STATUS OF COASTAL WETLANDS IN GEORGIAN BAY AND THE NORTH CHANNEL

for inclusion in

LAKE HURON COASTAL STATUS

Review, assessment and synopsis of the condition of coastal wetlands and associated habitats

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Introduction

There are more than 3700 coastal wetlands along the eastern coast of Georgian Bay (Fracz and Chow-Fraser 2013). These wetlands provide spawning and nursery habitat for migratory fish of Lake Huron as well as habitat for obligate wetland fish species. Coastal wetlands provide habitat for more than 80 species of fish in the Laurentian Great Lakes (Jude and Pappas 1992, Wei et al 2004). These wetlands also provide habitat for birds, mammals, amphibians and birds, including species-at-risk like the Blandings Turtle (*Emydoidea blandingii*). The benefits and ecosystem services that wetlands provide have been well documented, and some of these include nutrient management, flood mitigation, and providing habitat for species (Mitch and Goselink 2015).

The coastal wetlands in eastern Georgian Bay are unique among other coastal wetlands in the basin of the Laurentian Great Lakes. They are some of the most pristine (Chow-Fraser 2006; Cvetkovic and Chow-Fraser 2011), and receive minimal impacts from agriculture, industry or urbanization. The largest current threat to coastal wetlands comes from increased cottage development and recent sustained low water levels (Midwood and Chow-Fraser 2012; Fracz and Chow-Fraser 2013; Leblanc et al. 2014). Secondly, the geomorphology of these wetlands is very different compared to those in Lakes Erie and Ontario, which are often densely vegetated with large expanses of cattails (*Typha spp.*) and nutrient rich. These large marshes of the lower Great Lakes have underlying sedimentary bedrock and shallow slopes, often occurring at rivermouths, behind barrier beaches and in protected embayments. By contrast, the wetlands in eastern Georgian Bay tend to be small (< 2 ha), and form wetland complexes that function as large wetland units (Midwood and Chow-Fraser 2015). These wetlands in eastern Georgian Bay have pre-Cambrian granitic rock that shapes the morphology of the wetlands. There are, however, some wetlands in the southeast portion of Georgian Bay that have sedimentary limestone bedrock, similar to that in the Bruce Peninsula and Manitoulin Island (Midwood et al 2012). The third aspect that makes eastern Georgian Bay unique is the archipelago, rumoured to have 30,000+ islands, that dot the coast between Severn Sound and the French River. Often, there are small protected wetlands in the lee of these islands that provide excellent habitat for turtles and fish. Similar to other wetlands of Lake Huron, those in Georgian Bay are naturally oligotrophic and have bulrushes (*Schoenplectus spp.*) as the dominant emergent vegetation.

Lakes Huron-Michigan have experienced sustained low water levels since the late 1990s. The lack of inter-annual water-level fluctuation has negatively impacted both the species richness and diversity of plant and fish communities in the wetlands (Midwood and Chow-Fraser 2012). This is because changing water levels prevent the establishment of plant monocultures, allowing species to occupy different niches as the water level changes, and diverse aquatic plant communities tend to attract a diverse community of fish (Cvetkovic et al. 2010). The low water levels have been attributed to factors including long-term climate variability and the more recent effects of global climate change, glacial isostatic rebound, as well as past dredging of the St. Clair River.

Methods:

Data Sources and Data Collection

The Chow-Fraser lab first began to survey coastal wetlands of eastern Georgian Bay in 1998, and has continued to sample in wetlands periodically over the past 17 years. Our data inventory includes information on water quality (primary nutrients, physical and chemical characteristics), and information on the fish and aquatic plant communities. These data were combined with those from a synoptic survey of other Great Lakes and used to develop

ecological indices that can be used for regular assessments of wetland health. The ones that will be discussed in detail in this report are the Water Quality Index (WQI; Chow-Fraser 2006), the Wetland Macrophyte Index (WMI; Croft and Chow-Fraser 2007) and the Wetland Fish Index (WFI; Seilheimer and Chow-Fraser 2007). Chow-Fraser (2006) developed the WQI using 12 water-quality parameters that are commonly collected by agencies (e.g. total phosphorus, soluble reactive phosphorus, total ammonia nitrogen, total nitrate-nitrite nitrogen, total nitrogen, chlorophyll, total suspended solids, turbidity, temperature, pH and conductivity). WQI scores can range from -3 (worst) to +3 (best) and reflects the degree of human disturbance impacting a particular site, based on inputs of nutrients and sediments from the watershed. Both the WMI and WFI can range from 1 (worst) to 5 (best) and were created to provide a more accessible means of determining wetland quality to managers that do not have the funding or the means to collect water-quality information (Croft and Chow-Fraser 2007, Seilheimer and Chow-Fraser 2006). Seilheimer et al. (2009) have conducted a direct comparison of these three indices, together with the Wetland Zooplankton Index (WZI; Lougheed and Chow-Fraser 2002). The WMI tended to be more sensitive to changes in wetlands that are poor quality. Readers are directed to the original publications to obtain details on how these indices were developed and used in wetland assessments. Some zooplankton, turtle and bird data have also been collected in wetlands of Georgian Bay for other projects, but we have not included these in this report because there are insufficient data to represent wetlands for the entire eastern shoreline.

In most cases, wetlands were sampled between June and August. Where plant, fish and water-quality information were collected for the same site, the majority of the sampling occurred within the same week. Since the plant data were collected to provide information on fish habitat, we focused solely on those plants that live in the high marsh (emergent vegetation) and low marsh (floating and submergent vegetation); Ontario Wetland Evaluation System (OWES)--Northern Manual; OMNR 2002). We used the stratified random method (Croft and Chow-Fraser 2009) to survey the plant community, as this proved to be best method to ensure that the rare species that are indicative of high quality are included. Some wet meadow plant data were also collected and upland plant surveys were conducted at some wetlands according to the OWES protocol. These data have been used by the Michigan Technical Univeristy to field-truth the classification of coastal wetlands in eastern Georgian Bay (Bourgeau-Chavez et al. 2015) and can be made available for other projects.

The fish communities in wetlands were either surveyed with fyke nets (set parallel to shore) or with boat elelctrofishing. Cvetkovic et al. (2012) showed that there were no significant differences between protocols when calculating WFI scores. Fyke nets were left overnight in the wetlands (see Seilheimer and Chow-Fraser 2006; 2007); fish were identified and released at the site near where they were caught. Sampling occurred between late June to end of August and excluded the spawning period. Both of these survey protocols targetted fish living in shallow vegetated areas of the wetlands, in water between 0.5 m to 2.0 m. We did not catch species that use deeper water such as walleye or adult muskies.

In this report, we have sorted the wetlands by quaternary watersheds (shapefile obtained from OMNR; see **Figure 1**) and then calculated mean wetland index scores for each watershed. All information were entered into a Geographic Information System (GIS; ArcMap 10.2) to create the maps for visualization and comparisons.

Result:

Timing of surveys

This report contains information for 157 wetlands sampled in 30 quaternary watersheds and that had been sampled between 1998 and 2014 for a total 233 wetland years (i.e. some wetlands had been sampled multiple times during this period). Given that environmental conditions have changed between 1998 and 2014, especially in regards to water levels, it is important to determine if these temporal differences are associated with regional biases. For this purpose, we have produced maps and tables showing the location of wetlands sampled in three general periods: prior to 2001; between 2001 and 2006 and between 2007 and 2014. Since our sites were not always sampled for all three indices, we have provided a separate map for the WQI, WMI and WFI (**Figures 2, 3, and 4**, respectively; **Table 1**). Note that fish surveys began in 2001, and therefore, we do not have any information prior to 2001 for wetland fish communities.

In general, there was considerable spatial overlap for the three time periods, and so we felt justified in disregarding when the data were collected and pooled all of the data to examine differences among the watersheds. A few of the wetlands have been deliberately sampled two or more times between 2002 and 2014 (e.g. for Midwood and Chow-Fraser 2012), and it may be desirable to determine how these wetlands have changed through time. Since the scope of this project was limited to comparing wetland quality among watersheds, an analysis of changes through time will have to be reserved for a future endeavour.

Comparison among quaternary watersheds

Mean scores of WQI, WMI and WFI for each quaternary watershed are presented in **Figures 5, 6 and 7**, respectively. Northern Georgian Bay (French River and Beaverstone Bay) has limited road access and is more remote compared to other areas in eastern Georgian Bay, and this has resulted in fewer wetlands sampled there. By contrast, southeastern Georgian Bay was well sampled, because this area is road accessible and is more easily sampled.

Wetland quality within Georgian Bay was assessed as Excellent or Very Good for the majority of sampling sites (**Table 2**; **Figures 5 to 7**), underscoring the fact that within the Great Lakes basin, Georgian Bay has some of the most pristine conditions (Cvetkovic and Chow-Fraser 2011). The only areas that showed some degree of impairment included Areas of Concern (AOC) such as Severn Sound and Collingwood Harbour and Spanish Harbour. Historic areas of concern (AOC) in Georgian Bay include Severn Sound (Sturgeon Bay and Matchedash) and Collingwood Harbour (Blue Mountain). Spanish Harbour is also the site of an AOC, and although conditions were not assessed as being impaired, they were only considered Good rather than Very Good or Excellent. It is important to mention that Severn Sound and Collingwood have since been delisted and Spanish Harbour is listed as an area in recovery, meaning that all actions have been taken to clean up the area. The Moderately Degraded condition that we gave to Collingwood in 1998 may well be different now that it has been delisted, and it would be useful to re-sample these areas using the same protocol and see if the area has recovered.

In addition to these AOCs, areas with lower index scores (poorer quality) tended to be found in areas with higher cottage density and road density such as the Sturgeon Bay-Hog Bay, and Matechdash Bay watersheds. DeCatanzaro et al. (2009) found that road density was negatively correlated with WQI. It is worth noting, however, that both watersheds currently have a good status with respect to the WQI, a moderately degraded status with respect to the WMI, but a very good status for the WFI. In fact, the WFI was uniformly Very Good to Excellent in

Georgian Bay, and was not useful in discriminating between areas with and without human disturbance. The watershed with the least impact was Shawanaga River, which was assessed as Excellent by both the WQI and WMI, and as Very Good by the WFI.

