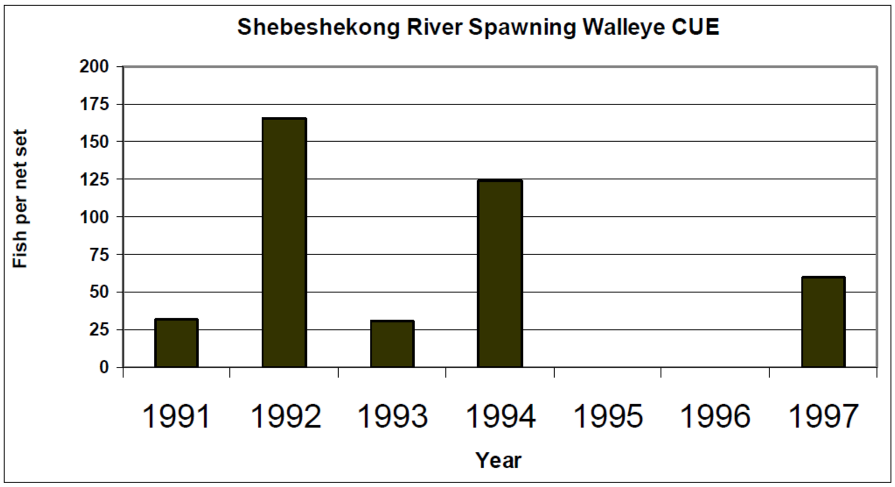


Figure 32. Shebeshekong River walleye CPUE from SWIN netting in the 1990s (MNRF, 2002).

EGBSC completed enhancement work on the Shebeshekong River in the fall of 2017 to improve fish passage and access to exceptional spawning habitat upstream. The Shebeshekong River walleye population will continue to be monitored in the coming years to evaluate the effectiveness of the enhancement work.

Seguin River

EGBSC's 2016 assessment of walleye at the Seguin River spawning bed resulted in a low number of walleye observed. At most, three walleye were observed during a single day or night survey and seven walleye were seen during one snorkel survey. Similarly, a low number of walleye eggs were collected using egg mats (total of 144 eggs counted for 4 egg mats cumulatively set for 33 days). Collectively, these results indicate that there is presently a very small walleye spawning population at the Seguin River.

Moon River

Walleye supported a historically important recreational fishery in the Moon River but the population has seen a long-term decline in abundance (Figure 33 and Figure 34). Moon River is an excellent example of how habitat degradation can have a profound effect on walleye reproduction. Due to hydropower development on the Moon River's source, the Muskoka River, Moon River flows have been reduced by 75% (Fielder et al., 2010). Fluctuating flows caused by quick increases and decreases of outflows from the Muskoka River can strand walleye eggs at a critical spawning location just below Moon Falls. These fluctuating flows are believed to account for over 85% of the variability in the year-class strength of the Moon River walleye population (Fielder et al., 2010).

To address the issue of fluctuating water levels over important spawning habitat, EGBSC led a project to enhance the spawning beds by providing optimal substrate for walleye spawning and incubation, specifically designed to be functional over a wide range of projected flows throughout the spawning and egg incubation periods. The work was completed below Moon Falls in the fall of 2008.

An EGBSC 2011 Moon River index spawners project report (McIntyre, 2011) describes walleye CPUE values as remaining low but consistent in recent years, suggesting spawning population abundance is small but stable. Twenty net nights of fishing effort with an 8' trap net resulted in a walleye CPUE of 15.3 fish per net night. In comparison, the walleye CPUE was 27.8 in 2010, 11.3 in 2009, 29.3 in 2007, and 15.4 in 2006.

More recently, UGLMU completed SWIN and ESTN surveys in 2013. Numerically, walleye was the third most abundant species captured (102 walleye) in the SWIN, making up 17.95% of the total catch and the seventh most abundant species (38 walleye) in the ESTN, comprising just 2.7% of the total catch. Walleye catch rates averaged 2.55 walleye per net lift for the SWIN and 1.19 for the ESTN. The SWIN POC was 0.58 while the ESTN POC was 0.47. The composition of the captured walleye in terms of age for the SWIN is shown in Figure 35.

Although there continues to be evidence of successful reproduction, the most recent reports on the Moon River walleye population state that overall, walleye relative abundance remains low. EGBSC lists the Moon River walleye population as a 'stressed population' as of 2015. However, anecdotal evidence from 2016 and 2017 suggests that the Moon River population is looking better than it has in recent years. Monitoring of the Moon River population and the spawning bed enhancement work completed in 2008 is slated for 2019.

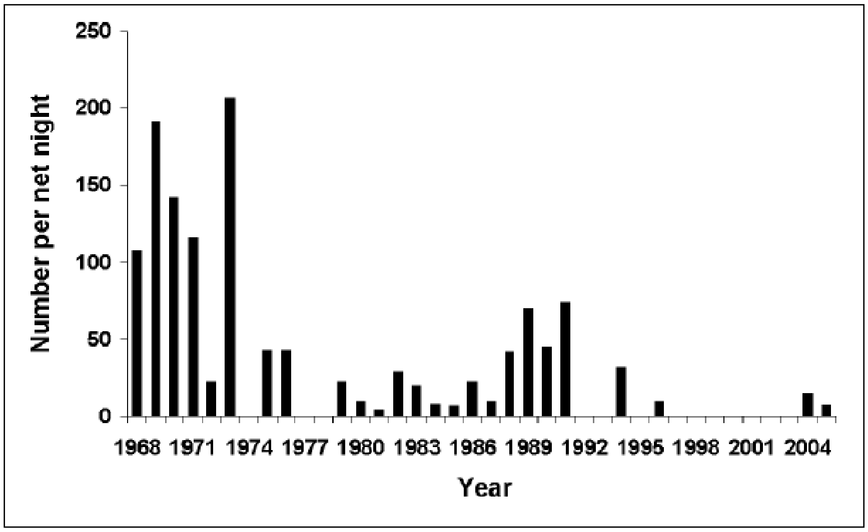


Figure 33. Walleye CPUE in spring trap net spawning-run assessments in the Moon River, 1968-2005. Zero catches indicate no netting effort conducted in that year (Fielder et al., 2010).

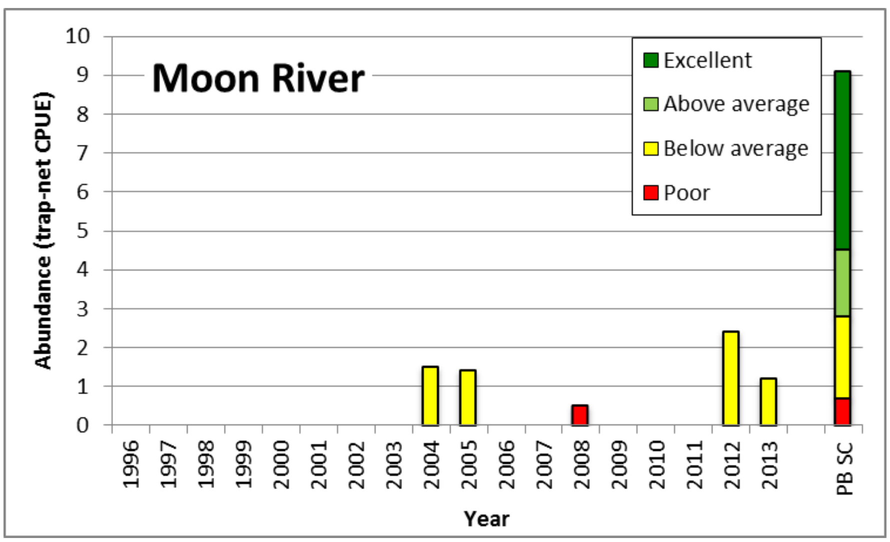


Figure 34. Moon River ESTN walleye CPUE compared to the South-Central provincial benchmarks (PB SC) for relative abundance (Liskauskas, 2015b). Zero catches indicate no netting effort conducted in that year.

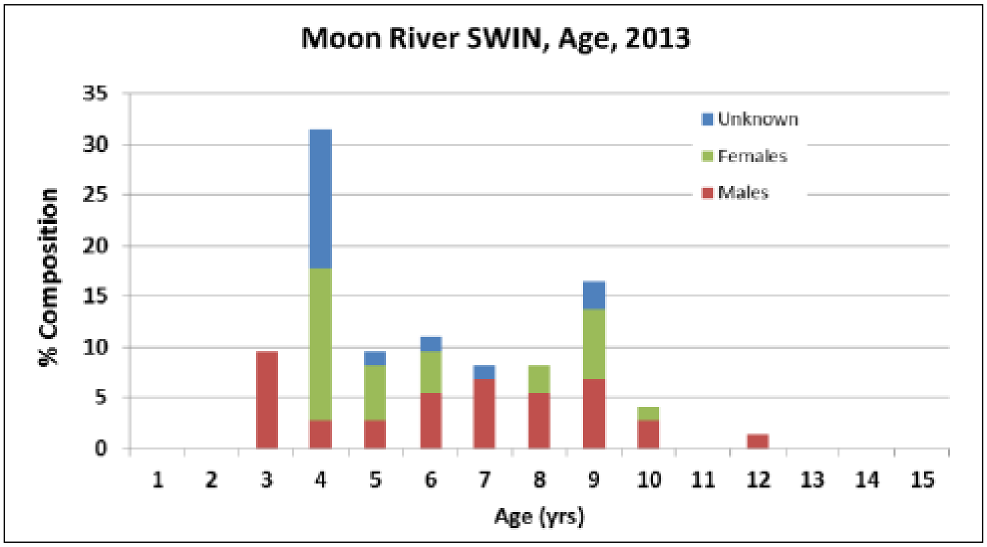


Figure 35. Age composition of walleye captured in 2013 Moon River SWIN (Fielder & Liskauskas, 2014).

Musquash River

A 2011 SWIN conducted by EGBSC using 8' trap nets resulted in the capture of 38 walleye from 9 net nights of fishing effort. Excluding two recaptures, 17 females and 19 males were captured. The CPUE for walleye was 4.2 compared to 2.3 in 2005. Both of these values are indicative of low walleye abundance and a small spawning population. Relative to walleye captured in 2005, male and female walleye captured in 2011 were smaller in terms of mean size. This relationship was attributed to the recent recruitment of one or more year classes. Overall, the results from this index netting project suggest that some measure of successful reproduction and recruitment was occurring in the population.

In an effort to rehabilitate the Musquash River walleye stock by ensuring adequate available spawning habitat of good quality, MNRF and EGBSC constructed spawning beds on the lower stretches of the Musquash River in 2012.

As of 2015, the Musquash River walleye population was described in EGBSC's (2015) *Walleye Woes* as a 'stressed population'.

Severn River

The Severn Sound area of Georgian Bay represents the largest warmwater recreational fishery in Georgian Bay. Although walleye have historically had a prominent role in this fishery, relative abundance of the Severn Sound walleye population has been consistently poor during the late 1990s and early 2000s as compared to provincial benchmarks. Moreover, age structure has been dominated by young year classes which are indicative of overexploitation. Excessive exploitation appears to be a more important factor controlling walleye abundance than water quality or habitat degradation given that Severn Sound was delisted as an Area of Concern in 2002 after undergoing intensive remediation efforts. Recreational fishing regulations were made more stringent in 2003 and commercial fishery walleye quotas were reduced to prevent further population declines. Despite these efforts, a severe decline in relative abundance has been seen since 2010 along with evidence of poor recent year classes.

In 2013, UGLMU carried out an ESTN survey in Severn Sound. A total of 32 walleye were captured in 14 of the 28 valid net sets making up 1.7% of the total catch. The walleye catch rate averaged 1.4 Walleye per net lift and POC was 0.50. The composition of the captured walleye in terms of age is shown in Figure 36. Figure 37 shows the 2013 CPUE compared to past years and the South-Central Ontario benchmarks. The South-Central Ontario benchmarks are used as they are regionally representative of walleye populations that are generally accessible and highly exploited.

The Severn Sound walleye population is described as a ‘stressed population’ in EGBSC’s *Walleye Woes.*

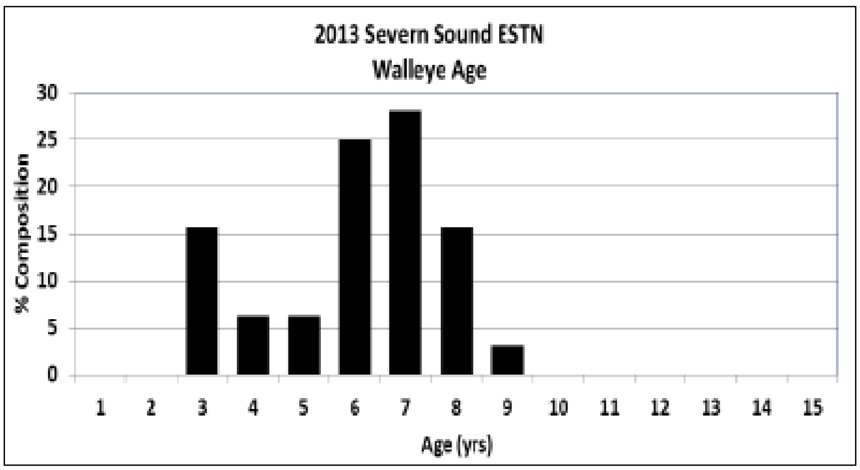


Figure 36. Age composition of walleye captured in 2013 Severn Sound ESTN (Fielder & Liskauskas, 2014).

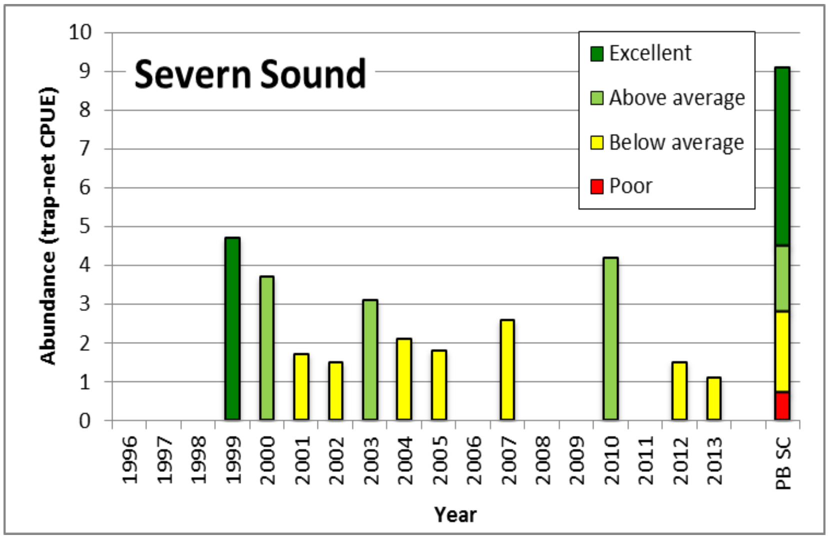


Figure 37. Severn Sound ESTN walleye CPUE compared to the South-Central provincial benchmarks (PB SC) for relative abundance (Liskauskas, 2015b).

Summary

Each walleye population is listed in Table 8 with its respective trend as determined using the most recent data available.

Table 8. Summary of walleye population trends.

Population	Trend
McGregor Bay	Deteriorating (remains low)
Killarney Bay	Undetermined
French River Delta	Unchanging (low)
Key River	Unchanging (low)
Magnetawan River	Unchanging (low)
Naiscoot River	Undetermined
Sucker Creek	Undetermined
Shawanaga River	Improving
Shebeshekong River	Undetermined
Seguin River	Undetermined
Boyne River	Undetermined
Port Rawson Bay	Undetermined
Blackstone Harbour	Undetermined
Moon River	Unchanging (low)
Musquash River	Undetermined
Severn River	Deteriorating (low)

3.8 Lake trout

3.8.1 What is measured?

Since the Ministry of Natural Resources and Forestry's (MNRF) *Lake Trout Rehabilitation Plan for Lake Huron (Canadian Jurisdiction)* was published in 1996 to form an approach for the rehabilitation of lake trout (*Salvelinus namaycush*) in Ontario waters of Lake Huron (MNRF, 1996), progress towards the goal and objectives outlined in the plan has been monitored at the 16 Lake Trout Rehabilitation Zones (LTRZs) established in the plan. A draft *Revised Lake Trout Rehabilitation Plan for Lake Huron* (henceforth the draft rehabilitation plan) has since been developed by MNRF outlining a revised goal, objectives, LTRZ boundaries, and evaluation criteria (MNRF, 2012). The criteria presently measured to evaluate progress towards achieving the short-, medium-, and long-term objectives include: age structure, lake trout survival/mortality, spawning stock size, natural reproduction, and relative abundance. These criteria were selected as they are considered to be in the form of directly measurable indicators capable of providing the necessary information to evaluate lake trout population status and thus, rehabilitation progress.

3.8.2 How is it measured?

Targeted sampling for lake trout on eastern Georgian Bay is undertaken by MNRF's Upper Great Lakes Management Unit (UGLMU). UGLMU collects data on lake trout via Fall Littoral Index Netting (FLIN), Fall Spawning Index Trap Net (FSIT), and creel surveys. Additionally, while not specifically targeted at lake trout, data from the Offshore Index Assessment Program (OSIA) and commercial harvest are used in evaluating lake trout populations. Each method is described briefly below.

FLIN involves sampling a lake's nearshore zone in the fall using short net sets (90-minute gill net sets) during daylight hours, reducing mortality compared to overnight sets. The purpose of the survey is to assess the relative abundance of lake trout at a given time and collect biological data. Catch per unit effort (CPUE), the mean number of individual lake trout caught per unit of fishing effort, is used as an indicator of the species' abundance. Lake trout caught in the nets have their fork length and round weight recorded, a scale sample taken, and are examined for clips, marks, and/or tags. In addition, dead lake trout also have their otoliths removed and information is gathered about sex and gonad condition. Information about species other than lake trout is collected at the discretion of the project leader based on available time.

FSIT uses trap nets oriented perpendicular to shore, starting onshore and extending to a maximum depth of approximately 4 m. The trap nets are set at fixed sites on spawning shoals for 24-96 hours. As the name suggests, this type of netting occurs during the fall when surface water temperatures drop below 15°C and lake trout are moving in to begin spawning. The use of this non-lethal netting technique helps determine if spawning populations are present and provides information on the status of lake trout populations.

Although the exact survey design can vary, creel surveys typically collect information on recreational fisheries in a certain area by asking anglers a series of questions about their fishing effort, catch, and harvest, and by measuring, weighing, and taking a scale sample from their catch. Angler participation in these surveys is entirely voluntary. There are four main types of creel surveys – roving, access, voluntary logs, and aerial boat counts. Roving creel surveys involve counting boats on a body of water and interviewing anglers. In an access creel survey, anglers are interviewed as they leave a body of water from one or more access points. Voluntary logs are a method in which books or forms are handed out to anglers before they head out on the water and are collected after the fishing trip is complete. Finally, aerial boat counts involve counting the number of boats from an aircraft in order to give an estimate of fishing effort.

The OSIA program is an annual index gill net survey intended to monitor the populations of commercially exploited species while simultaneously collecting information about the offshore fish community. Accordingly, the OSIA program is useful in quantifying progress toward efforts to restore lake trout populations as it provides an indication of overall lake trout abundance in terms of CPUE. Data from the OSIA can also aid in determining when and where subsequent fishery-independent netting, targeting lake trout, is warranted. The program consists of overnight bottom sets of standardized gill net gear set at various locations perpendicular to depth contours (10 m to over 100 m). Surveys can be undertaken in the spring or summer when weather and lake conditions are more stable and safe.

As a requirement of having a commercial fishing license or an Aboriginal commercial fishery fishing agreement on Lake Huron, commercial fishermen are required to report effort, catch, and harvest information each year to MNRF. These data are used to help describe and manage the fisheries of Lake Huron by individual Quota Management Area (QMA), by basin, and at a lake level. The annual *Commercial Fishing Summary* reports on harvest, effort, targeted CPUE, quota, and percent quota taken.

Other methods of netting and surveying undertaken in eastern Georgian Bay by UGLMU and several other agencies and organizations including the Ministry of Environment and Climate Change (MOECC), Anishinabek/Ontario Fisheries Resource Centre (AOFRC), and Severn Sound Environmental Association (SSEA) periodically capture lake trout but are not focused specifically on describing their populations.

This report uses data and summaries from the following sources: UGLMU's draft rehabilitation plan; LTRZ 2012 summary reports; 2015 FLIN and FSIT project completion reports; OSIA 2013 and 2015 summary reports; and the *Lake Huron Commercial Fishing Summary for 2015* (MNRF, 2016). These sources are used to evaluate the criteria introduced in section 3.8.1. Table 9 details how the evaluation criteria are measured, when possible, given the necessary data are available.

Table 9. Criteria and means of measurement used to evaluate progress towards lake trout rehabilitation at each Lake Trout Rehabilitation Zone (MNRF, 1996).

Evaluation Criteria	Measurement
Age structure	• Number of year classes older than age four • Mean age of the spawning population
Lake trout survival/mortality	• Total annual mortality – index • Total annual mortality – commercial
Spawning stock size	• Mature cohorts on spawning sites • Catch rates of adults per net night in trap net sets near spawning reefs in the fall • Catch rates of adults per hour in short-set gill nets • Catch rates of spawners per 305 m of large mesh gill nets in the fall
Natural reproduction	• Catches of unclipped juvenile fish per standard UGLMU index net • Wild juvenile cohorts • Percent of unclipped fish • Percent of spawning population unclipped
Abundance	• Catch per unit effort (CPUE) derived from either spring or summer assessment programs using graded-mesh gill nets • Commercial gill net CPUE

3.8.3 Why is it important?

As a native top predator, lake trout are considered a useful indicator of the health of Georgian Bay's offshore oligotrophic waters and fish community. Assessing the health of lake trout populations can provide insights on food web productivity, the presence and effects of invasive species, and the availability and quality of habitat. In addition to their important ecological role, Lake Huron lake trout have been, and continue to be, pursued recreationally as a sport fish and commercially as a wholesome food source and source of revenue.

Lake trout were historically the top cold water predator in Lake Huron, including Georgian Bay. Eastern Georgian Bay supported numerous populations that resided in the deep offshore waters and utilized shallower waters for spawning in the fall and feeding in the spring. The invasion of sea lamprey (*Petromyzon marinus*), in combination with over-exploitation and the decline of major food sources, deepwater ciscoes (*Coregonus spp.*) and cisco (*Coregonus artedii*) (Eshenroder et al., 2016), caused lake trout populations in Lake Huron to collapse (Figure 38) in all but two isolated locations, Iroquois Bay and Parry Sound. Efforts to rehabilitate this species have been ongoing since 1969, primarily through sea lamprey control, stocking, and restrictions on harvest. In Parry Sound, the persistence of a native, locally adapted strain of lake trout, together with restrictive harvest regulations, establishment of a no-fishing for lake trout sanctuary, and stocking of Parry Sound strain lake trout until 1997, all contributed to the rehabilitation of this population. Outside of Lake Superior, this is the only population of lake trout to be considered fully rehabilitated across the Great Lakes (Reid et al., 2001).

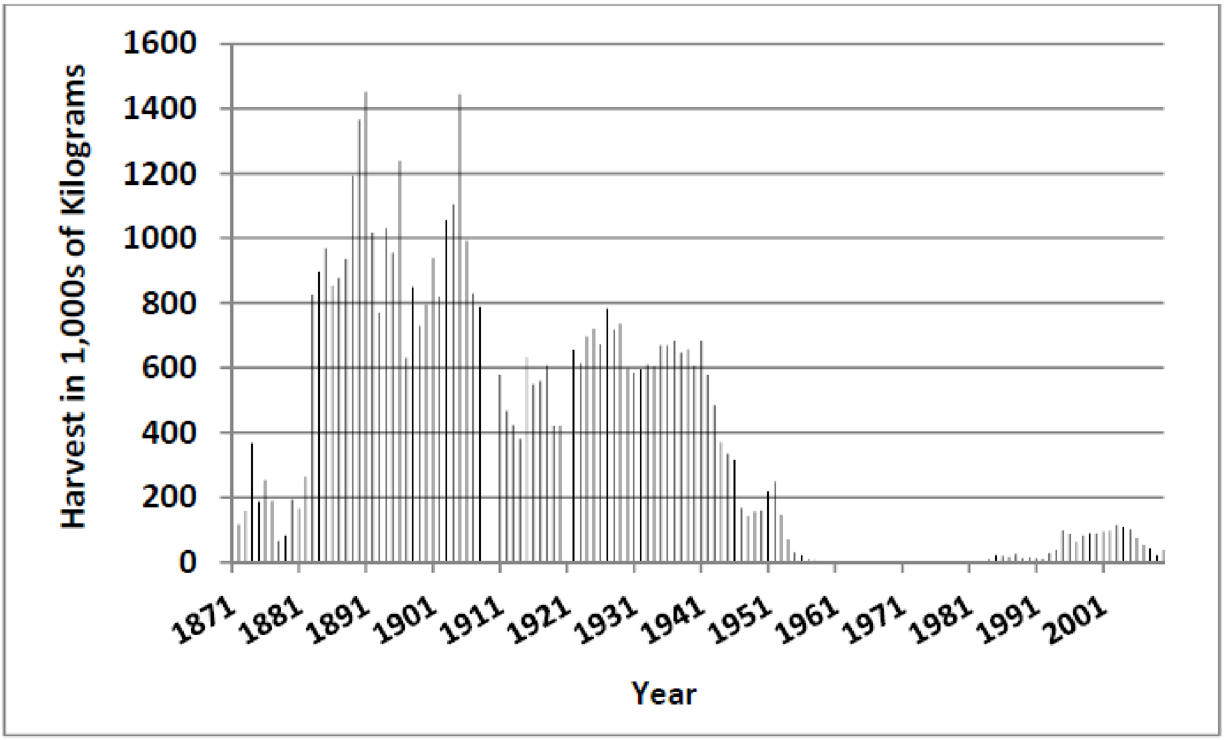


Figure 38. Historical lake trout commercial harvest in Georgian Bay (ULGMU, pers. comm., 2013).

In spite of the success in Parry Sound, lake trout populations have not been established in most locations where they were found historically. The draft rehabilitation plan outlines objectives and strategies forming an approach for the rehabilitation of lake trout to meet the overarching goal of restoring self-sustaining populations of this native top predator. The plan identifies five LTRZs within the *State of the Bay* reporting area (Figure 39) – Parry Sound (LTRZ 6), Limestone Islands (LTRZ 7), Watcher Islands (LTRZ 8), Iroquois Bay (LTRZ 5), and Frazer Bay (LTRZ 3).

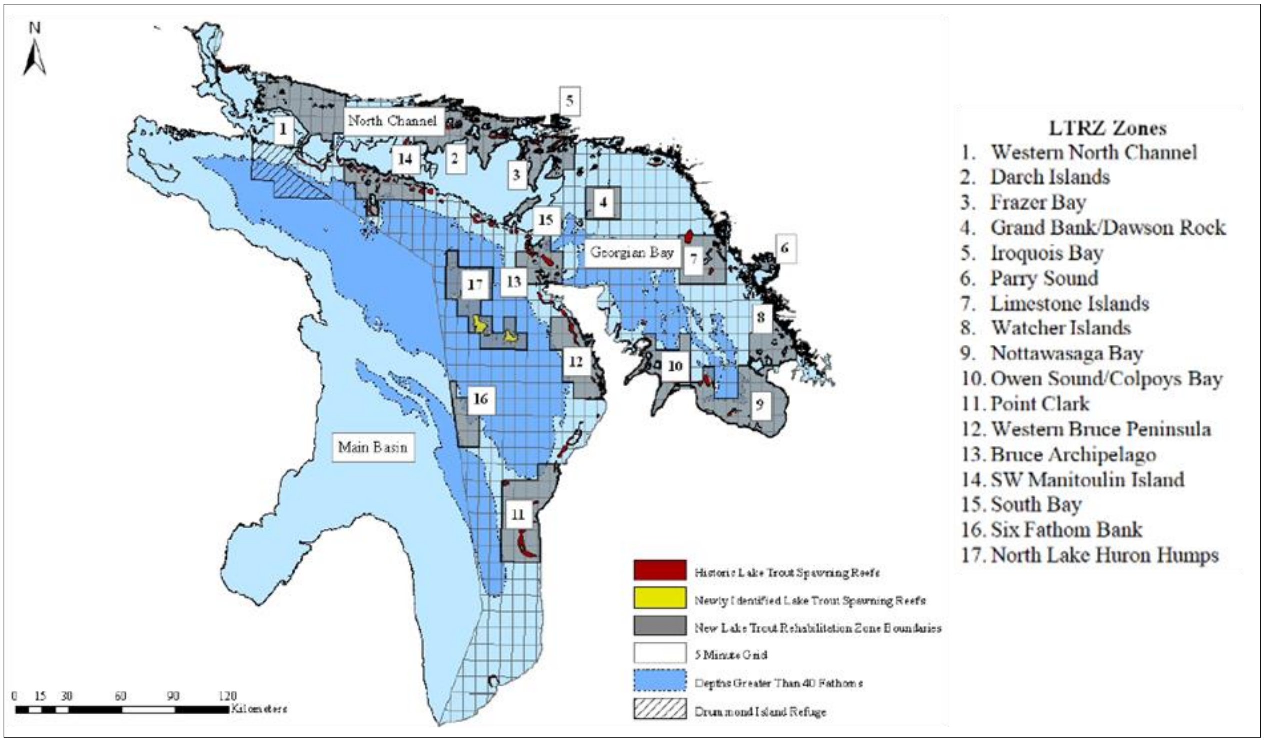


Figure 39. Lake Huron lake trout rehabilitation zones (LTRZs) based on the 5 minute grid layers and the 40 fathom contour line. Depths deeper than 40 fathoms are indicated in dark blue (MNRF, 2012).

