State of the Bay

2023 TECHNICAL REPORT FOR EASTERN GEORGIAN BAY

STATEOFTHEBAY.CA

GEORGIAN BAY BIOSPHERE
MNIDOO GAMII

LAND ACKNOWLEDGEMENT

The Georgian Bay Mnidoo Gamii Biosphere gratefully acknowledges that we are located on *Anishinaabek* territory and that our office is currently located where the *Ziigwan* (spring) or *Gizhiijwan* (fast-flowing river) meets *Mnidoo-gamii,* Great Lake of the Spirit.

We respect and recognize the inherent rights and governance of the *Anishinaabek* pre-confederation and acknowledge the rights recognized in the Robinson-Huron Treaty of 1850 and the Williams Treaty of 1923.

There are a diversity of Indigenous cultures across Turtle Island. We honour the United Nations Declaration on the Rights of Indigenous Peoples and we strive to meet the Calls to Action set out by the Truth and Reconciliation Commission of Canada.

We are committed to our responsibility of relationship building with Indigenous peoples and respect their knowledge and ways of being.

We appreciate each of the communities in the region and thank them for sharing their knowledge and time with us.

- Wiikwemkoong Unceded Territory
- Dokis First Nation
- Henvey Inlet First Nation
- Magnetawan First Nation
- Shawanaga First Nation
- Wasauksing First Nation
- Moose Deer Point First Nation
- Chimnissing First Nation
- Wahta Mohawks
- Moon River Métis Council
- Georgian Bay Métis Council

Our organization is privileged and is working to unlearn some of what we have been taught and decolonize our ways of knowing and being. We need to hear the truth so we can reconcile with our past, create new relationships, and move forward together in a good way.

We wish to honour Indigenous resilience since time immemorial. We wish to express our gratitude to our Indigenous relations for continuously leading the way in sustainability, respect, and reciprocity.

We are grateful, Mother Earth. *Miigwetchwendam Shkakmigkwe.*

ACKNOWLEDGEMENTS

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A NOTE FROM THE AUTHORS

For the third iteration of *State of the Bay,* it was clear that a deeper understanding of the changes happening to the lands and waters of Georgian Bay (*Mnidoo-gami*) could be created by bringing together stories from elders, knowledge holders, researchers, and scientists. As such, with the help of many cultural advisors, the Georgian Bay Mnidoo Gamii Biosphere is taking a new approach to State of the Bay – one that values both Indigenous knowledge and western science. Taking this new approach is a long-term process. As a starting point, work towards honouring multiple ways of knowing has focused largely on the *State of the Bay* magazine. In the technical report, where possible we have highlighted examples of work being done in the region that draws on multiple ways of knowing.

To make clear the perspective from which this technical report is produced, the authors would like to state that they are largely of European settler descent, and as such this body of work is being presented from a western perspective.

COVER ART

“Tranquility” by William Anthony Monague (1956-2019) "*Abwaudung*" (The Visionary or Dreamer). Self-taught Beausoleil First Nation artist William Monague grew up with the People of Chimnissing. In his piece, “Tranquility” painted in 2001, the painted turtles (*mskwaadesi*) embody the symbol of healing and the reconstruction of Mother Earth. The Eagle represents the Ojibwe belief of the messenger answering our prayers; giving us the gift of strength and protection. *Miigwech* to Brenda St. Denis and for reprint permission from the Estate of William Monague.

Compiled by the Georgian Bay Mnidoo Gamii Biosphere.

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LIST OF ACRONYMS

List of acronyms that appear in the 2023 *State of the Bay* Technical Report.

Acronym	Description
AIS	Aquatic invasive species
AOCs	Areas of Concern
AOFRC	Anishinabek/Ontario Fisheries Resource Centre
BEAST	Benthic Assessment of Sediment model
BRPs	Biological reference points
BsM	Broadscale Monitoring
CABIN	Canadian Aquatic Biomonitoring Network
CanESM2	Canadian Earth System Model
CIS	Canadian Ice Service
CPUE	Catch-per-unit-effort
CSMI	Cooperative Science and Monitoring Initiative
CWRM	Coastal Wetland Response Model
CWS-ON	Canadian Wildlife Service - Ontario Region
DFO	Department of Fisheries and Oceans
ECCC	Environment and Climate Change Canada
EGB	Eastern Georgian Bay
EPA	U.S. Environmental Protection Agency
ESTN	End of Spring Trap Netting
FLIN	Fall Littoral Index Gill Netting
FMZ	Fisheries management zone
FRSC	French River Stewardship Council
FSIS	Fish Stocking Information System
FSIT	Fall Spawning Index Trap Net
FWIN	Fall Walleye Index Netting
GB	Georgian Bay
GBB	Georgian Bay Mnidoo Gamii Biosphere
GBLT	Georgian Bay Land Trust
GCM	Global Climate Model
GFDL-ESM2M	Geophysical Fluid Dynamics Labortory Earth System Model
GHG	Greenhouse gases
GLERL	Great Lakes Environmental Research Laboratory
GLFC	Great Lakes Fisheries Comission
GLM	Generalized linear model

GLNPO	Great Lakes National Program Office
GLSC	Great Lakes Science Center
GLWQA	Great Lakes Water Quality Agreement
HVBA	High value biodiverisity area
IJC	International Joint Commission
IK	Indigenous knowledge
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
LAMP	Lakewide Action and Management Plan
LH	Lake Huron
LHPWG	Lake Huron Partnership Working Group
LPP	Lake Partner Program
LTRZ	Lake Trout Rehabilitation Zones
MCI	Muskies Canada Incorporated
MCWI	McMaster Coastal Wetland Inventory
MECP	Ministry of Environment, Conservation and Parks
MFN	Magnetawan First Nation
MNRF	Ministry of Natural Resources and Forestry
MOE	Ministry of the Environment
NGB	Northern Georgian Bay
NGO	Non-governmental organization
NOAA	National Oceanic and Atmospheric Administration
OECMs	Other Effective Area-Based Conservature Measures
OSIA	Offshore Index Assessment Program
OTI	Oligochaete Trophic Indices
PA	Protected Area
PSW	Provinicially significant wetland
PWQO	Provincial Water Quality Objective
QMA	Quota Management Area
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
RI	Resilience Index
S.T.A.R.T.	Saving Turtles at Risk Today
SatChl	Satellite-derived imagery
SAV	Submerged aquatic vegetation
SEGB	Southeastern Georgian Bay
SFN	Shawanaga First Nation
SMIN	Spring Muskellunge Index Netting
SRP	Soluble reactive phosphorus

SSEA	Severn Sound Environmental Association
SWIN	Spring Walleye Index Netting
TL	Total length
TOC	Township of Claring
TP	Total phosphorus
UGLMU	Upper Great Lakes Management Unit
USGS	United States Geological Survey
VIn	Vulnerability Index
WFI	Wetland Fish Index
WFN	Wasauksing First Nation
WMI	Wetland Macrophyte Index
WQI	Water Quality Index
YAO	Yearling-and-older
YOY	Young-of-the-year

LIST OF ANISHINABEMOWIN

List of Anishinabemowin words that appear in the 2023 *State of the Bay* Technical Report.

English	Anishinabemowin
Lake trout	nmegos
Smallmouth bass	noosa owesi
Northern pike	gnoozhe
Muskellunge	maashkinoozhe
Walleye	ogaa
Lake sturgeon	nme
Blueberries	miinan
Massasauga rattlesnake	zhiishiigweg
Eastern foxsnake	gchi-gnebig
Snapping turtle	mikinaak
Blanding's turtle	mooskadoons
Midland painted turtle	mskwaadesi
Eastern wolf	ma'iingan
Fire	shkode

INTRODUCTION

Working with dozens of partners, the Georgian Bay Mnidoo Gamii Biosphere (GBB) initiated the *State of the Bay* project in 2008 to monitor changes in, and better understand the health of, eastern Georgian Bay, designated by UNESCO as a region of global ecological significance. Together with expert advisors and partners, ecosystem health indicators were identified to help tell the story of the lands and waters of eastern Georgian Bay.

In 2013, the first *State of the Bay* technical report was released reporting on six ecosystem health indicators for ten regions in northern and eastern Georgian Bay. Grades (A to F) were assigned to indicators based on condition. The report also highlighted three key environmental issues – water levels, invasive species, species at risk – as well as data gaps and research needs. The technical report was accompanied by a public-friendly magazine and website, both based on the content in the technical report.

Five years later, in 2018, the second edition of *State of the Bay* was released with a new technical report, magazine, and an updated website (www.stateofthebay.ca). The new *State of the Bay* reported on eleven ecosystem health indicators including new information on climate change, landscape biodiversity, and a recognition of the work of conservation groups and Indigenous communities. Indicator trends, instead of grades, were reported in the new report.

The third edition of the *State of the Bay,* released in 2023, continues to build on past editions and has the following three goals:

1. Communicate the condition of the Georgian Bay Biosphere region as informed by multiple knowledges;
2. Bring attention to research needs and knowledge gaps and actively pursue ways to fill those needs and gaps; and
3. Inspire stewardship action.

The indicators/themes included in the 2023 *State of the Bay* report are listed below.

1. Climate change
2. Total phosphorus
3. Lower food web
4. Prey fish
5. Smallmouth bass
6. Northern pike
7. Muskellunge
8. Walleye
9. Lake trout
10. Coastal wetlands
11. Landscape biodiversity

Each chapter details the reasons for the selection of these indicators and any changes in how the indicator is being reported on from the 2018 report. Information on the indicators is gathered from numerous sources including government agencies, non-governmental organizations, university researchers, First Nations, and citizen science programs.

Every effort was made to report results at the scale of eastern Georgian Bay. Where this was not possible, results were reported at the Georgian Bay, or in some cases, Lake Huron scale.

Trends and their definitions have been adopted from the *State of the Great Lakes* reports prepared by Environment and Climate Change Canada and the U.S. Environmental Protection Agency. 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.

Table 1 presents a summary of the 2023 results. The trend for the coastal wetlands sub-indicators of vulnerability, sensitivity, and adaptive capacity are listed in Table 1 as undetermined for three eastern Georgian Bay wetlands. Scores (very low to very high) were determined for these sub-indicators rather than trends. Finally, the landscape biodiversity trend is listed as N/A. This indicator is more descriptive or discussion based in nature and does not lend itself to the determination of a trend.

As with the previous reports, there is a continued effort to identify and highlight data gaps and research needs for each indicator. The intent of continuing to flag data gaps and research needs is that these needs will be strategically filled, making new data and research available for future reporting.

The *State of the Bay* project would not be possible without the continued support of partners and sponsors. Special thanks to the Echo Foundation, the McLean Foundation, the Ministry of Environment, Conservation and Parks via the Canada-Ontario Agreement respecting the Great Lakes Basin Ecosystem, Iron City Fishing Club via the Great Lakes Basin Conservancy, and the many businesses, First Nations, municipalities, and organizations who have become sponsors of the project.

Table 1. Summary of the 2023 *State of the Bay* findings.

Indicator		Sub-indicator/Measure	Trend
Climate change		Maximum annual ice cover	• Deteriorating (GB)
		Summer surface water temperature	• Deteriorating (GB)
Total phosphorus		Average total phosphorus	• Offshore long-term: deteriorating (GB) • Offshore 10-year: unchanging (GB) • Nearshore: location dependent, generally unchanging (EGB)
Aquatic ecosystem health	Lower food web	Phytoplankton	• Deteriorating (LH)
		Zooplankton	• Unchanging (LH)
		Benthic invertebrates	• Unchanging - deteriorating (LH)
	Prey fish	Offshore and nearshore demersal and pelagic prey fish	• Undetermined (LH, GB, EGB)
	Smallmouth bass	Catch per unit effort	• Unchanging (EGB)
	Northern pike	Catch per unit effort	• Unchanging (EGB)
	Muskellunge	Catch per unit effort, mean and maximum total length	• Unchanging (EGB)
	Walleye	Catch per unit effort, spawning stock size, age structure	• Unchanging (EGB)
	Lake Trout	Age structure, survival/ mortality, spawning stock size, natural reproduction, abundance	• Improving (Lake Huron) • Undetermined (EGB) • Unchanging (Parry Sound)
Coastal wetlands		Vulnerability	• Undetermined – vulnerability score for three EGB wetlands
		Sensitivity	• Undetermined – sensitivity scores for three EGB wetlands
		Adaptive capacity	• Undetermined – adaptive capacity scores for three EGB wetlands
Landscape biodiversity		N/A	• N/A

LH = Lake Huron, GB = Georgian Bay, EGB = eastern Georgian Bay

CLIMATE CHANGE

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1. INTRODUCTION

Since the industrial revolution, humans have been burning fossil fuels (e.g., coal, oil, natural gas) to produce energy to fuel cars, heat buildings, and power industries (IPCC, 2018). The extraction and burning of fossil fuels releases greenhouse gases into Earth's atmosphere which act like a blanket, trapping more heat from the sun and making the Earth warmer than it would be otherwise (IPCC, 2018). Human activities in the past several decades have contributed significantly to the addition of greenhouse gas (GHG) emissions. Working Group III of the Intergovernmental Panel on Climate Change (IPCC) reported in the sixth assessment report that historical cumulative CO_2 emissions from 1850 to 2019 were 2400 ± 240 $GtCO_2$, equating to approximately 2400 billion tonnes of CO_2 (IPCC, 2022b). Of these net CO_2 emissions, 42% were added in just the last 30 years (1990-2019) and 17% in the past decade (IPCC, 2022b). Visualizing cumulative CO_2 emissions (Figure 1) paints an even clearer picture of the rapid acceleration of emissions in the past 30 years.

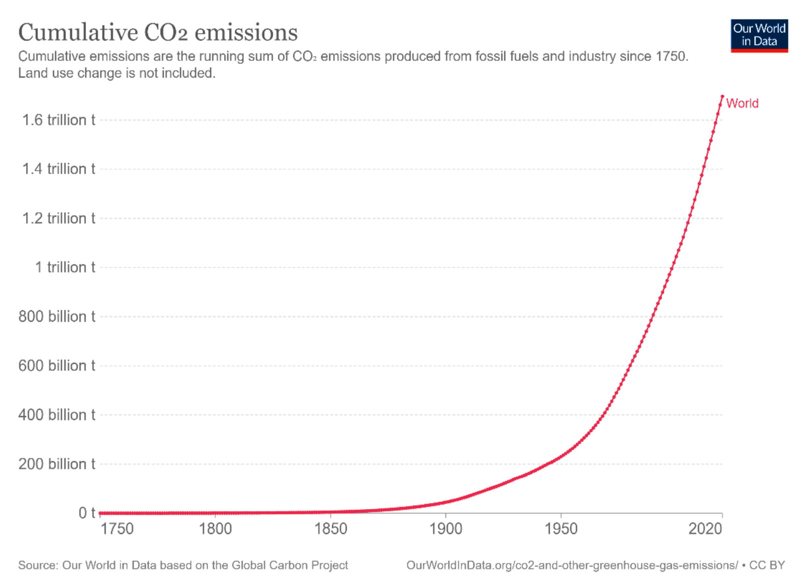

Figure 1. Global cumulative CO2 emissions (Figure from Our World in Data, n.d.).

As stated in the IPCC's *Global Warming of 1.5°C* special report; "Human-induced warming reached approximately 1°C (*likely* between 0.8°C and 1.2°C) above pre-industrial levels in 2017, increasing at 0.2°C (*likely* between 0.1°C and 0.3°C) per decade (*high confidence*)" (Allen et al., 2018, p. 51). The IPCC simulated five climate scenarios through the near-term (2021-2040), mid-term (2041-2060), and the long-term (2061-2100) to understand how the planet may respond. These five scenarios range from low emissions – representing a decrease in current emissions – to high emissions – representing roughly a doubling in emissions from current levels, and each equates to a change in global surface temperature (e.g., the intermediate GHG scenario (SSP2-4.5) projects temperatures to be 2.1°C to 3.5°C higher) (Figure 2). This global warming is affecting many of Earth's natural processes, causing unprecedented impacts such as the melting of polar ice caps, global sea level rise, and more frequent and intense extreme events (IPCC, 2022a).

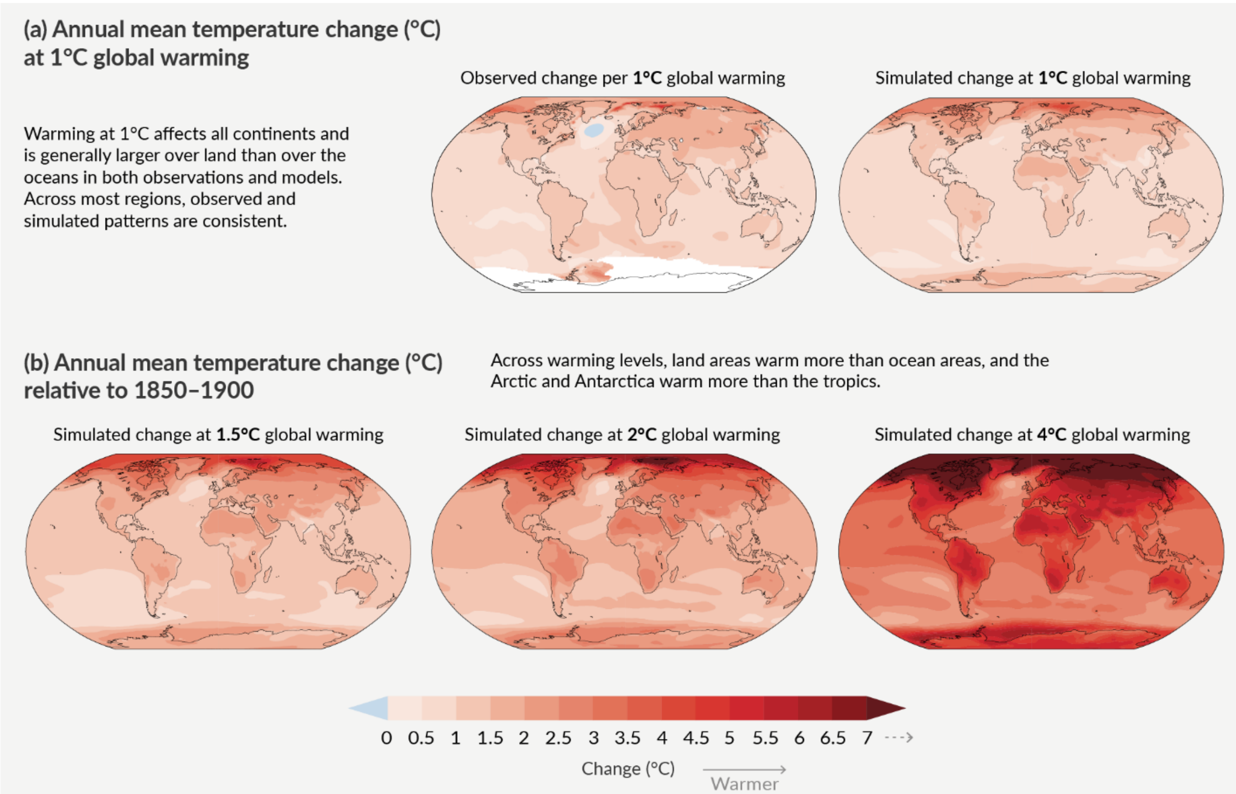

Figure 2. Annual mean temperature changes under different climate scenarios (Figure SPM.5a and SPM.5b from IPCC, 2021).

Warming is intensified in Arctic regions. As such, Canada is experiencing warming at more than double the global rate (Bush & Lemmen, 2019). Already Canadians are experiencing extreme heat, greater risk of wildfire and drought, increased precipitation, reductions in ice cover, shorter snow seasons, and changes to terrestrial and aquatic ecosystems (Bush & Lemmen, 2019). By 2100, Ontario could experience 4.7 more hot days (maximum temperature above 30°C) each year under a low emissions scenario, or 38 more hot days under a high emissions scenario (Douglas & Pearson, 2022; Zhang et al., 2019). With drier conditions projected across the province, the incidence of wildfire events could potentially double by 2040 under a high emissions scenario (Douglas & Pearson, 2022). With regard to precipitation, from 1948 to 2016, Ontario's mean annual precipitation increased by 9.7% and extreme rainfall intensity has been shown to be increasing as well (Douglas & Pearson, 2022).

The Georgian Bay Mnidoo Gamii Biosphere region is already experiencing the effects of climate change. A thunderstorm in July 2017 produced extreme winds that affected the Parry Sound area causing Oastler Lake Provincial Park to close (CTV Barrie, 2017). In 2018, the Parry Sound 33 wildfire occurred amidst uncharacteristically dry summer conditions (CBC News, 2018). In 2019, heavy rains caused extreme flooding in Muskoka and the southern end of eastern Georgian Bay (Global News, 2019). The entire Great Lakes basin experienced record-setting warm temperatures in mid-May of 2021 (NOAA, 2021b) and on August 26, 2021, the water temperature of Lake Huron was a record-breaking 23.2°C (NOAA, 2021c). Winter 2023 experienced temperatures 4°C above normal with January 2023 experiencing temperature 6°C above normal (NOAA, 2023b). At the time of writing, warm air temperatures in winter 2022/2023 have resulted in record low ice cover on the Great Lakes, with only 7% coverage recorded on February 13, 2023 (NOAA, 2023a). This is 35-40% below the expected ice cover for this time of year (NOAA, 2023a).

The effects of climate change on the eastern shore of Georgian Bay go beyond extreme weather events. A changing climate has direct effects on the abiotic conditions (habitat conditions) which support all biota (flora and fauna). Moreover, climate change is considered a threat multiplier, meaning it exacerbates other threats such as invasive species. 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 model the specific timing and magnitude of these impacts at a local geographic scale is limited. For a high-level summary of these impacts, readers are directed to the report titled *Climate Change in the Great Lakes Basin: Summary of Trends and Impacts* (Lam & Dokoska, 2022). Readers are also encouraged to explore the Climate Atlas of Canada which provides projections of localized climate impacts for two emissions scenarios – a “Low Carbon” scenario (RCP 4.5) and a “High Carbon” scenario (RCP 8.5). As examples, (Figure 3) and (Figure 4) present the localized interaction of temperature and precipitation in the Town of Parry Sound for low (RCP 4.5; Figure 3) and high (RCP 8.5; Figure 4) emission scenarios.

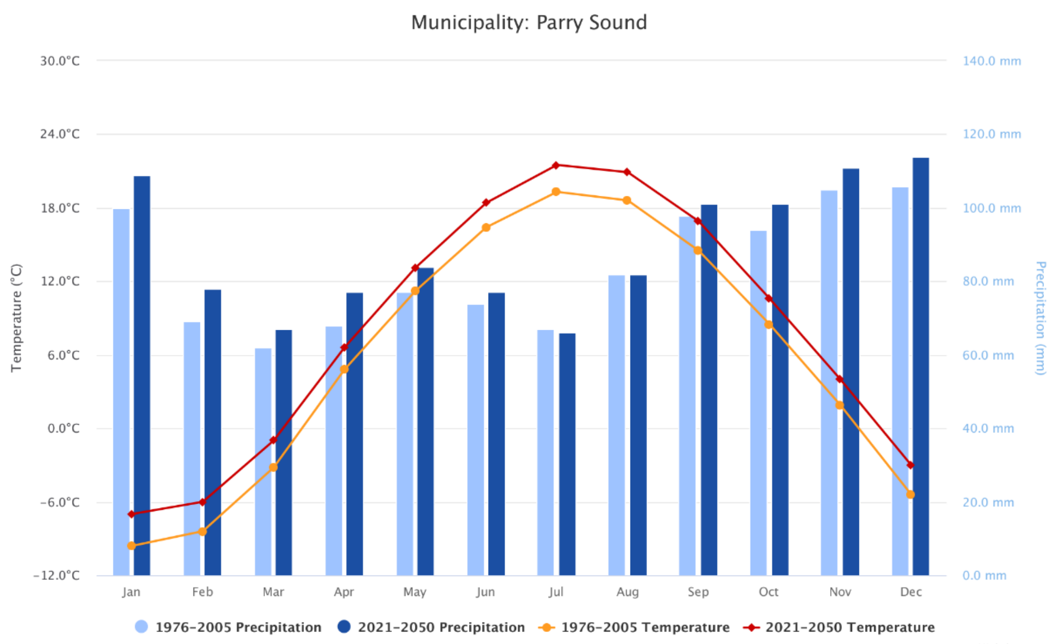

Figure 3. Temperature and precipitation amount under RCP 4.5 emissions scenario for Parry Sound (Figure from Climate Atlas of Canada, n.d.).

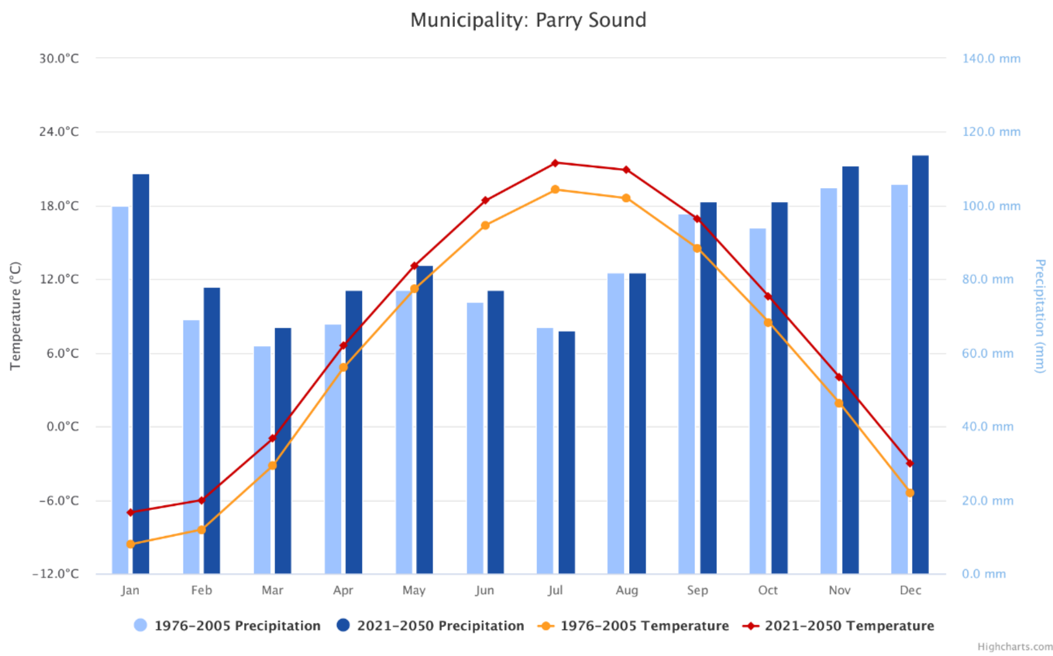

Figure 4. Temperature and precipitation amount under RCP 8.5 emissions scenario for Parry Sound (Figure from Climate Atlas of Canada, n.d.)

Climate change is a cross-cutting theme throughout this report. While the focus of this chapter is water temperature and ice cover, other chapters of this report address climate change as it relates to specific indicators or themes. For example, the vulnerability of coastal wetlands to climate change is the focus of the Coastal Wetlands chapter. The impacts of warming water temperatures caused by climate change on the lower food web and fish communities are discussed in the Aquatic Ecosystem Health chapter.

2. HOW IS CLIMATE CHANGE STUDIED IN EASTERN GEORGIAN BAY?

A variety of indicators relate to the causes or effects of climate change. Changes in biotic (living) and abiotic (physical non-living) features of the biosphere correlate with changing climate trends over time. These changes and trends can be monitored, measured, and communicated in a variety of ways, using multiple types of knowledges or ways of knowing.

2.1 CONNECTING GUARDIANS IN A CHANGING WORLD

A unique research project involving 12 Anishinaabek communities in the upper Great Lakes region of the Robinson-Huron Treaty Area, including two communities in eastern Georgian Bay, was undertaken in 2019 to elevate Anishinaabek concerns, observations, and perspectives about climate change impacts and future research needs (Menzies et al., 2022). The researchers describe the project as an example of truly Indigenous-led climate change research, “it was motivated by community concerns, developed and implemented by Indigenous communities and allied researchers, uses Indigenous research methodologies, and addresses issues that are important to the communities involved” (Menzies et al., 2022, p. 512). Three main topics related to climate change were explored during a two-day workshop titled "Guardians in a Changing World": (1) key concerns related to the environment; (2) key concerns related to community and ways of life; and, (3) future research priorities (Menzies et al., 2022).

2.2 NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION GREAT LAKES ENVIRONMENTAL RESEARCH LABORATORY

The Great Lakes Environmental Research Laboratory (GLERL) functions as the Great Lakes regional node in delivering the National Oceanic and Atmospheric Administration's (NOAA) 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.

2.3 ENVIRONMENT AND CLIMATE CHANGE CANADA

Since 1973, Environment and Climate Change Canada's (ECCC) Canadian Ice Service (CIS) has produced ice cover imaging of Canada's navigable waters. 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 online

Data for wind, waves, atmospheric pressure, air, and water temperatures are also available via two buoy stations on Georgian Bay managed by ECCC (Figure 5). Data are reported hourly and are available on ECCC's Marine Forecasts website and on NOAA's National Data Buoy Center website.

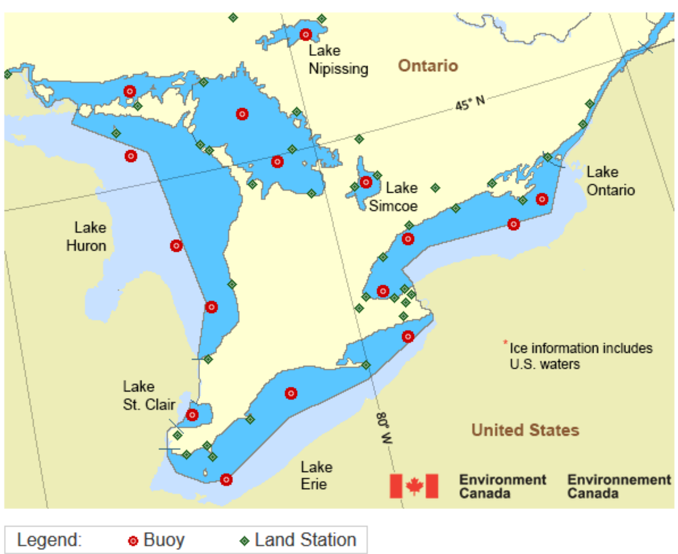

Figure 5. Location of current ECCC buoy and land meteorological monitoring stations. The land station on Beausoleil Island was discontinued in 2007. Figure from Environment Canada (https://weather.gc.ca/marine/forecast_e.html?mapID=10&siteID=05500)

2.4 SEVERN SOUND ENVIRONMENTAL ASSOCIATION

The Severn Sound Environmental Association (SSEA) routinely monitors various climate indicators for the Severn Sound area, including water and air temperature and timing of ice on/off. The SSEA used their own datasets (e.g., biweekly open water temperature profiles, Ice Spotters citizen science data), 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).

3. WHAT ARE THE RESULTS?

As biotic changes can be attributed to many factors beyond climate change, including changes in nutrient and food availability, disease, competition, and habitat loss, abiotic features can be viewed as a more stable and predictable category of climate change measures. *State of the Bay 2018* reported on two abiotic, or physical, features of the environment – maximum annual ice cover and summer surface water temperature – to inform our understanding of climate change and its consequences for Georgian Bay over time. Data for maximum annual ice cover and summer surface water temperature are available, easily accessible, and allow for historical and long-term trend analysis. More importantly, these measures of climate change are recognized and recommended by the wider science community. For example, 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".

Five years after the 2018 report, the current iteration of *State of the Bay* provides a trend update for maximum annual ice cover and summer surface water temperature at the Lake Huron scale. New for this 2023 report, is a summary of the findings from a regional project utilizing a two-eyed seeing approach to understand "Anishinaabe concerns, observations, and perspectives about climate change impacts and future research needs" (Menzies et al., 2022). Projects of this nature provide a holistic understanding of climate change in a regional context by considering the social and ecological systems as highly interconnected, and honours the centuries of observation of ecosystem change and oral knowledge sharing passed down for generations.

3.1 MAXIMUM ANNUAL ICE COVER & SUMMER SURFACE WATER TEMPERATURE

At the scale of Lake Huron, there is sound evidence for a warming trend over the past ~40 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 continue to be assigned a trend of 'deteriorating' (metrics show a change away from acceptable conditions).

Ice cover results for Lake Huron are presented first, followed by summer surface water temperature results. In these sections, results are also presented for Severn Sound based on information provided by the SSEA.

3.1.1 Maximum Annual Ice Cover

Scientists at GLERL have determined that on average, Great Lakes annual maximum ice cover is decreasing by about a half percent each year, or roughly 5% per decade (Farina, 2022). For the period of 1973-2020, this represents a basin-wide ice loss of 22.1% (ECCC & EPA, 2022b).

Across Lake Huron, ice cover has been declining since the CIS began recording ice data in 1973 (Nguyen et al., 2017; Yang et al., 2020; ECCC & EPA, 2022b). Lake Huron maximum annual ice cover is decreasing at a rate of 0.41% per year or 4.1% per decade (Farina, 2022). Unlike the other Great Lakes, the trend for Lake Huron ice cover is not quite statistically significant (Farina, 2022). In conjunction with this decline, cycles in annual maximum ice cover have become more variable compared to historic cycles (Wang et al., 2018). The percent ice cover for each year from 1973-2022 is shown in Figure 6.

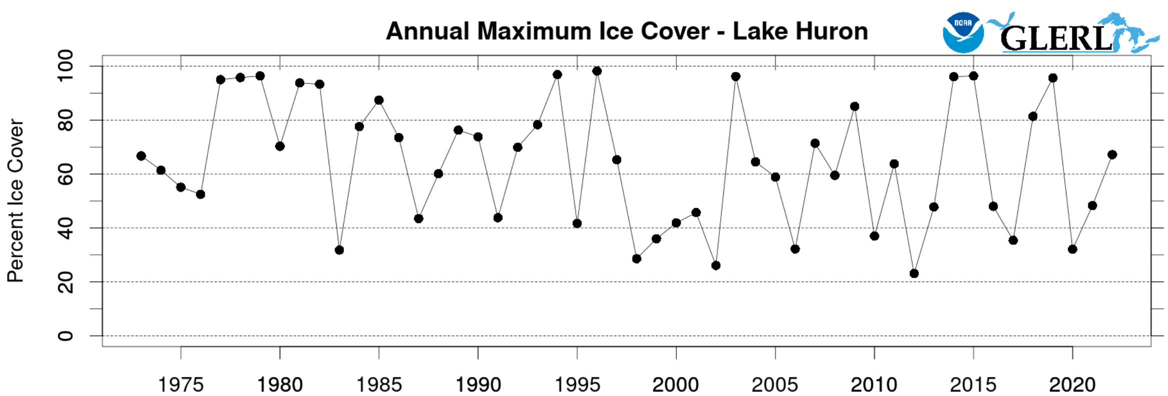

Figure 6. Maximum percent ice cover from 1973-2022 (Figure from NOAA GLERL, 2022).

In Georgian Bay, analysis conducted by the Georgian Bay Mnidoo Gamii Biosphere has confirmed a statistically significant downward trend in ice cover from 1973 to 2023 (Figure 7). Figures 8 and 9 depict percent ice cover across Georgian Bay in the first year of CIS monitoring – 1973—and the most recent monitoring year – 2023. Due to the variability of ice cover across year, Figures 8 and 9 should not be used as evidence of a declining trend. However, upon plotting the percent area of ice cover each year from 1973 to 2023, the declining trend becomes apparent (Figure 7). A simple linear regression analysis was conducted to confirm this trend was statistically significant ($R^2 = 0.19$, $F(1, 49) = 11.47$, $p = 0.001$).

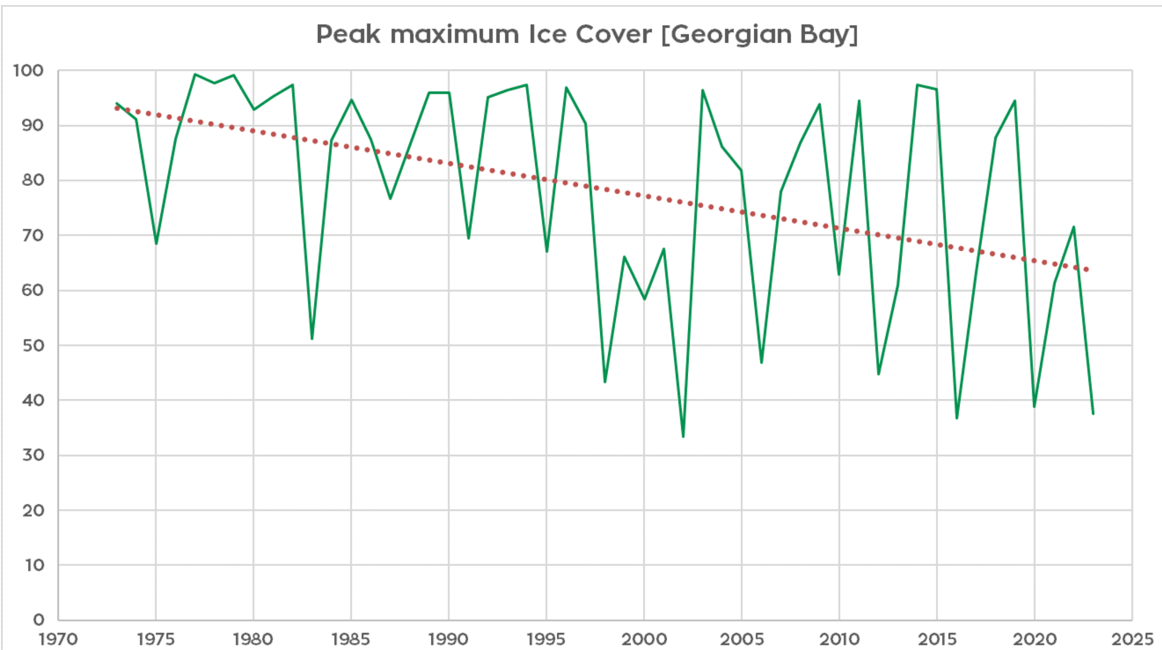

Figure 7. Georgian Bay peak maximum ice cover from 1973 to 2023. Red dashed line represents a statistically significant trend confirmed via a simple linear regression analysis ($R^2 = 0.19$, $F(1, 49) = 11.47$, $p = 0.001$).

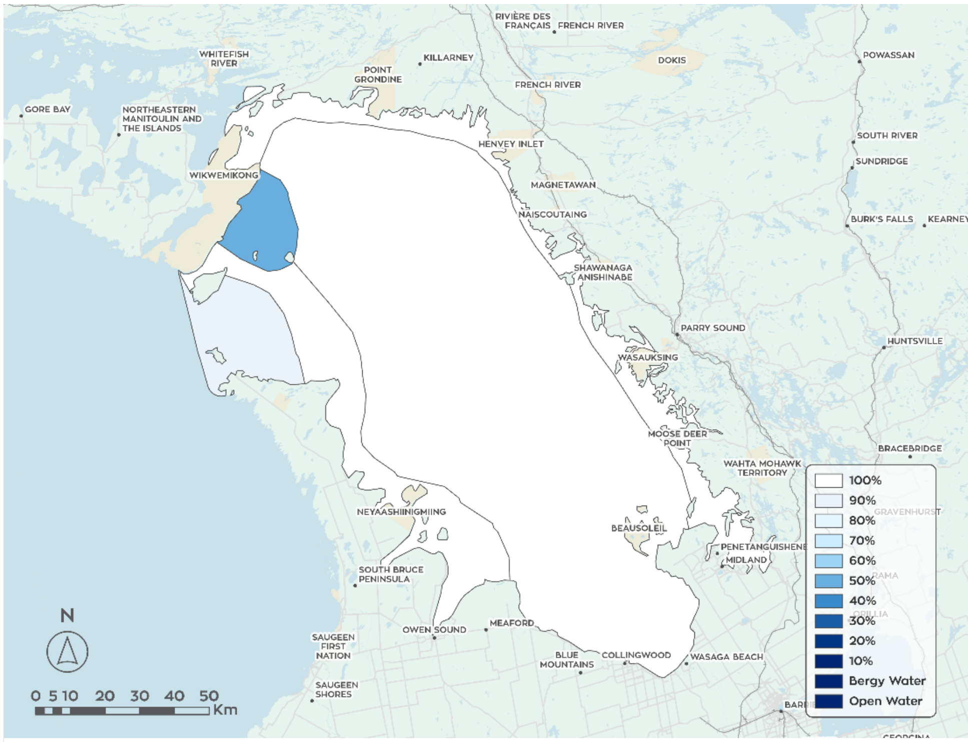

Figure 9. Peak maximum ice cover in Georgian Bay in 1973.

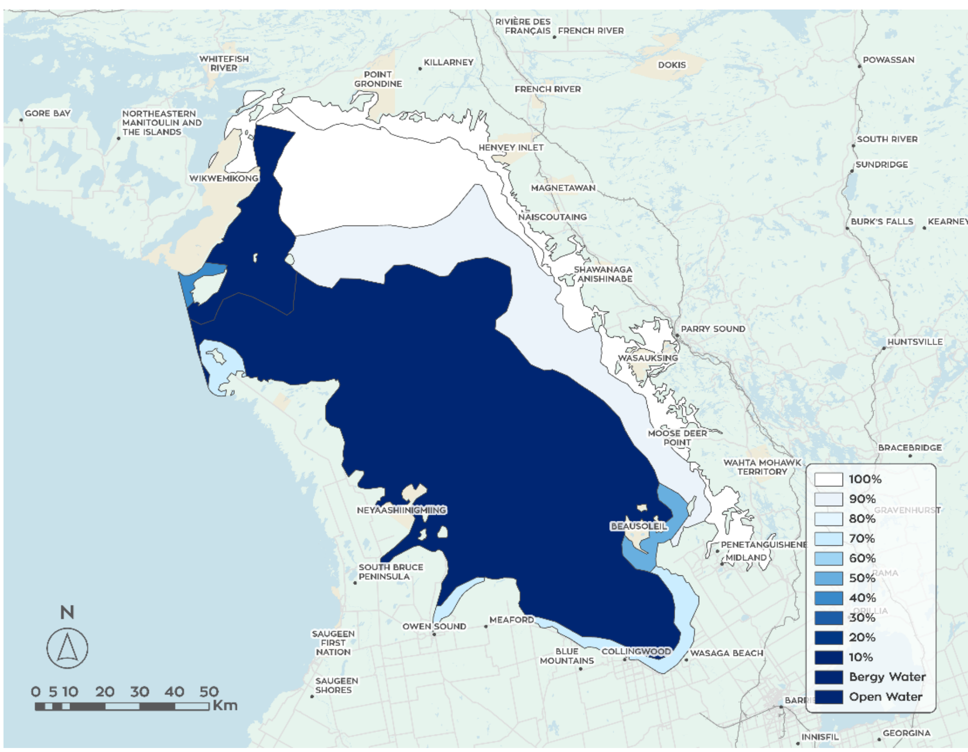

Figure 8. Peak maximum ice cover in Georgian Bay in 2023.

Mason et al. (2016) performed a fine-scale analysis of trends in ice duration and lake summer surface water temperature across the Great Lakes and found significant differences between spatial regions. Their study found that the highest rates of declining ice cover were in the northern parts of the Great Lakes, although rapid declines were also noted in the coastal areas of the eastern shoreline for each lake. Unsurprisingly, Georgian Bay was identified as one of the areas within the Great Lakes experiencing high rates of decreasing ice cover duration (Mason et al., 2016). Baijnath-Rodino et al. (2018) determined that the Lake Huron-Georgian Bay system lost 0.67 days/year of ice cover during the period they studied between 1994-2013. They found that the decline in ice cover occurred during the months of January through March and was attributed to warming lake surface temperature (Baijnath-Rodino et al., 2018).

Murfitt & Brown (2017) note that non-climatic features of a lake can affect the timing of ice on/off dates. Morphological features, like size and depth determine a lake's volume, which directly correlates to the heat storage capacity of that lake and affects when ice forms and melts. As well, hydrological features relating to the inflow of water from other sources can bring additional heat energy or incoming currents to a lake, both of which affect ice on/off dates (Murfitt & Brown, 2017). In eastern Georgian Bay where the abundant islands give the region unique morphological features, primarily a greater extent of shallow, nearshore water, these features undoubtedly affect the timing and duration of ice cover.

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 the SSEA's study as these data are not available at a fine scale. More recent data indicate that while trends remain weak, ice is forming slightly later and going off slightly earlier on many inland lakes and Severn Sound embayments (SSEA, 2023a).

A recent report titled *Climate Change in the Great Lakes Basin: Summary of Trends and Impacts* (Lam & Dokoska, 2022) documents future ice cover projections for each Great Lake. The projections were developed by the Nelson Institute Center for Climatic Research and are available for RCP 8.5. Projections were simulated by six model runs with resolutions of approximately 25 km by 25 km. Both annual average ice cover and length of the ice season between December and May are discussed in the report. The key findings of the ice cover projections are listed below (Lam & Dokoska, 2022, p. 33).

- Ice cover projections indicate significant decreases in future lake ice cover across all lakes, especially in the months of February and March under the high-emissions scenario.
- Projections indicate the potential for more years with little to no ice cover and shorter ice seasons. For deeper lakes such as lakes Superior and Huron, ice growth may also peak earlier (in February instead of March).
- Average ice cover over lakes Superior and Erie show the greatest declines, followed by Lake Huron.
- Lake Michigan is expected to see the greatest decline in the average length of the ice season between December and May, followed by lakes Erie and Ontario.

Projections specific to Lake Huron are presented in Tables 1 and 2. The report also discusses potential consequences of reduced ice cover for the aquatic ecosystem and those living in the Great Lakes basin.

Table 1. Historical and projected average ice cover by ice season (December to May) and season under RCP 8.5, by time period (Table from Lam & Dokoska, 2022). DJF refers to December, January, February. MAM refers to March, April, May.

	Historical and Projected Values Under RCP 8.5 (%)			Difference from Corresponding 1980-1999 Values (%)		
	Ice Season	Winter (DJF)	Spring (MAM)	Ice Season	Winter (DJF)	Spring (MAM)
Historical (1980-1999)	22.3	38.0	17.8	-	-	-
2040-2059	14.3	18.1	10.5	-8%	-9%	-7%
2080-2099	8.4	11.2	5.7	-14%	-16%	-12%

Table 2. Historical and projected ice season length between December and May under RCP 8.5, by time period. The 5th and 95th percentile values highlight the range of possibilities for the length of the ice season, which may vary from year to year (Table from Lam & Dokoska, 2022).

	Historical and Projected Ice Season Length During Winter and Spring Under RCP 8.5 (days)			Difference from Corresponding 1981-1999 Values (days)		
	5th	Average	95th	5th	Average	95th
Historical (1980-1999)	105	131	156	-	-	-
2041-2059	109	118	126	4	-13	-30
2081-2099	65	93	118	-41	-38	-38

3.1.2 Summer Surface Water Temperature

There is a consistent, increasing trend in summer surface water temperature across the Great Lakes basin which is also resulting in warmer winter surface water temperatures (Baijnath-Rodino et al., 2018). Large open areas of water and a lack of ice cover combine to increase the Great Lakes' exposure to solar radiation, warming them and further reducing ice cover during the winter (Baijnath-Rodino et al., 2018).