A total of 58 fish species have been found in the coastal wetland of Georgian Bay (**Table 3**). The five most abundant species were Pumpkinseed, Bluntnose Minnow, Brown bullhead, Blacknose Shiner and Largemouth bass. A significant amount of research has been done to identify muskellunge spawning and nursery habitat (Leblanc et al 2014; Weller et al.,, unpub. data). Although juvenile muskellunge were only found on three occasions during fyke net surveys, it is well known that they depend on coastal wetlands for nursery habitat. These fish are net avoiders, and cannot be adequately sampled with passive techniques such as fyke nets. Instead, seine surveys must be used to catch these elusive fish.

The eastern Georgian Bay archipelago consists of more than 30,000 islands, a network that provides protection from wind and wave action, and allowing organic matter to accumulate to form wetlands. There are more than 2,200 km^2 of islands, and only a small percentage of habitat type on the islands are wetlands (95 km^2; 4.3%) (**Table 4**). Very few of these wetlands have been surveyed, largely because they occur on islands and can only be accessed by boat. The wetlands tend to be small, and function as a larger wetland complex when in close proximity to other small wetlands. Because of their small size and exposure to great wind and wave action, there is a limited amount of suitable substrate for plant growth. This makes these small island wetlands particularly vulnerable to sustained low water levels, and highly valued by wildlife, especially the Blanding's turtle, which is a threatened species in Ontario and which require the use of bogs and vernal pools for feeding, mating, reproduction and overwintering on these islands (Markle and Chow-Fraser 2014).

Sustained low water levels in Lake Huron are having a significant negative impact on wetlands. Low water levels can lead to wetlands becoming stranded if they get cut off from the lake as the water level drops (Chow-Fraser 2009; Fracz and Chow-Fraser 2013,). Sustained low water levels has also been shown to have a negative impact on fish species diversity (Midwood and Chow-Fraser 2012). The other main threat to these coastal wetlands is increased cottage development and the associated shoreline modifications and nutrient and sediment inputs that come with development.

There is a substantial body of research on coastal wetlands of Georgian Bay; research on water quality, fish, plants, zooplankton and turtles have been published in 39 peer-reviewed papers since 1998 (see **Appendix A**). Wetlands in eastern and northern Georgian Bay are clearly very unique, and although they are considered some of the best quality wetlands in the Great Lakes, we need to monitor them regularly to ensure that they do not become degraded. To see a snapshot of each of the sub-watersheds in this study, please refer to **Appendix B,** where you will find index scores, geology, watershed size, number of wetlands sampled, photos and maps associated with each quaternary watershed.

Research needs

Continued research in Georgian Bay is needed in order to monitor the impacts of low water levels, and increased development in Georgian Bay. Specific focus of future research should include wetland inventories of the Georgian Bay archipelago as well as revisiting sites that were first monitored more than a decade ago.

Table 1: Number of wetlands sampled for the Water Quality Index (WQI), Wetland Macrophyte Index (WFI) and Wetland Fish Index (WFI) each year.

Year	WQI	WMI	WFI
1998	7	7	
2000	2	3	
2002	4	4	2
2003	17	17	9
2004	33	35	19
2005	31	29	28
2006	30	31	22
2007	7	5	23
2008	8	3	11
2009	11	20	23
2010	3		
2011	8	7	8
2014			18

Table 2: All quaternary watersheds in this study with associated wetland conditions, n = wetland years.

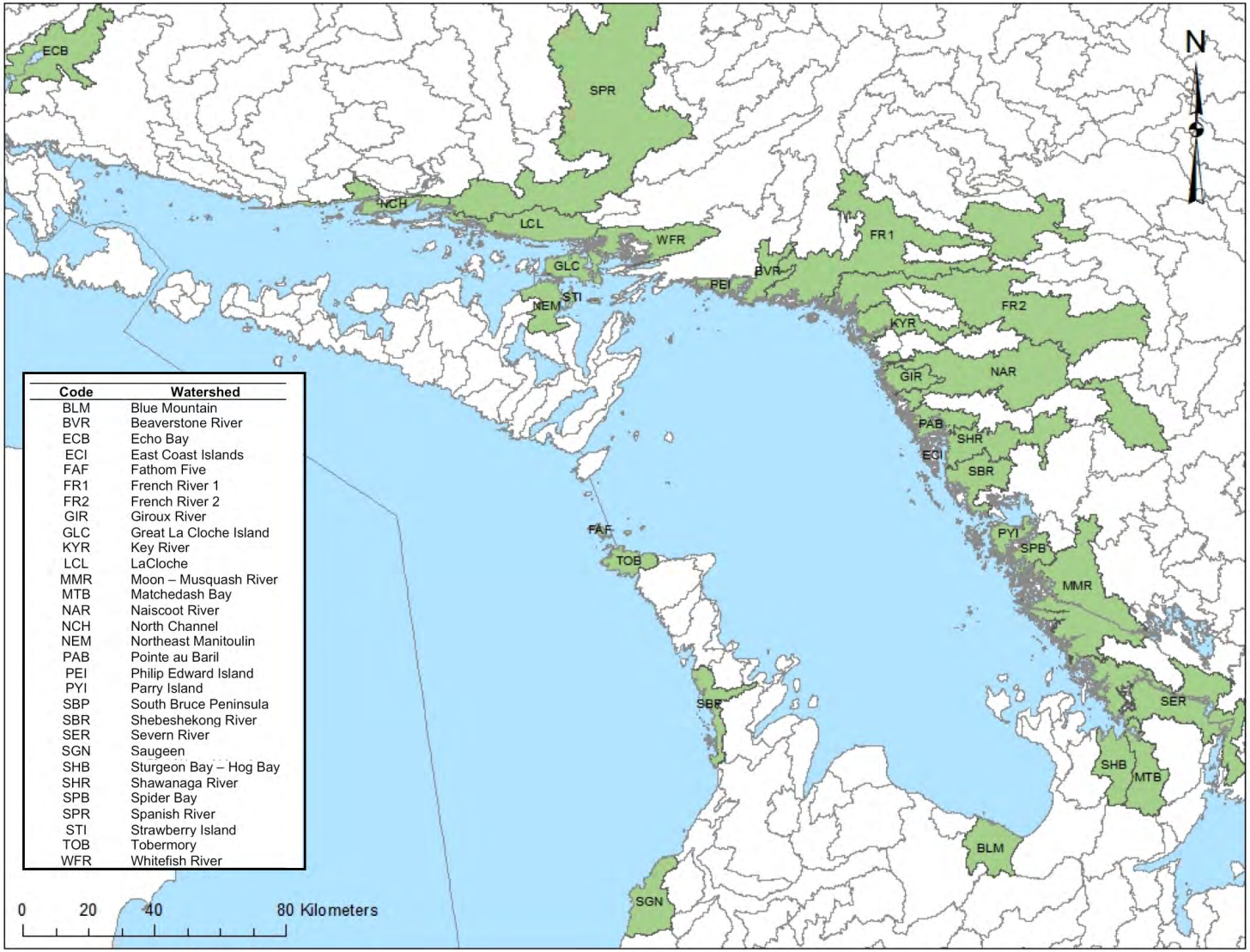
Watershed	Area Sq Km	Type	Geology	Water Quality Index		Wetland Macrophyte Index		Wetland Fish Index	
				n	WQI_Quality	n	WMI_Quality	n	WFI_Quality
Sturgeon Bay – Hog Bay	189.8	Mainland	Sedimentary	4	Good	4	Moderately Degraded	4	Very Good
Matchedash Bay	220.8	Mainland	Sedimentary	9	Good	6	Moderately Degraded	8	Very Good
Severn River	702.4	Mainland	Granitic	26	Very Good	28	Very Good	63	Very Good
Moon – Musquash River	717.1	Mainland	Granitic	29	Very Good	35	Excellent	20	Very Good
Spider Bay	89.4	Mainland	Granitic	3	Very Good	3	Very Good	1	Excellent
Parry Island	76.7	Mainland	Granitic	4	Very Good			2	Excellent
East Coast Islands	118.5	Island	Granitic	10	Good	9	Excellent	9	Excellent
Shebeshekong River	193.4	Mainland	Granitic	3	Very Good	4	Excellent	3	Excellent
Shawanaga River	312.6	Mainland	Granitic	3	Excellent	3	Excellent	1	Very Good
Pointe au Baril	117.5	Mainland	Granitic	5	Very Good	5	Excellent	3	Very Good
Naiscoot River	944.5	Mainland	Granitic	5	Very Good	5	Very Good	2	Excellent
Giroux River	102.4	Mainland	Granitic	3	Very Good	3	Excellent	2	Very Good
Key River	195.4	Mainland	Granitic	3	Very Good	3	Excellent	4	Very Good
French River 2	1059.1	Mainland	Granitic	2	Very Good	2	Excellent	3	Very Good
French River 1	1259.2	Mainland	Granitic	2	Very Good	2	Excellent	2	Very Good
Beaverstone River	127.4	Mainland	Granitic	4	Very Good	3	Excellent	3	Very Good
Philip Edward Island	49.1	Mainland	Granitic	4	Very Good	4	Very Good	4	Very Good
Great La Cloche Island	96.4	Mainland	Granitic	5	Very Good	6	Excellent	6	Excellent
Whitefish River	266.4	Mainland	Granitic	11	Very Good	10	Very Good	9	Very Good
Northeast Manitoulin	137.0	Mainland	Sedimentary	1	Very Good	1	Very Good	1	Very Good
Strawberry Island	16.3	Island	Sedimentary	2	Good	2	Very Good	2	Excellent
LaCloche	271.0	Mainland	Granitic	3	Very Good	3	Excellent	1	Very Good
Spanish River	5565.3	Mainland	Granitic	2	Good	3	Good	1	Very Good
North Channel	139.0	Mainland	Granitic	2	Good	2	Very Good		
Echo Bay	403.4	Mainland	Granitic	3	Good	3	Good		
Tobermory	93.5	Mainland	Sedimentary	5	Very Good	2	Very Good	3	Very Good
Fathom Five	13.7	Island	Sedimentary	4	Good	3	Very Good	4	Very Good
South Bruce Peninsula	136.5	Mainland	Sedimentary	1	Good	1	Good	1	Excellent
Saugeen	222.6	Mainland	Sedimentary	1	Very Good	1	Very Degraded		
Blue Mountain	205.6	Mainland	Sedimentary	1	Moderately Degraded	1	Very Degraded		

Table 3: Fish species found in Georgian Bay coastal wetlands between 2001 and 2014.

