Changes in low-marsh habitat as a function of Lake Huron water level in coastal wetlands of eastern Georgian Bay

Technical Report

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Objectives and deliverables

A. Is wetland extent increasing or decreasing and at what rate?

1) Compare the current (2015/2016) and historical (2002-2008) extent of wetlands for 20 to 25 wetlands and calculate the rate of change, report on the outcome with considerations.

Background

To address this question, we follow the convention of the Ontario Ministry of Natural Resources and Forestry by referring to the zone with permanently inundated vegetation as "low marsh" (**LM**), and to the seasonally inundated vegetation as "high marsh" (**HM**). The dominant vegetation in these two habitats include **meadow (ME)** vegetation, which occur at the highest elevation, just below the forest edge. Closer to the shoreline of the marsh, a band of **emergent (EM)** dominate, sometimes extending below the shoreline, where it transitions to a zone dominated by **floating (FL)** vegetation. From about 1 to 5m, the **submerged aquatic vegetation (SAV)** dominate. Therefore, the FL and SAV correspond to LM habitat, while the EM and ME correspond to HM habitat. It is important to point out that in HM habitats the vegetation types, ME or EM, do not overlap, but LM may consist of overlapping occurrence of FL and SAV; hence, when the areal extent of FL and SAV are added, the sum may exceed the total area of LM habitat.

Great Lakes coastal marshes are subject to large inter-annual water-level fluctuations that lead to huge variations in the size of HM habitat. The HM in coastal wetlands of Lake Ontario are known to decline predictably as a function of increasing water level (Chow-Fraser et al. 1998; Chow-Fraser 2005; Wei and Chow-Fraser 2008) that reflects the maximum water depth tolerated by the dominant emergent vegetation. With an increase in water level, the meadow and emergent vegetation tend to die back, allowing the submergent vegetation to proliferate. Given that Georgian Bay (Lake Huron) has experienced a sustained period of low water levels from 2000 to 2014 and then rebounded to levels above the long-term mean in 2015 and 2016 (Figure 1), we would therefore expect a concomitant decrease in proportion of HM and an increase in LM when we compare wetland vegetation before and after the rebound.

Method

We compared data for 22 wetlands in eastern Georgian Bay (see Figure 2). For each wetland, we digitized the HM and LM habitat using image data acquired during the period of sustained low water levels (Period 1; IKONOS satellite imagery acquired July/August 2002-2008), and during the recent period of higher water levels (Period 2; DJI Phantom 2 Vision+ unmanned aerial vehicle (UAV) image data acquired in July/August of 2015-2016). The UAV was flown 300-400 ft above ground level. After processing in Pix4D software, we imported all image data into a GIS using ArcMap 10.4 (Esri, Redlands, California), and then manually digitized the dominant aquatic vegetation zones in wetlands. Since the HM vegetation did not overlap, we combined them into a single class (ME-EM), whereas areas occupied by SAV and FL vegetation were digitized separately.

Results

Areal cover of the three dominant vegetation classes (ME-EM, FL, and SAV) in each of 22 wetlands were calculated for images acquired during Period 1 and Period 2 (Table 1). On average, the amount of ME-EM vegetation decreased from 1.22±0.32 ha in Period 1 to 0.94±0.26 in Period 2, which is a decrease of 0.28 ha or 23% of the original amount measured in Period 1. During the same time period, the amount of SAV expanded from 2.25±0.55 ha to 2.42±0.61, an increase of 0.17 ha or 8%. Corresponding amount of FL increased from 0.45±0.15 to 0.58±0.26, which is an increase of 0.13 ha or 29%. On average, when we compared the sum of all three classes, there was only a small increase from 3.92±0.85 to 3.94±0.95 ha. The areal cover of ME-EM to FL was reduced from a ratio of 3:1 to 2:1 over this time period, a reflection of the overall reduction in ME-EM vegetation and a slight increase in FL when water levels returned to levels above the long-term mean.

To examine how individual wetland area changed between Period 1 and 2 across the 22 sites, we calculated the net change in cumulative vegetation cover (i.e. sum of HM and LM area; Table 2; Figure 3). This parameter ranged from a maximum increase of 0.6 ha for the Green Island wetland to a loss of 2.2 ha in Matchedash, with a mean gain across the 22 sites of 0.02 ha. There was an overall net loss in total HM and LM (0.11 ha; Table 2); however, when data were expressed as proportion of total wetland size, and FL and SAV were separately compared, we found a proportionate increase in both FL and SAV but a proportionate decrease in ME-EM. Our finding that HM vegetation declines with increasing water level has been reported in the literature, but our finding that there was a concomitant increase in LM habitat is an advancement since no published study has attempted to quantify this in the past.

We were asked to estimate a rate of change for this report. Since the amount of time that had elapsed between time periods for the 22 wetlands was variable, ranging from 7 to 14 years, we decided to use 10 years to calculate the rate of change. Overall, the rate of change was an increase of 0.02 ha per 10 years (0.002 ha/y). We can also express this change as a function of water-level increase. There was a mean difference of 0.50 m between 2005 (176.09 m) and 2015 (176.59 m), and therefore the increase of 0.02 ha represented an increase of 0.04 ha $\bullet m^{-1}$ increase in water level. This corresponded to a net loss of 0.56 ha of ME-EM vegetation, and a gain of 0.23 ha of FL and 0.34 ha of SAV per meter increase in water level.

2) Comment on how function might change (species diversity and populations)

Method

We compared the species composition of the fish and macrophyte communities in 22 wetlands (see Figure 2) during the two time periods (2004-2013 inclusive for Period 1 and 2015-2016 for Period 2; Figure 1). The same sampling protocol was used to survey the macrophyte (Stratified method; Croft and Chow-Fraser 2007; 2009) and the fish communities (fyke nets; Seilheimer and Chow-Fraser 2007) during the two time periods. All macrophytes found in quadrats (0.75 x 0.75 m) were identified to species if possible; sampling ceased once no new species were found in 2 consecutive quadrats (total number of quadrats varied among wetlands from a minimum of 10 to a maximum of 15). Quadrats were placed in different vegetation zones (e.g. EM, SAV and FL) except in the meadow zone since we were mainly interested in characterizing fish habitat. Hence, any meadow species that were noted in this study were those that were inundated or occurred at the water's edge. We travelled from quadrat to quadrat in a canoe or boat, or by walking along the shoreline in waders.

The fish community in each wetland was surveyed with three sets of paired fyke nets, set parallel to shore. We used 2 sets of large nets (12.7 mm bar mesh, 4.25 m length, 1m X 1.25 m front opening) and 1 set of small nets (4.8 mm bar mesh, 2.1 m length, 0.5 m X 1.25 m front opening); each pair of nets was connected with a 7-m lead and 2.5-m wings on each side. Nets were ideally set in a mixture of emergent, floating, substrate SAV, and canopy SAV. The nets were left to soak for 20-24 h, after which all fish were collected, identified, counted and measured. After processing, all fish were released unharmed back to the wetland location where they had been caught.

