Project Name: Vulnerability of wetlands of eastern Georgian Bay to changes in water levels of Lake Huron

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Background

The International Upper Great Lakes Study Board is in the third year of a five-year study for the International Joint Commission (IJC). The Study Boards will make decisions that could affect the Upper Great Lakes for decades, based on its estimate of the impacts from various lake-level regulation options. The Ecosystem Technical Work Group (ETWG) is charged with the task to inform the Study Board if potential ecological impacts from alternative water level regulation scenarios. Consistent with the Study Board's approved method of study, ETWG will estimate both positive and negative impacts on performance indicators that may results from changes to water levels/flows at specific sites in the Upper Great Lakes. The ETWG has chosen several sites where ecological impacts will be assessed. The selection was based on: ecological representation/significance; data availability and certainty; sensitivity to water level regulations; and geographic coverage.

One of the sites is eastern and northern Georgian Bay, chosen because of the presence of unique coastal wetland complexes that occur on Pre-Cambrian Shield, and that are known to be some of the least human-disturbed systems remaining in the Great Lakes. These wetlands have been recognized for their excellent water quality, high plant biodiversity and importance as spawning and nursery habitat for Great Lakes fishes. Many of these wetlands occur in a rock-water matrix that makes them vulnerable to stranding by low water levels. These sites have also be chosen because of availability of existing data and access to IKONOS satellite imagery that had been acquired in 2002 and 2008 for three regions: Oak Bay/Matchedash Bay which are impacted by recreational development and agricultural activities; North Bay/ Honey Harbour which are impacted by cottage development and recreational activities; and Tadenac Bay, which has been protected from human development over the past 100 years.

Objective:

1. Develop a better understanding of coastal wetland vegetation dynamics and provide expert opinion on ecological impacts of water level regulation on eastern Georgian Bay coastal wetlands

Tasks:

1. Complete fieldwork for and create high resolution Digital Elevation Models of 7 eastern Georgian Bay coastal marshes
2. Complete change analysis of wetland vegetation in two regions using satelllite imagery (IKONOS) acquired in 2002 and 2008
1. Model vegetation change in response to water level fluctuations
2. Provide expert opinion on the potential for wetland stranding and the use of technologies pertaining to water level regulation in the region

Deliverables:

1. A report that lays out the following:
    a. Methodology used for the creation of DEMs of coastal wetlands
    b. Changes in broad marsh vegetation groups (high marsh and low marsh) between 2002 and 2008 in two regions of Georgian Bay
    c. Vegetation response curves to changes in water level for eastern Georgian Bay coastal marshes
    d. Expert opinion provided to ETWG on other potential ecological impacts from water-level regulation through attendance at meetings
2. Digital Elevation Models of 7 coastal marshes including the data from which it was created

Final Report:

1. Methodology for Digital Elevation Model creation for 7 Georgian Bay coastal marshes

Study Sites

7 sites along the eastern shore of Georgian Bay, Lake Huron were selected for this study (Figure 1). Although the sites were not selected at random they are not atypical sites and are representative of the region's coastal wetlands. We focused the sites in the southeastern portion of the bay (Figure 1) due to having multitemporal (2002 and 2008) high-resolution IKONOS imagery (Geoeye, Dulles, VA, USA) that will aid in the modeling of plant communities. The distribution of human impact levels range from little to no disturbance in the Tadenac Bay area to moderate levels in the North Bay and Oak Bay regions. Site accessibility and locations where prior research had been completed influenced site selection. The sites range in size from small protected embayments such as North Bay 5 to large more exposed embayments such as Oak Bay.

Bathymetry Data Collection

Raw depth and elevation data were collected in the field using 3 sources: differential GPS (dGPS) with a base unit and roving unit, manual depth measurements using a graduated pole and GPS (herein referred to as Mobile GPS), and a boat mounted sonar depth sounder (Table 1; Figure 2C) in July-September 2009. The accuracies associated with each source vary with the dGPS being the most accurate with sub-meter GPS and centimeter elevation capabilities. The Mobile GPS source is accurate to the meter for location and accurate to the half centimeter for depth. The depth sounder is the least accurate with moderate GPS accuracy (3 meter) with good depth accuracy to the centimeter.