Common Name	Total Abundance	Length (mm)			
		Min	Max	Range	Median
Pumpkinseed	12186	6	284	278	85
Bluntnose Minnow	5286	6	414	408	53
Brown Bullhead	4536	15	1154	1139	90
Blacknose Shiner	3797	6	75	69	50
Largemouth Bass	1963	10	505	495	56
Yellow Perch	1788	20	250	230	91
Rockbass	1711	22	225	203	96
Blackchin Shiner	1526	16	75	59	50
Mimic Shiner	1519	23	79	56	45
Bluegill	833	40	184	144	102.5
Banded Killifish	811	24	80	56	53
Golden Shiner	483	26	139	113	71
Pugnose Minnow	470	27	76	49	42
Longear Sunfish	452	40	193	153	71
Common Shiner	418	7	168	161	63
Bowfin	414	30	755	725	550
Round Goby	351	26	112	86	67
Smallmouth bass	291	24	445	421	49
Tadpole Madtom	234	41	95	54	68
Spottail Shiner	193	35	100	65	60
Emerald Shiner	149	38	99	61	56.5
Longnose gar	149	35	1180	1145	800
Black Crappie	148	22	280	258	96
Johnny Darter	126	18	59	41	43.5
Spotfin Shiner	101	21	100	79	74.5
White Sucker	100	35	525	490	115.5
Northern Pike	85	56	850	794	152
Brook Silverside	83	49	667	618	74
Common Carp	69	22	700	678	66
Iowa Darter	55	33	62	29	47
Shorthead Redhorse	50	63	635	572	89
Sand Shiner	46	36	68	32	55
Central Mudminnow	42	40	93	53	66
Northern Redbelly Dace	33	26	60	34	44
Brassy Minnow	28	5	94	89	60
Ninespine Stickleback	16	47	75	28	64.5
White Crappie	10	42	124	82	60
Rosy-faced Shiner	9	50	70	20	56
Slimy Sculpin	9	51	90	39	55
Logperch	7	51	80	29	73
Brook Stickleback	6	22	45	23	29
White Perch	6	35	265	230	235
Creek Chub	5	84	115	31	89
Alewife	4	60	87	27	72.5
Least Darter	4	52	62	10	55
Blacknose Dace	3	37	90	53	62

Table 4: Area and percentages of wetland habitat types in islands of the Georgian Bay archipelago

	Area (km^2)	Percentage of Total
Total Area	2238.2	-
Wetland	95.4	4.3
Vernal Pools	1.9	0.1
Wetland + Vernal Pool	97.3	4.4



Code	Watershed
BLM	Blue Mountain
BVR	Beaverstone River
ECB	Echo Bay
ECI	East Coast Islands
FAF	Fathom Five
FR1	French River 1
FR2	French River 2
GIR	Giroux River
GLC	Great La Cloche Island
KYR	Key River
LCL	LaCloche
MMR	Moon – Musquash River
MTB	Matchedash Bay
NAR	Naiscoot River
NCH	North Channel
NEM	Northeast Manitoulin
PAB	Pointe au Baril
PEI	Philip Edward Island
PYI	Parry Island
SBP	South Bruce Peninsula
SBR	Shebeshekong River
SER	Severn River
SGN	Saugeen
SHB	Sturgeon Bay – Hog Bay
SHR	Shawanaga River
SPB	Spider Bay
SPR	Spanish River
STI	Strawberry Island
TOB	Tobermory
WFR	Whitefish River

Figure 1: Map showing the quaternary watersheds used in this report.

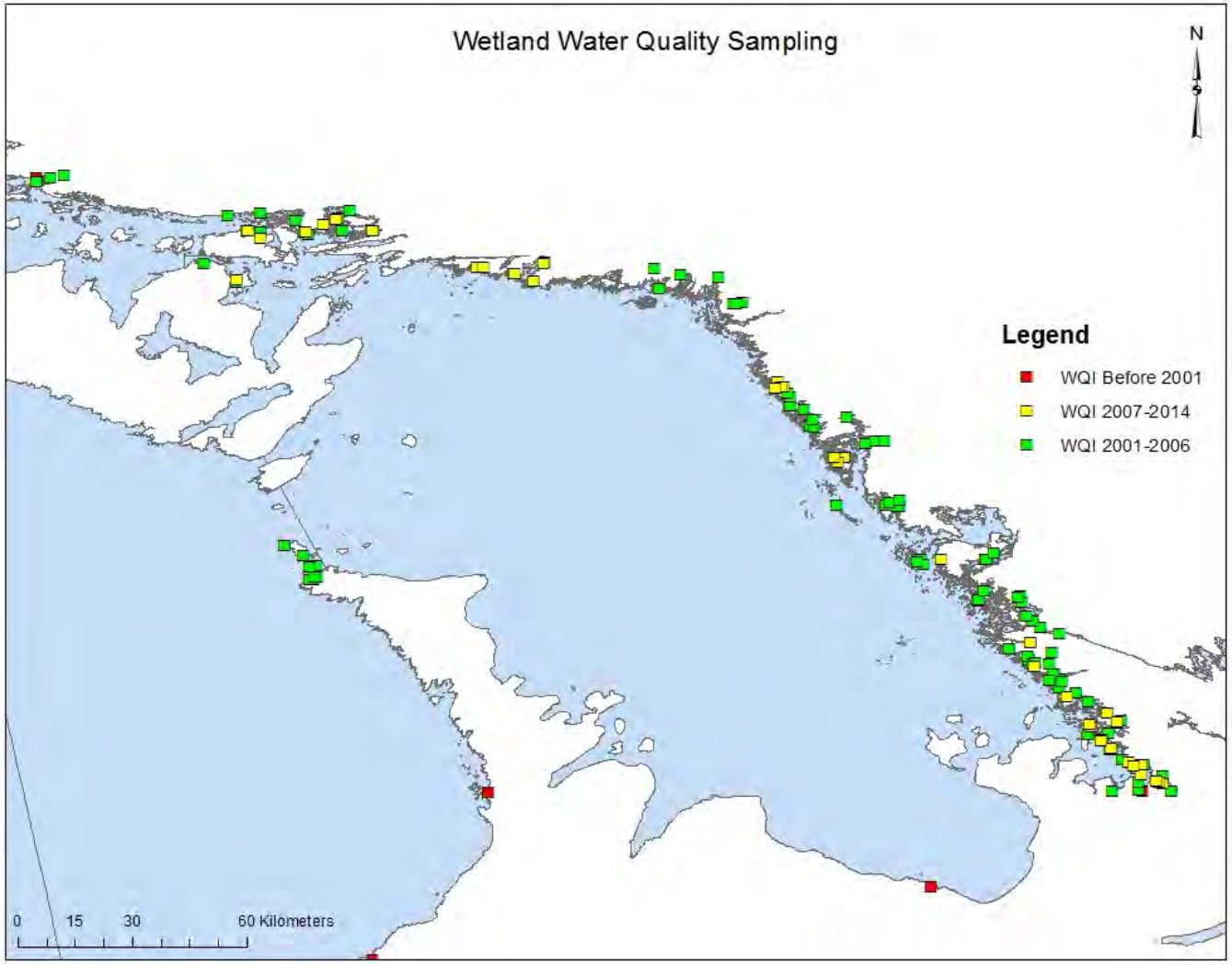


Figure 2: Distribution of sites sampled for **WQI** scores during three periods: before 2001 (red), between 2001 and 2006 (green) and between 2007 and 2014 (yellow).