The importance of healthy lake trout populations in Georgian Bay and Lake Huron more broadly, has been recognized by several agencies and formalized in numerous documents and strategies in addition to the draft rehabilitation plan. For example, reinstating lake trout as the dominant species in a diverse salmonine community is part of the salmonine objective detailed in the 1995 *Fish Community Objectives for Lake Huron* (DesJardine et al., 1995). As another example, the *Strategic Vision of the Great Lakes Fishery Commission 2011-2020* lists the encouragement of management actions to increase natural reproduction of lake trout as one of several strategies to achieve the first of three pillars, "healthy Great Lakes ecosystems and sustainable fisheries" (GLFC, 2011, p. 9). These and other documents highlight the need to monitor and report on lake trout populations in eastern Georgian Bay.

3.8.4 What are the results?

Results for each of the five LTRZs within eastern Georgian Bay are described in the sections that follow, using the criteria for monitoring species recovery listed in Table 9. Overall trends for all zones are summarized using the trends outlined in section 1.

Lake Trout Rehabilitation Zone 3 – Frazer Bay

LTRZ 3 is located in the northwest corner of Georgian Bay, beginning at Little Current in the west and including Manitowaning Bay, Frazer Bay, and the waters of Georgian Bay between Cape Smith and

Killarney. LTRZ 3 is comprised of several historic lake trout spawning shoals, abundant islands, and extensive shoreline spawning habitat. A relatively small commercial fishery operates in this area but does not specifically target lake trout. Conversely, lake trout are targeted by recreational anglers including during the winter. LTRZ 3 has a long history of stocking which has consisted of Iroquois Bay strain lake trout since 2002. LTRZ 3 began as priority 4 but was bumped to priority 5 in the draft rehabilitation plan.

The latest available data show that in terms of age structure, few year classes (<6.0) older than age four, the age when full recruitment to assessment gear occurs, are present in the LTRZ 3 population. The target for a population is to have at least seven age classes older than age four. The average age of the LTRZ 3 spawning population (7.0-7.9) is near or above the threshold of at least one year older than the mean age to maturity. Results from the 2013 OSIA state that the mean age of lake trout captured in Frazer Bay was 4.1 with a minimum age of 1 and maximum age of 16.

Total annual lake trout mortality in LTRZ 3 is considered low as it falls below the 30% target. The frequency of sea lamprey-induced wounds has decreased nearly every year after 2009 and has been below the target of five wounds per 100 lake trout in recent years. Of potential concern is the fact that lake trout harvest has experienced an increasing trend in LTRZ 3 since 1991.

With regard to abundance and spawning stock size, more than four cohorts (4.0-4.9 mature cohorts) were found to be using spawning habitat. However, spawning survey gill net CPUE was reported as <0.5. Relative abundance is said to have been increasing for several years although CPUE remains below target levels and is highly variable. Specifically, nearshore and index gill net CPUE (<5.0) and commercial CPUE (<10.0) are consistently below their respective thresholds. The *Lake Huron Commercial Fishing Summary for 2015* (MNRF, 2016) details the percentage of the lake trout quota taken in QMA 6-3 from 1998-2015. In all but four of those years (2001-2004), percent quota taken has been under 60% in this QMA. An average CPUE of 0.73 per net was calculated from a 2015 FLIN conducted in Frazer Bay.

The extent of natural reproduction in the LTRZ 3 population, as determined by the percentage of wild (unclipped) fish captured during netting, has varied significantly over the years around the threshold to terminate stocking. Overall, the percentage of unclipped fish has been increasing since 2000 in both commercial and nearshore fishing gear. The LTRZ 3 2012 summary reports 30-49% wild fish in index gear, the 2011 OSIA found 57.6% of lake trout were unclipped, the 2013 OSIA found 50% of lake trout were unclipped, and 78% of lake trout captured in the 2015 FLIN were unclipped. The most recent data available suggest that there are 3.0-3.9 wild juvenile cohorts and 25-29% of spawners captured in index gear were wild.

Lake Trout Rehabilitation Zone 5 – Iroquois Bay

Located in the extreme northwest corner of Georgian Bay, Iroquois Bay is a secluded bay characterized by several nearshore spawning shoals and deep offshore habitat. Initially, LTRZ 5 had a total area of 496 ha but has since been adjusted to incorporate an area of 1,028 ha. LTRZ 5 is considered a high priority rehabilitation zone (priority 2) with one of only two remnant populations in Lake Huron. This zone has been stocked at densities higher than any other LTRZ. The only source of harvest in LTRZ 5 is the recreational fishery which features restrictions including size-based (maximum size limits) and catch-and-release regulations as well as a closed winter fishery. There is no commercial fishery in this LTRZ.

A recognized knowledge gap and assessment need for LTRZ 5 is around age structure and characterizing the existing lake trout population, particularly with regard to spawning aged fish. The 2012 LTRZ 5 summary reports that the average age of the spawning population is below target, although this changed in 2010 when 10 year classes were observed. At present, little is known about the number of year classes older than age four. Spawning surveys and large-mesh gill netting were scheduled for 2015 and 2016. Results from these surveys were not available at the time of writing.

The total annual lake trout mortality is below the 30% target in LTRZ 5 with the most recent data available reporting zero sea lamprey-induced wounds per 100 fish, albeit with a small sample size. Despite this positive information and a high rate of survival for stocked fish, the adult population does not appear to be building. Past creel surveys indicated relatively high yields of lake trout in the recreational fishery which may have resulted in excessive adult and sub-adult mortality. However, strict regulations were introduced in 2001 (e.g., no wild fish harvest) and anecdotal information suggests a subsequent decline in angling effort targeting lake trout.

In terms of abundance and spawning stock size, fewer than four cohorts (3.0-3.9 mature cohorts) were found to be using spawning habitat. The spawning survey gill net CPUE was reported as 1.0-1.4 and spawning surveys in the 1990s and 2004 indicated only small numbers of large, old fish present in the spawning population. Nearshore CPUE for LTRZ 5 has been increasing but is still consistently found to be below target. An average CPUE of 1.88 per net was calculated from a 2015 FLIN conducted in Iroquois Bay. The incomplete data available regarding abundance and spawning stock size for LTRZ 5 reinforces the aforementioned need for an updated characterization of the existing lake trout population.

With regard to natural reproduction in LTRZ 5, the percentage of wild fish caught in surveys over the years has fluctuated considerably. The percentage of unclipped fish found in 1996 was roughly 35%. FLIN surveys conducted in 2009 and 2010 did not catch any wild lake trout of any age group, and more recently, 18% of lake trout captured in a 2015 FLIN were unclipped. A second consecutive year of FLIN was conducted in 2016, results were not available at the time of writing.

Lake Trout Rehabilitation Zone 6 – Parry Sound

LTRZ 6 is the priority 1 LTRZ and includes Parry Sound, the waters out to the western point of Parry Island, and the waters surrounding Killbear Provincial Park. Found within LTRZ 6 are numerous spawning shoals and adjacent deepwater habitat. Similar to LTRZ 5, LTRZ 6 supports one of only two remnant lake trout populations. As such, the Big Sound strain is routinely used for stocking other LTRZs. LTRZ 6 is unique in eastern Georgian Bay as it represents the only rehabilitated lake trout population. The Parry Sound population was rehabilitated through a combination of extensive regulation of the recreational fishery (and the absence of commercial fishing since 2003) and diligent stocking. Evidence exists of the LTRZ 6 population moving into the surrounding waters of Georgian Bay which suggests that the population is expanding its range (MNRF, 2012).

The most current reports on LTRZ 6 describe the lake trout population as robust with a good number of fish spanning a wide range of sizes. The number of year classes older than age four is consistently above the target and at least three sexually mature cohorts have been observed. Moreover, at the time the 2012 LTRZ 6 summary was written, the mean age of the spawning population was above the target for the past nine years that data were collected. Of potential concern, however, is that the frequency of juveniles (age five or below) is considered low.

After 1999, total annual mortality in LTRZ 6 has been below the target. As mentioned, the small, sporadic commercial fishery in LTRZ 6 ceased after 2003 and restrictive recreational fishery regulations remain in place to maintain harvest levels below 0.33 kg/ha. Conversely, sea lamprey marking has been highly variable and at times, above the target.

With regard to abundance and spawning stock size, the LTRZ 6 lake trout population appears to be doing quite well with a good number of spawning fish observed. The data presented in the 2012 LTRZ 6 summary are as follows: >4.9 mature cohorts on spawning sites; spawning survey trap net CPUE of >19.9; spawning survey gill net CPUE of 1.0-1.4; large-mesh survey gill net CPUE of 0.5-0.9; and a commercial CPUE exceeding the target in the last years of the fishery's operation. In addition, a 2015 FLIN in LTRZ 6 resulted in a CPUE of 3.45 and a 2015 trap net resulted in a CPUE of 14.56.

In terms of natural reproduction, the FLIN and trap netting conducted in 2015 in LTRZ 6 each found 98% of lake trout were unclipped. Conclusions from both netting efforts were that the lake trout bearing fin clips likely lost their adipose fins through injury rather than being stocked fish. If this was in fact the case, 100% of the lake trout in LTRZ 6 could be considered wild.

Lake Trout Rehabilitation Zone 7 – Limestone Islands

LTRZ 7 encompasses the Limestone Islands, located 16 km to the northwest of Parry Sound. This area has several islands, reefs, and shoals providing abundant spawning, nursery, and summer habitat for lake trout. The small commercial fishery that previously operated in portions of LTRZ 7, ceased in 2003 and there is little to no recreational exploitation due to the Limestone Islands' distance offshore. The draft rehabilitation plan recommends implementing sanctuary status for this zone as was planned, but never formally carried out, in the past. LTRZ 7 is part of a pulse-stocking experiment in which Big Sound strain lake trout are stocked at higher than normal densities on a cycle of three years on, three years off. Due to the location of the Limestone Islands, many of the fish are not stocked within the LTRZ 7 boundaries or in close proximity to spawning habitat. LTRZ 7 is currently listed as priority 4, down from priority 3 in 2010.

The 2012 LTRZ 7 summary describes the average age of the lake trout spawning population as above the target in index gear (>8.9), an increase from what was historically seen in commercial fishing gear. In terms of year classes older than age four, the latest data available suggest 7.0-7.9 year classes older than age four in LTRZ 7.

With regard to lake trout survival/mortality, total annual lake trout mortality in LTRZ 7 is reported to be below the upper threshold for both commercial fishing gear (30-39), when the commercial fishery was still active, and index gear (30-39); however, sea lamprey marking rates are at or above the target level.

Index CPUE (<5.0) in LTRZ 7 is listed as below the target, as was commercial CPUE (<10.0) when the commercial fishery was active. As for spawning stock size, little is known about this population. As stated in the draft rehabilitation plan, collection of relative abundance measures on spawning reefs in the fall has proven to be difficult, if at all possible, in the more exposed, offshore LTRZs like the Limestone Islands.

Although some were caught in 2011, unclipped lake trout juveniles are considered to be effectively absent in LTRZ 7 (<1.0 wild juveniles per index gill net and <1.0 wild juvenile cohorts). When looking at the population as a whole, in a 2008 fisheries independent survey, wild lake trout represented over 50% of the catch and in the 2012 LTRZ 7 summary, wild fish in the index as a percentage is reported as 30%-49%. Finally, in the same summary, 30%-34% is the percentage range given for wild spawners in the index.

Lake Trout Rehabilitation Zone 8 – Watcher Islands

LTRZ 8 is focused on the Watcher Island complex located in the southeast corner of Georgian Bay. This LTRZ exhibits an abundance of lake trout spawning habitat with deepwater habitat nearby. Although less active than in the past, a commercial fishery, primarily focused on lake whitefish (*Coregonus clupeaformis*), exists in LTRZ 8. More recently, lake trout have become a larger component of the commercial harvest. Similarly, while recreational fisheries in the area focus on nearshore species, fisheries for lake trout and chinook salmon (*Oncorhynchus tshawytscha*) have also sprung up in offshore regions of LTRZ 8. As in LTRZ 7, LTRZ 8 is part of a pulse-stocking experiment utilizing the Big Sound strain. However, fish have not been stocked in close proximity to spawning habitat in the Watchers and in some cases, have not been stocked within the LTRZ 8 boundaries. LTRZ 8 is listed as priority 11 in the draft rehabilitation plan.

In LTRZ 8, the average age of the spawning population is generally above the target, especially after 2006, but the catch is comprised of few cohorts. The 2012 LTRZ summary indicates that less than six year classes older than age four are present in the LTRZ 8 lake trout population. Results from the 2016 OSIA state that the mean age of lake trout captured in Georgian Bay near the Watcher Islands was 4.1 with a minimum age of 1 and maximum age of 7. A second consecutive OSIA incorporating LTRZ 7 was scheduled for 2017. Data from this assessment will provide additional information on the age structure of the LTRZ 8 lake trout population.

In terms of total annual mortality, estimates from index (40%-49%) and commercial (20%-29%) data is regularly above the target level. Sea lamprey wounding rates saw a general increase from zero in 2003 to three times the acceptable minimum value of five wounds per 100 lake trout in 2011. The draft rehabilitation plan states that this high occurrence of mortality must be reduced if progress is to be made towards rehabilitating the LTRZ 8 lake trout population. Furthermore, the plan suggests the encouragement of the use of live-capture gear (e.g., trap nets) or modified gill nets that reduce incidental catches of lake trout in the commercial fishery to bring down mortality rates.

The most recent data available specific to LTRZ 8 suggest that CPUE in both index (<5.0) and commercial fishing gear (<10.0) are below the target except in 2004 and 2005. More recent data for all of QMA 5-7, the QMA that LTRZ 8 falls within, show fluctuating CPUE values. The CPUE values for 2013, 2014, and 2015 are 13.1, 4.6, and 18.2, respectively. The percentage of lake trout quota taken in QMA 5-7, as detailed in the *Lake Huron Commercial Fishing Summary for 2015* (MNRF, 2016), was well over 100% from 1998-2005 (highest value of 1,226.6% in 2005) and consistently under 50% from 2006-2015 (lowest value of 13.4% in 2004).

Despite the experiment with pulse stocking and the availability of spawning habitat, wild lake trout make up a very small percentage of the catch in LTRZ 8. This is evidenced by the values for wild juveniles per index gill net (<1.0), wild juvenile cohorts (1.0-1.9), wild fish in index as a percentage (<10), and wild spawners in index as a percentage (<20). In addition, the 2016 OSIA found only 2.1% of lake trout were unclipped. Accordingly, natural reproduction in LTRZ 8 is considered insufficient (i.e., <25%).

Summary

Based on the latest data available, LTRZ 3 is showing signs of recovery, LTRZ 5 remains a high priority but has not seen consistent signs of recovery, LTRZ 6 remains rehabilitated with a healthy naturally reproducing population, LTRZ 7 has shown signs of a deteriorating trend but collection of assessment data has been limited by the difficulties associated with the exposed location of this LTRZ, and finally, LTRZ 8 remains priority 11 but as with LTRZ 7, collection of assessment data has been limited. In summary, although some progress is being made, the status of lake trout populations in these areas suggests that the rehabilitation objectives outlined in the revised plan are still not being achieved. With reduced productivity in the offshore waters and other ecosystem changes, the prospects for lake trout rehabilitation in Georgian Bay are uncertain. At a broader scale, however, the trend for lake trout populations in Lake Huron as a whole is listed as ‘improving’ in the *State of the Great Lakes 2017 Technical Report* (EC & EPA, 2017).

Table 10. Summary of Lake Trout Rehabilitation Zone trends.

LTRZ	Trend
Frazer Bay (LTRZ 3)	Improving
Iroquois Bay (LTRZ 5)	Unchanging
Parry Sound (LTRZ 6)	Unchanging
Limestone Islands (LTRZ 7)	Deteriorating/Undetermined
Watcher Islands (LTRZ 8)	Unchanging/Undetermined

3.9 Data gaps and research needs

The main data gaps and research needs with respect to the aquatic ecosystem health indicator are summarized below.

3.9.1 Lower food web

The main lower food web data gaps and research needs are centered on establishing regular monitoring programs to measure and help understand lower food web productivity and trophic interactions:

1. Phytoplankton - Assessment of seasonal plankton production, especially spring bloom conditions and possible implications for zooplankton timing and larval fish food supply at locations throughout eastern Georgian Bay. Late summer blue-green algae blooms are also important to track in a variety of locations in order to better understand causes of dominance in some locations and not others.

2. Zooplankton - Studies to identify the drivers of recent shifts in zooplankton community structure (e.g., roles of *Bythotrephes* and *Leptodora*, top-down versus bottom-up mechanisms, and declines in *Diporeia* populations) including a detailed examination of trophic interactions. Food preferences of the dominant Great Lakes zooplankton need to be investigated, and whether they are able to tolerate shifting diets.

3. Benthic macroinvertebrates - Studies are required to better characterize the spatial differences across eastern Georgian Bay. Programs should include under-sampled species and aquatic habitat types (e.g., rocky substrates and depositional areas). Monitoring would include protocols like that of the GLNPO and CABIN including nearshore and hard substrates in addition to soft substrates, to identify temporal and spatial trends in the benthic community.

Assuming that many of the identified trends in this report will continue, it will be important to identify the potential future impacts of these trends on the entire aquatic food web. Detailed seasonal sampling of phytoplankton, zooplankton and benthos is needed to better characterize trophic interactions. With better understanding it may be possible to predict future effects on the higher trophic levels (i.e., coldwater fisheries). In order to complete the sort of sample analysis necessary to better characterize the lower food web, efforts need to be made to training a new generation of taxonomists.

Additional research needs have been identified by Severn Sound Environmental Association (SSEA) for the Severn Sound area that also likely apply to other parts of the Georgian Bay coastline. SSEA has identified a gap in knowledge on conditions in the shallow nearshore (i.e., <3m depth) in terms of nutrient variability, algae growth (both phytoplankton and periphyton), and benthic invertebrates. Anecdotal evidence exists of increased productivity in this zone, in some areas resulting in heavy growth on rocks and built structures. It is unclear whether this periphyton production is the result of point source nutrient loading like septic runoff and greywater discharge, or a lack of invertebrate grazers. There are indications to suggest a combination of the two factors. Similarly, in the water column, the growth of algae may be due to nutrients or a lack of zooplankton grazers. Qualitative observation has shown an increase in suspended algae in the shallow nearshore over the last 5-10 years across Severn Sound. The shallow nearshore ecosystem is complex and sampling it adequately is outside the scope of large monitoring programs. This type of work could be made more feasible by partnering with university researchers, local cottage associations, and citizen scientists.

3.9.2 Prey fish

The data gaps and research needs with respect to the prey fish indicator are:

1. Coordinated studies to better characterize the linkages between the lower and upper food web.

2. Improve quantification and biomass estimates for key and under-sampled components of the food web (e.g., fish production – including round goby).

3. Continued assessment of the forage community (benthos, zooplankton, prey fish) structure and function relative to the suite of environmental stressors on this system.

4. Investigation of the factors controlling the distribution and structure of the prey fish populations.

5. Addressing the knowledge gap for round goby biology, importance as prey, abundance/distribution/spread.

3.9.3 Smallmouth bass

The data gaps and research needs with respect to the smallmouth bass indicator are:

1. Enhanced spatial and temporal coverage of smallmouth bass data. At present, smallmouth bass data are collected at a limited number of locations and, with the exception of Severn Sound, there is insufficient data to assess trend through time.

2. Quantify predation impacts on eggs and fry from round goby on nesting bass.

3. Shoreline development and alteration to nearshore cobble and rubble spawning habitat for smallmouth bass.

3.9.4 Northern pike

The data gaps and research needs with respect to the northern pike indicator are:

1. Enhanced spatial and temporal coverage of northern pike data. At present, northern pike data are collected at a limited number of locations and, with the exception of Severn Sound, there is insufficient data to assess trend through time.

2. Development and alteration of riverine and deltaic wetlands spawning and nursery areas supporting northern pike.

3.9.5 Muskellunge

The data gaps and research needs with respect to the muskellunge indicator are:

1. Enhanced spatial and temporal coverage of muskellunge data. At present, muskellunge data are collected at a limited number of locations and, with the exception of Severn Sound, there is insufficient data to assess trend through time.

2. Invasive species (e.g., round goby) impacts (e.g., predation of eggs) on coastal wetland spawning and nursery areas supporting muskellunge.

3. Shoreline development and alteration of critical coastal wetland spawning and nursery habitats.

3.9.6 Walleye

The data gaps and research needs with respect to the walleye indicator are:

1. Improve understanding around the attributes that Shawanaga River exhibits in order to support such a robust spawning population of walleye, compared to other areas in Georgian Bay.

2. Develop a comprehensive estimate of recreational and Indigenous subsistence walleye harvest across the basin.

3. Conduct netting surveys at locations where walleye spawning stocks have not been assessed in many years.

4. Monitor locations where spawning bed enhancement work has been undertaken in order to evaluate success and identify the need for additional work.

3.9.7 Lake trout

The data gaps and research needs with respect to the lake trout indicator are:

1. Improve understanding of:
    a. The impacts of invasive species on lake trout populations;
    b. Changes in the prey community and their impacts on lake trout populations; and
    c. Key attributes of lake trout spawning habitat that have been associated with successful natural reproduction.

2. Updated reviews of all LTRZs and the draft lake trout rehabilitation plan according to designated timelines.

3.10 What can I do to help?

1. Support the work of the Eastern Georgian Bay Stewardship Council
    - www.georgianbaystewardship.ca

2. Use MNRF's Fish ON-Line tool to submit information about fishing effort, location, and catch.
    - www.ontario.ca/fishonline

3. Learn and abide by fishing regulations for the zone(s) you angle in including size and catch limits, open seasons, sanctuaries, and specific rules for the waterbody or zone.
    - www.ontario.ca/document/ontario-fishing-regulations-summary

4. Consider practicing conservation principles when fishing and do not catch your limit.

5. Help stop the spread of invasive species. Learn how to identify aquatic invasive species and report those you encounter to the Invading Species Hotline (1-800-563-7711) or using EDDMapS Ontario.
    - www.invadingspecies.com/stop-the-spread/
    - www.eddmaps.org/ontario/

6. Complete self-evaluations of your property and lifestyle practices to identify ways to improve your local water quality and fish habitat.
    - www.gbbr.ca/our-environment/life-on-the-bay-guide/

7. Plan any work in or near the water carefully to prevent or minimize impacts to fish and fish habitat. Fisheries and Oceans Canada (DFO) has details on their website about the impacts to fish and fish habitat from projects such as dredging and shoreline stabilization. These resources also include information about controlling aquatic plants and how to plan your project to minimize potential impacts to the aquatic environment.
    - www.dfo-mpo.gc.ca/habitat/habitat-eng.htm

3.11 Where can I learn more?

For more information on preserving water quality and natural shorelines, as well as protecting and improving fish habitat, refer to the LandOwner Resource Centre's Water and Wetlands Extension Notes: www.lrconline.com/Extension_Notes_English/water/water_index.html

To learn about how fish resources are managed in Fisheries Management Zone (FMZ) 14, visit the FMZ 14 webpage which includes monitoring reports, management plans, and information on the advisory council: www.ontario.ca/page/fisheries-management-zone-14-fmz-14#section-5

For the latest fisheries information from the Lake Huron Committee, visit the Great Lakes Fishery Commission's Lake Huron webpage: http://www.glfc.org/lakecom/lhc/lhchome.php#pub

3.12 References

Barbiero, R.P., Lesht, B.M., & Warren, G.J. (2011). Evidence for bottom-up control of recent shifts in the pelagic food web of Lake Huron. *Journal of Great Lakes Research, 37*, 78-85.

Bunnell, D.B., Davis, B.M., Warner, D.M., Chriscinske, M.A., & Roseman, E.F. (2011). Planktivory in the changing Lake Huron zooplankton community: *Bythotrephes* consumption exceeds that of *Mysis* and fish. *Freshwater Biology, 56*, 1281-1296.

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

DesJardine, R.L., Gorenflo, T.K., Payne, R.N., & Schrouder, J.D. (1995). *Fish community objectives for Lake Huron.* Great Lakes Fisheries Commission Special Publication 95-1.

Dobiesz, N.E., McLeish, D.A., Eshenroder, R.L., Bence, J.R., Mohr, L.C., Ebener, M.P., et al. (2005). Ecology of Lake Huron fish community, 1970-1990. *Canadian Journal of Fisheries and Aquatic Sciences, 62*(6), 1432-1451.

Eastern Georgian Bay Stewardship Council (EGBSC). (2015). *Walleye woes: looking for solutions to ensure walleye have a future in eastern Georgian Bay.* Retrieved from https://georgianbaystewardship.ca/wp-content/uploads/2016/07/walleye-woes.pdf

Environment Canada (EC) and the U.S. Environmental Protection Agency (EPA). (2009). *State of the Great Lakes 2009*. Cat No. En161-3/1-2009E-PDF. EPA 950-R-09-031. Retrieved from http://binational.net

Environment Canada (EC) and the U.S. Environmental Protection Agency (EPA). (2014). *State of the Great Lakes 2011*. Cat No. En161-3/1-2011E-PDF. EPA 950-R-13-002. Retrieved from http://binational.net

Environment Canada (EC) 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 http://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/

Eshenroder, R.L., Vecsei, P., Gorman, O.T., Yule, D., Pratt, T.C., Mandrak, N.E., et al. (2016). *Ciscoes (Coregonus, subgenus Leucichthys) of the Laurentian Great Lakes and Lake Nipigon*. Retrieved from www.glfc.org/pubs/misc/Ciscoes_of_the_Laurentian_Great_Lakes_and_Lake_Nipigon.pdf

Fielder, D.G., & Liskauskas, A. (2014). *Status of Lake Huron walleye* [Presentation slides].

Fielder, D.G., Liskauskas, A.P., Gonder, D.J.A., Mohr, L.C., & Thomas, M.V. (2010). Status of walleye in Lake Huron. In E. Roseman, P. Kocovsky, & C. Vandergoot (Eds.), *Status of walleye in the Great*

Lakes: proceedings of the 2006 Symposium (pp. 71-90). Great Lakes Fisheries Commission Technical Report 69.

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). (2013). *State of the bay background report*. Retrieved from https://www.gbbr.ca/about-us/documents/

Great Lakes Fishery Commission (GLFC). (2011). *Strategic vision of the Great Lake Fishery Commission 2011-2020.* Retrieved from http://glfc.org/glfc-publications-reports.php

Great Lakes Science Advisory Board (GLSAB). (2016). *Future improvements to Great Lakes indicators.* Retrieved from http://www.ijc.org/en_/sab/Reports

Harvey, B. (2009). A biological synopsis of northern pike (*Esox lucius*). *Canadian Manuscript Report of Fisheries and Aquatic Sciences, 2885*.

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.

Hinderer, J.M., Murray, M.W., & Becker, T. (2011). *Feast and famine in the Great Lakes: how nutrients and invasive species interact to overwhelm the coasts and starve the offshore waters*. Ann Arbor, MI: National Wildlife Federation.