For this report, we will only be able to provide a qualitative comparison of differences between time periods with respect to the fauna and flora. We found 51 plant taxa in common in both time periods (Table 3). The 14 plants that were unique in Period 1 tended to be predominantly SAV, whereas the 12 plants unique to Period 2 tended to be predominantly ME-EM taxa. Since our plant surveys were intended to be used for assessment of fish habitat, we mainly focused on the LM habitat rather than the HM. Therefore, inclusion of trees and meadow species in Period 2 reflected flooding of the previously ME-EM zone. The apparently higher species richness of canopy-forming SAV during Period 2 is an artefact of the sampling protocol used and not necessarily a reflection of the disappearance of species. This is because the water level during Period 2 had increased by almost a meter over that experienced in Period 1 (see Figure 1). Consequently, SAV that had been present in the Period 1 survey were too deep for us to positively identify to species using a rake from a boat or canoe. We therefore interpret changes in the species list in Table 3 as a function of the shift towards deeper water depth of the various plant zones.

The fish assemblages in Georgian Bay wetlands are normally very diverse compared to those in other Great Lakes coastal wetlands and reflect their excellent water quality and plentiful SAV (Table 4; Cvetkovic et al. 2010). Twenty-four taxa species were common to both time periods and only 12 species were unique to Period 1, while only 2 species were unique to Period 2. The fish species found only in Period 1 appear to be those that are more tolerant of conditions under sustained low water levels in which dense floating and emergent vegetation dominate. These species are predominantly small-bodied prey fish species and are not well suited to survive in dense emergent habitat caused by an increase in water depth. The 2 fish species that were found only in Period 2 are not necessarily indicative of higher water level; only one individual of the grass pickerel had been caught and therefore we refrain from drawing conclusions about its intolerance to shallow water. The presence of round gobies was only noted during Period 2, but we do not interpret this as indicative of its intolerance for shallow depths, but rather a reflection of the timing of colonization by this species in Georgian Bay, which occurred after 2005.

Overall discussion for Objective A

Midwood et al. (2012) created the McMaster Coastal Wetland Inventory for eastern and northern Georgian Bay (MCWI; Midwood et al. 2012); they calculated a mean size of the 3,771 LM units to be 1.4 ha (using IKONOS imagery acquired during Period 1). This is a relatively small wetland size compared to those that currently exist in southern Ontario (i.e. coastal Lake Ontario and Lake Erie). Nevertheless, these wetlands provide critical habitat for aquatic species including sport fish such as northern pike and muskellunge, because they tend to occur as clusters and function as complexes (Midwood and Chow-Fraser 2015). The 22 wetlands that we used in this project varied from 0.70 ha to 15.79 ha, with a mean of 3.47 ha and median of 2.10 ha (Table 1), and are therefore slightly larger than most of those that exist in the MCWI. Given the large variation in distribution of vegetation classes (i.e. ME-EM, FL and SAV) within our dataset, it is prudent to follow up with further studies with a statistically valid sample size and wetlands that are randomly selected from the MCWI.

We have compared vegetation and fish communities in two time periods that vary with respect to mean annual water level (difference of 80 cm), and it is tempting to attribute any observed changes to the increase in water level. We caution against this, however, because there was a lack of inter-annual fluctuations in Period 1 that may have been a greater factor in limiting wetland vegetation than the low water level itself. In other words, water levels that remain high without fluctuations may eventually lead to similar community of fish/plants. Secondly, there may be a lag time of 2-3 years before changes may be realized (e.g. the shrubs and trees that are now inundated must die off and decompose before the EM and SAV can become re-established).

Since distribution of the three dominant vegetation zones is restricted primarily by water depth, wetland bathymetry is the overriding factor that dictates how wetland zonation will change in response to water-level fluctuations. Therefore, a promising approach to understand how wetlands may respond to water-level changes is to superimpose a given hydrograph on a fine-scale digital elevation model to simulate how vegetation classes will be distributed across a region within Georgian Bay.

B. Determine how wetland extent will change with an additional 50, 100 cm increase or 50, 100 decrease in water level below chart datum (176.0 m)

1) *Provide estimates of wetland extent for 20 to 25 wetlands corresponding to 4 lake elevations (175.0, 175.5, 176.5 and 177.0 m) using the fine-scale bathymetric data from Objective A.*

Method

Note that in this report, all elevations are meters above sea level (m asl). For simplicity, “m asl” will not be repeated each time that the elevation is mentioned. Areal extent was determined for 25 wetlands based on landscape features derived from digital elevation models (DEMs). We used the Topo to Raster function in ArcGIS 10.2 to construct a fine-scale DEM (5m resolution) for each site. A suite of topographic and bathymetric data sources was used to assemble the DEMs; these included field surveys and existing, open-access topographic and bathymetric data sets (Table 5). The actual data source varied for each wetland because of limited availability of regional-scale data (Table 6). To obtain an approximate boundary of wetlands, we overlaid the LM layer derived from the MCWI, which had been delineated under low water conditions (approximately 176.0 m). Within the respective MCWI boundaries for each wetland, we extracted all elevation values from the DEMs. We used the upper 90% of the distribution of elevation values to determine the maximum extent of LM habitat, which corresponded to a depth of 1.9 m. This is a conservative value because field observations have confirmed that SAV in some wetlands may extend to a maximum depth of 5 m. We therefore operationally defined the wetland extent to be the surface area delineated by the shoreline to the 1.9 m depth contour in the GIS. We calculated wetland extent associated with four lake elevations (175.0, 175.5, 176.5 and 177.0) for each wetland site, and used the surface area of LM from the MCWI to approximate wetland extent for lake elevation of 176.0.

Results

Overall, the estimated extent of wetlands across the 25 sites increased with higher lake elevations (Figure 4). Based on the literature, we expected water levels above chart datum (176.0) to generate greater LM area, and water levels below chart datum to result in loss of LM habitat. Our results were consistent with expectation, with total extent of LM across all sites increasing from a minimum of 76.19 ha at 175.0 to a maximum of 299.55 ha at 177.0. The increase in water level from 175.5 to 176.0 was associated with the greatest increase in LM extent; put another way, the greatest rate of loss in LM would be experienced at water levels below chart datum. On a site-by-site basis, we observed an increase in projected areas of LM with water levels that mirrored the overall trend in Figure 4 (Figure 5). It is worth mentioning, however, that at seven sites, LM extent began to decrease as water levels increased above 176.5. We also found two wetlands, Quarry Island and Musky Bay to be extremely susceptible to low water levels. In the case of Quarry Island, LM area was reduced from 4.60 ha to 0.12 ha when water levels dropped from 176.0 to 175.0, and for Musky Bay, the LM habitat actually disappeared.

2) Provide estimates of wetland extent for eastern Georgian Bay (from Key River to Severn Sound) using medium resolution (30-m) bathymetric and elevation models corresponding to the 4 lake elevations.