The *State of the Great Lakes 2022 Report* (ECCC & EPA, 2022b) states that based on data collected at two surface buoys in Lake Huron from 1980-2020, a statistically significant increase in summer surface water temperature is occurring on the order of 0.06 ± 0.02°C per year. Similarly, the *2017-2021 Lake Huron LAMP* (ECCC & EPA, 2018) reports a 2.9°C increase in summer surface water temperatures in Lake Huron between 1968 and 2002. These figures, based on a paper by Dobiesz and Lester (2009), represent an annual increase in surface water temperature of 0.084°C or an increase of 0.84°C per decade.

In Severn Sound, the mean ice-free season (May-October) surface water temperature at five locations increased significantly from 1969-2021 (n=53 years) (Figure 10). Seasonal mean surface water temperature has risen by an average of 2.3°C over the last 53 years, or 0.4°C each decade, with the temperature in early October increasing at double the rate for mean temperature (SSEA, 2023b). Between 1975-2018, annual average air temperature increased by 1.9°C in Midland.

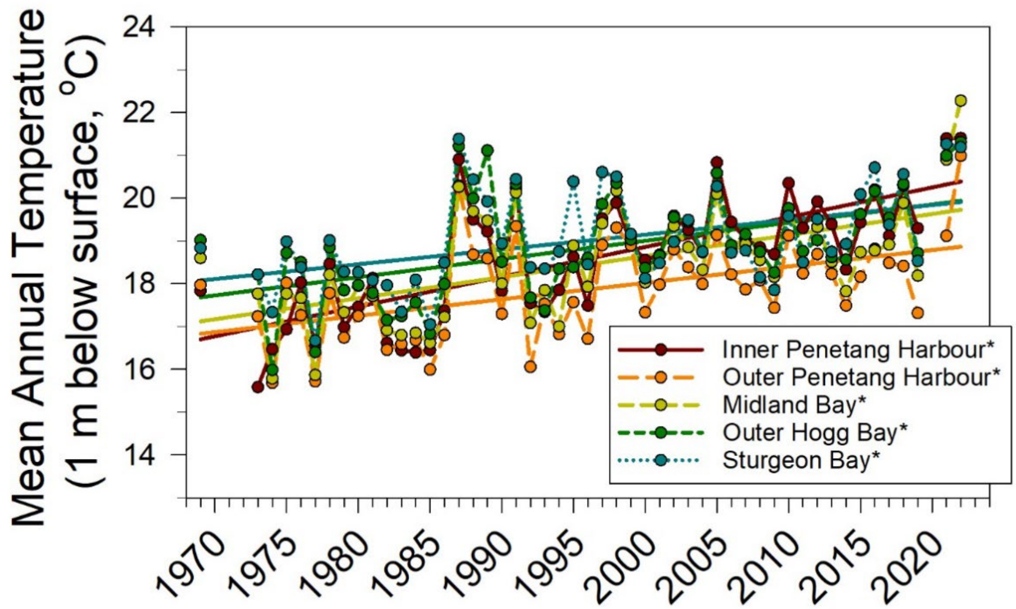

Figure 10. Mean annual summer surface water temperature for the Severn Sound area from 1969-2020. * indicates significant trends over this period (Figure from Chiandet, pers comm, 2023).

Shallow water closer to shore is warming faster than offshore waters (Baijnath-Rodino et al., 2018). This is particularly relevant to eastern Georgian Bay with its large number of islands. Research also shows that upwellings from deep offshore waters can buffer the increases in surface water temperature (Mason et al., 2016) and areas like the Big Sound of Parry Sound are some of the deepest waters in all of Georgian Bay. This deep water is a heat absorbing reservoir with a finite thermal capacity that is being depleted by each such exchange, thereby decreasing habitat for deep coldwater species (Anderson et al. 2021). Such upwellings depend on the strength and direction of wind speed, which is also predicted to be affected by climate change (Mason et al., 2016).

A recent Ministry of Natural Resources and Forestry (MNRF) report looks at the projected effects of climate change on the thermal conditions of inland lakes in Ontario using the representative concentration pathway (RCP) 4.5 and 8.5 emissions scenarios for the 2020s, 2050s, and 2080s (Smith et al., 2021). The report presents results at the provincial scale and by fisheries management zone (FMZ). Like the Great Lakes, surface water temperature in inland lakes is predicted to increase. Smith et al. (2021) state that "by the 2050s, surface temperatures may increase by 3.0 and 4.1°C under the RCP 4.5 and 8.5 scenarios, respectively" (Figure 11). Similarly, the ice-free season is projected to lengthen by 37 and 53 days by the 2050s under the RCP 4.5 and 8.5 scenarios, respectively. These changes will have considerable impacts on fish habitat across the province (see Smith et al., 2021 for details).

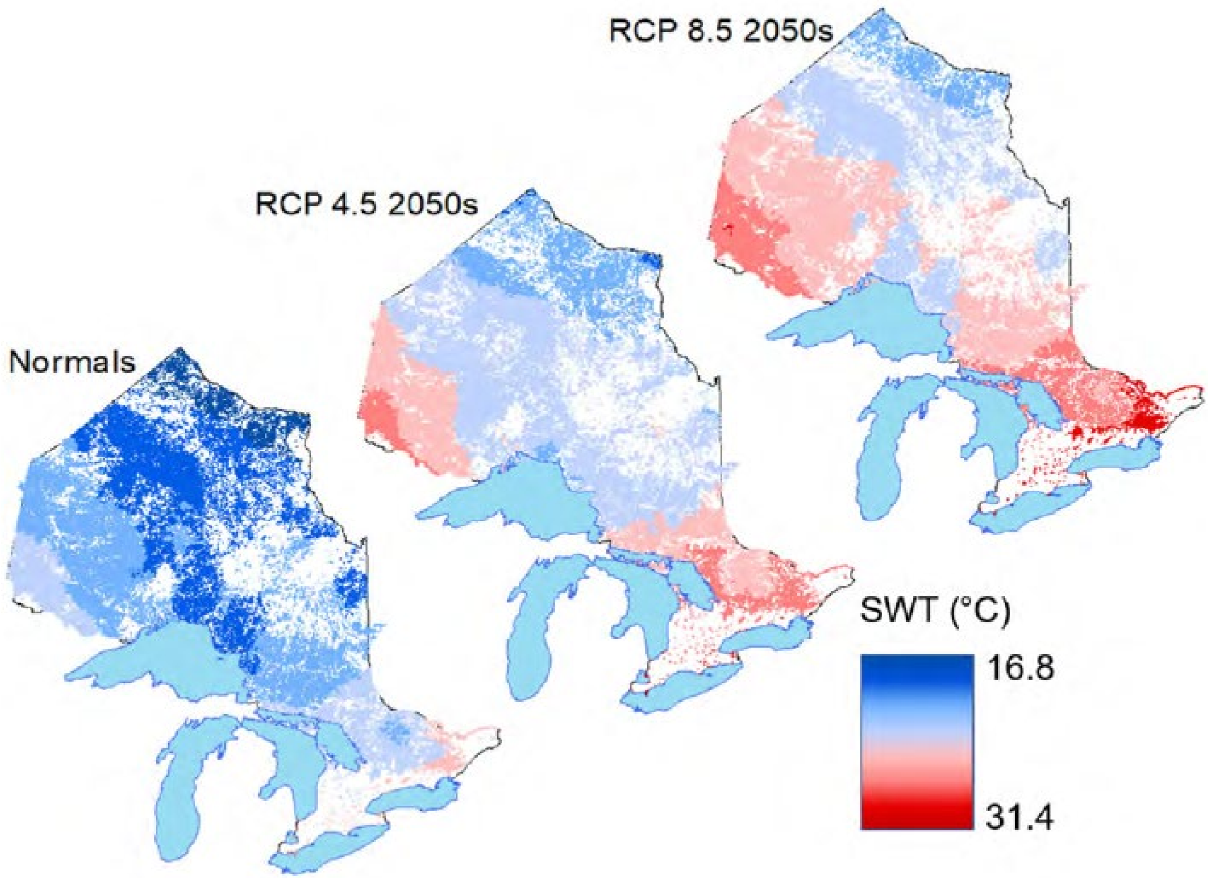

Figure 11. Current (1981–2010 climate normals) and projected changes in maximum surface water temperatures under the 2050s RCP 4.5 and 8.5 emissions scenarios for lakes (5–250,000 ha) in Ontario (Figure from Smith et al., 2021).

Although this chapter deals with summer surface water temperature, as noted above, subsurface water temperatures in parts of the Great Lakes have been shown to be increasing as well. In a recently published paper, Anderson et al. (2021) present the results of three decades of high frequency subsurface water temperature data from Lake Michigan. The researchers found that deep water temperatures are increasing in the winter, on average by around 0.6°C per decade. The potential effects of this warming are numerous and interconnected. Data of this type have not been collected in Georgian Bay which represents a knowledge gap.

3.2 CONNECTING GUARDIANS IN A CHANGING WORLD

A total of 37 participants from 12 Anishinaabek communities in the upper Great Lakes region (Figure 12) of the Robinson-Huron Treaty Area took part in the two-day “Connecting Guardians in a Changing World” workshop in 2019 (Menzies et al., 2022). Through a series of facilitated sharing circles, Elders, Knowledge Holders, youth, and environmental professionals discussed three major themes: the greatest climate change concerns related to the environment; the greatest climate change concerns related to community and ways of life; and climate change research priorities and future directions (Menzies et al., 2022). Table 3 summarizes the top concerns/priorities brought up during the sharing circles and the number of votes each received during a dot-voting exercise. For each theme, participants had one vote to assign to the concern/priority they perceive as the most important.

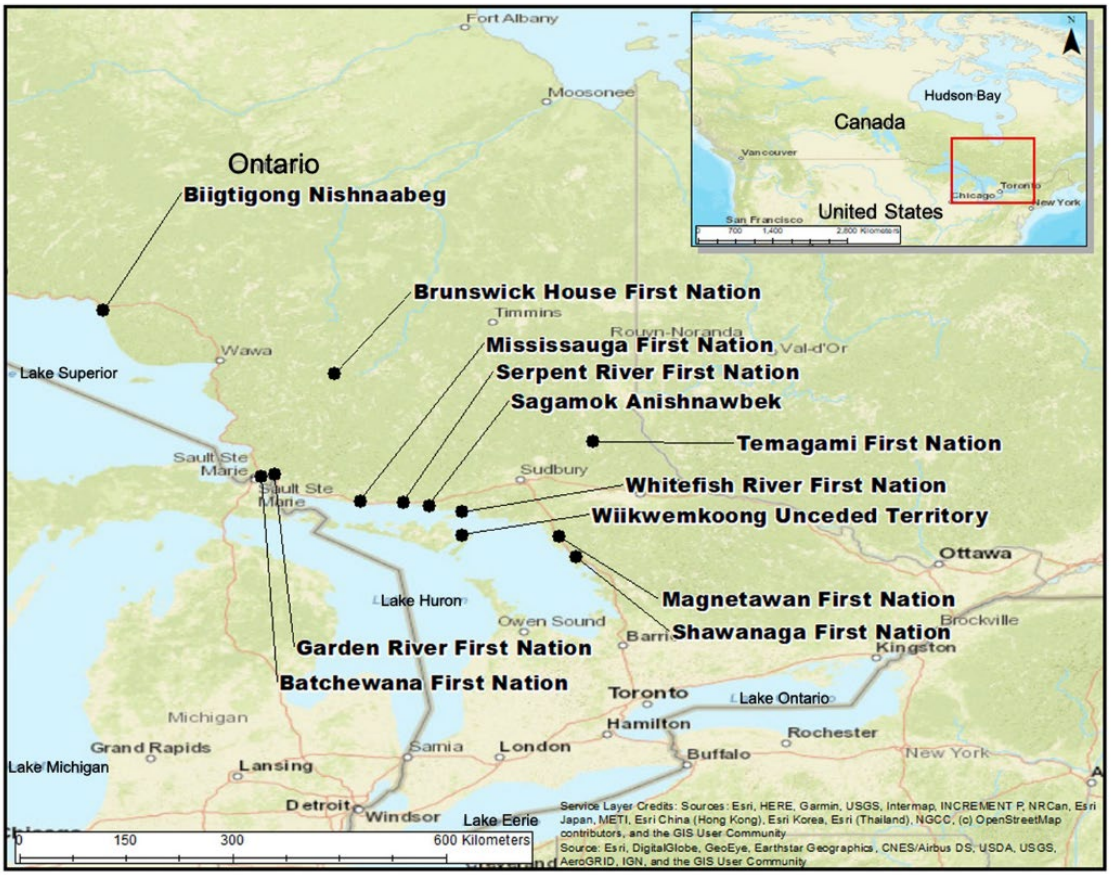

Figure 12. Locations of the 12 Anishinaabek communities who participated in the "Guardians in a Changing World" workshop (Figure from Menzies et al., 2022).

Table 3. Top concerns/priorities discussed during sharing circles and number of votes received during dot-voting exercise (Table from Menzies et al., 2022).

Concern or Priority	Number of Votes
Greatest concern for the environment	
Animal and plant life cycles are changing	9
Water cycle and quality are changing	8
Biodiversity is shifting	4
Disease and parasites	2
Animal and plant distributions are changing	1
Greatest concern for community and ways of life	
Traditional and spiritual practices	13
Understanding the land is becoming more difficult and unpredictable	9
We need to identify where to allocate resources	2
Decreased opportunities to harvest wildlife and medicines	0
Limited capacity of communities to address climate change	0
Future research priorities	
Research and policies that weave Indigenous and Western knowledge	9
Baseline animal and plant inventory and long-term monitoring	6
More holistic, ecosystem-level approaches	6
Risk assessment for communities	1
Water quality and quantity	1

Not only are biophysical changes in the environment already being experienced by communities as a result of climate change, they are subsequently affecting traditional livelihoods, with further impacts on physical, cultural, and emotional well-being. Participants expressed that they are finding it difficult to separate concerns related to the environment from those related to community and traditional ways of life, pointing to the interconnections between the two. As summarized by Menzies et al. (2022, p. 517), "These discussions further reinforce the vulnerability of Indigenous Peoples to climate change due to the strong connection between environmental well-being and ways of life which, ultimately, affect physical health, cultural integrity, and emotional well-being".

4. DATA GAPS AND RESEARCH NEEDS

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 subsurface) and river flow, and climate variables like wind. In 2021, two real-time weather stations were set up in the Severn Sound area to begin addressing these gaps in coverage for meteorological data, including air temperature, precipitation, and wind speed and direction.

The prescribed goal under Annex 9 of the 2012 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 5; 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 National Data Buoy Centre 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.

In future *State of the Bay* reporting it may be beneficial to tap in to alternate sources of data for wind and river flow such as hydrometric data in the HYDAT database collected by the Water Survey of Canada and wind data from regional climate stations of the adjusted and homogenized Canadian climate data provided by ECCC. However, analysis of the data is still required.

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. In addition, investing in tracking and reporting on subsurface water temperatures in Georgian Bay as done by NOAA GLERL in Lake Michigan may provide greater insight into how climate change is impacting the region. This would require the implementation of a monitoring program similar to that employed in Lake Michigan which uses a thermistor string to record temperatures at different depths over decades (NOAA, 2021a).

Additional data gaps and research needs associated with climate change are found throughout the other chapters of this report.

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TOTAL PHOSPHORUS

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1. INTRODUCTION

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

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 (TP) is a measure of all these forms of phosphorus combined – organic and inorganic, dissolved, and particulate.

TP is also an indirect indicator of recreational water quality, as changes in TP affect 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 in the Great Lakes basin (IJC, 2021).

Maintaining the right balance of nutrients for a particular system is a significant challenge (ECCC & EPA, 2022a). TP levels that are too low result in negative effects on the productivity of the lower food web, and from there, prey fish and top predators. TP levels that are too high can lead to elevated levels of benthic macro-algae (e.g., *Cladophora*, *Chara*, periphyton) and potentially harmful algal blooms (ECCC & EPA, 2022a; 2022b), decreased oxygen concentrations in bottom waters (eutrophication), and loss of optimal habitat for cold water stenotherms like lake trout (*Salvelinus namaycush*) and whitefish (*Coregonus clupeaformis*).

Based on data collected by Environment and Climate Change Canada (ECCC) and the U.S. Environmental Protection Agency (EPA), long-term trends show significant TP declines in the offshore waters of Lake Huron, with the most dramatic declines observed since the mid- to late-1990s (ECCC & EPA, 2022b). While the factors responsible for this decline are not entirely understood, a combination of long-term reductions in TP loadings following the implementation of the Great Lakes Water Quality Agreement (GLWQA) and dreissenid-driven changes in nutrient cycling are believed to have played a significant role (Hecky & DePinto, 2020; Rudstam et al., 2020). The impacts of this falling productivity are still being studied, but are already evident in changes to the lower food web and prey fish populations (Rudstam et al., 2020).

More recently, offshore TP concentrations leveled out between 2010 and 2016 at concentrations well below the GLWQA objective of 5 µg/L (Hecky & DePinto, 2020). Current offshore TP concentrations may be too low to support healthy lake productivity based on the historic food web and nutrient conditions (Rudstam et al., 2020). The trophic status of offshore Lake Huron and Georgian Bay is now described as ultra-oligotrophic (ECCC & EPA, 2022a; 2022b; Hecky & DePinto, 2020).

In contrast to the offshore waters of Georgian Bay, nearshore waters along the coast of eastern Georgian Bay have not experienced the same dramatic loss of nutrients. In fact, some nearshore areas and embayments have the opposite problem of elevated nutrients contributing to nuisance algal conditions (ECCC & EPA, 2022a; 2022b). In select nearshore areas, excess nutrient pollution can potentially lead to harmful algal blooms (HABs) (ECCC & EPA, 2022a; 2022b). Unlike the relatively homogenous offshore waters, there is greater variability in nearshore conditions which are more directly impacted by coastal anthropogenic and natural influences from adjacent watersheds (Hecky & DePinto, 2020; Howell, 2023).

The result of this dichotomy between the low nutrient offshore waters and more productive nearshore waters is an offshore-nearshore TP gradient, as described in detail by Howell (2023).

The remainder of this chapter describes how TP is studied in eastern Georgian Bay, TP trends for the offshore and nearshore waters, and finally, data gaps and research needs related to TP.

2. HOW IS TOTAL PHOSPHORUS STUDIED IN EASTERN GEORGIAN BAY?

Long-term water sampling for average TP concentration is done via several different programs in eastern Georgian Bay (including inland lakes and nearshore and offshore sites), typically as part of a broader water quality monitoring program (Table 1). These programs are conducted by all levels of government, First Nations, non-governmental organizations (NGOs), and citizen scientists using various standard and accepted protocols. The scope of these monitoring programs differs in terms of scale, objectives, parameters, and monitoring frequency.

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. Offshore surveys are, therefore, undertaken only by federal or provincial agencies using research vessels outfitted with specialized sampling equipment. Surveys often occur several years apart due to the need to survey 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 and inland lakes that large boats cannot access.

Table 1. Summary of long-term total phosphorus sampling in eastern Georgian Bay. Please note, TP sampling is only one part of these sampling programs, more information about these programs can be found in GBB's Summary of Water Quality Monitoring Programs Along Eastern Georgian Bay.

Agency/Organization	Program Name	Sampling Stations	Sampling Frequency
Environment and Climate Change Canada	Great Lakes Surveillance Program	26 stations throughout Georgian Bay, primarily offshore open waters	Roughly every two years (spring, summer, fall)
Ministry of Environment, Conservation and Parks	Great Lakes Nearshore Index Station Network	8 stations along eastern Georgian Bay	6-year cycle (2022 most recent sampling)
Ministry of Environment, Conservation and Parks	Great Lakes Nearshore Assessment	135 stations along eastern Georgian Bay	Roughly every 10 years (2003-2005 most recent sampling)
Ministry of Environment, Conservation and Parks	Lake Partner Program (citizen science program)	Varies based on volunteer involvement, stations in open water, embayments, and inland lakes	Typically once per year in the spring for lakes on the Canadian Shield
Severn Sound Environmental Association	Open Water Monitoring Program	11 stations in Severn Sound open water, 3 in Honey Harbour	Biweekly during ice free season (May-October)
District Municipality of Muskoka	Lake System Health Program	193 stations on 164 lakes (includes some embayments of eastern Georgian Bay)	During ice free season (May-October), lakes sampled on rotational basis

3. WHAT ARE THE RESULTS?

The 2013 *State of the Bay* report featured 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 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 2013 *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 showed that offshore phosphorus concentrations had decreased to values 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 TP is potentially too low to sustain the productive aquatic ecosystems of the past. Instead, the 2018 *State of the Bay,* and now the 2023 *State of the Bay,* report on TP trend.

Results are reported first at the Lake Huron and Georgian Bay scale, specifically looking at the offshore, open waters. Next, results for the nearshore of eastern Georgian Bay are discussed, followed by a brief discussion of broad trends for inland lakes.

3.1 LAKE HURON AND GEORGIAN BAY (OFFSHORE)

The *State of the Great Lakes 2022 Technical Report* (ECCC & EPA, 2022b) lists the status for nutrients in Lake Huron as 'fair' with an 'unchanging' 10-year trend and 'deteriorating' long-term trend (1970-2019). The rationale given for this trend is that offshore phosphorus concentrations have declined significantly to values that are well below the GLWQA target of 5 µg/L, and there is no indication of a recovery (ECCC & EPA, 2022b; Figure 1).

TP concentrations in the offshore waters of Georgian Bay are also presently very low (T. Howell, pers. comm., 2017). Recent offshore concentrations are the lowest on record and below the target set to maintain an oligotrophic state (Dove & Chapra, 2015). 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) (Hecky & DePinto, 2020; ECCC & EPA, 2022a; 2002b; Rudstam et al., 2020).

Offshore TP concentrations leveled out between 2010 and 2016 (Hecky & DePinto, 2020; Rudstam et al., 2020), suggesting the lake may be approaching a, "steady state with regard to TP concentrations and external and internal P loadings, mussel populations and their effect, along with other recent drivers of algal productivity change." (Hecky & DePinto, 2020, p. 36).

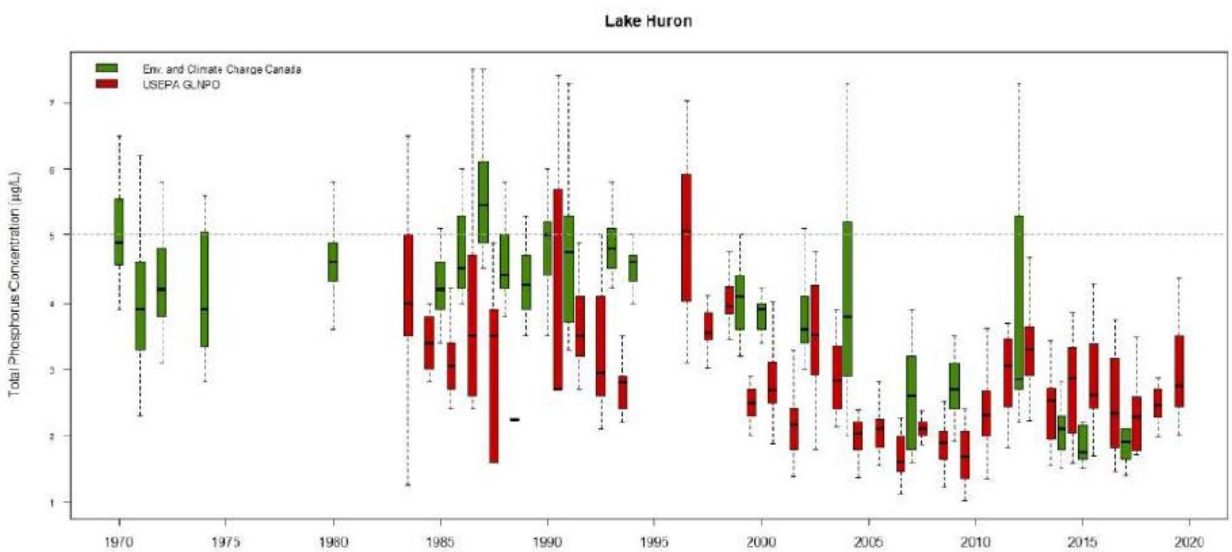

Figure 1. U.S. and Canadian long-term record of offshore, spring (April - May) TP (µg/L) in Lake Huron. Horizontal dashed line represents the interim GLWQA TP objective of 5 µg/L. Boxes show the median values and interquartile range. Georgian Bay data are not shown but the temporal trends closely match those in Lake Huron (Figure from ECCC & EPA, 2022b).

It is not fully understood what caused the decline in phosphorous and productivity in Lake Huron since 1990, but there are likely several contributing factors (Bunnell et al., 2014; Hecky and DePinto, 2020; Howell, 2023; Rudstam et al., 2020).

To a certain extent, the long-term decline in spring TP was expected based on declines in phosphorus loading following the implementation of the GLWQA (Chapra & Dolan, 2012; Hecky & DePinto, 2020; Howell, 2023;

Rudstam et al., 2020). Between the 1970s and 1990s, management actions led to a reduction in phosphorus inputs from wastewater treatment plants and other point sources. This resulted in significantly reduced concentrations of phosphorus in the nearshore (ECCC & EPA, 2022a). However, the rate of phosphorus decline was faster than what would have been expected from reduced phosphorus loading alone (Hecky & DePinto, 2020; Rudstam et al., 2020).

The invasion of dreissenid mussels is believed to be an additional contributing factor (Barbiero et al., 2018; Howell, 2023). Dreissenid mussels have an immense capacity to filter nutrients and particulate matter from the water. They sequester large amounts of phosphorus in their tissues, removing it from the water column (ECCC & EPA, 2022a; Hecky & DePinto, 2020; Rudstam et al., 2020). The initial invasion of zebra mussels (*Dreissena polymorpha*) in shallow waters resulted in nutrients being intercepted and trapped in the nearshore, increasing nearshore benthic productivity and decreasing pelagic primary productivity (Hecky & DePinto, 2020; Rudstam et al., 2020). As described by Rudstam et al. (2020, pp. 34-35), zebra mussels had "large initial ecosystem effects in shallow water… but have declined in abundance and are no longer a major component of the benthic fauna of Lake Huron".

Quagga mussels (*Dreissena bugensis*) took the place of zebra mussels and have continued to expand into depths not previously occupied by zebra mussels (Figure 2). However, quagga mussel abundance in the 0-30m depth and 31-50m depth zones declined in Lake Huron after 2009 (Rudstam et al., 2020). At present, quagga mussel abundance is much higher in the deep, cold, offshore waters of the lake (ECCC & EPA, 2022b). It is believed that quagga mussel filter feeding activity in these waters is responsible for removing nutrients/plankton from the water that historically drove the spring phytoplankton bloom (ECCC & EPA, 2022a). In the summer, however, mussels below the thermocline do not have access to epilimnetic production and therefore cannot have considerable direct effects on summer phytoplankton and zooplankton (Rudstam et al., 2020). For this reason, and the fact that mussels in deeper, colder water grow more slowly and filter at lower rates, quagga mussels in deep water are considered to have less effect on the ecosystem than mussels in shallow water (Rudstam et al., 2020). Accordingly, Rudstam et al. (2020) explain that the impact on the ecosystem of an increase in quagga mussels in deep water is less than that of an increase of dreissenid mussels in shallower water. Barbiero et al (2018) summarize this by stating that nearshore mussels are more important than overall mussel abundance in affecting the lower trophic level changes that have been seen over the last two decades in Lakes Huron and Michigan.

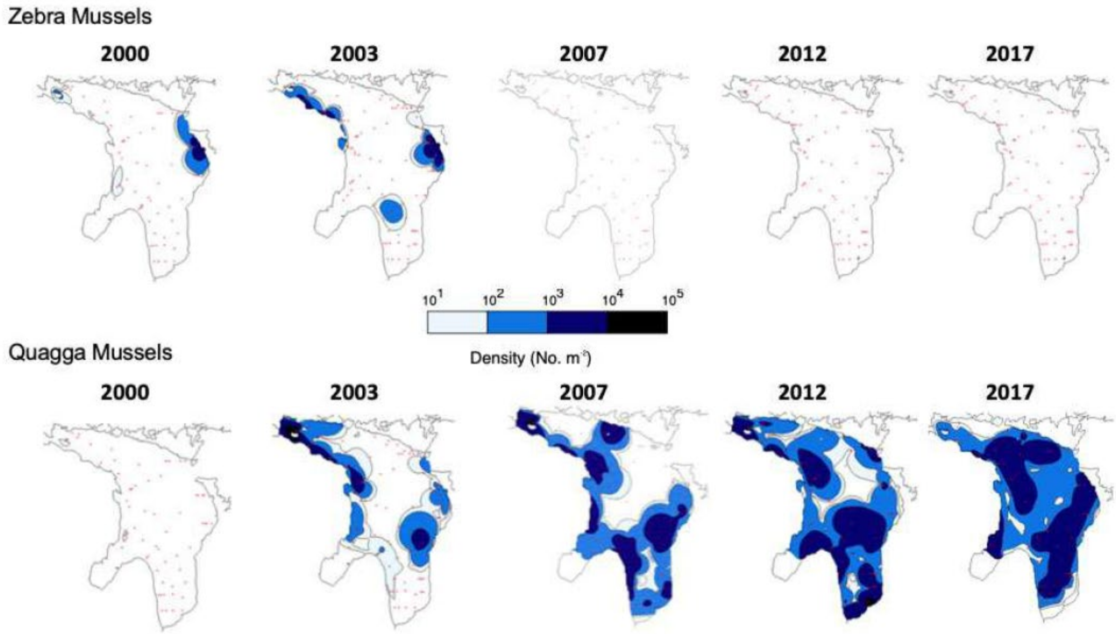

Figure 2. Densities (number per square metre) of zebra and quagga mussels in Lake Huron from 2000-2017 (Figure from ECCC & EPA, 2022). While not shown in this figure, similar trends were experienced in Georgian Bay.

Current TP concentrations in many offshore areas of Lake Huron are less than 50% of those measured several decades ago, and are below the target set to maintain an oligotrophic state (Dove & Chapra, 2015). The trophic status of offshore Lake Huron waters is now described as ultra-oligotrophic and, as would be expected, along with falling TP concentrations, spring Secchi depth has increased since the mid-1990s. Rudstam et al. (2020) report that water clarity was higher in the 2011-2017 period than in any previous period on record.

There are concerns that TP concentrations may now be too low to support a healthy level of lake productivity based on the historic food web and nutrient conditions (ECCC & EPA, 2022a; 2022b; Hecky & DePinto, 2020; Rudstam et al., 2020). While further investigation of these changes is needed (ECCC & EPA, 2022a), evidence of falling productivity is already apparent in the lower food web (Rudstam et al., 2020) and fish production is likely limited as well, even for oligotrophic species (Hecky & DePinto, 2020). More details on these changes are presented in the Aquatic Ecosystem Health chapter of this report.

The 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 (Annex 4 of the 2012 GLWQA). 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 have decreased to values that are well below levels required to support a healthy level of lake productivity.

3.2 EASTERN GEORGIAN BAY (NEARSHORE)

The dramatic decline in TP concentrations experienced in the offshore waters of Georgian Bay has not been echoed in the nearshore waters of eastern Georgian Bay. Unlike the offshore waters, trophic conditions in most of eastern Georgian Bay have not changed since 1990 (Howell, 2023). TP concentrations in most areas along eastern Georgian Bay are generally below the Provincial Water Quality Objective (PWQO) of 20 µg/L (Figure 3). Additional guidelines offered by the Ministry of Environment, Conservation and Parks (MECP) 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 and hard to distinguish from natural variability (Howell, 2023).

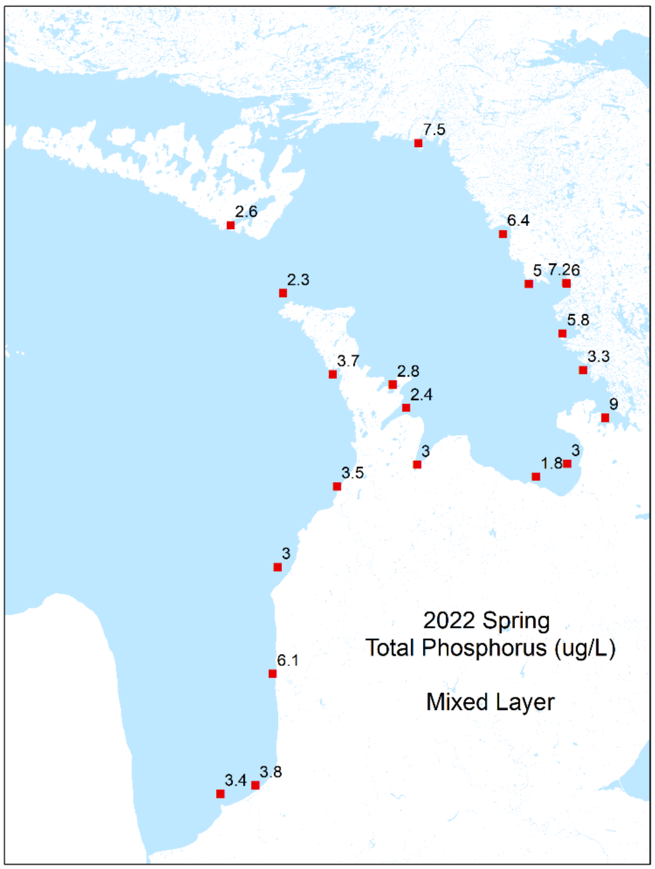

Figure 3. Spring 2022 total phosphorus (µg/L) concentrations sampled at Great Lakes Nearshore Index Station Network sites by the Ministry of Environment, Conservation and Parks (Figure from T. Howell, pers. comm., 2023).

Embayments of large oligotrophic lakes are typically more productive than exposed nearshore areas, and especially the offshore waters (Howell, 2023). Embayments receive nutrients from the watershed and have varying degrees of water exchange with the nutrient-poor offshore waters, limiting dilution. Furthermore, embayments are less exposed to wind and waves and therefore experience greater particle settling, which Howell (2023) explains contributes to higher productivity by enabling internal cycling of phosphorus. In addition, the water entering the nearshore of eastern Georgian Bay off the Canadian Shield is low in calcium, offering some protection from dreissenid mussels that require a certain level of calcium in the water for successful invasion (Girihagama et al., 2022). The combination of these factors has allowed trophic status in the nearshore of eastern Georgian Bay to remain fairly stable while productivity in the offshore waters declined dramatically (Howell, 2023).

While the open, offshore waters of Georgian Bay are generally considered one large water mass with minimal spatial variability in TP concentrations (Moll et al., 1985), the complexity of the eastern Georgian Bay shoreline (i.e., numerous islands and embayments) results in less exchange between offshore and nearshore waters and greater watershed influence (Girihagama et al., 2022; Howell, 2023). Girihagama et al. (2022) refer to an estuarine-like mixing model for the coastal band of eastern Georgian Bay. Spatial and temporal gradients of water quality among embayments along the coast are the result of the varying degree of water exchange that different embayments have with Georgian Bay, as well as differences in volume of watershed discharge (Figure 4) (Girihagama et al., 2022; Howell, 2023).

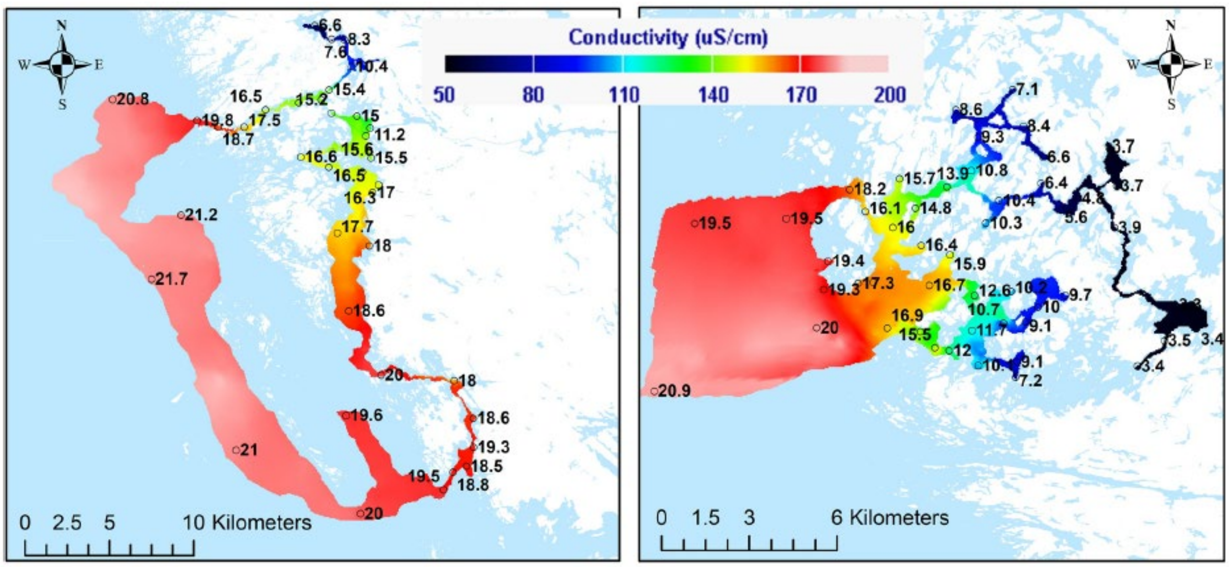

Figure 4. Spatial distribution of specific conductivity in Shawanaga River region (left) for June 16-17, 2015 and Moon River region (right) for June 21-23, 2015. The numbers denote the calcium concentration (mg/L) measured periodically along the survey route (Figure from Girihagama et al., 2022).

Some nearshore areas and embayments experience, or have historically experienced, elevated nutrient levels leading to nuisance and/or harmful algal blooms (e.g., Sturgeon Bay, Deep Bay, French River, Severn Sound – Figure 5). In areas of Lake Huron where there is excess nutrient pollution, high levels of benthic macro-algae (e.g., *Cladophora*, *Chara*, periphyton) are being seen along with the potential for HABs (ECCC & EPA, 2022a; 2022b). At this time, "*Cladophora* is not found at macroscopically visible levels in the nearshore of eastern Georgian Bay nor has it been reported to foul shorelines in Georgian Bay except in enclosed harbours" (ECCC & EPA, 2022b, p. 547). Dreissenid mussels are believed to play an important role in the presence of *Cladophora* because their filter feeding activity improves water clarity and makes dissolved phosphorus more available in the areas where *Cladophora* grows (Dayton et al., 2014; Martin, 2010; Ozersky et al., 2009; Stefanoff et al., 2018). As previously stated, the low-calcium water entering the nearshore of eastern Georgian Bay from the watershed may be hindering dreissenid mussel proliferation (Girihagam et al., 2022) and in turn, limiting the growth of *Cladophora.* Similarly, the water entering the Bay from the watershed is highly coloured which reduces light penetration through the water column, also limiting *Cladophora* growth (T. Howell, pers. comm., 2022).

Although nuisance and harmful algal blooms are generally not considered a serious concern at this time in eastern Georgian Bay, climate change may increase their rate of occurrence and severity (Hecky & DePinto, 2020). Increasing water temperatures may be enhancing plankton and algal growth rates (ECCC & EPA, 2022a; 2022b) and could increase abundance of bloom-forming cyanobacteria (Hecky & DePinto, 2020). More extreme precipitation events may result in large inputs of nutrient-rich waters from stormwater runoff and soil erosion, potentially fueling nearshore blooms (ECCC & EPA, 2022a; 2022b). In addition, lake level fluctuations and high wind and waves can cause erosion and disturb sediments, potentially releasing stored nutrients (ECCC, 2022; ECCC & EPA, 2022a). The impacts of climate change on nutrient pollution continue to be studied (ECCC & EPA, 2022b).

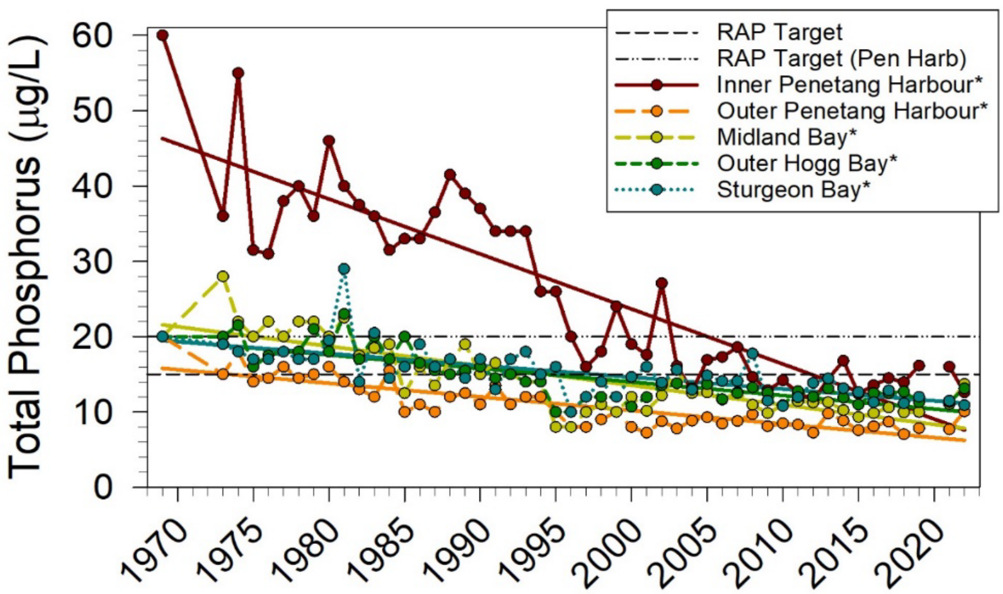

Figure 5. Total phosphorus concentrations have decreased below the Severn Sound Regional Action Plan (RAP) target of 15 µg/L for Severn Sound overall and 20 µg/L for Penetanguishene Harbour. Reduced phosphorus loads due to remedial actions have played an important role in reducing nutrient algae growth and restoring the water quality of Severn Sound (Figure from SSEA, 2023). * indicates a statistically significant increasing or decreasing trend in annual median.

3.3 INLAND LAKES

While not the focus of this report, there is some evidence that phosphorus concentrations in inland lakes have decreased (oligotrophication) in recent years for reasons other than those attributed to reduced anthropogenic loads (Clark et al., 2010). Long-term studies at the Dorset Environmental Science Centre 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). Spring TP concentrations began to decline around 1990, abruptly declined around 2000, and are continuing this trend.

4. DATA GAPS AND RESEARCH NEEDS

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.

Additional data gaps and research needs are listed below.

- Improve understanding of nutrients (sources, sinks, pathways, and loadings) and nutrient-related issues (nuisance and harmful algal blooms) in the nearshore and offshore.
- Improve understanding of physical and biological processes that move nutrients/energy horizontally (between nearshore and offshore) and vertically (between benthic and pelagic zones), with consideration of the influence of invasive species (e.g., mussels, round gobies) and nearshore algal growth (e.g., *Cladophora* and other filamentous green algae, cyanobacteria, *Chara*, periphyton).
- Examine possible effects of high water levels on nutrient-phosphorus loading to the Bay and impacts on shoreline water quality in high fetch regions of shoreline due to erosion and other shoreline disruptions (e.g., impacts on septic systems).
- Tributary discharge data reflective of runoff to the Bay is needed for a representative suite of tributaries along eastern and northern Georgian Bay to support the analysis of nutrient loading and climate-related hydrologic changes affecting water quality. Investments should be made to reactivate gauging stations which have historical data, and install additional stations based on a needs assessment.
- Explore the causal relationships accounting for patterns of variability in phosphorus and water quality (tributary loading, exposure, circulation and flushing, thermal regime, anthropogenic development, invasive species).
- Consider deploying buoys with high frequency sensor arrays (temperature, oxygen, algae pigments (chlorophyll *a*, phycocyanin) photosynthetically active radiation, turbidity, conductivity, etc.) in different embayments on a rotating basis to obtain detailed information on lake processes.
- Monitor changes to nearshore nutrients following the Parry Sound 33 forest fire.
- Determine nutrient conditions and dynamics 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.
- For future monitoring of algal blooms along eastern Georgian Bay, consider partnering with ECCC to use satellite images to track the intensity and duration of blooms in order to provide a more comprehensive overview of bloom dynamics and a chance to link these to external (especially climate) drivers.
- Explore phosphorus speciation in Georgian Bay (SRP versus TP, inorganic versus organic TP). Determine how soluble reactive phosphorus (SRP) changes in different watersheds. McMaster University and the University of Toronto have existing datasets to begin an analysis of this kind.

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AQUATIC ECOSYSTEM HEALTH

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1. INTRODUCTION

Georgian Bay, and the Great Lakes more broadly, have undergone significant changes over the past century. Over-harvest of fish, point source and non-point source pollution, continued introduction of invasive species, deforestation in the watershed as well as other landscape use changes, urban development, and more recent pressures of climate change are some 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, organizations, and communities have been monitoring aquatic populations and communities over time in order to identify trends, inform management decisions, and highlight future research needs.

Seven indicators were carefully selected for the 2018 *State of the Bay* report to capture aquatic ecosystem health in eastern Georgian Bay:

- lower food web (phytoplankton, zooplankton, benthic invertebrates);
- prey fish;
- smallmouth bass (*noosa owesi, Micropterus dolomieu*);
- northern pike (*gnoozhe, Esox Lucius*);
- muskellunge (*maashkinoozhe, Esox masquinongy*);
- walleye (*ogaa, Sander vitreus*); and
- lake trout (*nmegos, Salvelinus namaycush*).

Indicators were selected based on their ability to shed light on different aspects of the aquatic ecosystem. These same indicators are used again for the 2023 *State of the Bay* repoECCCrt.

The following sections of this chapter describe the seven indicators in terms of why they are important, how they are monitored, 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 (EC & EPA, 2014):

- '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.

Finally, the chapter ends with a summary of data gaps and research needs.

2. LOWER FOOD WEB

2.1 INTRODUCTION

The lower food web, described in this report as consisting of phytoplankton, zooplankton, and benthic invertebrates, forms the foundation of a healthy food web (Figure 1; please note that aquatic plants are not covered in this report). 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 new food resource pressures due to non-native consumers. Similarly, zooplankton health can indicate changes in the flow of food resources in a food web due to changes in vertebrate or invertebrate predation. 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. These are just some examples of trophic interactions, and it is important to recognize that there are interactions both bottom-up, governed by growth limiting nutrients, and top-down, reflecting predation of one organism type by another.

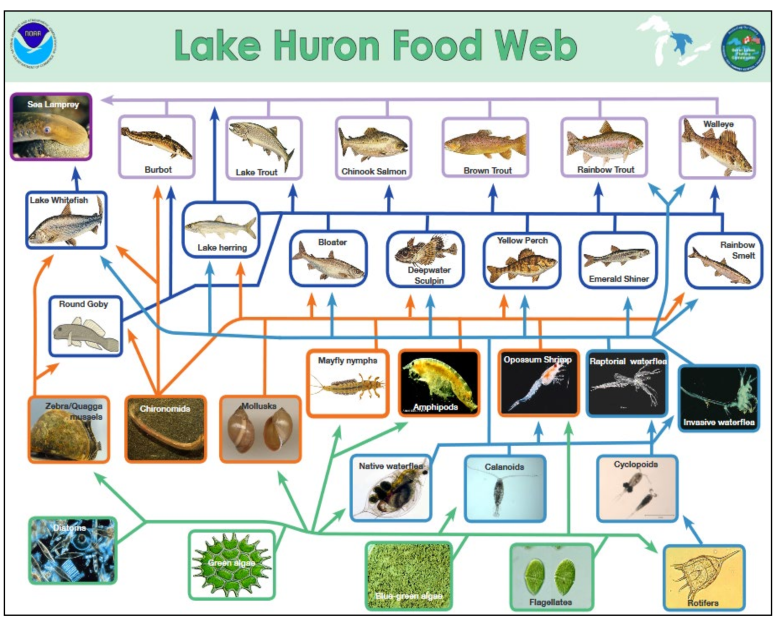

Figure 1. Lake Huron food web including phytoplankton (green outline), zooplankton (light blue outline, benthic invertebrates (orange outline), prey fish (dark blue outline), and top predators (light purple outline) (Figure from NOAA Great Lakes Environmental Research Laboratory, 2009).