Multiple data sources were used because data were necessary for both inundated and terrestrial habitat (Figure 2B). The dGPS (Magellan ProMark 3®) was used for all of the terrestrial habitat and up to ~1.2m depths as to not sustain water damage to the roving unit. The dGPS is ideal for collecting data from the emergent zone shallower than 1m to the wet meadow/ upland forest boundary. The unit; however, loses its satellite signal and connection to the base unit when under the forest canopy and therefore was used only up to the treeline and not into the upland forest. For areas deeper than 1.2m data were collection we using a boat mounted sonar depth sounder (Lowrance® sonar unit) that simultaneously records depth and GPS location. We developed the Mobile GPS source (using a single Magellan ProMark 3® unit) for collection in areas too deep for dGPS collection, where the substrate is highly organic and difficult to access by foot, and where the density of aquatic vegetation is high enough to impair boat access or to sustain damage to the aquatic vegetation with the boat. This data was collected via canoe and a single GPS unit in which the depths are manually entered and linked to the GPS location.

Deriving Elevation

To convert the depth data collected in the field to elevation, we used hourly Parry Sound water level data (Canadian Hydrographic Service [CHS] of the Department of Fisheries and Oceans [http://waterlevels.gc.ca/C&A/wldata/parythis.htm]; m, IGLD 1985 datum) for the exact times when data were collected in the field. We subtracted depth data from the water level data to derive elevation for the depth sounder and Mobile GPS sources. Although the dGPS records elevation, without a known ground control point elevation for the base unit meant that we had to correct the data and scale all the values using data points collected at the water mark using the Parry Sound water level data.

Digital Elevation Model Development

A Digital Elevation Model (DEM) for each wetland was created in a GIS using ArcGIS 9.2 (Redlands, CA, USA; Figure 2D; Appendix A), where all of the data sources were merged into one data layer (Figure 2C). Outliers were identified and removed from the dataset and interpolation of the elevation data was completed using the “Topo to Raster” function from the Spatial Analyst extension of ArcGIS 9.2. This technique was specifically made for hydrologically consistent DEM creation and for the purposes of hydrologic modeling using neighbouring data points to reduce sinks or outliers using an inverse distance weighted interpolation (de Smith et al, 2007). We set the interpolation of the data for a final cell size of 5 (5m). After the initial DEM creation and analyzing the data points for outliers and distributions some areas along the shoreline beyond the wetland did not have any data points and the interpolation illustrated lower elevation near the shore. We know that this is incorrect and we enhanced the data set with manually added shoreline points using expert image interpretation of IKONOS imagery given elevation from the water level elevation observed in Parry Sound within 30 minutes of imagery acquisition (Table 1). This served to improve the DEM significantly when interpolated with this enhanced shoreline. Maps of the DEM data and sites can be found in Appendix A.

2. Changes in marsh vegetation between 2002 and 2008 in Georgian Bay coastal wetlands

Study Sites and Methods

2 regions in southeast Georgian Bay were used for which 2002 and 2008 1m-resolution IKONOS satellite imagery was acquired (Figure 3). The imagery was georeferenced using ENVI™ (ITT Visual Informations Solutions, White Plains, New York, United States; v4.1) to complete the temporal analyses. All coastal wetland habitats in these regions were manually delineated for each year. Wetland habitat was identified as either permanently inundated vegetation or low marsh (LM) and seasonally inundated vegetation or high marsh (HM). LM encompasses emergent, floating and submergent vegetation and HM encompasses meadow and shrub vegetation. We couldn't fully account for submergent habitat because satellite imagery cannot penetrate water. We therefore define the lower boundary of wetlands as visible aquatic vegetation. In most cases this was the lake-ward boundary of floating vegetation. Marshes were also classified as protected or fringing to determine if differently shaped wetlands change differently. Protected wetlands are those found in embayments and fringing wetlands are those found along a shoreline segment (Figure 4). Area of each habitat type was calculated in a GIS. Paired t-tests were used to test for significant differences between mean LM and HM areas and mean % LM and % HM areas between 2002 and 2008. Data were $Log_{10}(x+1)$ transformed or arcsine transformed to increase normality of the dataset.