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

International Joint Commission (IJC). (2014). *Great Lakes ecosystem indicator project report.* Retrieved from http://www.ijc.org/en_/AOP/Ecosystem

Kerr, S.J. (2004). *Characteristics of Ontario muskellunge fisheries based on volunteer angler diary information*. Peterborough, ON: Ontario Ministry of Natural Resources, Fish and Wildlife Branch.

Kerr, S.J. (2007). Characteristics of Ontario muskellunge (*Esox masquinongy*) fisheries based on volunteer angler diary information. *Environmental Biology of Fish, 79*, 61-69.

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

Leblanc, J.P., Weller, J.D., & Chow-Fraser, P. (2014). Thirty-year update: changes in biological characteristics of degraded muskellunge nursery habitat in southern Georgian Bay, Lake Huron, Canada. *Journal of Great Lakes Research, 40,* 870-878.

LimnoTech. (2015a). *DRAFT Lake Huron Partnership science and monitoring synthesis.* Report prepared for Environment Canada. Retrieved from https://www.lakehuroncommunityaction.ca/wp-content/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/resources-links/

Liskauskas, A. (in press). Managing and monitoring muskellunge populations in eastern Georgian Bay and the North Channel of Lake Huron: a twenty-year retrospective. *American Fisheries Society Symposium, 85*.

Liskauskas, A., Johnson, J., McKay, M., Gorenflo, T., Woldt, A., & Bredin, J. (2007). *Environmental objectives for Lake Huron: report of the Environmental Objectives Working Group of the Lake Huron Technical Committee.* Great Lakes Fishery Commission.

Liskauskas, A. (2015a). Georgian Bay: changing lake ecology and fish community response [Presentation slides].

Liskauskas, A. (2015b). Recent walleye trends in Lake Huron [Presentation slides].

Loveridge, C.C., & Cook, D.G. (1976). A preliminary report on the benthic invertebrates of Georgian Bay and North Channel. Environment Canada Fisheries and Marine Service Technical Report No. 610.

Mason, L.A., Riseng, C.M., Groneworld, 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. *Climate Change, 138*, 71-83.

McIntyre, E. (2011). *2011 Moon River index spawners and walleye culture project summary report.* Retrieved from https://georgianbaystewardship.ca/documents-to-download/

Messick, G.A., Overstreet, R.M., Nalepa, T.F., & Tyler, S. (2004). Prevalence of parasites in amphipods *Diporeia* spp. from Lakes Michigan and Huron, USA. *Diseases of Aquatic Organisms, 59*, 159-170.

Ministry of Natural Resources and Forestry (MNRF). (1996). *Lake trout rehabilitation plan for Lake Huron (Canadian jurisdiction)*. Ontario Ministry of Natural Resources, Lake Huron Management Unit, Report 02-96.

Ministry of Natural Resources and Forestry (MNRF). (2002). *Georgian Bay and the North Channel walleye assessment update 2002*. Ontario Ministry of Natural Resources, Lake Huron Management Unit.

Ministry of Natural Resources and Forestry (MNRF). (2012). *A revised lake trout rehabilitation plan for Ontario waters of Lake Huron*. Ontario Ministry of Natural Resources, Upper Great Lakes Management Unit.

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

Ministry of Natural Resources and Forestry (MNRF). (2016). *Lake Huron commercial fishing summary for 2015.* Ministry of Natural Resources and Forestry, Upper Great Lakes Management Unit. Report TR-LHA-2015-01.

Morgan, G. (2013). *Walleye data review for Lake Huron* [Presentation slides]. Upper Great Lakes Management Unit Annual Meeting, Owen Sound, November 27-28, 2013.

Nalepa, T.F., Fanslow, D.L., Pothoven, S.A., Foley, A.J., & Lang, G.A. (2007). Long-term trends in benthic macroinvertebrate populations in Lake Huron over the past four decades. *Journal of Great Lakes Research, 33*, 421-436.

National Oceanic and Atmospheric Administration Great Lakes Environmental Research Laboratory (NOAA GLERL). (2009). *Lake Huron food web.* Retrieved from https://www.glerl.noaa.gov//pubs/brochures/foodweb/LHfoodweb.pdf

O'Brien, T.P., Esselman, P.C., Lenart, S., Farha, S., Armenio, P., Olds, C., et al. (2017). *Status and trends of pelagic prey fish in Lake Huron, 2016*. 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.

Reavie, E.D., Sgro, G.V., Estepp, L.R., Bramburger, A.J., Shaw Chraibi, V.L., Pillsbury, R.W., et al. (2017). Climate warming and changes in *Cyclotella sensu lato* in the Laurentian Great Lakes. *Limnology and Oceanography, 62*(2), 768-783.

Reckahn, J.A., & Thurston, W.D. (1991). The present (1989) status of walleye stocks in Georgian Bay, North Channel, and Canadian waters of southern Lake Huron. In P.J. Colby, C.A. Lewis, & R.L. Eshenroder (Eds.), *Status of walleye in the Great Lakes: case studies prepared for the 1989 workshop* (pp. 85-114). Great Lakes Fisheries Commission Special Publication 91-1. Retrieved from http://www.glfc.org/pubs/SpecialPubs/Sp91_1.pdf

Reid, D.M., Anderson, D.M, & Henderson, B.A. (2001). Restoration of lake trout in Parry Sound, Lake Huron. *North American Journal of Fisheries Management, 21*, 156-169.

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

Riley, S.C., Roseman, E.F., Hondorp, D.W., Chriscinske, M.A., Galassini, E., & Smith, M. (2017). Status and trends of the Lake Huron offshore demersal fish community, 1976-2016. Retrieved from http://www.glfc.org/pubs/lake_committees/common_docs/CompiledReportsfromUSGS2017.pdf

Sale, P., Lammers, R., Yan, N., Hutchinson, N., Trimble, K., Dinner, P., et al. (2016). *Planning for climate change in Muskoka.* Muskoka, ON: Muskoka Watershed Council. Retrieved from http://www.muskokawatershed.org/resources/planning-for-climate-change/

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

Taillon, D., & Heinbuck, T. (in press). Ontario's muskellunge angler log program: 1995-2015. *American Fisheries Society Symposium, 85*.

Upper Great Lakes Management Unit (UGLMU). (2008). *Moon River Delta muskellunge population assessment survey, 2008.* Upper Great Lakes Management Unit, Lake Huron Office.

Upper Great Lakes Management Unit (UGLMU). (2016a). *Shawanaga River area End of Spring Trap Netting (ESTN) survey: summary report, 2016.* Upper Great Lakes Management Unit, Lake Huron Office.

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

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

U.S. Environmental Protection Agency (EPA). (2017a). *Great Lakes Biology Monitoring Program.* Retrieved from https://www.epa.gov/great-lakes-monitoring/great-lakes-biology-monitoring-program

U.S. Environmental Protection Agency (EPA). (2017b). *Great Lakes zooplankton monitoring*. Retrieved from https://www.epa.gov/great-lakes-monitoring/great-lakes-zooplankton-monitoring

Weller, J.D., Leblanc, J.P., Liskauskas, A., & Chow-Fraser, P. (2016). Spawning season distribution in subpopulations of muskellunge in Georgian Bay, Lake Huron. *Transactions of the American Fisheries Society, 145*(4), 795-809.

Winder, M., & Schindler, D.E. (2004). Climate change uncouples trophic interactions in an aquatic ecosystem. *Ecology, 85*(8), 2100-2106.

Yousef, F., Schuchman, R., Sayers, M., Fahnenstiel, G., & Henareh, A. (2017). Water clarity of the upper Great Lakes: tracking changes between 1998-2012. *Journal of Great Lakes Research, 43*, 239-247.

4. Coastal Wetlands

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4.1 Introduction

In the first *State of the Bay* (2013) report, wetland condition was measured using two indicators: coastal wetland plant diversity and percent cover (or distribution) showing the total area of coastal wetlands compared to other vegetation or landbase types (e.g., forest, open rock, water). Over time, percent cover trends can indicate wetland gain or loss in particular areas. However, the context for wetland change is directly related to water level fluctuations. The focus in this 2018 report is not simply on net loss or gain of coastal wetlands, but rather establishing some links between cover, water level fluctuations, and climate change – in order to inform future management and conservation decisions in eastern and northern Georgian Bay.

Following a description of wetland types, functions, and monitoring approaches, a variety of new studies, assessments, and data sources are considered in order to enhance our understanding of complex wetland dynamics. In particular, long-term monitoring data that is publicly accessible will be needed to continue reporting in the future. Highly technical studies using satellite imagery, along with established Great Lakes monitoring programs, can be combined with local knowledge and citizen science data for the most comprehensive regional understanding of coastal wetland change in Georgian Bay.

4.2 Coastal wetlands

Wetlands are a diverse group of ecosystems that are either permanently or seasonally inundated. This inundation causes the soil to be saturated with water long enough to form hydric (waterlogged) soils and the growth of hydrophytic (water-loving) or water tolerant plants (MNRF, 2014). There are four wetland types in Ontario: swamps, bogs, fens, and marshes (MNRF, 2017). Swamps take many years to develop and are largely dominated by trees and shrubs. These ecosystems are the most common type of wetland found in southern Ontario. Conversely, bogs are more common in northern Ontario and are characteristically low in nutrients and strongly acidic. Bogs are very old wetlands (thousands of years old) formed in peat-covered areas receiving water only from rainfall or surface runoff. Fens are similar to bogs in terms of their prevalence in northern Ontario, but they are less acidic and more nutrient-rich which allows for a greater diversity of plant life. Finally, marshes are the least common type of wetland in Ontario. Marshes are identified by open areas of water with floating (e.g., water lilies) and emergent plants (e.g., cattails, pickerelweed).

Coastal wetlands form along shorelines of large water bodies, such as lakes, and are typically inundated with water for the majority of the year. They exist at the interface between terrestrial and aquatic habitats and naturally form in shallow, protected embayments (Midwood et al., 2011). Provincially, coastal wetlands are defined in the *Ontario Wetland Evaluation System* as any wetland (bog, fen, swamp, marsh) that is:

> "on the Great Lakes (Lakes Ontario, Erie, Huron and Superior) or their connecting channels (Lake St. Clair, St. Mary's, St. Clair, Detroit, Niagara, and St. Lawrence Rivers) or, any wetland that is on a tributary to the Great Lakes or their connecting channels and lies, either wholly or in part, downstream of a line located 2 km upstream (as 'the crow flies') of the 1:100 year floodline (plus wave run-up) of the large water body to which it is connected." (MNRF, 2014, p. 159).

Coastal wetlands are dynamic ecosystems influenced by large lake processes such as water level fluctuations, wave action, and wind tides or seiches. Periodic inundation of wetlands during high lake levels plays an important role in maintaining habitat complexity in these highly productive ecosystems (GBBR, 2013). Fluctuating water levels allow for plants, animals, and physio-chemical characteristics to shift along a dynamic hydrological gradient (Uzarski et al., 2016). The vegetation zones in coastal wetlands are organized along this hydrological gradient and different taxa relocate at varying rates depending on their dispersal capabilities (Uzarski et al., 2016) (Figure 40).

Although interior/inland wetlands (i.e., wetlands located on in-land lakes and rivers) are also important to the environmental health of the Georgian Bay watershed, this chapter focuses specifically on Georgian Bay's coastal wetlands.

The remainder of this chapter briefly describes Georgian Bay's coastal wetlands, their importance, and the key threats facing these ecosystems (for more detailed information, readers are encouraged to refer to the 2013 *State of the Bay* report). From there, discussion on why it is important to monitor coastal wetlands, how this can be achieved, and the approach to reporting on coastal wetlands in the 2018 *State of the Bay* report as compared to the 2013 report follows. After summarizing the results, data gaps and research needs are identified and resources for further reading are provided.

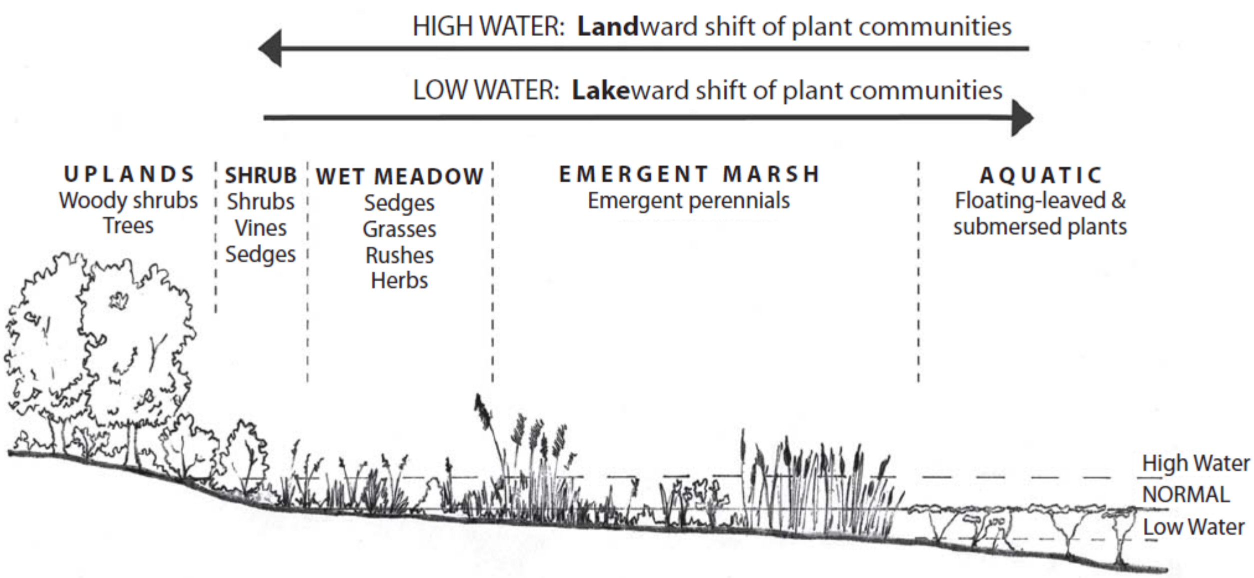

Figure 40. Shifting plant communities with fluctuating water levels (Lake Huron Centre for Coastal Conservation, 2012).

4.3 Georgian Bay coastal wetlands

Eastern Georgian Bay is one of the world's largest freshwater archipelagos with an abundance of wetland habitat along its highly complex shoreline. This region is host to a disproportionately large number of pristine wetlands (compared to other Great Lakes), with high biodiversity of plants and animals (Chow-Fraser, 2006; Croft & Chow-Fraser, 2007; Seilheimer & Chow-Fraser, 2007). According to the McMaster Coastal Wetland Inventory (MCWI), eastern and northern Georgian Bay had the fifth highest percentage (7.7%) of coastal wetlands within the Great Lakes (GBBR, 2013). The 2013 *State of the Bay* reported that the MCWI identified 12,629 wetland units along the eastern and northern coast of Georgian Bay totalling 17,350 hectares.

Unlike coastal wetlands of the lower Great Lakes which are underlain by sedimentary bedrock and have shallow slopes, the morphology of the wetlands in eastern Georgian Bay is shaped by pre-Cambrian granitic rock with varying types and sizes of wetlands distributed among the islands, in sheltered back bays, and river outflows (Chow-Fraser & Croft, 2015). Eastern Georgian Bay coastal wetlands are better described from a functional perspective as wetland complexes, where many smaller units (< 2 ha) spread across the landscape, act in concert (Midwood, 2012). The wetland complexes of eastern Georgian Bay are unique as they are relatively intact and represent high quality habitat. The convoluted shorelines of the archipelago are more difficult to access by roads, and development has historically been quite low relative to that in southern Ontario. Unfortunately, the majority of coastal wetland habitat in the Great Lakes has already been lost to human impacts (e.g., dredging, filling, conversion to other land uses, shoreline hardening).

4.4 Importance of coastal wetlands

Wetlands are critical for their provision of ecosystem services, and the wide array of habitat functions that support incredible biodiversity. Wetlands make up less than 1% of the earth's terrestrial surface, yet the estimated global annual valuation of wetland ecosystem services is $4.9 trillion (Constanza et al., 1997). For comparison, forests make up 26% of global cover, with an estimated annual ecosystem service value of $4.7 trillion, less than that of wetlands (Constanza et al., 1997).

As illustrated in Figure 41, wetlands provide numerous important ecosystem services such as providing fish and wildlife habitat (including habitat for species at risk), erosion reduction, water filtration, recreation and tourism (e.g., canoeing, fishing, bird watching), and cultural and spiritual significance. Indigenous knowledge of wetland plants for food and medicine, including crops such as wild rice and cranberries, is still prevalent. All of these services benefit society in various ways and are reduced or eliminated when wetlands are directly (e.g., filling, dredging) or indirectly (e.g., modifying the hydrologic regime, introduction of invasive species) altered or destroyed as a result of human activities. For example, healthy, functional wetlands provide flood-attenuation services which can aid in adapting to more frequent extreme weather events resulting from climate change (MNRF, 2017). As another example, wetlands reduce reliance on stormwater and water treatment infrastructure by intercepting rainfall and filtering pollutants from the water (MNRF, 2017).

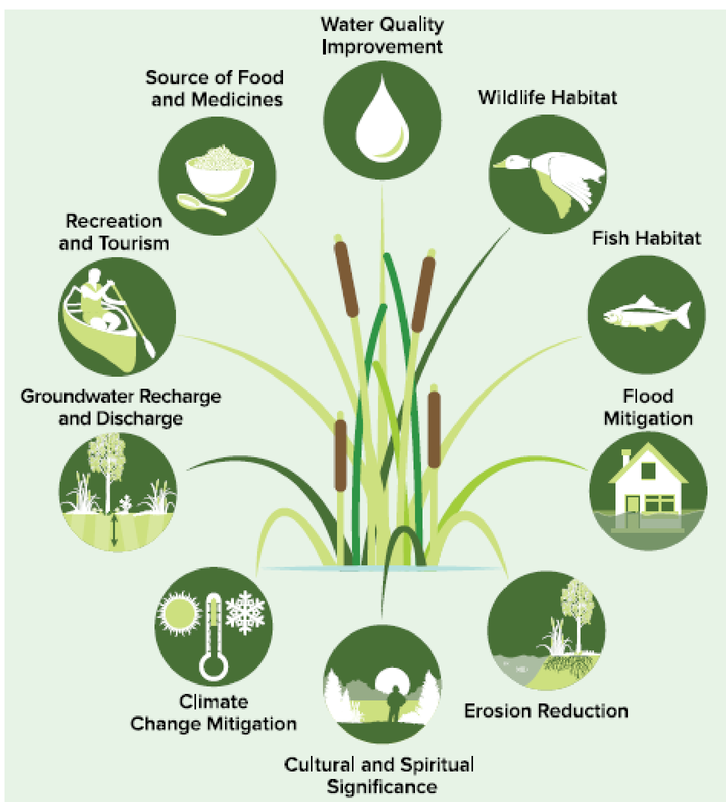

Figure 41. Wetland ecosystem services (MNRF, 2017).

Wetlands of all kinds and sizes are important for regional biodiversity. Coastal wetlands, in particular, support high levels of biodiversity because they are transitional environments providing habitat for both aquatic and terrestrial species. A large number of birds, reptiles, amphibians, fish, insects, and mammals use coastal wetlands at some point in their life cycle (Midwood et al., 2011). For example, the *Lake Huron Lakewide Action and Management Plan (LAMP)* (ECCC & EPA, 2018, p. 11) reports that:

> "Coastal marshes (the predominant [coastal] wetland type) provide nesting, resting, and feeding places for hundreds of thousands of migratory and nesting birdlife, including at least 30 species of shorebirds, 27 species of ducks, geese and swans, and several species of terns and gulls".

Using the example of coastal marshes again, large coastal wetlands also provide diverse habitat capable of supporting many species of wildlife, in part due to "interspersion" of different vegetation types. Large coastal marshes are characterized by a mix of submergent and emergent vegetation, open water, meadow marsh, and shrubs. High levels of interspersion provide higher quality and more diverse habitat for a wider variety of species. Marshes are very dynamic systems so the ratio, structure, and configuration of these different habitat types can vary considerably from year to year (EC, 2006).

Small coastal wetlands (for example, coastal marshes) are often important areas for breeding amphibians and waterfowl. Small wetlands have the ability to provide essential habitat for springtime pairing of waterfowl and feeding grounds, especially where they form wetland complexes (EC, 2006). In addition to waterfowl, other species of wildlife such as the eastern foxsnake, Massasauga rattlesnake, northern harrier, and herons are adapted to exploit wetland complexes and will readily move between them to forage.

Coastal wetlands represent critical spawning, nursery, rearing, and/or foraging habitat for many Great Lakes fish species as well (ECCC & EPA, 2018). Macrophytes (aquatic vegetation) provide the structure in these complex aquatic habitats that supports high levels of fish diversity (Midwood, 2012). Aquatic vegetation offers refuge from predators, shade, thermal refuge, and supports the food sources that fish rely on (e.g., benthic invertebrates, prey fish) (Midwood, 2012). As stated in the *Lake Huron LAMP* (ECCC & EPA, 2018), 59 species of Lake Huron fish are found in coastal wetlands and approximately 80% of Lake Huron fish species depend on coastal wetlands for some portion of their lifecycle. While the vast majority of fish species remain in a single wetland throughout the year, one study showed that northern pike use multiple wetlands over relatively large areas during the active season (Midwood, 2012). The northern pike (*Esox lucius*) in this study tended to be young (2-5 years) and small (<600 mm), on average moving among wetlands that were 1.4 km apart, although some moved as far as 3.9 km.

4.5 Key threats to coastal wetlands

One of the greatest threats facing coastal wetlands in Georgian Bay is development (e.g., cottages, homes, roads) (Chow-Fraser & Croft, 2015). Development can impact coastal wetlands directly and indirectly. Filling, dredging, and draining wetlands are examples of direct impacts. Indirect impacts may include shoreline modifications, increased sediment and nutrient inputs, and altered hydrology through increased runoff or water withdrawals. Common development activities such as road construction, vegetation removal from swimming areas, lawn maintenance or the creation of beaches with sand fill, represent threats to wetland function. Whether direct or indirect, impacts from development hinder the ability of coastal wetlands to provide the valuable ecosystem services described above.

Invasive species are another serious threat facing coastal wetlands. Invasive species (e.g., plants, fish benthic invertebrates) impact coastal wetlands and the native species that inhabit them in a variety of ways. Generally, invasive species compete with, and in some cases outcompete, native species (including species at risk) for space/light, food, and nutrients. For example, phragmites (*Phragmites australis*), or common reed, is a particularly aggressive plant that can spread rapidly, form dense clusters, and directly attack native species by secreting toxins from its roots to the surrounding soil.

Since coastal wetlands are connected to the open water of lakes, fluctuating water levels naturally have an impact on these ecosystems. Wetland vegetation responds rapidly to changes in water level and water quality (Lougheed et al., 2001; Hudon, 2004; Chow-Fraser, 2006). The expansion and contraction of the extent of floating and emergent vegetation, due to these fluctuating water levels, has a direct impact on the amount of critical fish habitat in the coastal wetlands of Georgian Bay. Between 1999 and 2008, water levels in Georgian Bay fluctuated at approximately 50 cm below the long-term average which led to major shifts in the wetland plant community, resulting in increased meadow vegetation (Midwood & Chow-Fraser, 2012). According to the National Oceanic and Atmospheric Administration (NOAA) Great Lakes Water Level Dashboard, water levels have been rising on Lake Huron and Georgian Bay to above average since July 2014.

Finally, the MNRF's (2017) *Wetland Conservation Strategy for Ontario 2017-2030* cites wetlands as among the ecosystems most vulnerable to climate change. As an example, the report states that "Increased runoff during severe rain events may alter wetland ecosystems, including changes to the resident plant and animal species and their relationships" (MNRF, 2017, p.9). Similarly, a future with a warmer and drier climate also poses a threat in terms of potentially reducing the size of wetlands, converting some wetlands to dry land, or shifting one wetland type to another (MNRF, 2017).

4.6 Monitoring coastal wetland condition and trends over time

Monitoring wetland condition and cover is important for establishing a baseline of information, detecting changes, and characterizing trends over time in order to inform management decisions, prioritize conservation efforts, and identify the need for further studies. Wetland condition can be inferred by monitoring specific measures of fish, macroinvertebrate, plant, bird, and amphibian communities known as indicators (Franks Taylor et al., 2010). Examples of indicators used by various organizations and agencies when considering wetland condition are listed in Table 11. Please note that this is not an exhaustive list. Rather, the examples found in Table 11 represent a selection of wetland condition indicators intended to demonstrate how different reports and agencies have evaluated wetland condition.

Table 11. Examples of indicators used for monitoring wetland condition.

Indicator	Great Lakes Coastal Wetlands Consortium (2008)	Lake Huron Biodiversity Strategy	Central Michigan University (Uzarski et al., 2016)	Ontario Biodiversity Council	State of the Great Lakes (2017)
Water Quality*	✓	✓	✓		
Vegetation	✓		✓		✓
Macroinvertebrates	✓		✓		✓
Fish Habitat (spawning)		✓			
Habitat (species composition and abundance)	✓	✓	✓		✓
Amphibians	✓		✓		✓
Bird Species	✓	✓	✓		✓
Size of Wetlands		✓			
Percent Natural Cover (connectivity)		✓			
Percent Rate of Wetland Loss / Changes in Wetland Area				✓	

* Water quality varies based on report and can encompass a variety of tests such as water chemistry, nutrients, contaminants, etc.

4.6.1 Coastal wetland plant diversity

Aquatic macrophytes, or aquatic vegetation, thrive in flooded environments and are primary producers in coastal wetland ecosystems. By monitoring changes in the distribution and composition of plant communities over time, it is possible to gain a better understanding of the impacts of human pressures on coastal wetlands in eastern and northern Georgian Bay. Research has shown that the degree of water quality impairment in a coastal wetland is reflected in the taxonomic composition of the aquatic plant community (Croft & Chow-Fraser, 2007). It is important to note that aquatic macrophytes may also vary with changing water levels.

Coastal wetland plants were evaluated in the 2013 *State of the Bay* report using the Wetland Macrophyte Index (WMI), developed by Chow-Fraser (2006). The WMI assumes aquatic plants (all species growing obligately in flooded areas but excluding those typically associated with wet meadows) will respond directly (through competition for light and nutrients) or indirectly (through food-web interactions) to changes in water quality conditions. Individual species are ranked based on their tolerance to degradation and their niche breadth. Based on the species composition in a wetland, these scores are tallied and an overall WMI score is calculated for a wetland. Unfortunately, no updated, publically available WMI information at the scale of eastern and northern Georgian Bay was available for the 2018 *State of the Bay* report. While there may be some new WMI results, more sites are needed to update coastal wetland plant diversity condition and trends. New WMI information may potentially be available for the 2023 reporting cycle.

New data sources may become available that are able to provide long-term, spatially relevant information. For example, Ciborowski et al. (2015) described, interpreted, and summarized several previously conducted surveys and map assessments aimed at describing Lake Huron coastal wetland status based on existing indices of biological condition and summaries of environmental stressors. One or more of these surveys or map assessments could potentially be used as a data source for future wetland condition reporting. As another example, Chow-Fraser and Croft (2015) compared coastal wetland quality among Georgian Bay and North Channel watersheds sampled between 1998 and 2014 using WMI, the Water Quality Index (WQI), and the Wetland Fish Index (WFI). Overall, the researchers found wetland quality within Georgian Bay to be 'Excellent' or 'Very Good' for the majority of sampling sites. Those areas showing impairment were typically historic Areas of Concern (AOC) and areas with higher cottage and road density (Chow-Fraser & Croft, 2015).

Any new data sources used in future *State of the Bay* reports should provide similarly valuable information about coastal wetland health, appear to be consistently available over the long-term, and preferably, incorporate a citizen science component. The addition of citizen science would help build a constituency of support for the *State of the Bay* program by incorporating their findings into subsequent editions. Furthermore, citizen science creates outreach and engagement opportunities to stimulate dialogue and explore new issues and opportunities. For example, Bird Studies Canada's Marsh Monitoring Program matches these criteria and could be expanded to include more sites and better spatial coverage in the *State of the Bay* reporting area.

4.6.2 Coastal wetland cover

With regard to wetland cover, the Great Lakes Coastal Wetland Consortium (GLCWC) initiated a bi-national inventory to map and classify all coastal wetlands on both the U.S. and Canadian shorelines (Ingram et al., 2004). In 2003, the GLCWC assembled existing aerial photographs and satellite images to create a comprehensive wetland inventory. They were successful in putting together comprehensive coverage of coastal wetlands in Lakes Ontario, Erie and Superior; however, they were unable to delineate all coastal wetlands of Lake Huron, especially in Georgian Bay and the North Channel because of a scarcity of high-resolution satellite imagery (Midwood, 2012).