Significant changes to the lower food web have been documented in Lake Huron in recent decades. 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 changes have prompted further research. In fact, the lower food web is a recurring topic of discussion in the *Lake Huron Lakewide Action and Management Plan* (LAMP) (ECCC & EPA, 2018; 2022a) and a focus of recent Lake Huron Cooperative Science and Monitoring Initiative (CSMI) efforts by Canadian and U.S. agencies.

2.2 HOW IS THE LOWER FOOD WEB STUDIED IN EASTERN GEORGIAN BAY?

Several agencies and organizations are involved in monitoring the lower food web, or components of it, on a regular basis and over the long-term (Table 1). Others have undertaken short-term studies to answer specific research questions or fill particular knowledge voids. Much of this research happens at the Lake Huron and/or Georgian Bay scale, with less focus on eastern Georgian Bay specifically.

Table 1. 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 (primary production) - Benthos - Larval fish - Invasive species - Climate change impacts
	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
	ECCC	Canadian waters of the Great Lakes including Lake Huron (main basin, Georgian Bay, and North Channel)	Great Lakes Surveillance Program - Chlorophyll *a* - Nutrients
Provincial	MECP	Eastern Georgian Bay (Shawanaga Inlet, outer Parry Sound, Moon Island, Go Home Bay, Severn Sound/Honey Harbour)	Diver-based Benthic Surveys (2014-2016; nonrecurrent) - Dreissenid mussel and macroalgae density and species - Round goby assessment - Ponar grab of soft substrate
	MECP	Canadian waters (nearshore) 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 - Benthic Invertebrates
Regional	SSEA	Severn Sound open water (stations in Severn Sound and Honey Harbour)	Open Water Monitoring Program - Water chemistry and physical parameters - Phytoplankton - Zooplankton

2.2.1 Great Lakes National Program Office Biology Monitoring Program

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 2). These data are utilized in *State of the Great Lakes* reports as well as LAMPs. At this time no regular GLNPO stations are located in eastern Georgian Bay and thus the data used from this program may not reflect the unique conditions of Georgian Bay's coastline.

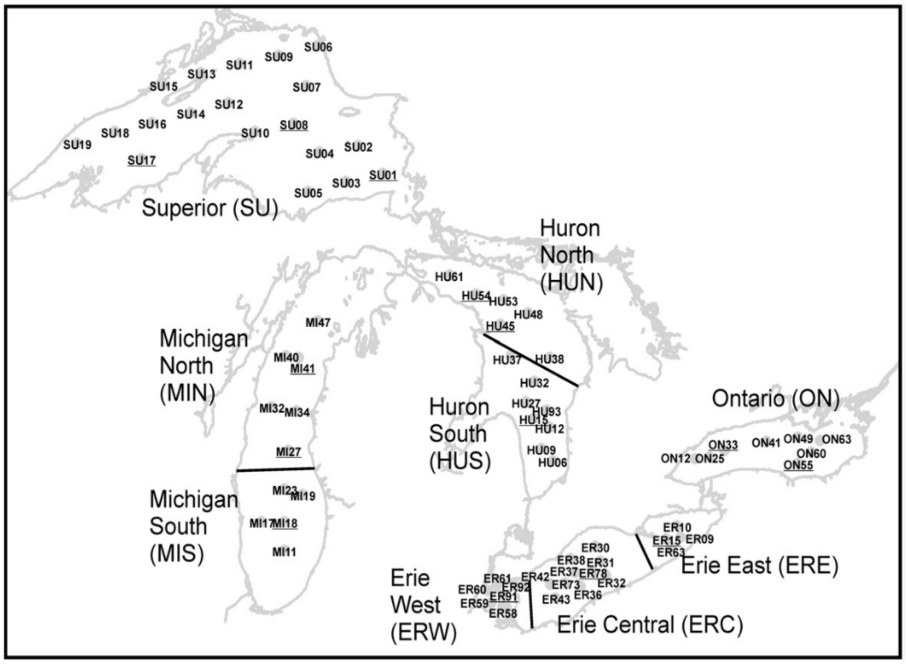

Figure 2. GLNPO Biology Monitoring Program sampling stations (Figure from Reavie et al., 2014).

Chlorophyll *a* is estimated from water samples as a measure of photosynthetic activity and algal biomass in lakes. GLNPO also estimates chlorophyll *a* from 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.

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, with two different mesh sizes. Zooplankton collected in all of these vertical tows are analyzed under a microscope by taxonomists. Biomass, as well as species diversity and density, are calculated for each Great Lake.

In 1997, the GLNPO began a standardized, long-term benthic monitoring program. Sampling occurs during the same periods as phytoplankton and zooplankton sampling, mainly in deep offshore areas. A Ponar grab sampler is used to collect sediment and benthic organisms from the lake bottom. 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. 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 Oligochaete Trophic Indices (OTI) 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. 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.

For more information on the U.S. EPA GLNPO Biology Monitoring Program, refer to the 2018 *State of the Bay* report.

2.2.2 Cooperative Science and Monitoring Initiative

The EPA, United States Geological Survey (USGS), and the National Oceanic and Atmospheric Administration (NOAA) collaborated on a CSMI food web study in 2017 and 2022 which included sampling water, zooplankton, and larval fish 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. Another 2017 CSMI study investigated benthic community composition and trends in each of Lake Huron's basins. This study utilized data collected from 129 stations across Lake Huron as part of the GLNPO Biology Monitoring Program (Figure 3). At the time of writing, methodology and results for the 2022 CSMI were not yet available. However, in the lead up to the 2022 CSMI field year, participating agencies identified priorities to guide their work. Priorities for the 2022 CSMI year included further studies of the Lake Huron food web, more specifically:

- Understanding the movement of nutrients and energy (how this influences food webs, nutrient sinks, sources, and recycling, invasive species, and nearshore versus offshore).
- Improving biomass estimates for under-sampled components of the food web (e.g., zooplankton, benthos (including dreissenids), macro algae), fish production and distribution, and increasing the spatial sampling of pelagic invertebrates and larval fish.
- Increasing understanding of the role invasive species have on food web dynamics with a focus on the link between benthic/nearshore and pelagic/offshore environments.

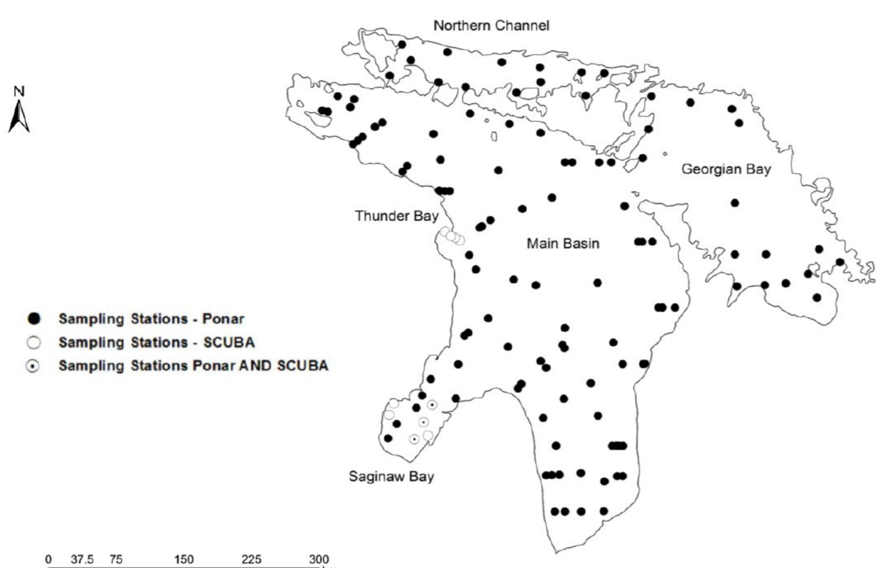

Figure 3. Location of Ponar, SCUBA, and Ponar and SCUBA sampling stations on Lake Huron in 2017 (Figure from Karatayev et al, 2020).

2.2.3 Environment and Climate Change Canada

Great Lakes Action Plan and CABIN (BEAST)

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 (Benthic Assessment of Sediment model) and are based on the reference condition approach. Samples collected as part of this program are analysed for sediment chemistry, grain size, toxicity, and benthic macroinvertebrate community structure.

Between 1991-2014, sampling locations included 44 Georgian Bay sites, 28 North Channel sites, and 6 main basin sites (Figure 4) to be used as potential reference sites for assessments conducted on sediments in Areas of Concern (AOCs) 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 AOC 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 must 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 reference sites are not reported on their own, only in comparison to those in AOCs, when required.

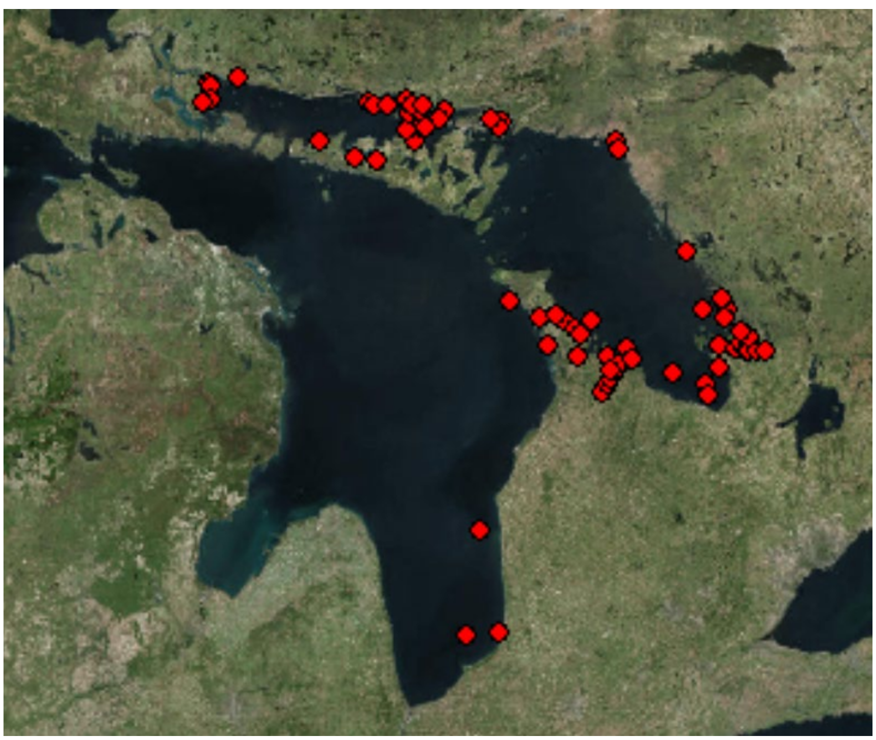

Figure 4. Upper Great Lakes BEAST reference stations (Figure from L. Grapentine, pers. comm., 2017). Map created by Danielle Milani of Environment and Climate Change Canada. Imagery from Environmental Systems Research Institute.

Great Lakes Surveillance Program

The Great Lakes Surveillance Program, run by ECCC, has sampled offshore waters of the Great Lakes in spring and summer since 1966 (Dove & Chapra, 2015). Spring samples are collected from surface waters while the lakes are isothermal and temperature is steady throughout the water column (Dove & Chapra, 2015). Accordingly, the samples provide information about the nutrients available to algae and plankton for the growing season (Dove & Chapra, 2015). Spring samples measure various forms of phosphorus (total phosphorus (TP) and soluble reactive phosphorus (SRP)), nitrogen (nitrate plus nitrite ($NO_3 + NO_2$) and ammonia (NH_3), and silica (concentrations of SiO_2). Summer samples are collected from multiple depths while the lakes are in stable thermal stratification (Dove & Chapra, 2015). Samples collected in the summer indicate how lakes responded to spring nutrient concentrations. The trends of two biological indicators – chlrophyll *a* and secchi depth – are analyzed in the summer samples.

2.2.4 Ontario Ministry of Environment, Conservation and Parks

Diver-Based Lakebed Benthos Surveys

From 2014 to 2016, the Ministry of the Environment, Conservation and Parks (MECP) conducted a series of nearshore water quality studies along eastern Georgian Bay. This included synoptic surveys of ecological features of the lakebed benthos from Severn Sound to Shawanaga Island and assessments of water quality in the Shawanaga Island, Parry Sound, Moon Island, Go Home, and Cognashene areas (Figure 5). Diver-based surveys of the hard lakebed of the outer coastline conducted at 47 sites, combined with Ponar grab sampling at 45 sites with soft sediment further inshore, were used to assess the distribution of invasive dreissenid mussels (zebra (*Dreissena polymorpha*) and quagga mussels (*Dreissena bugensis*)). Together, observations on benthic algae and round gobies on the hard substrate and benthic invertebrate composition and sediment quality on the soft sediments provide a reference point for the ecological features of the benthos of the coast. Disruption of the lakebed benthos by invasive species has strong linkages with changes in lower food web water quality and proliferation of algae on the lakebed in other Great Lakes, the status of which was not know in eastern Georgian Bay at the time. The area-wide water quality surveys at five regions along the coastline, while

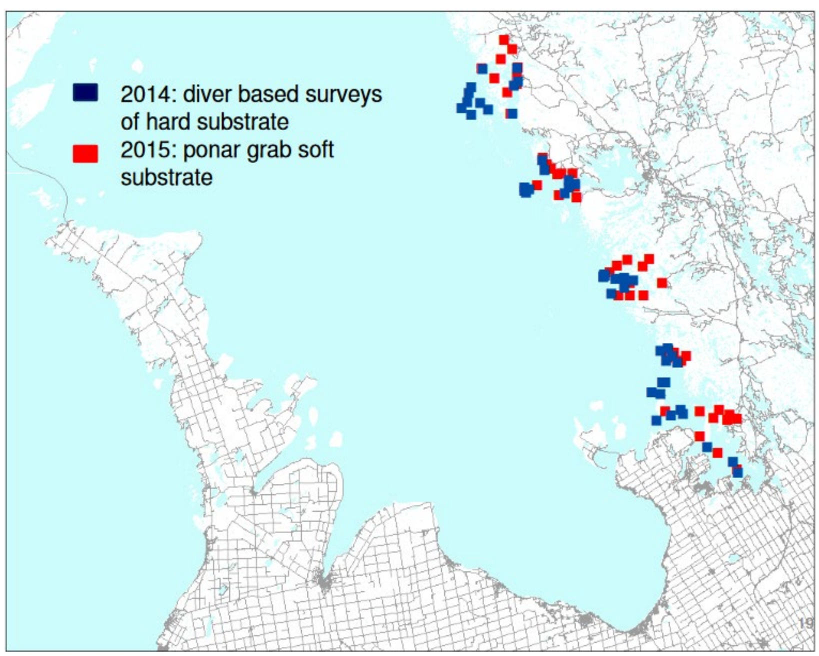

Figure 5. Locations of 2014 and 2015 MECP diver-based benthic surveys (Figure from Howell, 2015).

connecting lakebed biological conditions to water quality, were a follow-up to earlier synoptic surveys of the coastline from 2003 to 2005 and intended to better identify dynamic and causal features of water quality. This work also included analysis of phytoplankton composition as an indicator of trophic conditions and potentially adverse features of water quality. Some results from this work have been published, others are forthcoming.

Great Lakes Nearshore Reference and Index Station Network

As part of the Great Lakes Nearshore Reference and Index Station Network surveys, MECP samples benthic invertebrates at locations throughout the Canadian waters of Lake Huron (Figure 6). 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); and indicators of habitat integrity (e.g., thermal and optical profiles of the water column including UV radiation, physical characterization of the lake bottom).

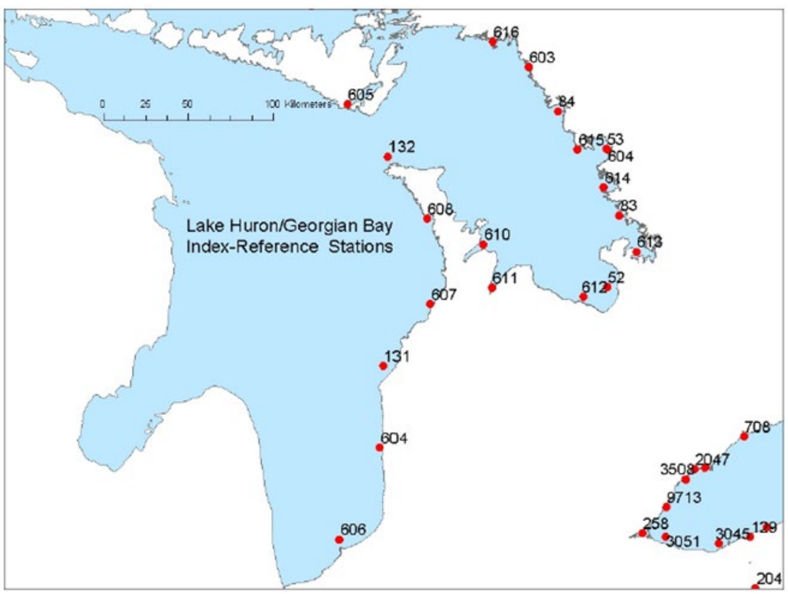

Figure 6. Lake Huron and Georgian Bay Nearshore Reference and Index Station Network sampling locations (Figure from Howell, 2015).

Approximately 10-18 Great Lakes stations are surveyed annually. Lake Huron stations are sampled every six years (last sampled in 2022). The sampling protocols employ standard MECP methodology, thereby permitting comparisons with historical and ongoing data collections elsewhere by the Ministry. The primary use for the information collected is as input to Great Lakes management programs. The information is useful for 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 AOCs). Up until 2014, these data were also used in biannual *Water Quality in Ontario* reports published by the former Ministry of Environment and Climate Change. 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. The data are publicly available through the Ontario Government data portal.

2.2.5 Severn Sound Environmental Association – Open Water Monitoring Program

Severn Sound was listed by the International Joint Commission (IJC) as an AOC 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, the MECP monitored trophic status indicators in Severn Sound. Beginning in 1997, the Severn Sound Environmental Association (SSEA) took over the Open Water Monitoring Program which consisted of monitoring the environmental quality of Severn Sound open water for indicators of eutrophication using the same sample collection and analytical methods as the MECP.

Presently, 11 open water stations are sampled biweekly during the ice-free season (May-October). In addition, the SSEA has been sampling three stations around Honey Harbour since 1998 (Figure 7). 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. Data collected through the Open Water Monitoring Program are used to provide updates on the status of Severn Sound and specific

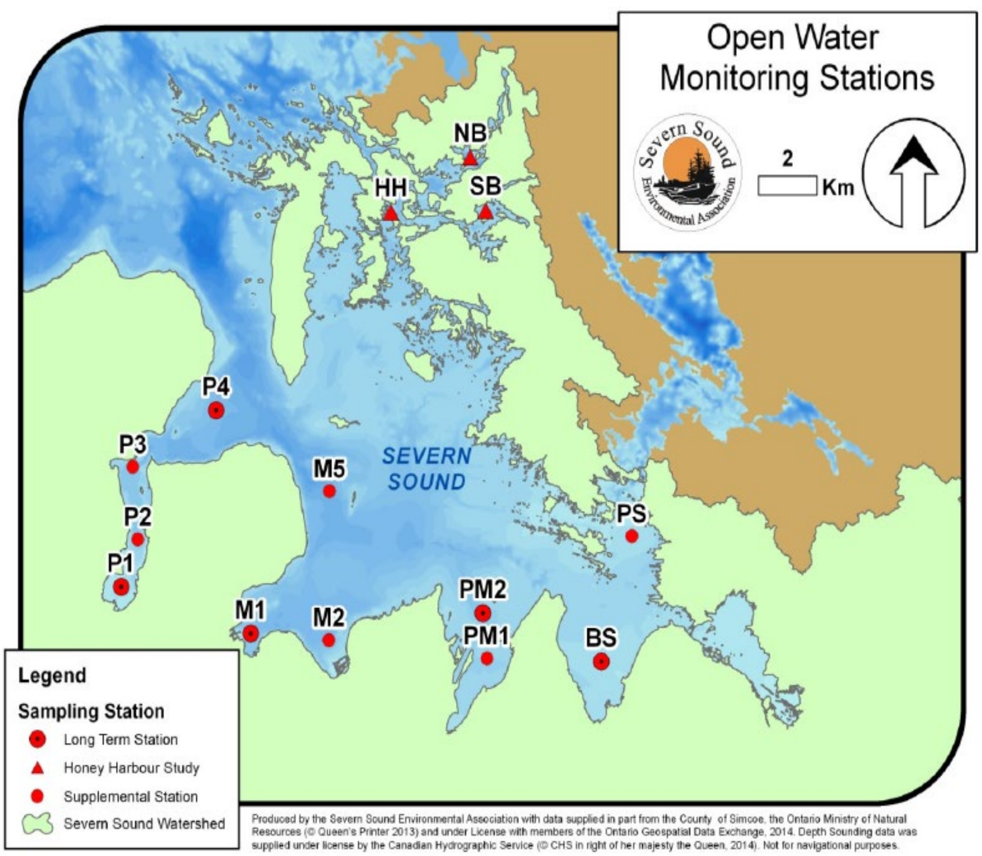

Figure 7. The SSEA's Open Water Monitoring Program stations (Figure from Chiandet & Sherman, 2014). Long term stations have data going back to 1969, while periods of record for supplemental stations and Honey Harbour stations vary. The newest station is M5, which was added in 2003.

embayments, as well as to provide background information for municipal works projects such as upgrades to wastewater treatment plants, Environmental Assessment studies, etc.

In 2023, the SSEA is celebrating 20 years since the delisting of the Severn Sound AOC in 2003. As part of this celebration, the SSEA is preparing a special *State of the Sound* report which will provide the most recent analysis of their Open Water Monitoring Program data. All publicly available reports can be found at www.severnsound.ca.

2.3 WHAT ARE THE RESULTS?

State of the Bay 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 on www.stateofthebay.ca.

The following results are presented first at the Lake Huron scale and then where possible, at the Georgian Bay, eastern Georgian Bay, and finer scales. Where the distinction is made, it is noted whether results are relevant to the nearshore or offshore. Much of the data available for the Lake Huron and Georgian Bay food web is collected in offshore regions and thus not necessarily representative of the state in the nearshore or coastal fringe. Finally, wherever possible, results are discussed in terms of trends and focus on abundance and/or biomass and community composition.

2.3.1 Lake Huron

Lower food web status and trends in Lake Huron, as assessed in the *State of the Great Lakes 2022 Technical Report,* are broken down into several categories summarized in Table 2.

Table 2. Summary of lower food web status and trends at the Lake Huron scale (Table from ECCC & EPA, 2022b). Time periods for long-term trends vary by indicator.

Component of Lower Food Web	Status	10-Year Trend	Long-term Trend
Phytoplankton	Fair	Deteriorating	Deteriorating (1950-2019)
Zooplankton	Fair	Unchanging	Deteriorating (1997-2019)
Benthic invertebrates			
• Open water benthos	Good	Unchanging	Unchanging (1998-2019)
• Coastal wetland benthos	Fair	Unchanging	N/A
• *Diporeia*	Poor	Deteriorating	Deteriorating (1972-2017)
• Dreissenid mussels	Poor	Deteriorating	Deteriorating (2000-2017)

Phytoplankton

Phytoplankton abundance and community composition in the open waters of Lake Huron are described in the *State of the Great Lakes 2022 Technical Report* as being in 'fair' condition with a 'deteriorating' 10-year and long-term (1950-2019) trend (ECCC & EPA, 2022b). The report 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" (ECCC & EPA, 2022b, p. 364) represents not only food web stress, but also likely an overall reduction in the carrying capacity for organisms higher in the food web of the lake (e.g., fishes).

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 biomass in the lake was comprised of 40 common species and varieties and all major groups were similarly abundant over this time period (Dobiesz et al., 2005). Phytoplankton growth in Lake Huron typically varied seasonally 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 (ECCC & EPA, 2017, 2018). A summer minimum was usually experienced from 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 northern main basin compared to the southern main basin.

In 2003, there was a marked decrease in the magnitude of the spring phytoplankton bloom and even further reductions seen through 2008 (ECCC & EPA, 2018, 2022b). Largely due to a decrease in diatom abundance, spring phytoplankton biovolume from 2003-2016 was measured at less than half that of the 2001-2002 biovolume (Rudstam et al., 2020). 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). 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 (ECCC & EPA, 2017, 2018, 2022b).

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). Satellite-derived imagery (SatChl) showed after declines in summer chlorophyll in 2005, concentrations in the main basin of Lake Huron remained relatively stable across all seasons (Rudstam et al., 2020). In Georgian Bay, fluctuations in SatChl were more common with higher concentrations of chlorophyll in 2009 and 2013 (Figure 8) (Rudstam et al., 2020).

A 2017 CSMI study identified cryptophytes (*Rhodomonas lens* dominant), centric diatoms *(Cyclotella* dominant), and chrysophytes (largely haptophytes) as the dominant taxa contributing to Lake Huron's spring biovolume (Reavie, 2020). Summer biovolume saw a particularly high abundance of chrysophytes, along with dinoflagellates (*Peridinium* dominant), diatoms (*Cyclotella* and *Asterionella formosa*), and cyanobacteria (Reavie, 2020). Overall, phytoplankton assemblages have been observed to be shifting, interpreted as a response to atmospheric warming and decreases in nutrient inputs, towards increased dominance by the genus *Cyclotella sensu lato,* which include smaller centric diatoms (Reavie et al., 2017; Rudstam et al., 2020).

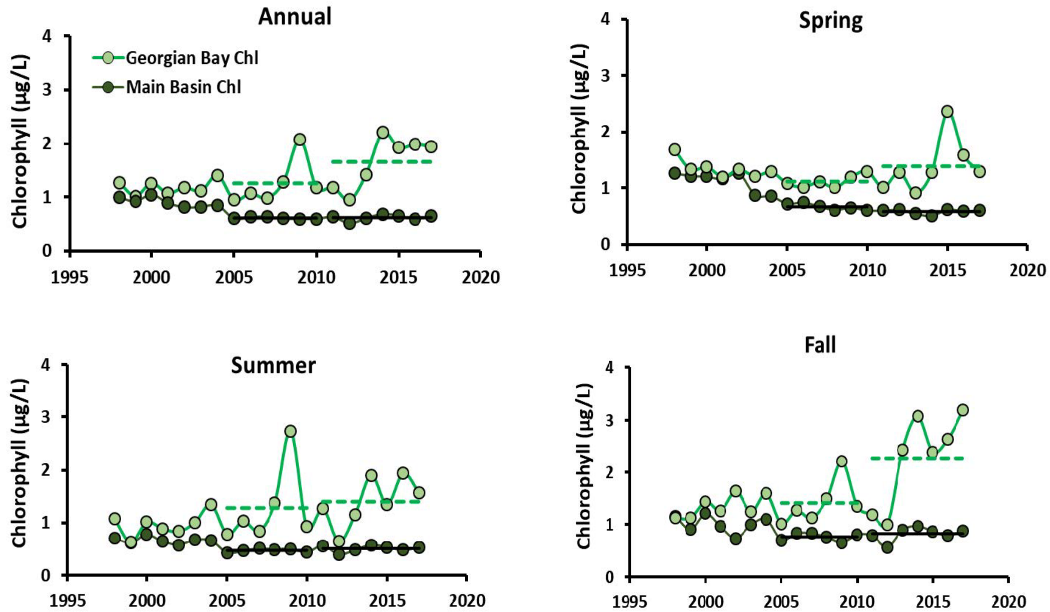

Figure 8. Chlorophyll concentrations by year in the main basin and Georgian Bay calculated from satellite imagery changes for areas with bottom depths >30 m. Horizontal lines indicate the averages for 2005-2010 and 2011-2017 (Figure from Rudstam et al., 2020).

Between 1971 and 2013, mean phytoplankton abundance declined 88% (ECCC & EPA, 2022a). 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 (ECCC & EPA, 2014). Moreover, Lake Huron has surpassed Lake Superior as the clearest Great Lake (Yousef et al., 2017). Research by Brothers et al. (2016) has shown that losses in planktonic primary productivity in the offshore waters of the Great Lakes are being compensated for by increases in nearshore benthic primary productivity, thus shifting the energetic base of the food web to the littoral zone. This supports Hecky et al.'s (2004) nearshore shunt hypothesis which suggests that pelagic zones are being starved as anthropogenic nutrient inputs are being reduced and nutrients are being increasingly taken up in the nearshore by organisms such as dreissenid mussels. Results from work by Stefanoff et al. (2018) further support the nearshore shunt hypothesis, finding dreissenid mussels to be drivers of benthic algae biomass in the nearshore waters of Lake Huron with zebra mussels accounting for 52% of variation in models for the benthic algae *Cladophora.* If, in the face of declines in phytoplankton and the shunting of nutrients to the nearshore by dreissenid mussels, benthic primary productivity can compensate for losses in planktonic primary productivity, it may be better to characterize this shift as structural rather than an overall loss in whole lake productivity (Brothers et al., 2016).

Based on available research, it appears that the dominant processes driving primary production are shifting. However, more research on food web dynamics in Lake Huron is needed for these changes to be fully understood. The past 200 years have seen multiple stressors including agriculture, industrialization (i.e., social and economic development, mining pollution), and forest clearing resulting in changes to the ecology of Lake Huron (Sgro & Reavie, 2018). Recently, possible factors contributing to the phytoplankton decline in Lake Huron are long-term declines in nutrient inputs (owing to the Great Lakes Water Quality Agreement, for example), and the proliferation of dreissenid mussels that filter phytoplankton out of the water. If nutrient concentrations are too low in some offshore regions, this may result in insufficient growth of key phytoplankton species (ECCC & EPA, 2017). Similarly, 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) note that declines in Lake Huron's spring phytoplankton biovolume occurred earlier, and were more severe, than that of Lake Michigan, despite the fact that Lake Michigan experienced a faster and larger dreissenid invasion. Further to this, Barbiero et al. (2018) suggest that during the key period of change identified for Lake Huron beginning in 2003 to 2005, dreissenid densities and filtration capacity would be insufficient to cause direct impact to phytoplankton in the deeper waters of Lake Huron. A broad suite of factors, including climatic factors ranging from precipitation to air temperature and ice cover, are likely involved in the changes being seen in Lake Huron's lower food web (Barbiero et al., 2018). While spring blooms remain absent and the causes behind this are unclear, monitoring data revised and updated from Reavie et al. (2014) show that summer algal abundance may be returning to levels not seen since before the dreissenid invasion (ECCC & EPA, 2022b).

Climate change is predicted to further influence changes to Great Lakes phytoplankton communities. As stated in the IJC's (2020, p. 5) report titled *Understanding Declining Productivity in the Offshore Regions of the Great Lakes*, "It has already been recognized that physical changes to Great Lakes pelagic environments caused by atmospheric warming are forcing reorganization of phytoplankton communities to species that are more tolerant of longer summers and stronger stratification."

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).

The status of Lake Huron zooplankton was assessed in the *State of the Great Lakes 2022 Technical Report* as 'fair' with an 'unchanging' 10-year trend and a 'deteriorating' long-term trend (1997-2019) (ECCC & EPA, 2022b). Biomass has remained low since declines in cladocerans and cyclopoid copepods in 2003 and no further change in community composition has been seen (ECCC & EPA, 2022b). 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 (ECCC & EPA, 2022b).

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 9) (ECCC & EPA, 2017, 2022a, 2022b). By 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.

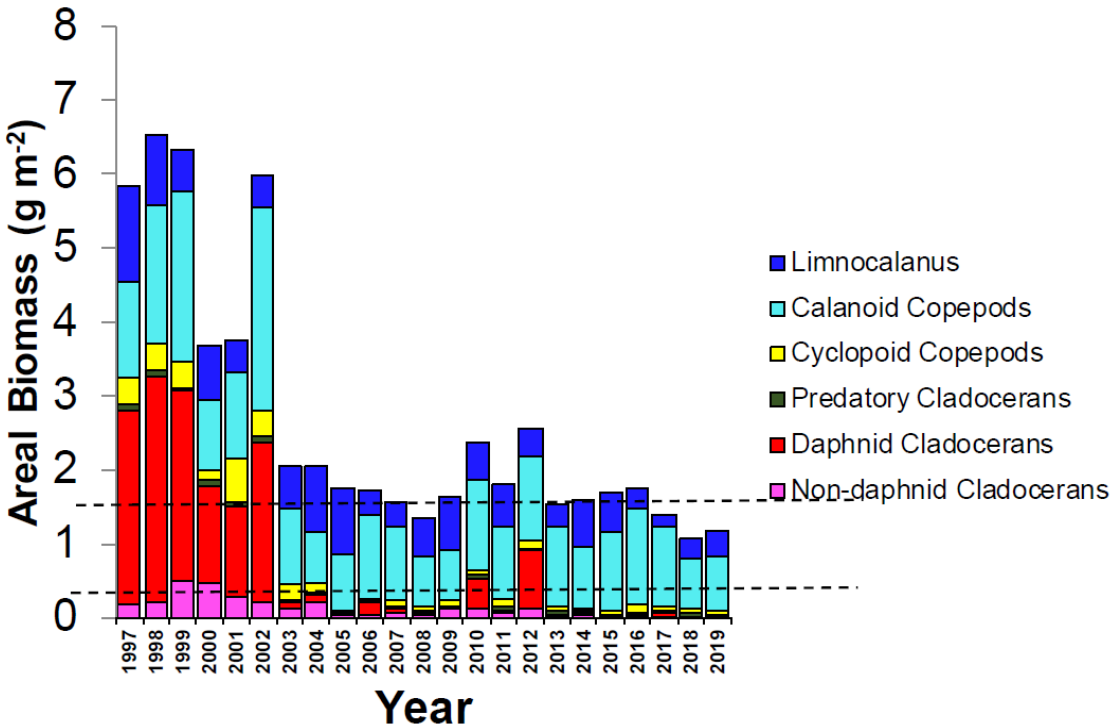

Figure 9. Decline in Lake Huron zooplankton biomass from 1997-2019. Dashed lines represent "Good" and "Poor" thresholds. When conditions fall between the dashed lines, they are assessed as "Fair" (Figure from ECCC & EPA, 2022b).

The drastic decline in cladoceran biomass, particularly *Daphnia*, as well as cyclopoid copepods, resulted in the 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* (ECCC & EPA, 2017, 2022b). This shift in community composition is now more consistent with the oligotrophic conditions of Lake Superior where biomass is deeper in the water column (LimnoTech, 2015b). This similarity may represent a shift towards more historical conditions in Lake Huron (Barbiero et al., 2019), however, these changes, coupled with continued reductions in *Diporeia* populations, may represent a decreasing food base for prey fish (ECCC & EPA, 2022b). 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). A strong correlation between cladocerans and chlorophyll *a* indicate the possibility that changes in zooplankton in Lake Huron could be due in part to bottom-up forces (Barbiero et al., 2019; Hecky & DePinto, 2019). Overall, a decline in zooplankton has ramifications for the food web as a 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 (ECCC & EPA, 2017, 2018, 2022a, 2022b). However, the exact mechanisms of zooplankton declines have yet to be fully determined, and even the mechanisms of nutrient reductions are poorly understood (ECCC & EPA, 2022b).

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 (ECCC & EPA, 2017, 2022b). As another example, the abundance and community composition of *Bythotrephes longimanus* (spiny waterflea) and *Cercopagis pengoi* (fishhook waterflea), non-native cladocerans, have been shown to have an impact on zooplankton predation and vertical distribution (ECCC & EPA, 2017; LHPWG, 2016). In fact, a study conducted by Bunnell et al. (2011) determined that *Bythotrephes* planktivory was the strongest factor in structuring zooplankton communities in Lake Huron, with *Bythotrephes* estimated to have eaten 78% of the native zooplankton consumed by predators. Consumption by fish accounted for only 3% of all zooplankton consumed in this study (Bunnell et al., 2011).

In addition to invasive species, climate change may pose a threat to zooplankton. Researchers have observed increasing surface 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. Zooplankton may also be indirectly affected by climate change due to the impact it has on phytoplankton, the food source of herbivorous zooplankters. As phytoplankton species composition shifts with increasing atmospheric and water temperatures, a higher abundance of species from the *Cyclotella sensu lato* group are being seen in the Great Lakes (Reavie et al., 2017). It is currently unknown how grazing zooplankton (e.g., *Limnocalanus*) will react to shifts in species composition brought on by climate change, thus there is a need for further research on whether Lake Huron's grazing zooplankton can adequately shift their diet to include *Cyclotella* and other climate-related taxa (Reavie et al., 2017).

Climate change could also potentially disrupt trophic linkages. A 2004 study in Lake Washington showed due to increasingly warmer springs since 1962, "the timing of thermal stratification and the spring diatom bloom have advanced by more than 20 days" (Winder & Schindler, 2004, p. 2100). Similarly, Wiltse et al.'s (2016) study lake showed earlier blooming than in the decade prior, but further research in their study area is needed to assess the possibility of mismatches between diatom blooms and zooplankton peaks in response to increasing temperatures. These potential mismatches pose a real threat to the rest of the food web as phytoplankton-zooplankton interactions form the basis for energy flux to higher trophic levels. At the time of writing, no studies were found suggesting this trophic mismatch is currently occurring in the Great Lakes.

Benthic Macroinvertebrates

Benthic macroinvertebrate status and trends in Lake Huron, as assessed in the *State of the Great Lakes 2022 Technical Report,* vary by sub-indicator (Table 3).

Table 3. Summary of benthic macroinvertebrate condition and trends for Lake Huron (Table from ECCC & EPA, 2022b).

Sub-Indicator	Status	10-Year Trend	Long-term Trend
Open Water Benthos	Good	Unchanging	Unchanging (1998-2019)
Coastal Wetland Benthos	Fair	Unchanging	N/A
Diporeia	Poor	Deteriorating	Deteriorating (1972-2017)
Dreissenid mussels	Poor	Deteriorating	Deteriorating (2000-2017)

The 2017 CSMI year involved an in-depth benthic survey on Lake Huron which ultimately identified 125 different taxa (Karatayev et al., 2020). Oligochaeta was the most abundant taxon lake-wide at 52% of total benthic density, followed by *Dreissena r. bugensis* at 32%, Chironomidae at 8%, Sphaeriidae at 3%, *Diporeia* at 1%, and Gastropoda at 0.7%. In terms of biomass, the dominant benthic taxa was *Dreissena r. bugensis* which accounted for 98% of the total wet biomass, indicating a near complete transformation of benthic invertebrate biomass relative to the pre-dreissenid era.

Diporeia were once the most abundant benthic organism in the cold, offshore profundal regions (greater than 30 m) of Lake Huron (ECCC & EPA, 2022b), and a key component of the food web in these regions. They were present but less prominent in the nearshore and naturally absent from shallow, warm bays, basins, and river mouths (ECCC & EPA, 2022b). *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, 2022a, 2022b). Because they are a lipid-rich prey (Garder et al. 1985), they historically provided a key source of energy to many different forage fishes in the upper Great Lakes (Wells, 1960; Crowder & Crawford, 1984).

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 by 99.8%, 90.0%, and 52.1%, respectively (Riley, 2013). By 2003, *Diporeia* populations fell to less than half their 2000 abundance (Figure 10) and biomass fell below levels in Lake Superior (ECCC & EPA, 2022b). Abundances in 2007 were lower by 93% compared to 2000, and 2012 abundances were even lower than those in 2007 (ECCC & EPA, 2014). Karatayev et al. (2020) found the *Diporeia* density in 2017 in Lake Huron's main basin to be 0 (mean ± SE, ind. m^{-2}) at 0-30 m and 31-50 m, increasing with depth to 6 (mean ± SE, ind. m^{-2}) at 51-90m and 161 (mean ± SE, ind. m^{-2}) at >90m. Their presence was also confirmed in deeper water as a result of their appearance in bloater (*Coregonus hoyi*) stomach contents (LimnoTech, 2015b). The 2017 CSMI benthic survey found *Diporeia* represented only 1% of the lake-wide benthic density (Karatayev et al., 2020).

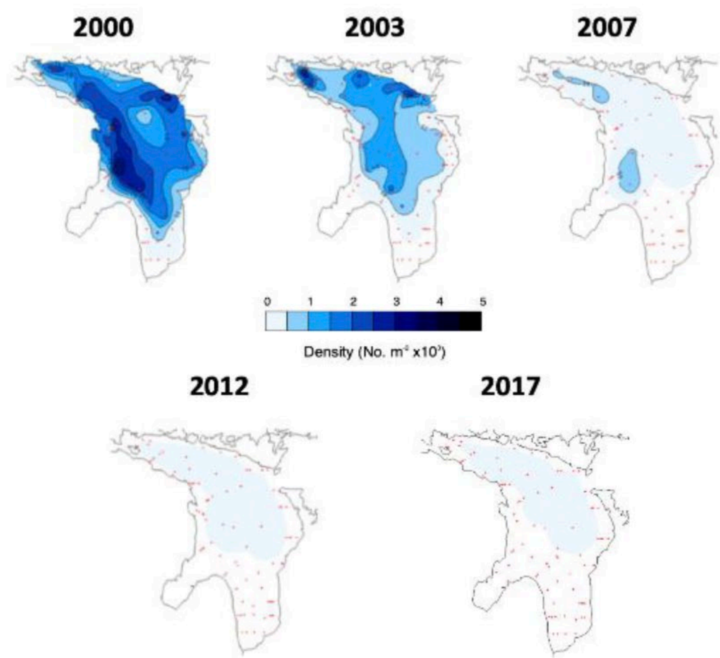

Figure 10. Decline of the amphipod *Diporeia* in Lake Huron from 2000-2017 (Figure from ECCC & EPA, 2022b).

The crash of *Diporeia* in Lake Huron coincided with the proliferation of dreissenids, however, the nature of these interactions are not yet well understood (Figure 11) (ECCC & EPA, 2022b; Rudstam et al., 2020). A commonly referenced hypothesis is that dreissenids are shunting energy and nutrients into a benthic pathway, thus reducing phosphorus availability for phytoplankton growth upon which *Diporeia*, pelagic zooplankton, and fish directly or indirectly depend (ECCC & EPA, 2014; LimnoTech, 2015b). Other theories suggest that waste products from dreissenids are toxic to *Diporeia* (Hinderer & Murray, 2011) and that diseases, pathogens, and parasites have played a role in the decline (Messick et al., 2004; Rudstam et al., 2020). 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 where no local populations of dreissenids were present (ECCC & EPA, 2014). Abundance can also be influenced by shifts in predation pressure resulting from changes in fish populations (ECCC & EPA, 2022b).

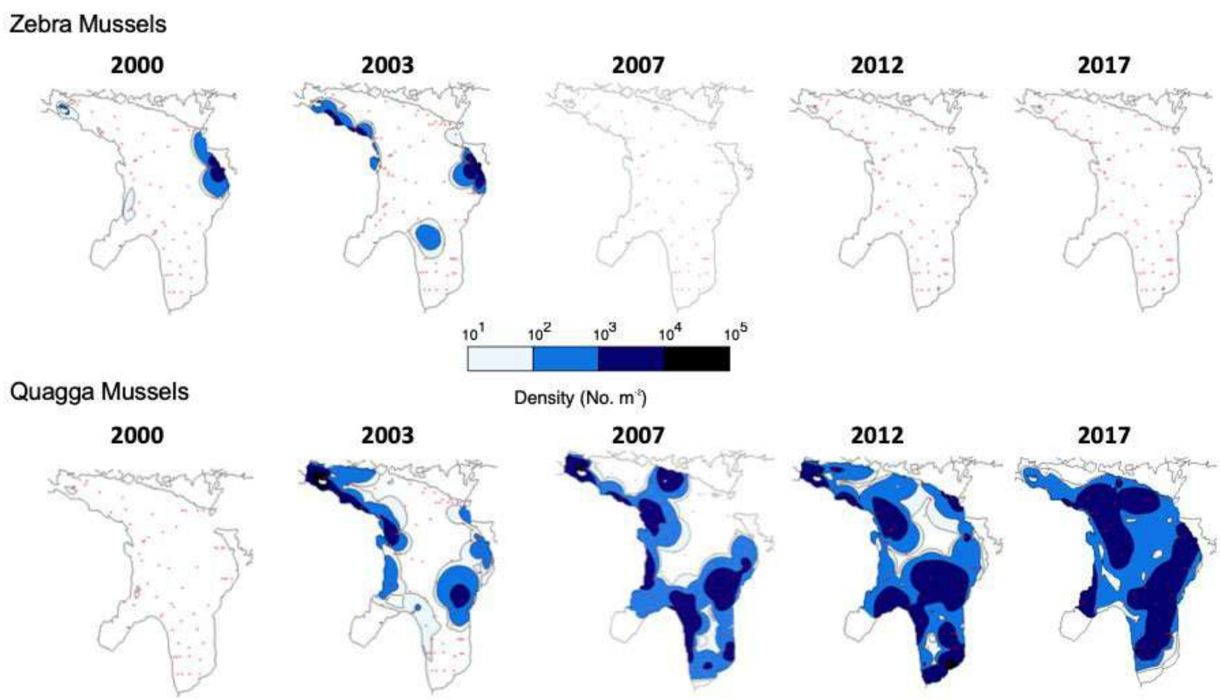

Figure 11. Dreissenid mussel invasion in Lake Huron from 2000-2017 (Figure from ECCC & EPA, 2022b).

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 such as lake whitefish and bloater (Rudstam et al., 2020). Consequently, fish populations have responded with changes in diet, movement to areas with more food, and reductions in weight and/or energy content (Pothoven & Madenjian, 2013; Dieter et al., 2022). These changes have implications for fish populations which include changes in distribution, abundance, growth, recruitment, and condition (ECCC & EPA, 2022b). For example, some prey fish appear to be eating more *Mysis*, the other large invertebrate found in the offshore region (Dieter et al., 2022; Jude et al., 2018).

While not as severe as *Diporeia*, declines in oligochaetes and sphaeriids were also observed from the early 1970s to 2000 across all depth intervals. 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 (LHPWG, 2016; LimnoTech, 2015b). The presence of dreissenid mussels has also be positive for oligochaetes as they have been increasing interstitial space and causing a greater accumulation of organic debris. Nalepa et al. (2018) identified 4.9-fold and 2-fold increases in oligochaete abundance from 2000 to 2012 in the 18-30 and 31-50 m depth intervals, respectively.

Overall, oligochaete worms have become proportionally more abundant 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). Mean densities of sphaeriids have trended lower at all depth intervals below 90 m, however, similar to Riley (2013), Nalepa et al. (2018) did not find a distinct declining trend in density from 2003 to 2012. More recently, the 2017 CSMI benthic survey found that sphaeriidae density has shown downward trends while chironomids have shown little change (Karatayev et al., 2020).

Whereas native *Diporeia* continue to decline in Lake Huron, invasive dreissenids continue to expand. The abundance of non-native, invasive dreissenid mussels can have a dramatic impact on the structure and abundance of aquatic communities. These filter feeders will coat lakebeds and 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). They have also been found in correlation with increasing benthic algae throughout the Great Lakes (Brothers et al., 2016; Stefanoff et al., 2018).

Zebra mussels became established in Lake Huron in the early 1990s and peaked in abundance in 2000-2003 in the main basin and 2007 in Georgian Bay. Within the same general time period, mean density of zebra mussels was <1/m^2 in the North Channel, likely owing to relatively low levels of calcium that prevent the larval veligers from growing shells and settling on the bottom as juveniles (Kirkendall et al., 2021).