Water Levels from 2002-2008

Mean annual Lake Huron water levels from 2002 to 2008 do not show great variation with a net change of about -10cm (Figure 5B). Coastal wetland vegetation present during a given year is thought to be a manifestation of a 5-year lag in colonization and succession. When we look back to the water level trend for the 5-year period prior to our imagery we see very different scenarios prior to 2002 and 2008. Prior to 2002 there was a large decrease from a localized peak in 1997, and prior to 2008 we see relatively little change (Figure 5B). Historically, water levels have shown great variation (Figure 5A) with peaks and troughs showing quick rebounding. Interestingly we see that from 2000 onwards there was little rebounding and sustained low levels.

Results

From manual delineation of wetlands, we identified 344 coastal marshes within our study area (Figure 6) with the majority (78%) being less than 1ha in size (Table 2).

Overall wetland area and for each habitat type significantly increase from 2002 to 2008 (Table 3). Total wetland area increased by 12.8% (LM by 5.8% and HM by 17.5%). The percent of total wetland area composed of LM and HM also significantly shifts towards greater composition of HM habitat in 2008 (Table 3). To determine the effect of wetland size, we divided wetlands as either >1ha or <1ha. We detect similar trends as the entire dataset; however, LM habitat does not significantly increase in 2008 for both size categories (Table 4). This indicates that although wetland area is increasing there is the trend towards increasing terrestrial components (HM) of coastal marshes.

Wetland shape was also classified, identifying 208 protected marshes (PRO) and 136 fringing marshes (FRN). Total area for both types of wetlands significantly increase from 2002 to 2008. HM area also follows this trend. The differences between these two wetland types arise from LM area change. PRO LM area significantly increases in 2008 but FRN LM area did not. The percent composition of LM and HM in PRO wetland did not change from 2002 levels; however, FRN wetlands display a significant shift towards greater composition of HM habitat (Table 5). Differences between rates of change were also analyzed (Table 6). We see that the amount of change between protected and fringing wetlands varies significantly. Protected wetlands increased significantly greater total area, HM area, and percent HM area in 2008. We also see that fringing wetlands lost significantly greater percent LM area in 2008 (Table 6). An example of a protected wetland with habitat delineations including habitat conversion types can be found in Figure 7.

From the manual delineation of a large sample of coastal wetlands we see that from 2002 to 2008 wetlands generally increased in area. Water levels showed very little variability during this time period and it could be possible that the general expansion of wetland habitat could be attributed to natural succession of wetland vegetation in the absence of water level fluctuation. Interestingly we also detect increases in both the area and percent area of high marsh habitat, yet there is a decrease in the percent area of low marsh habitat. This indicates that low marsh habitat may not be experiencing this general expansion at the same rate at high marsh habitat. This trend may continue if water levels do not rebound in the future. Our results also illustrate that geomorphological characteristics also influence the amount of change observed during the interval. Fringing wetlands do not experience the expansion of low marsh habitat, which has implications for fish habitat. These wetlands; however, are less prevalent in the landscape and in general do not have extensive low marsh habitat. The implications of this study on water regulation of the Great Lakes is that regulation must include natural and historic fluctuation levels to ensure the persistence of both aquatic and terrestrial habitats without favouring the succession that may ultimately result in less diverse habitat for wildlife.