Method

We used open-access bathymetric, topographic and elevation data to create a 30-m resolution DEM to estimate extent of LM habitat in wetlands of eastern Georgian Bay (Severn Sound to Key River). The bathymetric data were provided by NOAA (1996) while the elevation data were extracted from the Ontario Radar Digital Surface Model (DSM). For the latter, the study area was isolated from the provincial DSM product and areas corresponding to water bodies (i.e. lakes) were removed. Since the elevation of water bodies is essentially constant across its surface, we derived a slope raster from the DSM and identified water bodies as regions where the slope was less than 0.01°. The modified DSM and Great Lakes contours for the study area were imported into GIS, and the Topo to Raster tool in ArcMap 10.2 was used to build the DEM for the study area.

We used the LM layer of the MCWI to guide the development of two landscape models to predict the extent of LM habitat in wetlands across the entire region of eastern Georgian Bay. Model 1 was based on depth only while Model 2 was based on depth, slope, and degree of exposure. Since MCWI wetlands were delineated when water levels were at chart datum (i.e. 176.0), we converted the elevation values in the DEM to depths relative to 176.0 and then derived a slope raster for the study area. We also built a "degree of exposure" (exposure) raster for water surface areas within 1 km from shore. In essence, exposure measures the amount of potential wave energy experienced by a given sample point on the water surface within the shore-to-1 km zone. Operationally, we calculate this by determining the area of water encompassing a set of contiguous straight lines radiating from a given point on the water, to the nearest point on land (i.e. waveshed in Figure 6). We carried out this operation for 25,000 points distributed across the shore-to-1 km zone. Since all cells in the waveshed were the same dimension (30m x 30m), we decided to use the number of cells rather than converting the count to an areal measurement. This calculation was performed for all 25,000 sample points, and then a raster layer was created by interpolation. Due to the resolution of the DEM and the delineation procedures for the MCWI wetlands, some areas classified as LM in the MCWI corresponded to elevations above the assumed shoreline at 176.0, and these had to be excluded from the analysis. The remaining LM habitat identified in the MCWI were used to extract the distribution of depth, slope, and exposure values over which all wetlands were found. We used the shallowest 90% quantile for the depth range, which corresponded to a value of 3.04m. The lower 90% quantiles were used to determine the range of values for slope and exposure, which corresponded to 2.4° and 14,240 units, respectively.

We used the derived depth, slope, and exposure thresholds for a binary reclassification to determine wetland extent under each lake-level elevation. We compared the estimated LM area corresponding to 176.0 from each model (Model 1 and Model 2) to the actual LM area delineated in the MCWI to evaluate the accuracy of each model. For evaluation purposes, we divided the entire study area into three regions, and grouped the wetlands according to boundaries of the tertiary watersheds. The North region spans the northern extent of the study area near Key River to south of Parry Sound at the southern boundary of the Magnetewan watershed. The Central region was delineated by the Muskoka watershed (Parry Sound to Cognashene Lake), while the South region spans the shoreline from Cognashene Lake to the southern extreme of the study boundary, primarily encompassing portions of the Black River –Lake Simcoe and Nottawasaga watersheds.

Results

At a lake elevation of 176.0, we had reasonably good agreement with respect to Total % area between the MCWI-derived LM values and those produced by Model 1 and Model 2 (87% and 70%, respectively; Table 7; Figure 7). Both Models over-estimated the total LM area, with Model 2 producing more conservative predictions. Although the Total % Agreement with Model 1 was higher than with Model 2, there were better predictions for overall extent and distribution of LM throughout the study area and the results were more consistent with field observations. In particular, inclusion of exposure as a parameter in Model 2 reduced errors of commission along the outer islands of eastern Georgian Bay. Given the overall quality the Model 2 projections relative to Model 1, we decided to use Model 2 projection for further analysis.

Projected wetland extent was highest at 176.5 across the whole study area and on a region-by-region basis (Figure 8; Table 8). Similar to the site-specific evaluations in B1, we found that water levels below 176.0 resulted in steep declines in the amount of LM area. Water level increases to 177.0 also resulted in loss of LM area relative to 176.0 and 176.5, although the drop in wetland extent with higher water levels did not appear to be as steep as those for water levels below 176.0.

Overall discussion for Projects A and B

For the most part, wetlands included in this study do not show any signs of negative impact reflective of water-quality impairment. Although we did not randomly select these sites for sampling, the wetlands in this project are distributed throughout eastern Georgian Bay and are very similar to the 150+ wetlands that we have visited over the course of our sampling program in Georgian Bay between 2003 and 2016. In spite of the long period of sustained low water levels followed by a relatively large increase in water level in recent years, the wetland biota and water chemistry in these wetlands are still indicative of very good to excellent conditions (Chow-Fraser, unpub. data). Therefore, the water-level regime of Lake Huron does not appear to have negatively affected the overall quality of coastal wetlands in terms of their overall trophic states and water transparency.

Based on digital image data acquired in the two time periods in this study, we can confirm that the areal extent of the high marsh has declined over time, while that of the low marsh has increased. To properly interpret the response of the low-marsh habitat to changes in water level, we must have measurements for vegetation that appears above the water surface as well as below the surface. Image data can provide an estimate of the ME-EM vegetation and FL, but they will not be very useful for predicting the extent of SAV. With available fine-scale (<10 cm resolution) bathymetric data, we can construct appropriate DEMs to determine the depth zone for SAV in each wetland.

Lake elevation and local bathymetry are the primary determinants of the amount of low marsh habitat; however, the structure of the plant community is additionally influenced by fluctuations in lake level. Fluctuating water levels and the continual disturbance to wetlands caused by repeated cycles of inundation and desiccation promote a diverse wetland plant community with many floating, emergent and floating taxa. In contrast, stable water levels over multiple (3-5) years are likely to lead to homogenization of the plant community and the establishment of several dominant species (e.g. this study; Midwood and Chow-Fraser 2012). In turn, the less diverse plant community tends to support a less diverse community of wetland fish, and may discourage the use of coastal wetland by young-of-the-year sport fish such as muskellunge and northern pike (Leblanc et al. 2014; Weller et al. 2016).

Based on both the fine-scale and regional projections of marsh habitat in Georgian Bay, it appears that the lake elevations between 176.0 and 176.5 will support the maximum possible wetland extent of low marsh. Lake elevations outside of this range tend to restrict the breadth of the depth zone suitable for coastal wetlands, and can result in a net loss of wetland area. Besides wetland loss resulting from moderate increases and decreases in lake level outside of this optimal zone (176.0-176.5), there is a greater concern that the actual decrease in lake elevation projected from Global Circulation Models would cause a more drastic decline in wetland area (e.g. to 174.0 m) and that this would result in a greater number of wetlands being lost due to loss of hydrological connectivity between the coastal wetlands and Georgian Bay proper (Fracz and Chow-Fraser 2013).