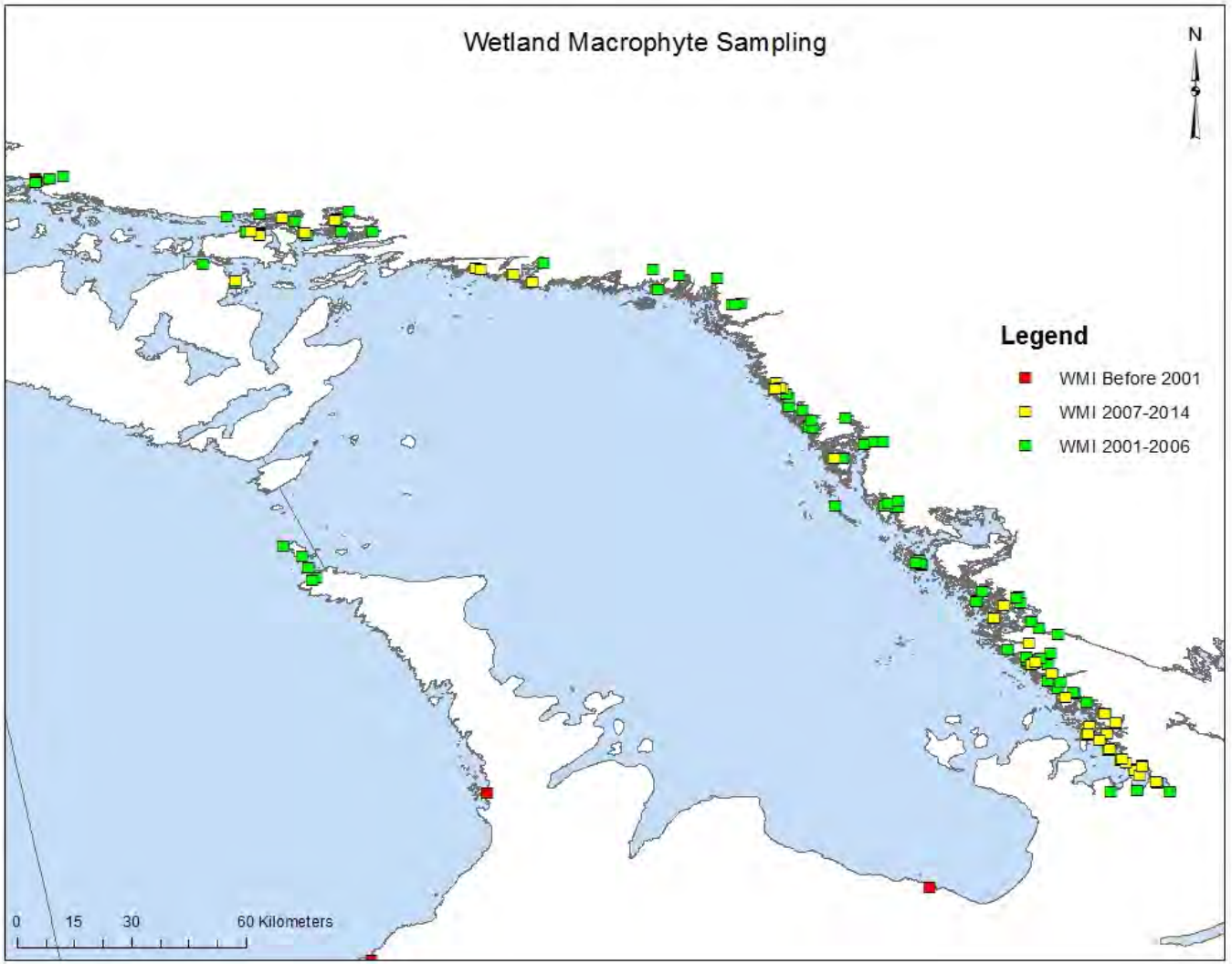


Figure 3: Distribution of sites sampled for **WMI** scores during three periods: before 2001 (red), between 2001 and 2006 (green) and between 2007 and 2014 (yellow).

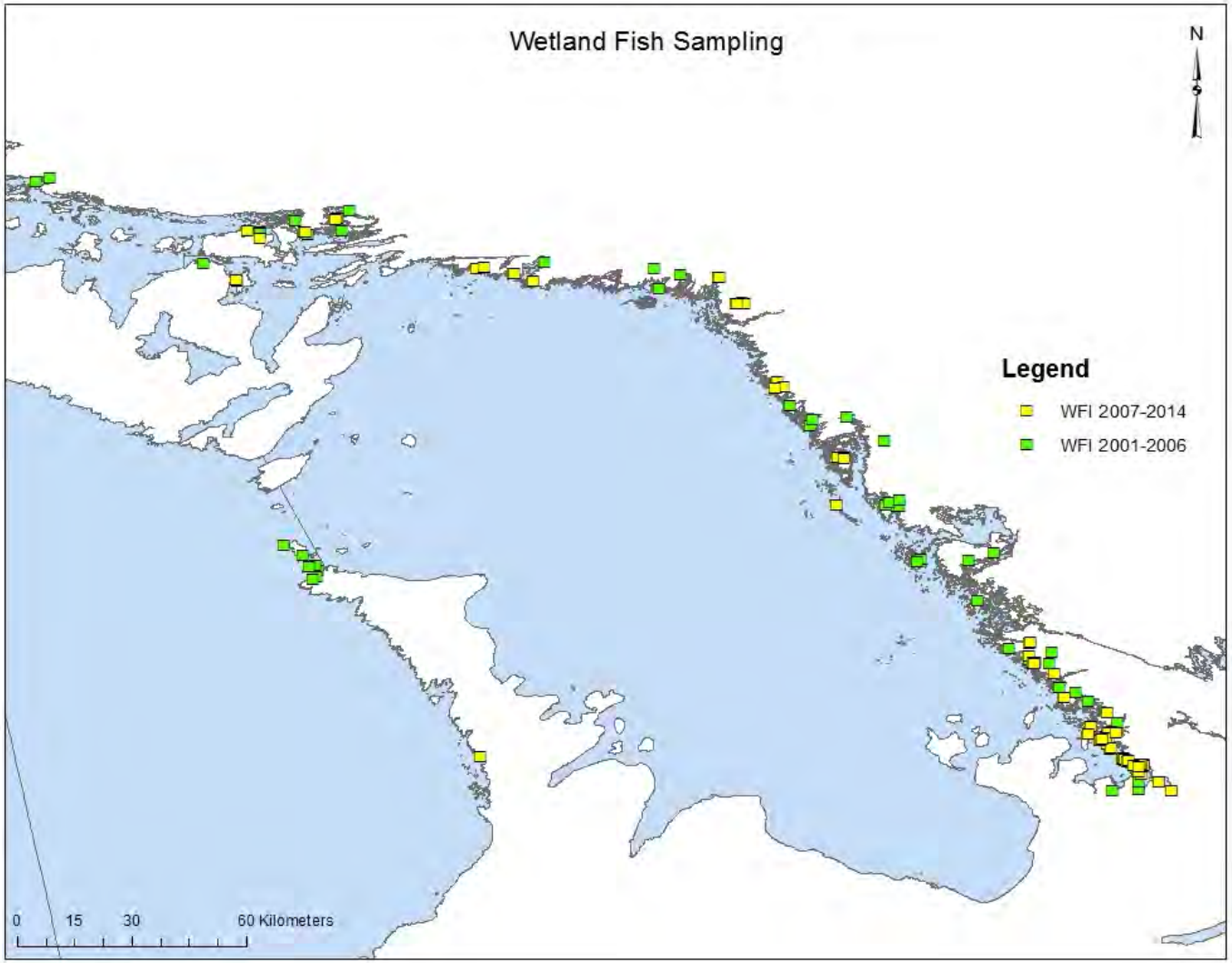


Figure 4: Distribution of sites sampled for **WFI** scores during two periods: between 2001 and 2006 (green) and between 2007 and 2014 (yellow).

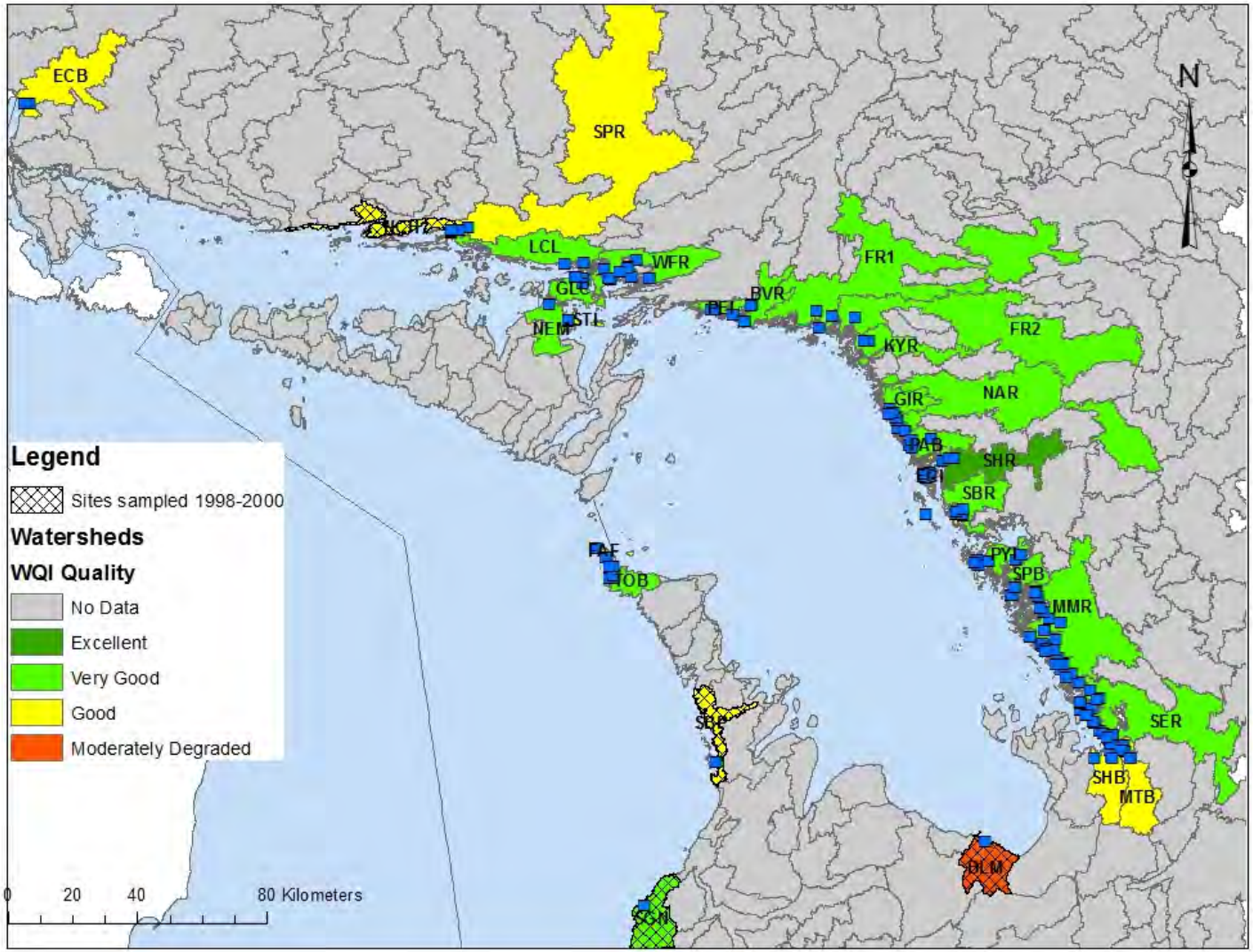


Figure 5: Comparison of **WQI** scores for quaternary watersheds in Georgian Bay.