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 (LimnoTech, 2015b; Riley, 2013). Peak biomass reported in 2015 was at 31-50 m, populations had stabilized at <90 m but were still climbing at >90 m (LimnoTech, 2015b).

The 2017 CSMI benthic survey measured *Dreissena* distribution in Lake Huron using video images and Ponar grab samples. Data analysis uncovered similar results to those found during surveys on Lake Michigan in 2015, including higher average densities and biomass in the 30-100 m zone when compared to shallower nearshore waters and deeper lake zones (Karatayev et al., 2020). Since 2012, *Dreissena* have declined in the shallowest zones by a factor of 8, remained stable at the 30-90 m zone, and more than doubled in the deepest zones at depths greater than 90 m. Zebra mussels have not been detected in Lake Huron surveys since 2007. However, quagga mussel density and biomass in Lake Huron were over 18 and 20 times higher than zebra mussels during their peak abundance in 2000 (Karatayev et al., 2020). Overall, Lake Huron has a low abundance of dreissenids relative to Lake Michigan and Lake Ontario (LimnoTech, 2015a).

Recent research is attempting to characterize potential effects of dreissenids on benthic communities in Lake Huron. An analysis of the 2015 and 2017 CSMI benthic data collected on Lake Michigan and Lake Huron found that diversity and biomass of benthos were higher in areas with quagga mussels compared to areas devoid of dreissenids (Bayba et al., 2022). The presence of quagga mussels in the offshore regions of lakes

Huron and Michigan appeared to elevate offshore benthic macroinvertebrate densities, something previous studies on *Dreissenid* mussels could not detect before quagga mussels became more prevalent in deeper waters (Bayba et al., 2022). Further research is needed to better understand correlations between dreissenids and benthos in offshore waters (Bayba et al., 2022).

2.3.2 Georgian Bay and Eastern Georgian Bay

Phytoplankton

Past results from the SSEA's Open Water Monitoring Program indicated that all Severn Sound bays showed a decrease in the total biovolume of phytoplankton since 1973, particularly after 1994/5 when wastewater treatment plants in Penetanguishene were upgraded and dreissenid mussels also became widespread across Severn Sound (Figure 12) (SSEA, 2023, SSEA, 2017b; Sherman, 2002). More 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.

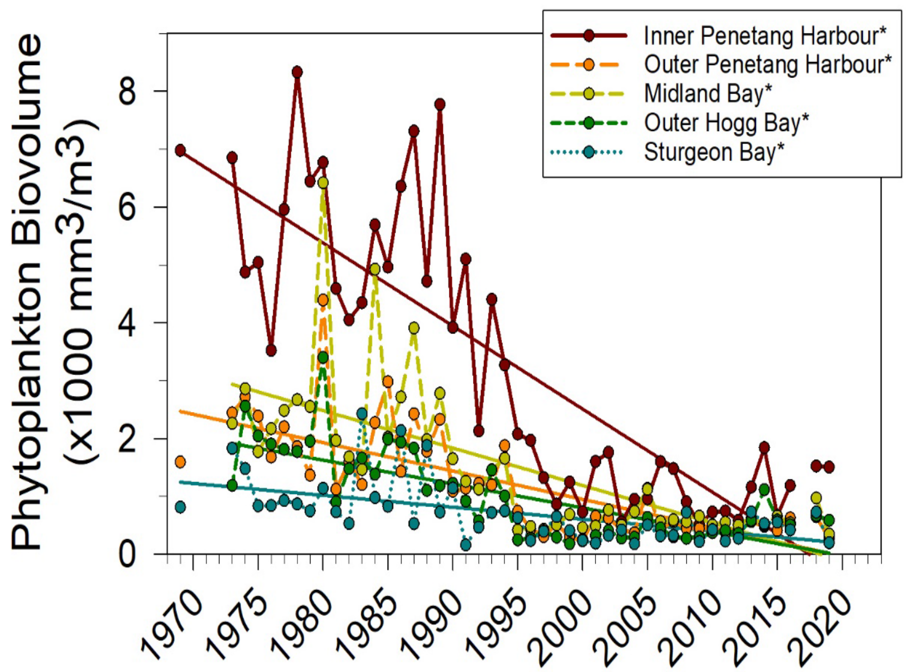

Figure 12. Annual phytoplankton biovolume at long term stations in Severn Sound from 1969-2020 * indicates significant trends over this period (Figure from Chiandet, pers. comm, 2023).

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). 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 1998-2012 with blooms occurring at 4-5 m depths for short periods throughout the season (Chiandet, 2019; Chiandet & Sherman, 2014). When highly abundant, these algae are not harmful to humans but may impact the taste and odour of drinking water in the area (Chiandet, 2019). 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 (Chiandet & Sherman, 2014). Blooms of blue-green algae, dominated by *Anabaena* and *Planktothrix* have been found in deeper waters of South Bay (Chiandet, 2019). At these depths, the blue-green algae blooms are not likely to impact humans through direct contact (Chiandet, 2019).

Conversely, more 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). Blooms of blue-green algae and golden algae have been found in deeper waters and specific depths (4-9 m) in South Bay and North Bay, respectively (Chiandet, 2019).

The SSEA will be releasing a *State of the Sound* report in 2023 with updated lower food web results for the Severn Sound area.

Outside of the Severn Sound area, Verschoor et al. (2017) assessed a Cyanobacteria-Ferrous conceptual model in four embayments along eastern Georgian Bay in the warmer summer of 2012 and cooler summer of 2014. Assessments of epilimnetic algal abundance occurred in one meso-eutrophic (Sturgeon Bay) and three oligotrophic (Deep Bay, Twelve Mile Bay, and North Bay) embayments of southeastern Georgian Bay (Figure 13). Deep Bay and Sturgeon Bay were sampled in 2012 and 2014 while Twelve Mile Bay was sampled only in 2012 and replaced by North Bay in 2014. In the warmer summer of 2012, cyanobacteria dominated the surface waters of all the embayments but less so in the cooler summer of 2014 (Verschoor et al., 2017). Sturgeon Bay in 2012 was the only embayment to experience a cyanobacteria bloom with the waters being visibly green (Verschoor et al., 2017). To assess the Cyanobacteria-Ferrous model, cyanobacteria biomass was monitored in each embayment for the two years. In 2012, cyanobacteria in Sturgeon Bay was dominant and accounted for 80% of the embayment's phytoplankton biomass by mid-July, contrasting 2014 where cyanobacteria accounted for only 33% of phytoplankton biomass by mid-September (Verschoor et al., 2017). Deep Bay had small cyanobacteria populations in both 2012 and 2014, with cyanobacteria dominating the epilimnion in 2012 but not the metalimnion and dominating neither layer in 2014 (Verschoor et al., 2017). Epi- and metalimnetic cyanobacteria biomass differed in 2012 for Twelve Mile Bay with the metalimnion dominated by non-N_2 fixer *Planktothrix* in late August and accounting for 89% of phytoplankton biomass by early September (Verschoor et al., 2017). Cyanobacteria biomass in the epilimnion was less, never exceeding 8% of phytoplankton biomass throughout the summer

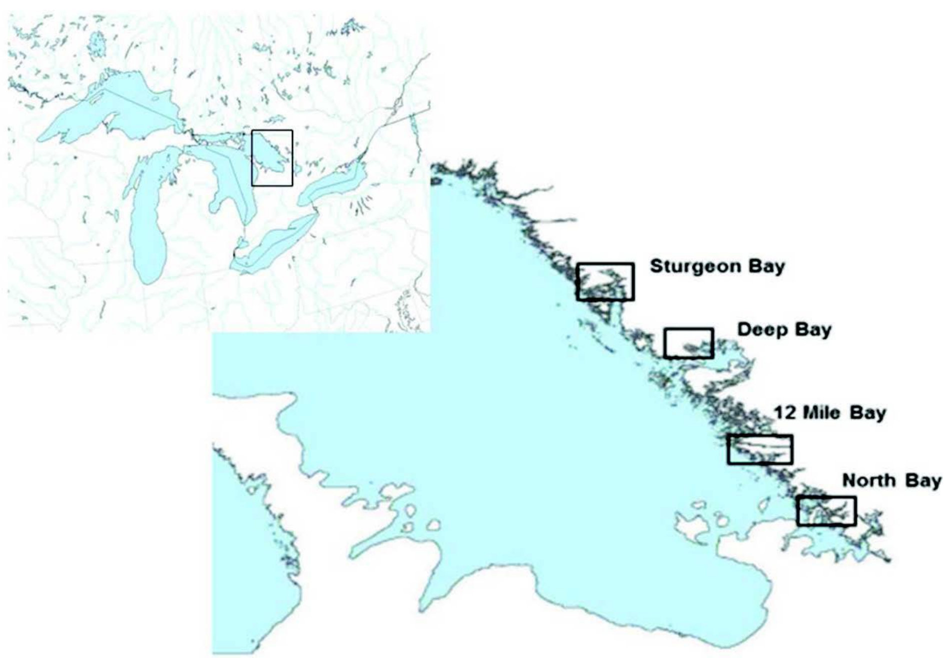

Figure 13. Location of study sites on eastern Georgian Bay. Sturgeon Bay is meso-eutrophic and Deep Bay, 12 Mile Bay and North Bay and oligotrophic (Figure from

(Verschoor et al., 2017). In North Bay, cyanobacteria biomass in the summer of 2014 was low in the epilimnion and metalimnion and accounted for 23% and 41% of phytoplankton biomass in the epilimnion and metalimnion, respectively. The overall results of this Cyanobacteria-Ferrous conceptual model assessment showed that cyanobacteria dominance is linked with warm summer temperatures and internal Fe^{2+} loading and high nutrient levels are needed for large algal blooms to form (Verschoor et al., 2017).

Zooplankton

Zooplankton taxonomic diversity is higher in Severn Sound compared to the open waters of Lake Huron due to greater habitat diversity and primary productivity. Forty-five genera have been documented in Severn Sound between 1987 and 2014 (Chiandet, pers. comm., 2018). While diversity has fluctuated, total density of crustacean zooplankton has seen declining in the Severn Sound area (Figure 14). Zooplankton density, biomass, and taxa richness in Honey Harbour 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. Interestingly, these changes in community composition parallel what has been documented in the open waters of the main basin of Lake Huron. Updated results will be available in the SSEA's upcoming *State of the Sound* report in 2024.

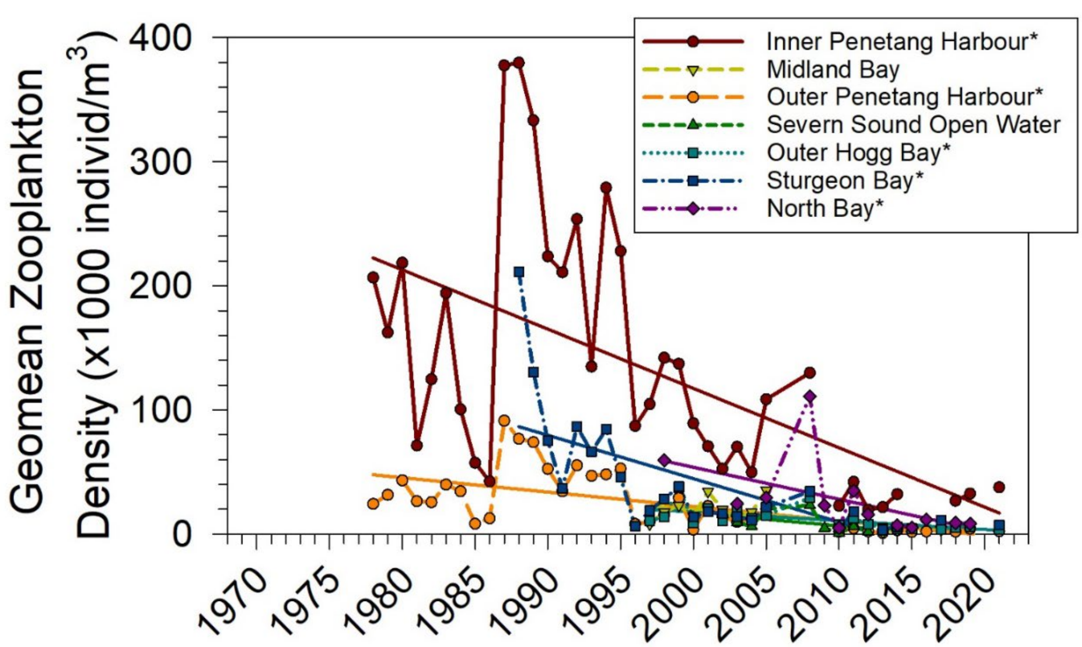

Figure 14. Zooplankton density at long term stations in Severn Sound from 1979-2020 * indicates significant trends over this period0 (Figure from Chiandet, pers. comm, 2023).

The 2017 CSMI documented zooplankton biomass at multiple transects throughout Lake Huron's basins (Figure 15). Compared to Georgian Bay, from May to July, zooplankton total biomass was consistently higher in the North Channel and northern and southern main basin (Bunnell et al., 2020). With support from the CSMI, previously collected autumn samples from 2009-2017 acoustic prey fish surveys were analyzed to identify trends in autumnal zooplankton biomass (Bunnell et al., 2020). The analysis of the autumnal data found minimal differences between Lake Huron's basins, again with biomass being lowest in Georgian Bay. No annual trends were identified (Bunnell et al., 2020).

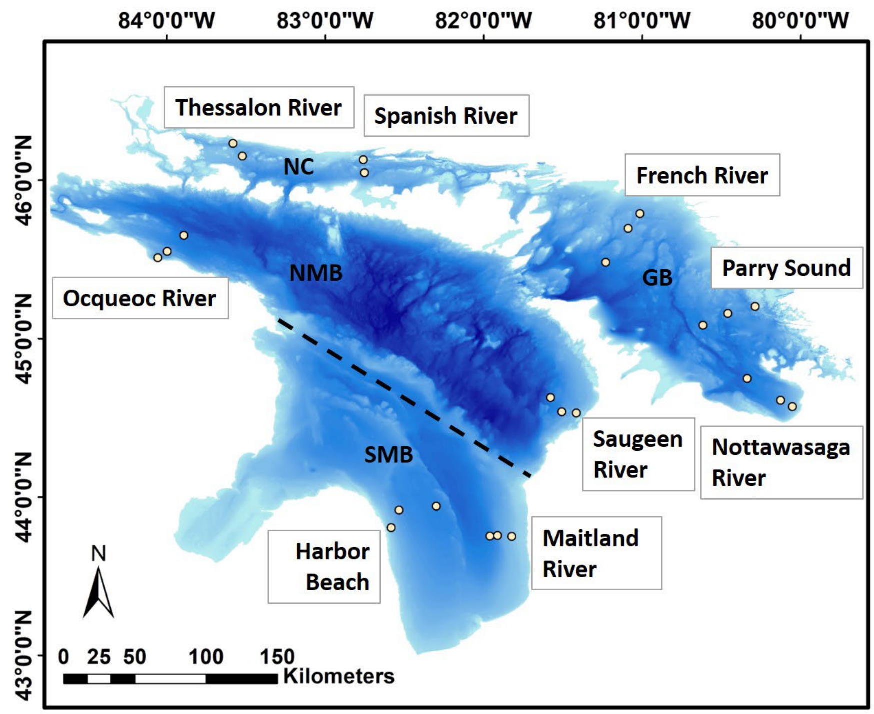

Figure 15. Transects sampled for chlorophyll *a* and zooplankton biomass during the 2017 Lake Huron CSMI by USGS and EPA (Figure from Bunnell et al., 2020).

Benthic Macroinvertebrates

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. 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 16). Results from surveys conducted in Georgian Bay in 2002 were compared to results from a 1973 survey by Loveridge and Cook (1976). 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 (OTI type 0) to more eutrophic taxa (mostly OTI type 1). The mean percentage of type 0 (preferring oligotrophic conditions and intolerant to enrichment) decreased from 97.5% in 1973 to 81.2% in 2002 (Nalepa et al., 2007). More recent insights on benthic invertebrate communities in Georgian Bay come from the MECP's benthic surveys in 2014-2015 and the 2017 CSMI benthos survey. The MECP surveys collected samples relatively close to shore (Figure 5) while the 2017 CSMI utilized offshore stations (Figure 3). At a high level, the benthic surveys revealed that when compared to similar habitat in Lakes Erie and Ontario, zebra and quagga mussels in nearshore areas <20 m were found to be less abundant in Georgian Bay (Howell, pers. comm., 2017). In the nearshore of eastern Georgian Bay, abundance of zebra and quagga mussels (as of 2014 to 2015) was relatively low but with a wide distribution (mostly <1000/m^2; maximum <3000/m^2) (Figure 17) (Howell, 2015).

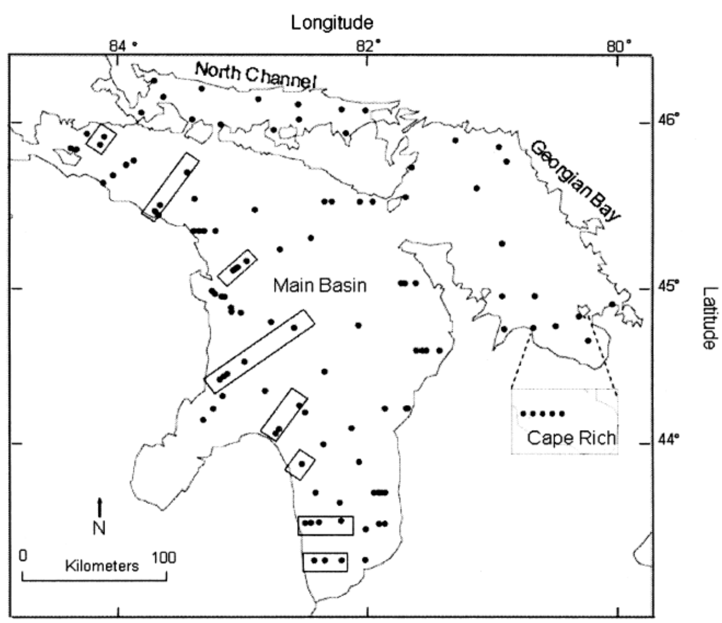

Figure 16. Sites sampled in the main basin of Lake Huron in 2000 and 2003, and sites sampled in the North Channel and Georgian Bay in 2002 (Figure from Nalepa et al., 2007).

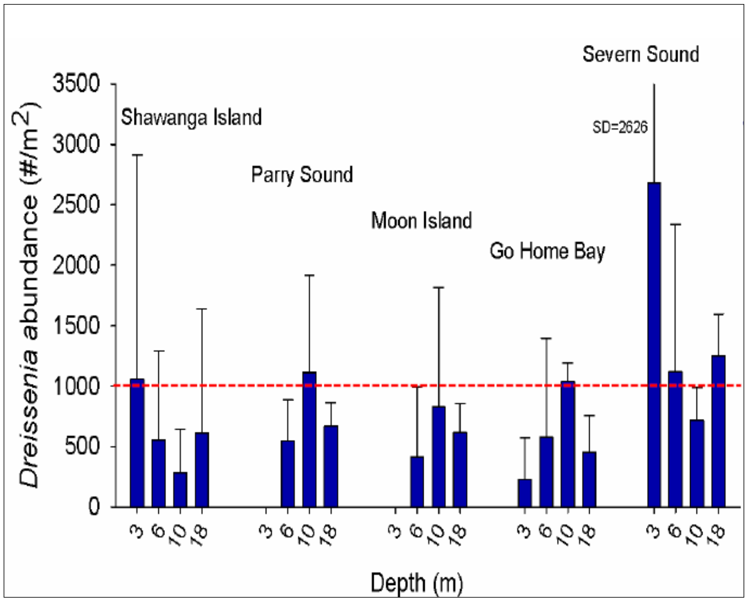

Figure 17. Dreissenid mussel abundance at various eastern Georgian Bay locations in 2014 (Figure from Howell, 2015).

Using data collected in the MECP benthic study, Girihagama et al. (2022) looked at the correlation between the conductivity of Georgian Bay waters, as a surrogate for calcium, and dreissenid abundance. The study considered how the widely varying calcium concentration of the coastline of eastern Georgian Bay can be used as a predictor of mussel distribution. Most dreissenid mussels were found in areas with specific conductivities of 140 µS/cm or greater (Girihagama et al., 2022). Conductivity was also strongly correlated with calcium concentration. Soft waters low in calcium entering eastern Georgian Bay from the Canadian Shield through rivers have a lower conductivity than offshore waters, and were below an empirically derived summer calcium concentration threshold of 14-15 mg/L for successful dreissenid mussel colonization (Girihagama et al., 2022). The inflow of river water into the Bay creates a gradient of solutes as waters from the open bay mix with nearshore waters at varying rates. This gradient appears to limit the distribution of dreissenids along eastern Georgian Bay, with varying influence at different times of year (Figure 18) (Girihagama et al., 2022). In the spring, when the influx of calcium poor waters from tributaries is higher, the gradient extends further offshore. Conversely, in the summer, river inflow is reduced and thus calcium concentrations in nearshore waters become more conducive for dreissenid colonization (Girihagama et al., 2022).

The 2017 CSMI benthos survey found that 71% of the total benthic density in Georgian Bay is comprised of oligochaetes, higher than any other Lake Huron basin (Karatayev et al., 2020). *D. r. bugensis* and Chironomidae were identified as making up only 13% of the total benthic density in Georgian Bay (Karatayev et al., 2020). Of the Lake Huron basins, Georgian Bay and the main basin were most similar. Their benthic communities were comprised predominantly of *Dreissena r. bugensis*, oligochaetes, *S. heringianus,* and Enchytraeidae (Karatayev et al., 2020). Differences in community composition were identified in areas invaded with dreissenid mussels compared to areas without. Areas hosting dreissenids were found to have increased densities of immature and unidentifiable Oligochaeta, Lumbriculidae, and Tubificidae, all members of the phylum Annelida. Areas devoid of dreissenid aggregations were found to have higher densities of *Diporeia* and *Pisidium,* a native freshwater mussel (Karatayev et al., 2020). In Georgian Bay, *Dreissena r. bugensis* biomass accounted for 98% of total wet biomass observed in the 2017 CSMI, similar to that of the main basin where they accounted for 99% of total wet biomass.

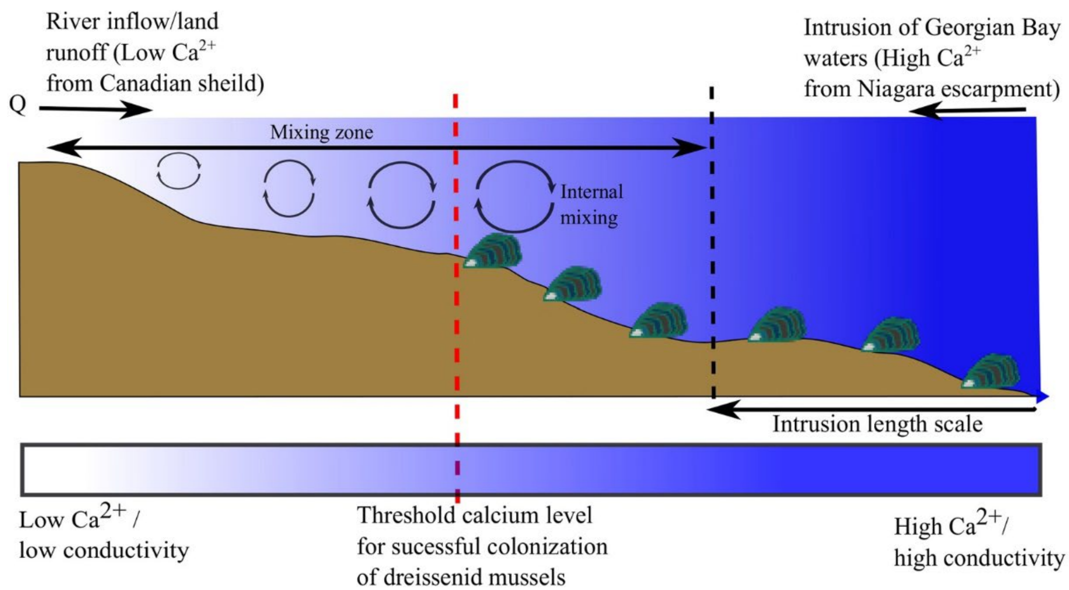

Figure 18. The solute gradient present in nearshore eastern Georgian Bay limiting Dreissenid colonization in waters below the calcium threshold (Figure from Girihagama et al., 2022).

In terms of *Diporeia,* Georgian Bay has experienced a declining trend between 2002 and 2017. Mean *Diporeia* densities across all depth intervals ranged from 50-100 individuals/m^2 in 2007 whereas in 2002, the same range had been 1400-1700 individuals/m^2. During 2012 surveys, *Diporeia* were found only at the 0-30 m depth interval with a mean of 3 individuals/m^2. Five years later in 2017, the range in mean densities was 2-5 individuals/m^2 at the shallowest and deepest depth intervals (Karatayev et al., 2020).

3. PREY FISH

3.1 INTRODUCTION

The prey fish component of the fish community refers to species that consume invertebrates for their entire life history, including pelagic, benthopelagic, and benthic species (EC & EPA, 2014). 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. Healthy, functional fish communities incorporate healthy populations at all levels of the food web. 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).

Historically, Lake Huron prey fish available in colder regions of the lake consisted of a mix of native species such as deepwater ciscoes (including bloater *(Coregonus hoyi)*, cisco/lake herring (*Coregonus artedi*), and several other species that are now extirpated), sculpins (*Cottus spp.*), ninespine stickleback (*Pungitius*

pungitius), and trout-perch (*Percopsis omiscomaycus*) (DesJardine et al., 1995; EC & EPA, 2014). In addition, spottail shiners (*Notropis hudsonius*), emerald shiners (*Notropis atherinoides*), young ciscoes and whitefishes (*Coregonus spp.*), and yellow perch (*Perca flavescens*) were also seasonally important in the diet of nearshore predators (DesJardine et al., 1995).

Over the past century, the Lake Huron prey fish community has been dramatically altered and is now comprised of a mix of native and non-native species. From the 1970s to the early 2000s, the prey fish community became dominated by introduced, non-native alewife (*Alosa pseudoharengus*) and rainbow smelt (*Osmerus mordax*) (Riley et al., 2020). In 2004, the alewife population collapsed and since that time, Lake Huron prey fish as a whole have experienced significant declines, including record low abundances of rainbow smelt and native sculpin species (Hondorp et al., 2022a). While no single species has filled the niche left by alewife, bloater and emerald shiner have experienced periodic increases in biomass, potentially in response to the absence of alewife (Riley et al., 2020). The invasive round goby is believed to have become a significant prey item that until recently, has been very difficult to survey. Increases in cisco numbers have also been observed since 2015 in Georgian Bay and the North Channel (Hondorp et al., 2022a). Lake Huron fishery managers began a cisco reintroduction program in Saginaw Bay in 2018 given that this was once the most important spawning habitat in Lake Huron for this once prominent prey fish. Ciscoes from gamete sources in northern Lake Huron are reared in hatcheries for 4-8 months with the goal of releasing 1,000,000 fish annually. Despite intermittent increases of select species, overall prey fish biomass remains low, creating a potential food web imbalance.

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 (He et al. 2015). Reduced primary and secondary production, which are hypothesized to be associated with decreased phosphorus availability in the offshore (LimnoTech, 2015b), and disruptions in the nearshore-offshore energy exchange induced by dreissenid mussel invasion (Barbiero et al., 2018), present a bottom-up limitation that could be negatively influencing growth and survival of fish or their larvae (Kao et al., 2016; Hondorp et al., 2022a; LHPWG, 2016). Adding to this bottom-up limitation is the changing composition of the crustacean zooplankton community, including the decline of *Diporeia,* an important prey for alewife, and the introduction of predatory zooplankters (e.g., spiny water flea (*Bythotrephes longimanus*)) (EC & EPA, 2014; Hondorp et al., 2022a; LHPWG, 2016; Nalepa et al., 2007). Given this combination of top-down and bottom-up pressures, prey fish may be 'squeezed' by adjacent trophic levels (Bunnell et al., 2014; 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. The Great Lakes Fisheries Commission's Science Transfer Program convened a team to address questions on changes in the aquatic food web, specifically nutrient impacts on lower trophic levels and how lower trophic level changes may impact the overall food web (Stewart et al., 2022). A model was developed indicating a positive relationship between total phosphorus concentration and total fish biomass, due to the correlation both have with algae – found in the lowest trophic level (Stewart et al., 2022). Despite this positive correlation, explanations for fishery-related events are not simple and often involve a variety of factors (Stewart et al., 2022).

3.2 HOW ARE PREY FISH POPULATIONS STUDIED IN EASTERN GEORGIAN BAY?

As described in the following sections, 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.

Prey fish are captured, incidentally or otherwise, in surveys other than those described in the following sections (e.g., Broadscale Monitoring, Offshore Index Assessment Program, End of Spring Trap Netting). 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 reports based on these surveys do not describe the state of the prey fish community.

3.2.1 Great Lakes Science Center

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 (Figure 19). 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, rainbow smelt, and bloater are separated into size-based age classes for analysis.

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 (first survey conducted in 1997) in each of the three basins of Lake Huron – main basin, North Channel, and Georgian Bay (Figure 19). 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 cut-offs. The density (fish/ha) and biomass (kg/ha) of individual species are estimated. Results from the integrated surveys of offshore pelagic prey fish are reported along with results from the offshore demersal fish bottom trawl surveys each year by the GLSC.

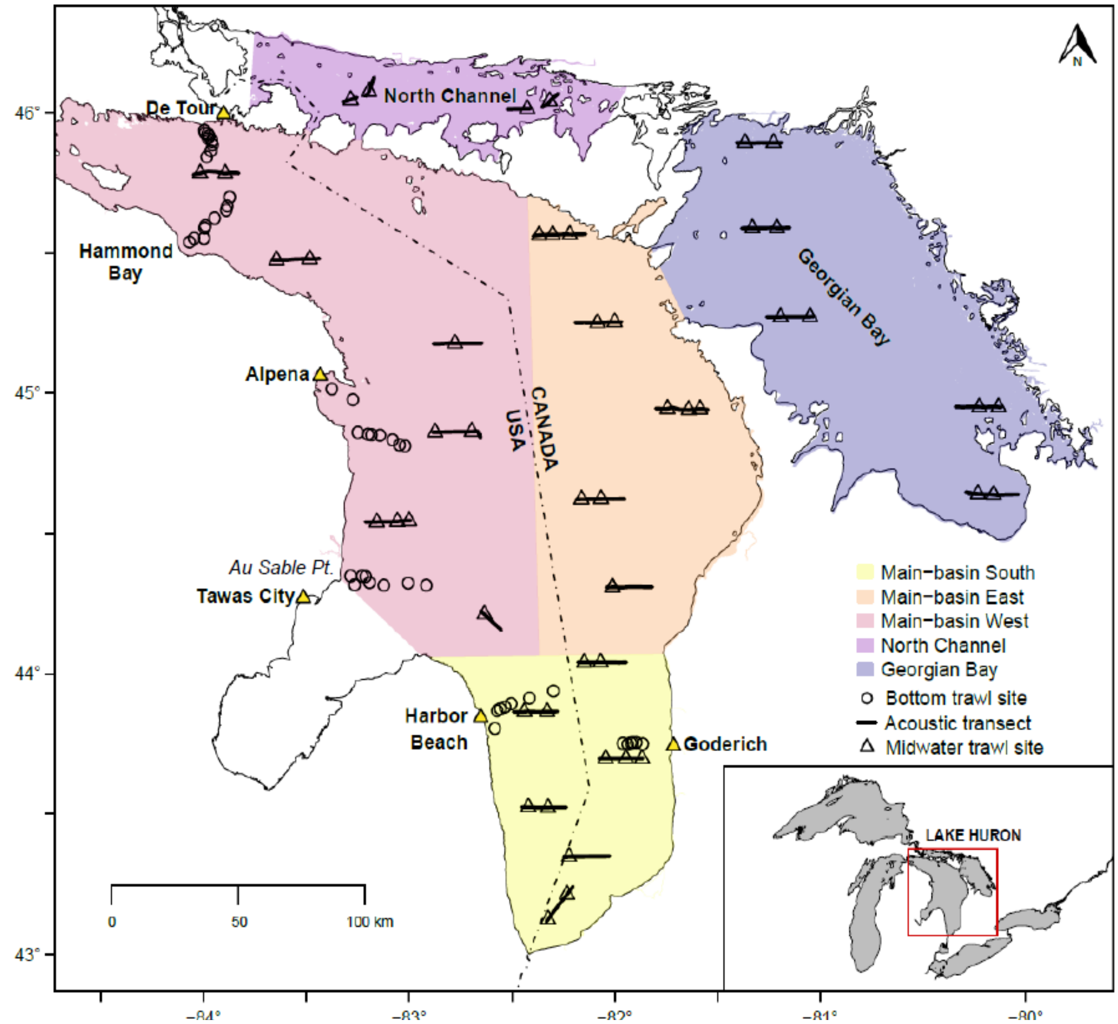

Figure 19. Location of bottom trawls, acoustic transects, and mid-water trawls sampled in Lake Huron by the USGS GLSC. Acoustic sampling strata (shaded areas) correspond to geographic regions: main-basin east, main-basin west, main-basin south, Georgian Bay, and North Channel (Figure from Hondorp et al., 2022a).

The invasive round goby is noted as being difficult to estimate abundance given that they tend to concentrate in nearshore and/or rocky habitats which are not conducive to bottom trawl surveys. The GLSC is employing new technologies such as the GobyBot to better study round goby and their habitat. GobyBot is an autonomous underwater vehicle that utilizes high resolution video and images to identify and quantify fish species found on the lake bottom (Liskauskas, 2022). In 2021, 150 km of GobyBot transects were collected in US waters of Lake Huron and an additional 300 km were planned for Canadian waters in summer 2022 (Esselman & Madenjian, 2022). Improving understanding of round goby status and trend is important for a number of reasons. Round goby compete with native bottom-dwelling species, prey on eggs and fry of native fish species, consume invasive dreissenid mussels, and are now also an important food source for native predator species.

3.2.2 Upper Great Lakes Management Unit

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 1996. 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 Environment and Climate Change Canada (ECCC) to supplement the traditional UGLMU Small Fish 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.

Up until 2019, the Small Fish 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, fork length, and round weight for non-native 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. Catch-per-unit-effort (CPUE) and biomass-per-unit-effort were calculated for several key subpopulations – invasive species, prey base, and sport fish.

Each July from 2014-2017, the MNRF (Aquatic Research and Monitoring Section) conducted hydro-acoustic surveys in Parry Sound 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. Surveys were conducted at night and a singly survey covered 59.8 km of transects over the course of two nights. In 2014 and 2015, a single survey was completed. The following two years, two replicate surveys were completed each year. Transects were designed to maximize coverage of pelagic habitats in Parry Sound (Trumpickas et al., 2020).

Similar to the GLSC, the ULGMU is testing out new methodologies to better understand round goby abundance. In the Owen Sound area an electrofishing unit was used alongside an underwater camera to count round gobies along 34 transects 30 to 50 m in length. The electrofishing device with an attached GoPro camera was lowered to the lake bottom at 1 m depth intervals and shocked for 10 seconds before moving to the next depth interval. Broadscale monitoring and small fish assessment projects in the area were undertaken simultaneously allowing the electrofishing results to be compared with Fyke nets and small mesh gill nets.

3.2.3 Cooperative Science and Monitoring Initiative

The U.S. Environmental Protection Agency (EPA), USGS, and National Oceanic and Atmospheric Administration (NOAA) collaborated on a Cooperative 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 20). 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. At the time of writing, methodology and results for the 2022 CSMI were not yet available. However, in the lead up to the 2022 CSMI field year, participating agencies identified priorities to guide their work. Priorities for the 2022 CSMI year included further studies of the Lake Huron food web, more specifically:

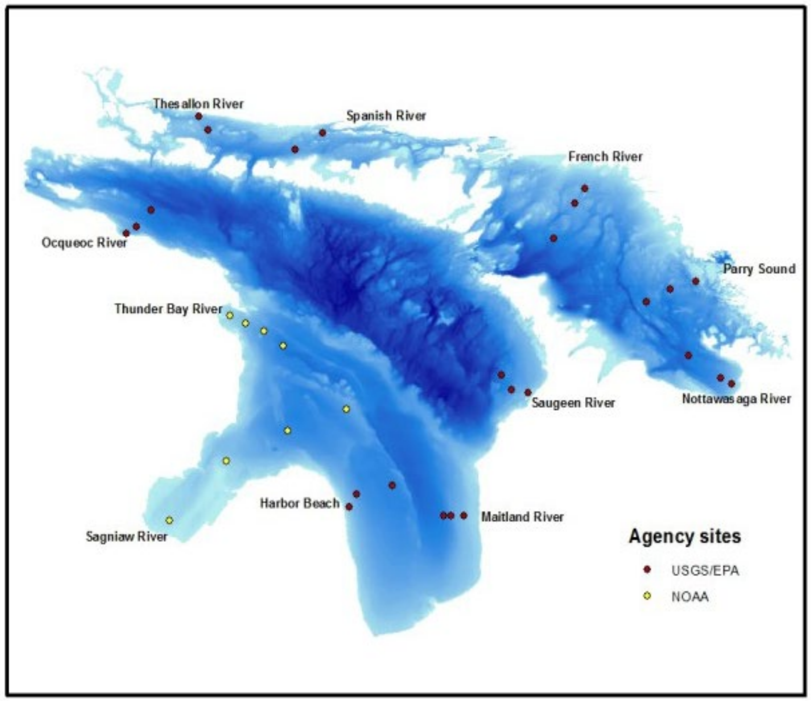

Figure 20. CSMI food web study nearshore to offshore transects (Figure from Clark, 2017).

- Understanding the movement of nutrients and energy (how this influences food webs, nutrient sinks, sources, and recycling, invasive species, and nearshore versus offshore).
- Improving biomass estimates for under-sampled components of the food web (e.g., zooplankton, benthos (including dreissenids), macro algae), fish production and distribution, and increasing the spatial sampling of pelagic invertebrates and larval fish.
- Increasing understanding of the role invasive species have on food web dynamics with a focus on the link between benthic/nearshore and pelagic/offshore environments.

3.3 WHAT ARE THE RESULTS?

This report utilizes the most recent available data and summaries from the following sources: *Status and Trends of the Lake Huron Prey Fish Community, 1976-2019* (Hondorp et al., 2022a), *1976-2020* (Hondorp et al., 2022b), and *1976-2021* (O'Brien et al, 2022); the "Status of offshore prey fish in Lake Huron in 2018" chapter of the *State of Lake Huron in 2018* (Riley et al., 2020); and the UGLMU's *Lake Huron CSMI Nearshore Biodiversity and AIS Monitoring* presentation (Ritchie, 2019). The results that follow are presented in order from general to specific starting with Lake Huron and Georgian Bay results, followed by eastern Georgian Bay results. Finally, an overall summary is provided in relation to trends.

3.3.1 Lake Huron and Georgian Bay

At the time of writing, 2019 and 2021 results were the most recent lake-wide and Georgian Bay specific results available from USGS GLSC bottom trawl and acoustic surveys. United States research vessels were not permitted to enter Canadian waters for surveys in 2020 due to the COVID-19 pandemic. Lake-wide results are presented here unless stated otherwise.

In Lake Huron, the peak estimated prey fish biomass occurred in the late 1980s and has generally declined since, with a notable collapse in 2004 (Hondorp et al., 2022b). In 2021, prey fish biomass in the main basin averaged 17.5 kg/ha, as estimated by bottom trawl surveys, and 12.5 kg/ha as estimated by acoustic surveys (O'Brien et al., 2022). The same year prey fish biomass averaged 8.6 kg/ha as estimated by acoustic surveys (O'Brien et al., 2022). These figures are well below levels observed during the early 2000s before basin-wide declines in prey fish biomass occurred (Figure 21). Bloater and rainbow smelt dominated the prey fish community in 2021, accounting for 92% (acoustic) and 90% (bottom trawl) of estimated biomass (O'Brien et al., 2022). These species have been the most abundant species in bottom trawl surveys since the alewife collapse in 2004.

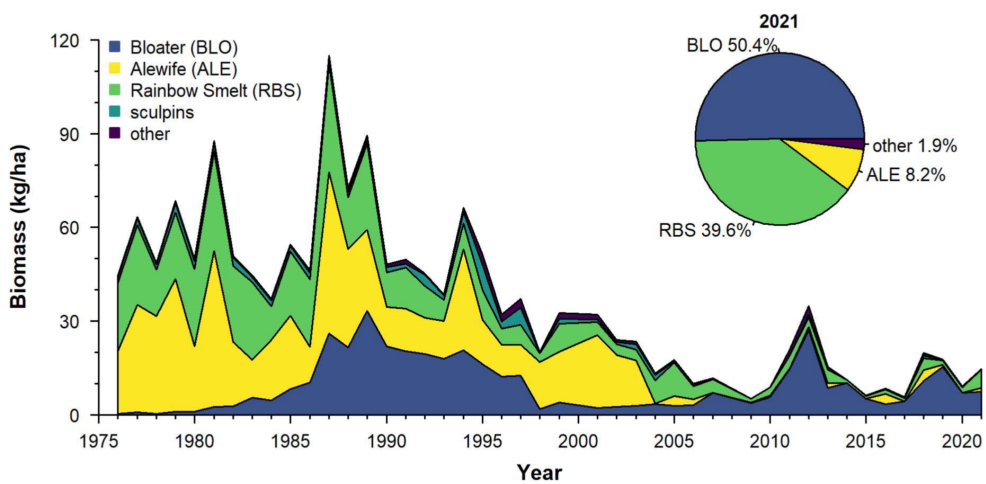

Figure 21. Prey fish biomass and species composition in the region sampled by the bottom trawl (9-110m depth) in Lake Huron from 1976-2019 (Figure from O'Brien et al., 2022).

Bloater biomass has fluctuated considerably over the time series (Hondorpo et al., 2022b). Biomass of yearling-and-older (YAO) bloater increased from 2017 to 2019 which was the highest observed since the 2012 peak based on the bottom trawl survey, and the highest lake-wide estimate observed in the time series based on the acoustic survey (Hondorp et al., 2022b). Since this 2019 high, YAO biomass has leveled off through 2020 and 2021, but 2021 survey bloater estimates were still consistent with the observed increased biomass since 2017 (O'Brien et al., 2022). In 2019, densities of young-of-the-year (YOY) bloater were the highest observed for both the bottom trawl and acoustic time series (Hondorp et al., 2022b). However, 2021 surveys estimated the second year of declines (O'Brien et al., 2022). In contrast, acoustic surveys – which were conducted in Georgian Bay and the main basin – estimated an increase in YOY bloater densities (O'Brien et al., 2022). Since the crash of alewife in 2004, large bloater year classes have occurred more often, believed to be related to the hypothesized negative effect of alewife on bloater recruitment.

Lake-wide biomass of rainbow smelt is currently low relative to historic levels. No distinct trends have been observed in lake-wide biomass since 2004 (Hondorp et al., 2022b). In 2019 and 2021, rainbow smelt were most abundant in Georgian Bay and the North Channel, dominating those prey fish communities and contrasting the main basin where bloater accounts for the greatest biomass (Hondorp et al., 2022b; O'Brien et al., 2022). The 2017 CSMI study estimated the energetic condition of rainbow smelt in different basins of Lake Huron and compared them to western Lake Erie, one of the most productive regions of the Great Lakes (Dai et al., 2019). Dai et al. (2019) reported rainbow smelt from Georgian Bay to have the lowest energy density among any of the Lake Huron sites and lower than what was measured in western Lake Erie. Hence, the declining productivity in Georgian Bay has had consequences for the energetic condition of prey fishes like rainbow smelt.

Prior to 2004, alewife were the most or second most abundant prey species in Lake Huron surveys. The *Status and trends of the Lake Huron prey fish community, 1976-2020* report suggests that adult alewife populations reached a historical low after the severe winter of 2002-2003 and the species' lack of recovery can be connected to restrictions from bottom-up and top-down forces (Hondorp et al., 2022a). Hondorp et al. (2022a) state that nutrient sequestration into dreissenid mussel biomass and a reduction in phosphorus inputs into Lake Huron likely caused alewife carrying capacity to be reduced to below historical levels. Since 2004, alewife abundance has been driven by sporadic catches of YOY fish. In 2019, alewife was the third most abundant species in bottom trawl catches with the largest concentrations of YOY alewife occurring offshore of the French River and in the western main basin north of Saginaw Bay. As lake trout populations recover, predation on alewife may ensure they remain below their current carrying capacity (Hondorp et al., 2022a).

Cisco numbers in Georgian Bay and the North Channel have increased since 2015 which Hondorp et al. (2022a) suggest could be indicative of current lake conditions favouring cisco recovery. Cisco are only sampled in acoustic surveys, which cover the main basin and Georgian Bay. After rainbow smelt and bloater, cisco made up the largest percentage of acoustic prey fish biomass in Georgian Bay in 2019, but cisco catch in the 2021 midwater trawls was low (Hondorp et al., 2022b; O'Brien et al., 2022). However, six adult cisco were still captured in 2021, two in Georgian Bay, and four in the North Channel (O'Brien et al., 2022).

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). A recent survey in Owen Sound lead by the UGLMU using high resolution underwater cameras and electrofishing devices estimated 118 million round goby during day surveys and 144 million during night surveys, amounting to over 200 thousand tons of round goby in the Owen Sound area (UGLMU unpublished data). Studies such as those carried out by the UGLMU and the GLSC and its GobyBot will help improve understanding of round goby abundance and biomass going forward. This is important as the species has become part of the diet of various native species including walleye, yellow perch, smallmouth bass, lake trout, and lake whitefish (Crane & Einhouse, 2016; Esselman et al., 2022; Reyjol et al., 2010; Roseman et al., 2014) and the species is likely directly impacting the lower food web through interaction with benthic invertebrates.

In summary, prey fish biomass in Lake Huron remains low. Hondorp et al. (2022a, p. 23) state that a return to historical levels of prey fish biomass is unlikely due to several factors, specifically, "reduced nutrient inputs, high predation levels by recovering piscivore populations (e.g., Lake Trout, Walleye), and changes in food web dynamics that potentially favour nearshore benthic species such as Round Goby". Furthermore, the authors assert that offshore prey fish communities in Lake Huron exhibit extremely low species diversity and as a consequence, are likely to be less resilient to climate change and other ecosystem-scale disturbances.

3.3.2 Eastern Georgian Bay

The UGLMU's Small Fish Community Assessment Program was run from 2003-2019. A summary report does not exist for all locations sampled over the life of the project. However, a 2019 report examines the project from 2007-2019 (years prior to 2007 were excluded due to variation in gear used) for the locations most recently sampled, including two eastern Georgian Bay locations – Britt and Blackstone Harbour (UGLMU, 2019g). The report states that the prey base is generally stable in Georgian Bay, with a small decline observed in Blackstone Harbour after 2014. Sampling locations in Georgian Bay are typically split between being dominated by Cyprinids (Minnows) and other fish species. In Britt, Cyprinids are becoming even more dominant, followed by Centrarchids (Basses). In Blackstone Harbour, Centrarchids are dominant and Cyprinids are less common, although they were more abundant in 2019. Biodiversity has remained relatively stable in Georgian Bay locations throughout the years and round goby abundance has remained low at less than 2% of the catch in all locations except Owen Sound (UGLMU, 2019g).