Our ability to predict how wetland habitat responds to changes in water levels over the long term is limited by the availability and coverage of field surveys, quality and quantity of digital image data, and fine-scale bathymetric data. This document represents the best analysis possible given these constraints. The advent of UAV has made it possible to update image data for these wetlands without the high cost of satellite and airborne sensors, and it would be worthwhile to arrange for updates of a randomly selected subset of wetlands for future analyses. With a suitable fine-scale bathymetry, a DEM can be derived and it is possible to then model how wetland habitat changes in response to different water-level scenarios. Unfortunately, accurate bathymetric and topographic data (preferably fine-scale) do not exist on a regional basis for eastern Georgian Bay, and this is a serious information/data gap that must be filled before we can conduct basin-wide assessments of the impacts of climate change on coastal wetland health and extent.

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Table 1. Summary of surface area (m^2) occupied by meadow-emergent (ME-EM), floating (FL) and submersed aquatic vegetation (SAV) in 22 coastal wetland units during Period 1 (I; 2002-2008) and Period 2 (II; 2015/2016). Data were digitized from IKONOS imagery acquired during July 2002, 2005 and 2008, and from UAV imagery acquired during July and August in 2015 and 2016. Wetlands sorted in descending order of % change in total wetland area between Period 1 and 2.

	ME-EM		FL		SAV		All classes	
Wetland	I	II	I	II	I	II	I	II
Green Island 1*	7856	7318	25	62	10084	16710	17965	24090
GB7	18771	16533	2302	3265	23607	30554	44680	50352
Roberts Bay	19772	17722	1706	1153	8460	14413	29938	33288
Musky Bay West	6434	5657	3363	4209	11997	14930	21794	24796
Tadenac Island	1696	2161	0	0	13425	14117	15121	16278
Musky Bay East	3784	4480	0	158	3217	3614	7001	8252
Black Rock 2	5899	6172	3018	2923	5256	5276	14173	14371
Corbman Bay	7748	2824	752	1915	22185	27247	30685	31986
Tadenac 2	3259	3033	0	169	15723	16015	18982	19217
Treasure Bay	3485	3836	614	1658	5843	5154	9942	10648
Tadenac 1	1340	1764	0	2150	19121	18353	20461	22267
Ojibway	2761	1585	324	1207	8438	8630	11523	11422
Quarry	27896	39931	23023	11194	28502	15262	79421	66387
Green Island 2*	4657	1910	1084	897	16857	18367	22598	21174
Matchedash 2	5127	10383	15683	14808	30248	23126	51058	48317
Inukshuk	7010	2755	0	554	7779	9859	14789	13168
Shawanaga	3273	1206	2145	1613	10458	10103	15876	12922
Hole in the Wall	30025	15368	22357	58002	127892	140035	180274	213405
Black Rock 1	9122	6869	9543	10751	17499	15581	36164	33201
Cormican	19525	6055	0	55	42019	49424	61544	55534
West Bay	67016	48106	4099	10055	30851	43015	101966	101176
Matchedash 1	11144	337	9780	1354	35917	33433	56841	35124
MEAN	**12164**	**9364**	**4537**	**5825**	**22517**	**24237**	39218	39426

Table 2. Net change (between Period 1 and Period 2; see Table 1) in vegetation cover for 22 wetlands of eastern Georgian Bay. Data include net change in cumulative vegetation cover (meadow-emergent (ME-EM), floating (FL) and submersed aquatic vegetation (SAV)), total HM and LM habitat (ME-EM and SAV only), as well as proportional change in each of the three vegetation classes.

Wetland	Cumulative vegetation cover	Total HM and LM habitat	Net proportional change		
			ME-EM	FL	SAV
Green Island 1*	6125	6088	-0.133	0.001	0.133
GB7	5672	4709	-0.092	0.015	0.092
Roberts Bay	3350	3903	-0.149	-0.025	0.149
Musky Bay West	3002	2156	-0.074	0.022	0.074
Tadenac Island	1157	1157	0.021	0.000	-0.021
Musky Bay East	1251	1093	0.013	0.020	-0.013
Black Rock 2	198	293	0.010	-0.015	-0.010
Corbman Bay	1301	138	-0.165	0.039	0.165
Tadenac 2	235	66	-0.012	0.009	0.012
Treasure Bay	706	-338	0.053	0.119	-0.053
Tadenac 1	1806	-344	0.022	0.107	-0.022
Ojibway	-101	-984	-0.091	0.089	0.091
Quarry	-13034	-1205	0.229	-0.205	-0.229
Green Island 2*	-1424	-1237	-0.122	-0.006	0.122
Matchedash 2	-2741	-1866	0.165	-0.001	-0.165
Inukshuk	-1621	-2175	-0.256	0.044	0.256
Shawanaga	-2954	-2422	-0.132	-0.014	0.132
Hole in the Wall	33131	-2514	-0.091	0.232	0.091
Black Rock 1	-2963	-4171	-0.037	0.120	0.037
Cormican	-6010	-6065	-0.208	0.001	0.208
West Bay	-790	-6746	-0.157	0.068	0.157
Matchedash 1	-21717	-13291	-0.227	-0.168	0.227
MEAN	208	-1080	-0.072	0.043	0.072

Table 3. A comparison of wetland macrophytes identified in the low-marsh zone, and along the shoreline during 2 different time periods. Period 1 includes sampling completed between 2004 and 2013 inclusive, during years when water levels were below the long-term mean. Sampling in Period 2 was completed between 2014 to 2016 inclusive, when water levels were above the long-term mean.

Sampled in both periods		**Sampled only during Period 1**	**Sampled only during Period 2**
Bidens beckii	*Potamogeton friesii*	*Lemna trisulca*	*Carex aquatilis*
Brasenia schreberi	*Potamogeton gramineus*	*Myriophyllum alterniflorum*	*Unidentified grass sp.*
Calltiriche sp.	*Potamogeton illinoensis*	*Myriophyllum heterophyllum*	*Lemna minor*
Chara sp.	*Potamogeton natans*	*Myriophyllum tenellum*	*Phragmites australis americanus*
Carex sp.	*Potamogeton pusillus*	*Potamogeton foliosus*	*Phragmites australis australis*
Ceratophyllum demersum	*Potamogeton richardsonii*	*Sagittaria cuneate*	*Schoenoplectus cyperinus*
Dulichium arundinaceum	*Potamogeton robbinsii*	*Utricularia cornuta*	*Acorus calamus*
Eleocharis acicularis	*Potamogeton spirillus*	*Utricularia geminiscapa*	*Alnus viridis*
Eleocharis smalli	*Potamogeton zoster*	*Utricularia resupinata*	*Pinus strobus*
Elodea canadensis	*Sagittaria graminea*	*Nymphaea tetragona*	*Calamagrostis Canadensis*
Equisetum fluviatile	*Sagittaria latifolia*	*Nuphar pumila*	*Iris versicolor*
Eriocaulon aquaticum	*Schoenoplectus americanus*	*Ranunculus reptans*	*Myrica gale*
Freshwater sponge sp.	*Schoenoplectus acutus*	*Eupatorium perfoliatum*	
Isoetes sp.	*Schoenoplectus subterminalus*		
Myriophyllum sibiricum	*Schoenoplectus validus*		
Myriophyllum spicatum	*Sparganium eurycarpum*		
Najas flexilis	*Sparganium fluctuans*		
Nitella sp.	*Typha sp.*		
Nuphar variegate	*Utricularia gibba*		
Nuphar odorata	*Utricularia minor*		
Nymphoides cordata	*Utricularia intermedia*		
Pontederia cordata	*Utricularia purpurea*		
Potamogeton amplifolius	*Utricularia vulgaris*		
Potamogeton crispus	*Vallisneria Americana*		
Potamogeton epihydrus	*Zisania sp.*		
51 taxa		**14 taxa**	**12 taxa**

Table 4. A comparison of fish taxa captured in fyke nets in 22 wetlands in eastern Georgian Bay under two water-level periods (Period 1: 2004 to 2013 inclusive; Period 2: 2014 to 2016 inclusive). * denote a single occurrence.