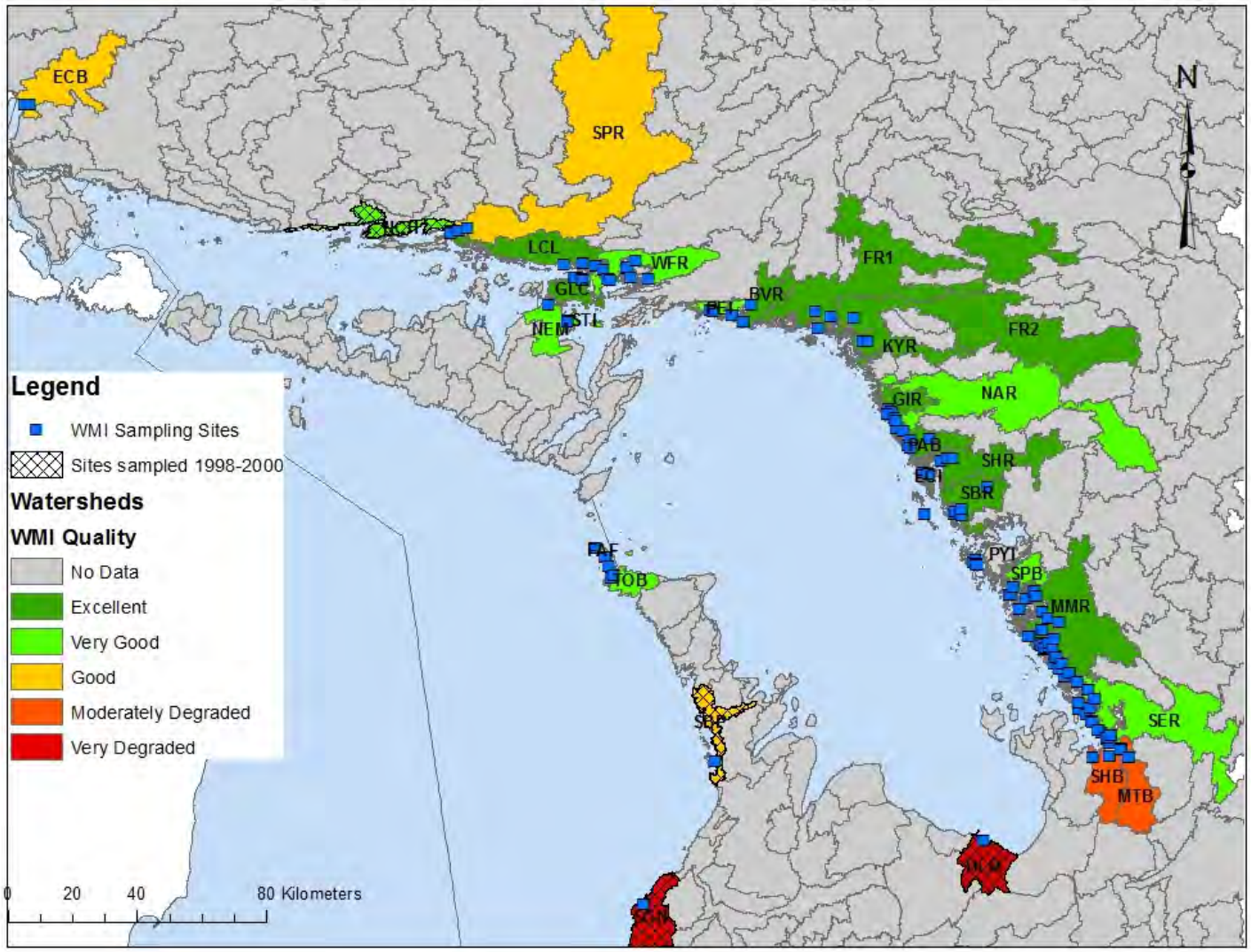


Figure 6: Comparison of mean **WMI** scores for quaternary watersheds in Georgian Bay.

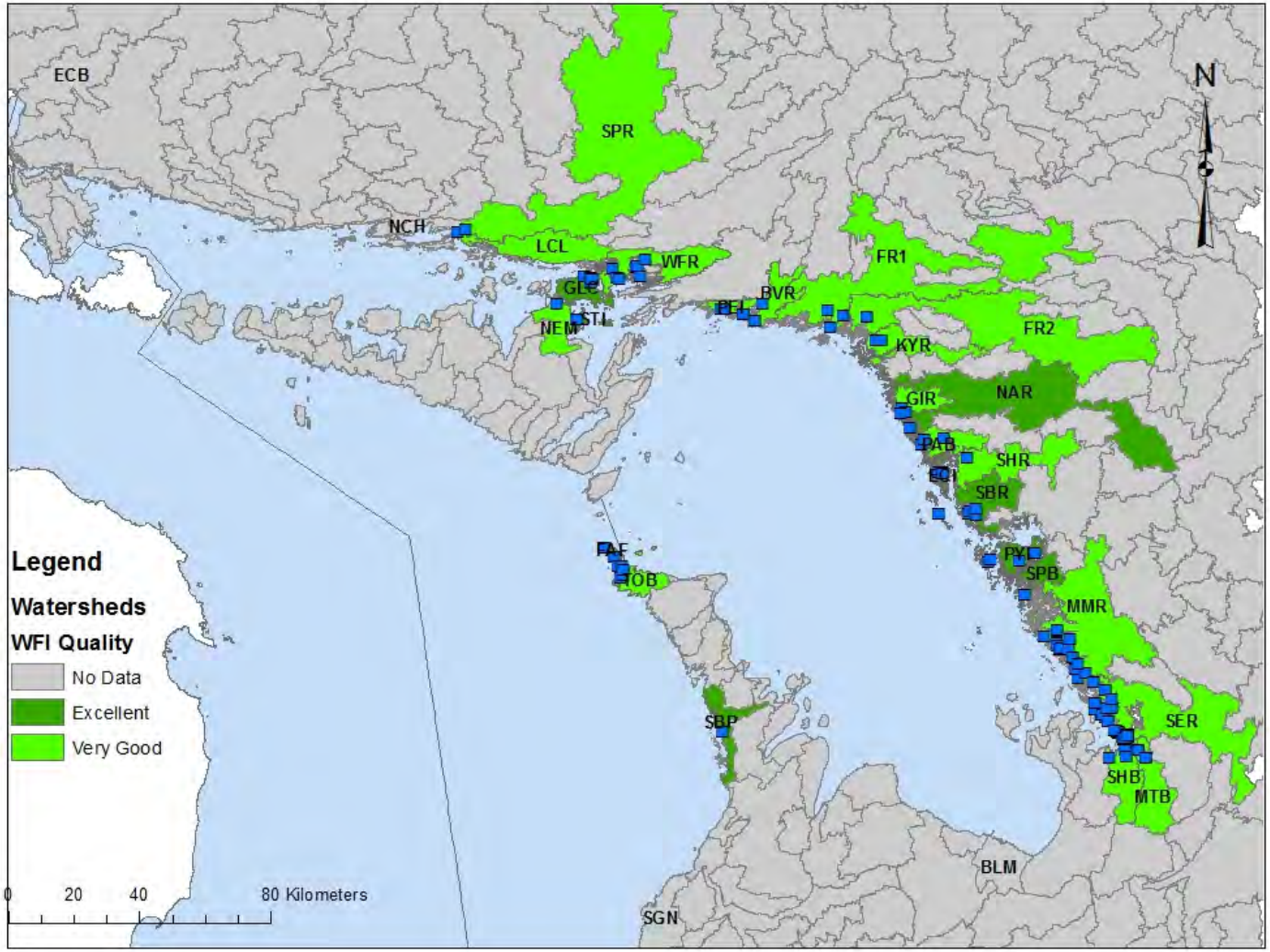


Figure 7: Comparison of mean **WFI** scores for quaternary watersheds in Georgian Bay