In 2007, Georgian Bay Forever (then GBA Foundation) awarded a grant to Dr. Chow-Fraser at McMaster University to create an accurate inventory of the coastal wetlands of eastern and northern Georgian Bay, known as the McMaster Coastal Wetland Inventory (MCWI). The MCWI consisted of manually digitized wetland polygons that were delineated from high-resolution IKONOS (a commercial earth observation satellite) imagery acquired during 2002 to 2008, a period of relatively stable low water levels.

The 2013 *State of the Bay* report used the MCWI mapping data to determine and report on coastal wetland cover. This landscape level indicator was selected to provide an understanding of the overall integrity and function of the coastal aquatic environment. Unfortunately, the MCWI mapping data has not been updated, thus there are no new results available for the 2018 *State of the Bay* report.

Further review of scientific indicators relating to coastal wetland cover and condition on the Great Lakes since the 2013 *State of the Bay* report revealed an emphasis on the importance of fluctuating water levels on the nearshore environment and particularly on wetlands, both seasonally and long term. For example, in 2016, the International Joint Commission (IJC) approved a revised water level regulation plan for the Lake Ontario and St. Lawrence River system recognizing that "patterns of water-level change are the driving force that determines the overall diversity and condition of wetland plant communities and the habitats they provide for a multitude of invertebrates, amphibians, reptiles, fish, birds, and mammals" (IJC, 2012, online).

Influence of water levels and climate change

The new emphasis on water level fluctuations and their influence on coastal wetlands, has modified our approach to tracking coastal wetland cover changes for the 2018 *State of the Bay.* Specifically, coastal wetland cover change over time is being considered as a function of water level fluctuations. In essence, the focus in this report is not on net loss or gain, rather the main message concerns how coastal wetlands naturally change with fluctuating water levels and how climate change will affect this relationship in the future. Understanding the link between coastal wetland cover, water level fluctuations, and climate change is important for informing future management and conservation decisions.

Georgian Bay Forever (GBF), the Ontario Ministry of the Environment and Climate Change (MOECC), and the Great Lakes St. Lawrence Cities Initiative partnered with NASA (Adams et al., 2015) on a project to monitor changes in wetland extent, due to decreasing lake levels, using satellite imagery. As stated on their website, GBF's intention with this study was to:

- see how wetland extent changes over time with declining water levels in Georgian Bay;
- educate policy makers who design and implement wetland protection strategies;
- create a template process that can be used to develop more maps, for more years in order to advance understanding in how wetlands react to different environmental conditions; and
- work with partners to find a cost effective methodology to measure wetland extent.

Study areas for this project included Lake Ontario and Georgian Bay. The Georgian Bay study used Landsat imagery from July 1987 and June 2013 from the United States Geological Survey (USGS) Global Visualization Viewer (GLOVIS). These years were selected based on historic high (1987) and historic low (2013) water levels. The methodology developed for this project provided a cost-effective solution to track long-term land cover changes over large areas by using NASA Earth observations (Adams et al., 2015). The results of the study were published in 2015 in a report titled *Great Lakes Climate II: Impact of Decreasing Lake Water Levels on Great Lakes Wetlands* and are utilized for this *State of the Bay* report.

4.7 What are the results?

Results for eastern Georgian Bay coastal wetland cover were derived from the joint GBF, MOECC, St. Lawrence Cities Initiative, NASA study (Adams et al., 2015). This study showed that between 1987 and 2013, coastal wetland cover in northern Georgian Bay increased by 7%. Conversely, in southern Georgian Bay there was a 10.8% loss of coastal wetland cover over the same time period (Figure 42). Although changes in northern and southern Georgian Bay coastal wetland extent that amount to a net loss of 3.8% may not seem significant, GBF (2018, online) explains that this information is important because:

> "The shifting of wetlands has impacts for those geographic regions. People often wonder for example, where have the fish gone that they historically remember in their area? For Southern Georgian Bay, the 10.8% loss is significant for the economic and ecosystems services that wetlands provide for that area."

From this study, a protocol has been developed for creating maps that track changes in wetland extent corresponding with fluctuating water levels. Moving forward, further analysis can be done in future years incorporating updated information.

Because wetland cover naturally changes to some degree with fluctuating water levels, this indicator is assigned a trend of 'undetermined'. While it is possible to determine a general increasing or decreasing trend in wetland extent over a specific time period (i.e., a net loss of 3.8% over the period 1987 to 2013), focusing solely on these general trends, at a broad scale, masks the fact that there are different implications for different habitats and regions (i.e., northern and southern Georgian Bay). In years of high water, terrestrial vegetation dies back, and in years of low water levels, aquatic vegetation disappears (Keddy & Reznieck, 1986). Without inter-annual water level variation, either the aquatic or the terrestrial vegetation would dominate at the expense of the other and the species that utilize those habitats. Considering sustained low water levels, Dr. Janice Gilbert made the following statement in an interview with GBF:

> "The bathymetry along much of the Georgian Bay shoreline is too steep to allow existing wetlands to migrate lake-ward as water levels decline. Many wetlands will therefore shrink, become perched and isolated from the Bay, or evolve into upland habitat. Such circumstances would significantly impact the range and distribution of fish and affect freshwater mussels, turtles, aquatic insects and other wetland-dependent wildlife."
> (GBF, 2018, online).

Accordingly, in order to draw more meaningful conclusions about the state of Georgian Bay coastal wetland extent, we encourage the interpretation of wetland extent changes through various disciplinary lenses and within a regional context rather than focusing on a general trend.

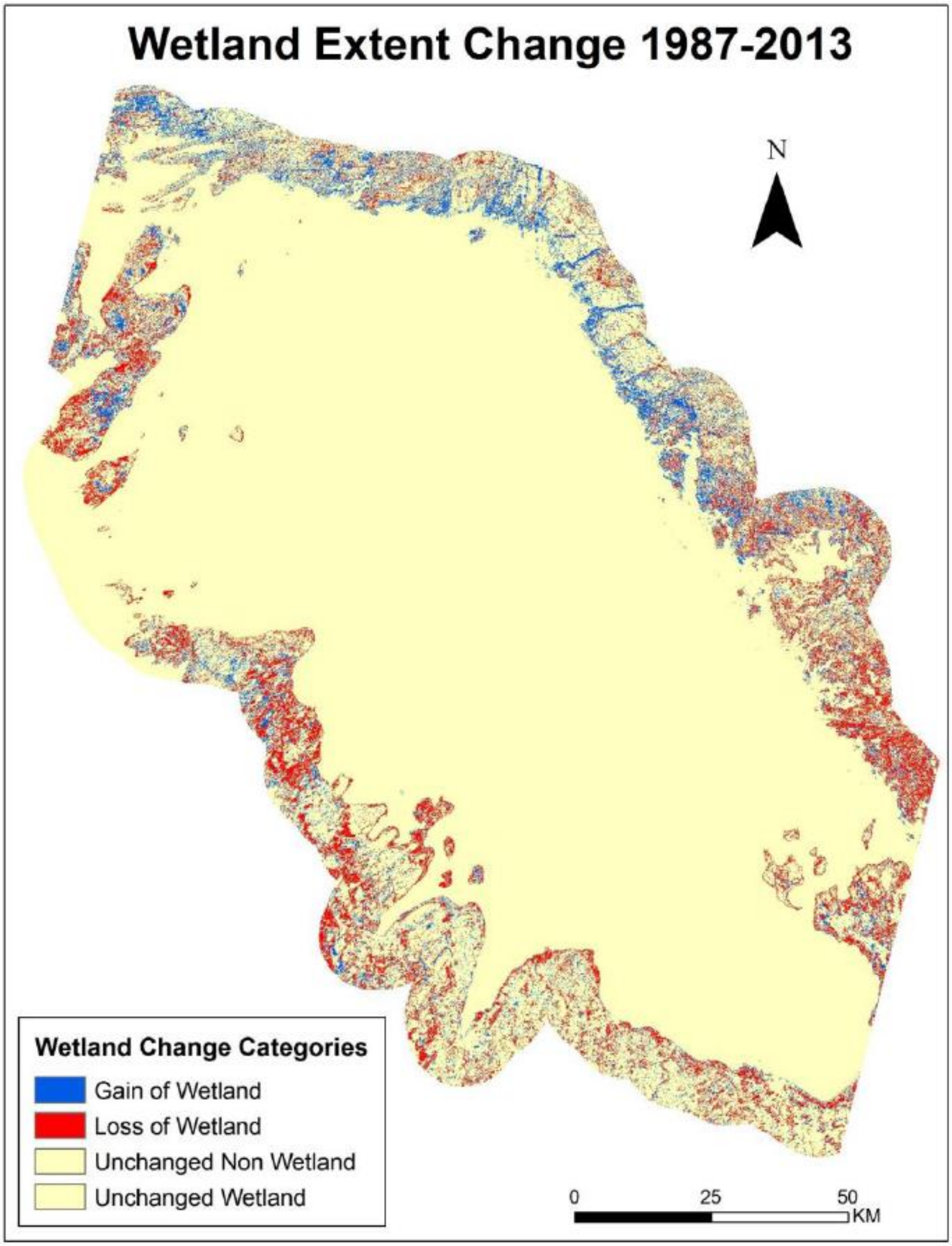

Figure 42. Wetland extent changes for Georgian Bay for the 1987-2013 period (Adams et al., 2015).

While not the primary data source for this report, it is also important to acknowledge the work of other researchers looking into the relationship between fluctuating water levels and wetland extent in Georgian Bay. As one part of a larger project, Chow-Fraser et al. (2016) used current (2015/2016) and historical (2002-2008) data for 22 coastal wetlands in eastern Georgian Bay to compare extent of wetlands between these two time periods, one period of low water levels and one of high water levels. The researchers found that for wetland aerial cover from the first period (low water levels, 2002-2008) to the second period (high water levels, 2015/2016), on average, there was "only a small increase from 3.92±0.85 to 3.94±0.95 ha" for each of the 22 wetlands (Chow-Fraser et al., 2016, p. 2). Specifically, meadow and emergent vegetation decreased 23%, submergent aquatic vegetation increased 8%, and floating vegetation increased 29%. The researchers also estimated how wetland extent would change under different water level scenarios (175.0, 175.5, 176.5, and 177.0 m asl) and found that "Projected wetland extent was highest at 176.5 [m asl] across the whole study area and on a region-by-region basis" (Chow-Fraser et al., 2016, p. 7).

In summary, it is important to remember that water level fluctuations are natural and desirable for the overall benefit of ecological systems. Future *State of the Bay* reports will continue to track coastal wetland cover with the understanding that this indicator will continue to change alongside water levels.

4.8 Data gaps and research needs

In summary, the main data gaps and research needs with respect to the coastal wetlands indicator are:

1. A sustainable, reliable source for coastal wetland cover information. NASA satellite imagery is not easy to obtain in Canada and is very costly. American scientists can access this data for free in the U.S., but due to a lack of sharing agreement, Canadian researchers must purchase the data. In order to monitor and report on coastal wetlands over the long term, as they relate to natural variation in water levels, it is crucial to determine a reliable, accessible long-term data source.

2. If possible, the next *State of the Bay* may report new WMI information (in order to report on wetland condition). Alternatively, new data sources could be sought. For example, one or more of the survey or map assessments described in the Ciborowski et al. (2015) report could potentially be used as a data source for future wetland condition reporting.

3. Greater involvement in citizen science, for example Bird Studies Canada's Marsh Monitoring Program, to supplement coastal wetlands related data collection. If citizen science data are to be used in future *State of the Bay* reports, more advertising and outreach will be required to engage a larger number of citizens.

4.9 Where can I learn more?

For more information on Georgian Bay Forever's wetlands research and related work, visit their website to view and/or download reports and newsletters: https://georgianbayforever.org/

To review the MNRF's Ontario wetland conservation strategy for 2017-2030, download the report here: https://www.ontario.ca/page/wetland-conservation-strategy

To learn more about Lake Huron's coastal wetlands more broadly, visit the Lake Huron Centre for Coastal Conservation's coastal wetlands webpage: https://www.lakehuron.ca/coastal-wetlands

For a list of reports and papers prepared by the Coastal Wetland Research Group at McMaster University, visit their website: http://greatlakeswetlands.ca/publications/

4.10 References

Adams, E., Del Valle Martinez, I., Harris, M., Zimmerman, S., & Ross, K. (2015). *Great Lakes climate II. Impact of decreasing water levels on Great Lakes wetlands*. NASA DEVELOP National Program, Langely Research Center. Retrieved from https://georgianbayforever.org/wp-content/uploads/2015/11/2015Spring_LaRC_GreatLakesClimateII_TechPaper.pdf

Chow-Fraser, P. (2006). Development of the Water Quality Index (WQI) to assess effects of basin-wide land-use alteration on coastal marshes of the Laurentian Great Lakes. In T.P. Simon & P.M. Stewart (Eds.), *Coastal wetlands of the Laurentian Great Lakes: health, habitat, and indicators* (pp. 137-166). Bloomington, IN: Authorhouse.

Chow-Fraser, P., & Croft, M. (2015). *Status of coastal wetlands in Georgian Bay and the North Channel for inclusion in Lake Huron coastal status - review, assessment and synopsis of the condition of coastal wetlands and associated habitats*. Technical report prepared for Environment and Climate Change Canada and in support of the Lake Huron Partnership Working Group.

Chow-Fraser, P., Weller, D., Marcaccio, J., & Boyd, L. (2016). *Changes in low-marsh habitat as a function of Lake Huron water level in coastal wetlands of eastern Georgian Bay.* Technical report submitted to Environment and Climate Change Canada.

Ciborowski, J.J.H., Chow-Fraser, P., Croft, M., Wang, L., Buckley, J., & Johnson, L.B. (2015). *Lake Huron coastal wetland status - review, assessment and synopsis of the condition of coastal wetlands and associated habitats*. Technical report prepared for Environment and Climate Change Canada and in support of the Lake Huron Partnership Working Group.

Croft, M., & Chow-Fraser, P. (2007). Use and development of the wetland macrophyte index to detect water quality impairment in fish habitat of Great Lakes coastal marshes. *Journal of Great Lakes Research, 33*, 172-197.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., et al. (1997). The value of the world's ecosystem services and natural capital. *Nature, 387*, 253-260.

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/

Environment Canada (EC). (2006). *How much habitat is enough? Second edition*. Toronto, ON: Environment Canada.

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. Retrieved from https://www.lakehuroncommunityaction.ca/wp-content/uploads/2016/03/LHBCS_Technical_Report.pdf

Georgian Bay Biosphere Reserve (GBBR). (2013). *State of the bay background report*. Retrieved from https://www.gbbr.ca/about-us/documents/

Georgian Bay Forever (GBF). (2018). *Impact of decreasing lake water levels on Georgian Bay wetlands.* Retrieved from https://georgianbayforever.org/impact-of-decreasing-lake-water-levels-on-georgian-bay-wetlands/

Hudon, C. (2004). Shift in wetland plant composition and biomass following low level episodes in the St. Lawrence River: looking into the future. *Canadian Journal of Fisheries and Aquatic Sciences, 61*(4), 603-417.

Ingram, J., Holmes, K., Grabas, G., Watton, P., Potter, B., Gomer, T., et al. (2004). *Development of a coastal wetlands database for the Great Lakes Canadian shoreline*. Final report to The Great Lakes Commission. Retrieved from https://www.glc.org/wp-content/uploads/2016/10/CWC-GLWetlandsInventory-CanadaInventoryReport.pdf

International Joint Commission (IJC). (2012). *Wetlands need variable levels.* Retrieved from http://www.ijc.org/loslr/en/background/w_wetlans.php

Keddy, P.A., & Reznicek, A.A. (1986). Great Lakes vegetation dynamics: the role of fluctuating water levels and buried seeds. *Journal of Great Lakes Research, 12,* 25-36.

Lake Huron Centre for Coastal Conservation. (2012). *Lake Huron's coastal wetlands - ecosystems of wonder.* Retrieved from https://docs.wixstatic.com/ugd/697a03_e2d492f3b25a4ead9e3e11471212f848.pdf

Lougheed, V.L., Crosbie, B., & Chow-Fraser, P. (2001). Primary determinants of macrophyte community structure in 62 marshes across the Great Lakes basin. *Canadian Journal of Fisheries and Aquatic Sciences, 58*, 1603-1612.

Midwood, J.D. (2012). *Assessing change in fish habitat and communities in coastal wetlands of Georgian Bay* (Unpublished doctoral dissertation). McMaster University, Hamilton.

Midwood, J., & Chow-Fraser, P. (2012). Changes in aquatic vegetation and fish communities following 5 years of sustained low water levels in coastal marshes of eastern Georgian Bay, Lake Huron. *Global Change Biology, 18*, 93-105.

Midwood, J., Smith-Cartwright, L., & Chow-Fraser, P. (2011). *Surveying aquatic vegetation in coastal wetlands of eastern Georgian Bay.* Hamilton, ON: Department of Biology, McMaster University.

Ministry of Natural Resources and Forestry (MNRF). (2014). *Ontario wetland evaluation system: northern manual.* Version 1.3. Retrieved from http://files.ontario.ca/environment-and-energy/parks-and-protected-areas/ontario-wetland-evaluation-system-northern-manual-2014.pdf

Ministry of Natural Resources and Forestry (MNRF). (2017). *A wetland conservation strategy for Ontario 2017-2030.* Toronto, ON: Queen's Printer for Ontario.

Seilheimer, T., & Chow-Fraser, P. (2007). Application of the wetland fish index to northern Great Lakes marshes with emphasis on Georgian Bay coastal wetlands. *Journal of Great Lakes Research, 33*, 154-171.

Uzarski, D.G., Brady, V.J., Cooper, M.J., Wilcox, D.A., Albert, D.A., Axler, R., et al. (2016). Standardized measures of coastal wetland condition: implementation at the Laurentian Great Lakes basin-wide scale. *Wetlands, 37*(1), 15-32.

5. Landscape Biodiversity

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5.1 Introduction

One of the core functions of UNESCO biosphere reserves is the conservation of landscapes, ecosystems, species, and genetic variation. Biodiversity (biological diversity) is the variety and variability of life on earth and can be viewed in terms of variability within species, between species, and between ecosystems. It includes species evolutionary histories, genetic variability within and among populations of species, and the distribution of species across habitats, ecosystems, and landscapes. This variety and variability is necessary to sustain the vital services that these biologically diverse ecological systems provide. The more diverse an ecosystem, or population, the better equipped it is to be resilient to pressures on that system.

One of the most recognized approaches to conserving biodiversity focuses on the establishment and preservation of large natural areas (Timonen et al., 2011) and the diversity of landscape types within an area. Large natural areas are typically defined as areas of forest, rock barrens, wetlands, and water features with a contiguous area of 200 ha or greater, and are important for the integrity of biodiversity and ecosystem health. Large natural areas often have a greater diversity of habitat types that will increase the diversity of species within an area, thereby contributing to the resiliency of the ecosystem.

Maintaining the natural state of large natural areas helps to ensure connectivity between habitats and thereby contributes to the preservation of biodiversity. Connectivity is best thought of as the opposite of fragmentation; it is the linkage of habitats, ecological communities, and ecological processes at multiple spatial and temporal scales. Key biodiversity processes such as population persistence and recovery after disturbance are strongly influenced by connectivity in a landscape (Lamberson et al., 1994). Studies have demonstrated that larger natural areas not only provide connectivity between habitats, they are also more resilient to change, that is, they have a greater capacity to accommodate change or absorb disturbance.

Conservation groups in eastern and northern Georgian Bay have considered the need to find a suitable methodology to analyze and track landscape level changes, and in May of 2016, held a meeting to learn about the Canadian Wildlife Service – Ontario Region's (CWS-ON) Biodiversity Atlas, and discuss its applicability to *State of the Bay*.

Recognizing that we do not have a regionally or locally appropriate method or benchmark to measure large natural areas in the context of the Georgian Bay coastline and archipelago, the 2018 *State of the Bay* has modified its approach for reporting on the state of the landscape. Understanding the importance of maintaining large natural areas, and considering the recommendations from 2013, the indicator for 2018 is now identified as 'landscape biodiversity', and is examined based on the work of the CWS-ON Biodiversity Atlas (ECCC, 2017), produced in partnership with the Nature Conservancy of Canada.

For the purposes of *State of the Bay* reporting in 2018, two related landscape biodiversity sub-indicators were identified from the work of the CWS-ON Biodiversity Atlas: (1) high value biodiversity areas, and (2) human footprint analysis. The CWS-ON Biodiversity Atlas can be used in order to identify areas with high levels of habitat diversity subject to low levels of disturbance by human activities. In summary, the landscape biodiversity indicator aims to report on the types of stressors that may threaten local biodiversity, and at what point impacts to local ecosystems may lead to significant declines of certain species or groups of wildlife.

5.2 Why is it important?

Biodiversity refers to the variety of species and ecosystems in a given area and includes the ecological processes of which these organisms are a part. The benefits of biodiversity in a general sense are numerous and they are an essential part of healthy ecosystems, human health, prosperity, security, and wellbeing. Not only is the diversity of both natural landscapes and species important for the health of the habitat, they are also a source of emotional, artistic, and spiritual inspiration, as well as a source of cultural identity in Canada (Government of Canada, 2003).

It is understood that habitat loss is the single most important factor contributing to the global biodiversity crisis (Pimm et al., 1995; Fahrig, 1999) and that there is a positive relationship between species richness and area for nearly every taxon. Considerable evidence has been collected that shows that the amount of habitat in an area has a much greater effect on biodiversity than the configuration of that habitat (Andren, 1999; Fahrig, 2001; Fahrig, 2003). The loss of habitat usually results in species population decline or loss and it usually occurs incrementally, which is commonly referred to as habitat fragmentation. In the case of many wildlife populations, large portions of contiguous habitat must be preserved to avoid drastic population declines or massive species loss (Rompre et al., 2010).

Two of the key land uses that disrupt connectivity in natural systems are road development and urbanization. The number of studies that demonstrate adverse effects of roads on wildlife is considerable (see for example Findlay & Bourdages, 2000; Haxton, 2000; Eigenbrod et al., 2009; Fahrig & Rytwinski, 2009). Research shows that amphibians, turtles, and small and large mammals are most affected, and that roads can disrupt connectivity of aquatic habitats for fish (i.e., when culverts are not appropriately sized or placed).

While the Georgian Bay ecoregion supports some of the highest levels of biodiversity in the province (McMurtry et al., 2008), cottage and recreational development pressures are present. When attempting to understand the impact that human influence has on biodiversity in this landscape, it is important to note that the landscape is influenced by island biogeographical principles – it is a naturally patchy landscape, a mosaic of dispersed habitats rather than contiguous natural areas. The complex relationship of species and adaptation to island systems should be considered while the landscape and its biodiversity are assessed. For example, patterns of biodiversity on islands can be influenced by size and proximity to other islands and the mainland (Henson et al., 2010).

The *Islands of Life: Biodiversity and Conservation Atlas of the Great Lakes Islands* (Henson et al., 2010) report, produced by the Ontario Ministry of Natural Resources, the U.S Environmental Protection Agency and The Nature Conservancy, describes the coastal environment of north and eastern Georgian Bay in terms of its island structure. The report states that there are 17,615 islands within 848 island complexes in an area of 37,945 ha and describes the dynamic influences on an island landscape. Furthermore, with respect to threats to biodiversity, Henson et al. (2010) found that northern and eastern Georgian Bay are collectively the second highest threatened coastal environment in all the Great Lakes. The main threats noted were: recreational development and associated increase in road densities, building densities, boat launches, and access points. The analysis revealed that the high level of threat is limited to 21 islands. Overall, two-thirds of the islands within northern and eastern Georgian Bay exhibit a very low level of threat. The report also outlines key islands for biodiversity conservation (Table 12).

Table 12. Top scoring islands for key biodiversity criteria (Henson et al., 2010). Note: some of these islands and complexes are under Indigenous Land Claim.

	Biodiversity Significance						
Island Name	Total Biodiversity Score	Colonial Nesting Waterbirds	Physical Diversity	Biological Diversity	Isolation	**Relative Threat Level**	**Primary Conservation Status**
Parry Island	290		Yes	Yes		Medium	Unprotected
Beausoleil Island	270		Yes	Yes		Lower/Medium	Protected
Irving Island Complex	244		Yes	Yes		Higher	Largely unprotected
Bradden Island Complex	215		Yes	Yes		Medium/Higher	Largely unprotected
American Camp Island Complex	213			Yes		Medium/Higher	Unprotected
Philip Edward Island	217		Yes	Yes		Lower	Protected
Moon Island	207			Yes		Lower/Medium	Protected
The Pines Island Complex	200		Yes			Medium/Higher	Unprotected
McLaren Island	199			Yes		Lower	Other land use designations
Sandy Island	179			Yes		Lower	Natural heritage designations
Mink Islands Complex	159	Yes		Yes		Lower	Other land use designations

Colin Rock Complex	150	Yes		Yes		Lower	Other land use designations
McCoy Islands Complex	126	Yes	Yes			Lower	Other land use designations

5.3 How is it measured?

5.3.1 Past approach – 2013 *State of the Bay* report

The 2013 *State of the Bay* report examined large natural areas as an indicator of terrestrial ecosystem health. Large natural areas are important to biodiversity in eastern Georgian Bay's unique interior, coastal, and archipelago landscapes. These areas are, "needed to facilitate the movement of wildlife from the mainland to the islands, and among the islands, which is critical for maintaining healthy ecosystems" (GBINP, 2006). As discussed in the 2013 *State of the Bay* report, methods used in other (non-island) landscapes to measure natural areas are not a good fit for Georgian Bay's island landscape. Work undertaken in eastern and southern Ontario recommends that in areas where conifer and deciduous forests are both naturally occurring, forest tracts of 200 ha for each forest type be maintained to support all or most native interior bird species (used as an indicator of forest health) (EC, 2006). This work is based on a largely-forested landscape in rural/agricultural southern Ontario.

In central Ontario, the Muskoka Watershed Council reports on large natural areas by measuring patches of interior forest. This model is appropriate for Muskoka and other inland areas that are often studied on a watershed basis; however, in a coastal landscape that has a mosaic of habitats and island archipelago structures, it cannot be applied in the same way. Assessing these areas in an archipelago is not straightforward. The 2013 *State of the Bay* report recommended that research into a method for assessing landscape-level impacts on biodiversity be pursued for future reporting.

5.3.2 Direction for 2018 *State of the Bay* report

Recognizing the importance of maintaining large natural areas, as discussed above, and considering the recommendations from 2013, the indicator for 2018 is now identified as 'landscape biodiversity', and is examined based on the work of the CWS-ON Biodiversity Atlas (ECCC, 2017), produced in partnership with the Nature Conservancy of Canada.

CWS-ON is responsible for terrestrial wildlife and habitat of federal concern. Together, the wildlife and habitat under federal mandate comprise the CWS biodiversity portfolio. To help achieve its conservation outcomes, CWS-ON has developed various information products that describe, assess, and map its biodiversity portfolio in southern and central Ontario. The CWS-ON Biodiversity Atlas is the product of a geospatial landscape assessment that uses habitat guidelines to map areas of high biodiversity value in order to guide programming and facilitate conservation action with partners. The CWS-ON Biodiversity Atlas is multi-scalar and progressively combines individual habitat and species elements to identify high value biodiversity areas. At the coarsest scale, 14 federal biodiversity attributes are evaluated with ecozones as the mapping unit. At the second tier, breeding birds and species at risk densities are assessed by physiographic region. At the finest unit of analysis, 5 ha and 2 ha hexagons are applied to Bird Conservation Region (BCR) 12 and 13, respectively, and criteria for forests, grasslands, wetlands, species at risk (SAR) and migratory birds are assessed. The results from these analyses allow CWS-ON to understand the distribution and configuration of habitat and to spatially describe biodiversity across the landscape.

As previously mentioned, for the purposes of *State of the Bay* reporting in 2018, two related landscape biodiversity sub-indicators were identified from the work of CWS-ON: (1) high value biodiversity areas; and (2) human footprint analysis. These sub-indicators were selected based on: *State of the Bay* criteria for indicator selection; the sub-indicators' ability to inform conservation planning; and alignment with agency and partner goals, as well as gaps identified in 2013. It should be noted that the CWS-ON work does not technically consider the high value biodiversity area and human footprint as 'indicators' – they are termed such for the purposes of *State of the Bay* reporting and ease of public communications. In their original form (CWS-ON work), they are derived from an analysis to identify places of high biodiversity value on the landscape across the province.