Captured in both periods	Captured in Period 1 only	Captured in Period 2 only
banded killifish	brook silverside	grass pickerel*
black crappie	common carp	round goby
blackchin shiner	creek chub*	
blacknose shiner	Iowa darter	
bluegill	least darter	
bluntnose minnow	logperch	
bowfin	mimic shiner	
brown bullhead	muskellunge*	
central mudminnow	northern redbelly dace	
common shiner	rosy-faced shiner	
emerald shiner	sand shiner	
golden shiner	spottail shiner	
johnny darter	white crappie	
largemouth bass	white perch*	
longear sunfish		
longnose gar		
northern pike		
pumpkinseed		
rockbass		
smallmouth bass		
spotfin shiner		
tadpole madtom		
white sucker		
yellow perch		
24 taxa	**14 taxa**	**2 taxa**

Table 5: Survey methods and data sources used to build the fine-scale DEMs for the 25 wetland sites (Objective B1).

Data Source	Description
Sonar	Commercially available sonar unit (Lowrance HDS 7 Gen2 or comparable) mounted on a 16ft aluminum boat or canoe. The sonar unit was used to collect bathymetric data up to approximately the 0.5-m depth contour. The survey pattern was highly dependent on site morphometry but typically consisted of a pass around the perimeter of the wetland following the 0.5-m depth contour and a series of parallel transects that were evenly spaced across the site. The number of transects collected during a survey was dependent on the size of the wetland and the bathymetric complexity of the site. Surveys typically took about 90 minutes.
Bathymetry Contours	Great Lakes bathymetry dataset from the National Oceanic and Atmospheric Administration (1996). Contour data from this dataset was extracted if it was contained within a wetland site boundary. The coverage of this dataset was typically lacking in most of the nearshore areas where the wetland sites were found.
dGPS	Spot locations collected using survey-grade differential GPS unit. Coverage ranged from approximately 0.5 m depth to 1.0-2.0 m above the water surface at the time of survey.
Handheld GPS	Spot locations or shoreline traces collected with commercially available handheld GPS devices (Garmin eTrex Lengend or comparable).
OIH DEM	The DEM from the Ontario Integrated Hydrology was used to provide the upland (above 176.0m) component of the specific wetland models.

Table 6: Data sourced used to build each wetland DEM for Objective B1. Bathymetry data collected by sonar surveys and topographic data from the Ontario Integrated Hydrology dataset were used for all 25 sites.

Wetland Site	**Longitude**	**Latitude**	**Bathymetry Contours**	**dGPS**	**Handheld**
Key River 3	-80.692681	45.88499			
Key River 1	-80.676401	45.88622			
Charles Inlet	-80.565824	45.64726			
Sturgeon Bay Central	-80.41455	45.6143			
Corbman Bay	-80.341304	45.40855			
Cormican Bay	-80.309086	45.40793			
West Bay	-80.304847	45.42089			
Alexander Bay	-80.005293	45.05483		x	x
Davids Bay	-80.002175	45.04654			
Coffin Rock	-79.987382	45.04776		x	
Tadenac 1	-79.986384	45.04021			
Tadenac 2	-79.986178	45.042			
Miners Creek	-79.946691	45.06204		x	x
Moreau Bay	-79.944386	45.01316			
Treasure Bay	-79.858709	44.87108		x	x
Ojibway Bay	-79.857793	44.88744			
Roberts Island	-79.83146	44.85474		x	
Picnic Island	-79.820166	44.85952		x	
Quarry Island	-79.808811	44.83402			
North Bay 5	-79.802741	44.88213		x	
North Bay 1	-79.794147	44.89778		x	x
Musky Bay	-79.780385	44.81232			
Potato Island	-79.755293	44.79308	x		
Green Island	-79.747131	44.78556	x	x	
Oak Bay	-79.737027	44.79851	x	x	x

Table 7: Comparison of wetland areas derived from the McMaster Coastal Wetland Inventory (MCWI; Midwood et al. 2012) and two models in which 1) coarse-resolution digital elevation model (DEM) is used (Model 1) and 2) DEM is used in conjunction with calculated slope and fetch (Model 2). Wetland area for the models correspond to chart datum (176 m asl).

	Total Area (ha)	MCWI Agreement (ha)	MCWI Commission (ha)	MCWI Omission (ha)	Total % MCWI Match
Model 1	42,169	2,573	39,596	396	87%
Model 2	19,784	2,087	17,696	881	70%

Table 8: Wetland area (ha) estimated under five water level scenarios for different regions of eastern Georgian Bay. Model 2 (see Table 5) was used to produce estimates.

	Water Level Scenario (m a.s.l.)				
Region	**175.0**	**175.5**	**176.0**	**176.5**	**177.0**
Total	8,145	17,929	19,784	22,616	11,019
South	2,004	3,047	2,900	3,174	2,023
Central	1,275	2,932	3,270	3,459	2,886
North	4,867	11,950	13,613	15,982	6,111