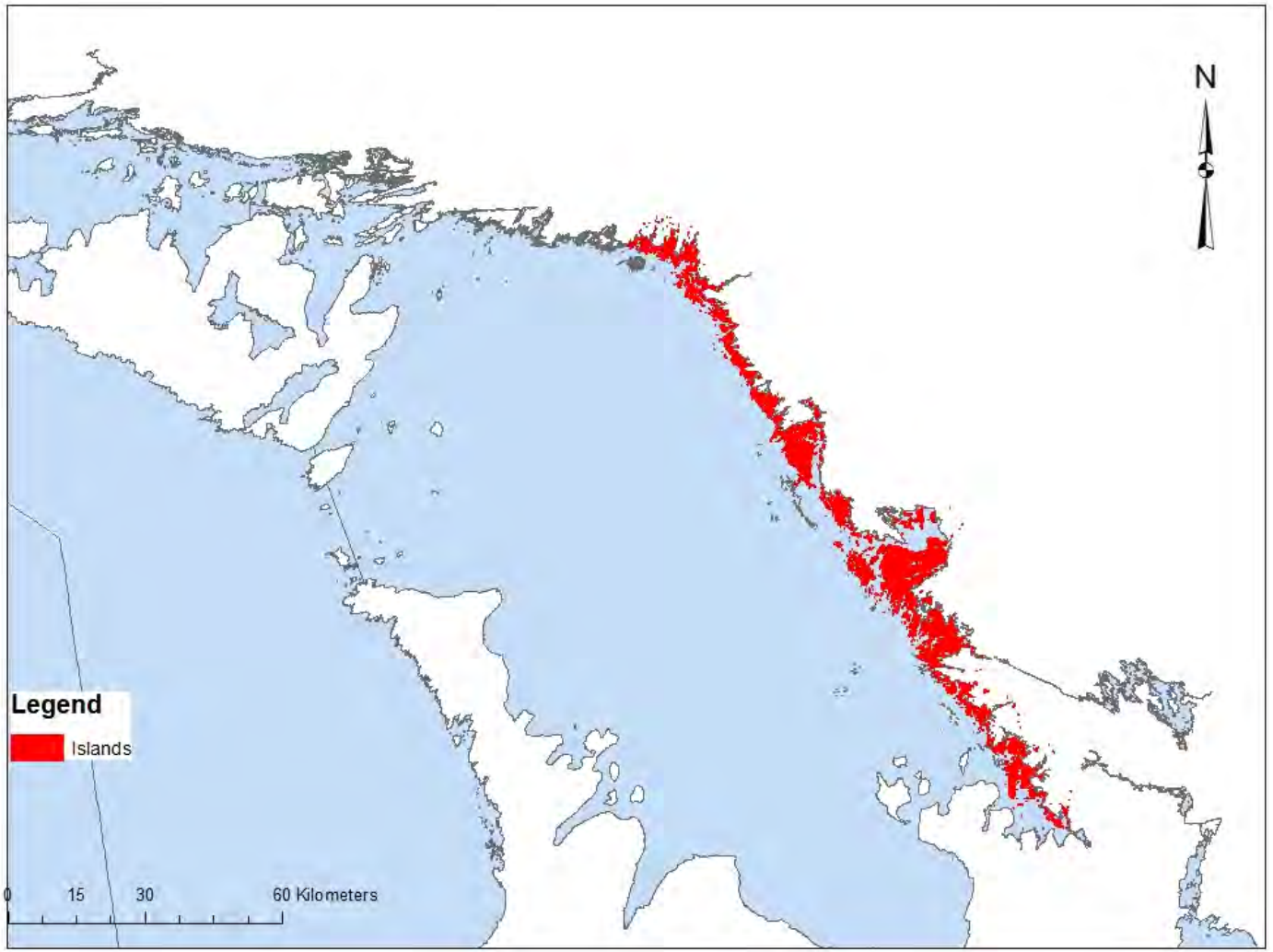


Figure 8: Location of islands of the Georgian Bay archipelago (designated International Biosphere Reserve).

Literature Cited

Bourgeau-Chavez, L., Endres, S., Battaglia, M., Miller, M.E., Banda, E., Laubach, Z., Higman, P., Chow-Fraser, P. and Marcaccio, J. 2015. Development of a bi-national Great Lakes coastal wetland and land use map using three season PALSAR and Landsat Imagery. Remote Sensing (In press).

Chow-Fraser, P. 2006. Development of the Water Quality Index (WQI) to assess effects of basin-wide land-use alteration on coastal marshes of the Laurentian Great Lakes. Coastal Wetlands of the Laurentian Great Lakes: health, habitat and indicators. Eds. Simon, T.P and Stewart, P.M.

Chow-Fraser, P. 2009. Coastal wetlands of Fathom Five National Marine Park: Biodiversity Values and Threats. Sources of Knowledge Forum: Sharing perspectives on the natural and cultural heritage of the Bruce Peninsula. Source of Knowledge Forum, Tobermory, ON, Canada p. 12-19

Croft, M. and Chow-Fraser, P. 2007. Use and development of the Wetland Macrophyte Index to detect water quality impairment in fish habitat of Great Lakes coastal marshes. Journal of Great Lakes Research. 33(Special Issue 3): 172-197.

Croft, M. and Chow-Fraser, P. 2009. Non-random sampling and its role in habitat conservation: a comparison of three wetland macrophyte sampling protocols. Biodiversity and Conservation. 18:2283-2306

Cvetkovic, M. and Chow-Fraser, P. 2011. Use of ecological indicators to assess the quality of Great Lakes coastal wetlands. Ecological Indicators. 11: 1609-1622.

Cvetkovic, M., Wei, A. and Chow-Fraser, P. 2010. Relative importance of macrophyte community versus water-quality variables for predicting fish assemblages in coastal wetlands of the Laurentian Great Lakes. Journal of Great Lakes Research. 36: 64:73.

Fracz, A. & Chow-Fraser, P. 2013. Impacts of declining water levels on the quantity of fish habitat in coastal wetlands of eastern Georgian Bay, Lake Huron. Hydrobiologia. 692. DOI 10.1007/s10750-012-1318-3

Jude, D.J. and Pappas, J. 1992. Fish utilization of great lakes coastal wetlands. Journal of Great Lakes Research. 18:651-672.

Leblanc, John Paul, Weller, J. Daniel and Chow-Fraser, Patricia. 2014. Thirty-year update: Changes in biological characteristics of degraded muskellunge nursery habitat in southern Georgian Bay, Lake Huron, Canada. J Great Lakes Research. 870-878.

Markle, Chantel E. and Chow-Fraser, Patricia. 2014. Habitat selection by the Blanding's Turtle (Emydoidea blandingii) on a Protected Island in Georgian Bay, Lake Huron. Chelonian Conservation and Biology 13(2): 216-226.

Midwood, J.D., Rokitnicki-Wojcik, D. and Chow-Fraser, P. 2012. Development of an inventory of coastal wetlands for eastern Georgian Bay, Lake Huron. ISRN Ecology. Vol 2012 doi:10.5402/2012/950173

Midwood, J.D. and Chow-Fraser, P. 2015. Connecting coastal marshes using movements of resident and migratory fishes. Wetlands. DOI 10.1007/s13157-014-0593-3.

Mitsch, W.J and Gosselink, J.G. 2015. Wetlands. John Wiley and Sons, 4th Edition.

OMNR. 2002. Ontario Wetland Evaluation System. Southern Manual, 3rd edition. Ontario Ministry of Natural Resources.

Seilheimer, T., Chow-Fraser, P. 2006. Development and validation of the Wetland Fish Index to assess the quality of coastal wetlands in the Laurentian Great Lakes. Can Journal of Fisheries and Aquatic Science. 63:354-366.

Seilheimer, T.S. and Chow-Fraser, P. 2007. Application of the Wetland Fish Index to northern Great Lakes marshes with an emphasis on Georgian Bay coastal wetlands. Journal of Great Lakes Research. 33(Special Issue 3):154-171.

Seilheimer, T. Mahoney, T. and Chow-Fraser, P. 2009. Comparative study of ecological indices for assessing human-induced disturbance in coastal wetlands of the Laurentian Great Lakes. Ecological Indicators. 9:81-91.

Wei, A., Chow-Fraser, P., and Albert, D. 2004. Influence of shoreline features on fish distribution in the Laurentian Great Lakes. Can J of Fisheries and Aquatic Science. 61:1113-1123

Appendix A: List of Relevant Publications

2015

Bourgeau-Chavez, L., Endres, S., Battaglia, M., Miller, M.E., Banda, E., Laubach, Z., Higman, P., Chow-Fraser, P. and Marcaccio, J. 2015. Development of a bi-national Great Lakes coastal wetland and land use map using three season PALSAR and Landsat Imagery. Remote Sensing (In press).

Midwood, J.D. and Chow-Fraser, P. 2015. Connecting coastal marshes using movements of resident and migratory fishes. Wetlands. DOI 10.1007/s13157-014-0593-3.

2014

Markle, Chantel E. and Chow-Fraser, Patricia. 2014. Habitat selection by the Blanding's Turtle (Emydoidea blandingii) on a Protected Island in Georgian Bay, Lake Huron. Chelonian Conservation and Biology 13(2): 216-226.

Midwood, Jonathan D. and Chow-Fraser, Patricia. 2014. Connecting Coastal Marshes Using Movements of Resident Migratory Fishes. Wetlands. (in press, published online)

Leblanc, John Paul, Weller, J. Daniel and Chow-Fraser, Patricia. 2014. Thirty-year update: Changes in biological characteristics of degraded muskellunge nursery habitat in southern Georgian Bay, Lake Huron, Canada. J Great Lakes Research. 870-878

Christensen, Robert, J. and Chow-Fraser, Patricia. 2014. Use of GPS loggers to enhance radio-tracking studies of semi-aquatic freshwater turtles. Herpetological Conservation and Biology. 9(1): 18-28.

2013

Fracz, A. and Chow-Fraser, P. 2013. Changes in water chemistry associated with beaver-impounded coastal marshes of eastern Georgian Bay. Can J Fish. Aquat. Sci. 70:834-840

Fracz, A. & Chow-Fraser, P. 2013. Impacts of declining water levels on the quantity of fish habitat in coastal wetlands of eastern Georgian Bay, Lake Huron. Hydrobiologia. 692. DOI 10.1007/s10750-012-1318-3

2012

Cvetkovic, M., Kostuk, K., Chow-Fraser, P. 2012. Gear-Type Influences on Fish Catch and a Wetland Fish Index in Georgian Bay Wetlands. N Am J of Fisheries Management. 32: 313-324.

Midwood, J.D., Rokitnicki-Wojcik, D. and Chow-Fraser, P. 2012. Development of an inventory of coastal wetlands for eastern Georgian Bay, Lake Huron. ISRN Ecology. Vol 2012. doi:10.5402/2012/950173

Smith-Cartwright, L. A., Cvetkovic, M., Tozer, D. and Chow-Fraser, P. 2012. Importance of Volunteer Training and Identification Ability on Results of Great Lakes Marsh

Monitoring Program Bird Surveys. Unpublished. www.greatlakeswetlands.ca/publications.

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

2011

Smith-Cartwright, L. A. and Chow-Fraser, P. 2011. Application of the index of marsh bird community integrity to coastal wetlands of Georgian Bay and Lake Ontario, Canada. Ecological Indicators. 2011(11) 1482-1486.

Rokitnicki-Wojcik, D., Wei, A. and Chow-Fraser, P. 2011. Transferability of object-based rule sets for mapping coastal high marsh habitat among different regions in Georgian Bay, Canada. Wetlands Ecology and Management. 19: 223-236.

DeCatanzaro, R. and Chow-Fraser, P. 2011. Effects of landscape variables and season on reference water chemistry of coastal marshes in eastern Georgian Bay. Can J of Fisheries and Aquat Sci. 68:1038-1050

Cvetkovic, M. and Chow-Fraser, P. 2011. Use of ecological indicators to assess the quality of Great Lakes coastal wetlands. Ecological Indicators. 11: 1609-1622.