CWS-ON habitat guidance

CWS-ON has developed draft habitat guidance for both the Ontario Mixedwood Plains and the southern Shield (Georgian Bay Ecozone [5E]). *How Much Habitat is Enough* (HMHE) (EC, 2013) is the most current edition of a framework that provides guidance for government and non-government organizations involved in activities such as natural heritage planning. *How Much Disturbance is Too Much* (HMDITM) (EC, 2014) addresses landscape metrics at various scales in order to deal with a dominant natural matrix with an embedded, but growing, human footprint and suggests maintaining local and regional habitat mosaics in order to retain biodiversity at a landscape scale through large natural areas. These draft habitat guidelines were developed as a response to requests for guidelines specifically for the Shield environment. The focus of HMHE is on how much habitat might be required in order to sustain certain levels of biodiversity within a highly settled, and highly fragmented, landscape. The southern Canadian Shield is largely ecologically intact compared to southern Ontario. The emphasis of HMDITM is on the types of stressors that may threaten local biodiversity, and at what point impacts to local ecosystems may lead to significant declines of certain species. HMDITM looks at opportunities to maintain a region in natural cover and habitat, but also addresses fine resolution needs such as the loss of shoreline vegetation, loss of habitat connectivity, and the ecological effects associated with roads. In order to manage a dominant natural matrix with an embedded, but growing, human footprint, preliminary guidance suggests that:

- Regional and local planning authorities should identify regional habitat mosaics and local habitat mosaics, respectively, that capture relatively high levels and/or concentrations of habitat diversity and are predominantly natural areas subject to low levels of disturbance by human activities; and
- Regional habitat mosaics and local habitat mosaics should cover at least 50-60% of their respective jurisdiction. These mosaics should include habitats that are uncommon in the landscape as well as good representations of more common habitat types, a diversity of age classes for forested habitats and promotion of landscape connectivity.

To look at local and regional habitat mosaics across the Georgian Bay Fringe, the CWS-ON Biodiversity Atlas can be used in order to identify areas with high levels of habitat diversity subject to low levels of disturbance by human activities. Furthermore, because the southern Canadian Shield is largely ecologically "intact", the emphasis of this planning document is on the types of stressors that may threaten the local biodiversity of the area, and at what point impacts to local ecosystems may lead to significant declines of certain species or groups of wildlife.

5.4 What are the results?

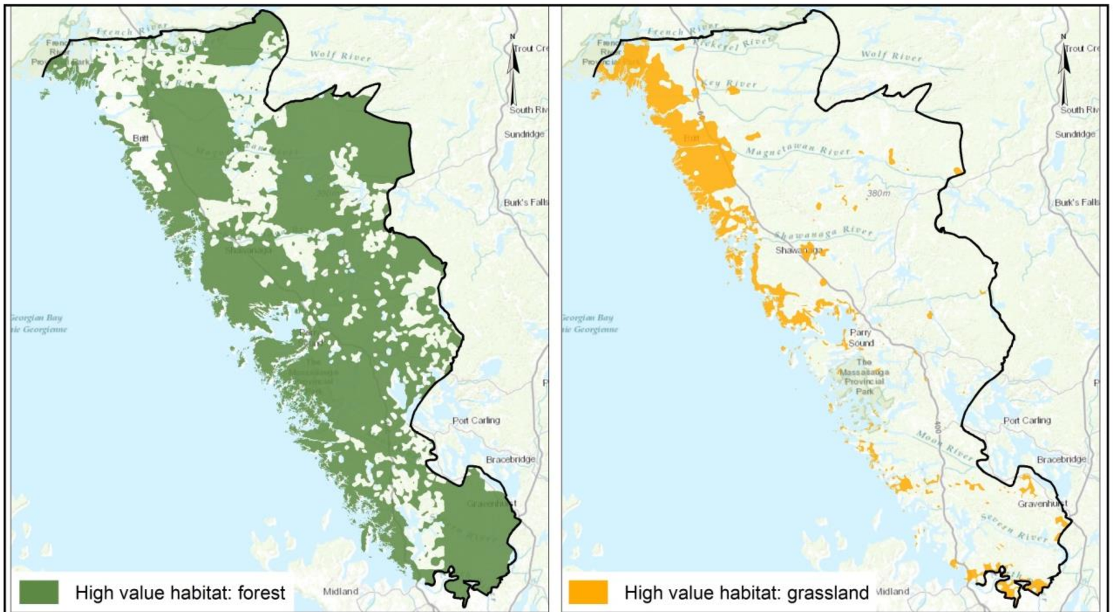
5.4.1 High value biodiversity areas

Using criteria adopted from *How Much Habitat is Enough?* (EC, 2013), each 5 ha study unit received a total forest, grassland, wetland, SAR, and migratory bird score (Table 13). These scores were combined to create high value habitat for each forest, grassland, and wetland (Figure 43). High value habitats are the highest quality forest, grassland, and/or wetland that also contain important habitat for SAR and/or migratory birds. To create high value biodiversity areas (HVBAs), the high value habitats were aggregated together into more natural-like and contiguous areas. Two filters were applied: coarse filter HVBA are those areas that contain at least one high value habitat (Figure 44); and fine filter HVBA are those areas that contain two or more high value habitats (Figure 45). The HVBAs represent areas across the region that capture relatively high levels or concentrations of habitat diversity.

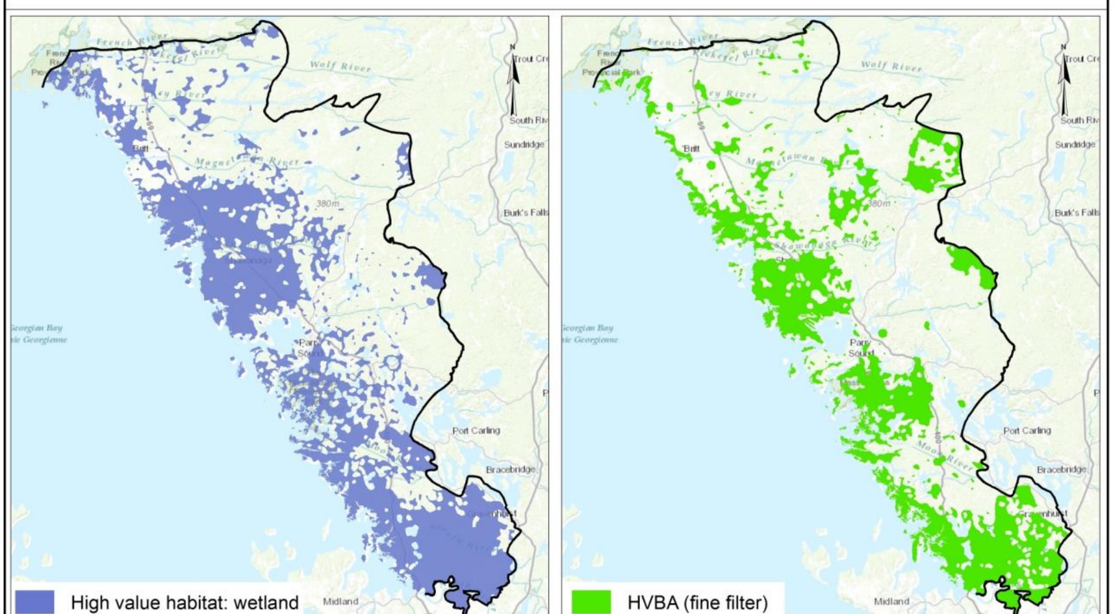
Note that CWS-ON Biodiversity Atlas did not include aquatic features such as Georgian Bay in the assessment; the percentage of natural cover that includes Georgian Bay would be higher than the current percentage within the Georgian Bay Fringe physiographic region.

Table 13. Summary of the criteria used to assess and map habitat conditions in the CWS-ON tier 3 analysis. Criteria adopted from HMHE guidelines for forest, wetland, and open country habitat; SAR and migratory bird criteria based on CWS-ON biodiversity portfolio; 5 ha hexagon is the unit of analysis in Bird Conservation Region (BCR) 12.

Habitat Type (Category)	Criteria
Forests	• Percent of forest cover by subwatershed • Large patch old growth interior habitat (>100 m from edge and >200 ha) • Watershed cover of old growth interior habitat (>10% forest interior habitat >100 m from edge) • Small and large forest patches in close proximity to each other • Connectivity (resistance values of pathways measurement)
Wetlands	• Percent of wetland cover in watershed • Location of coastal wetlands (from Great Lake or large inland lakes and/or other waterbodies) • Wetlands with adjacent natural cover (within 120 m of wetlands boundaries) • Wetland size • Proximity of wetland to another wetland (or water body)
Open Country (grasslands)	• Documented grassland/barren habitats (natural) • Proximity to other grasslands or barrens • Size of grasslands or barrens >50ha and 100ha • Heterogeneity – grasslands with >30% natural cover within 750 m buffer
Species at Risk and Rare Vegetation Communities	• Diversity (number of different rare communities/landscapes by hexagon) • Richness (number of different SAR element occurrences by hexagon) • Irreplaceability (number of irreplaceable SAR element occurrences by hexagon) • Global rarity (number of different globally rare SAR element occurrences by hexagon) • Candidate species (number of different candidate SAR element occurrences by hexagon) • Probability of critical habitat (number of species with natural habitat in critical habitat)
Migratory Birds	• Colonial nesting waterbirds (number of nesting sites) • Landbird stopover habitat (sites of very high to high values) • Waterfowl stopover habitat (sites of high to very high values) • Shorebird stopover habitat (sites of high to very high values) • Grassland bird density (grassland habitats in high density regions) • Forest bird density (forest habitats in high density regions) • Waterfowl density (wetland habitats in high density areas)



One of the significant challenges for conservation is the identification of key areas where actions and resources can be best focused. High value habitats are the highest quality (based on criteria for size, proximity, configuration etc.) forest, grassland and/or wetland that also contain high densities of species at risk (SAR) or migratory birds. Fine filter high value biodiversity areas (HVBA) are those areas on the landscape that contain at least two high value habitats (forest, grassland and/or wetland), meaning that they are high quality habitats important for SAR and/or migratory birds. They represent areas with multiple and overlapping conservation value.



Base	Sources	Scale
—— Georgian Bay Fringe boundary	Map produced by Environment and Climate Change Canada ©2018 with data produced in partnership with the Nature Conservancy of Canada | Includes material © the Queen in Right of Ontario | ESRI World Topographic Map ArcGIS 10.2.2 ©2017 | All Rights Reserved Government of Canada / Gouvernement du Canada	UTM Zone 17N North American Datum 1983 25 12.5 0 25 Kilometres

Figure 43. High value habitat for each forest, grassland, and wetland for the Georgian Bay Fringe.

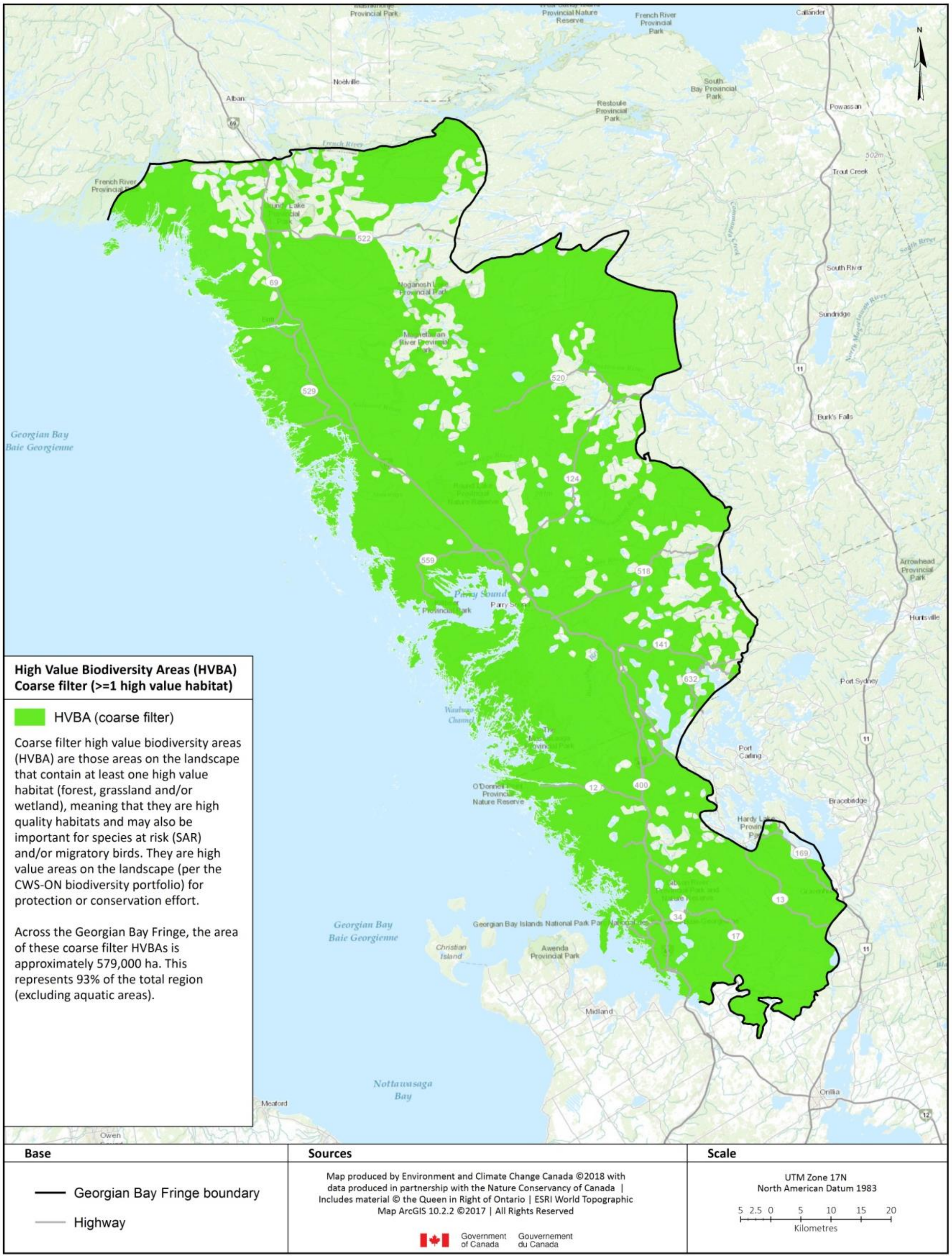


Figure 44. Coarse filter HVBA contain at least one high value habitat for the Georgian Bay Fringe.

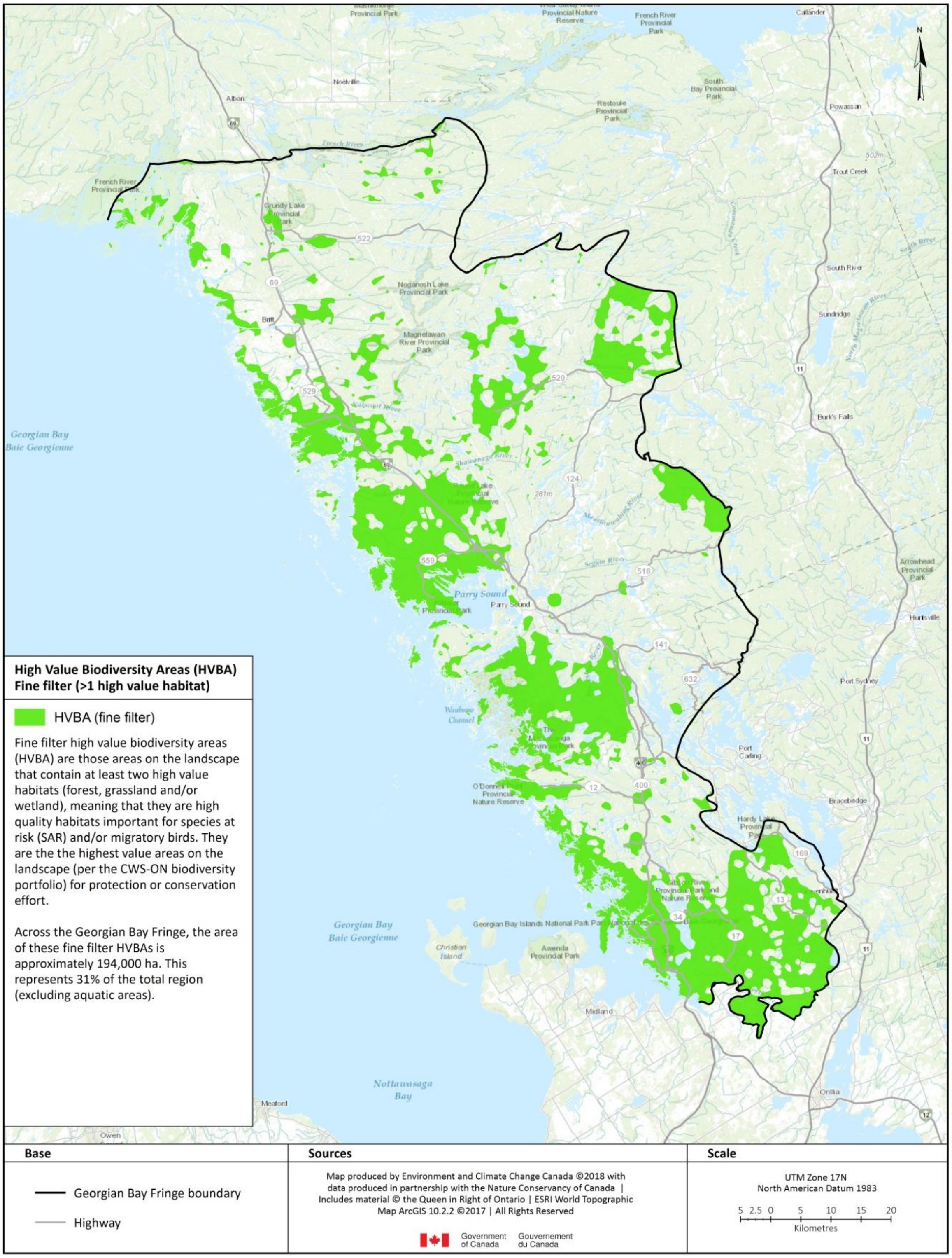


Figure 45. Fine filter HVBA contain two or more high value habitats for the Georgian Bay Fringe.

5.4.2 Human footprint analysis

Human footprint analysis is used to identify areas on the landscape with varying levels of human influence. Five categories are used to assess human influence, each with relevant criteria for a total of ten individual scoring values (Table 14). The highest scoring areas are those areas on the landscape with the highest levels of human influence, and, likely, are also the least natural areas.

Table 14. Human footprint criteria and values for landscape analysis (Landscape and Conservation Assessment for the Mixedwood Plains (BCR-13) and Southern Canadian Shield (BCR-12), 2016).

Category	Criteria	Value
Residential and Commercial Development	Housing and urban areas	Developed areas (as urban areas)
Agriculture and Aquaculture	Crops	Location of agricultural cropland
	Plantations	Location of plantations (coniferous trees)
Energy Production and Mining	Mining and quarrying	Location of active open pits and mines
	Renewable energy	Location of wind farms
Transportation and Service Corridors	Roads	Distance to roads, includes scores for expressways, primary/secondary highways, primary and secondary roads, vehicular trails.
	Railways	Distance to railway lines
	Utility and service lines	Distance to major utility corridors
Natural System Modifications	Fire and fire suppression	Location of burns and cutovers
	Dams and water management use	Location of dams

The results from the human footprint analysis (Figure 46) are somewhat predictable. Areas of higher human influence (oranges to reds) are focused along the main transportation route (highway 69/400), while areas of least influence (greens) are evident in the least accessible areas, and especially closer to the coastline and islands, where the road network is less dense or non-existent. Communities and urban centres, particularly Parry Sound and Port Severn, display an obvious higher valuation of human influence. Rail corridors tend to be in proximity to main road corridors and all infrastructures tend to converge in urban areas. These resulting maps can be used as a tool for planning purposes on a local and regional scale.

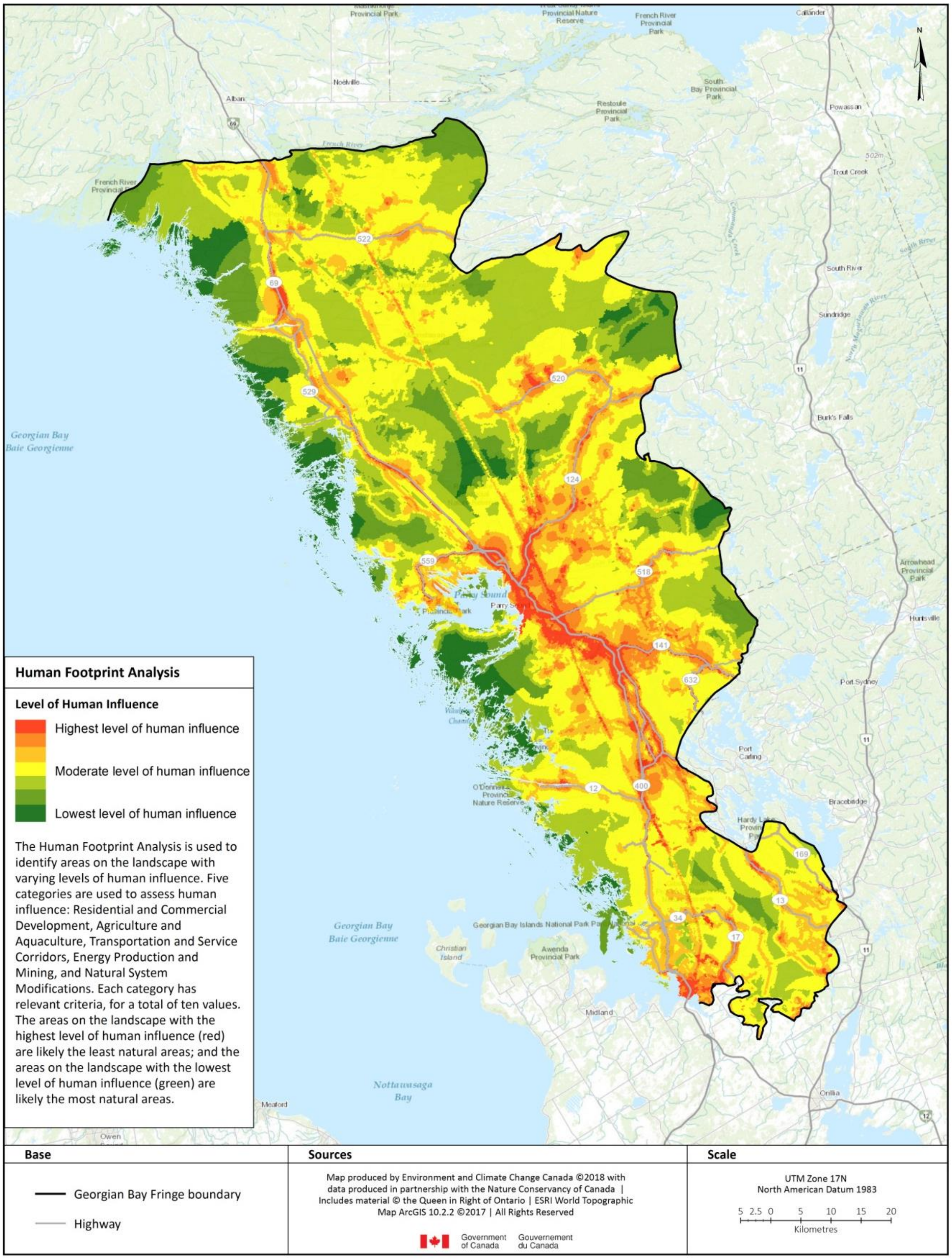


Figure 46. Results from the human footprint analysis for the Georgian Bay Fringe.

Caveats associated with the human footprint analysis:

1. Vintage of data – produced using data with a vintage between 1998 and 2015; more recent data may yield different results.
2. Resolution of data – coarse resolution data used, for the most part; when considering local levels of influence, consider mining for finer resolution data.
3. Planning and policy – the analysis did not take into consideration any planning or policy associated with features, for example roads – can see that Killbear Provincial Park comes out as having moderate-to-high influence due its road network, however these roads are likely not having the same impact as roads outside of a provincial park.
4. Land tenure – no integration of land tenure, for example provincial parks or other protected areas; also consider that municipal areas may come out as having high value biodiversity as CWS-ON is concerned with habitat for species at risk, and these habitats may include a woodlot in a municipal area.
5. Data gaps related to boat traffic, shoreline development, and seasonal homes.

5.4.3 Local and regional habitat mosaics

From a landscape perspective, the Georgian Bay Fringe remains largely natural in terms of its land cover. The purpose of this indicator was to identify high scoring sites which can then be used as a tool for planning purposes on a local and regional scale. To look at local and regional habitat mosaics across the Georgian Bay Fringe, the CWS-ON Biodiversity Atlas can be used in order to identify areas with high levels of habitat diversity subject to low levels of disturbance by human activities.

Different habitat mosaic scenarios can be 'modeled' or represented by removing existing human influence (as mapped in the human influence analysis). This is an exercise in scenario modelling. In the scenario modelling, the HVBAs represent natural areas, however human influence features (e.g., roads or towns) were not removed, thus the natural areas overlap anthropogenic features in some cases. To get a more realistic view of where the highest value biodiversity areas are, the human footprint is overlaid and the highest influence areas are progressively removed from the HVBAs in order to get the various 'habitat mosaic scenarios'.

The resulting scenarios (Figure 47, Figure 48, Figure 49) show the highest value (per the CWS-ON biodiversity portfolio) natural areas that capture relatively high levels and/or concentrations of habitat diversity and are subject to increasingly low levels of disturbance by human activities. By removing human influence, the scenarios use HVBAs as a proxy for natural cover.

In Scenario 1 (Figure 47), the top 25th percentile of human footprint scores have been removed from coarse filter HVBAs, yielding approximately 74% natural cover across the region. In Scenario 2 (Figure 48), the top 50th percentile of human footprint scores have been removed from coarse filter HVBAs, yielding approximately 40% natural cover across the region. In Scenario 3 (Figure 49), the top 75th percentile of human footprint scores have been removed from coarse filter HVBAs, yielding approximately 17% natural cover across the region. Parks and other protected areas were not included in this analysis, but Scenario 3 may be likened to identifying networks of potential protected areas; after removing the areas of highest human influence, the remaining HVBAs may be considered as the 'most pristine' areas for conservation or identification of habitat mosaics.

Simply put, generating habitat mosaic scenarios helps to narrow down the total amount of HVBA to the areas that are least influenced (or, most wild). This is why, in Scenario 3, when the 75th percentile of scores are removed, the remaining HVBAs are largely overlapping with existing protected areas.

It is important to note that the analysis does not account for planning or policy as it applies to roads. For example, roads within a provincial park are weighted equal to roads within and around Parry Sound (with the exception of proximity to expressways, which received a higher weight). This results in a high human footprint in areas that contain resource or secondary roads, such as in Killbear Provincial Park where there is an extensive network of roads within the campground.