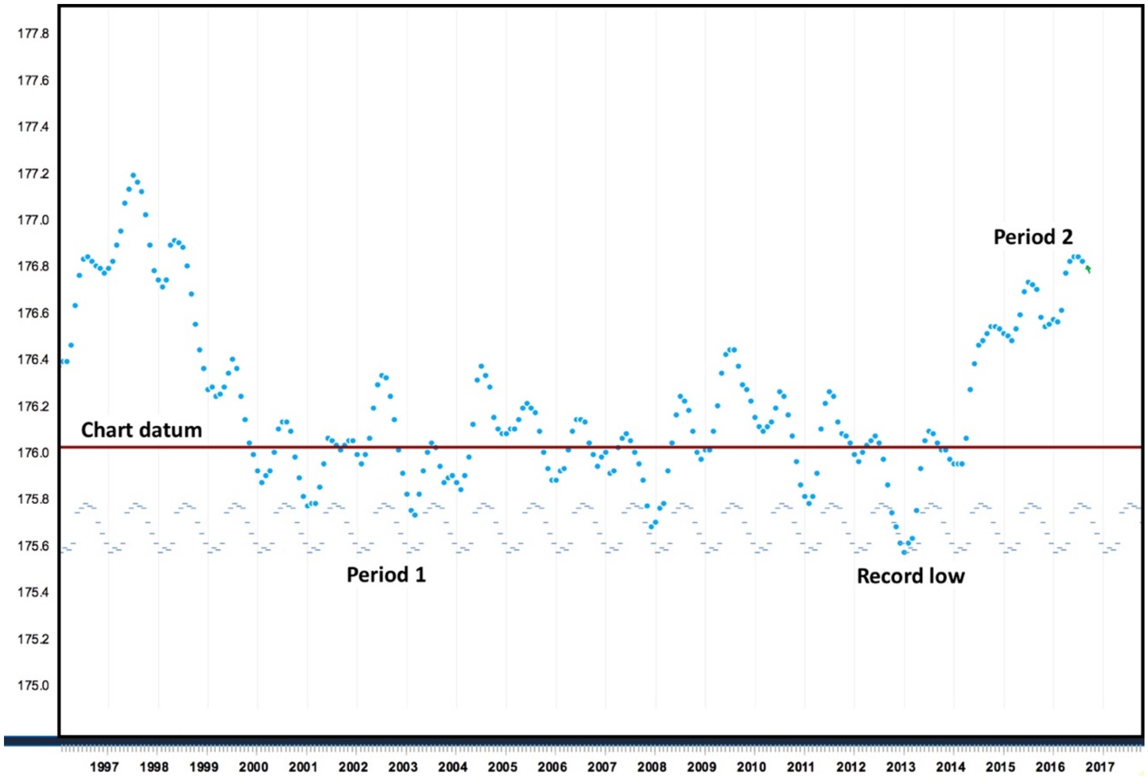

Figure 1. Changes in water level (m, asl) of Lake Huron (Georgian Bay).

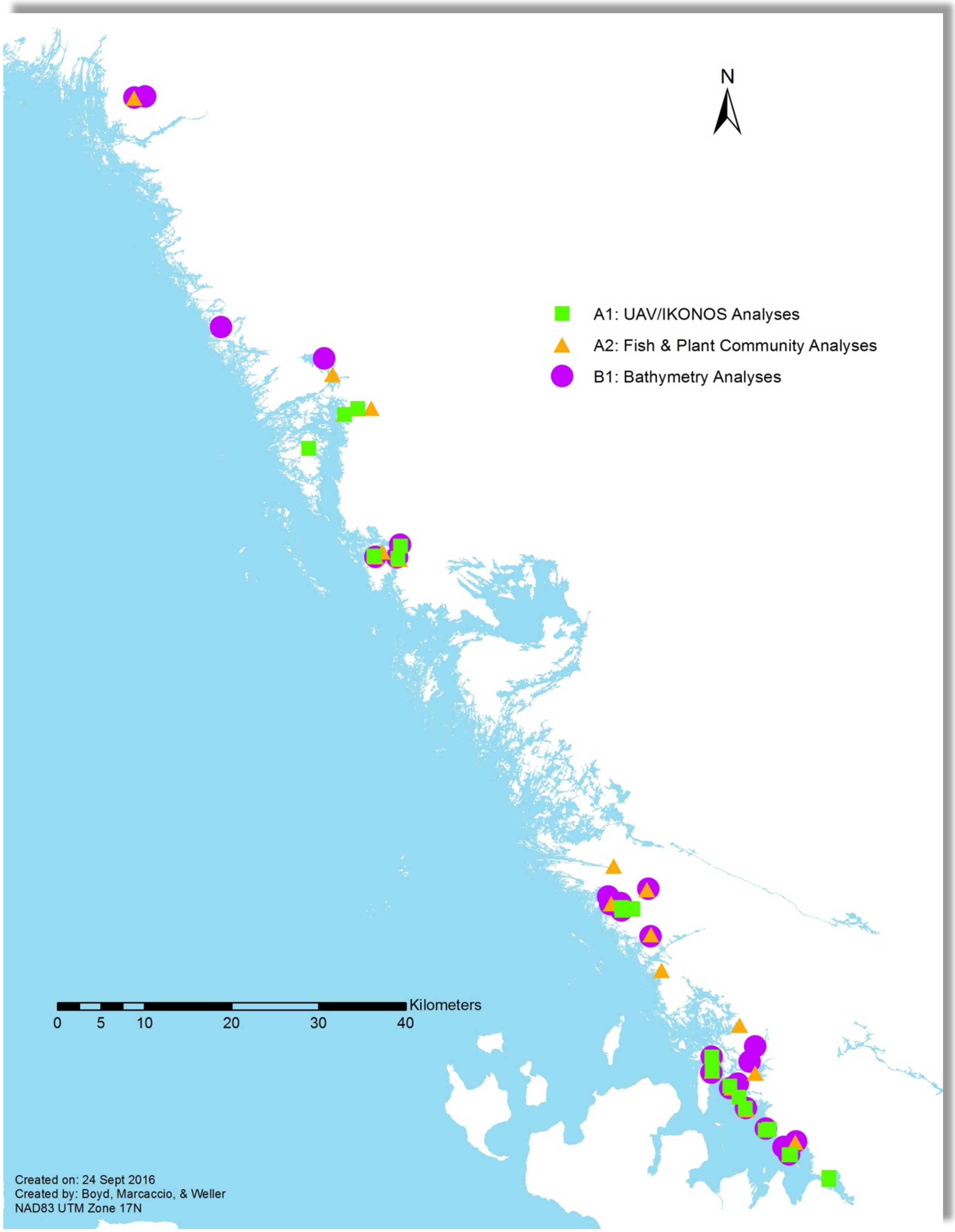

Figure 2: Location of wetlands for all projects.