2010

Midwood, J.D. and Chow-Fraser, P. 2010. Mapping floating and emergent aquatic vegetation in coastal wetlands of eastern Georgian Bay, Lake Huron. Wetlands. 2010(30) 1141-1152.

Cvetkovic, M., Wei, A. and Chow-Fraser, P. 2010. Relative importance of macrophyte community versus water-quality variables for predicting fish assemblages in coastal wetlands of the Laurentian Great Lakes. Journal of Great Lakes Research. 36: 64:73.

DeCatanzaro, R. and Chow-Fraser, P. 2010. Relationship of road density and marsh condition to turtle assemblage characteristics in the Laurentian Great Lakes. Journal of Great Lakes Research. 36:357-365.

Smith, L. and Chow-Fraser, P. 2010. Impact of adjacent land use and isolation on marsh bird communities. Environmental Management. 45:1040-1051.

Midwood, J. and Chow-Fraser, P. 2010. Regional approach to map floating and emergent aquatic vegetation in coastal wetlands of eastern Georgian Bay, Lake Huron, Canada.. Wetlands. 30: 1141-1152.

2009

Mary Muter. 2009. Down the Drain: Georgian Baykeeper battles to save the Middle Lakes. Waterkeeper Magazine. Winter 2009. 5(3):32-36.

Seilheimer, T. Mahoney, T. and Chow-Fraser, P. 2009. Comparative study of ecological indices for assessing human-induced disturbance in coastal wetlands of the Laurentian Great Lakes. Ecological Indicators. 9:81-91.

Croft, M. and Chow-Fraser, P. 2009. Non-random sampling and its role in habitat conservation: a comparison of three wetland macrophyte sampling protocols. Biodiversity and Conservation. 18:2283-2306

DeCatanzaro, R., Cvetkovic, M. and Chow-Fraser, P. 2009. The relative importance of road density and physical watershed features in determining coastal marsh water quality in Georgian Bay. Environmental Management. 44:456-467.

Chow-Fraser, P. 2009. Coastal wetlands of Fathom Five National Marine Park: Biodiversity Values and Threats. Sources of Knowledge Forum: Sharing perspectives on the natural and cultural heritage of the Bruce Peninsula. Source of Knowledge Forum, Tobermory, ON, Canada p. 12-19

2008

Chow-Fraser, P. 2008. Wetlands Status and Trends – for Coastal Wetlands. www.greatlakeswetlands.ca/publications.

Wei, A. and Chow-Fraser, P. 2008. Testing the transferability of a marsh-inundation model across two landscapes. Hydrobiologia. 600:41-47.

2007

Wei, A. and Chow-Fraser, P. 2007. Use of IKONOS imagery to map coastal wetlands of Georgian Bay. Fisheries. 32:167:173.

Croft, M. and Chow-Fraser, P. 2007. Use and development of the Wetland Macrophyte Index to detect water quality impairment in fish habitat of Great Lakes coastal marshes. Journal of Great Lakes Research. 33(Special Issue 3): 172-197.

Seilheimer, T.S. and Chow-Fraser, P. 2007. Application of the Wetland Fish Index to northern Great Lakes marshes with an emphasis on Georgian Bay coastal wetlands. Journal of Great Lakes Research. 33(Special Issue 3):154-171.

Johannsson, O.E., Charlton, M., Chow-Fraser, P. Dermott, R.M., Howell, E.T., Makarewicz, J.C., Millard, E.C., Mills, E.L. and Richardson, V. Productivity and Limnology. The State of Lake Ontario in 2003. Eds. B.J. Morrison and S.R. LaPan. for the Great Lakes Fishery Commission

2006

Seilheimer, T., Chow-Fraser, P. 2006. Development and validation of the Wetland Fish Index to assess the quality of coastal wetlands in the Laurentian Great Lakes. Can Journal of Fisheries and Aquatic Science. 63:354-366.

Chow-Fraser, P. 2006. Development of the Water Quality Index (WQI) to assess effects of basin-wide land-use alteration on coastal marshes of the Laurentian Great Lakes.

Coastal Wetlands of the Laurentian Great Lakes: health, habitat and indicators. Eds. Simon, T.P and Stewart, P.M.

2004

Wei, A., Chow-Fraser, P., and Albert, D. 2004. Influence of shoreline features on fish distribution in the Laurentian Great Lakes. Can J of Fisheries and Aquatic Science. 61:1113-1123.

2003

McNair, S.A. and Chow-Fraser, P. 2003. Change in biomass of benthic and planktonic algae along a disturbance gradient for 24 Great Lakes coastal wetlands. Can J of Fisheries and Aquatic Sciences. 60:676-689.

2002

Lougheed, V.L. and Chow-Fraser, P. 2002. Development and use of a zooplankton index to monitor wetland quality in the Laurentian Great Lakes basin. Ecological Applications. 12(2):474:486

2001

Lougheed, V.L., Crosbie, B. and Chow-Fraser, P. 2001. Primary determinants of macrophyte community structure in 62 marshes across the Great Lakes basin: latitude, land use, and water quality effects. Can J of Fisheries and Aquatic Sciences. 58:1603:1612.

1999

Crosbie, B. and Chow-Fraser, P. 1999. Percentage land use in the watershed determines the water- and sediment-quality of 21 wetlands in the Great Lakes basin. Can J of Fisheries and Aquatic Sciences. 56:178:1791.

1998

Chow-Fraser, P. and Albert, D. 1998. Identification of Eco-Reaches of Great Lakes Coastal Wetlands that have high biodiversity values. Discussion paper for SOLEC ’98. Environment Canada - US Environmental Protection Agency.

Appendix B

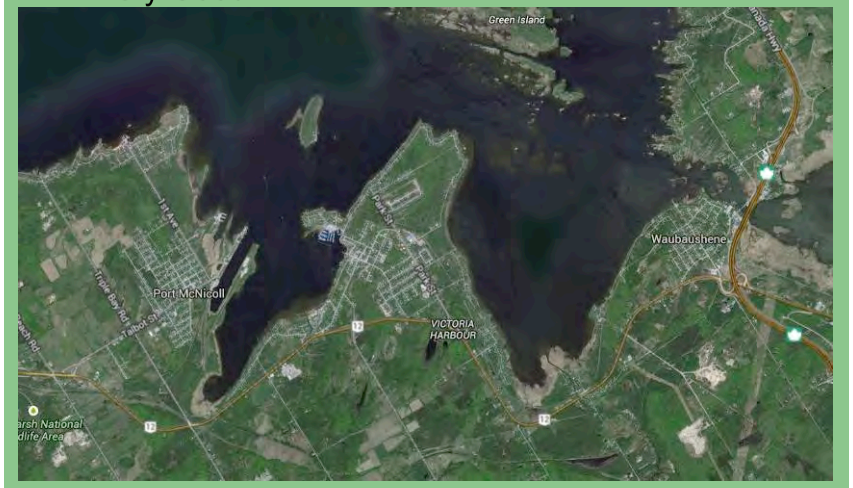
Overview of wetlands

Sturgeon Bay – Hog Bay

Size : 189.8 km^2
Geology : Sedimentary

 # Wetlands Sampled = 4

WQI: Good
WMI: Moderately Degraded
WFI: Very Good



Severn Sound was listed as an Area of Concern (AOC) due to eutrification, impaired fish and benthic communities and high bacterial levels. Improvements in sewage treatment plants and septic systems, as well as advances in agricultural nutrient management practices has lead to the AOC being delisted in 2003.

Matchedash Bay

Size : 220.8 km^2
Geology : Sedimentary

 # Wetlands Sampled = 9

WQI: Good
WMI: Moderately Degraded
WFI: Very Good

The wetlands in the Matchedash bay watershed are largely cattail marshes and are more similar to the wetlands found in the Southern Great Lakes. The cottage density and road density in this watershed is higher than in more remote areas of Georgian Bay. This watershed was also part of the Severn Sound AOC.

Severn River

 # Wetlands Sampled = 63

Size : 702.4 km^2
Geology : Granitic

WQI: Very Good
WMI: Very Good
WFI: Very Good

Wetlands in the Severn River watershed are dominated by bulrushes. The road density and cottage density in this watershed are higher than more remote watersheds. This watershed is also part of the Severn Sound AOC.

Moon – Musquash River

 # Wetlands Sampled = 35

Size : 717.1 km^2
Geology : Granitic

WQI: Very Good
WMI: Excellent
WFI: Very Good

Although this watershed is in southern Georgian Bay and has higher road density and more cottages than northern Georgian Bay it still has very good water quality and the wetlands have a high diversity of plants and fish.

Spider Bay

 # Wetlands Sampled = 3

Size : 89.4 km^2
Geology : Granitic

WQI: Very Good
WMI: Very Good
WFI: Excellent

This watershed is part of the Massassaguaga Provincial Park. It has few cottages and future development will be limited. This watershed has very good water quality and plant index scores and excellent fish index score.

Parry Island

 # Wetlands Sampled = 4

Size : 76.6 km^2
Geology : Granitic

WQI: Very Good
WMI:
WFI: Excellent

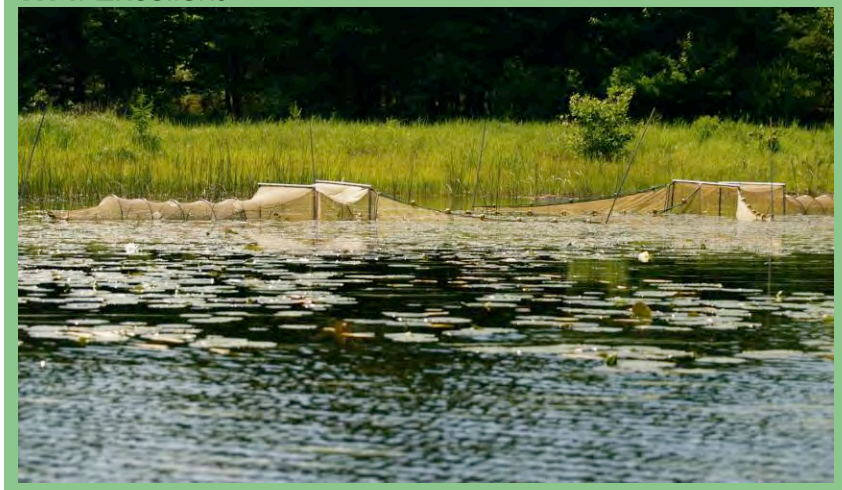
Parry Island is one of the larger islands on the east coast of Georgian Bay. It is home to the Wasauksing First Nation. This watershed has very good water quality and an excellent fish index scores. Plant surveys were not conducted in these wetlands.