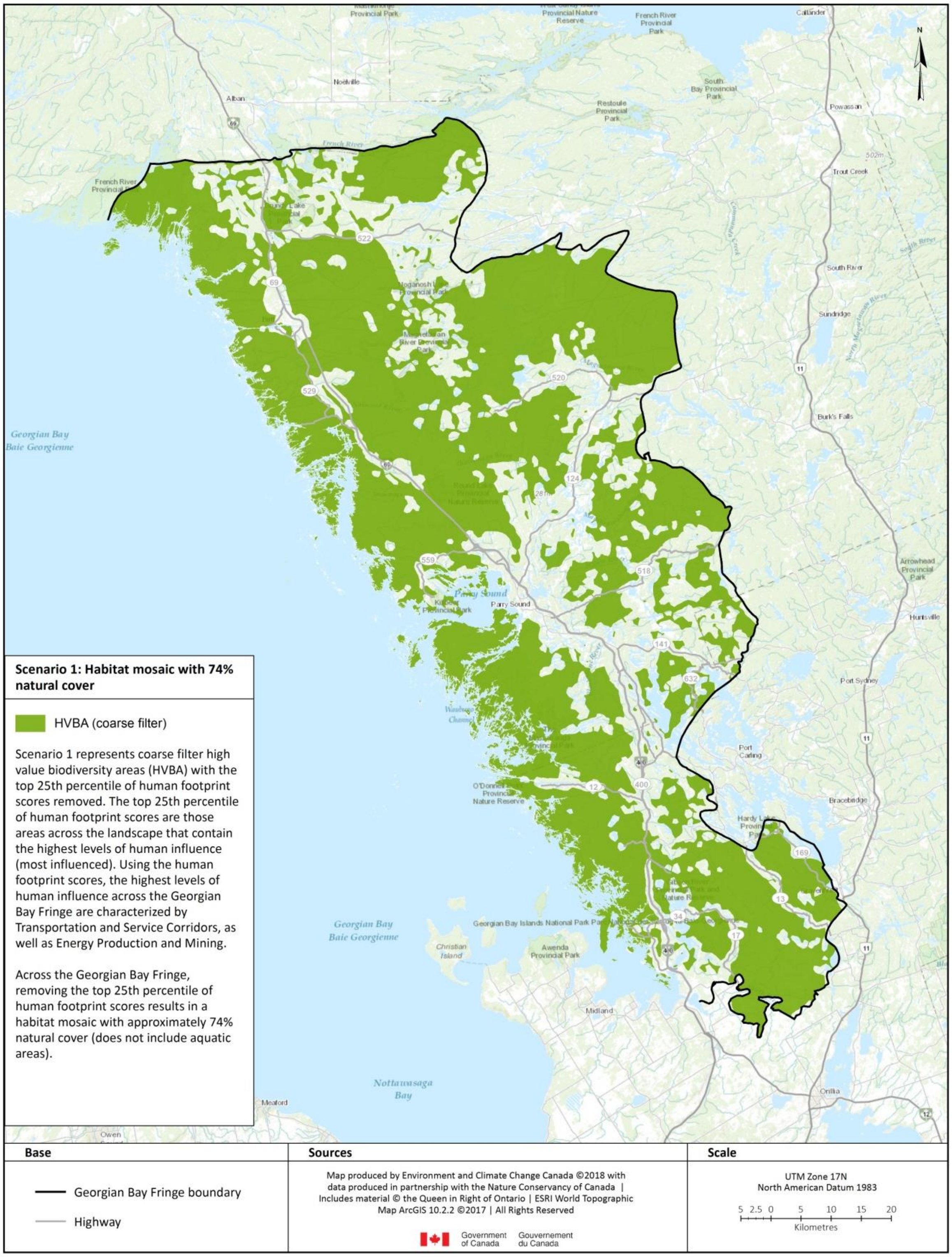


Figure 47. The top 25th percentile of human footprint scores have been removed from coarse filter HVBAs, yielding approximately 74% natural cover across the region.

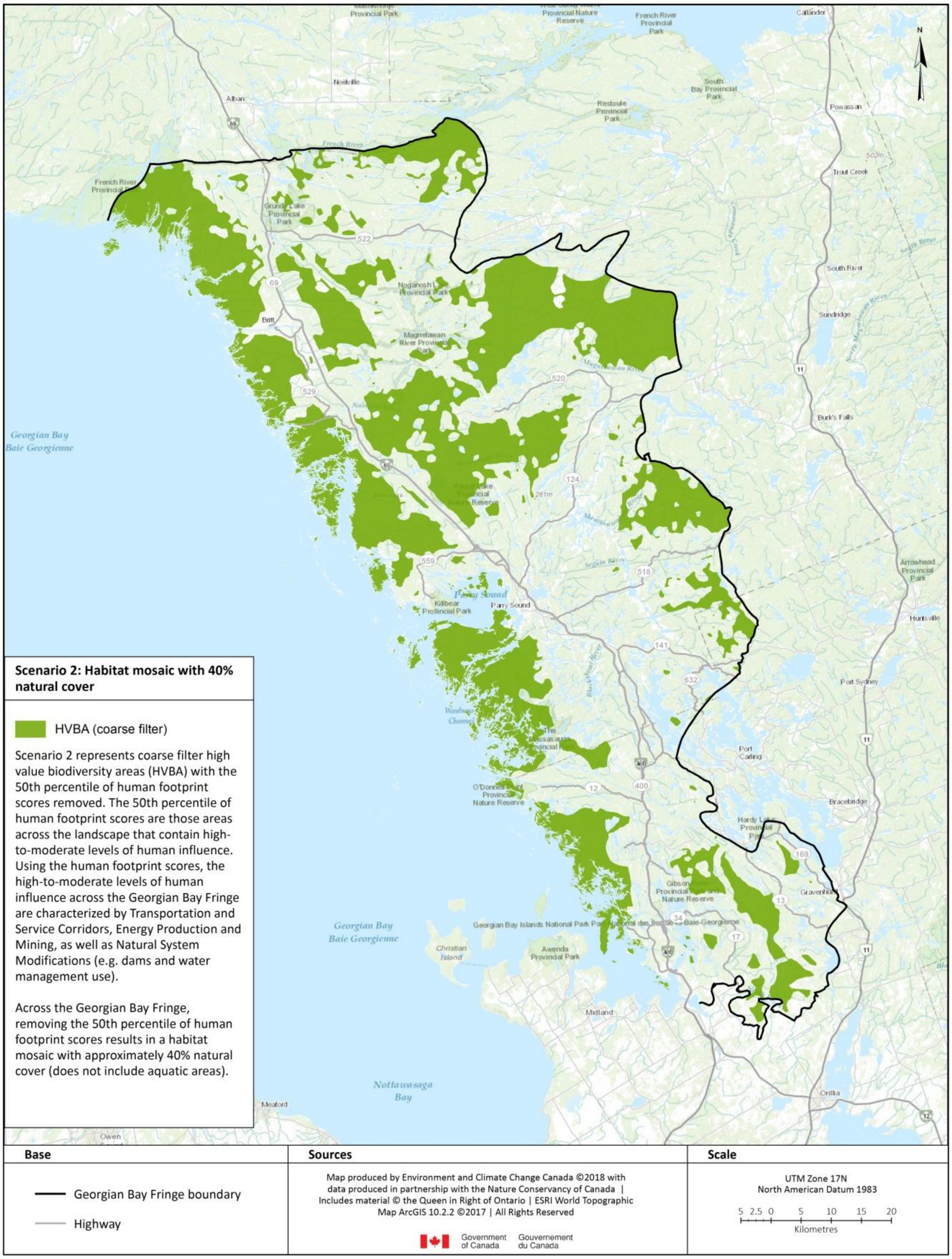


Figure 48. The top 50th percentile of human footprint scores have been removed from coarse filter HVBAs, yielding approximately 40% natural cover across the region.

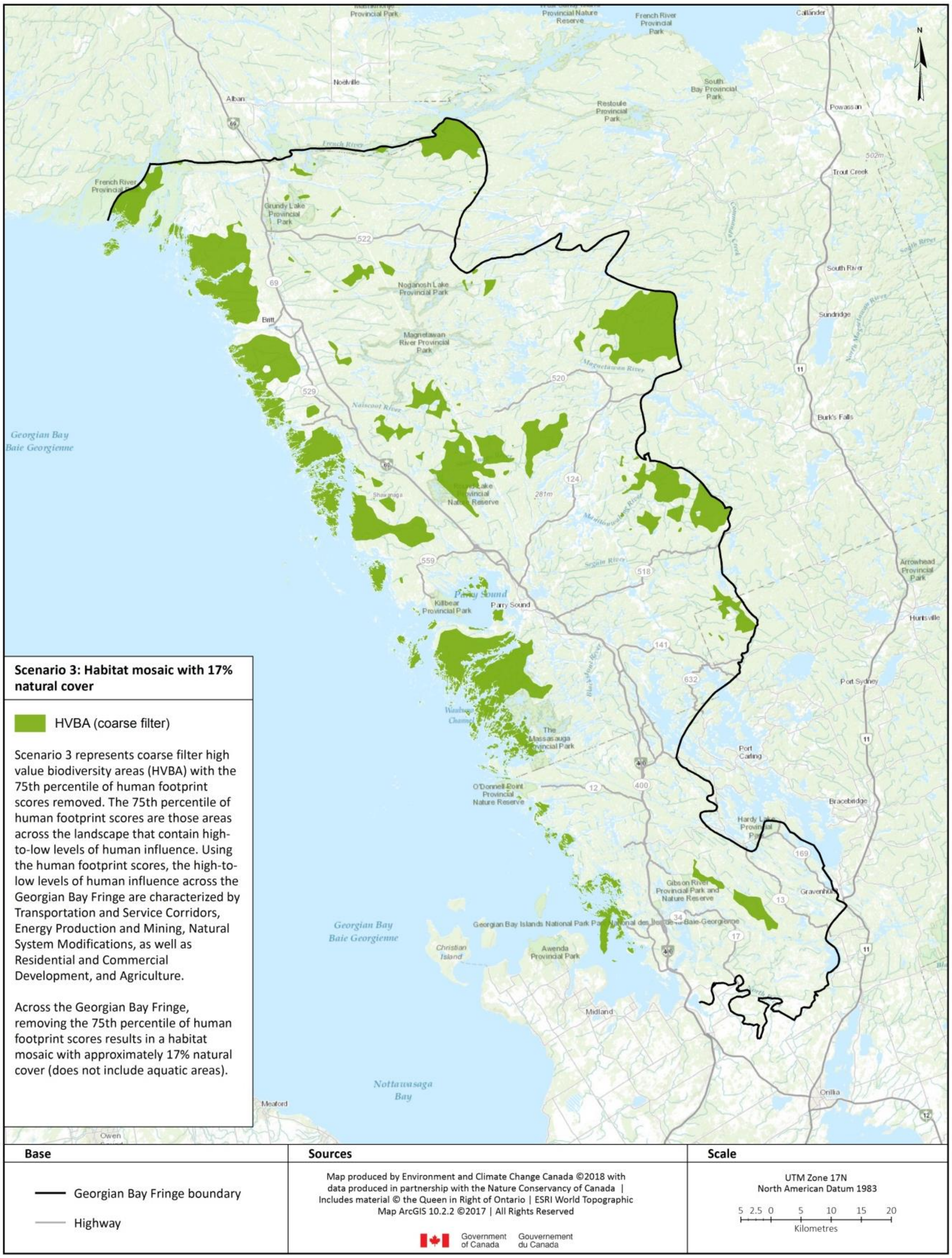


Figure 49. The top 75th percentile of human footprint scores have been removed from coarse filter HVBAs, yielding approximately 17% natural cover across the region.

5.4.4 Importance of Georgian Bay Fringe to regional habitat mosaic

Preliminary guidance recommends identifying regional and local habitat mosaics that cover at least 50-60% of their respective jurisdiction. To see what a 50% regional habitat mosaic would look like across BCR 12 (Figure 50), the CWS-ON Biodiversity Atlas uses coarse filter HVBAs as a proxy for natural cover and removes the areas of highest human influence (top 25th percentile of human footprint scores). BCR 12 units that have at least 50% natural cover, after the areas of highest human influence have been removed, represent opportunities to maintain landscape biodiversity through habitat mosaics. Looking at just those BCR 12 units that have at least 50% natural cover, results in a BCR 12 regional habitat mosaic of roughly 55%. The Georgian Bay Fringe contributes significantly to this mosaic, and as the area is increasingly impacted by human development, losses to natural cover could bring the regional mosaic down to around 50%, the minimum recommended extent to maintain landscape biodiversity. What is significant to note is that the BCR units that have >50% natural cover are primarily those within the Georgian Bay Ecoregion (5E). Loss of natural cover in these units will significantly lessen the regional habitat mosaic, and therefore may begin to threaten landscape biodiversity.

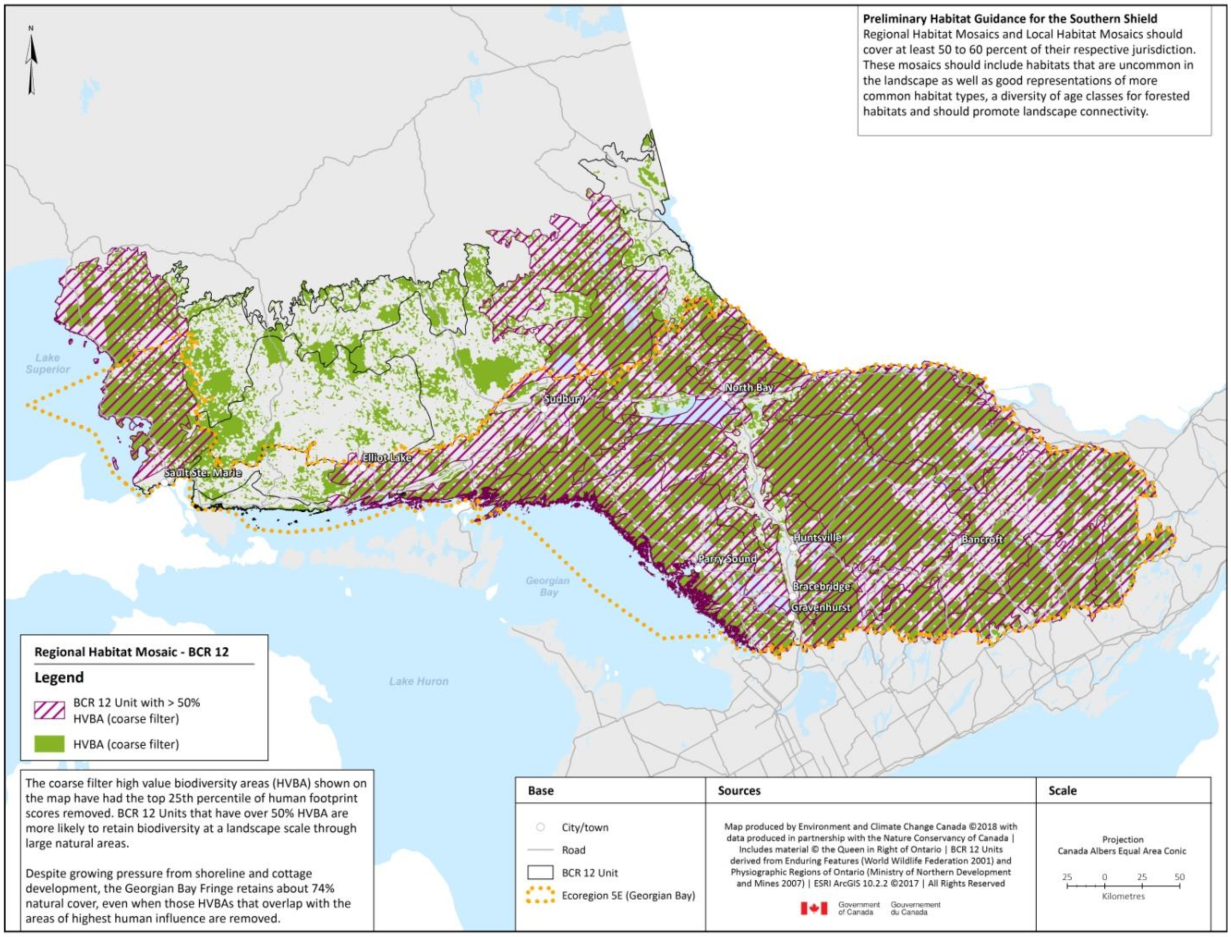


Figure 50. A 50% regional habitat mosaic across BCR 12. Of particular importance is that BCR units with >50% natural cover are primarily those within the Georgian Bay Ecoregion.

Landscape indicators in Great Lakes reporting

As noted in the introduction (section 1), the landscape biodiversity indicator, including its two sub-indicators (high value biodiversity areas and human footprint analysis), is assigned a trend of 'deteriorating'. This trend reflects increasing human impacts and habitat fragmentation, as well as rising numbers of species at risk, resulting in biodiversity declining locally and globally. Future application of this tool will help show more specific trends over time.

Annex 7 (Habitat and Species) of the 2012 *Great Lakes Water Quality Agreement* aims to conserve, protect, maintain, restore, and enhance the resilience of native species and their habitat, and to support essential ecosystem services. This annex also seeks to establish a Great Lakes Basin Ecosystem target of net habitat gain and measure future progress, which is reported in *State of the Great Lakes* documents.

The *State of the Great Lakes 2017 Technical Report* (EC & EPA, 2017) has six watershed sub-indicators including: forest cover, land cover, watershed stressors, hardened shorelines, tributary flashiness, and human population (for Lake Huron, Table 15). While these sub-indicators are not directly comparable to *State of the Bay* landscape indicators (high value biodiversity areas and human influence analysis), there are parallels in the objectives of these landscape indicators (i.e., reporting and tracking changes to natural areas and human impacts).

Table 15. SOGL watershed sub-indicator trends for Lake Huron.

Sub-Indicator	Trend
Forest Cover	Unchanging
Land Cover	Unchanging
Watershed Stressors	Unchanging
Hardened Shorelines	Undetermined
Tributary Flashiness	No lake was assessed separately Great Lakes Basin trend is Unchanging
Human Population	Increasing

5.5 Data gaps and research needs

In summary, the main data gaps and research needs with respect to the landscape biodiversity indicator are:

1. As noted in discussions with ECCC-CWS, the criteria used to assess and map habitat conditions does not take into consideration rock barrens, which is a significant habitat type along northern and eastern Georgian Bay. For example, Figure 43 presents a significant portion of rock barren habitat as 'grassland'. Rock barrens are important habitats for certain reptiles at risk, and as islands, may provide safer nesting locations for several species of birds.

2. As noted in discussions with ECCC-CWS, the bird data for the boreal hardwood transition is not comprehensive. Ideas are needed to determine how to improve this and how to make various citizen science programs work for this area (Breeding Bird Survey, atlas, etc.).

3. As noted in discussions with ECCC-CWS, the human influence analysis considers built up/developed areas, but does not capture much of the Georgian Bay seasonal 'footprint' such as: cottages, camps, and other housing areas, particularly along shorelines and within littoral areas of Georgian Bay. An example of a potential gap of human influence data may be the mouth of the Key River where there is a dense collection of camps and cottages and the accompanying boat traffic that comes with this 'roadless' environment. Approaches are needed to assess areas like this in the future.

4. The human influence layer of the CWS analysis does not include boat channels. Because roads are in fact not densely located in much of the archipelago landscape, boating is the main transportation method for accessing waterways, bays, and islands. How this type of human disturbance pattern affects the integrity of the biodiversity is not well understood, and should likely be included in a

human disturbance analysis of eastern and northern Georgian Bay. The human traffic instigated by boats for commuting, fishing, or touring includes disturbances such as: noise; pollution (e.g., release of fuel emissions); wastewater and garbage; disturbance from wakes and shoreline wash; and increased potential for collisions with wildlife on local and longer range migration routes.

5. Potential sources for boat traffic data were explored for 2018 *State of the Bay* reporting. However, none were specifically available for our purposes. The Canadian Coast Guard (CCG) keeps commercial traffic records for all of Canada, not for Georgian Bay specifically. Dalhousie University conducted research called *Search and Rescue Needs Analysis 2006 – 2008***,** during which they did surveys via marinas. It is possible that these methods could be duplicated in a future study regarding boat traffic for Georgian Bay.

6. Other potential resources for boat traffic include Dalhousie University's *Maritime Activity and Investigation Network (MARIN)* that studies maritime activity and incident levels of Search and Rescue clients across Canada. One particular study, *Canadian Maritime Traffic Patterns in 2000-2004*, evaluated traffic density, incident density, and seasonal activity trends. It is possible that their scientific methods could be duplicated for studies specific to Georgian Bay.

7. Consider incorporating new data from Ministry of Natural Resources and Forestry (MNRF) in future *State of the Bay* iterations. In the coming years, the MNRF will conduct an inventory and complete mapping of Great Lakes shoreline ecosystems as part of their role in a baseline assessment (Annex 7 of GLWQA) and complementary to the Nearshore Framework for monitoring and assessment. The inland scope will likely extend up to 2-5 km.

8. Cumulative effects of multiple factors in cottage country need to be explored, as is noted in *How Much Disturbance is Too Much*? (EC, 2014, p.39): "Overall, what is missing with respect to edge effects to forests in the context of the southern Canadian Shield is research on the cumulative effects of cottage developments, and associated infrastructure, on plant communities and wildlife species on a landscape scale".

5.6 References

Andren, H. (1994). Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review. *OIKOS,* 7, 355-366.

Eigenbrod, F., Hecnar, S.J., & Fahrig, L. (2009). Quantifying the road-effect zone: threshold effects of a motorway on anuran populations in Ontario, Canada. *Ecology and Society, 14*(1), 24.

Environment Canada (EC). (2006). *How much habitat is enough? Second edition*. Toronto, ON: Environment Canada

Environment Canada (EC). (2013). *How much habitat is enough? Third edition*. Toronto, ON: Environment Canada.

Environment Canada (EC). (2014). *How much disturbance is too much?: Habitat conservation guidance for the southern Canadian Shield*. *Draft*. Toronto, ON: Environment Canada.

Environment and Climate Change Canada (ECCC). (2017). *The CWS biodiversity atlas: southern and central Ontario*. *Draft*. Toronto, ON: Environment and Climate Change Canada.

Environment Canada (EC) 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 http://binational.net

Fahrig, L. (1999). Forest loss and fragmentation: which has the greater effect on persistence of forest dwelling animals? In J.A. Rochelle, C.A. Lehmann, & J. Wisniewski (Eds.), *Forest fragmentation: wildlife and management implications* (pp. 87-95). Boston, MA: Brill Academic Publishers.

Fahrig, L. (2001). How much habitat is enough? *Biological Conservation, 100*, 65-74.

Fahrig, L. (2003). Effects of habitat fragmentation on biodiversity. *Annual Review of Ecology, Evolution, and Systematics, 34*, 487-515.

Fahrig, L., & Rytwinski, T. (2009). Effects of roads on animal abundance: an empirical review and synthesis. *Ecology and Society, 14*(2), 21.

Findlay, C.S.T., & Bourdages, J. (2000). Response time of wetland biodiversity to road construction on adjacent lands. *Conservation Biology, 14*(1), 86-94.

Georgian Bay Islands National Park (GBINP). (2006). *Georgian Bay Islands National Park – Ecosystem model*.

Government of Canada. (2003). *Canada's 4th national report to the United Nations Convention on Biological Diversity*. Retrieved from https://www.cbd.int/doc/world/ca/ca-nr-04-en.pdf

Haxton, T. (2000). Road mortality of snapping turtles, *Chelydra serpentine*, in central Ontario during their nesting period. *Canadian Field-Naturalist, 114*(1), 106-110.

Henson, B.L., Kraus, D.T., McMurtry, M.J., & Ewert, D.N. (2010). *Islands of life: a biodiversity and conservation atlas of the Great Lakes islands.* Retrieved from https://www.conservationgateway.org/Documents/Islands-of-Life-final-4-printers.pdf

Lamberson, R.H., Noon, B.R., Voss, V., & McKelvey, R. (1994). Reserve design for territorial species: the effects of patch size and spacing on the viability of the Northern Spotted Owl. *Conservation Biology, 8*, 185-195.

McMurtry, M.J., Bakowsky, W.D., Brinker, S.R., Jones, C.D., Oldham, M.J., & Sutherland, D.A. (2008). *Life science reconnaissance of selected sites in the land between*. Final Report. Peterborough, ON: Natural Heritage Information Centre, Ontario Ministry of Natural Resources.

Pimm, S.L., Russell, G.J., Gittleman, J.L., & Brooks, T.M. (1995). The future of biodiversity. *Science, 269*, 347-350.

Rompre, G., Boucher, Y., Belanger, L., Cote, S., & Robinson, W.D. (2010). Conserving biodiversity in managed forest landscapes: the use of critical thresholds for habitat. *The Forestry Chronicle, 86*, 589-596.

Timonen, J., Gustafsson, L., Kotiaho, J.S., & Monkkonen, M. (2011). Are woodland key habitats biodiversity hotspots in boreal forests? CEE review 09-020 (SR81). Retrieved from http://www.environmentalevidence.org/wp-content/uploads/2014/07/SR81.pdf

6. Climate Change

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6.1 Introduction

Climate plays an important role in determining the state of the Georgian Bay environment and, therefore, the status of Georgian Bay ecosystems. Climatic conditions vary for many reasons, and anthropogenic additions of greenhouse gases (GHGs) to the atmosphere are driving a global warming trend that affects local climate (IPCC, 2014). While climate science is making major advances, the complexity of the planet's climate system makes projection of future climate, particularly at the local scale, very difficult to do with precision. In this chapter, we focus on observed physical changes to the Georgian Bay environment resulting from climate change, such as ice cover and water temperature, which have implications for ecosystems.

Although climate change was named as an important and complex influence on ecosystem health in the 2013 *State of the Bay* report, this is the first time that climate change is being incorporated as a measurable indicator. This chapter is intended to provide readers with an introduction to climate change in a Georgian Bay context. Specifically, it addresses how we can monitor and assess physical changes caused by climate change and some of the potential impacts of a changing climate on the Georgian Bay environment. This chapter is not intended to provide a detailed explanation of climate science, nor does it claim to provide an exhaustive list of likely consequences of climate change. For a more detailed local discussion of climate change, we direct readers to the Muskoka Watershed Council's report, *Planning for Climate Change in Muskoka* (Sale et al., 2016) and the 2015 *State of Climate Change Science in the Great Lakes Basin* report (McDermid et al., 2015).

The key message communicated in this chapter is that climate change is a global reality that can be seen affecting Georgian Bay locally; however, the complexity of climate change makes it impossible to predict future changes in terms of magnitude, duration, and time span. As our understanding of climate change and its impacts on Georgian Bay improves over the next five years, we anticipate that this chapter will be enhanced in terms of the depth and specificity of information for the next iteration of *State of the Bay*. Many research partners across a variety of disciplines are incorporating climate analysis into their studies and will have local data to share for the next publication in 2023.

6.2 What is measured?

Climate change is assessed using a wide and complex array of measures. Changes in biotic (living) and abiotic (physical) features of the biosphere can be observed and correlated with changing climate trends over time, but not many can be measured on a spatial scale that is meaningful for Georgian Bay unless we look at data and trends from larger systems (e.g., Great Lakes). Biotic changes can be attributed to many factors beyond climate change, including changes in nutrient and food availability, disease, competition, and habitat loss. Physical features of the environment are a more stable and predictable category of climate change measures, and data are available for temperature and ice cover, for example.

At the Great Lakes and Lake Huron scale, several physical features of the environment are commonly employed as measures for assessing impacts of climate change. These measures include: ice cover (maximum and average ice concentrations, duration, and timing of ice-on and ice-off) (IJC, 2014; OBC, 2015), water levels (seasonal and long-term fluctuations) (IJC, 2014), and water temperatures (thermal stratification date, turnover date, annual summer surface average temperature) (IJC, 2014).

In order to inform our understanding of climate change and its consequences for Lake Huron and Georgian Bay over time, our assessment focuses on two measures – maximum annual ice cover and summer surface water temperature. Data for these measures are available, easily accessible, and include historical and long term trend analysis. More importantly, these measures of climate change are recognized and recommended by the wider science community. For example, the U.S. National Oceanic and Atmospheric Administration (NOAA) (2017) states that "studying, monitoring and predicting ice coverage on the Great Lakes plays an important role in determining climate patterns, lake water levels, water movement patterns, water temperature structure, and spring plankton blooms". Ice cover and summer surface water temperature are considered and described primarily at the Lake Huron scale for this report.

6.3 How is it measured?

The Great Lakes Environmental Research Laboratory (GLERL) functions as the Great Lakes regional node in delivering NOAA's CoastWatch program. In this role, GLERL studies the relationships between ice cover, lake thermal structure, and regional climate. They have developed, maintained, and analyzed historical models of ice cover, surface water temperature, and other variables of the Great Lakes for over 30 years making it possible to observe trends through time.

Since 1973, Environment and Climate Change Canada's (ECCC) Canadian Ice Service (CIS) has produced ice cover imaging of Canada's navigable waters for the purpose of producing information for shipping in Canada ranging from weekly to daily intervals. The CIS archive holds the data for average sea ice conditions for each year and makes ice coverage records available on their website. Since 1989, the U.S. National Ice Center, a multi-agency center operated by the U.S. Navy, NOAA, and the U.S. Coast Guard, has been combining Canadian satellite imagery with their own to produce data for end users. The data, including ice cover and surface temperature imagery, are now derived using near real-time observations from satellites and other in situ measurements, and are available on the CoastWatch website.

GLERL acquires satellite-derived surface water temperature data daily from NOAA's National Environmental Satellite, Data, and Information Service (NESDIS). Data are presented on their website in the form of several image products. Daytime Sea Surface Temperatures (SST) are reported with different types of satellite imagery including AVHRR (Advanced Very High Resolution Radiometer) imagery. In addition, in situ data, statistical summaries, and other types of data are available. For example, NOAA's National Data Buoy Center (NDBC) also collects data on surface water temperature but unlike data from NESDIS, the NDBC operates a network of buoys collecting data in situ. Figure 51 is an example of imagery showing surface water temperatures via AVHRR imagery.