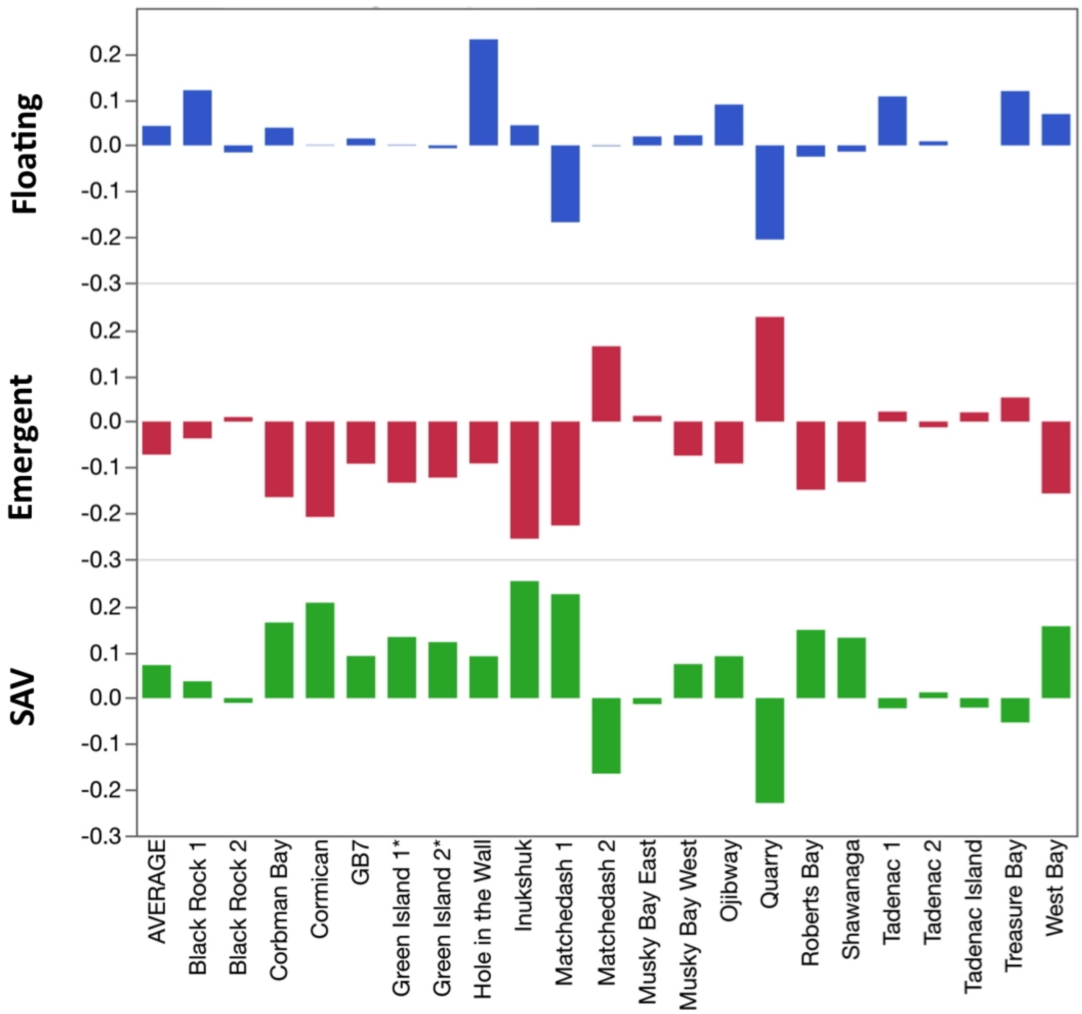

Figure 3. Proportional change in areal cover of emergent, floating and submersed aquatic vegetation (SAV) in 22 coastal wetlands of eastern Georgian Bay.

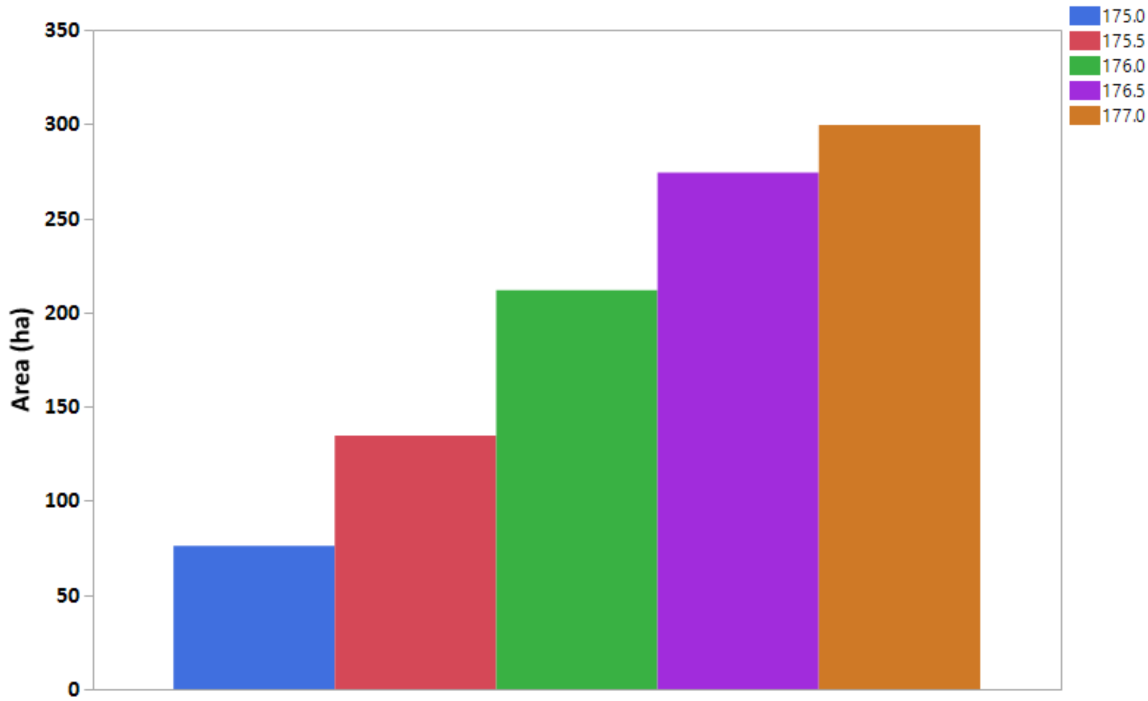

Figure 4. Changes in total wetland area of 20-25 wetlands as a function of WL. Areas calculated using fine-scale bathymetric information.

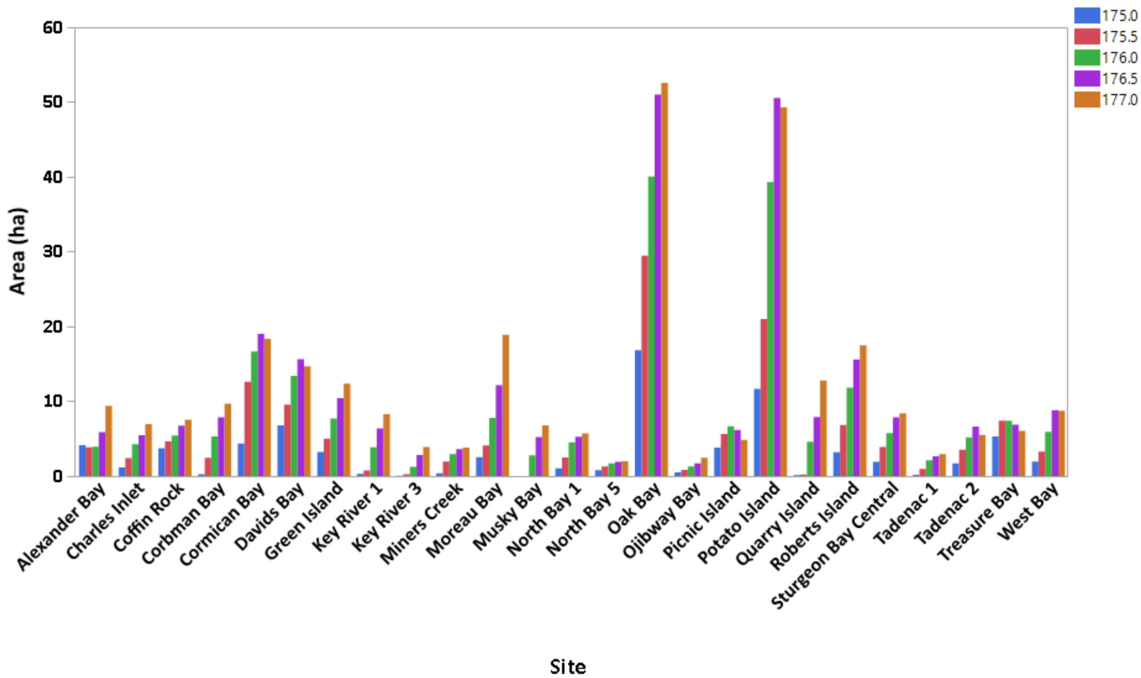

Figure 5. Changes in wetland area of 20-25 wetlands as a function of WL. Areas calculated using fine-scale bathymetric information.