An earlier summary report discusses some high-level results for four additional eastern Georgian Bay locations sampled in 2016 – Deep Bay (Parry Sound), Sturgeon Bay, Shawanaga River, and Shebeshekong River (UGLMU, 2016a). 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, 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.

Hydro-acoustic surveys conducted in Parry Sound from 2014-2017 indicate that the pelagic community is dominated numerically by rainbow smelt, alewife, and cisco or lake herring (*Coregonus artedi*). The Parry Sound alewife population is notable given the low densities of alewife elsewhere in Lake Huron. Similarly, Parry Sound stands out for its lake trout population. Of the large-bodied fish species (>300 m total length) encountered in the surveys, lake trout were among the most common (Trumpickas et al., 2020).

3.3.3 Summary

The Lake Huron prey fish community continues to exhibit reduced diversity and biomass, but a higher representation of native species (Liskauskas, 2022). The *State of the Great Lakes 2022 Technical Report* highlights the status of Lake Huron prey fish as being fair with an 'unchanging' 10-year trend and an 'undetermined' long-term trend (ECCC & EPA, 2022b). 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.

4. SMALLMOUTH BASS

4.1 INTRODUCTION

As an important native predator of the nearshore warmwater fish community, smallmouth bass (*noosa owesi*, *Micropterus dolomieu)* are a useful indicator of aquatic ecosystem health. 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, their populations are impacted by human activities including harvesting and nearshore habitat disturbance/alteration. Populations are also impacted by summer temperatures, lake levels, and changes to the lower food web. The *Fish Community Objectives for Lake Huron* (DesJardine et al., 1995), *Environmental Objectives for Lake Huron* (Liskauskas et al, 2007), and the *Biodiversity Conservation Strategy for Lake Huron* (Taylor et al., 2010) each acknowledge the importance of sustaining smallmouth bass populations at or near their recent abundance or recreationally attractive levels.

4.2 HOW ARE SMALLMOUTH BASS POPULATIONS STUDIED IN EASTERN GEORGIAN BAY?

No surveys are routinely carried out specifically targeting the monitoring of smallmouth bass populations in eastern Georgian Bay. However, several types of surveys conducted by the Upper Great Lakes Management Unit (UGLMU) of the Ministry of Natural Resources and Forestry (MNRF) regularly capture smallmouth bass (e.g., End of Spring Trap Netting, Spring Muskellunge Index Netting, Spring Walleye Index Netting, Broadscale Fish Community Monitoring) (see Appendix A for a full list of UGLMU in surveys Georgian Bay from 2013-2020).

When captured in survey nets, smallmouth bass are sampled for fork and total length, round weight, sex, and age. Information regarding relative abundance, age structure, mortality, and maturity can be determined from these measures. Additional measures specific to a particular 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).

Research looking specifically at smallmouth bass in eastern Georgian Bay is limited, likely due to the fact that at this time, the species is widespread and abundant in the region.

4.3 WHAT ARE THE RESULTS?

For the purpose of this report, data presented in the UGLMU's End of Spring Trap Netting (ESTN) reports are utilized (see section 7.2 for a detailed description of ESTN). The ESTN reports are the most readily available, numerous, and cover the longest time period compared to reports for other types of surveys that also regularly capture smallmouth bass. Table 4 details smallmouth bass relative abundance calculated from individual ESTN surveys for nine populations within the *State of the Bay* reporting area. Average CPUE is also provided for each survey area.

Table 4. Smallmouth bass CPUE and average CPUE for eastern Georgian Bay ESTN surveys (Table compiled from UGLMU, 2016b, 2018d, 2019c, 2023).

Survey Area	Year	CPUE	Average CPUE
Byng Inlet	2005	3.4	4.6
	2011	5.7	
French River	2014	1.4	1.4
	2015	1.5	
Key River	1998	1.8	3.6
	2019	3.2	
	2022	5.7	
Moon River	2004	7.5	9.1
	2005	12.7	
	2008	5.7	
	2012	8.9	
	2013	10.8	
Parry Island Area	2010	1.2	1.2
Severn Sound	1999	7.5	9.5
	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	
	2017	3.4	
	2018	4.5	
Shawanaga River	2009	7.6	11.5
	2015	17.1	
	2016	9.9	
Twelve Mile Bay	2008	4.2	4.2
Wah-Wah-Taysee	2010	14.4	14.4

The smallmouth bass populations in the Shawanaga River area, Severn Sound, and Key River area are described in more detail in recent reports (UGLMU, 2016b, 2018d, 2019c). During the 2016 Shawanaga River area ESTN, smallmouth bass were caught in every valid net lift and were the most abundant fish sampled during the survey (UGLMU, 2016b). Data from 2009, 2015, and 2016 reveal that smallmouth bass continue to be a prominent species in the Shawanaga River area fish community with strong recruitment. This trend of successful recruitment is consistent with smallmouth bass populations in Georgian Bay more broadly since the mid-1990s.

Smallmouth bass were caught in 67% and 72% of trap net sets and were widely distributed throughout the survey area during the 2017 and 2018 Severn Sound ESTNs (UGLMU, 2018d; UGLMU unpublished data). They were the third most caught species in both years and represented the third and fourth highest biomass respectively in 2017 and 2018. Despite this, a CPUE of 3.4 (2017) and 4.5 (2018) smallmouth bass/net were the lowest seen in the time series. Relative abundance for all nearshore species declined and appears to have been decreasing since 2010, with smallmouth bass abundance having fallen the most. Smallmouth bass total length ranged from 220 mm to 534 mm with an average length of 385 mm, similar length distributions to 2013 data. A detailed report is not available for the ESTN survey conducted the following year in 2018.

Most recently, ESTN surveys were conducted in the Key River area in 2019 and 2022. The 2019 ESTN survey had a total of 55 net sets during the survey period capturing 956 fish, with smallmouth bass representing 18.3% of this total (UGLMU, 2019c). In the Key River, smallmouth bass were the second most caught species and represented the third highest biomass (CPUE 3.2), similar to the 2017 Severn Sound ESTN. Average size for smallmouth bass in the Key River was 385 mm with a maximum size of 576 mm. In 2022, smallmouth bass were the species caught the most often (23.8% of total catch) with a CPUE of 5.7. The average size of smallmouth bass in the Key River was 395 mm with a maximum size of 525 mm.

In summary, the available smallmouth bass relative abundance data as presented in the ESTN reports suggests that there are no definitive trends. Accordingly, the smallmouth bass populations across eastern Georgian Bay are described as ‘unchanging’. However, *The State of Lake Huron in 2018* report states that smallmouth bass populations appear to be increasing in several areas of the lake (Fielder et al., 2020). Evidently, enhanced spatial and temporal coverage of smallmouth bass data for eastern Georgian Bay would be ideal. 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 trends through time.

The *State of Lake Huron in 2018* report suggests that 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*) (Fielder et al., 2020). In fact, it appears that smallmouth bass have benefited from feeding on round goby (Fielder et al., 2020; LimnoTech, 2015b), a relationship that has also been observed in other parts of the Great Lakes (Crane & Einhouse, 2016; Kaemingk et al., 2012). Smallmouth bass populations in eastern Georgian Bay are said to be comprised of broad size ranges, multiple year-classes, and abundant juveniles, all signs of strong recruitment (Fielder et al., 2020).

Smallmouth bass populations in the Great Lakes may also be benefitting from warming waters in response to climate change. Parker (2019) states that fish communities across Ontario’s Great Lakes have been increasing their range northward by 12-17 km per decade. For smallmouth bass, this means range expansion into new habitats which were once too cold (Parker, 2019). While this range expansion may be viewed favourably by anglers, the introduction of smallmouth bass to areas where they were not previously found can have negative consequences for the ecosystem as a whole. For example, Alofs et al. (2014) report that across the province, range expansion by smallmouth bass is predicted to extirpate more than 25,000 populations of several small cyprinid species. Future monitoring in eastern Georgian Bay could potentially reveal increasing trends in smallmouth bass populations based on this combination of increased habitat and a prolific food source in round goby.

5. NORTHERN PIKE

5.1 INTRODUCTION

Northern pike (*gnoozhe, Esox lucius*) are a native top predator in nearshore waters and embayments. Based on the status of northern pike populations, insights can be drawn regarding the productivity and health of the nearshore food web. Northern pike status can also be used to understand the state of coastal wetlands as the species is reliant on functional coastal wetlands for successful spawning and nursery habitat. Therefore, reproductive success of northern pike is tied to changes in habitat availability and quality.

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). Today, northern pike are not a highly sought-after species in the Georgian Bay commercial fishery. In 2020, commercial catch of northern pike in Georgian Bay amounted to 108 kg, roughly 3% of the allowable quota (UGLMU, 2022a).

Conversely, northern pike are an important sport fish, facing substantial fishing pressure in Georgian Bay. However, recreational fishing harvest rates have fallen from an average of 5,000 fish in Severn Sound through the 1980s and 1990s to 1,200 more recently. This drop is likely a result of reduced fishing effort, more restrictive harvest regulations, and more catch and release (Fielder et al., 2020).

5.2 HOW ARE NORTHERN PIKE POPULATIONS STUDIED IN EASTERN GEORGIAN BAY?

There are no surveys routinely carried out specifically targeted at understanding northern pike populations. Nevertheless, several types of surveys conducted by the Upper Great Lakes Management Unit (UGLMU) of the Ministry of Natural Resources and Forestry (MNRF) routinely capture northern pike (e.g., End of Spring Trap Netting, Spring Muskellunge Index Netting, Spring Walleye Index Netting, Broadscale Monitoring) (see Appendix A for a full list of UGLMU in surveys Georgian Bay from 2013-2020).

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

Northern pike have also been studied in eastern Georgian Bay in relation to coastal wetland habitat and water level changes. Persistent low water levels in Georgian Bay from 1999 to 2013, and the subsequent decrease in plant biodiversity in coastal wetlands, led to declines in habitat for fish such as the northern pike (Fracz & Chow-Fraser, 2013). Impacts on this species are noted in work by Montocchio and Chow-Fraser (2021), discussing how water level changes affect coastal wetlands in eastern Georgian Bay and how these water level changes impact the performance of ecological indices. Montocchio and Chow-Fraser (2021) look at the impacts of human disturbance and water level changes on three indices, the Water Quality Index (WQI), Wetland Macrophyte Index (WMI), and Wetland Fish Index (WFI). Their study found that water level changes had a limited impact on the WMI and WFI scores, the two indices of note for northern pike. However, changes in submerged aquatic vegetation (SAV), a critical habitat component for fish communities such as northern pike, were noted between water level periods. More meadow species and fewer SAV species were documented during the high-water period following the low period. Montocchio and Chow-Fraser (2021) reason that the meadow species which established during low water conditions did not allow for SAV to return to the flooded areas under high water conditions. It is emphasized that the WMI does not indicate changes in macrophyte biodiversity which other studies have shown to decrease under low water levels, supporting a less diverse community of SAV and providing less suitable habitat for northern pike (Montocchio & Chow-Fraser, 2021; Weller & Chow-Fraser, 2019b, 2019a).

5.3 WHAT ARE THE RESULTS?

This report utilizes data presented in the End of Spring Trap Netting (ESTN), Fall Walleye Index Netting (FWIN), and Spring Muskellunge Index Netting (SMIN) reports (see section 7.2 for a detailed description of ESTN and FWIN, and section 3.6.2 for a description of SMIN).

Table 5 lists relative abundance, as measured by CPUE, for nine northern pike populations within the *State of the Bay* reporting area. This includes CPUE calculated from ESTN, FWIN, and SMIN surveys. Also included in the table is mean total length based on ESTN surveys. Although total length is not considered in the fish community objective for northern pike (DesJardine et al., 1995), large individuals are the main focus of sport fishing targeting this species.

Table 5. Northern pike CPUE and mean total length for eastern Georgian Bay ESTN, FWIN, and SMIN surveys (Table compiled from UGLMU, 2016b, 2018a, 2018d, 2019b, 2019d, 2022b, 2023; UGLMU unpublished data).

Survey Area	Year	CPUE (ESTN)	Average CPUE (ESTN)	CPUE (FWIN)	CPUE (SMIN)	Mean Total Length (mm)
Byng Inlet	2005	0.4	0.5			775
	2011	0.5				637
French River	2014	0.5	0.6	1.04		631
	2015	0.7				582
Key River	1998	1.4	1.2			633
	2019	1.2		0.58	2.09*	653
	2022	1.0				
Magnetawan River	2022				1.8*	552
Moon River	2004	2.4	2.1			639
	2005	2.0				672
	2008	3.4				591
	2012	1.5				607
	2013	1.3				660
Parry Island / Wasauksing Area	2010	0.6	0.6			677
Severn Sound	1999	2.4	4.0			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
	2013	7.7				646
	2017	1.1		1.77	3.49*	612
	2018	1.4		1.28	6.37* 2.62**	658
Shawanaga River	2009	1.3	1.2			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	1.0			658
Wah-Wah-Taysee	2010	1.4	1.4			717

*trap net CPUE, **hoop net CPUE

The northern pike population in Severn Sound is described in more detail in the 2017 Severn Sound ESTN report (UGLMU, 2018d) and a 2018 Spring Walleye Index Netting (SWIN) summary presentation (UGLMU, 2018a). During the 2017 and 2018 Severn Sound ESTN, northern pike were captured in 50.9% and 56.6% of the trap net sets and were widely distributed throughout the survey area. Despite widespread distribution, a CPUE of 1.1 and 1.4 represents some of the lowest catch rates for northern pike in the time series. Conversely, during the 2018 SWIN, covering a much more limited sampling area, northern pike CPUE was 15.9 with northern pike making up 39% of the catch, up 20% from the 2017 SWIN.

Most recently, ESTN and SMIN surveys were conducted in the Key River area in 2019 and 2022. The 2019 ESTN survey caught northern pike averaging 653 mm with the largest being 1080 mm (UGLMU, 2019c). ESTN northern pike CPUE was 1.2 in 2019 and 1.0 in 2022. The 2019 SMIN survey involved 22 trap net lifts and captured a total of 3,896 fish with 17 different species, northern pike representing 1.18% of the total catch (UGLMU, 2019e). The 2022 Key River ESTN survey caught 48 northern pike averaging 666 mm in 49 net lifts (UGLMU, 2023). The 2022 Magnetawan River SMIN caught 22 northern pike averaging 552 mm with a CPUE of 1.8 (UGLMU, 2022b).

As with smallmouth bass, greater spatial and temporal coverage of northern pike data is necessary to properly comment on trend through time. Based on the data that are available, levels of abundance do not show any definitive trends and are therefore described as ‘unchanging’.

The “Status of Nearshore Fish Communities in Lake Huron in 2018” chapter of *The State of Lake Huron in 2018* report (Fielder et al., 2020) describes northern pike populations in different parts of the lake, including Georgian Bay. The report indicates that Georgian Bay northern pike relative abundance remained low during the current reporting period of 2011-2017 and was similar to levels observed during the previous reporting period of 2005-2010. This is believed to be a response to low lake levels that persisted until 2013. The report also cites evidence of increased recruitment within the 2011-2017 reporting period, particularly around Severn Sound, Moon River, Shawanaga River, and French River. Severn Sound is described as having an age structure dominated by younger year classes with few large adults. The Moon, Shawanaga, and French Rivers, on the other hand, showed a broad size structure including older and larger adults (Fielder et al., 2020).

6. MUSKELLUNGE

6.1 INTRODUCTION

Muskellunge (*maashkinoozhe*, *Esox masquinongy)* are a native apex 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, 2017). 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.

6.2 HOW ARE MUSKELLUNGE POPULATIONS STUDIED IN EASTERN GEORGIAN BAY?

The Upper Great Lakes Management Unit (UGLMU) of the Ministry of Natural Resources and Forestry (MNRF) has been assessing muskellunge populations in eastern Georgian Bay since 1996. Collecting data related to spawning stocks facilitates the management of self-sustaining muskellunge populations which is the primary management goal for the species in Ontario. 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 on as well. These two measures are considered in this report, as abundance and size are indicators of the species' overall health.

The UGLMU's assessment of muskellunge populations in Georgian Bay has primarily involved Spring Muskellunge Index Netting (SMIN) (UGLMU, 2008). The SMIN protocol was designed by the UGLMU specifically to assess muskellunge populations during the spawning run. The 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).

Since the last *State of the Bay* report was published, four additional targeted muskellunge spawning surveys (SMINs) have been conducted in eastern Georgian Bay, two in Severn Sound, and two in the Key River area. Muskellunge are also occasionally captured incidentally during other surveys including Spring Walleye Index Netting (SWIN), End of Spring Trap Netting (ESTN), Fall Walleye Index Netting (FWIN), and Fall Littoral Index Gill Netting (FLIN) (see Appendix A for a full list of UGLMU in surveys Georgian Bay from 2013-2020).

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, the MNRF-sponsored programs and the Muskies Canada Incorporated (MCI) angler diary program. The 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.

Muskellunge in eastern Georgian Bay have also been the focus of research studies looking at coastal wetlands and water level changes. Coastal wetlands along eastern Georgian Bay require fluctuations in water level to maintain plant diversity and produce high-quality habitat for fish communities (Weller & Chow-Fraser, 2019a). As lake levels change over time, the extent and makeup of coastal wetland habitats change as well (Leblanc et al., 2014; Weller & Chow-Fraser, 2019b). Historically, Lake Huron has undergone 2 m fluctuations in water level, however, persistent low water conditions from 1999 to 2013 created a new dynamic (Weller & Chow-Fraser, 2019b). A key component of eastern Georgian Bay's low marsh habitat is submerged aquatic vegetation (SAV). Diverse communities of SAV provide critical nursery habitat for muskellunge (Montocchio & Chow-Fraser, 2021). During times of persistent low water levels, coastal wetlands can be expected to shift towards more homogenous structures, supporting less SAV and thus, less suitable nursery habitat for muskellunge (Montocchio & Chow-Fraser, 2021; Weller & Chow-Fraser, 2019a, 2019b). Due to the site fidelity exhibited by muskellunge in Georgian Bay, there is a need to protect nursery habitat which may be susceptible to changes under low water conditions and understand both resilient and vulnerable muskellunge habitat along eastern Georgian Bay (Weller et al., 2016; Weller & Chow-Fraser, 2019a; Wilson et al., 2016).

6.3 WHAT ARE THE RESULTS?

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 the 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.

Figure 22 presents the average muskellunge catch (CPUE) in 10 target areas across a portion of the UGLMU's assessment period (1996-2018) (Liskauskas, 2020). Most recently, SMIN surveys were conducted in the Key River area in 2019 and 2022, Severn Sound in 2017 and 2018, and the Magnetawan River area in 2022. Possibly due to survey timing, the 2019 Key River area SMIN did not result in any muskellunge captures (CPUE 0.0). However, 10 muskellunge (6 males, 3 females, 1 unknown) were captured incidentally during an ESTN survey in the area that same year. Total length information is summarized in Table 6, along with information from other recent surveys for comparison.

A total of 25 muskellunge (18 males, 7 females) were captured in the 2017 Severn Sound SMIN with an additional 10 (6 males, 3 females, 1 unknown) available for biological sampling from a SWIN survey near Port Severn and an ESTN survey in the Severn Sound area. In 2018, a total of 7 muskellunge (3 males, 4 females) were captured during the SMIN and an additional 4 (1 male, 2 female, 1 unknown) were available for biological sampling from the SWIN and ESTN. Trap net CPUE for 2017 is reported as 0.31, and 0.12 in 2018. Hoop net CPUE is reported for 2018 only and is 0.15. Six previously tagged fish were captured in 2017 (one from 2005) and four in 2018 (one from 2013).

The 2022 Magnetawan River area SMIN resulted in the capture of 36 muskellunge for a CPUE of 0.7, 3 additional muskellunge were caught during ESTN surveys for a total of 39 muskellunge (20 males, 11 females, 8 unknown) caught across the two surveys.

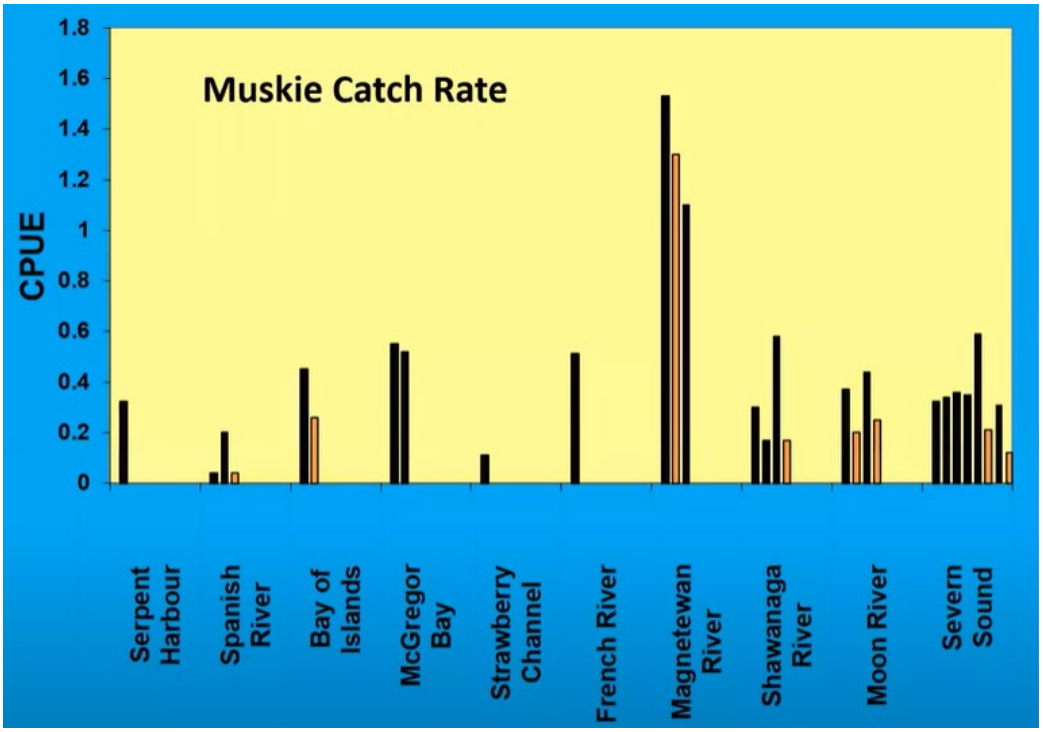

Figure 22. Average Muskellunge CPUE in UGLMU assessment sites from 1996-2018 (Figure from Liskauskas, 2020).

Table 6. Summary of muskellunge average total length information for locations in eastern Georgian Bay (Table compiled from UGLMU, 2013, 2015, 2017, 2018c, 2019e, 2022b).

Location	Year	Male total length average	Female total length average	Longest and heaviest fish
Severn Sound	2013	985 mm (33.8 in)	1,196 mm (47.1 in)	Female – 1,410 mm (55.5 in), 20.5 kg (45.2 lb)
Severn Sound	2017	1,071 mm (42.2 in)	1,254 mm (49.4 in)	Female – 1,370 mm (54 in), 14.8 kg (33 lb)
Severn Sound	2018	1,057 mm (41.6 in)	1,148 mm (45.2 in)	Female – 1,315 mm (51.8 in), 15.5 kg (34.1 lb)
Shawanaga River Area	2015	1,083 mm (42.6 in)	1,175 mm (46.3 in)	Female – 1,338 mm (52.7 in), 18.0 kg (39.7 lb)
Key River Area	2019	993 mm (39.1 in)	1,130 mm (44.5 in)	Female – 1,305 mm (51.4 in), 17.5 kg (38.5 lb)
Magnetawan River	2022	999 mm (39.3 in)	1,112 mm (43.8 in)	Female – 20.3 kg (44.8 kg)

Angler diary records were collected from 1979 to 2015 and compiled in various reports and journal articles (Kerr, 2004, 2007; Taillon & Heinbeck, 2017). The MNRF-sponsored and MCI angler diary programs provide information on Ontario muskellunge sport fisheries from experienced, specialized anglers targeting muskellunge. The available data suggests that overall, Ontario's muskellunge fisheries appear to be stable and sustainable. The most recent data (1995-2015) published in a report by Taillon and Heinbuck (2017), states 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 & Heinbeck, 2017). 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 in 2012 and 2013, young-of-the-year (YOY) muskellunge were not 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 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". To begin addressing the need for the protection of suitable muskellunge spawning habitat, Weller and Chow-Fraser (2019a) developed a multi-scale resilience index to allow for the identification of wetlands in eastern Georgian Bay which are resilient to low lake levels. They noted that the differences in the presence/absence of YOY muskellunge in southeastern Georgian Bay (SEGB) and northern Georgian Bay (NGB) identified by Leblanc et al. (2014) may stem from hydrogeomorphic features that increase the suitability of NGB coastal wetlands over SEGB coastal wetlands, where YOY muskellunge were not found (Weller & Chow-Fraser, 2019a).

In summary, the UGLMU has been assessing muskellunge populations in eastern Georgian Bay since 1996; these surveys have confirmed the widespread distribution and presence of mature muskellunge throughout this area. Accordingly, muskellunge populations in eastern Georgian Bay appear to be 'unchanging' and sustainable. Nevertheless, there is continued concern over the potential for high-quality spawning and nursery habitat to become degraded and subsequently impact reproduction and recruitment. It is also important to note that YOY muskellunge were absent in historically confirmed nursery habitat during a 2014 study in southeastern Georgian Bay (Leblanc et al., 2014) following years of low water levels. At the time of writing, reports from more recent surveys for YOY muskellunge in southeastern Georgian Bay were not available. Further studies are needed to determine whether recruitment has improved in this area since water levels have come back up.

7. WALLEYE

7.1 INTRODUCTION

Walleye (*ogaa, Sander vitreus*) are a top predator of the coolwater, nearshore community. Healthy walleye populations suggest productivity and health of the nearshore food web. 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. In fact, they are considered the most sought after and caught sport fish in Ontario (Fisheries and Oceans Canada, 2019; Lester et al., 2000). Moreover, walleye are an important species for Indigenous communities for food, ceremony, and commerce.

Historically, Georgian Bay was renowned for its abundant walleye populations and the considerable size of many fish. 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. The Fish Stocking Information System (FSIS) provides stocking records for walleye going back to 1985, with around 23 different areas being stocked across Lake Huron. The most extensive walleye stocking has been undertaken in the Shawanaga River (13.8 million) and Moon River (8.7 million) (UGLMU, 2019a). The overwhelming majority of that stocking has involved fry (80%), with some summer fingerling (~10%) and eyed egg (~10%) stocking as well (UGLMU, 2019a). However, these efforts have been met with variable degrees of success. It should also be noted that previous studies of walleye genetics including Georgian Bay (Gatt et al., 2002; Stepien et al., 2010) have shown many genetically distinct native population stocks remain and that caution should be exercised when selecting brood sources for stocking programs in order to preserve this adaptive diversity.

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* (Taylor et al., 2010), and by their continued use as an indicator in the *State of the Great Lakes* reports. Furthermore, the Upper Great Lakes Management Unit is in the process of drafting a Walleye Management Plan for Ontario waters.

7.2 HOW ARE WALLEYE POPULATIONS STUDIED IN EASTERN GEORGIAN BAY?

Several types of netting methods are used to gather information on walleye in eastern Georgian Bay, 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 undertaken in eastern Georgian Bay by the Upper Great Lakes Management Unit (UGLMU) of the Ministry of Natural Resources and Forestry (MNRF), and intermittently by the Anishinabek/Ontario Fisheries Resource Centre (AOFRC) and the French River Stewardship Council (FRSC) (see Appendix A for a full list of UGLMU in surveys Georgian Bay from 2013-2020).

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 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.

More recently, the UGLMU has also started using the BsM survey type to describe walleye populations and the broader fish community. 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 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. In Lake Huron, this program runs from mid-June to mid-September when surface water temperatures are 18°C and above. Sampling of fish is similar to that of the FWIN protocol.

The Eastern Georgian Bay Stewardship Council undertook a Fish Habitat Assessment project from 2015-2018 with a goal of assessing whether there is sufficient accessible habitat (spawning, nursery, rearing, foraging) to support walleye, lake sturgeon (*nme, Acipenser fulvescens*), and sucker species (Catostomidae family, *Nmebin*) 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 along with the other target species.

Several other surveys are undertaken in eastern Georgian Bay by agencies and organizations, including the UGLMU, the Ministry of Environment, Conservation and Parks (MECP), AOFRC, and FRSC, that periodically capture walleye but are not focused specifically on describing their populations.

7.3 WHAT ARE THE RESULTS?

Since the 2018 *State of the Bay* report, the UGLMU drafted the *Report of the Status of Walleye in the Ontario Waters of Lake Huron* (UGLMU, 2019a) (henceforth the draft status report). The draft status report summarizes available assessment data on a number of known and presumed walleye spawning populations to evaluate stock status and ultimately inform a Lake Huron Walleye Management Plan. Key findings from this report relevant to Georgian Bay are summarized here. The full draft status report can be requested from the corresponding author, Chris Davis (1-222-668-8929, Chris.Davis@ontario.ca).

The draft status report provides a review of historic information as well as contemporary analysis. Sources informing the historical context include historical data on commercial fisheries, recreational fishery assessments, and stocking history. The contemporary analysis draws on independent assessment data sources (e.g., ESTN, FWIN, BsM) and fishery-dependent data sources (e.g., creel surveys) to report on several metrics including abundance, size structure, age structure, mortality, and growth rate. Each survey type employed in the independent assessment (e.g., ESTN, FWIN, BsM) is compared to previously established biological reference points (BRPs). This comparison is undertaken by analyzing the collected data against the quartile (25, 50, 75%) and median values of the established BRPs. However, not all metrics have established BRPs, or the original data for the metric is unavailable to inform the creation of reference points by the UGLMU, therefore comparisons were not able to be made for all metrics under all survey types. It is important to note that the BRPs are only reference points and should not be used as targets or thresholds.

Where possible, results for eastern Georgian Bay and Georgian Bay are provided. Lake Huron results are presented where Georgian Bay results are not available.

7.3.1 Commercial Fishery Harvest

The earliest available records in Lake Huron on commercial walleye harvesting date back to 1867. However, there are some discrepancies in the early data (1870-1922) for the Ontario waters of Lake Huron, reducing the reliability of these data. For example, Georgian Bay is used to label all Ontario data for Lake Huron from 1870-1906, while data in 1907 and on is reported as three individual basins (North Channel, Georgian Bay, main basin). As another example, from 1867 to 1922 Ontario landings differ between the UGLMU and the Great Lakes Fisheries Commission (GLFC) data, with higher numbers being reported by the GLFC. Nevertheless, the records for Lake Huron show substantial walleye harvest in Ontario with the Georgian Bay basin averaging 34,390 kg from 1910-1980 (this average includes less reputable data from the years before 1923).

7.3.2 Recreational Fishing

From 1989 onward, data from 291 angler surveys across 49 different locations on Lake Huron are available for analysis, with a small gap in data in 2010, 2011, and 2018. Generally, the target species of these surveys has not been walleye. In fact, walleye capture was reported in only 55 (19%) of these surveys. For the 138 surveys conducted in Georgian Bay, walleye were the targeted species for only 4.4% of the total effort. Along eastern Georgian Bay, the areas with the greatest walleye-targeted effort are the Shawanaga River and Severn Sound.

In terms of harvest rates, recent surveys from the Spanish and Shawanaga Rivers revealed open water harvest rates of 4,453 kg and 3,489 kg, respectively. These are the highest harvest rates from all the surveys. The Spanish and Shawanaga Rivers are thought to be the most significant recreational walleye fisheries in the North Channel and Georgian Bay at this time. The St. Marys River sees considerable walleye harvest as well, but it is unclear what portion is occurring in Ontario waters.

Fishing pressure and harvest are reduced in the winter months, but still present. Recent data shows that Shawanaga River winter harvest was 14% of summer harvest (summer 3,489 kg, winter 502 kg), and Severn Sound winter harvest was 42% of summer harvest (summer 479 kg, winter 201 kg).

7.3.3 Fishery Independent Assessments

The fishery independent assessments are comprised of an extensive body of UGLMU projects focused on assessing walleye populations in nearshore areas of Lake Huron. From 1994 to 2018, 143 nearshore projects in 14 locations across the Ontario waters of Lake Huron have collected information on walleye (Figure 23).

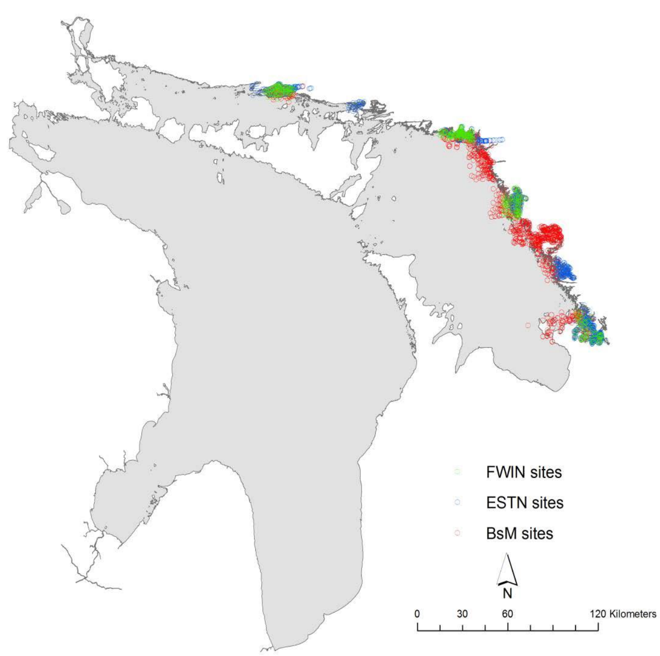

Figure 23. Georgian Bay and North Channel nearshore ESTN, FWIN, and BsM sampling events from 1992 to 2018 (Figure from UGLMU, 2019a).

In the past 26 years, ESTN, FWIN, and BsM surveys have been conducted at 1,050, 627, and 1,814 netting sites, respectively. These surveys have been spread across the Spanish, Whitefish, French, Key, Shawanaga, Moon, Severn, Magnetawan, and Shebeshekong Rivers, and Severn Sound. While the ESTN survey method has been the most used methodology, it is currently lacking BRPs, therefore, only within-lake trends can be analyzed. This contrasts with the FWIN and BsM surveys which can be compared to their respective BRPs utilizing various classes and metrics as detailed in the sections below. The BsM survey's BRPs are termed "Cycle 1" lakes and are based on a set of 497 surveys conducted across Ontario between 2007 and 2012. The BRPs for the FWIN surveys were developed by Morgan et al. (unpublished data) based on the first complete round of FWIN surveys.

Abundance

CPUE was determined for the BsM and FWIN surveys to understand walleye abundance. The CPUE metric for both survey types found the abundance of walleye populations to be very low when compared to BRPs. FWIN survey results indicate that the mean from all 14 surveys (0.62 fish/net/night) equates to approximately one third of the BRP median (2 fish/net/night) (Figure 24). The 24 BsM surveys conducted on Lake Huron produced an overall mean walleye CPUE of 0.49 fish/net/night which is only 19% of the mean (2.59 fish/net/night) for Cycle 1 lakes (Figure 25). The BsM surveys also found that when measuring abundance in terms of biomass, data from the Lake Huron surveys fell below the lower quartile for Cycle 1 lakes, similar to the CPUE metric.

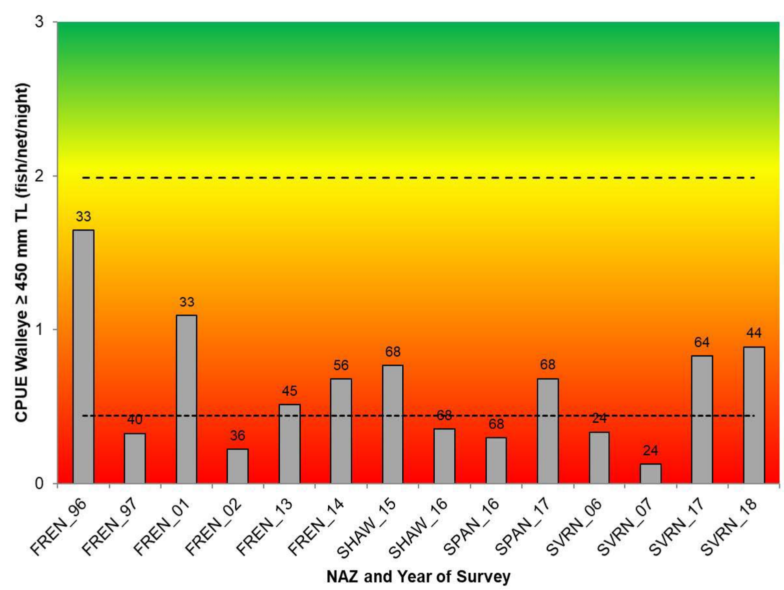

Figure 24. CPUE of walleye ≥450 mm total length (TL), representing the fully mature portion of the walleye population from FWIN surveys on Lake Huron. Lake Huron data are compared to the median (large dashes) and 25th percentile (small dashes) of the BRPs (Figure from UGLMU, 2019a).

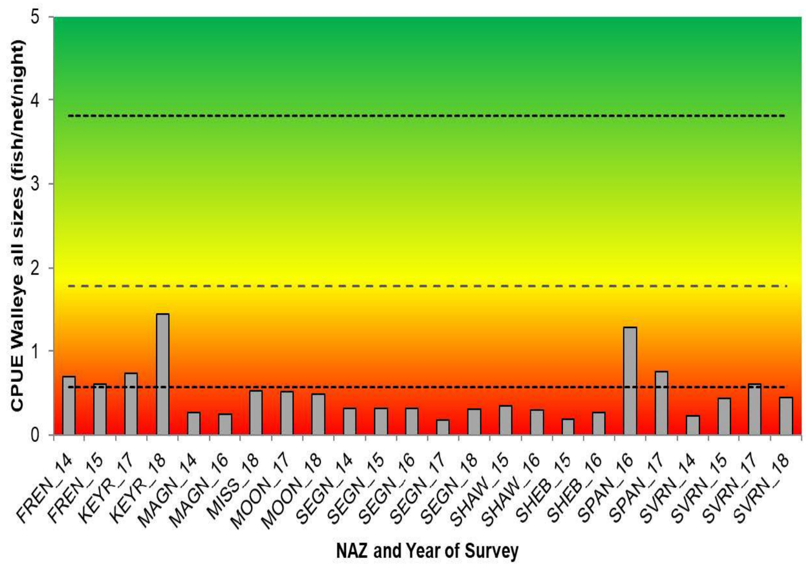

Figure 25. CPUE of walleye of all sizes from BsM surveys on Lake Huron. Lake Huron data is compared to the median, upper, and lower quartiles of the BRPs as represented by the dashed lines (Figure from UGLMU, 2019a).

Size and Age Structure

For the BsM surveys, the maximum total length and mean length of samples were larger than those of Cycle 1 lakes. Metrics under the age structure class were generally low when compared to Cycle 1 lakes and BRPs for both the BsM and FWIN surveys. The number of age classes for walleye in Lake Huron was determined to be variable between individual FWIN surveys, but generally similar to reference groups. The maximum age for walleye was significantly lower in Lake Huron BsM surveys when compared to Cycle 1 lakes. FWIN survey data showed that 11 of the 14 surveys analyzed had a maximum age falling below the BRP's lower quartile (Figure 26).

Utilizing BsM survey data, the Shannon Diversity Index values indicated that walleye age class diversity is low in Lake Huron when compared to Cycle 1 lakes. On the other hand, FWIN age class diversity values were generally higher than BsM values and 10 of the 14 FWIN surveys were higher than BRPs. It is important to note that the FWIN surveys had a higher sample size than the BsM surveys.

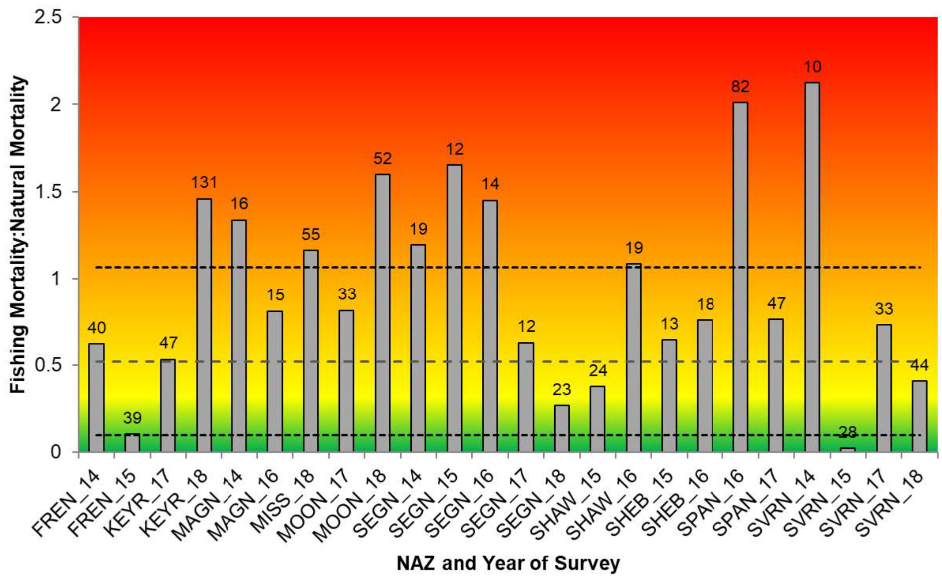

Figure 26. Fishing mortality to natural mortality ratio for walleye ≥350 mm total length from BsM surveys. Lake Huron data is compared to the median, upper, and lower quartiles of the BRPs as represented by the dashed lines. A 0.75 F:M ratio is often a recommended upper threshold for the sustainability of a walleye population (Figure from UGLMU, 2019a).

Mortality and Growth Rate

In Lake Huron, the natural mortality rate – proportion of fish dying from causes other than fishing (e.g., disease, predation, starvation) – of walleye was estimated at 0.234 in BsM surveyed areas (Table 7). Catch-curve calculated fishing mortality rate averaged 0.22, 52% higher than Cycle 1 lakes. Generally, walleye fishing mortality was found to be higher in Lake Huron surveys compared to reference surveys, with 19 of 24 surveys falling above the reference median and 10 of these falling above the upper quartile. Alongside high fishing mortality rates, the fishing to natural mortality ratio (F:M) was 31% higher for walleye ≥350 mm in the BsM surveys when compared to Cycle 1 lakes. With a 0.75 threshold often recommended as a sustainable F:M target, 14 of 24 BsM surveys in Lake Huron exceeded this threshold (Figure 27). While the sample size was relatively low in the BsM surveys which can introduce problems for individual survey rate considerations, the overall pattern of F:M ratios in Lake Huron was high.

The final metric determined through the BsM surveys was growth rates, including length at age 3. In general, the data showed that Lake Huron walleye had faster growth rates in comparison to Cycle 1 lakes. The overall total length mean for Lake Huron walleye was 78 mm larger than Cycle 1 lakes. Of the 24 BsM surveys conducted, length at age 3 for 20 surveys were above the upper quartile for the reference lakes (Figure 28).

Table 7. Broadscale Monitoring program metrics for Cycle 1 lakes (497 surveys from 2007 to 2012) and Lake Huron surveys (24 surveys from 2014 to 2018) (Table compiled from UGLMU, 2019a).

Class	Metric	Cycle 1	Lake Huron
Lake Characteristics	Lake Area (ha) Max Depth (m) Mean Depth (m) Spring Secchi (m) TDS (ppm)	2774 29.5 8.3 3.3 54.3	25 378 62.9 15.5 6.7 147.4
Abundance	CPUE all Walleye (fish/net/night) CPUE Walleye ≥350 mm TL (fish/net/night) CPUE Walleye <350 mm TL (fish/net/night) CPUE Female Walleye ≥350 mm TL (fish/net/night) Biomass all Walleye (kg/net/night) Biomass Walleye ≥350 mm TL (kg/net/night) Biomass Walleye <350 mm TL (kg/net/night)	2.59 1.77 0.82 1.34 1.80 1.64 0.17	0.49 0.36 0.12 0.10 0.35 0.33 0.02
Size Structure	Mean Total Length (mm) Mean Total Length of Walleye ≥350 mm TL Max Total Length (mm)	415 472 631	470 506 649
Age Structure	Max age (years) Age Diversity (Shannon Index)	15.4 0.78	10.2 0.73
Mortality	Natural Mortality (M) of Walleye ≥350 mm TL Fishing Mortality (F) of Walleye ≥350 mm TL F:M for Walleye ≥350 mm TL	0.203 0.144 0.717	0.234 0.220 0.939
Growth Rate	Total Length at Age 3 (mm)	319	397

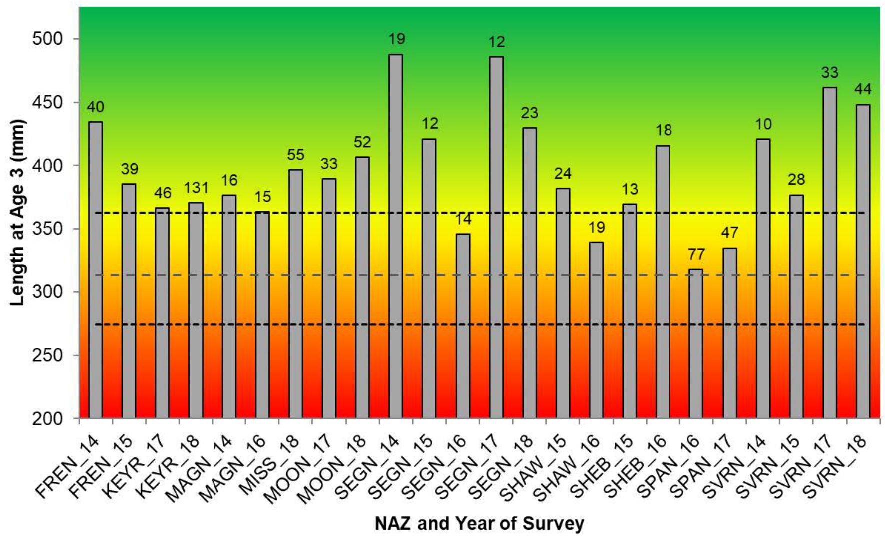

Figure 28. Length at age 3 for walleye from the BsM surveys. Lake Huron data is compared to the median, upper, and lower quartiles of the BRPs as represented by the dashed lines (Figure from UGLMU, 2019a).

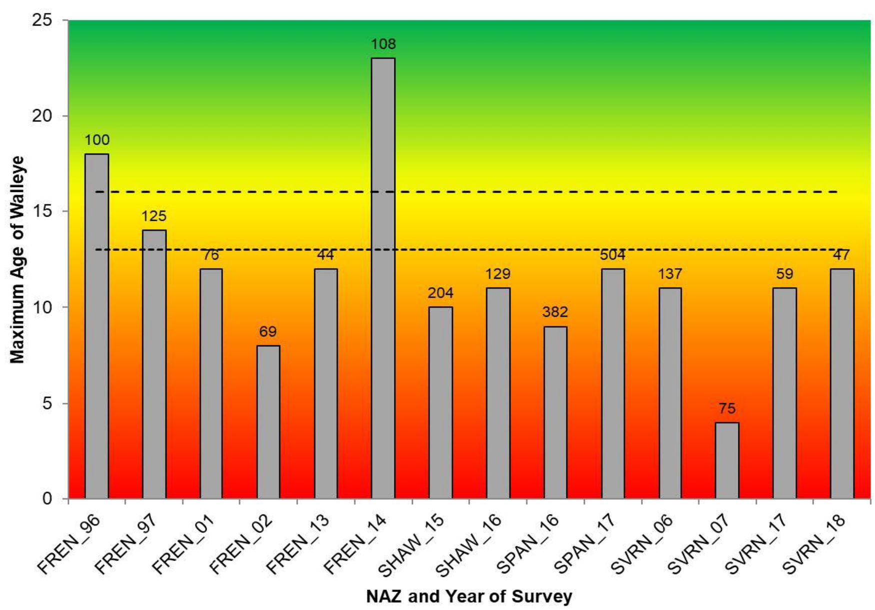

Figure 27. Maximum age of walleye from FWIN surveys on Lake Huron. Lake Huron data are compared to the median (large dashes) and 25th percentile (small dashes) of the BRPs. The median value of 16 is considered a threshold, and populations below this median are compared to the median (large dashes) and 25th percentile (small dashes) of the BRPs. The median value of 16 is considered a threshold, and population below this median are considered "stressed" (Figure from UGLMU, 2019a).