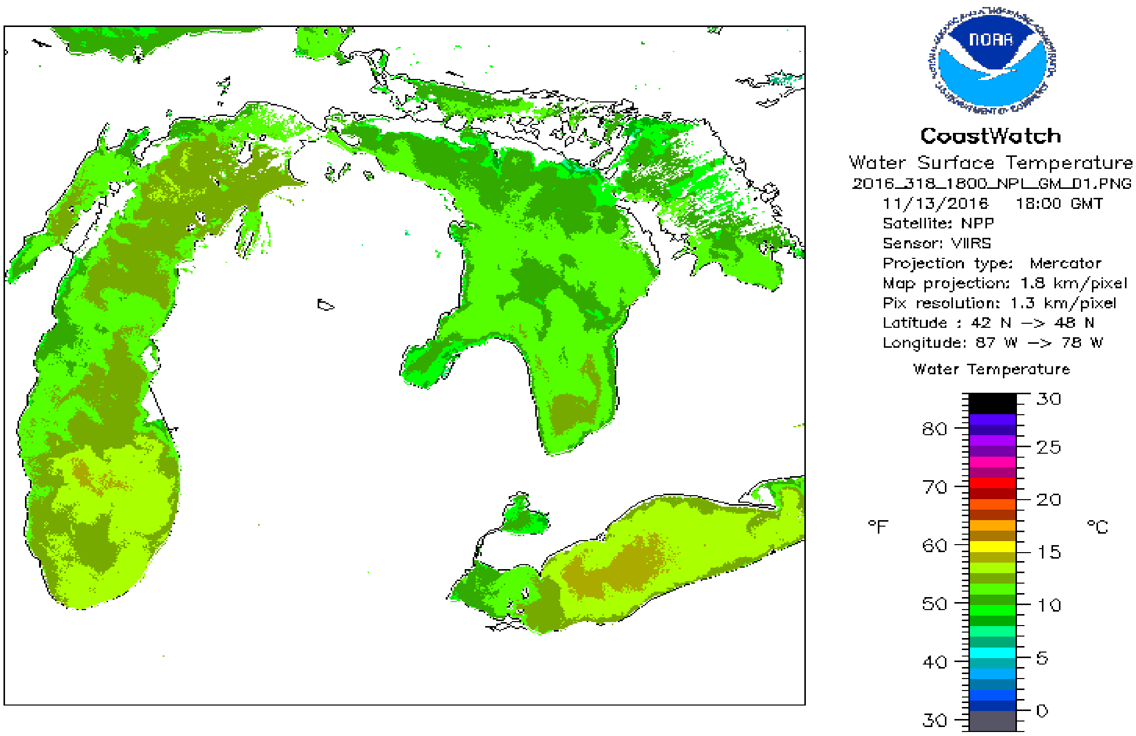

Figure 51. Surface water temperatures on November 13, 2016 (CoastWatch, 2016).

As surface water temperatures and ice conditions are directly related, another way to show the surface conditions of the Great Lakes is by observing the data together in winter conditions. Figure 52 provides an example of Great Lakes Surface Environmental Analysis (GLSEA) imagery from 2017 which also shows ice concentration data. GLERL has also produced an animation of historical Great Lakes ice cover from 1973 to present which can be found at the following website: www.glerl.noaa.gov/data/ice/historicalAnim/.

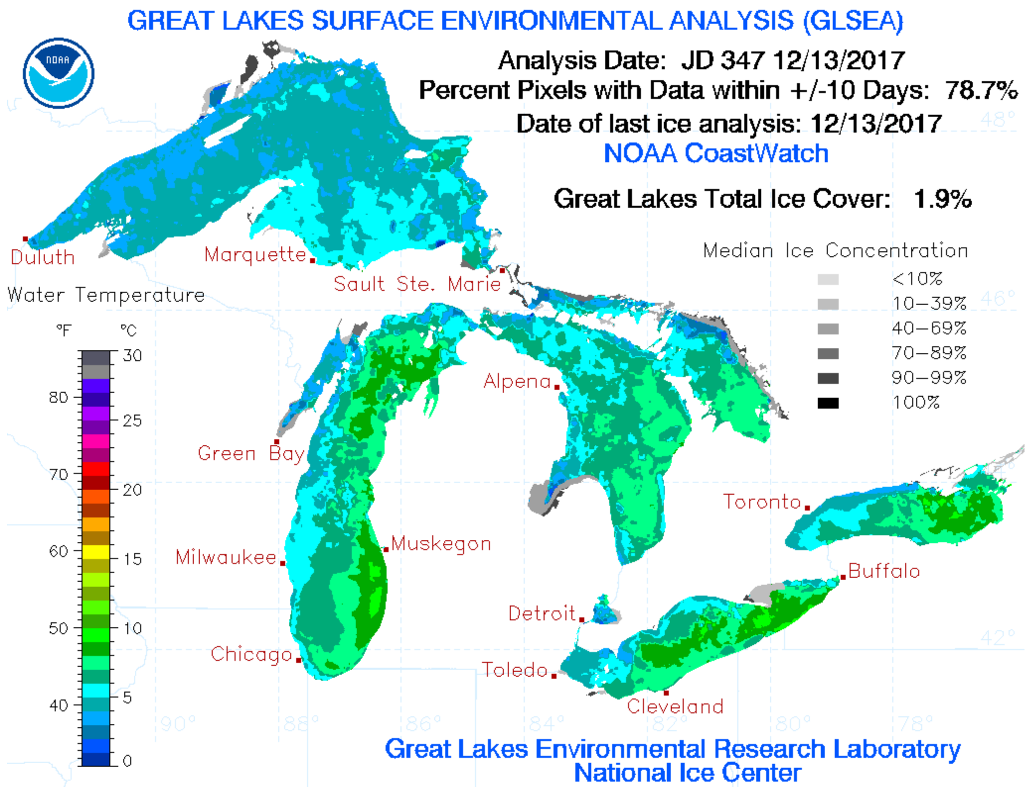

Figure 52. GLSEA imagery showing surface water temperatures and median ice concentration data for December 2017. Ice cover in mid-December was limited to a few small regions such as the eastern shore of Georgian Bay (CoastWatch, 2017a).

New products are being developed by GLERL that will include ice-type classification and mapping. In addition, a new utility is available on the website called JAVA GIS that allows retrieval of physical parameters including surface temperature and ice cover. The water surface temperature imagery is in TIF format, is produced from CoastWatch data files (1.3 km resolution), and is obtained from NOAA 14 and NOAA 15 AVHRR satellite sensors (NOAA, 2016).

Specific to eastern Georgian Bay, Severn Sound Environmental Association (SSEA) conducted a study looking at various climate indicators for the Severn Sound area, including water and air temperature, as well as timing of ice on/off. SSEA used their own datasets (e.g., biweekly open water temperature profiles), ECCC datasets (e.g., weather station data, CIS ice charts), and others (e.g., IceWatch data, citizen ice cover observations) to create local climate profiles for southern Georgian Bay (Chiandet et al., 2017).

6.4 What are the results?

At the scale of Lake Huron, there is sound evidence for a warming trend over the past ~30 years. This is seen in ice cover data and summer surface water temperature data. A decrease in maximum annual ice cover and an increase in summer surface water temperature indicate a rapid environmental change consistent with global climate change models. Accordingly, both climate change sub-indicators have been assigned a trend of 'deteriorating'.

Data were retrieved directly from the CoastWatch and CIS websites for analysis. Additional analysis from the 2017 *State of the Great Lakes* report (EC & EPA, 2017) and *Lake Huron Lakewide Action and Management Plan (LAMP)* (ECCC & EPA, 2018) is also referenced here. Ice cover results for Lake Huron are presented first, followed by summer water temperature results. In these sections, results are also presented for Severn Sound based on information provided by SSEA.

6.4.1 Ice cover

Maximum annual ice coverage, or ice concentration, data are collected and presented by GLERL via the CoastWatch program. Data are available from 1973 to present and are reported for each Great Lake. The following graph (Figure 53) shows the maximum ice cover for Lake Huron from 1973 to 2016.

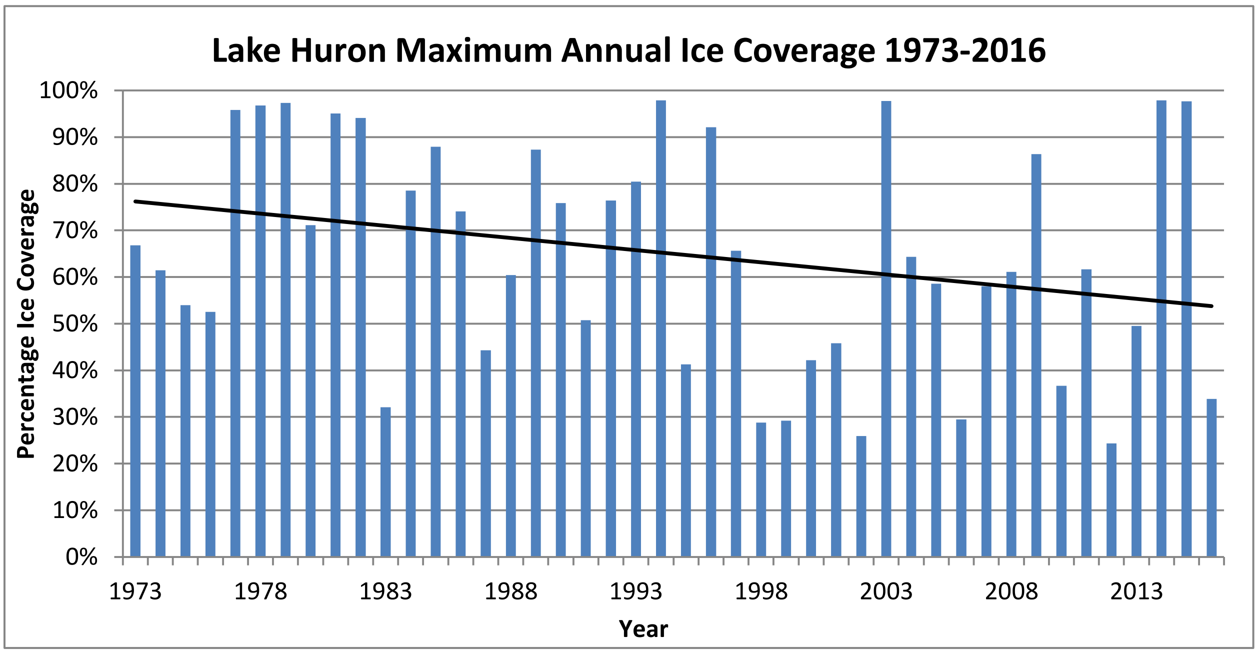

Figure 53. Annual maximum ice cover for Lake Huron from 1973 to 2016 (CIS, 2016). Blue bars indicate percentage ice coverage, the black line represents the linear trend in maximum ice cover over the 43 years.

The linear trend line (black line) in Figure 53 indicates a long-term declining trend in maximum annual ice cover from 1973 to 2016, with a considerable amount of variation from year to year. For example, in 2002 there was very little ice coverage (approximately 26%) while in 2003 there was almost full coverage (97.7%). In 2012, which has the lowest maximum ice coverage on record for the time period, there was only approximately 24% coverage, and in 2014, there was almost full coverage again. The years 1994 and 2014 have the highest maximum ice coverage on record for the time period (97.9%). These data exemplify an important feature of most climate-related data – there is considerable year-to-year variation coupled with a clear, long-term trend. Global climate drivers such as changing patterns in the jet stream and climate oscillations like the El Niño-Southern Oscillation cycle contribute to interannual variation in ice cover.

When the ice cover data are run through a Generalized Linear Model (Figure 54) (with 95% C.I.) there is an apparent decreasing trend in ice cover, but it is not statistically significant (P<0.05) (S. Parker, pers. comm., February 5, 2018).

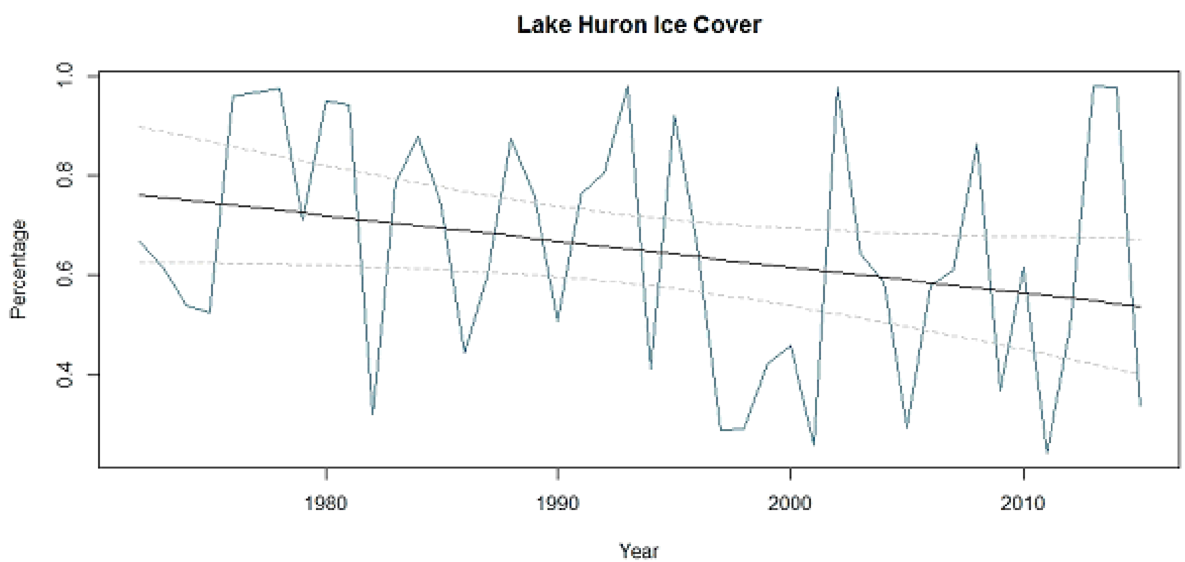

Figure 54. Generalized Linear Model (with 95% C.I.) of annual maximum ice cover for Lake Huron from 1973 to 2016 (S. Parker, pers. comm., February 5, 2018).

Figure 55 shows the long term average pattern of seasonal change in ice concentration for Lake Huron compared to the seasonal pattern for 2017. Ice concentration in 2017 was consistently below the long term average throughout the winter season.

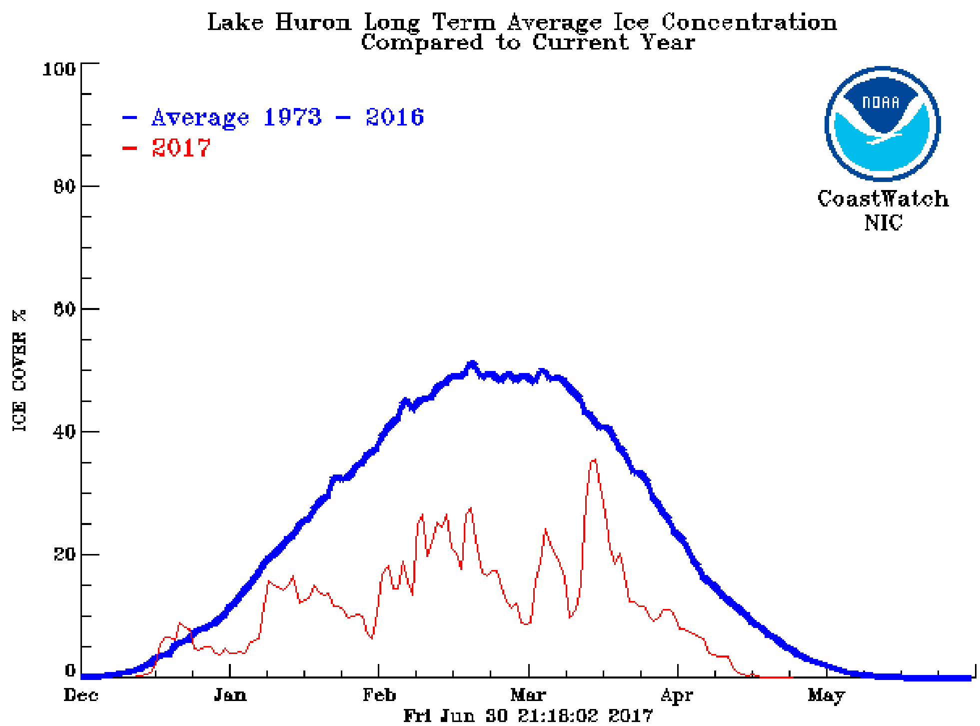

Figure 55. Lake Huron long term average seasonal pattern in ice concentration compared to 2017 (CoastWatch, 2017c).

Ice phenology, the timing of freeze and breakup, for Severn Sound embayments and local inland lakes showed no statistically significant monotonic trends (based on CIS 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 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.

6.4.2 Water temperature

The 2017 *State of the Great Lakes* report (EC & EPA, 2017) states that 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) (Figure 56). 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.

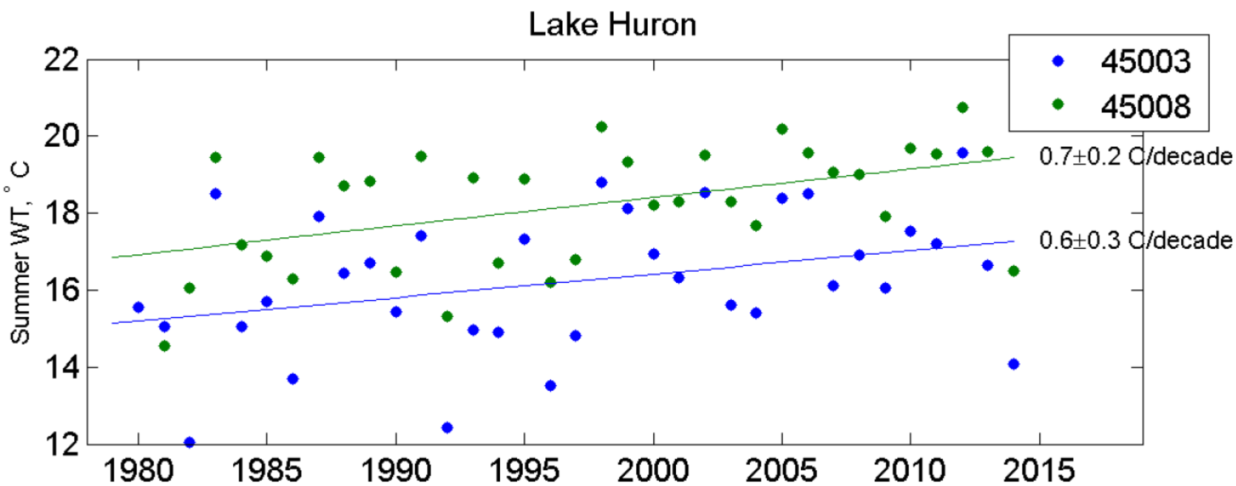

Figure 56. Summer (July-September) surface water temperature trends for Lake Huron (buoys 45003 and 45008 are located in the main basin of Lake Huron) (EC & EPA, 2017).

Figure 57 shows the seasonal pattern of Lake Huron average surface water temperature (1992-2017) compared to 2017. Temperatures in 2017 were often higher than the long-term average.

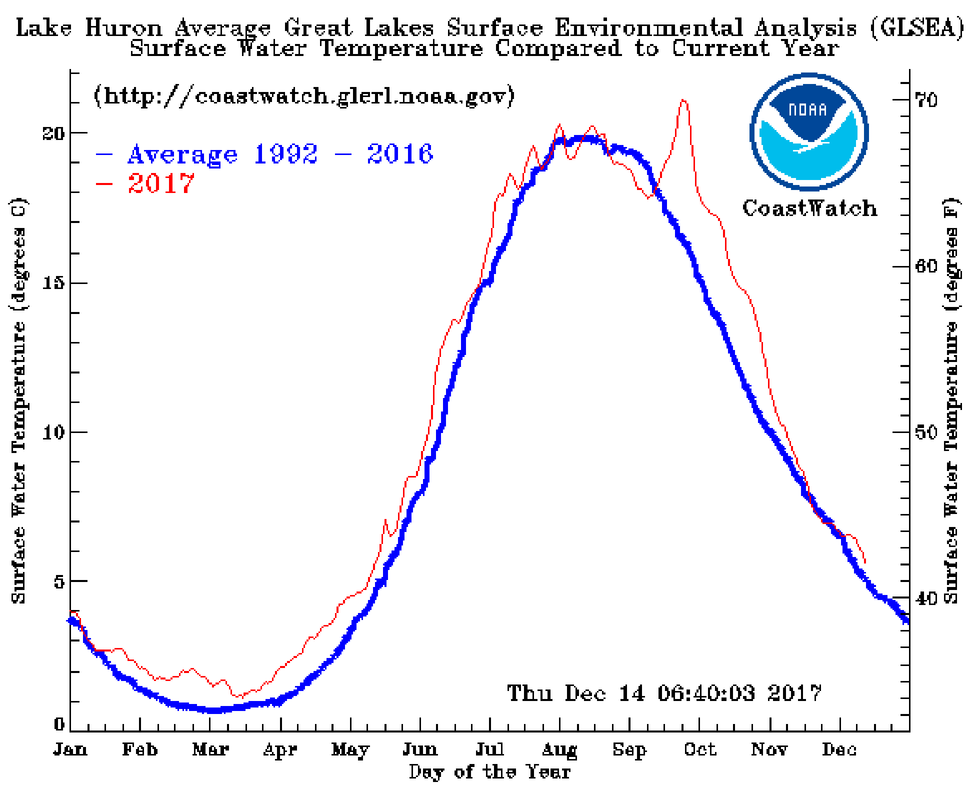

Figure 57. Seasonal pattern in Lake Huron long term average surface water temperatures compared to 2017 (CoastWatch, 2017b).

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. Furthermore, 6 of the top 10 warmest average surface water temperatures in Severn Sound since 1986 have occurred within the last 7 years (Chiandet et al., 2017).

6.5 Why is it important?

The effects of climate change are complex and difficult to mitigate. A changing climate has direct effects on the abiotic conditions (habitat conditions) which support all biota (flora and fauna). There is growing consensus among scientists as to what some of the climate change impacts will be on the Great Lakes region, including Lake Huron and Georgian Bay, although the precision with which scientists are able to project the specific timing and magnitude of these impacts at a local geographic scale is low.

The International Biodiversity Conservation Strategy for Lake Huron (Franks Taylor et al., 2010) recognizes climate change as a high ranking critical threat and identifies six major types of physical changes specifically due to climate change: increased annual average air temperature and surface water temperatures; increased duration of water column stratification; changes in the direction and strength of wind and water currents; flashier precipitation (increases in the intensity of storms and the length of drier periods in between); decreased ice cover; and changes in lake levels. As described in more detail below, we can project some general consequences of these physical changes for future weather, terrestrial ecosystems, aquatic ecosystems, wetlands, and biodiversity in eastern Georgian Bay.

Our weather patterns can be expected to change, resulting in shifts in timing of season changes (earlier springs and later falls). In addition, local municipalities and residents would be prudent to anticipate more frequent and severe extreme weather events which subsequently produce conditions such as flood, drought, and winter and summer storms. Floods can damage shorelines and shoreline structures and bring large amounts of nutrients into the lake, drought can result in more frequent wild fires and lower water levels, and extreme wind and hail storms all create conditions capable of damaging habitats, infrastructure, and crops.

As a result of rising air temperatures, our terrestrial ecosystems are anticipated to show changes in: growing conditions for vegetation communities; species' ranges, including invasive species; forest cover, structure, and regeneration; and community composition. These changes in flora affect the conditions on which insects, birds, mammals, amphibians, and reptiles depend for food and habitat. Relatively rapid changes that occur over decades and centuries, rather than millennia, will force many species to adapt by migrating to new locations, changing their breeding seasons, and/or seeking new food sources. Less adaptable species may disappear from their current habitats (MNRF, 2016). In addition, rising air temperatures may be favourable for invasive species and forest pests that would otherwise have been killed off by harsher winter weather conditions. Forests will also be impacted by increased frequency of wildfire and drought, further reducing their resilience to disease and invasive species.

Warming water temperatures will directly affect aquatic ecosystems in several ways. One is by altering habitat conditions for fish and other aquatic species. It is expected that a shift in distribution and abundance of biota will occur. For example, available thermal habitat for warm water fish, such as largemouth bass (*Micropterus salmoides*), that occupy the epilimnion during summer is expected to increase (McDermid et al., 2015). Habitat for cold water fish, such as lake trout (*Salvelinus namaycush*), will likely decrease as a result of a loss of hypolimnetic volume (Dove-Thompson et al., 2011). Changes in water temperature may also influence: spawning cues for some fish species; timing of various lifecycle stages of invertebrates; the timing of interactions between predator and prey species; changes to the productivity of the lower food web; spread of invasive species; and changes in community composition and ranges of species. Changes in lake levels and river flow may impact spawning and egg incubation in lakes, rivers, and wetlands. Furthermore, less ice cover and a reduced duration of ice cover on Georgian Bay may limit the benefits associated with ice cover. Ice cover can reduce the amount of evaporation from the bay in the winter and protects fish eggs (e.g., whitefish eggs) from destructive wind and wave action. Moreover, stable nearshore ice protects shorelines from erosion. Longer ice-free periods may be responsible for increases in algae production (Clites & Woloszyn, 2014). Increases in surface water temperatures are expected to cause increases in the frequency and severity of harmful and nuisance algae blooms (IJC, 2017).

Coastal wetlands in particular may be negatively impacted by climate change through reduced water levels and water quality; increased exposure to intense storms and wave energy; increased water temperatures; and enhanced movement of invasive species northward. Coastal wetlands may shrink, become perched and isolated from Georgian Bay, or evolve into upland habitat due to the nature of the bathymetry of eastern Georgian Bay. In 2015, Georgian Bay Forever (GBF) collaborated with NASA on a study to monitor changes in wetland extent due to decreasing lake levels. Over the period from 1987-2013, a period of decreasing lake levels, the study showed a 10.8% loss and 7.0% gain of wetlands in the southern and northern regions of Georgian Bay, respectively (Adams et al., 2015).These types of changes to wetland systems would directly affect biodiversity, habitat for fish spawning, and the range and distribution of wetland-dependent plant and animal species, including species at risk (GBF, 2017). There are 50 species at risk within the Georgian Bay Biosphere Reserve, with the majority of these species dependent on wetlands for some aspect of their life cycle. According to wetland ecologist Dr. Janice Gilbert, the species at risk most vulnerable to the anticipated changes in their habitat due to climate change are spotted turtle (*Clemmys guttata*), blanding's turtle (*Emydoidea blandingii*), least bittern (*Ixobrychus exilis*), eastern foxsnake (*Elaphe gloydi*), and common snapping turtle (*Chelydra serpentina*) (GBF, 2017).

Biodiversity refers to the variety of living things on earth and how they interact with each other. The rate at which changes to the landscape will occur due to climate change is a concern for genetic diversity, species diversity, and ecosystem/habitat diversity. As the abiotic environment undergoes changes in response to climate change, some species will be forced to seek habitat outside of their normal ranges. In order to migrate to new habitat, species require corridors to facilitate this migration. Habitat fragmentation can impact the availability of corridors, potentially cutting species off from suitable habitat. When species are successful in migrating to new habitat, they may pose a threat to the species already present in that habitat through increased competition for food and resources. Many species may not be able to adapt quickly enough because genetic change happens much more slowly than the changes that will occur due to climate change. In addition to changes in species' range, threats to biodiversity also manifest as changes in local abundance and viability of species, and change in timing of seasonal events like seed or egg production (phenology) (Franks Taylor et al., 2010).

Evidently, Ontario's ecological landscape, both aquatic and terrestrial, is expected to be reshaped by the effects of climate change (OCCIAR, 2017). The potential effects of climate change on the social system of the Great Lakes region are also of concern, and researchers can only speculate as to what might occur. For example, extreme weather events and changes in temperature and growing season could affect crops and food production in the basin. Changes in air pollution patterns as a result of climate change could affect respiratory health, and new disease vectors and agents could migrate into the region (EPA, 2017). Historically uncommon or absent parasites and diseases are already spreading north to the Great Lakes region. Ticks carrying Lyme disease, mosquitoes carrying West Nile, and other viruses are increasing in range due to a changing climate, and will pose an increasing threat. The Federation of Ontario Cottagers' Associations (FOCA, 2016) reported that models suggest that the geographic range of tick species that transmit Lyme disease may expand significantly due to climate change, with a northern expansion of about 200 km projected by the year 2020 (FOCA, 2016).