Figure 6. Example of a “waveshed” calculated for one sample point.

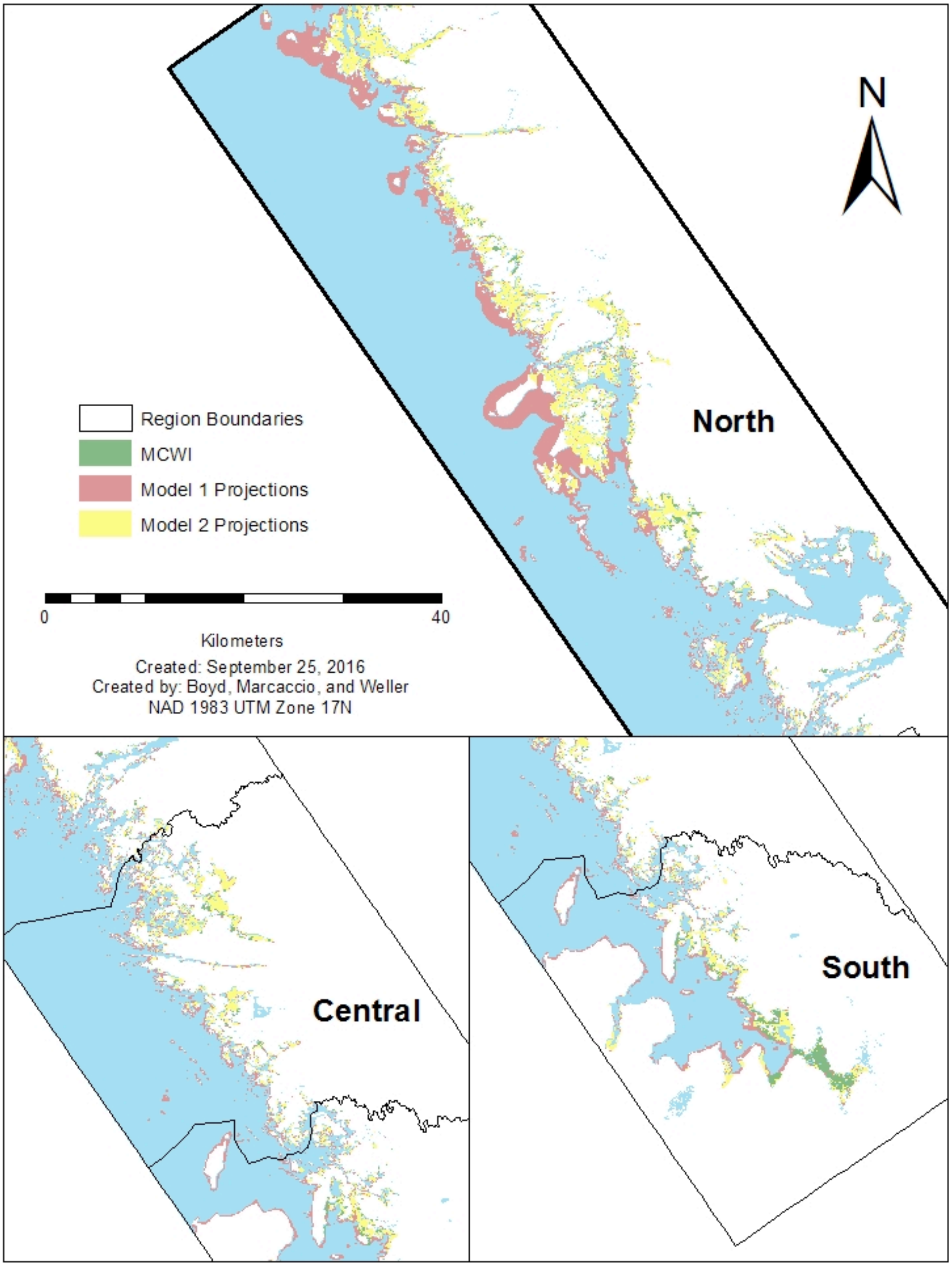

Figure 7. GIS Figure that shows the MCWI overlaying the wetland areas estimated with Model 1 and Model 2

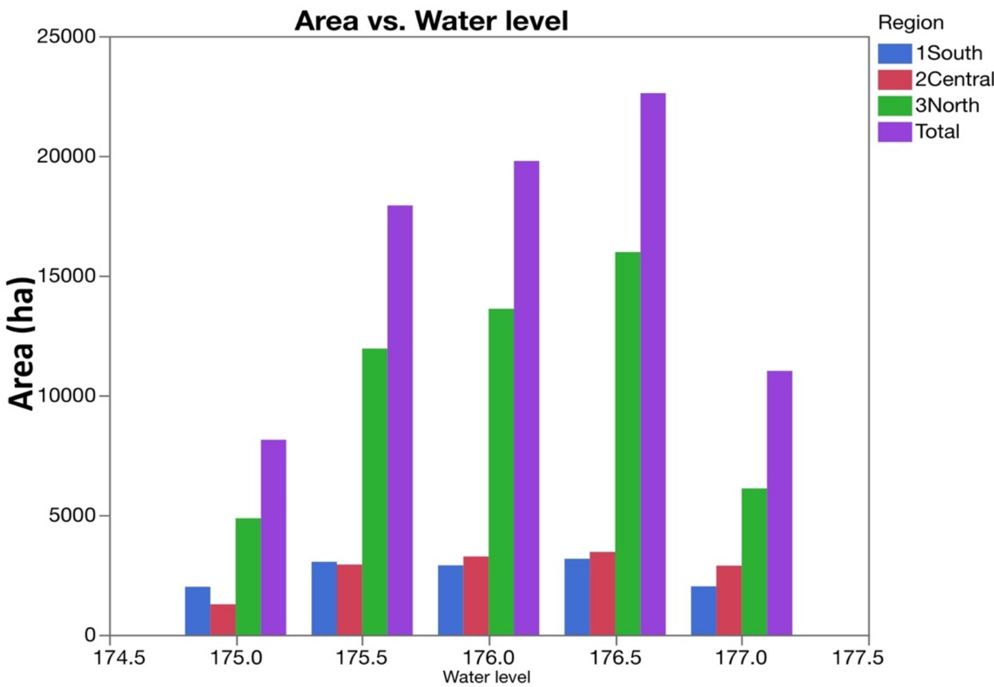

Figure 8. Changes in amount of wetland area in different regions of Georgian Bay as a function of water level (m, asl).