3. Vegetation response curves to changes in water level for eastern Georgian Bay coastal marshes

Rationale

Water-level disturbance caused either by lake-level regulation or by global climate change has been identified as one of the most significant stressors affecting coastal wetlands. Traditionally, the development of vegetation response curves to changes in water level relies on long-term field surveys or historical remote sensing data (Chow-Fraser 2005), and therefore it is not applicable to areas where long-term archived data are not available. Wei and Chow-Fraser (2005, 2008) proposed to use DEM to investigate the response of emergent vegetation to different water-level regimes at both local and regional scales. The key ecological principle underlying the new approach is the robust relationship between occupied habitat and potential habitat (Wei and Chow-Fraser 2008). A potential habitat is the maximum theoretical habitat occupied by aquatic vegetation. A study of 10 coastal wetlands of Lake Ontario indicated that there was a significantly positive relationship between the occupied habitat and the potential habitat (Wei and Chow-Fraser 2008). With a high-resolution DEM, we can calculate the potential habitat for emergent plants and submergent plants relating to different water levels in any wetland. For wetlands that lack of long-term observations, a closely coupled relationship between the changes in potential habitat and water level become a very useful management tool to assess the response of aquatic vegetation to water-level disturbances caused either by lake-level regulation or by global climate change scenarios.

Approach

The potential habitat for emergent cover and submerged cover are defined as follows: The potential habitat for emergent cover represents a habitat space from the edge of a wetland to shallow water at a depth of 50 cm. Potential habitat for submergent cover includes water at a depth of 10 cm to the euphotic depth, which is the depth at which light intensity falls to 1% of the value at the surface. The average euphotic depth for wetlands in Georgian Bay may exceed 6 m (Jon Midwood, personal observation). The 7 sites in this study have an approximate mean depth of 1 m, which is much lower than the observed euphotic depth.

Steps in this DEM-based approach are summarized as follows: (1) Import the DEMs into a GIS; (2) Calculate the potential habitats for the sites using 10 cm as a change unit in water level; and (3) Quantify the relationship between the changes in potential habitats and water levels.

Results

The vegetation response curves to changes in water level for the 7 Georgian Bay coastal marshes are presented in Figures 8-19. The s-shaped curves in Figures 8a-15a are the vegetation response curves to changes in water level at an interval of 10 cm. Figures 8b-15b reflect the percent change in potential habitat area between two change units (i.e., 10 cm) in water level. There are distinct peaks in the % areal change for emergent and submergent vegetation at all study sites.

Since the vegetation response curves resemble a typical sigmoid curve, we combined the data from all sites and modeled the s-shaped curves of vegetation response to changes in water level (Figures 16-17). The fitted models accounted for 95.5% and 95.3% variance in the emergent and submergent respectively. The fitted curves can be expressed as follows:

(1) Emergent_potential% = 1.875 + 95.96/(1 + Exp(-1.8042*(water level - 176.04))).
(2) SAV_potential% = 5.48 + 92.74/(1+Exp(-1.88*(water level -175.59))).

The fitted Double Gaussian curves of the % areal change between two intervals of changes in water level are shown in Figures 18-19 and can be summarized as follows:

(1) Areal_change_in_Emergent_potential = 0.614 + 4.768*PRNORMAL(water level; 175.7891; 0.4506^2) + 1.696* PRNORMAL(water level; 175.7891; 0.4506^2), variance accounted for 51.8%
(2) Areal_change_in_SAV_potential% = 0.6815 + 4.610* PRNORMAL(water level; 175.2920; 0.4388^2) + 1.626*PRNORMAL(water level; 175.2920; 0.4388^2), variance accounted for 51.2%

Results from the models suggest that the emergent and submergent vegetation experience the most rapid change when the water level approaches 175.79 m and 175.29 m respectively.

References

de Smith, M.J., Goodchild, M.F., Longley, P.A. 2007. Geospatial Analysis: A comprehensive guide to principles, techniques and software tools. Troubador, New York, 516pp.

Chow-Fraser, P. 2005. Ecosystem response to changes in water level in Great Lakes marshes: lessons from the restoration of Cootes Paradise Marsh. *Hydrobiologia* 539: 189-204

Wei, A. & Chow-Fraser, P. 2005. Untangling the confounding effects of urbanization and high water level on the cover of emergent vegetation in Cootes Paradise Marsh, a degraded coastal wetland of Lake Ontario. *Hydrobiologia* 544: 1-9.

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

Table 1: Summary of data collection for each data source at each site. Enhanced shoreline points are points included from 2008 IKONOS expert image interpretation of shoreline areas lacking data points given elevation of the water level at image acquisition. Values in the Site Total column are the total number of in field collected data with values in parentheses include the enhanced shoreline points added after field data collection.