In summary, the metrics presented in the BsM (Table 7) and FWIN surveys indicate that Georgian Bay walleye populations are in an overall poor condition. The data analysis presented in the contemporary FWIN and BsM surveys suggest that walleye populations are struggling largely due to low adult densities and low recruitment rates. The *State of the Great Lakes 2022 Technical Report*, suggests that walleye in Georgian Bay and the North Channel "remain depressed and unchanging", contrasting with conditions in other areas of the Lake

Huron basin such as Saginaw Bay where walleye abundance has increased substantially in recent years (ECCC & EPA, 2022b, p. 499).

8. LAKE TROUT

8.1 INTRODUCTION

Lake trout (*Salvelinus namaycush, Nmegos*) are a native top predator that serve as 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 continue to be pursued recreationally as a sport fish and commercially.

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 29) 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 sanctuary, and stocking of Parry Sound strain lake trout until 1997, all contributed to the rehabilitation of this population (Reid et al. 2001).

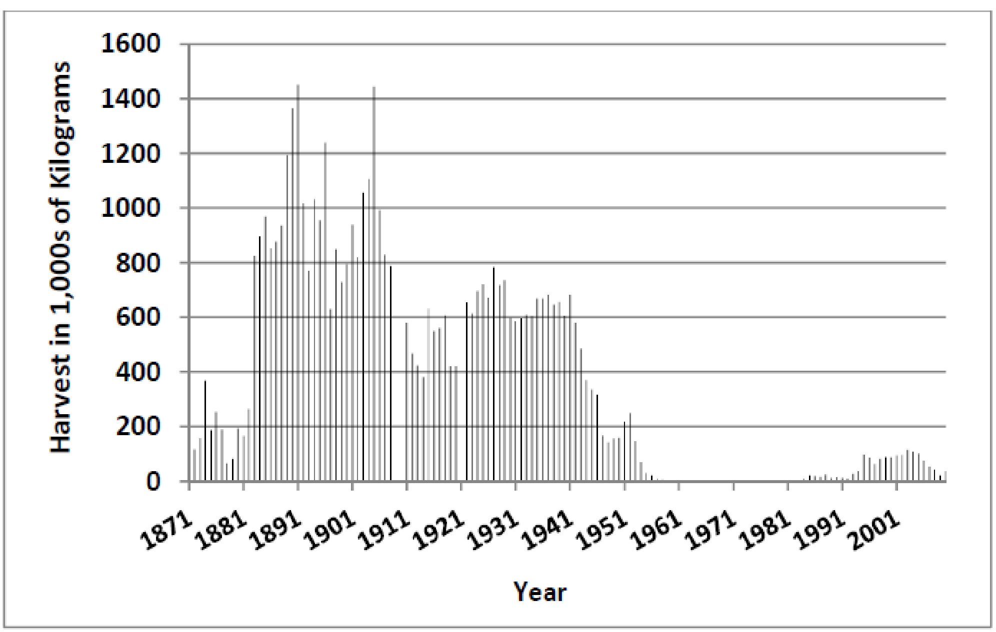

Figure 29. Historical lake trout commercial harvest in Georgian Bay (Figure from ULGMU, pers. comm., 2013).

The importance of healthy lake trout populations in Georgian Bay and Lake Huron has been recognized by several agencies and formalized in numerous documents and strategies. 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.

The Ministry of Natural Resources and Forestry's (MNRF) Upper Great Lakes Management Unit's (UGLMU) *Lake Trout Rehabilitation Plan for Lake Huron (Canadian Jurisdiction)* was published in 1996 to form an approach for the rehabilitation of lake trout in Ontario waters of Lake Huron (MNRF, 1996). The plan established 16 Lake Trout Rehabilitation Zones (LTRZs) for which progress towards the goal and objectives would be monitored. A draft *Revised Lake Trout Rehabilitation Plan for Lake Huron* (henceforth the draft rehabilitation plan) was subsequently developed outlining a revised goal, objectives, LTRZ boundaries, and evaluation criteria (MNRF, 2012).

The draft rehabilitation plan outlines objectives and strategies for the rehabilitation of lake trout to meet the overarching goal of restoring self-sustaining populations of this native top predator. The plan identifies three LTRZs within the *State of the Bay* reporting area (Figure 30) – Parry Sound (LTRZ 6), Limestone Islands (LTRZ 7), and Watcher Islands (LTRZ 8).

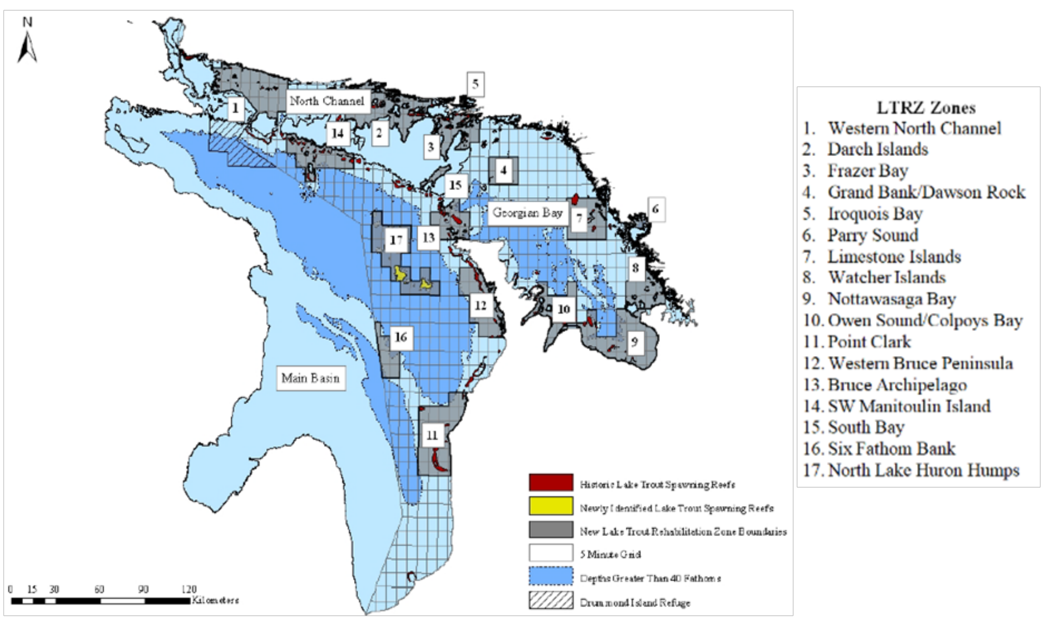

Figure 30. Lake Huron Lake Trout Rehabilitation Zones (LTRZs) (Figure from ULGMU, pers. comm., 2013).

8.2 HOW ARE LAKE TROUT POPULATIONS STUDIED IN EASTERN GEORGIAN BAY?

Targeted sampling for lake trout in eastern Georgian Bay is undertaken by the UGLMU. The UGLMU collects data on lake trout via Fall Littoral Index Netting (FLIN), Fall Spawning Index Trap Net (FSIT), and creel surveys (see Appendix A for a full list of UGLMU in surveys Georgian Bay from 2013-2020). 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 safer.

As a requirement of having a commercial fishing license or an Aboriginal commercial fishery fishing agreement on Lake Huron, commercial fishers are required to report effort, catch, and harvest information each year to the 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 by the UGLMU, the Ministry of Environment, Conservation, and Parks (MECP), the 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.

8.3 WHAT ARE THE RESULTS?

This report uses data and summaries from the following sources: the UGLMU's draft rehabilitation plan; LTRZ 2012 summary reports; 2015 FLIN and FSIT project completion reports; OSIA 2013, 2015, and 2017 summary reports; Limestone Islands Large Mesh Gill Netting project completion report (UGLMU, 2019f); and the *Lake Huron Commercial Fishing Summary for 2020* (UGLMU, 2021). These sources are used to evaluate the criteria presently measured to evaluate progress towards achieving the short-, medium-, and long-term objectives in the draft rehabilitation plan. The criteria include age structure, lake trout survival/mortality, spawning stock size, natural reproduction, and relative abundance. Table 8 details how the evaluation criteria are measured, when possible, given the necessary data are available.

Table 8. Criteria and means of measurement used to evaluate progress towards lake trout rehabilitation at each Lake Trout Rehabilitation Zone (Table from 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

Results for each of the LTRZs within eastern Georgian Bay are described in the sections that follow, using the criteria listed in Table 9.

8.3.1 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. 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 throughout Georgian Bay. The Parry Sound population was rehabilitated through a combination of extensive regulation of the recreational fishery (and the absence of commercial fishing since 2003 in offshore waters adjacent to the Big Sound) 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 recent 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.

Regarding 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. A more recent lake trout trap netting survey conducted in the fall of 2020 captured 388 lake trout in 31 net lifts with 1 to 50 lake trout caught in each net, with the exclusion of one net (UGLMU, 2020). Of the lake trout captured, 281 were male, 105 were female (29 pre-spawning, 17 spent, and 59 spawning) (UGLMU, 2020).

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. The 2020 lake trout trap netting survey found 98.7% of the 388 lake trout captured were unclipped (UGLMU, 2020).

8.3.2 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%. In the same summary, 30%-34% is the percentage range given for wild spawners in the index. More recently, a completion report for a 2019 Large Mesh Gill Netting project indicates that the majority (73%) of mature spawning lake trout present in LTRZ 7 were unclipped and presumed wild.

8.3.3 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. The following year mean age was 5 years with a range of 2-13 years (UGLMU, 2018b).

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. CPUE values for all of QMA 5-7, the QMA that LTRZ 8 falls within, fluctuate over time but have been gradually increasing over the past three years. The CPUE values for 2018, 2019, and 2020 are 13.0, 14.6, and 15.9, respectively. The percentage of lake trout quota taken in QMA 5-7, as detailed in the *Lake Huron Commercial Fishing Summary for 2020* (UGLMU, 2021), was well over 100% from 1998-2005 (highest value of 1,226.6% in 2005) and consistently under 50% from 2006-2020 (lowest value of 13.4% in 2004). Thirty percent (3,628 kg) of the lake trout quota was taken in 2020.

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, only 7.1% were unclipped in the 2017 OSIA. Accordingly, natural reproduction in LTRZ 8 is considered insufficient (i.e., <25%).

8.3.4 Summary

Based on the latest data available, 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. Finally, LTRZ 8 remains priority 11 but as with LTRZ 7, collection of assessment data has been limited. In summary, some progress is being made and at a lake wide scale, recovery of lake trout in Lake Huron is the most pronounced in the Great Lakes outside of Lake Superior (ECCC & EPA, 2022b). Recovery in Georgian Bay is slow but indicators recently have been showing more positive trends than previously (Lenart et al., 2020). However, the status of lake trout populations in the eastern Georgian Bay LTRZs suggests that the rehabilitation objectives outlined in the revised plan are still not being achieved.

In an effort to meet objectives, it is important that measures for the control of sea lamprey continue to be implemented to reduce the stress they place on adult lake trout (Lenart et al., 2020). Sea lamprey controls, including the application of lampricide, have largely been successful in reducing the threat posed by sea lamprey. However, in recent years there has been an increase in the number of adult sea lamprey found in Lake Huron (Liskauskas, 2022). This increase could be due in part to reductions in lamprey control efforts in 2020 as a result of the COVID-19 pandemic (Liskauskas, 2022).

With reduced productivity in the offshore waters, alterations in the prey fish community, 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 2022 Technical Report* (ECCC & EPA, 2022b).

Table 9. Summary of Lake Trout Rehabilitation Zone trends.

LTRZ	Trend
Parry Sound (LTRZ 6)	Unchanging
Limestone Islands (LTRZ 7)	Deteriorating/Undetermined
Watcher Islands (LTRZ 8)	Unchanging/Undetermined

9. DATA GAPS AND RESEARCH NEEDS

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:
    - Better characterize the composition of the phytoplankton assemblages in eastern Georgian Bay to enable detection of changes that may affect food availability for grazers and onset of environmental changes impacting the phytoplankton food base.

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.
    - Better understanding of variations between coastal and pelagic zooplankton assemblages and the implications potential differences may have for the prey base.

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 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. In addition to seasonal sampling, questions around variable conditions in the lower food web in the nearshore versus offshore need to be addressed and an effective monitoring program needs to be developed for the coastal band. With better understanding of the offshore and nearshore lower food web conditions, 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.

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.

9.2 FISH COMMUNITIES

Data gaps and research needs applicable to all fish communities include:

1. Investigate the impacts of climate change (e.g., changing water levels, increasing water temperatures) on fish communities.

2. Enhance spatial and temporal coverage of fish community data to better assess trend through time.

3. Develop a comprehensive inventory of critical, sensitive, and quality reproductive habitat for indicator and non-indicator species. This process could be repeatable and involve all levels of government (ECCC, DFO, MNRF, MECP, Municipalities, NGOs, First Nations, Métis).

9.2.1 Prey Fish

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 prey fish populations.

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

9.2.2 Smallmouth Bass

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

2. Improve understanding of the impacts of shoreline development and alteration on nearshore cobble and rubble spawning habitat for smallmouth bass.

9.2.3 Northern Pike

1. Improve understanding of the impacts of development and alteration of riverine and deltaic wetlands on spawning and nursery areas supporting northern pike.

9.2.4 Muskellunge

1. Improve understanding of invasive species (e.g., round goby) impacts (e.g., predation of eggs) on coastal wetland spawning and nursery areas supporting muskellunge.

2. Improve understanding of the impacts of shoreline development and alteration on critical coastal wetland spawning and nursery habitats.

9.2.5 Walleye

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.

5. Develop biological reference points for ESTN surveys to allow for comparisons in walleye abundance and biomass in Georgian Bay.

9.2.6 Lake Trout

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

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

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COASTAL WETLANDS

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1. INTRODUCTION

Eastern Georgian Bay is one of the world's largest freshwater archipelagos with an abundance of coastal wetland habitat along its complex shoreline. Compared to other Great Lakes, this region is host to a disproportionately high number of pristine wetlands with high plant and animal biodiversity (Chow-Fraser, 2006; Croft & Chow-Fraser, 2007; Seilheimer & Chow-Fraser, 2007). According to the McMaster Coastal Wetland Inventory (MCWI), there are 12,629 distinct wetland units along the eastern and northern coast of Georgian Bay, totalling 17,350 hectares (Midwood et al., 2012).

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). The small wetlands of eastern Georgian Bay are generally considered to have either shallow substrate or exposed granite with low nutrients, and good water clarity (Montocchio & Chow-Fraser, 2021). 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.

Coastal wetlands are dynamic ecosystems described by Weller and Chow-Fraser (2019a) as 'lacustrine systems'. Weller and Chow-Fraser (2019a) explain that coastal wetlands are predominantly influenced by lake level and the geomorphology of the shoreline which determines how exposed a site is to lake processes such as waves and wind tides or seiches. Seasonal fluctuations in water levels play an important role in maintaining habitat complexity in these highly productive ecosystems. Water level fluctuations 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). Water levels in Lake Huron-Michigan are known to have long-term fluctuations of 30-33 years (Baedke & Thompson, 2000), as well as shorter term 8 to 12-year oscillations (Hanrahan et al., 2009, Montocchio & Chow-Fraser, 2021). However, an extended low period was measured between 1999 and 2013, followed by a 1 metre increase in water level, lasting for approximately 5 years (Montocchio & Chow-Fraser, 2021). Montocchio and Chow-Fraser

(2021) point out that the impact of these water level changes on the health of eastern Georgian Bay coastal wetlands has yet to be studied.

Wetlands are critical for their provision of ecosystem services and their wide array of habitat functions that support incredible biodiversity. Coastal wetlands, in particular, support high levels of biodiversity because they are transitional environments providing habitat for both aquatic and terrestrial species. Many birds, reptiles, amphibians, fish, insects, and mammals use coastal wetlands at some point in their life cycle (Midwood et al., 2011). Despite their importance, coastal wetlands in Georgian Bay face several serious threats including development and shoreline alteration, invasive species, nutrient and sediment loading, and climate change and associated changes to water level fluctuations (Chow-Fraser & Croft, 2015; ECCC, 2022b; Midwood & Chow-Fraser, 2012; MNRF, 2017; Montocchio & Chow-Fraser, 2021). For more information on the importance of, and threats to, coastal wetlands, readers are encouraged to refer to the 2013 and 2018 *State of the Bay* reports.

2. HOW ARE COASTAL WETLANDS STUDIED IN EASTERN GEORGIAN BAY?

Multiple agencies, organizations, and researchers are interested in studying coastal wetlands in eastern Georgian Bay. The methods used vary greatly depending on the goals of each study and whether they are short- or long-term studies. Table 1 provides examples of indicators that have been used for monitoring wetland condition.

Table 1. Examples of indicators used for monitoring wetland condition. Please note this is not an exhaustive list, the examples represent a selection of wetland condition indicators intended to demonstrate how different reports and agencies have evaluated 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 (2022)	ECCC Baseline Coastal Habitat Survey
Water Quality*		✓	✓			
Vegetation	✓		✓		✓	
Macro-invertebrates	✓		✓		✓	
Fish Habitat (spawning)		✓				
Habitat (species composition and abundance)	✓	✓	✓			
Amphibians	✓		✓		✓	
Bird Species	✓	✓	✓		✓	
Size of Wetlands/ Wetland Extent		✓				✓
Percent Natural Cover (connectivity)		✓				
Percent Rate of Wetland Loss / Changes in Wetland Area				✓		
Wetland Diversity						✓

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

The remainder of this section describes coastal wetlands research and monitoring conducted in eastern Georgian Bay since the release of the last *State of the Bay* report in 2018. For summaries of older studies, please refer to the 2013 and 2018 *State of the Bay* reports.

2.1 COASTAL WETLAND RESEARCH GROUP, MCMASTER UNIVERSITY

2.1.1 Coastal Wetland Indices

In a 2021 study by Montocchio and Chow-Fraser, three ecological indices – the Water Quality Index (WQI), Wetland Macrophyte Index (WMI), and Wetland Fish Index (WFI) – were reviewed to determine their performance in assessing human disturbance on eastern Georgian Bay coastal wetlands under different water levels. The WQI, WMI, and WFI scores were compared between two periods with major changes in water levels, but minimal changes in human disturbance (Period 1: low waters from 2003-2013, Period 2: high water from 2014-2019) (Montocchio & Chow-Fraser, 2021). Increases in WQI, WMI, and/or WFI scores are considered a positive outcome (i.e., conditions are improving) and decreases in scores are considered negative (i.e., conditions are degrading; Chow-Fraser, 2006). Results from this study found significant increases in the WQI from the sustained low-water level period to the high-water level period, whereas the WMI remained numerically and statistically the same (Montocchio & Chow-Fraser, 2021). Between the low- and high-water period, the WFI decreased slightly, but not significantly (Montocchio & Chow-Fraser, 2021). However, because of the relatively unpredictable effects of climate change on water level patterns in the Great Lakes, the authors explain that caution should be taken when interpreting WQI results and comparing across water level scenarios due to a possible dilution effect (Montocchio & Chow-Fraser, 2021).

2.1.2 Coastal Wetlands as Habitat

Coastal wetland condition and extent can be understood by looking at the habitat of species at risk such as the eastern musk turtle (*Sternotherus odoratus*). A study conducted in eastern Georgian Bay coastal wetlands collected data from 2003 to 2015 on the occupancy of eastern musk turtles in order to better understand habitat and landscape features associated with the species (Markle et al., 2018). Wetlands which supported eastern musk turtles typically had more forest cover and fewer roads, buildings, and docks in the surrounding landscape (Markle et al., 2018). The conditional occupancy of eastern musk turtles across the study area from 2003-2015 suggested that eastern Georgian Bay's coastal wetland eastern musk turtle habitat was in good condition (Markle et al., 2018), but with recent changes in water level regimes and habitat availability (Montocchio & Chow-Fraser 2021; Weller and Chow-Fraser 2019a; Weller and Chow-Fraser 2019b) an updated survey is recommended.

In response to differences in the number of age-0 muskellunge found in nursery sites between southeastern Georgian Bay (SEGB) and northern Georgian Bay (NGB) during the low water period (1999-2013), Weller and Chow Fraser (2019b) developed a multi-scale Resilience Index (RI) to identify coastal wetlands which may be more resilient to stable low lake levels. This was completed at three different scales – local, regional, and basin-wide. The local scale was developed using data from two ~1 ha regions of SEGB and NGB, the regional scale was categorized as a large embayment of 1,000 – 10,000 ha, and the basin-wide scale covered the entirety of eastern and northern Georgian Bay (Weller & Chow-Fraser, 2019b). At the basin-wide scale, coastal regions that had been assessed as being vulnerable to low lake levels were identified. Basin-wide RI scores were used to establish the Vulnerability Index (VIn) which placed stretches of shoreline into different vulnerability categories and identified areas along Georgian Bay that support vulnerable coastal wetlands (Figure 1) (Weller & Chow-Fraser, 2019b). Weller and Chow-Fraser (2019b) suggest the use of the regional RI for assessing the needs of target areas for field studies while the basin-wide VIn can be used to identify the average vulnerability across a larger geographic area. Tools such as these vulnerability and resilience indices can be assets to the development of conservation and management strategies for eastern Georgian Bay's coastal wetlands.

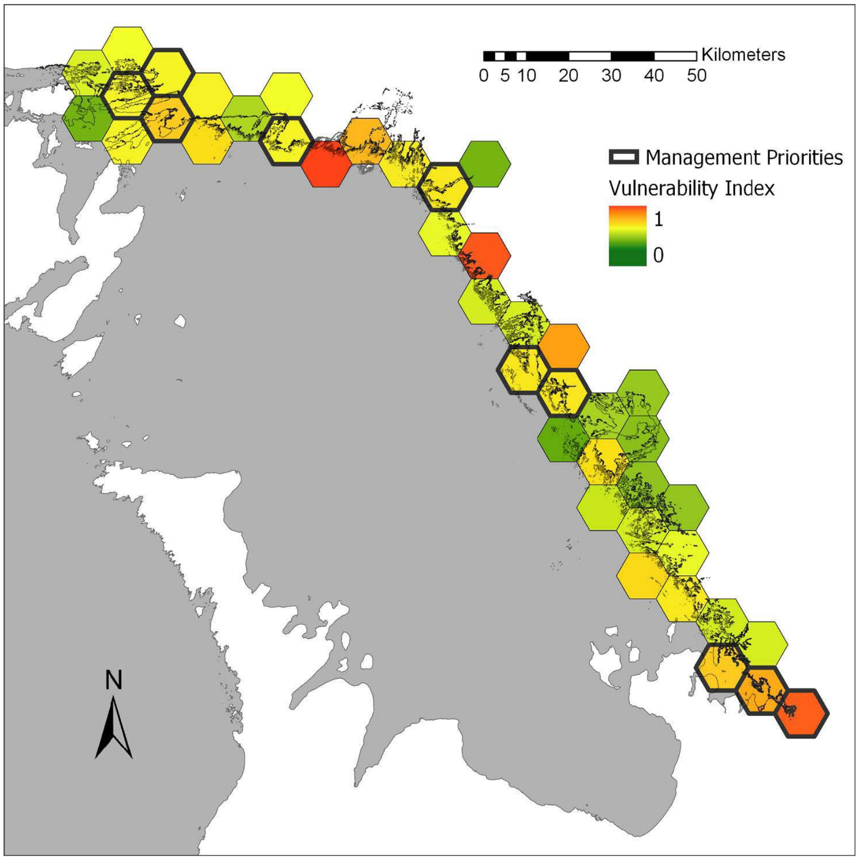

Figure 1. Eastern Georgian Bay basin-wide coastal wetland vulnerability index (figure from Weller & Chow-Fraser, 2019b). Management priority areas are selected based on the VIn score and the total wetland area. These priority areas often support large wetlands, and they are considered more vulnerable to shifts in community composition when low water levels are stable (Weller & Chow-Fraser, 2019b).

2.1.3 Climate Change and Water Levels

To understand a potential impact of climate change on coastal wetlands, researchers with the Coastal Wetland Research Group at McMaster University have developed a generalized linear model (GLM) to simulate changes in low marsh habitat in eastern and northern Georgian Bay under different water level conditions (Weller & Chow-Fraser, 2019a, 2019c). Three hydrogeomorphic parameters were used to guide this model and estimate the amount of low marsh habitat, water depth, substrate slope, and wave exposure, as derived by a digital elevation model developed by Weller and Chow-Fraser (2019a).

Lake Huron water levels have historically fluctuated by approximately 2 m (Weller & Chow-Fraser, 2019c). As such, low marsh habitat was modeled under simulated lake levels ranging between 175.5 m and 177.5 m with 0.5 m increments (Weller & Chow-Fraser, 2019c). Despite the suggestion in the literature that "…under low water level conditions, low marsh (aquatic habitat) would retreat in favor of high marsh (wet meadow)" (Weller & Chow-Fraser, 2019c, p. 490), Weller and Chow-Fraser (2019c) found that low marsh habitat peaked at 176.0 m, slightly lower than the mean lake levels measured during the 1999-2013 low water period. The GLM showed low marsh habitat area pivoting around 176.0 m with area declining as water levels increase or decrease from 176.0 m. Weller and Chow-Fraser (2019c) explain that the average elevation profile for simulated low marsh in Georgian Bay derived from hypsographic curves exhibited “a gradually sloping section between 176.0 and 175.5 m that essentially formed a “step” in the elevation profile”. The upslope of the step (176.0-177.5 m) was steeper compared to the downslope of the step. Weller and Chow-Fraser (2019c) state that the “position of the step relative to the lake level was an important factor determining whether composition of the depth zone was predominantly deep, intermediate, or shallow”. The authors therefore suggest that total area may not be the best parameter for assessing impacts of water level fluctuations (Weller & Chow-Fraser, 2019c). Rather, habitat volume informs a better understanding of the impacts of changing water levels on coastal wetlands in Georgian Bay, as habitat volume is more directly related to habitat quality.

While the GLM appeared to show total area of low marsh increasing at or near 176.0 m, the majority of low marsh habitat area identified was in less than 0.5 m of water. Weller and Chow-Fraser (2019c) hypothesize that in the low water conditions from 1999-2013, low marsh shifted from high-quality habitat to denser, more benthic-oriented habitat. Higher water levels (depth >0.5 m) had a greater affect on the prevalence of submerged aquatic vegetation (SAV), supporting a greater diversity of fish species. When depths decreased to <0.5 m, the SAV was largely replaced by dense floating vegetation more conducive to benthic species. Therefore, while the GLM found the extent of low marsh habitat is likely to be sufficient to support coastal wetland species in historical and predicted lake levels, the condition or quality of low marsh habitat – closely related to volume – may be of greater concern (Weller & Chow-Fraser, 2019c).

The GLM was trained using the McMaster Coastal Wetland Inventory (MCWI) and it is suggested that some caution be taken when interpreting results (Weller & Chow-Fraser, 2019c). As the MCWI was collected during prolonged low water levels, this model does not consider annual fluctuations in water levels and assumes levels have been stable for approximately 3-years (Weller & Chow-Fraser, 2019c). Therefore, the model represents changes in the wetland vegetation community at a 3 to 5-year time lag as it assumes 3-years have elapsed for lake levels to stabilize and coastal wetland vegetation communities have shifted to their optimal depths (Weller & Chow-Fraser, 2019c). However, Weller and Chow-Fraser (2019c) suggest the “somewhat novel conditions under which the model was developed (i.e., stable, low lake levels) may become more common” (Weller & Chow-Fraser, 2019c, p. 494).

2.2 ENVIRONMENT AND CLIMATE CHANGE CANADA

2.2.1 Baseline Coastal Habitat Survey

Pursuant to the commitments in the Habitat and Species Annexes of the 2012 Great Lakes Water Quality Agreement and the 2021 Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health, Environment and Climate Change Canada (ECCC), the Ontario Ministry of Natural Resources and Forestry (MNRF), and Fisheries and Oceans Canada recently completed a Great Lakes Baseline Coastal Habitat Survey for over one million hectares of habitat, including coastal wetlands, shorelines, uplands, and tributaries. The Lake Huron survey extends from Sarnia to the head of the St. Mary’s River, from the shoreline to roughly two kilometres inland. The survey establishes a baseline of existing habitat conditions (extent, biodiversity, condition, function, protection, and restoration) and the results and geospatial files provided through the Government of Canada’s Open Data portal allow regional and local conservation groups to use the information to identify conservation needs and opportunities for habitat conservation, protection, and restoration. At the time of writing of this report, the Lake Huron Technical Report was not available; however, the spatial catalogue is found online at Lake Huron Canadian Baseline Coastal Habitat Survey - Environment and Climate Change Canada Data.

Key highlights for Georgian Bay include:

- Eastern Georgian Bay and the North Channel contain the greatest abundance of natural habitats within the Lake Huron survey.
- The largest contiguous wetlands are located in Georgian Bay, and together with the North Channel, this region contains approximately 70% of all inland and coastal wetlands.
- Eastern Georgian Bay and the North Channel contain the greatest extent of coastal wetlands by hydrogeomorphic type, representing 64.5% of all coastal wetlands and approximately 92% of all the fens within the Lake Huron survey area.
- Some of the largest contiguous treed areas in the Lake Huron coastal ecosystem occur throughout Georgian Bay. Rockland is the second largest coastal habitat class in abundance, with the majority (60%) located within eastern Georgian Bay, which also contains 77% of all barren habitats.
- The Parry Sound to Key River coastal unit had the greatest number of tributaries and the longest total length of tributaries relative to other coastal units in the Lake Huron survey. Georgian Bay and the North Channel had more tributary impedances compared to coastal units to the north and south.
- Eastern Georgian Bay has the greatest extent of protection (53,483 hectares), representing 48.2% of all protected areas across the Lake Huron landscape.

2.2.2 Assessing and Enhancing the Resilience of Great Lakes Coastal Wetlands

Canada's Assessment of the Resilience of Great Lakes Coastal Wetlands to a Changing Climate study was led by Environment and Climate Change Canada and launched in 2017 under the Great Lakes Protection Initiative. The study focused on improving the understanding of Great Lakes coastal wetland vulnerability to plausible climate change scenarios and identified coastal wetlands most at risk of becoming degraded or lost. The study also explored adaptation approaches best suited to enhancing coastal wetland resilience to projected future climate changes. This information guides management decisions and is currently being used by stakeholders and partners to collaboratively develop priorities for action to improve coastal wetland health, function, and resilience.

Understanding the factors that contribute to climate change vulnerability is essential for decision-makers to prepare for, and adapt to, climate change impacts. This study deconstructed vulnerability into its three components – exposure to climate change, sensitivity, and adaptive capacity (Figure 2). Combining climate change, lake levels, wetland surveys and remote sensing data, integrated ecosystem response modelling, and geographic information systems, coastal wetland vulnerability was determined to the end of the 21st

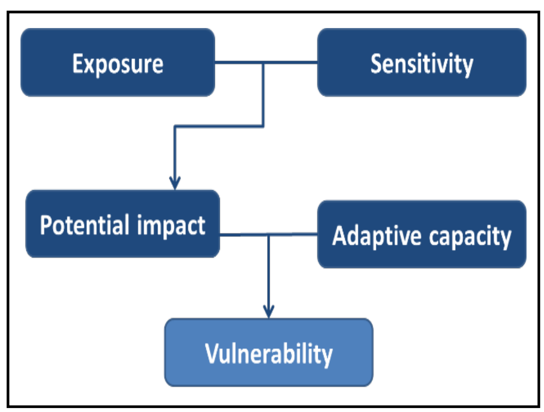

Figure 2. A framework for climate change vulnerability showing the integration of exposure, sensitivity, and adaptive capacity (Figure from ECCC, 2022c).

century. Refer to the detailed technical reports for more information on this study (ECCC, 2022a; b; c; d; e; f).

Coastal wetland response modelling (CWRM)

An important component of this study is the Coastal Wetland Response Model (CWRM). This model was developed to simulate wetland change under future possible lake levels by integrating physical (lake levels, water depth, waves, and topography) and ecological (wetland plant class distribution) conditions spatially and temporally. The intent is to understand successional processes and the spatial distribution of wetland classes from the recent past to the end of the century under various climate scenarios. The CWRM relies on historically observed physical and biological conditions to elucidate the relationship between these two important ecosystem dimensions and allows for a numerical representation of wetland ecosystem and hydrological processes. This aspect of the study pursued four main objectives:

1) Integrate two-dimensional lake models (hydrodynamic) and wave models to simulate physical conditions near coastal wetlands;
2) Collect, transform, and integrate geo- and time-referenced environmental data (topography and plant distribution) on selected wetlands;
3) Build two-dimensional predictive models of wetland classes and invasive plant distribution; and
4) Estimate the changes in wetland composition and the potential of expansion for two invasive plants expected under the projected climate by the end of the current century.

Climate simulations produced by Global Climate Models were selected from the ensemble of models to account for the range of potential future conditions under an intermediate emission scenario (RCP 4.5). Within this climate scenario, projections made by the Canadian Earth System Model (CanESM2) were selected to represent a *"lower-bound"* RCP 4.5 scenario, wherein changes in lake levels may be stable or slightly lower than the long-term average. Conversely, projections made by the Geophysical Fluid Dynamics Laboratory Earth System Model (GFDL-ESM2M) were selected to represent an *"upper-bound"* of the RCP 4.5 scenario, wherein projected changes in lake levels are higher than the long-term average.

Data on land cover/use, elevation, and wetland classes were integrated to understand where large wetland classes currently exist, and under what environmental conditions. Using supervised machine learning, the CWRM forecasted changes in the size and distribution of wetland plant communities (Table 2, Figure 3).

Table 2. A description of the wetland plant communities modelled with examples of plant species.

Community		Description	Examples
Submerged aquatic vegetation (SAV)		Submerged and floating-leaved rooted plants, stoneworts, and coontails	Leafy pondweed (*Potamogeton foliosus*) White water lily (*Nymphaea odorata*) Northern watermilfoil (*Myriophyllum sibiricum*) Slender naiad (*Najas flexilis*)
Emergent marsh		Plants with above substrate growth that emerge from the water column	Broadfruit bur-reed (*Sparganium eurycarpum*) Broadleaf arrowhead (*Sagittaria latifolia*) Hard-stem bulrush (*Schoenoplectus acutus*) Broadleaf cattail (*Typha latifolia*)
Meadow marsh		Sedges, grasses, ferns, and forbs	Tussock sedge (*Carex stricta*) Canada bluejoint (*Calamagrostis canadensis*) Canada anenome (*Anenome canadensis*) Sensitive fern (*Onoclea sensibilis*)
Swamp	Shrubby swamp	Woody perennials with low-branching stems	Red-osier dogwood (*Cornus stolonifera*) Buttonbush (*Cephalanthus occidentalis*)
	Treed swamp	Woody perennials with high-branching stems	Green ash (*Fraxinus pennslyvanica*) Crack willow (*Salix fragilis*)

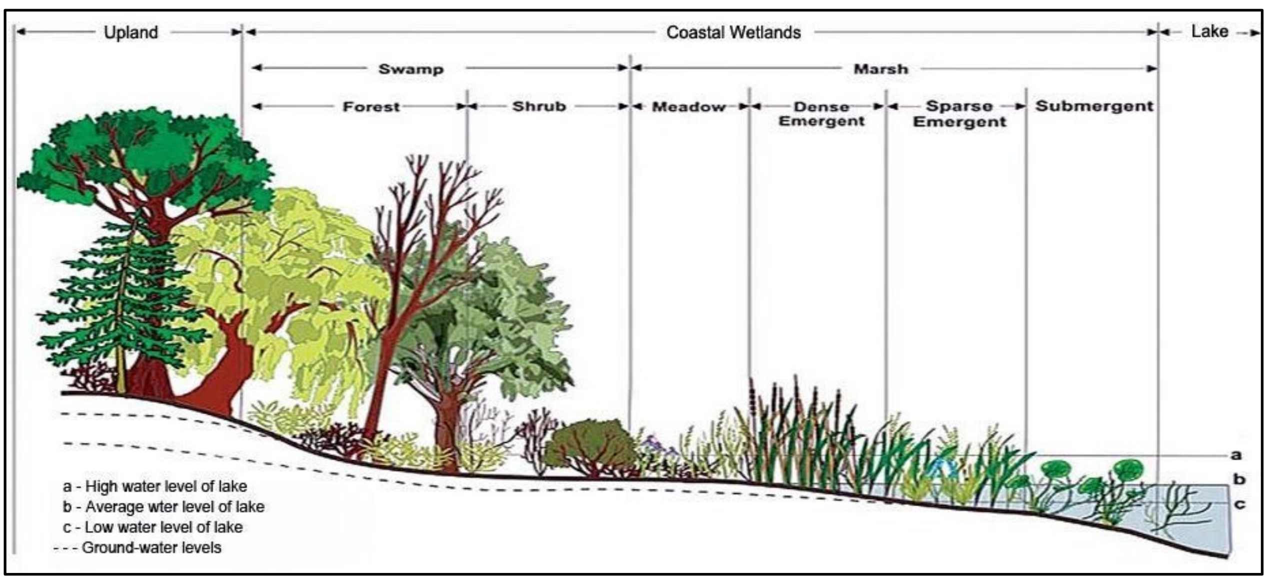

Figure 3. The vertical profile of a typical Great Lakes coastal wetland showing the transitions between plant communities in relation to lake level (Figure from Wilcox et al., 2022).

Changes in wetland vegetation classes between the simulated past (1980-2010) and future (2070-2100) were compared to detect an adverse response to climate change as well as risk to the continued provision of valued ecosystem services. A detailed description of the methodology to create the CWRM, as well as model results, can be found in the technical report, *Great Lakes coastal wetland response to climate change using a coastal wetland response model (CWRM)* (ECCC, 2022f).

3. WHAT ARE THE RESULTS?

Results are presented here for each component of the vulnerability assessment at the Lake Huron-Georgian Bay scale. The results are further broken down for three eastern Georgian Bay coastal wetlands – Treasure Bay, Hog Bay, and Frances Point.

3.1 LAKE HURON AND GEORGIAN BAY

3.1.1 Exposure to Climate Change

In the context of this study, exposure to climate change refers to changes in temperature, precipitation, and water levels across the Great Lakes over time. Given that the scale of global and national climate assessments is too large to reflect the Great Lakes region, climate projections were developed from Regional Climate Model (RCM) simulations forced by Global Climate Models (GCMs). This study selected two forcing scenarios called Representation Concentration Pathways (RCPs). The first scenario is the intermediate future greenhouse gas concentration trajectory, wherein emissions peak around 2040 then begin to decline (RCP 4.5). The second scenario is an increasing greenhouse gas concentration trajectory, or business as usual scenario (RCP 8.5). In terms of an increase in global average near-surface air temperature, RCP 4.5 projects warming of 2.5°C above pre-industrial levels by 2100, whereas RCP 8.5 projects a 5 °C increase.

The method used 13 RCM-GCM combinations in the climate prediction process. Data for over-lake precipitation, over-lake evaporation, and watershed runoff into the lake were extracted from the RCMs to calculate 'net basin supply' for each lake (total precipitation on the lake surface plus the runoff coming into the lake from the surrounding watersheds, minus over-lake evaporation). A Coordinated Great Lakes Routing and Regulation Model was used to calculate lake levels and flows for connecting channels (ECCC, 2022d).

This study found that over-land air temperatures are projected to increase significantly across the Great Lakes compared to a reference period of 1961-2000. Under RCP 4.5, average annual land air temperatures could increase by approximately 3.6˚C over the Lake Huron basin. Under RCP 8.5, average annual land air temperatures could increase by 5.2˚C. Over-lake precipitation is anticipated to increase in all seasons and over time for both climate scenarios for all lakes. Annual total over-lake precipitation could increase by 13% over Lake Huron under RCP 4.5 or 19% under RCP 8.5 by the end of the century.

Lake levels have fluctuated by as much as two metres for Lake Huron between the maximum and minimum monthly average over the historical period of water level monitoring. With a warming climate, lake levels are projected to increase in variability resulting in even more extreme high and low levels. Extreme changes in hydroclimate variables and water levels occur most markedly under high emission scenarios (i.e., under RCP 8.5; in extreme cases, roughly one metre above historical extremes are possible by the end of the century), while lake level changes under more moderate climate change scenarios (RCP 4.5) may result in water level extremes up to 0.5 metres. Unregulated Lake Michigan-Huron shows the greatest variation under both climate scenarios, which is consistent with its historical lake level fluctuations and large watershed. These expanding ranges of extremes should be considered when developing conservation and adaptation plans likely to be impacted by future lake levels.

There are various sources of uncertainty in climate and lake level projections, ranging from socio-economic assumptions on emissions, mitigation, and modelling uncertainties, to regional scale adaptation and assumptions about how the Great Lakes would respond under the extreme climate scenarios. Note that these projections do not predict water levels for a certain year, but rather provide a range of possible values.

For more information on climate and lake level modelling, refer to the technical report *Future hydroclimate variables and lake levels for the Great Lakes using data from the Coupled Model Intercomparison Project Phase 5* (ECCC, 2022d).

3.1.2 Coastal Wetland Sensitivity

Wetland sensitivity was assessed by selecting valued ecological attributes of healthy wetland habitat (Table 3), and by extracting the modelled outputs to quantify possible negative impacts to wetland extent, structure, and function.

The sensitivity analysis revealed that all wetland ecological attributes were sensitive to climate change, demonstrating a risk to wetlands and associated ecosystem services. Wetland area is expected to fluctuate over time with both gains and losses. However, this analysis showed that all wetland sites on Lake Huron were assessed as being at risk in the upper-bound lake level simulation, except Whiskey Harbour on Manitoulin Island, which scored critically at risk (note that sensitivity may have been overestimated due to coarser-grained resolution of land cover data used in the CWRM).

Table 3. Sensitivity and adaptive capacity sub-indicators

Sub-Indicators	Description
Sensitivity	
Wetland Area	Two-dimensional areal measurement of a coastal wetland
Vegetation community diversity	Number and relative proportion of plant communities measured through the Shannon Diversity Index
Interspersion	The ratio of wetland vegetation to open water
Meadow Marsh Area	The two-dimensional extent of the wet meadow plant community dominated by sedges and grasses
Submerged aquatic vegetation (SAV)	The three-dimensional extent of the flooded, low marsh that supports submerged and floating-leaved plants

For more information on the coastal wetland sensitivity methodology and results, refer to the technical report *Assessing the Sensitivity of Great Lakes Coastal Wetlands to Climate Change* (ECCC, 2022b).

3.1.3 Adaptive Capacity

Coastal wetland vulnerability not only depends on the exposure to climate change variables and wetland sensitivity, but also on the capacity of wetlands to cope with shocks and disturbances based on current wetland condition, structure, and function, as well human factors. Five sub-indicators were assessed using Geographic Information System mapping and analysis including:

1) The amount (area) of invasive *Phragmites* within and surrounding each wetland;
2) The amount (area) of protection within and surrounding each wetland site;

3) The extent of natural land cover surrounding each wetland;
4) The potential for upslope and downslope wetland migration by determining the vertical migration limits based on lake level projections and adjacent land use; and
5) Wetland plant species richness, determined from two-years of field surveys.

A composite indicator score was developed by aggregating the sub-indicators and variables.

Wetland sites with a high adaptive capacity score are found across Lake Huron. Despite these relatively high adaptive capacity scores, one or more sub-indicators of adaptive capacity scored in the mid to low range in the studied Lake Huron wetland sites. Lake Huron study sites have high biological condition, and two sites are partially protected by their respective national parks (Georgian Bay Islands and Fathom Five). However, Treasure Bay and Hay Bay are considered to have moderate to low migration potential due to the bedrock geology, hindering the wetlands ability to migrate. The adaptive capacity of wetland sites in Lake Huron can be enhanced by addressing protection, migration potential, and landscape condition.

For complete details on the coastal wetland adaptive capacity assessment methodology and results, refer to *Great Lakes Coastal Wetland Adaptive Capacity to Climate Change* (ECCC, 2022e).

3.1.4 Coastal Wetland Vulnerability

This study was the first of its kind for Great Lakes coastal wetlands that integrates simulated climate and lake level projections, the modelled response and sensitivity of wetland plant communities, and measures of coastal wetland adaptive capacity, into a vulnerability assessment of climate change impacts. The assessment arrives at a five-level series of scores (i.e., very high, high, medium, low, and very low), wherein very high

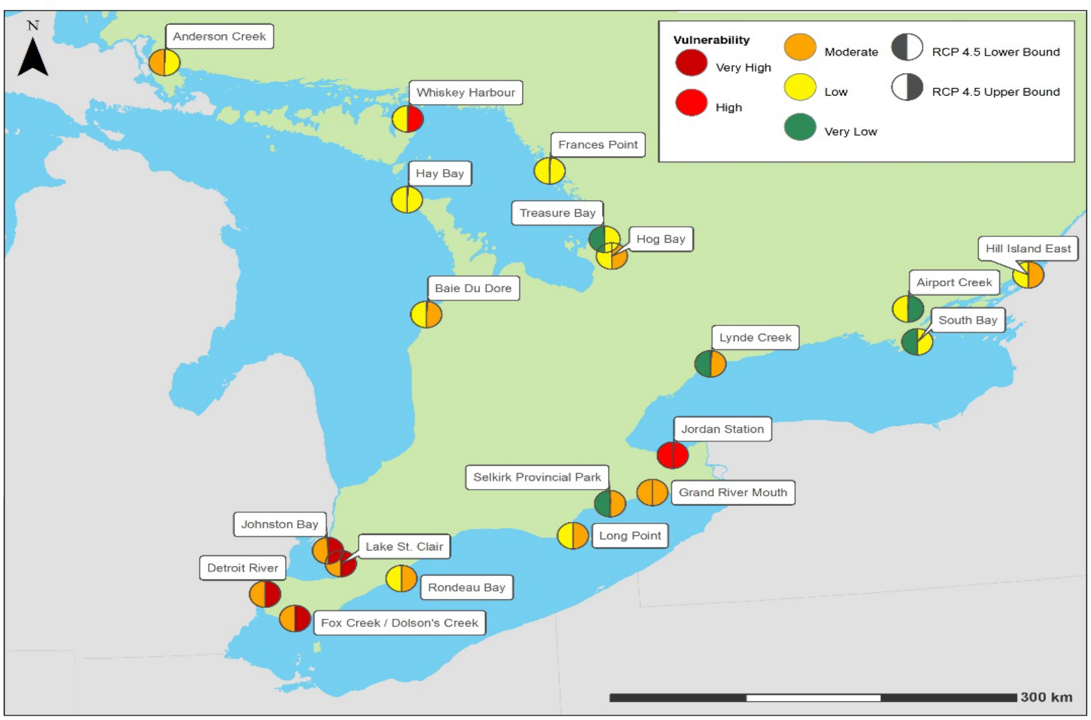

Figure 4. Vulnerability categorizations for all coastal wetlands assessed (Figure from ECCC, 2022c). The left-hand side of each point are vulnerability categorizations for the RCP 4.5 lower-bound, and the right-hand side of each point are vulnerability categorizations for the RCP 4.5 upper-bound.

vulnerability results from combining high impact with low adaptive capacity, and low wetland vulnerability results from combining low impact with high adaptive capacity (Figure 4).