East Coast Islands

 # Wetlands Sampled = 10

Size : 118.5 km^2
Geology : Granitic

WQI: Good
WMI: Excellent
WFI: Excellent



This archipelago is composed of hundreds of islands. Sandy Island and Franklin Island are some of the larger islands. This archipelago has good water quality and excellent fish and plant index scores.

Shebeshekong River

 # Wetlands Sampled = 4

Size : 193.4 km^2
Geology : Granitic

WQI: Very Good
WMI: Excellent
WFI: Excellent

This watershed has limited cottage development and road density. This watershed had excellent plant and fish index scores and very good water quality scores.

Shawanaga River

 # Wetlands Sampled = 3

Size : 312.6 km^2
Geology : Granitic

WQI: Excellent
WMI: Excellent
WFI: Very Good

This watershed was rated as Excellent for both the water quality index and the macrophyte index. It has low cottage density and low road density.

Point au Baril

 # Wetlands Sampled = 5

Size : 117.5 km^2
Geology : Granitic

WQI: Very Good
WMI: Excellent
WFI: Very Good

Point au Baril has very good water quality and fish community, and excellent plant community. The human impact in this watershed is limited to a few cottages as well as shoreline modification for docks.

Naiscoot River

 # Wetlands Sampled = 5

Size : 944.5 km^2
Geology : Granitic

WQI: Very Good
WMI: Very Good
WFI: Excellent

Naiscoot River watershed has very good water quality and plant index scores, and excellent fish index scores. This area is popular with sport fisherman.

Giroux River

 # Wetlands Sampled = 3

Size : 102.4 km^2
Geology : Granitic

WQI: Very Good
WMI: Excellent
WFI: Very Good

Giroux river watershed has very good water quality, excellent plant community and very good fish index scores.

Key River

 # Wetlands Sampled = 4

Size : 195.4 km^2
Geology : Granitic

WQI: Very Good
WMI: Excellent
WFI: Very Good

The Key river watershed has very good water quality and fish and excellent plant index scores. There is limited road access in this watershed and most cottages can only be reached by boat.

French River 2

 # Wetlands Sampled = 3

Size : 1059.1 km^2
Geology : Granitic

WQI: Very Good
WMI: Excellent
WFI: Very Good

This area of Georgian Bay is very remote with limited road access. Many of the cottages are only accessible by boat. There are several fishing camps that cater to recreational fisherman. With very good water quality, excellent plant and very good fish index scores the wetlands in this watershed are in great condition.

French River 1

 # Wetlands Sampled = 2

Size : 1259.2 km^2
Geology : Granitic

WQI: Very Good
WMI: Excellent
WFI: Very Good

Historically, the French River area was renowned for logging. The water is dystrophic due to high levels of dissolved humus. In some areas the coloured water limits the depth of aquatic plant growth. This area has an excellent plant index and very good water quality and fish index scores. This watershed is in French River Prov Park.

Beaverstone River

 # Wetlands Sampled = 4

Size : 127.4 km^2
Geology : Granitic

WQI: Very Good
WMI: Excellent
WFI: Very Good

The Beaverstone watershed is home to some large bulrush marshes. Intensive surveying has identified this area as important spawning and nursery habitat for Muskellunge. It has very good water quality, excellent plant index and very good fish index scores.

Philip Edward Island

 # Wetlands Sampled = 4

Size : 49.1 km^2
Geology : Granitic

WQI: Very Good
WMI: Excellent
WFI: Very Good

This large island watershed on the north shore of Georgian Bay has very good water quality and fish index scores, and excellent macrophyte index scores.

Great La Cloche Island

 # Wetlands Sampled = 6

Size : 96.4 km^2
Geology : Granitic

WQI: Very Good
WMI: Excellent
WFI: Excellent

This island watershed had very good water quality index scores and excellent fish and macrophyte index scores. This area of the north channel has limited cottage development and road access.

Whitefish River

Size : 266.4 km^2
Geology : Granitic

 # Wetlands Sampled = 11

WQI: Very Good
WMI: Very Good
WFI: Very Good

Most of the north channel has very little development, with only a fraction of the cottages compared to southern Georgian Bay. The water quality, fish and macrophyte index scores were all very good.

Northeast Manitoulin

Size : 137.0 km^2
Geology : Sedimentary

 # Wetlands Sampled = 1

WQI: Very Good
WMI: Very Good
WFI: Very Good

Manitoulin is the largest freshwater island in the world. The wetland sampled in this watershed has very good index scores for water quality, fish and plants.

Strawberry Island

 # Wetlands Sampled = 2

Size : 16.3 km^2
Geology : Sedimentary

WQI: Good
WMI: Very Good
WFI: Excellent

Stawberry island is a relatively large island in Georgian bay with a shallow slope. Extensive bulrush marshes are found in the protected embayments of Strawberry Island. They provide excellent habitat for fish and as a result the fish index score is excellent.

La Cloche

 # Wetlands Sampled = 3

Size : 271.0 km^2
Geology : Granitic

WQI: Very Good
WMI: Excellent
WFI: Very Good

The human impacts in the north channel are limited. With few cottages and low road density most areas remain undeveloped. The water quality and fish index scores were very good and the macrophyte index score was excellent.

Spanish River

 # Wetlands Sampled = 3

Size : 5565.3 km^2
Geology : Granitic

WQI: Good
WMI: Good
WFI: Very Good

Spanish Harbour was classified as an Area of Concern (AOC) and is currently listed as an area in recovery, meaning that all measures have been taken to improve the site and it is now just a matter of time for the site to naturally recover.

North Channel

 # Wetlands Sampled = 2

Size : 139.0 km^2
Geology : Granitic

WQI: Good
WMI: Very Good
WFI:

This watershed had good water quality index scores, and very good macrophyte index scores. Fish surveys were not conducted in this watershed.

Echo Bay

Size : 403.4 km^2
Geology : Granitic

 # Wetlands Sampled = 3

WQI: Good
WMI: Good
WFI:

This watershed is at the mouth of the St Mary's River that drains Lake Superior. Water quality and plant community are good. Fish sampling was not conducted in this watershed.

Tobermory

Size : 93.5 km^2
Geology : Sedimentary

 # Wetlands Sampled = 5

WQI: Very Good
WMI: Very Good
WFI: Very Good

Wetlands on the northern tip of the Bruce peninsula provide important fish nursery habitat for Lake Huron and Georgian Bay. The main stressors in this watershed are cottage development and sustained low water levels.

Fathom Five

 # Wetlands Sampled = 4

Size : 13.7 km^2
Geology : Sedimentary

WQI: Good
WMI: Very Good
WFI: Very Good

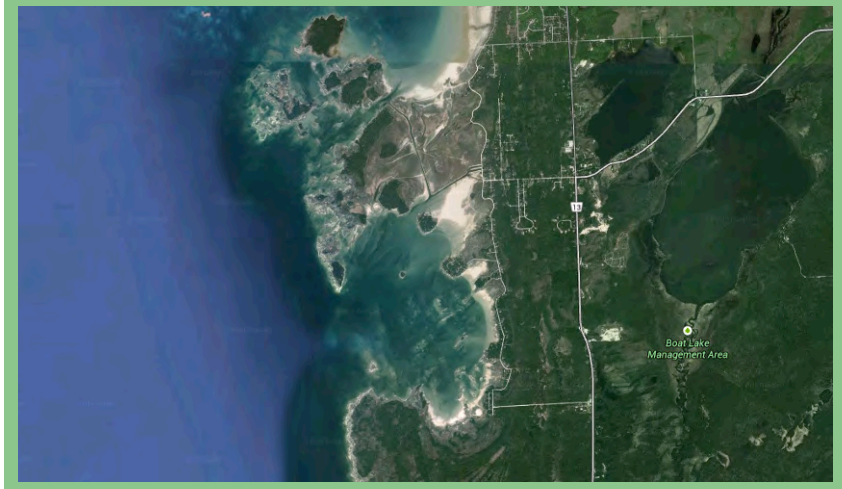
Wetlands found the Fathom Five islands are very unique. Low nutrient waters combined with increased wave action means there is very little sediment accumulation for plant growth.

South Bruce Peninsula

 # Wetlands Sampled = 35

Size : 136.5 km^2
Geology : Sedimentary

WQI: Good
WMI: Good
WFI: Excellent



This watershed is predominantly agricultural land use. With the high degree of wind and wave exposure due to the prevailing westerly winds there are a limited number of wetlands on the eastern side of Lake Huron. This makes the existing wetlands very important spawning and nursery habitat for some fish.

Saugeen

 # Wetlands Sampled = 1

Size : 222.6 km^2
Geology : Sedimentary

WQI: Very Good
WMI: Very Degraded
WFI:

This watershed is largely agricultural land-use. The wetlands on the east side of lake Huron are very exposed. The poor wetland plant community is a reflection of the wave exposure and the lack of adequate sediment. This wetland is adjacent to the Bruce Nuclear Power Station.

Blue Mountain

 # Wetlands Sampled = 1

Size : 205.6 km^2
Geology : Sedimentary

WQI: Moderately Degraded
WMI: Very Degraded
WFI:

Collingwood harbour was listed as an Area of Concern (AOC) in 1987 due to industrial, agricultural and urban land-use in the harbour and in the watershed. It was delisted in 1994 but still has moderately degraded water quality.