	Number of Data Points				
Site	dGPS	Depth Sounder	Mobile Mapping	Enhanced Shoreline	Site Total
Alexander Bay	622	249	-	218	871 (1089)
Coffin Rock	361	160	-	58	521 (579)
Miners Creek	245	106	160	30	511 (541)
North Bay 1	247	199	30	27	476 (503)
North Bay 5	183	188	-	12	371 (383)
Oak Bay	763	499	369	21	1631 (1652)
Treasure Bay North	530	276	67	21	873 (894)

Table 2: Summary of the number of wetlands delineated in the vegetation change study.

Area Range	Number of Wetlands	Frequency
<1ha	269	0.782
1-2ha	36	0.105
2-5ha	17	0.049
>5ha	22	0.064
Total	344	1.000

Table 3: Marsh habitat changes from 2002 to 2008 for 344 eastern Georgian Bay coastal wetlands. Data presented are mean values for the year indicated. P-values presented are for paired t-tests of $Log_{10}(x+1)$ area data or Arcsine transformed percent data.

Parameter	Marsh Type	Year 2002	Year 2008	P-value
Total Area (ha)	Both	1.48	1.67	<0.0001
Area (ha)	Low Marsh	0.68	0.72	0.0335
Area (ha)	High Marsh	0.80	0.94	<0.0001
% of Total Area	Low Marsh	41.5	38.4	0.0007
% of Total Area	High Marsh	58.5	61.6	0.0007

Table 4: Marsh habitat changes from 2002 to 2008 for wetlands greater and less than 1 ha. Data presented are mean values for the year and wetland size indicated. P-values presented are for paired t-tests of $Log_{10}(x+1)$ area data or Arcsine transformed percent data. Non-significant differences are highlighted.

Parameter	Marsh Type	Year 2002	Year 2008	P-value
Total Area (>1ha)	Both	5.93	6.54	<0.0001
Area (>1ha)	Low Marsh	2.75	2.87	0.0622
Area (>1ha)	High Marsh	3.17	3.67	<0.0001
% of Total Area (>1ha)	Low Marsh	45.6	42.6	0.0013
% of Total Area (>1ha)	High Marsh	54.4	57.4	0.0070

Table 5:Marsh habitat changes from 2002 to 2008 for protected (PRO) and fringing (FRN) wetlands. Data presented are mean values for the year and wetland size indicated. P-values presented are for paired t-tests of $Log_{10}(x+1)$ area data or Arcsine transformed percent data. Non-significant differences are highlighted.

		Year		
Parameter	**Marsh Type**	**2002**	**2008**	**P-value**
Total Area (PRO)	Both	2.20	2.44	<0.0001
Total Area (FRN)	Both	0.39	0.48	<0.0001
Area (PRO)	Low Marsh	1.03	1.09	0.0028
Area (FRN)	Low Marsh	0.15	0.17	0.9353
Area (PRO)	High Marsh	1.17	1.35	<0.0001
Area (FRN)	High Marsh	0.24	0.32	<0.0001
% of Total Area (PRO)	Low Marsh	0.43	0.42	0.1613
% of Total Area (FRN)	Low Marsh	0.40	0.33	0.0002
% of Total Area (PRO)	High Marsh	0.57	0.58	0.6705
% of Total Area (FRN)	High Marsh	0.60	0.66	0.0016

Table 6: Differential changes in marsh habitat in protected vs fringing eastern Georgian Bay wetlands from 2002-2008. Values presented are the mean difference between 2002 and 2008 data for each parameter for both wetland types. P-values presented are for paired t-tests of $Log_{10}(x+1)$ area data or Arcsine transformed percent data. Significant differences are highlighted.