Under the lower-bound RCP 4.5 climate simulation associated with stable or lower lake level averages (lower-bound scenario), Treasure Bay scored very low in vulnerability. This wetland had a low sensitivity and no detectable risk across most ecosystem attributes and was considered to have high adaptive capacity. Most wetlands assessed had a low vulnerability score under the RCP 4.5 lower-bound simulation. Five of these wetlands are found in Lake Huron, including Whiskey Harbour, Hay Bay, Baie du Doré, Frances Point, and Hog Bay. Notably, Frances Point was responsive in terms of wetland loss. Frances Point and Hog Bay showed moderate adaptive capacity. These wetlands are unprotected, and Frances Point has a limited ability to migrate in response to lake level changes.

Under the RCP 4.5 climate simulation associated with higher lake level averages (upper-bound scenario), Lake Huron wetlands were assessed as having low climate change vulnerability. These include Anderson Creek, Frances Point, Treasure Bay, and Hay Bay. Treasure Bay and Hay Bay are considered to be highly adaptive, whereas Anderson Creek and Frances Point are considered to be moderately adaptive. All wetlands scored moderate to high in biological and landscape condition; however, Anderson Creek and Frances Point showed a low migration potential and protection.

Table 4. Vulnerability index scores for all coastal wetlands assessed. Sites are organized by Great Lakes basin and hydrogeomorphic classification (Table from ECCC, 2022c). Vulnerability occurs on a continuous range from 0.00 to 2.00. Where model-specific vulnerabilities differ, overall vulnerability has been expressed as a range.

Basin	Wetland	Wetland Type	Model-specific Vulnerability				Overall Vulnerability
			RCP 4.5 lower-bound		RCP 4.5 upper-bound		
St. Marys River	Anderson Creek	Open Drowned River-mouth	0.77	Moderate	0.54	Low	Low - Moderate
Lake Huron	Baie Du Dore	Open Embayment	0.49	Low	0.81	Moderate	Low - Moderate
	Frances Point	Protected Embayment	0.48	Low	0.55	Low	Low
	Hay Bay	Protected Embayment	0.43	Low	0.40	Low	Low
	Hog Bay	Protected Embayment	0.37	Low	0.73	Moderate	Low - Moderate
	Treasure Bay	Protected Embayment	0.00	Very Low	0.29	Low	Very Low - Low
	Whiskey Harbour	Protected Embayment	0.51	Low	1.29	High	Low - High

For more information on the coastal wetlands vulnerability methodology and results, refer to the technical report *Assessing the vulnerability of Great Lakes Coastal Wetlands to Climate Change* (ECCC, 2022c).

3.1.5 Invasive Plants

A separate modelling exercise was undertaken to understand climate change impacts on the amount of suitable habitat, and the population growth and expansion, of invasive common reed (*Phragmites australis* subsp. *australis)* and hybrid cattail (*Typha* x *glauca*) (ECCC, 2022b). Overall, it was determined that the expansion of these invasive plants in wetlands will be facilitated by climate change, but to varying degrees across the Great Lakes basin. Currently, sites on Lake Huron are marginally being affected by these target invasive species (relative to other areas in the basin). There are no projected increases in suitable habitat in Lake Huron (including Georgian Bay) targeted wetland sites for *Phragmites* under future climate conditions, with the exception of Frances Point which is projected to see suitable habitat area increasing to 45%. No significant changes are projected for other sites located in eastern Georgian Bay under the lower- or upper-bound scenario (ECCC, 2022b). For *Typha* habitat, it is predicted that climate change will not favour *Typha*, with suitable habitat being reduced or facing no significant changes. Under the upper-bound scenario, eastern Georgian Bay wetlands will see a reduction in habitat area by 18% (Treasure Bay), 37% (Hog Bay), and 10% (Frances Point).

Despite a potential reduction in suitable habitat, the abundance of *Typha* is expected to be higher than *Phragmites* for most sites in Lake Huron. The results suggest that *Phragmites* invasion varies across Lake Huron's wetland sites, making a basin-wide conclusion on *Phragmites* invasion challenging. Conversely, *Typha* invasion is relatively similar across sites throughout Lake Huron, with both Treasure Bay and Hog Bay having similar invasion results under the lower- and upper-bound scenarios. Under the upper-bound, Frances Point is predicted to favour *Typha* expansion. In the eastern Georgian Bay sites, the lower-bound scenario predicts *Phragmites* invading all three sites.

3.2 EASTERN GEORGIAN BAY

Three of the 20 Great Lakes wetlands studied are located in eastern Georgian Bay. These wetlands are the focus of the remainder of this results section.

3.2.1 Treasure Bay

Treasure Bay is a protected embayment on Beausoleil Island within Georgian Bay Islands National Park. Treasure Bay's overall vulnerability rating ranges from very low to low, with sensitivity scores for the different attributes falling in the low to moderate range. Based on current wetland conditions, Treasure Bay has Bay has an overall high adaptive capacity score with the landscape and biological conditions sub-indicators scoring high, and the migration potential and protection sub-indicators scoring moderate.

Table 5. Vulnerability, sensitivity, and adaptive capacity results for Treasure Bay.

Treasure Bay	RCP 4.5 lower-bound	RCP 4.5 upper-bound
Vulnerability	Very Low	Low
Sensitivity		
Wetland Area	Low	Moderate
Vegetation community diversity	Low	Moderate
Interspersion	Low	Moderate
Meadow Marsh Area	Moderate	Moderate
Submerged aquatic vegetation (SAV)	Moderate	Moderate
Adaptive Capacity	Based on current factors	
Landscape Condition	High	
Biological Condition	High	
Migration Potential	Moderate	
Protection	Moderate	

3.2.2 Hog Bay

Hog Bay is a protected embayment with a provincially significant wetland designation in Severn Sound, near Midland, Ontario. Hog Bay's overall vulnerability ranges from low to moderate and most attributes have a moderate sensitivity in the lower- and upper-bound scenario. The exception is wetland area which has a low sensitivity in the lower-bound scenario and a high sensitivity in the upper-bound scenario. According to current wetland conditions, Hog Bay has an overall moderate adaptive capacity with the biological condition sub-indicator scoring high, the landscape condition and migration potential sub-indicators scoring moderate, and a low score for the protection sub-indicator.

Table 6. Vulnerability, sensitivity, and adaptive capacity results for Hog Bay.

Hog Bay	RCP 4.5 lower-bound	RCP 4.5 upper-bound
Vulnerability	Low	Moderate
Sensitivity		
Wetland Area	Low	High
Vegetation community diversity	Moderate	Moderate
Interspersion	Low	Moderate
Meadow Marsh Area	Moderate	Moderate
Submerged aquatic vegetation (SAV)	Moderate	Moderate
Adaptive Capacity	Based on current factors	
Landscape Condition	Moderate	
Biological Condition	High	
Migration Potential	Moderate	
Protection	Low	

3.2.3 Frances Point

Frances Point is a protected embayment on the northeastern tip of Franklin Island near Brooks Landing, Ontario, part of the Parry Sound District. Frances Point's overall vulnerability is low in the lower- and upper-bound scenario and its sensitivity across attributes ranges from low to moderate. According to current wetland conditions, Frances Point has an overall moderate adaptive capacity with the landscape and biological conditions sub-indicators scoring high, and the migration potential and protection sub-indicators scoring low.

Table 7. Vulnerability, sensitivity, and adaptive capacity results for Frances Point.

Frances Point	RCP 4.5 lower-bound	RCP 4.5 upper-bound
Vulnerability	Low	Low
Sensitivity		
Wetland Area	Moderate	Moderate
Vegetation community diversity	Low	Moderate
Interspersion	Moderate	Low
Meadow Marsh Area	Moderate	Moderate
Submerged aquatic vegetation (SAV)	Moderate	Low
Adaptive Capacity	**Based on current factors**	
Landscape Condition	High	
Biological Condition	High	
Migration Potential	Low	
Protection	Low	

4. DATA GAPS AND RESEARCH NEEDS

The white paper *Adapting to Climate Change: Solutions to Enhance Great Lakes Coastal Wetland Resilience*, a component of Environment Climate Change Canada's Assessment of the Resilience of Great Lakes Coastal Wetlands to a Changing Climate study, was produced to provide insights and guidance to advance adaptation efforts to protect coastal wetlands against climate change shocks and disturbances (ECCC, 2022a). This included the identification of management gaps that may influence coastal wetland vulnerability. A strategic approach is to identify refugia at broad coastal scales that: (1) are projected to experience less severe climate and development changes; (2) contain a diversity of physical and topographic features; and (3) are projected to retain or remain within suitable climatic conditions (Michalak et al., 2020). Climate change refugia science (Michalak et al., 2020; Morelli et al., 2016; 2020) advances adaptation planning by:

- Protecting land where components of biodiversity can persist in, retreat to, and potentially expand from under changing environmental conditions (Keppel et al., 2012).
- Protecting land that is buffered from climate change over time (e.g., low exposure to thermal change at coastal fens) and water level extremes (Krawchuk et al., 2016; Morelli et al., 2020).
- Acquiring and protecting lands where soil and hydrology can support wetland rehabilitation, restoration, and creation.
- Enabling wetland migration landward or waterward.

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LANDSCAPE BIODIVERISITY

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1. INTRODUCTION

Biodiversity, or biological diversity, refers to the variety of living things 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 biologically diverse ecological systems provide. The more diverse an ecosystem or population, the better equipped it is to be resilient to pressures.

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. Maintaining these large natural areas helps to ensure a greater diversity of habitat types and connectivity between habitats.

Connectivity refers to 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 (Lamberson et al., 1994). The loss of habitat and connectivity often occurs incrementally as a result of habitat fragmentation, and usually results in species population declines. For these reasons, connectivity and how species use landscapes is a key theme that is explored in this chapter.

The Georgian Bay Mnidoo Gamii Biosphere (GBB) region comprises 347,000 ha of island archipelago, shorelines, wetlands, rock barrens, forests, and other habitat types. The region supports some of the highest levels of biodiversity in the province (McMurtry et al., 2008) and is home to over 60 species at risk (MECP, 2023b). While the region supports high biodiversity, it faces many pressures including development (e.g., residential, recreational), human activities (e.g., roads, railways, persecution), and climate change. Therefore, it is important to study how this landscape is used by species and how to maintain ecosystem function throughout the region in the face of current and future stressors.

When studying landscape biodiversity in the region, the influence of island biogeographical principles should be taken into account. The GBB region is a naturally patchy landscape, a mosaic of dispersed habitats rather than contiguous natural land areas. This complex relationship of species and how they adapt to island systems should be considered when the landscape and its biodiversity are assessed. Thus, approaching biodiversity conservation and protection at the landscape scale, while also addressing threats at the local level, will be key to maintaining biodiversity in the region.

1.1 CARING FOR LANDSCAPES IN GEORGIAN BAY, (*MNIDOO-GAMII,* GREAT LAKE OF THE SPIRIT)

Since time immemorial, the lands and waters of Georgian Bay (*Mnidoo-gamii,* Great Lake of the Spirit) have been cared for by Indigenous peoples, predominantly the Anishinaabek people. Hunting, fishing, gathering, and fire are used to shape, control, and manage land (Crafts, 2022). Following colonization, the preservation of large natural areas became the favoured approach to conserve ecological functions. This approach often follows protectionist ideals that try to minimize human influence on the landscape (More, 2002). It is important to recognize, however, that social and ecological systems are, and have always been, inherently interconnected (Colding & Barthel, 2019). Conservationists have strived to conserve large natural areas while also working towards maintaining functional biodiversity across the system as a whole. Today, the traditional lands of the First Nation communities along the eastern coast of Georgian Bay are some of the largest intact natural areas in the region.

Currently, landscape protection exists on the coast through a variety of caretaking actions and through the designation of lands (e.g., provincial and national parks, conservation reserves, Indigenous protected and conserved areas, and land trust properties). Biosphere regions, while not considered a traditional method of protecting land, also play an integral role in the conservation of biodiversity. Areas established with the intent of land protection represent the core and buffer zones of biosphere regions. Core and buffer zones are defined as protected and conserved areas that have reduced human impacts and that contribute to the conservation of landscapes, ecosystems, species, and genetic variation (UNESCO, 2019). GBB's core areas cover 52,509 ha of land and include national and provincial parks. Buffer areas cover roughly 39,594 ha of land and include conservation reserves. Transition areas in the biosphere region include other International Union for Conservation of Nature (IUCN) class protected areas such as enhanced management areas. Other lands such as Crown-Treaty lands, First Nations lands, and private lands do not fall under an IUCN protected areas class, though these areas make up a large portion of relatively intact and stewarded lands.

This chapter describes regional initiatives and research happening across eastern Georgian Bay focused on enhancing understanding of ecosystem function, the connection of these functions across landscapes, and threat mitigation. It also identifies research needs and data gaps. Furthermore, the chapter highlights the importance of adopting frameworks that utilize more than one knowledge system in order to improve outcomes for the conservation of biodiversity and the functioning of ecosystems where the landscape is undergoing changes.

2. HOW IS LANDSCAPE BIODIVERSITY STUDIED IN EASTERN GEORGIAN BAY?

2.1 PAST APPROACHES - 2013 AND 2018 STATE OF THE BAY REPORTS

The 2013 *State of the Bay* report highlighted large natural areas as an important indicator of terrestrial ecosystem health. However, the report pointed out that methods used in non-island landscapes to measure natural areas are not a good fit for Georgian Bay's island landscape. Accordingly, the 2013 *State of the Bay* report was limited to recommending research into a method for assessing landscape-level impacts on biodiversity for future reporting (see the 2013 technical report for more information).

Following from the 2013 recommendations, conservation groups held a meeting in 2016 to learn about the Canadian Wildlife Service – Ontario Region's (CWS-ON) Biodiversity Atlas (ECCC, 2017), produced in partnership with the Nature Conservancy of Canada, and discuss its applicability to *State of the Bay*. Based on conversations stemming from this meeting, what was the "large natural areas" indicator in the 2013 *State of the Bay* report became the "landscape biodiversity" indicator for the 2018 *State of the Bay* report.

Two related landscape biodiversity sub-indicators were identified from the work of the CWS-ON Biodiversity Atlas for the 2018 *State of the Bay* report: high value biodiversity areas and human footprint analysis. These sub-indicators were selected based on their ability to inform conservation planning and their alignment with agency and partner goals. As context for the remainder of this chapter, high level results from the 2018 report are discussed here. Complete details of the analysis and a discussion of the results and limitations can be found in the 2018 technical report.

2.1.1 High Value Biodiversity Areas and Human Footprint Analysis

High value biodiversity areas (HVBAs) are aggregations of high value habitats – the highest quality forest, grassland, and/or wetland that also contain important habitat for species at risk and/or migratory birds. Figure 1 shows these high value habitats individually (forest, grassland, wetland) as well as HBVAs that contain two or more high value habitats for the Georgian Bay fringe, representing areas with multiple and overlapping conservation values.

Human footprint analysis was used to identify areas on the landscape with varying levels of human influence (e.g., roads, railways, residential and commercial development) (Figure 2). Areas of higher human influence are focused along the main transportation corridor (highway 69/400). Areas of lower human influence 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.

To get a more accurate understanding of the highest value biodiversity areas in the region, the human footprint analysis was overlaid on the HBVAs and the areas with the highest human influence were progressively removed. This process revealed that areas with high levels of habitat diversity are subject to low levels of human disturbance.

The HVBA and human footprint analysis sub-indicators were assigned a trend of 'deteriorating' in the last *State of the Bay* report. This trend reflects increasing human impacts and habitat fragmentation, as well as rising numbers of species at risk, collectively threatening biodiversity.

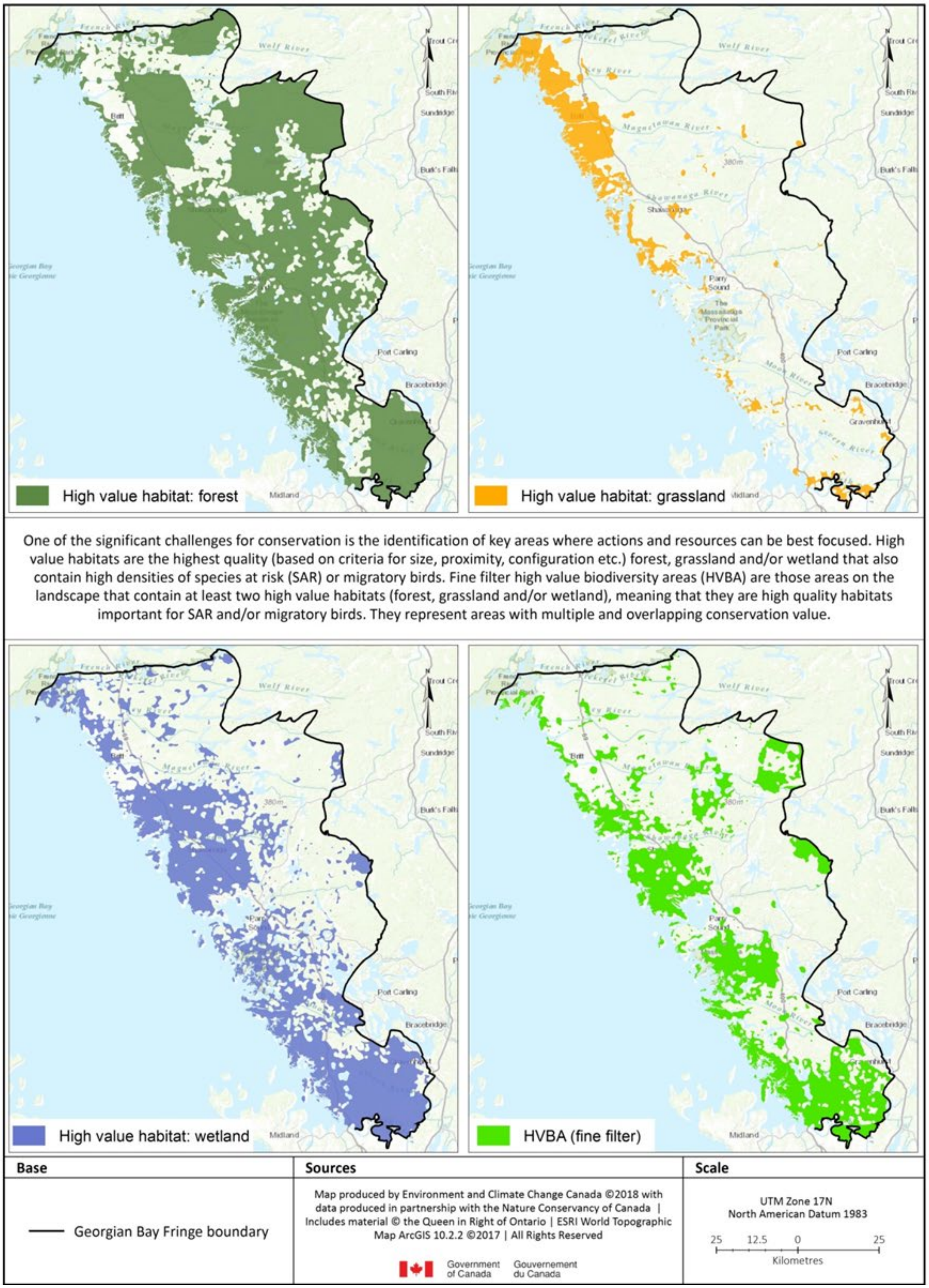

Figure 1. High value habitat for each forest, grassland, and wetland for the Georgian Bay fringe (Figure from ECCC, 2017).

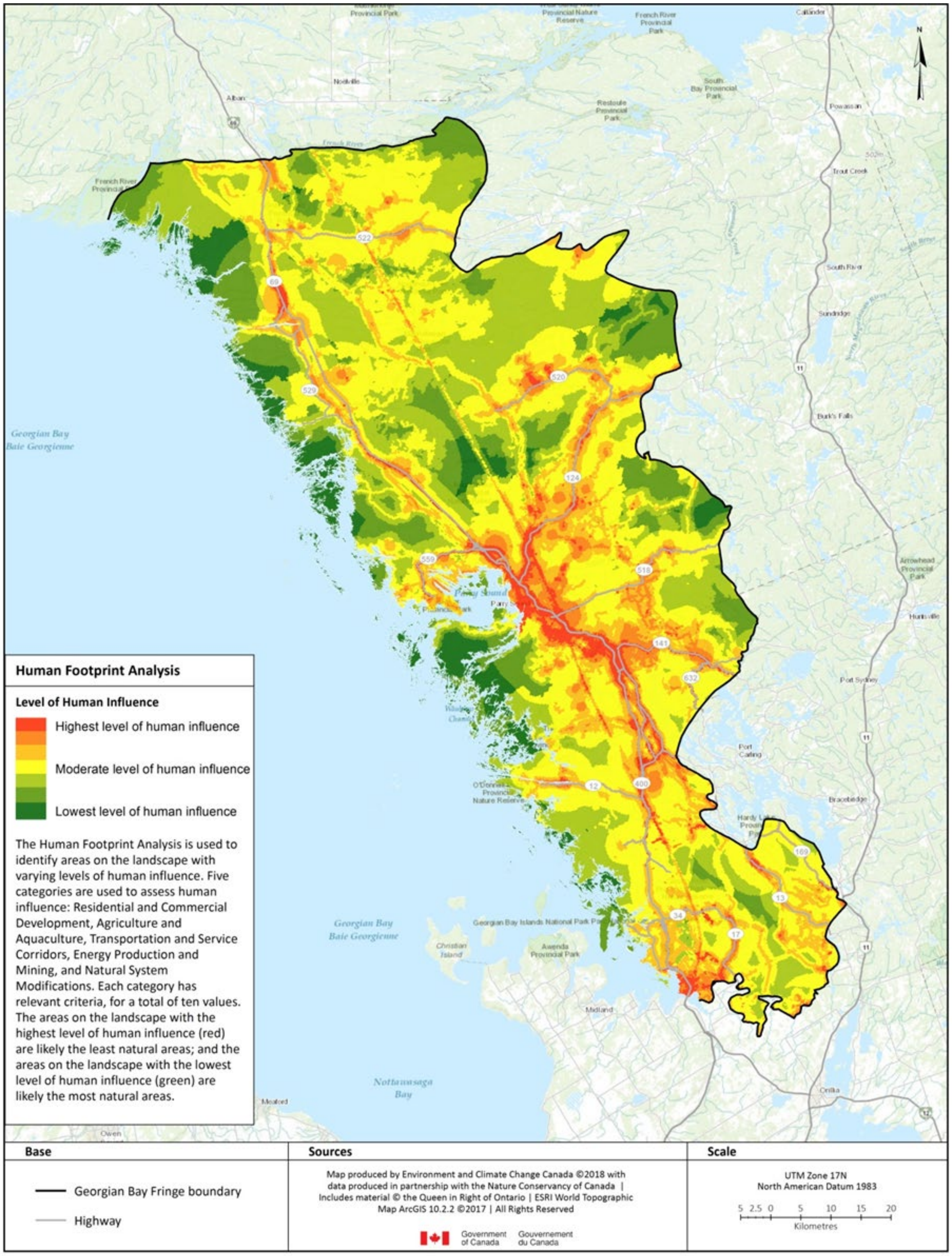

Figure 2. Results from the human footprint analysis for the Georgian Bay fringe (Figure from ECCC, 2017).

2.2 CURRENT APPROACH

Although the 2018 *State of the Bay* helped identify areas on the landscape where threats might be most detrimental to habitats and species, there are still many unknowns with regard to how the landscape is used by species, and where important corridors for connectivity are located. Where appropriate, intentional weaving of knowledge systems (see Table 1) can help address some of these knowledge gaps and provide a more thorough understanding of the landscape and species.

Since the 2018 *State of the Bay* report, a significant amount of work involving multiple ways of knowing has occurred along the coast, undertaken by First Nations, academic researchers, non-governmental organizations, government agencies, and other stakeholders to further understand how species are using the landscape. The 2023 *State of the Bay* summarizes examples of this work, highlighting what has been learned about wildlife in this region, the threats they face, and strategic actions to advance recovery and protection.

Table 1. Definitions of terms used in this chapter.

Multiple ways of knowing	Recognition of the fact that there are different knowledge systems and worldviews and that these inform one's understanding of the world. Acknowledging that there are multiple knowledge systems allows one to identify ways to hold and honour these moving forward in order to better understand caretaking practices for the land.
Western science systems/lens	A body of knowledge traditionally acquired through rigorously controlled and repeatable experiments that follow the scientific method. Disciplines are often broken down into understandable silos. Emphasis is placed on measurable outcomes, logic, rationality, and objectivity (Stinson, 2018).
Indigenous knowledge systems/lens	Indigenous knowledge is a deep awareness and co-existence with natural systems that has accumulated from a connection to the land and that has adapted overtime (Battiste & Henderson, 2000; Berkes, 2012; McGregor, 2004; 2021). This knowledge from past systems informs present understanding and caretaking, but also highlights any changes in natural ways (Ogar, et al. 2020).
Two-eyed seeing approach or weaving of knowledges	Defined by Mi'kmaw Elder Albert Marshall, a two-eyed seeing approach refers to learning to see from one eye with the strengths of Indigenous knowledges, and from the other eye with the strengths of western knowledges, and learning to use both eyes together, for the benefit of all (Bartlett et al., 2012). In the language of *Mnidoo-gamii* (Georgian Bay), it has been shared as "Seeing Both Sides" (*Edwi-waabndamang*) by Waabishki-mukwa, Dr. Brian McInnes of Wasauksing First Nation (WFN). Balancing Indigenous and western science knowledge systems is a long-term process of mutually respectful learning (Whyte, 2013) and a two-eyed seeing approach is a way to honour the strength of these knowledges to create a more complete understanding (Reid et al., 2021, Vincent, 2022). This approach should be carried out where appropriate, consciously, and with great mutual respect where both knowledge systems are on equal footing.

3. WHAT ARE THE RESULTS?

3.1 UNDERSTANDING LANDSCAPE THREATS

Human-made, linear features on the landscape directly and indirectly impact wildlife in a multitude of ways including habitat fragmentation, barrier effects, and mortality from vehicle collisions (Dorsey et al., 2015; Popp & Boyle, 2017; Van Der Ree et al., 2011). Two forms of these linear features, roads and railways, are the focus of recent studies conducted in eastern Georgian Bay.

3.1.1 Roads

The number of studies that demonstrate adverse effects of roads on wildlife is considerable (see for example Eigenbrod et al., 2009; Fahrig & Rytwinski, 2009; Findlay & Bourdages, 2000; Haxton, 2000; Howell & Seigel, 2019; Piczak et al., 2019). Many of these studies focus on amphibians, turtles, and mammals, potentially suggesting that these groups are most negatively affected by roads. Roads, and structures under roads (i.e., culverts), have also been shown to disrupt connectivity of aquatic habitats for fish when they are improperly designed, constructed, and/or maintained (Ottburg & Blank, 2015). Furthermore, roads can reduce overall habitat quality (DeCatanzaro & Chow-Fraser, 2010), fragment the landscape impacting gene flow (Laporte et al., 2013), and skew population sex ratios (Gibbs & Steen, 2005).

In order to reduce the threat of road mortality, it is imperative to understand where wildlife cross roads most frequently and how to best deter them from interacting with roads in the first place. Determining locations of road mortality hotspots helps inform where mitigation efforts would be best focused to reduce road access and mortality. Testing mitigation strategies is not only important to determine which are most suitable for a particular species, but also which strategies are compatible with road maintenance practices in the area. The remainder of this section describes partnerships in the region that involve testing innovative mitigation strategies to reduce reptile road mortality.

Mitigating Construction Effects and Assessing the use of Rip-Rap in the Township of The Archipelago

In 2020, GBB partnered with the Township of The Archipelago, Tatham Engineering Limited, Hall's Construction, and Shawanaga First Nation (SFN) to mitigate the impacts of upcoming roadwork on the surrounding wetland complexes. These complexes are known habitat for a variety of reptiles, many of which use the road for nesting purposes.

The project consisted of two components. The first component involved the removal of turtle eggs/nests prior to and during construction, followed by the release of hatchlings back into their home wetlands. Construction crews were trained on species identification, natural history of turtle species, and supported staff by identifying the location of nesting turtles and their nests. Over two seasons (2020 and 2021), 3,377 hatchlings from 144 nests were incubated and released post-construction. Turtle species that are most likely to interact with the road, including Blanding's turtles (*mooskadoons, Emydoidea blandingii*), snapping turtles (*mikinaak, Chelydra serpentina*), and midland painted turtles (*mskwaadesi, Chrysemys picta marginata*), were among those collected, hatched, and released in this project. The turtle nesting and incubation work highlighted the importance of developing relationships with those working at the construction sites and providing them with training to recognize species at risk and turtle nests, and what to do if either were found.

The second component of the project involved studying an alternative mitigation strategy for reducing road threats to local turtle communities. Exposed gravel at wetland crossings was replaced with rip-rap and paved road shoulders (Figure 3). The aim of the mitigation design was to deter females from nesting along the road and instead encourage them to nest in the natural rock barrens nearby.

Figure 3. Example of alternative mitigation strategy for reducing road threats to local turtle communities (Figure from Kentel, 2023).

The first purpose of the study was to evaluate the effectiveness of the mitigation strategy. While results showed that there was a slight (15%) decrease in the number of female turtles nesting at the mitigated wetland crossings, females continued to nest further up the road where mitigation efforts ended (Kentel, 2023). This means that while the rip-rap embankment discouraged nesting, turtles continued to find nesting sites further along the roadway or where chip and tar had not been well compacted.

The second purpose of the study was to investigate the availability and suitability of natural nesting habitats in the surrounding rock barrens (Kentel, 2023). Kentel (2023) found that while road shoulders met the nesting requirements for all three turtle species, only 1% of rock barrens in the study area were suitable for nesting. This highlighted that limited nesting habitat across the landscape could contribute to the continued selection of road shoulders by nesting turtles.

Overall, the study concluded that this mitigation strategy should not be used to deter nesting turtles without further research, especially in areas with limited natural nesting habitat. Future research should look at the interaction between turtles of all age classes and rip-rap, as well as alternative designs that include rip-rap, such as filling in gaps with other smaller aggregate.

Testing a Concave Fence Design in the Township of Carling

In 2022, GBB partnered with the Township of Carling (TOC) on improvements to a road that bisects a provincially significant wetland (PSW). The PSW is known to provide habitat for species at risk, including eastern foxsnake (*gchi-gnebig, Pantherophis vulpinus*), Massasauga rattlesnake (*zhiishiigweg, Sistrurus catenatus*), snapping turtle, Blanding's turtle, and midland painted turtle. The intent of the road improvement project was to reduce road mortality in this specific stretch of road which was known from previous monitoring to be a hotspot.

Through discussions between GBB, the TOC public works department, and First Nations, eastern foxsnakes, massasauga rattlesnakes, and snapping turtles, were chosen as the target species for the improvement project due to their ability to climb over traditional mesh wildlife fencing. To account for the climbing abilities of eastern foxsnakes, a fence is required that is a minimum of 2 m in height with an overhang (per provincial guidelines). With these and other considerations in mind (Table 2), it was decided that traditional vertical wildlife fencing would not be a viable option as it would not only be easy to climb over, but it would also make road maintenance difficult and prevent access to traditional hunting lands. Instead, GBB and the TOC agreed to pilot an innovative fencing design and study its efficacy in reducing road mortality, as well as its compatibility with road maintenance (e.g., snow plowing, roadside mowing).

Researchers from Laurentian University began studying the efficacy of this design in 2023 which will help fill critical knowledge gaps highlighted in species at risk recovery documents. Lessons learned from this pilot project in the coming years will inform future eastern foxsnake conservation efforts in the region and beyond.

Table 2. Summary of wildlife fencing design considerations.

	Metal wire mesh fence	Non-metal mesh, vertical fence	Half-pipe mesh fence
Fence Integrity and Durability	• Metal mesh rusts and degrades quickly in water • Vertical design impedes access to land and road maintenance • Requires regular maintenance due to fallen trees and large wildlife	• Does not degrade in water • Snow loads created by snow plowing would damage the fencing • Requires regular maintenance due to fallen trees and large wildlife	• Does not degrade in water • Withstands impacts from roads • Likely withstands impact from fallen trees and large wildlife
Road Maintenance	• Vertical design would impede road maintenance	• Vertical design would impede road maintenance	• Allows for road maintenance, including loads created by snow plowing

Species' Needs	• Foxsnakes and snapping turtles can easily climb mesh • Needs to be 2 m tall to prevent foxsnakes from climbing over it • Has the ability to entrap wildlife without regular maintenance • Requires specially designed "jump-outs" to prevent wildlife from getting trapped on the road	• Foxsnakes and snapping turtles can easily climb mesh • Needs to be 2 m tall to prevent foxsnakes from climbing over it • Has the ability to entrap wildlife without regular maintenance • Requires specially designed "jump-outs" to prevent wildlife from getting trapped on the road	• Smooth interior prevents foxsnakes and snapping turtles from climbing it • Ability to be shorter than 2m due to curvature • Does not trap wildlife on roads or need specially created jump-outs
Visual Aesthetics and Accessibility	• 2 m height would be a barrier to viewing the landscape • Vertical design would impede access to land	• 2 m height would be a barrier to viewing the landscape • Vertical design would impede access to land	• Allows for easier access to land • Allows access for Indigenous communities to access traditional lands • Curve allows it to be shorter than 2 m and at grade with the road (minimizes visual barrier)

3.1.2 Railways

The impacts of railways on wildlife are largely understudied (Popp & Boyle, 2017; Vincent, 2022) despite being on the landscape in Canada for nearly 200 years. Many wildlife species are documented to be impacted by railways including mammals (Barrientos et al., 2019; Clair et al., 2019; Jerem & Mathews, 2021), birds (Tremblay & St. Clair, 2009), reptiles (Heske, 2015; Platt et al., 2022; Vincent, 2022), amphibians (Bartoszek & Greenwald, 2009; Heske, 2015), and insects (Bhattacharya et al., 2002). Some studies have examined the use of warning devices (Backs et al., 2017) and wildlife underpasses (Matsuzawa, 2017; Pelletier et al., 2005) to mitigate this threat, however mortality continues to persist.

A recent study in eastern Georgian Bay brought Indigenous knowledge (IK) and western science together to investigate the complex issue of wildlife on railways (Vincent, 2023). The study sought to identify causes leading to turtle and amphibian entrapment on railways, identify hotspots along the railway within SFN and Magnetawan First Nation (MFN), and offer additional insights that could inform mitigation efforts on a broader scale.

Interviews with community members from SFN and MFN revealed concerns for local wildlife and provided valuable insights on, and specific locations of, wildlife railway use and mortality. Much of the knowledge shared during interviews helped with the identification of current knowledge gaps with regard to railway ecology and what species the community is commonly finding along railway corridors .

Visual surveys conducted during this study found 42 species along the target railway. Of the total observations, 76% were mortalities, and of those mortalities, 87% were amphibians and reptiles (Vincent, 2022). Reptiles and amphibians were identified in interviews with community members as likely being the most susceptible to railway mortality (Vincent, 2022). Several community members explained that rather than turtles being killed by collisions with trains, most die as a result of rail entrapment and heat stress (Vincent, 2022). This observation is consistent with previous findings (Kornilev et al., 2006; Rautsaw et al., 2018), and was also the leading suspected cause of turtle mortality from Vincent's (2022) surveys. A novel cause of mortality for freshwater turtles, entrapment in creosote tar leached from a railway tie (Vincent et al., 2022), was described in an interview by a community member from SFN. This cause of mortality was previously unreported in the scientific literature.

Vincent's (2022) study highlights the value of collaborative research bringing together complementary knowledge systems. Understanding that reptiles and amphibians may be particularly susceptible to railway mortality, the study also identified areas to target future mitigation both locally and in relation to broad scale landscape features for turtles and anurans (Vincent, 2022).

3.2 PROTECTION AND ARTIFICIAL INCUBATION OF TURTLE NESTS

Nesting is a critical life stage during which reproductively active female turtles make terrestrial movements in search of suitable nesting habitat (Obbard & Brooks, 1981; Edge et al., 2010). The nesting behaviour of female turtles, such as the location where they decide to nest (i.e., road shoulder versus natural nesting habitat), can have long-term consequences on turtle population persistence by impacting both adult female and hatchling fitness (Hughes & Brooks, 2006; Spencer & Thompson, 2003; Wilson, 1998). During the nesting season, female Blanding's turtles, for example, have been recorded traveling as far as 6 km from wetland habitat to find a nesting site (Edge et al., 2010; Millar & Blouin-Demers, 2011). These movements put females at risk of desiccation, depredation, and human-related hazards such as road mortality (Spencer, 2002; Steen et al., 2006).

Nesting habitat characteristics differ based on the turtle species and the surrounding landscape, but generally include open canopy, lack of herbaceous vegetation cover, and well-drained soils (Hughes & Brooks, 2006). The landscape along eastern Georgian Bay is largely dominated by rock barrens and wetland complexes (Kentel, 2023; Markle et al., 2021) which provide a unique nesting habitat found in the pockets of shallow soil formed by lichens and mosses (Hudson et al., 2020). Despite the abundance of rock barren habitat on the landscape, recent studies have found that there is limited availability of suitable nesting sites (~3% suitable habitat) due to reduced canopy openness and shallow soil depth that does not meet most of the local turtle species' oviposition needs (Kentel, 2023; Markle et al., 2021). Climate change is expected to impact lichen and moss mats in eastern Georgian Bay due to increased drought conditions (Mortsch et al., 2000; Price et al., 2013; Trenberth, 2011; Hudson et al. 2020). As a result, the mechanisms for soil creation will be altered, likely causing the reduction of organic soil accumulation and further limiting the amount of habitat with the appropriate soil depth for nesting (Hudson et al., 2020). With increased drought conditions and a higher risk of wildfires (Braun et al., 2010; Wotton et al., 2017), it is important to research solutions to mitigate these threats to the turtle community across this landscape.

3.2.1 Nesting Turtles on Roadsides

With limited suitable nesting habitat on the landscape (Kentel, 2023), road shoulders have created an anthropogenic nesting habitat to which females migrate (Baldwin et al., 2004). In one study, roads were found to meet the requirements for both soil depth and canopy openness necessary for nesting (Kentel, 2023). Kentel (2023) found that snapping turtles made up a high proportion of all species that nested on the road. This suggests that larger-bodied turtles may be more likely to use road shoulders as nesting habitat, especially if the natural habitat is limited by soil depth and canopy openness.

While roadside habitats may provide more suitable and preferable conditions for nesting turtles (i.e., soil depth, canopy openness, and thermal regime), these areas can also act as ecological traps by exposing females and their offspring to road mortality and reducing nest success as a result of predation, compaction, and/or pollution (Baldwin et al., 2004; Marchand & Litvaitis, 2004; Steen et al., 2006). Observations made during monitoring conducted by GBB also found instances of roadside nests incubating at temperatures that were too high, causing them to solidify (Burke, pers. obs. 2022).

Nest predation is a major threat to turtle populations and has been shown to vary between populations (Congdon et al., 2003 - 82% of nests predated; Urbanek et al., 2016 - 92% of nests predated; Wirsing et al., 2012 - 57%-83% of nests predated). In some sites, nest predation has reached up to 100% (Geller, 2012). Nest predation can be artificially increased near human settlements as a result of human-mediated predators. Raccoons, foxes, ravens, and other predators of turtle nests benefit from the increased amount of food available near humans (garbage, pet food, backyard gardens). At the same time, humans reduce the number of apex predators that would otherwise control the populations of these meso-predators (Prugh et al., 2009; Ritchie & Johnson, 2009). Combined, this leads to an increase in turtle nest predators.

With regard to the threat of roads, several mitigation practices exist including fencing to redirect wildlife away from roads, artificial nesting mounds away from roadsides, artificial nesting mounds away from roadsides, use of turtle nesting cages, and the artificial incubation of turtle nests. Artificial nesting mounds can be a beneficial nesting alternative for females, especially in southern Ontario and in areas with minimal or degraded nesting habitat (natural or human-caused). However, the success of this high-density nesting area is often dependent on size (i.e., surface area sufficient for population nesting in the area), protection from predators, and annual maintenance (Beaudry et al., 2010; Buhlmann & Osborn 2011; Dowling et al., 2010; Paterson et al., 2013). A new strategy has been suggested and is currently being explored by Markle et al. (2021) to instead encourage nesting in the natural rock barren landscape. This would involve supplementing suitable crevice and ledge sites on rock barrens, that turtles would travel over during nesting season, with substrate characteristic of the landscape (i.e., sandy-loam soil and moss or lichen) (Markle et al., 2021).

Nesting cages have been used across Ontario as a way to reduce meso-predator interaction with turtle nests during natural nest incubation. Nest cages have been found to presurce most of the thermal characteristics that female turtles use to maximize hatching success (Riley & Litzgus, 2013). However, some differences in hatchling body conditions were found depending on nest cage type (i.e., above ground vs. below ground) and this was also dependent on species. More research is needed to understand the potential mechanisms driving these differences (Riley & LItzgus, 2013). Other studies have found that within a short-term period (~2 years), nest cages or nest flags likely will not attract nest predators, however over time they may likely become a 'learned' cure of a food source for some predatrs (i.e., corvids (Rollinson & Brooks, 2007); and racoons (Mroziak et al., 2000)). Further long-term studies on meso-predator interactions and nest cages would be beneficial. With community support and application, nest cages have the potential to also be an important educational tool to engage communities in turtle conversation. Overall, nest cages are a positive conservation tool that maintains natural levels of hatching success, whole also increasing the number of successful nests through the protection of the nest from predators.

Without a panacea for turtle protection on the landscape, many communities and organizations along the eastern coast of Georgian Bay have developed turtle incubation programs. Artificial incubation of turtle nests can be an excellent tool in mitigating the effect of human activity on turtle populations. Excavation and incubation of freshwater turtle nests ex situ is more effective than nest caging in situ, yet far less expensive than captive-breeding and headstarting strategies (Mullin et al., 2020). Artificial incubation can address increased nest-predation rates caused by human-mediated predators by removing nests before they are predated. Some examples of these programs along the coast are included below.

For over 10 years, MFN's species at risk program has worked to protect the reptile community on their traditional territory and beyond. Part of this work has been through a turtle incubation program that, since 2018, has helped to protect 4,540 turtle eggs, with the hatchlings being released back into community wetlands. These efforts have protected turtles from areas with high predation rates, construction sites, high-traffic areas, and other areas where turtle eggs are highly vulnerable. Since hatchling turtles are released directly into their home wetlands, artificial incubation also prevents hatchlings from being hit by cars on their way to find water. The knowledge that has been gained through this program has been shared throughout the coastal community to better protect turtles and has fostered the development of similar programs at GBB.

The Georgian Bay Mnidoo Biosphere has begun to work with partners along the eastern coast of Georgian Bay to protect high-risk turtle nests. Since 2020, this program has helped to protect turtle eggs that are in construction areas, other high-risk areas, or areas of high predation. Since 2020, over 6,300 hatchlings have been released back into their home wetlands. Efforts in turtle incubation have also been coupled with cultural knowledge as turtle eggs are welcomed into our facility through a ceremony and smudge and release of hatchlings are marked with another release ceremony to start their next stage of life off in a good way.

For over 5 years, SFN's species at risk program has worked to learn more about the species at risk found within their traditional territory and protect them. Turtle conservation on SFN has taken a two-pronged approach: 1) incubate nests in areas of high disturbance and species of particular concern, and 2) use nest cages as a community initiative to protect other identified nests. Having a visual presence for community members has increased awareness on roads helping to increase knowledge and protection for adult turtles and their nests. This program has helped protect over 6000 eggs through incubation and nest caging.

Scales Nature Park's Saving Turtles at Risk Today (S.T.A.R.T.) project has also worked to protect turtles and their nests throughout the Parry Sound and Muskoka regions. This incubation program began in 2015 and has resulted in the incubation of over 12,000 eggs and release of approximately 11,000 hatchlings back into their home wetlands.

3.2.2 Township of Carling Turtle Incubation Partnership

In 2021 and 2022, the TOC partnered with GBB for species at risk training, turtle nest monitoring, mitigation, and hatchery care and release services. The objective of this partnership was to eliminate and/or mitigate impacts to nesting turtles from a road resurfacing project. Due to the length of the road, complexity of wetlands, and timing, it was impossible to use silt fencing along the entire road length to deter turtles from accessing the roadway. Instead, monitoring and incubation was identified as a preferred method.

With support from MFN, nesting turtles were monitored and all eggs were removed and incubated during two nesting seasons (late-May to early-July) in 2021 and 2022. Over the two years of monitoring, a total of 3,036 eggs from 132 nests were collected along the road. The majority of nests and eggs were from snapping turtles. A large number of northern map turtle nests were also collected, with fewer midland painted turtles and Blanding's turtles excavated and incubated.

Over the two years, 2,610 turtle hatchlings were successfully hatched and released back into their home wetlands (86% success rate). The 14% of eggs that did not successfully hatch reflects naturally occurring infertile eggs and developmental abnormalities. With an estimated 80% of turtle nests being depredated when left on the landscape, these numbers show the importance of incubation programs to help with the recruitment of turtles.

To ensure the collected turtle eggs, and subsequently the hatchlings, were given the best chance of survival, GBB strived to approach incubation and care of hatchlings in a way that honoured Indigenous knowledge and Anishnaabek worldview. At the onset of incubation, a ceremony was held at the GBB office including a water ceremony, feast, and smudge of the facility. Turtle releases began with a ceremony facilitated by members of WFN and/or SFN to send turtles back to their home wetlands in a good way. Individuals from the TOC, GBB, Killbear Provincial Park, and community members were also in attendance to learn and release the turtle hatchlings.

Two types of outreach events occurred alongside this work, hatchery tours and turtle releases. Hatchery tours welcomed members of the public into the GBB facility to learn about the work being done in the TOC, how the eggs are incubated, and how the hatchlings are cared for up until release. Turtle release events brought registered and invited guests together to release hatchlings into their home wetlands. At both event types, Anishinaabek cultural knowledge, including the Turtle Island creation story, was shared. Participants learned about road ecology, why the biology of turtles makes them especially susceptible to road mortality, and ways for individuals to help turtles they come across. To date, over 600 people have participated in these events.

3.3 UNDERSTANDING LARGE LANDSCAPE MOVEMENTS VIA MOTUS TOWERS

For effective conservation of migratory species, it is important to understand species' movement patterns, habitat requirements, and how they use habitats at different times of year (i.e., breeding territories, migratory stopover sites, wintering areas) (Marra et al., 2011; Taylor et al., 2017). Information gained from researching these habitat preferences and uses, as well as the inferences drawn from it, have been used for developing conservation and management strategies to enhance species protection on the landscape, which is especially important for those species in decline (Grahame et al., 2021).

The Motus Wildlife Tracking System (Motus) is an international collaborative network of researchers and educators that use automated radio telemetry to track birds, bats, and insects. This automated radio telemetry system functions as a network of collaborating researchers and organizations managing independent arrays of receiving towers with all data processed through a centralized database (Taylor et al., 2017). Digitally coded tags allow tagged individuals to be tracked simultaneously on a single frequency by any receiver in the network (Taylor et al., 2017). Since 2013, the Motus network has grown to over 1,000 stations across 31 countries. Twenty-five thousand animals have been tagged contributing to 373 projects, resulting in over 120 scientific publications (GBLT, 2021). As of 2021, there were over 950 partners and collaborators involved in the network worldwide making this an amazing example of collaborative partnerships benefiting many species. On the coast of Georgian Bay, collaborators include the Georgian Bay Land Trust (GBLT), SFN, MFN, Ontario Parks, and GBB.