6.6 Data gaps and research needs

Our assessment of the available data suggests it would be valuable to continue, and to increase the spatial coverage of monitoring in the Georgian Bay area for physical variables like water temperature (especially in the nearshore) and river flow, and climate variables like wind (especially in the Severn Sound area). The prescribed goal under Annex 9 of the Great Lakes Water Quality Agreement is to enhance monitoring of relevant climate and Great Lakes variables to validate model predictions and understand current climatic changes and their impacts. With this in mind, improved monitoring on Georgian Bay could be considered and facilitated by installing more instrumentation. Currently, there are two buoy stations on Georgian Bay managed by ECCC (Figure 58; station 45137 – Georgian Bay and station 45143 – south Georgian Bay) that monitor wind, waves, atmospheric pressure, air, and water temperatures. Data are reported hourly and are available on ECCC's Marine Forecasts website and on NOAA's NDBC website. There are four land based weather stations relevant for eastern Georgian Bay: Killarney, Parry Sound, Western Islands (offshore), and Muskoka (inland). Data gaps exist for the Severn Sound and French River areas.

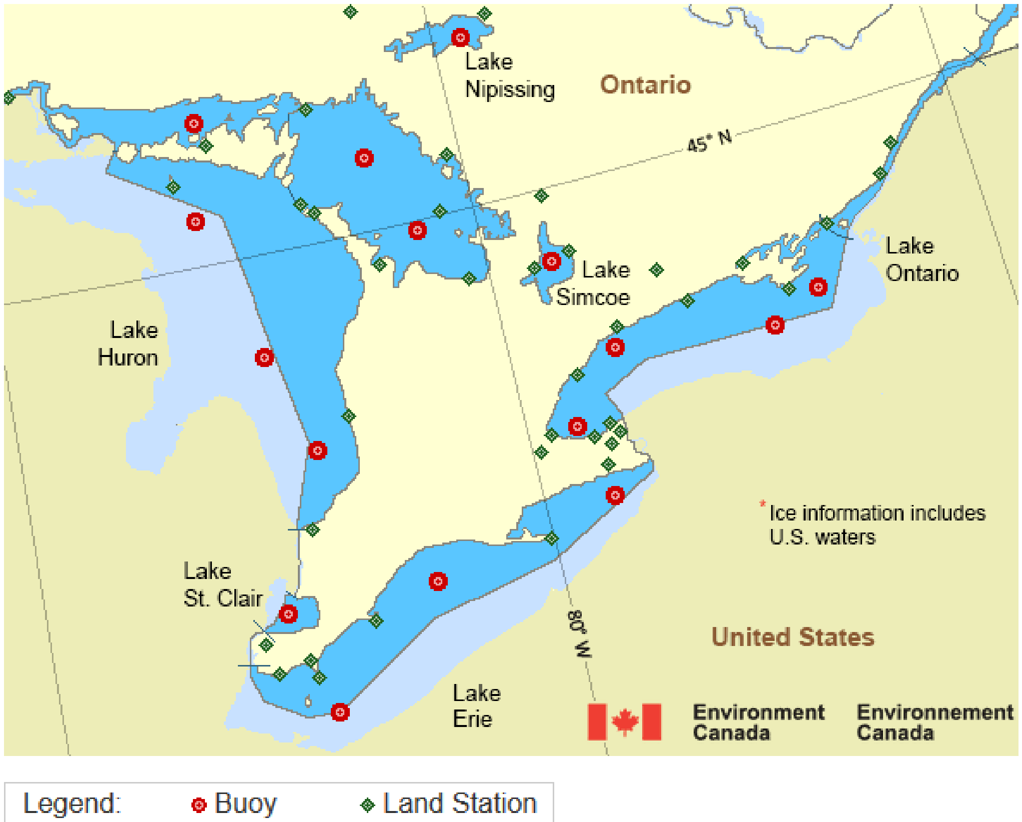

Figure 58. Location of current ECCC buoy and land meteorological monitoring stations. The land station on Beausoleil Island was discontinued in 2007.

The water temperature and ice cover data derived by CoastWatch is analysed and presented on a Lake Huron scale. It may be of interest to understand the water temperature and ice cover data on a Georgian Bay scale in order to look at trends specific to Georgian Bay. George Leshkevich, scientist at CoastWatch, suggested that Georgian Bay data would likely show very similar trends to Lake Huron data, but that the water temperature and ice cover on Georgian Bay may show a difference in the timing of changes.

6.7 What can I do to help?

Citizens can take action on climate change on two fronts: mitigation and adaptation. It is not possible to prevent climate change from occurring based on the amount of CO_2 that has been released up to this point, however it is possible to prevent it from getting worse by reducing CO_2 emissions, thereby protecting the health and wellbeing of future generations. There are many resources available on how individuals can reduce their carbon footprint. Sustainable Severn Sound is working to create a local Climate Change Action Plan that will reduce the carbon footprint in the Severn Sound area, updates can be found here: www.sustainableseverensound.ca.

In terms of adaptation, citizens are encouraged to learn about ways to make their homes and properties more resilient to the potential impacts of climate change, such as severe weather, flooding, and drought. This also means ensuring that properties are protected by the right types of insurance where possible. Shoreline properties can be particularly susceptible in terms of changing water levels and storms, and shoreline owners are encouraged to maintain a natural shoreline with native plants and shrubs, which is better able to withstand wave energy over the long term.

The Lake Huron-Georgian Bay Watershed Canadian Initiative for Community Action lists the following individual actions to reduce your climate change impacts:

- **Be energy efficient by greening your home.** Change your lightbulbs to LED bulbs; turn off the lights and unplug electronics and appliances when not in use; look for ENERGY STAR labels when buying new electronics or appliances; heat and cool smartly; and seal and insulate your home. You will also save money on your electricity bill!
- **Choose green power.** Switch your energy source to renewable energy such as wind or solar.
- **Plant trees!** Trees sequester carbon, helping to remove carbon dioxide and other greenhouse gases from the air.
- **Choose sustainable transportation**. Transportation produces about 14% of global greenhouse gas emissions (IPCC, 2014). Walk, cycle, carpool, or take public transit when you can. Purchase a smaller, fuel-efficient, low-greenhouse gas vehicle.
- **Conserve water**. Take shorter showers; install low-flow shower heads and toilets. Use the dishwasher and washing machine only when you have full loads. Wash clothes in cold water.
- **Eat locally**. Buy organic and locally grown food, as it does not have to travel as far. Avoid buying processed foods.
- **Reduce your waste**. Garbage buried in landfills produces methane, a potent greenhouse gas. Compost when you can. Recycle paper, plastic, metal, and glass. Buy products with minimal packaging. Buy LESS.
- **Follow the 6 Rs of Sustainability:** Rethink, refuse, reduce, reuse, repair, and recycle.
- **Get involved and informed!** Follow the latest news on climate change, voice your concerns, and spread the word to family and friends!

6.8 Where can I learn more?

A number of organizations in Canada and the United States collect and evaluate data on physical environment and climate. Many of these, as well as a number of consortia, provide such data and evaluations to the public via their websites. Among the most useful of these are the following:

<u>Local Level</u>

Muskoka Watershed Council's report: Planning for Climate Change in Muskoka
This report is about the climate that Muskoka is likely to experience at mid-century and examines the likely impacts of that mid-century climate on Muskoka lakes and waterways, forests, built infrastructure, communities, and way of life. It recommends actions to address some of those impacts for consideration of provincial agencies, district and municipal governments, local businesses, community

groups, and individual Muskokans. https://www.muskokawatershed.org/resources/planning-for-climate-change/

Sustainable Severn Sound's Local Climate Change Action Plan
This plan is in the development stage. Sustainable Severn Sound is working with their municipal partners in the Severn Sound area and the larger community to develop an Action Plan. The Action Plan will include both a corporate and community inventory of greenhouse gas (GHG) emissions, identify a GHG reduction target, and prioritize actions to reduce municipal and community contributions to climate change. https://www.sustainableseversound.ca/

Simcoe Muskoka District Health Unit (SMDHU)
The SMDHU recognizes that there are challenges to the public's health posed by climate change, and many of these challenges will vary in severity depending on the individuals affected. Through the winter of 2016-2017 staff completed an assessment of the areas where members of the public are most vulnerable. That assessment can be found here:
http://www.simcoemuskokahealth.org/Topics/climatechange.aspx.

Regional Level

Canadian Ice Service (CIS)
The CIS's mission is to provide the most accurate and timely information about ice in Canada's navigable waters, working to promote safe and efficient maritime operations and to help protect Canada's environment. For the latest ice conditions, visit their website and click the appropriate regional area on the map: https://www.ec.gc.ca/glaces-ice/.

U.S. National Snow and Ice Data Center (NSIDC)
The NSIDC began in 1976 and supports and conducts research on snow, ice, glaciers, frozen ground, and climate interactions that make up the cryosphere (the frozen parts of Earth). In addition to educating the public about the cryosphere, NSIDC manages, distributes, and makes scientific data accessible via their website: http://nsidc.org/.

Great Lakes Ice Atlas
NOAA's Great Lakes Ice Atlas (https://www.glerl.noaa.gov/data/ice/atlas/) provides information on Great Lakes ice cover climatology. It offers a benchmark of ice cover and ice cover variation of the Great Lakes during the last quarter of the 20th century and early years of the 21st Century. The U.S. National Ice Center and the Canadian Ice Service use information from this atlas in making operational analysis products of Great Lakes ice cover.

NOAA National Centers for Environmental Information
NOAA's National Centers for Environmental Information provides free access to an archive of historical weather and climate data (primarily for the U.S.) in addition to station history information through Climate Data Online (CDO). CDO also offers mapping tools which allow users to view data by regions and provides links to additional data resources available through other branches of NOAA:
https://www.ncdc.noaa.gov/cdo-web/.

Great Lakes Observing System (GLOS)
GLOS is one of 11 regional bodies in the U.S. that brings together federal, state, academic, and private sector entities engaged in collecting data on coastal waters. The GLOS Data Portal provides users with access to near real-time and archived observations including water levels, wave heights, and air and water temperatures to model forecasts for the Great Lakes: http://www.glos.us/.

Great Lakes Integrated Science and Assessments (GLISA)
GLISA is a partnership between the University of Michigan and Michigan State University, housed in the Graham Sustainability Institute's Climate Center. As one of ten NOAA-funded regional centers, GLISA builds capacity to manage risks from climate change and variability in the Great Lakes region. The GLISA website (http://glisa.umich.edu/) hosts a collection of climate data resources from different institutions that provide international, regional, and local climate data at a variety of temporal resolutions.

Great Lakes Climate Quarterly
The Great Lakes Climate Quarterly is a publication produced jointly by NOAA and ECCC. The information provided summarizes current and forecasted weather and water level conditions and weather and water level-related impacts over the Great Lakes. Past publications can be found at the following website: http://ec.gc.ca/eau-water/default.asp?lang=En&n=F5329B03-11.

Ontario Centre for Climate Impacts and Adaptation Resources (OCCIAR)
OCCIAR is a university-based resource hub for researchers and stakeholders searching for information on climate change impacts and adaptation. The centre communicates the latest research on impacts and adaptation, liaises with partners across Canada to encourage adaptation to climate change, and aids in the development of tools to assist with municipal adaptation. OCCIAR's website hosts up-to-date information pertaining to climate change impacts, vulnerabilities, and adaptation: http://www.climateontario.ca/.

Ontario Climate Change Data Portal (Ontario CCDP)
CCDP was launched in 2014 by the Ministry of Environment and Climate Change to ensure that technical and non-technical end-users (e.g., municipalities, private sector) have easy and intuitive access to the latest climate data throughout the province. The CCDP data portal (http://www.ontarioccdp.ca/) provides both visual representations of, and data downloading functions for, climate scenarios across Ontario including typical climate change indicators (e.g., temperature, precipitation) at a range of temporal scales.

ClimateWizard
A joint project of the Nature Conservancy, the University of Washington, and University of Southern Mississippi, the ClimateWizard website (http://www.climatewizard.org/) allows users to view historic temperature and rainfall maps as well as future predictions of temperature and rainfall around the world. Users can also view and download climate change maps.

6.9 References

Adams, E., Del Valle Martinez, I., Harris, M., Zimmerman, S., & Ross, K. (2015). *Great Lakes climate II. Impact of decreasing water levels on Great Lakes wetlands*. NASA DEVELOP National Program, Langely Research Center. Retrieved from https://georgianbayforever.org/publications/

Canadian Ice Service (CIS). (2016). *Lake Huron maximum ice coverage graph 1972 to 2016.* Retrieved from http://www.ec.gc.ca/glaces-ice/default.asp?lang=En&n=63C9A1CC-1

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.

Clites, A., & Woloszyn, M. (2014). *Ice cover on the Great Lakes.* Retrieved from http://mrcc.isws.illinois.edu/cliwatch/eNews/observer_201401_full.html

CoastWatch. (2016). *Lake Michigan VIIRS imagery*. Retrieved from https://coastwatch.glerl.noaa.gov/viirs/viirs.php?region=m&prd=d1&page=1

CoastWatch. (2017a). *Great Lakes Surface Environmental Analysis (GLSEA).* Retrieved from https://coastwatch.glerl.noaa.gov/glsea/glsea.html

CoastWatch. (2017b). *Lake Huron average Great Lakes surface environmental analysis (GLSEA) surface water temperature compared to current year.* Retrieved from https://coastwatch.glerl.noaa.gov/statistic/gif/avgtemps-h_1992-2015.gif

CoastWatch. (2017c). *Lake Huron long term average ice concentration compared to current year*. Retrieved from http://www.ec.gc.ca/glaces-ice/default.asp?lang=En&n=63C9A1CC-1

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-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 Canada (EC) 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 http://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/

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. Retrieved from https://www.lakehuroncommunityaction.ca/wp-content/uploads/2016/03/LHBCS_Technical_Report.pdf

Georgian Bay Forever (GBF). (2017). *Threats to Georgian Bay wetlands: the interview with wetland ecologist Dr. Janice Gilbert.* Retrieved from https://georgianbayforever.org/threats-to-georgian-bay-wetlands-the-interview-with-wetland-ecologist-dr-janice-gilbert/

International Joint Commission (IJC). (2014). *Great Lakes ecosystem indicator project report.* Retrieved from http://www.ijc.org/en_/AOP/Ecosystem

International Joint Commission (IJC). (2017). *Human health effects of cyanobacterial toxins in the Great Lakes region: a science and monitoring assessment*. Report submitted by the Health Professionals Advisory Board. Retrieved from http://ijc.org/files/tinymce/uploaded/HPAB/HPABAlgalBloomFinal_02Mar2017.pdf

IPCC. (2014). *Climate change 2014: synthesis report*. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland: IPCC.

McDermid, J.L., Dickin, S.K.,Winsborough, C.L., Switzman, H., Barr, S., Gleeson, J.A., et al. (2015). *State of climate change science in the Great Lakes basin: a focus on climatological, hydrological and ecological effects.* Ontario Climate Consortium and Ontario Ministry of Natural Resources and Forestry. Retrieved from https://climateconnections.ca/our-work/great-lakes-basin/

Ministry of Natural Resources and Forestry (MNRF). (2016). *Climate change and natural resources.* Retrieved from https://www.ontario.ca/page/climate-change-and-natural-resources

National Oceanic and Atmospheric Administration (NOAA). (2016). *Great Lakes CoastWatch Java GIS.* Retrieved from https://coastwatch.glerl.noaa.gov/gis/html/avhrr/java-gis.html

National Oceanic and Atmospheric Administration (NOAA). (2017). *Great Lakes ice cover.* Retrieved from https://www.glerl.noaa.gov/data/ice/

Ontario Biodiversity Council (OBC). (2015). *State of Ontario's biodiversity*. Peterborough, ON: Ontario Biodiversity Council. Retrieved from http://ontariobiodiversitycouncil.ca/sobr

Ontario Centre for Climate Impacts and Adaptation Resources (OCCIAR). (2017). *Ecosystems: in a changing climate.* Retrieved from www.climateontario.ca/factsheets.php

Sale, P., Lammers, R., Yan, N., Hutchinson, N., Trimble, K., Dinner, P., et al. (2016). *Planning for climate change in Muskoka*. Muskoka, ON: Muskoka Watershed Council. Retrieved from https://www.muskokawatershed.org/resources/planning-for-climate-change/

United States Environmental Protection Agency (EPA). (2017). *Climate impacts on human health.* Retrieved from https://19january2017snapshot.epa.gov/climate-impacts/climate-impacts-human-health_.html

7. Appendix A – UGLMU Lake Huron surveys 2013-2017

Year	Project Code(s)	Project Name	Area(s)	Project Type
2013	LHA_SC13_AIR	Aerial Boat Count Survey	Owen Sound And Colpoys Bay	Creel Survey
2013	LHA_CF13_001	Commercial Catch Sampling		Commercial Catch Sampling
2013	LHA_IA13_258	French River Delta FWIN	French River	Nearshore Index Netting
2013	LHA_FS13_001	Lake Huron Fish Stocking		Fish Stocking
2013	LHA_IS13_031	Lake Sturgeon Program	Nottawasaga River	Sturgeon Assessment
2013	LHA_IA13_022	Moon River ESTN	Moon River	Nearshore Index Netting
2013	LHA_IA13_116	Moon River SWIN	Moon River	Nearshore Index Netting
2013	LHA_IS13_007	North Channel Lake Trout Spawning Assessment	North Channel	Fall Spawning Survey
2013	LHA_IA13_002 / 003 / 005 / 006 / 007 / 008	Offshore Index Assessment	Cape Rich, Clapperton Island, Collingwood, Frazer Bay, Grand Bend, Southampton	Offshore Index Netting
2013	LHA_SC13_000 / 001	Owen Sound Creel	Owen Sound	Creel Survey
2013	LHA_SF13_501	Owen Sound Salmon Spectacular Derby	Owen Sound	Derby Monitoring
2013	LHA_SC13_033	Parry Sound Winter Creel	Parry Sound	Creel Survey
2013	LHA_IA13_251	Severn Sound ESTN	Severn Sound	Nearshore Index Netting
2013	LHA_IA13_249 / 250	Severn Sound SMIN	Severn Sound	Nearshore Index Netting
2013	LHA_SC13_053	Severn Sound Winter Creel	Severn Sound	Creel Survey
2013	LHA_IA13_701	Small Fish Assessment	Fathom Five	Small Fish Assessment
2013	LHA_IA13_119, LHA_IS13_119	South Bay FLIN / Trap Net	South Bay	Fall Spawning Survey

Year	Project Code(s)	Project Name	Area(s)	Project Type
2013	LHA_FA13_STO	Stomach Analysis and Diet Study		Diet Analysis
2014	LHA_IA14_18F, LHA_IS14_018	Parry Sound FLIN / Trap Net	Parry Sound	Fall Spawning Survey
2014	LHA_IA14_801 / 802 / 803 / 804	Broadscale Monitoring - Britt	Britt, Deep Bay Parry Sound, French River, Severn Sound	Broadscale Monitoring
2014	LHA_BM14_802 / 803 / 804	Broadscale Monitoring Small Fish	Deep Bay Parry Sound, French River, Severn Sound	Small Fish Assessment
2014	LHA_CF14_001	Commercial Catch Sampling		Commercial Catch Sampling
2014	LHA_FA14_CTM	Contaminant Collection		Tissue Collection and Analysis
2014	LHA_AS14_081	Evaluation Of Maxilla For Aging Lake Trout		Aging QAQC
2014	LHA_IA14_021	French River Delta ESTN	French River	Nearshore Index Netting
2014	LHA_IA14_017	French River Delta SWIN	French River	Nearshore Index Netting
2014	LHA_IA14_258	French River FWIN	French River	Nearshore Index Netting
2014	LHA_TE14_AA2 / AA1	Glatos Acoustic Array Sturgeon And Walleye Movement Study		Telemetry
2014	LHA_FS14_001	Lake Huron Fish Stocking		Fish Stocking
2014	LHA_IS14_031	Lake Sturgeon Program	Nottawasaga River	Sturgeon Assessment
2014	LHA_IA14_002 / 003 / 005 / 006 / 007 / 026	Offshore Index Assessment	Cape Rich, Clapperton Island, Collingwood, Grand Bend, Southampton, Stokes Bay	Offshore Index Netting
2014	LHA_SF14_501	Owen Sound Salmon Spectacular	Owen Sound	Derby Monitoring
2014	LHA_SC14_033	Parry Sound Summer Roving Creel	Parry Sound	Creel Survey
2014	LHA_SC14_052	Severn Sound Fall On-water Creel	Severn Sound	Creel Survey
2014	LHA_IA14_250	Severn Sound SMIN	Severn Sound	Nearshore Index Netting

Year	Project Code(s)	Project Name	Area(s)	Project Type
2014	LHA_IA14_700-712	Small Fish Assessment	Blackstone Harbour, Britt, Bruce Mines, Campbell Bay, Fathom Five, Goderich, Grand Bend, Midland Bay, Mississagi River, Owen Sound, South Baymouth, Stokes Bay, Whalesback Channel	Small Fish Assessment
2014	LHA_FA14_STO	Stomach Analysis and Diet Study		Diet Analysis
2015	LHA_IA15_F14	Frazer Bay FLIN	Frazer Bay	Fall Spawning Survey
2015	LHA_IA15_F13	Iroquois Bay FLIN	Iroquois Bay	Fall Spawning Survey
2015	LHA_IA15_18F, LHA_IS15_018	Parry Sound FLIN / Trap Net	Parry Sound	Fall Spawning Survey
2015	LHA_IA15_802-805 / 808	Broadscale Monitoring	French River, Parry Sound, Severn Sound, Shawanaga, Shebeshekong	Broad Scale Monitoring
2015	LHA_TE15_AA2	Bruce to Manitoulin Acoustic Array	Bruce Archipelago	Telemetry
2015	LHA_SC15_06A / 06S	Colpoys Bay (Wiarton) Creel	Colpoys Bay	Creel Survey
2015	LHA_CF15_001	Commercial Catch Sampling		Commercial Catch Sampling
2015	LHA_FA15_CTM	Contaminant Collections		Tissue Collection and Analysis
2015	LHA_AS15_081	Evaluation Of Maxilla For Aging Lake Trout		Aging QAQC
2015	LHA_AS15_091	Evaluation Of Maxilla For Aging Lake Whitefish		Aging QAQC
2015	LHA_IA15_021	French River Delta ESTN	French River	Nearshore Index Netting
2015	LHA_IA15_017	French River Delta SWIN	French River	Nearshore Index Netting
2015	LHR_IA15_300	Hydroacoustics Companion Netting and Trawling	Parry Sound	Broad Scale Monitoring

Year	Project Code(s)	Project Name	Area(s)	Project Type
2015	LHA_FS15_001	Lake Huron Fish Stocking		Fish Stocking
2015	LHA_IA15_002 / 003 / 005 / 006 / 007	Offshore Index Assessment	Cape Rich, Clapperton Island, Collingwood, Grand Bend, Southampton	Offshore Index Netting
2015	LHA_SC15_000 / 001	Owen Sound Creel	Owen Sound	Creel Survey
2015	LHA_SF15_501	Owen Sound Salmon Spectacular derby	Owen Sound	Derby Monitoring
2015	LHA_IA15_257 / 259	Shawanaga SMIN	Shawanaga River	Nearshore Index Netting
2015	LHA_IA15_236	Shawanaga FWIN	Shawanaga River	Nearshore Index Netting
2015	LHA_SC15_040	Shawanaga On water Boat creel	Shawanaga River	Creel Survey
2015	LHA_IA15_233	Shawanaga ESTN	Shawanaga River	Nearshore Index Netting
2015	LHA_IA15_230	Shawanaga River SWIN	Shawanaga River	Nearshore Index Netting
2015	LHA_IA15_700 / 702-712	Small Fish Assessment	Blackstone Harbour, Britt, Bruce Mines, Campbell Bay, Goderich, Grand Bend, Midland Bay, Mississagi River, Owen Sound, South Baymouth, Stokes Bay, Whalesback Channel	Small Fish Assessment
2015	LHA_BM15_802-805 / 807 / 808	Broadscale Monitoring Small Fish	French River, Parry Sound, Severn Sound, Shawanaga, Shebeshekong, Sturgeon Bay	Small Fish Assessment
2015	LHA_SC15_05A	Southampton Boat Access Creel	Southampton	Creel Survey
2015	LHA_FA15_STO	Stomach Analysis and Diet Study		Diet Analysis
2016	LHA_IA16_F14	Frazer Bay FLIN	Frazer Bay	Fall Spawning Survey
2016	LHA_IA16_F13	Iroquois Bay FLIN	Iroquois Bay	Fall Spawning Survey

Year	Project Code(s)	Project Name	Area(s)	Project Type
2016	LHA_IA16_305	Spanish Delta FWIN	Spanish River	Nearshore Index Netting
2016	LHA_IA16_303	Spanish River ESTN	Spanish River	Nearshore Index Netting
2016	LHA_IA16_801 / 802 / 805 / 808 / 809	Broadscale Monitoring - Britt	Britt, Parry Sound, Shawanaga, Shebeshekong, Spanish	Broad Scale Monitoring
2016	LHA_CF16_001	Commercial Catch Sampling		Commercial Catch Sampling
2016	LHA_AS16_334	Evaluation of Walleye Ageing Structures		Aging QAQC
2016	LHA_FA16_MAT	Lake Trout Length At Maturity		Synthesis and Analysis
2016	LHA_IA16_002 / 003 / 005 / 006 / 007 / 027 / 029	Offshore Index Assessment	Cape Rich, Clapperton Island, Collingwood, Grand Bend, Point Clark, Southampton, Watcher Islands	Offshore Index Netting
2016	LHA_SF16_501	Owen Sound Salmon Spectacular Derby	Owen Sound	Derby Monitoring
2016	LHA_IA16_257 / 259	Shawanaga SMIN	Shawanaga River	Nearshore Index Netting
2016	LHA_IA16_233	Shawanaga ESTN	Shawanaga River	Nearshore Index Netting
2016	LHA_IA16_236	Shawanaga FWIN	Shawanaga River	Nearshore Index Netting
2016	LHA_IA16_230	Shawanaga SWIN	Shawanaga River	Nearshore Index Netting
2016	LHA_SC16_043	Shawanaga Winter Creel	Shawanaga River	Creel Survey
2016	LHA_IA16_700 / 702-712	Small Fish Assessment	Blackstone Harbour, Britt, Bruce Mines, Campbell Bay, Goderich, Grand Bend, Midland Bay, Mississagi River, Owen Sound, South Baymouth, Stokes Bay, Whalesback Channel	Small Fish Assessment
2016	LHA_BM16_802 / 805 / 807 / 808	Small Fish Assessment - Parry Sound	Parry Sound, Shawanaga, Shebeshekong, Sturgeon Bay	Small Fish Assessment

Year	Project Code(s)	Project Name	Area(s)	Project Type
2016	LHA_SC16_200	Spanish Boat Creel	Spanish River	Creel Survey
2016	LHA_IA16_301 / 302	Spanish River Delta SMIN	Spanish River	Nearshore Index Netting
2016	LHA_IA16_304	Spanish River SWIN	Spanish River	Nearshore Index Netting
2016	LHA_IA16_300	Spanish River Walleye Spawning Electrofishing	Spanish River	Nearshore Index Netting
2016	LHA_IM16_52S	Thornbury Fishway Monitoring (Spring)	Beaver River (Thornbury)	Fishway Monitoring
2017	LHA_IA17_251	Severn Sound ESTN	Severn Sound	Nearshore Index Netting
2017	LHA_IA17_303	Spanish River ESTN	Severn Sound	Nearshore Index Netting
2017	LHA_IA17_S05 / S07	Lake Whitefish larval beach seining	Blind River, Fishing Islands	Nearshore Index Netting
2017	LHA_IL17_T05 / T07	Larval Whitefish Trawling	Blind River, Fishing Islands	Nearshore Index Netting
2017	LHA_IA17_002 / 003 / 005 / 006 / 007 / 027	Offshore Index Assessment	Cape Rich, Clapperton Island, Collingwood, Grand Bend, Southampton, Watcher Islands	Offshore Index Netting