Data collected by Motus is integral to furthering understanding of migratory animals. Used for a wide variety of studies, Motus research has aided in:

- Recovery planning for species at risk;
- Understanding how species may be impacted in areas of development and how to alleviate these threats;
- Learning about species migration including where they overwinter and when they begin migration; and
- Identifying where birds stop during migration (stop-over sites) to protect habitat that is key to their survival during this period.

For a complete list of publications using Motus telemetry data, visit: motus.org/data/publications.

3.3.1 Expanding the Motus Network in Eastern Georgian Bay

In 2020, as part of the Maamwi Anjiakiziwin initiative, seven Motus towers were installed within the biosphere region. These towers supplement existing towers in the region installed by the GBLT and MFN. The towers were strategically placed in areas along the coast where they would provide further coverage and where partners could host and make use of them.

The seven towers installed in 2020 can be found at the following locations:

- Thomson Reserve
- Little McCoy
- Sandy Island
- Shawanaga First Nation
- Grundy Lake
- Mallet Property
- Killbear Provincial Park

In the two years that these towers have been operational, 22 species and 49 individuals have been detected. Four of the detected species and 31 of the individuals were species at risk. Species have been detected that help support research projects across the Americas including the ovenbird (part of a Costa Rican study) and the northern saw-whet owl (part of the Indiana Audubon).

As a UNESCO biosphere site, GBB has a role in facilitating collaboration amongst partners for the placement and installation of these towers. At present, research utilizing the towers is led by other partners on the coast. Studies led by SFN and the GBLT are profiled below.

Apakawaanaajiinh Mnidoo Gamii - Bats of Georgian Bay

Bats in the GBB region are a mix of temperate-zone hibernating bats (little brown myotis (*Myotis lucifugus)*, northern myotis (*Myotis septentrionalis)*, tri-colored bat (*Perimyotis subflavus)*, eastern small-footed myotis *(Myotis leibii)*, big brown bat (*Eptesicus fuscus*)) and other species that migrate south to overwinter (ECCC, 2018; Lowe, 2012). Four of the eight bat species in Ontario - little brown myotis, northern myotis, tri-colored bat, and eastern small-footed myotis - are listed as endangered and have declined in Ontario over the last decade (Humphrey, 2017; Humphrey & Fotherby, 2019). This decline has primarily been due to white-nose syndrome (WNS), a disease caused by the fungus *Pseudogymnoascus destructans*. Understanding life stages and how habitat is used during these stages is key to protecting the species and the different sites that are required to complete their seasonal functions (e.g., maternity roost habitats, roosting sites, hibernation sites).

In an effort to help preserve and better understand Ontario's bat species, SFN launched the Apakwaanaajiinh Mnidoo Gamii (Bats of Georgian Bay) project. This project assesses bat population sizes, health, and distribution within SFN and across eastern Georgian Bay. Preliminary work using acoustic detectors suggests that seven of the eight Ontario species exist within habitats on SFN traditional territory. The project seeks to understand the movements of bat species at both a local scale (within SFN traditional territory) and landscape scale (across the biosphere region and beyond).

SFN identified Motus towers as essential for the project given its regional scale. Without the use of Motus towers, bats would have to be radio tracked by hand which would involve a significant level of effort and limit the team to one survey location at a time.

In order to affix bats with radio telemetry tags, mist nets are deployed to capture bats entering and exiting roosts, caves, tunnels, and other structures that serve as bat habitat. Each captured bat is measured for morphometric data (e.g., size, sex, fitness), has a pit tag inserted, and a unique ID band applied. With the help of the consulting firm Myotistar, tiny pea-sized transmitters are affixed to the backs of select bats to track their movements both locally through radio tracking and regionally through the Motus network. Forty-four bats were banded in 2021, and another 99 were banded in 2022. One bat captured in 2022 was a recapture from 2021.

Female little brown myotis and their pups congregate in maternity roost habitats during their reproductive period which supports social thermoregulation — possibly benefitting energy conservation and reproductive fitness (Olson & Barclay, 2013). These sites can be in hollow trees and anthropogenic structures such as houses and other structures with small enclosed spaces (Olson & Barlcay, 2013). At SFN, community knowledge of the area led the team to monitor the community church in 2018 and it has since become the primary netting, banding, tagging, and transmitter application site in Shawanaga. From applying transmitters at the church and hand-tracking, half a dozen new roosting sites were detected within the community in 2022 alone.

Hibernation habitats, or hibernacula, for Ontario's non-migratory bat species include underground tunnels, caves, crevices, and other protected structures that provide sheltered, stable conditions during the winter months (ECCC, 2018; MECP, 2023a; NCC, n.d.). Until recently there were no known hibernacula across the eastern Georgian Bay region. In recent years SFN biologists have been studying a dozen cave-like structures with radio tracking and netting efforts. They have confirmed five previously unidentified sites as hibernation locations hosting up to three bat species. Similar structures have been identified elsewhere in the region, and with Motus telemetry work, there is hope to confirm even more hibernation habitat. Temperature and humidity loggers have been deployed to record and study the habitat conditions inside suspected and confirmed hibernacula, allowing for better prediction of potential habitat suitability.

SFN hopes to develop a long-term monitoring and conservation project to fill the many knowledge gaps that exist for Ontario's bats. Using Motus as a tool, they are building a greater understanding of critical habitat hotspots for bats around Georgian Bay. As Motus coverage expands to fill gaps in Georgian Bay, more will be learned about bats and their short- and long-distance movement patterns.

Tracking Songbirds to Inform Land Management

The coast of eastern Georgian Bay is used extensively by migrating songbirds. Understanding the needs and behaviours of migratory birds is key to making informed land management and conservation decisions to benefit all bird species throughout their life cycles. To better understand the role land trust properties play an dhow they can better serve birds, the GBLT partnered with Western University to research the breeding and post-breeding movements of adult and juvenile songbirds.

While the island archipelago of Georgian Bay provides habitat crucial for bird populations, it is unclear how songbirds use this landscape after the breeding season. Beauchamp (pers. comm., 2021) is seeking to explore how songbirds, specifically the song sparrow (*Melospiza melodica*), white-throated sparrow (*Zonotrochia albicollis*), red-eyed vireo (*Vireo olivaceus),* and ovenbird (*Seiurus aurocapilla*), move in the fragmented island and coastal habitats of Georgian Bay after breeding season. This study also seeks to understand whether these movements differ based on the age of the bird (i.e., adult versus juvenile).

In the summer of 2021 and 2022, four species of songbirds were captured and radio tagged by Western University researchers on properties owned or stewarded by the GBLT (A. Beauchamp, pers comm., 2021; Figure 4). Six Motus stations deployed in the area monitored the movements of radio tagged birds, with

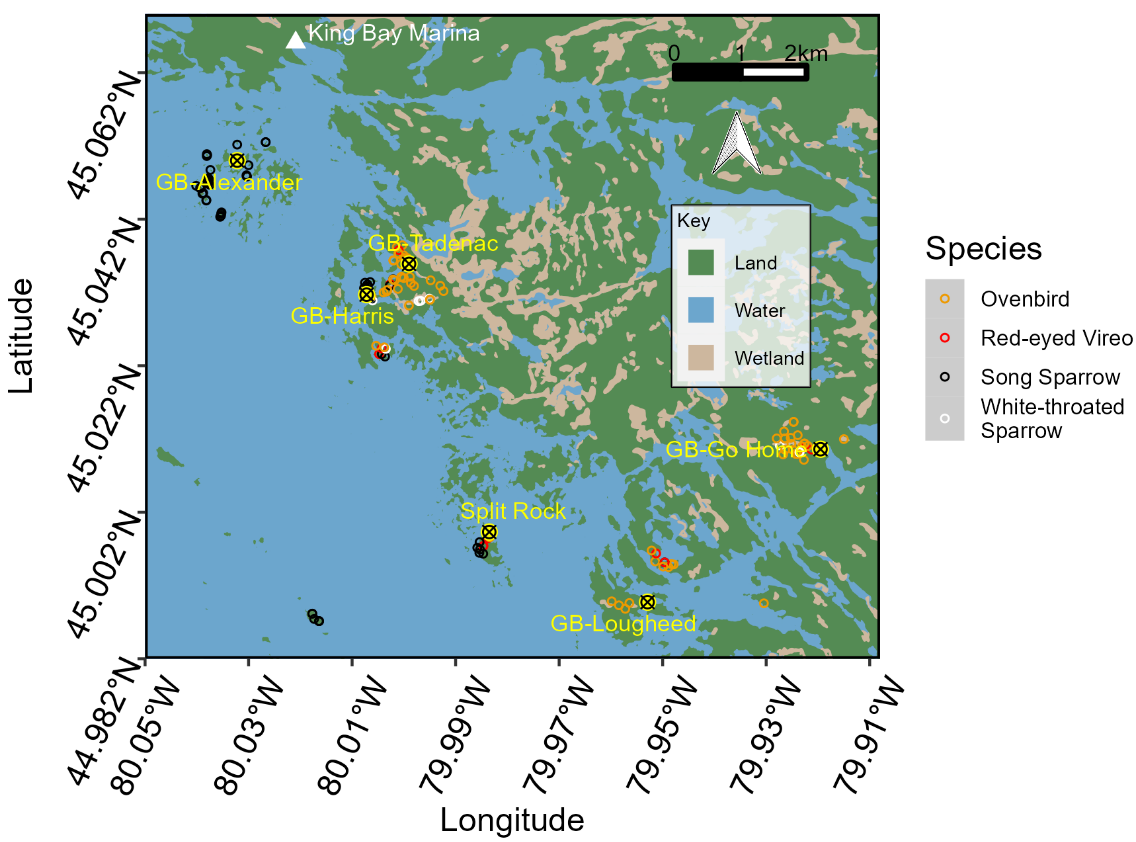

Figure 4. Capture locations of birds radio tagged in the summer of 2021 and 2022. Colour indicates different species, with yellow icons and text indicating the location of local Motus stations (Figure from A. Beauchamp, pers comm., 2023). Map layer data from DMTI Spatial and Land Information Ontario.

almost 45 million detections received on the local towers across the summer months and into fall migration (A. Beauchamp, pers comm., 2021).

Preliminary results from manual tracking and Motus data suggest that adults remained near their nesting location, whereas younger birds tended to move within the region during the weeks prior to fall migration (A. Beauchamp, pers comm., 2021). Analyses of these data are ongoing. Most birds initiated fall migration from the Go Home Bay area in early to mid-September (A. Beauchamp, pers comm., 2021). Once birds departed Georgian Bay for fall migration, their long-distance migratory movements were tracked by Motus towers throughout the Motus Network (A. Beauchamp, pers comm., 2021; Figure 5).

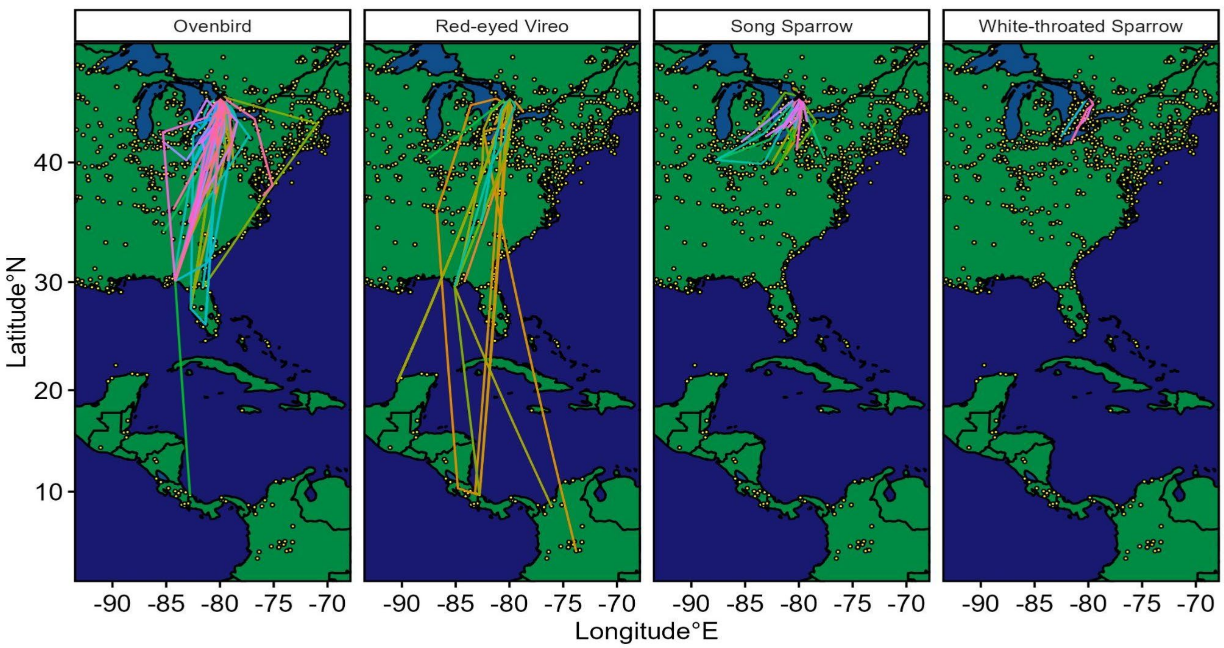

Figure 5. Fall migration tracks of four songbird species recorded using the Motus Wildlife Tracking System. Color indicates different birds tagged in the Go Home Bay region in either 2021 or 2022. Yellow points indicate the location of Motus stations during this time period (Figure from A. Beauchamp, pers comm., 2023).

Building on this work, researchers were interested in studying the prairie warbler (*Setophaga discolor*). Eastern Georgian Bay represents the northernmost extent of the prairie warblers' breeding range and the region is believed to host many of the estimated 300 or fewer breeding pairs present in the species' Canadian range (ECCC, 2019). Evidence of declines in prairie warbler abundance have been noted (Lambert & Smith, 1984; Sutherland, 1987; Sutherland & Harris, 2007).

Prairie warblers overwinter in the Caribbean and Florida. During this time there is potential for spatial overlap between Canadian breeding birds and those that breed in other areas. Currently, it is unknown whether individuals from the larger southern breeding range in the United States and elsewhere immigrate to the Georgian Bay breeding range during spring migration or throughout other parts of the species' annual cycle. No exchange of individuals between southern breeding birds and Canadian breeding birds would indicate that birds in eastern Georgian Bay are a breeding subpopulation, meaning they may benefit from more regional research into their genetics, habitat use and persistence, population management, and conservation efforts (Esler, 2000).

While information is known about the home ranges and habitat use of prairie warbler populations in the United States (Nolan, 1978; Nolan et al., 2020), the physical geography of that region differs considerably from coastal Georgian Bay. Currently, it is unclear if these differences in habitat impact space and habitat use of the population found here on Georgian Bay. Understanding the space use and habitat requirements of prairie warblers in this region will be key to preserving areas for this regionally unique species.

Tagging prairie warblers will provide researchers with local scale insights about territory size and habitat use, as well as larger scale insights about where individuals migrate to and overwinter (A. Beauchamp, pers comm., 2023). Enhancing understanding regarding the demographic connectivity, migratory connectivity, space use, and habitat use by prairie warblers in Ontario can aid in conservation and land management decisions intended to protect this species of conservation concern at their most northern extent.

3.4 LEARNING THROUGH FIRE (*SHKODE*)

The use of fire (*shkode*) as a land management tool has been practiced by Indigenous peoples across the world since time immemorial (Hoffman et al., 2021; Kimmerer & Lake, 2001; Lake & Christianson, 2019; Turner et al., 2013). Lewis (1975) notes that Indigenous peoples across the globe have over 70 uses of fire including tree felling, clearing travel corridors, fireproofing settlements, and hunting. Fire as a cultural practice and as a tool, has been used by humans to shape environments and thus ecosystem structure and biodiversity as a result of this practice (Bond & Keeley, 2005; Hoffman et al., 2021; Lake et al., 2017). Hoffman et al. (2021) also noted examples of Indigenous groups occupying the same ecosystem but applying different fire practices relating to their diet requirements (i.e., managing the same ecosystem for moose versus caribou). On Turtle Island (North America), and specifically in Georgian Bay, *Mnidoo-gamii*, the Anishinaabek use fire as a way of influencing the land and restoring ecosystems (Bond & Keeley, 2005; Lake et al., 2017). These fire management practices help avoid large-scale fires which have the potential to cause more damage to the landscape. Techniques used by the Anishinaabek have influenced and informed contemporary fire management practices.

According to Crafts (2020), “Women are given the role of water keepers in Anishinaabe traditions. Men are given the role of fire keepers. Two spirit people have many roles in society and ceremony. Some two spirit people can also be fire keepers, water carriers, carry eagle feathers, and conduct ceremonies”. Fire keepers would monitor the age and health of forested areas and ecosystems by observing abundance of harvest plants and animals, and biodiversity. When organizing burning times, factors such as wind, which aids in controlling the direction that fire moves through an area, and time of year would be considered. Burning would often take place during the fall and spring when the ground is typically wetter.

Colonization negatively impacted the use of fire for land management. In 1878, to protect valuable timber resources, a Fire Act was put into place and fire became viewed as a destructive force. Jail time was introduced for people who caused or started fires (Davidson-Hunt, 2003). It is likely that the fire tower on Tower Hill in Parry Sound was one of the stations used to patrol fires on WFN (Crafts, 2020). Despite these laws, Anishinaabek were resilient and had low burning fires to help clear understory around blueberry (*miinan*) bushes allowing blueberry plants to thrive (Crafts, 2020). The history behind the loss of this traditional knowledge (and other types of knowledge) is important to note as many of these practices no longer take place.

Assimilation efforts resulted in the loss of knowledge and oral traditions and Anishinaabek became disconnected from fire practices. This loss of knowledge has contributed to a disconnect of roles amongst communities. Forests adapted to Indigenous-controlled burnings, but through colonization these burnings were suppressed requiring forests to adapt to regimes without burning. Kimmerer and Lake (2001, p. 37) state that "... forest science, including ecological classification of vegetation types, arose from observation of forests that were essentially in transition from conditions of indigenous fire management to post-colonial fire suppression".

The revitalization of culture and land-based practices presents the opportunity to restore traditional knowledge of fire and fire as a management tool. However, multiple barriers have been identified for the revitalization of Indigenous-led fire stewardship in Canada. These barriers include:

1. Lack of understanding by wildfire management agencies, decision-makers, and the general public of the relationship between Indigenous peoples and fire;
2. Government systems that may devalue, depower, or tokenize Indigenous knowledge systems;
3. Lack of access to accreditation and training for applied wildfire science that also includes Indigenous fire stewardship;
4. Complexities surrounding liability and insurance; and
5. Limited capacity and resources for bringing back this management style in a landscape that has been disconnected from it for so long (Hoffman et al, 2022).

Creating space for knowledge, perspectives, and experiences is critical to removing these barriers for Indigenous fire stewardship and to also shift colonial perceptions of fire, increasing the understanding of its use as a tool to enhance ecosystems and biodiversity as a whole.

3.4.1 The Impact of Fire on Turtle Habitat in Georgian Bay

Many of the ecosystems found in eastern Georgian Bay are adapted to, and benefit from, occasional low-intensity fire (Gauthier et al., 1996). Georgian Bay is home to a variety of species that depend on the natural fire regimes historically found in this area. Species across the Georgian Bay landscape, such as blueberries (*miinan*), thrive after fire burns due to the release of nutrients creating better growing conditions (Stolz, 2018). Species such as Jack pine (*okikaadag*) require heat from low-intensity fires to properly germinate (Gauthier et al., 1996). Wildfires can also increase canopy openness, creating diverse microhabitats for reptiles (Dovčiak et al., 2013; Litzgus & Mousseau, 2004) and temporary turtle nesting habitat (Beaudry et al., 2010). Conversely, fires that occur with greater intensity and frequency can have negative consequences (Van Sleeuwen, 2006), especially in soil limited landscapes such as rock barrens.

The Parry Sound 33 wildfire of 2018 affected >11,000 ha of land, predominantly rock barrens, along the northeast coast of Georgian Bay (Markle et al., 2020b). It is believed that the increasing severity of summer droughts across the Canadian boreal forest (Wang et al., 2014), the extreme fire-danger rating in the Georgian Bay region before the 2018 fire (Natural Resources Canada, 2018), and the recent history of fire suppression (Ward & Mawdsley, 2000), causing the build-up of wildfire fuels, were all factors in determining the severity of Parry Sound 33. Fortunately, the Parry Sound 33 wildfire has provided an opportunity to learn about fire in this habitat type where traditional fire management practices have been suppressed.

It was predicted that the Parry Sound 33 wildfire may have resulted in unusually high burn severity and had a disproportionately negative effect on nesting habitats of at-risk turtle species. Wildfires have also been noted to negatively affect habitat that turtles rely on for aestivation (e.g., junipers (*Juniperus* spp.) on rock outcrops (Litzgus & Brooks, 2000); overwintering (e.g., peatlands (Markle & Chow-Fraser, 2014)); and travel corridors (e.g., vernal pools (Markle & Chow-Fraser, 2014)). Eight months after the fire was extinguished, the burned landscape was found to have lower soil presence, volume, and available depth, and a change in vegetation cover type (Markle et al., 2020b). It is predicted that the difference in soil volume and depths observed between burned and unburned plots was a result of the combustion of organic components of the soil and the redistribution of the remaining soil on the landscape during rain events (Markle et al., 2020b). Crevices on rock barrens seemed to be more resilient to the wildfire event or were more likely to collect remnant soil during these rain events, as this was the location where available nesting habitat for turtles almost exclusively remained within the burned landscape. A number of other nest-site characteristics are also influenced by fire including soil temperature, drainage ability, and susceptibility to flooding (Figure 6).

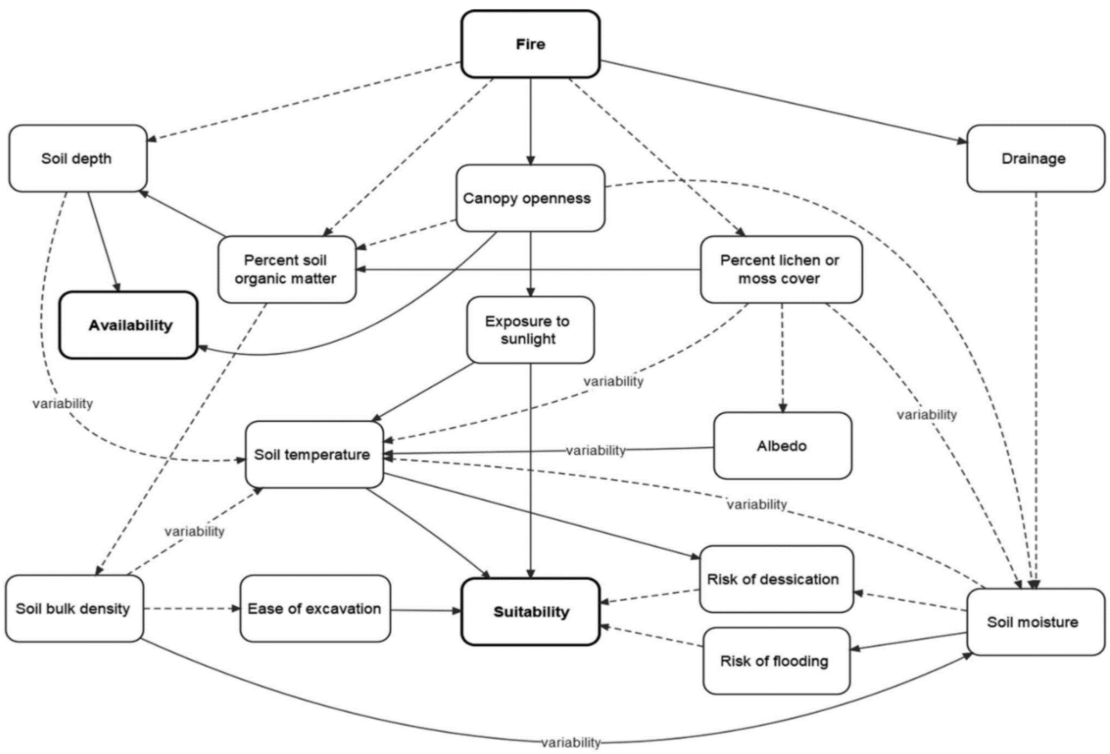

Figure 6. A conceptual model of major post-fire environmental changes on an open rock barrens landscape that directly and indirectly affect turtle nesting habitat availability and suitability. Dashed lines = negative effects, solid line = positive effects. Variability refers to increased fluctuations in soil temperature or moisture conditions. (Figure from Markle et al., 2020b).

Despite the negative effects that fire can have on turtle nesting habitat through changes in soil depth, soil organic matter, lichen and moss cover, and drainage (Figure 6), wildfire can also increase nesting habitat availability through the creation of early-successional vegetation communities in burned areas. Although the loss of tree and shrub cover further decreases water storage capacity, the opening of the canopy may attract more turtles for nesting (Litzgus & Mousseau, 2004), increase the surface temperature of previously shaded areas (Webb et al., 2005), and provide more thermally diverse microhabitats (Litzgus & Mousseau, 2004). It is possible that during traditional forest management pre-colonization, low-burn fire events may have resulted in increased nesting habitat for turtle species. These types of fires typically maintain early-successional vegetation communities, increased canopy openness, and result in less soil combustion and erosion.

Therefore, by creating new management policies to restore forest health and plant biodiversity through the use of fire and uplifting traditional forest management techniques suppressed through colonization, it may be possible to improve the health of these ecosystems. Along with a predicted lengthening of the forest fire season, due to increased temperatures and instances of drought as a result of climate change, fires are expected to have a higher burn severity (Flannigan et al., 2009, Hoffman et al. 2021). It is important to research these patterns and changes in fire to further understand the role that fire plays on the landscape. Similarly, monitoring vegetation recovery trajectories can serve as a starting point to understand the natural recovery of turtle nesting habitat in the long term. Future research should focus on quantifying the trade-offs between decreases in habitat suitability and availability in open rock barren nesting habitat, and increases in nesting opportunities in previously forested areas after fire opens the canopy.

3.5 UNDERSTANDING HYDROLOGY ACROSS THE LANDSCAPE

Wetlands are some of the most biodiverse ecosystems and provide ecosystem services that include: carbon storage (Gorham, 1991; Loisel et al., 2014), water storage (Holden, 2005; Mitsch et al., 2009), nutrient retention (Cheng et al., 2020), wildlife habitat (Markle et al., 2020a), and refugia from environmental change (Stralberg et al., 2020). Understanding water level dynamics in wetlands is critical to understanding wetland ecosystems and the stresses placed on them, especially in areas where there is increased or planned human development (North et al., 2023).

iWetland, a community science wetland water level monitoring platform, was developed in 2016 by the McMaster Ecohydrology Lab. iWetland ran from 2016-2019 in 24 wetlands throughout eastern Georgian Bay, including provincial parks, recreation trails, and First Nations lands. This project engaged community members in wetland science while also improving understanding of the spatiotemporal variability in this region's wetlands (North et al., 2023). This method of community science was successful in recording water level dynamics in deep and shallow peatlands, lower water levels with warmer mean air temperatures, and recording the lowest water levels in the fall, which is consistent with the seasonal water level cycle within the Great Lakes (North et al., 2023). This small study shows how partnerships and community science can help inform understanding of the landscape as a whole.

Other hydrological research along the coast has focused on the complex needs of the eastern Massasauga rattlesnake, a climate sensitive species that relies on peatland hummocks for winter refugia (Markle et al., 2020a; Rouse & Willson, 2002; Smolarz et al., 2018). This geographic setting, in the southern Canadian Shield, is also unique for how peatlands are formed, creating the need for research that is specific for this area and its large and small-scale spatiotemporal differences.

The coast of eastern Georgian Bay is at the northern limit of the Massasauga's range, placing additional survival stressors onto these reptiles needing to survive harsh, long winters in an area where their populations may be less tolerant to environmental changes and fluctuations (García-Ramos & Kirkpatrick, 1997; Smolarz et al., 2018). Massasaugas are likely able to tolerate short term inundation of hibernation sites, however, long-term flooding and water level fluctuations may be detrimental (Smith, 2009; Smolarz et al., 2018). This sensitivity was highlighted in 2014-2015 after a mass mortality event of Massasaugas believed to have been caused by flooding of hibernation sites due to freeze-thaw events (MNRF, 2016).

The 'zone of resilience' has been described by Smolarz et al. (2018) as "an area which provides access to oxygen while also buffering against an advancing frost line and a fluctuating water table to minimize the chance of massasaugas drowning or freezing within the hibernacula". Previous research by Smolarz et al. (2018) found that, in general, overwintering habitat in taller hummocks were more resilient to changes and fluctuations than smaller ones. Since then, more research has been conducted to understand the spatial heterogeneity and distribution of unflooded wintering habitat.

Through the creation of spatially explicit surface models, Markle et al. (2020a) were able to quantify the habitats within peatlands that were most likely to remain unflooded during the overwintering period and identify further key characteristics that would be associated with higher habitat availability, such as the presence of white pine (*zhingwaak, Pinus strobus)* and maple (*aninaatig, Acer spp.*).

Understanding the specific habitat characteristics required by a species throughout their life stages allows researchers to begin identifying areas across the landscape that meet these requirements and that may serve as critical habitat. Identified habitats could then be the focus of targeted management efforts.

3.6 STUDYING THE EASTERN WOLF (*MA'IINGAN*)

The eastern wolf (*ma'iingan, Canis lycaon*) has been extirpated from most of its original range over the last 400 years as a result of persecution, land clearing, and the invasion of non-endemic coyotes (COSEWIC, 2015). Today, the estimated eastern wolf population is less than 1,000 mature individuals (COSEWIC, 2015). Eastern wolves typically occur in deciduous and mixed forest landscapes with low human density (COSEWIC, 2015).

Currently, major threats to wolves include habitat loss, hunting, trapping, road mortality, and hybridization with coyotes. However, much is still unknown about their true population size, habitat use, and movements. To understand how wolves are dealing with threats on the landscape, an Indigenous-led, collaborative project was started along Georgian Bay with participation from: SFN, MFN, Wiikwemkoong Unceded Territory, the Ministry of Natural Resources and Forestry, the University of Guelph, and a graduate student from Trent University. This collaborative project follows an approach introduced by Mi'kmaw Elder Albert Marshall termed "Two-Eyed Seeing". The intent of taking this approach is to utilize and braid together the strengths of both Indigenous knowledge and western science to better understand eastern wolf populations, behaviour, and spatial ecology.

Knowledge gaps on the eastern wolf at a landscape scale have been identified in the literature, however, community members from SFN, MFN, and Wiikwemkoong Unceded Territory also raised concerns about the populations of wolves within each of their respective traditional territories. Members from each community identified knowledge gaps and research questions they would like addressed. By creating a more respectful and inclusive approach to this research, initial conversations with community members have led to knowledge that has assisted researchers in locating wolves more efficiently.

To address the questions and concerns around eastern wolves raised by community members, the research team deployed radio collars to track wolf movements. A total of 14 wolves have been collared with each collar being deployed for up to one and a half years, sending GPS data locations every 90 minutes. Collaring allows the research team to understand home range sizes, pack size, diet, genetics, level of hybridization (with coyotes) in the packs, and how the wolves are responding to human-caused changes to the landscape. While the wolves are being collared, genetic samples are taken via blood or scat samples. These samples can provide further information on the individual's genetic composition to determine the exact species (i.e., eastern wolf) or species make-up (i.e., hybrid) of the individual.

This Indigenous-led project is fully guided and interpreted by each of the First Nation communities as a way of carrying on traditional ecological knowledge relating to wolves for future generations.

This project represents an important approach to addressing concerns of landscape biodiversity in eastern Georgian Bay. As wolves are one of the last large-bodied mammals in this area, and require large swathes of connected land, they are a critical species to study from a landscape biodiversity perspective. This project represents continuous Indigenous-led wolf population monitoring to ensure the longevity of wolf populations and to help gain a better understanding of the health of the landscapes in Georgian Bay. At the time of writing, project results were not yet available.

3.7 EXPLORING SPACES FOR BIODIVERSITY CONSERVATION

The Exploring Spaces for Biodiversity Conservation project is an opportunity to extend biodiversity conservation work within the GBB. The main goal is to understand how spaces in the region are contributing to the conservation of biodiversity, and further expand and/or enhance spaces to support high biodiversity value. Generally, work towards this goal falls under two main avenues: updating zonation and establishing new areas for protection.

In the coming years GBB hopes to revisit how protected spaces are being categorized and determined as part of the Biosphere zonation. The intention is to redefine what protected areas are, what constitutes protection, and acknowledge how places and spaces which are cared for in a variety of ways contribute to the conservation of biodiversity.

GBB is working to support the federal government’s commitment to conserving 25% of land and 25% of inland waters by 2025, and 30% by 2030. The establishment of new Protected Areas (PAs) and/or Other Effective Area-Based Conservation Measures (OECMs) will add to the total amount of protected and conserved areas in Canada.

A PA is a clearly defined geographical space, recognized, dedicated, and managed through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values. An example of this is a provincial park.

An OECM is land that may not have the conservation of biodiversity as its primary goal, but is managed in a way that results in the effective and enduring conservation of biodiversity. An example of this would be special management zones in county forests such as Northumberland County Forest.

This project intends to evaluate and grow community knowledge of biodiversity values, functions, and their importance; build community support for biodiversity conservation through outreach and engagement activities; and, assess and improve management actions through stewardship and/or restoration of priority areas.

As a collaborative effort, this project is expected to have numerous shared benefits. At the community level, engaging with this project reinforces common goals and values about conservation, caretaking/stewardship, and sustainable land use. On a global scale, biodiversity conservation offers several broader benefits, including water security, food security, climate change mitigation, livelihood/economic prosperity, and disaster risk reduction, among others.

As this project is still in its early stages, no results are available at this time. Future *State of the Bay* reports will provide updates on the outcomes of the project.

4. DATA GAPS AND RESEARCH NEEDS

This chapter only highlights some of the work being done along the coast with regards to landscape biodiversity.

Much of the work highlighted in this State of the Bay chapter is ongoing. Work continues to be developed to understand biodiversity needs as they relate to different perspectives, ways of knowing, and braiding these knowledge systems together. Some particular areas of future direction include:

- More complex and accurate habitat mapping for greater understanding of all habitat types and their connections across the coast, including islands;
- Greater understanding of how core and buffer areas function for connectivity and how Other Effective Area-Based Conservation Measures may fit in;
- Revisiting how protected spaces are being categorized and determined as part of the Biosphere zonation. Using an updated lens, the intention is to redefine what protected areas are, what constitutes protection and acknowledge how places and spaces which are cared for in a variety of ways contribute to the conservation of biodiversity.
- Increasing the number of connections where science is informed by community needs and knowledge, and then helps address community concerns with reciprocity.
- Encouragement of future Indigenous-led monitoring and traditional knowledge initiatives to gain a better understanding of the health of the landscapes in Georgian Bay.
- Investigate the interaction between turtles of all age classes and rip-rap, as well as alternative designs that include rip rap, such as filling in gaps with smaller aggregate types (i.e. sand or gravel).
- Greater understanding of how the archipelago landscape is used for migration of species through tracking, Motus, and traditional knowledge;
- Understanding the short- and long-distance movement patterns of avian species along eastern Georgian Bay, including bats, monarch butterflies, and SAR birds.
- Enhancing understanding regarding the demographic connectivity, migratory connectivity, space use, and habitat use of species along the coast, e.g. prairie warblers.
- Further understanding the complexity of biological systems (i.e. hydrology, hibernation and nesting habitats, fire) and how these may positively or negatively affect biodiversity.

- Monitor vegetation recovery trajectories post-fire to understand the natural recovery of turtle nesting habitat in the long term.
- Quantifying the trade-offs between decreases in habitat suitability and availability in open rock barren nesting habitat, and increases in nesting opportunities in previously forested areas after fire opens the canopy.
- Encouragement of multi-species approaches to the evaluation of conservation techniques.

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APPENDIX A – UGLMU LAKE HURON SURVEYS 2013-2020

Year	Project Code(s)	Project Name	Relevant 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	Relevant 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	Relevant 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
2015	LHA_FS15_001	Lake Huron Fish Stocking		Fish Stocking

Year	Project Code(s)	Project Name	Relevant Area(s)	Project Type
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
2016	LHA_IA16_305	Spanish Delta FWIN	Spanish River	Nearshore Index Netting
2016	LHA_IA16_303	Spanish River ESTN	Spanish River	Nearshore Index Netting

Year	Project Code(s)	Project Name	Relevant Area(s)	Project Type
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
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

Year	Project Code(s)	Project Name	Relevant Area(s)	Project Type
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_AS17_334	Evaluation of Walleye Ageing Structures	French River, Shawanaga	Aging QAQC
2017	LHA_IA17_802 / 803 / 806 / 810	Broad-scale Monitoring	Key River Area, Moon River Area, Parry Sound Area, Severn Sound Area	Broad Scale Monitoring
2017	LHA_CF17_001	Commercial Catch Sampling 2017	Southern main basin, eastern Georgian Bay, Manitoulin Island area	Commercial Harvest and Stock Status Reporting
2017	LHA_CH17_001	Commercial Harvest and Stock Status Reporting	EGB	Commercial Harvest and Stock Status Reporting
2017	LHA_SF17_404	Chantry Chinook Classic Derby Sampling 2017	Kincardine, Wiarton	Derby Monitoring
2017	LHA_SF17_501	Owen Sound Salmon Spectacular Derby Sampling 2017	Owen Sound	Derby Monitoring
2017	LHA_FA17_STO	Stomach Analysis and Diet Study		Diet Analysis
2017	LHA_IA17_03F	Nottawasaga Bay FLIN Lake Trout Assessment 2017	Nottawasaga Bay	Fall Spawning Survey
2017	LHA_IS17_03L	Nottawasaga Bay LMGN Lake Trout Assessment 2017	Nottawasaga Bay	Fall Spawning Survey
2017	LHA_FS17_001	Fish Stocking	Watcher Islands, Limestone Islands, Iroquois Bay	Stocking reporting
2017	USG_HA17_001	Fall Preyfish Hydroacoustic Survey (USGS)	GB	Hydroacoustic
2017	LHA_FA17_LAM	Sea Lamprey Wound Monitoring and Reporting	GB	Lamprey Monitoring and Reporting
2017	LHA_IA17_251	Severn Sound ESTN	Severn Sound	Nearshore Index Netting
2017	LHA_IA17_258	Severn Sound Fall Walleye Index Netting	Severn Sound	FWIN

Year	Project Code(s)	Project Name	Relevant Area(s)	Project Type
2017	LHA_IA17_249	Severn Sound SMIN (Hoopnet)	Severn Sound	SMIN (hoopnet)
2017	LHA_IA17_250	Severn Sound SMIN (Trapnet)	Severn Sound	SMIN (trapnet)
2017	LHA_IA17_255	Severn Sound Spawning Walleye Index Netting	Severn Sound	SWIN
2017	LHA_IA17_002 / 003 / 027	Offshore Index Assessment	Cape Rich, Collingwood, Watcher Islands	Offshore Index Netting
2017	LHA_IA17_703 / 704 / 702 / 700	Small Fish Assessment	Blackstone Harbour, Britt, Midland Bay, Owen Sound	Small Fish Assessment
2017	LHA_AR17_001	Non-Fish Species Reporting		Synthesis and Analysis
2017	LHA_TR17_CWT	Coded Wire Tag Recovery		Tag Recovery and Analysis
2017	LHA_TR17_001	Tag Recoveries	EGB	Tag recovery
2017	LHA_TE17_AA2	Bruce to Manitoulin Acoustic Array	Bruce Peninsula, south Manitoulin Island	Telemetry
2017	LHA_CC17_001	Contaminants Collections	EGB	Tissue Collection and Analysis
2018	LHA_IA18_802 / 803 / 806 / 810	Broad-scale Monitoring	Key River Area, Moon River Area, Parry Sound Area, Severn Sound Area	BsM
2018	LHA_CF18_001	Commercial Catch Sampling	EGB	Commercial catch sampling
2018	LHA_CH18_001	Commercial Harvest and Stock Status Reporting	EGB	Commercial harvest reporting
2018	LHA_SF18_501	Owen Sound Salmon Spectacular Derby Catch Sampling	Owen Sound	Derby Monitoring
2018	LHA_FA18_STO	Fish Stomach Collections	EGB	Diet analysis
2018	LHA_IA18_14F	Owen Sound and Colpoys Bay Fall Littoral Index Netting	Owen Sound, Colpoys Bay	Fall Spawning Survey

Year	Project Code(s)	Project Name	Relevant Area(s)	Project Type
2018	LHA_IS18_14L	Owen Sound and Colpoys Bay Large Mesh Gill Netting	Owen Sound, Colpoys Bay	Fall Spawning Survey
2018	LHA_FS18_001	Fish Stocking	Watcher Islands, Limestone Islands, Iroquois Bay, Severn Sound, Owen sound, south-western Georgian Bay	Stocking reporting
2018	LHA_FA18_LAM	Sea Lamprey Wound Monitoring and Reporting	GB	Lamprey Monitoring and Reporting
2018	LHA_IA18_265	Severn River Spawning Walleye Electrofishing	Severn Sound	Nearshore Index Netting
2018	LHA_IA18_255	Severn Sound Spawning Walleye Index Netting	Severn Sound	Nearshore Index Netting
2018	LHA_IA18_251	Severn Sound Area End of Spring Trap Netting	Severn Sound	Nearshore Index Netting
2018	LHA_IA18_258	Severn Sound Fall Walleye Index Netting	Severn Sound	Nearshore Index Netting
2018	LHA_IA18_249	Severn Sound Spring Muskie Index Netting (Hoopnet)	Severn Sound	Nearshore Index Netting
2018	LHA_IA18_250	Severn Sound Spring Muskie Index Netting (Trapnet)	Severn Sound	Nearshore Index Netting
2018	LHA_IA18_002	Cape Rich Offshore Index Assessment	Cape Rich	Offshore Index Netting
2018	LHA_IA18_003	Collingwood Offshore Index Assessment	Collingwood	Offshore Index Netting
2018	LHA_IA18_703 / 704 / 702	Small Fish Assessment	Blackstone Harbour, Britt, Midland Bay	Small fish assessment
2018	LHA_IA18_700	Owen Sound Small Fish Assessment	Owen Sound	Small fish assessment

Year	Project Code(s)	Project Name	Relevant Area(s)	Project Type
2018	LHA_AR18_001	Lake Huron Non-Fish Species Reporting	GB	Synthesis and Analysis
2018	LHA_TR18_CWT	Coded Wire Tag Recovery	GB	Tag Recovery and Analysis
2018	LHA_TR18_001	Tag Recoveries	GB	Tag Recovery and Analysis
2018	LHA_TE18_AA2	Bruce to Manitoulin Array	Bruce Peninsula, south Manitoulin Island	Telemetry
2018	LHA_CC18_001	Lake Huron Fish Collected for Contaminant Sampling	GB	Tissue Collection and Analysis
2018	LHA_CC18_C01	Owen Sound Targeted Contaminant Collection	Owen Sound	Tissue Collection and Analysis
2019	LHA_IA19_802 / 810 / 814	Broad-scale Monitoring	Key River Area, Musquash River Area, Parry Sound Area	Broad Scale Monitoring
2019	LHA_CF19_001	Commercial Catch Sampling	EGB	Commercial catch sampling
2019	LHA_CH19_001	Commercial Harvest and Stock Status Reporting	EGB	Commercial Harvest and Stock Status Reporting
2019	LHA_SF19_501	Owen Sound Salmon Spectacular Derby Catch Sampling	Owen Sound	Derby Monitoring
2019	LHA_FA19_STO	Fish Stomach Collections	EGB	Diet analysis
2019	LHA_IS19_13L	Bruce Archipelago Large Mesh Gill Netting	Bruce Archipelago LTRZ	Fall Spawning Survey
2019	LHA_IS19_07L	Limestone Islands Large Mesh Gill Netting	Limestone Islands LTRZ	Fall Spawning Survey

Year	Project Code(s)	Project Name	Relevant Area(s)	Project Type
2019	LHA_FS19_001	Fish Stocking	Watcher Islands, Limestone Islands, Iroquois Bay, GB	Stocking reporting
2019	LHA_FA19_LAM	Sea Lamprey Wound Monitoring and Reporting	GB	Lamprey Monitoring and Reporting
2019	LHA_IA19_232	Key River Area End of Spring Trap Netting	Key River	Nearshore Index Netting
2019	LHA_IA19_228	Key River Fall Walleye Index Netting	Key River	Nearshore Index Netting
2019	LHA_IA19_224	Key River Spawning Walleye Electrofishing	Key River	Nearshore Index Netting
2019	LHA_IA19_225	Key River Spawning Walleye Index Netting	Key River	Nearshore Index Netting
2019	LHA_IA19_226	Key River Spring Muskellunge Index Netting (Trap)	Key River	Nearshore Index Netting
2019	LHA_IA19_203	Southern Georgian Bay Offshore Index Assessment	Southern Georgian Bay	Offshore Index Netting
2019	LHA_IA19_703 / 704 / 702 / 700	Small Fish Assessment	Blackstone Harbour, Britt, Midland Bay, Owen Sound	Small fish assessment
2019	LHA_AR19_001	Lake Huron Non-Fish Species Reporting	GB	Synthesis and Analysis
2019	LHA_AR19_DEP	Offshore Index Species' Core Depth Assessment	GB	Synthesis and Analysis
2019	LHA_TR19_CWT	Coded Wire Tag Recovery	GB	Tag Recovery and Analysis
2019	LHA_TR19_001	Tag Recoveries	GB	Tag recovery

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2019	LHA_TE19_AA2	Bruce to Manitoulin Array	Bruce Peninsula, south Manitoulin Island	Telemetry
2020	LHA_CH20_001	Commercial Harvest and Stock Status Reporting	GB	Commercial harvest reporting
2020	LHA_IA20_130	Bruce Archipelago Offshore Index Assessment	Bruce Archipelago	Fish Community Monitoring
2020	LHA_IA20_814	Broad-scale Monitoring	Musquash River Area	Broad Scale Monitoring
2020	LHA_IA20_203	Southern Georgian Bay Offshore Index Assessment	Southern Georgian Bay	Fish Community Monitoring
2020	LHA_TR20_CWT	Coded Wire Tag Recovery	GB	Fish Distribution and Movement
2020	LHA_TE20_GRB	East Nottawasaga Acoustic Telemetry Tagging	East Nottawasaga	Fish Distribution and Movement
2020	LHA_TE20_NAW	Nawash Acoustic Telemetry Tagging	Nawash	Fish Distribution and Movement
2020	LHA_AA20_001	Ontario Waters of Lake Huron Acoustic Receiver Maintenance		Fish Distribution and Movement
2020	LHA_TR20_001	Tag Recoveries	GB	Fish Distribution and Movement
2020	LHA_FS20_001	Lake Huron Fish Stocking	GB	Fishing Stocking
2020	LHA_FA20_STO	Fish Stomach Collections	GB	Foodweb and Ecological Interaction
2020	LHA_FA20_LAM	Sea Lamprey Wound Monitoring and Reporting	GB	Lamprey Wounding

Year	Project Code(s)	Project Name	Relevant Area(s)	Project Type
2020	LHA_IS20_018	Parry Sound Trap Net Lake Trout Spawning Assessment	Parry Sound	Trapnet