	Mean 2002-2008 Difference		
Parameter	**Protected Wetlands**	**Fringing Wetlands**	**P-value**
Total Area (ha)	+0.24	+0.09	**0.0002**
Low Marsh Area (ha)	+0.06	+0.02	0.2920
High Marsh Area (ha)	+0.19	+0.07	**0.0137**
% Low Marsh Area	-0.01	-0.06	**0.0092**
% High Marsh Area	+0.06	+0.01	**0.0002**

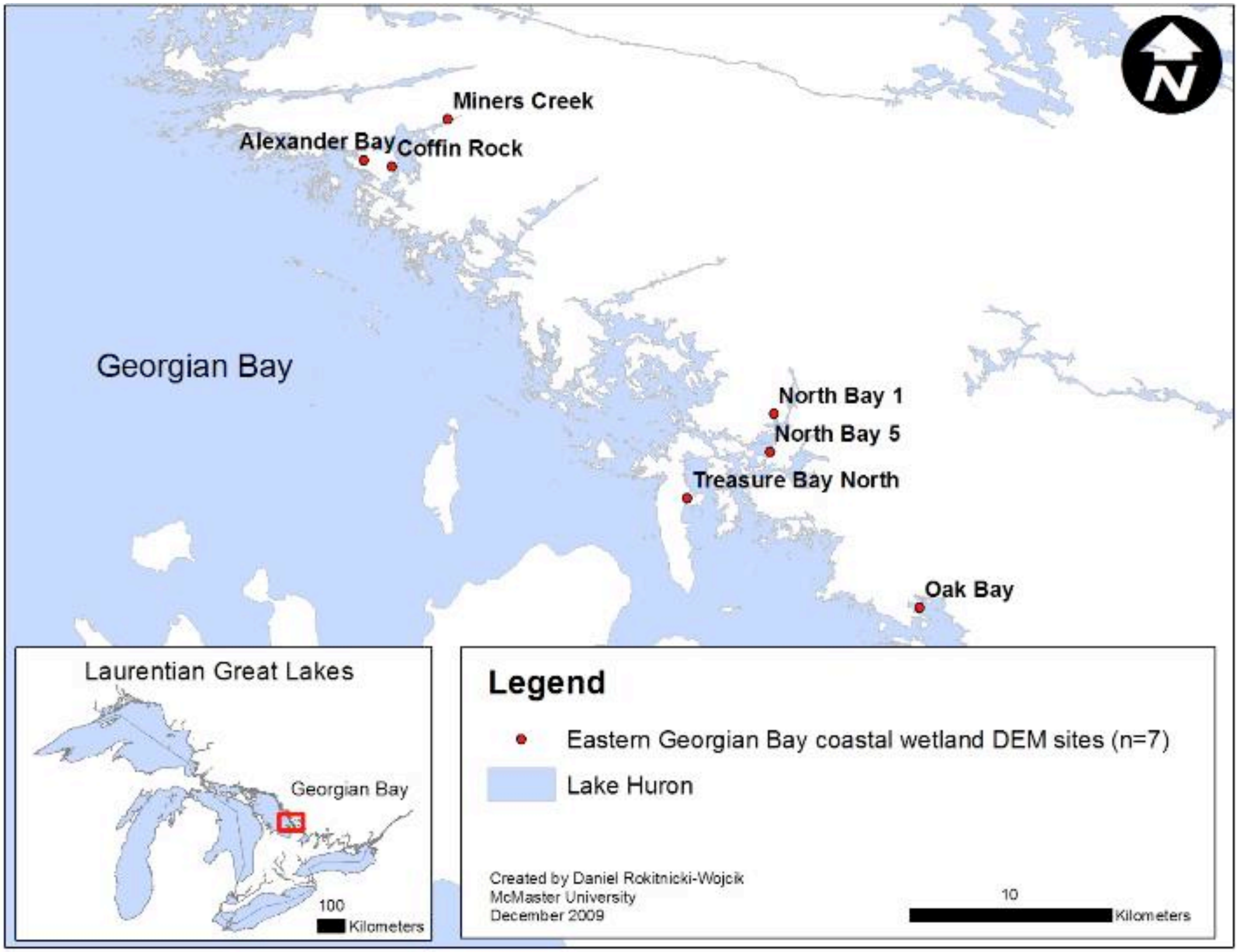


Figure 1: Site-specific locations of the 7 wetlands studied in southeastern Georgian Bay, Lake Huron.

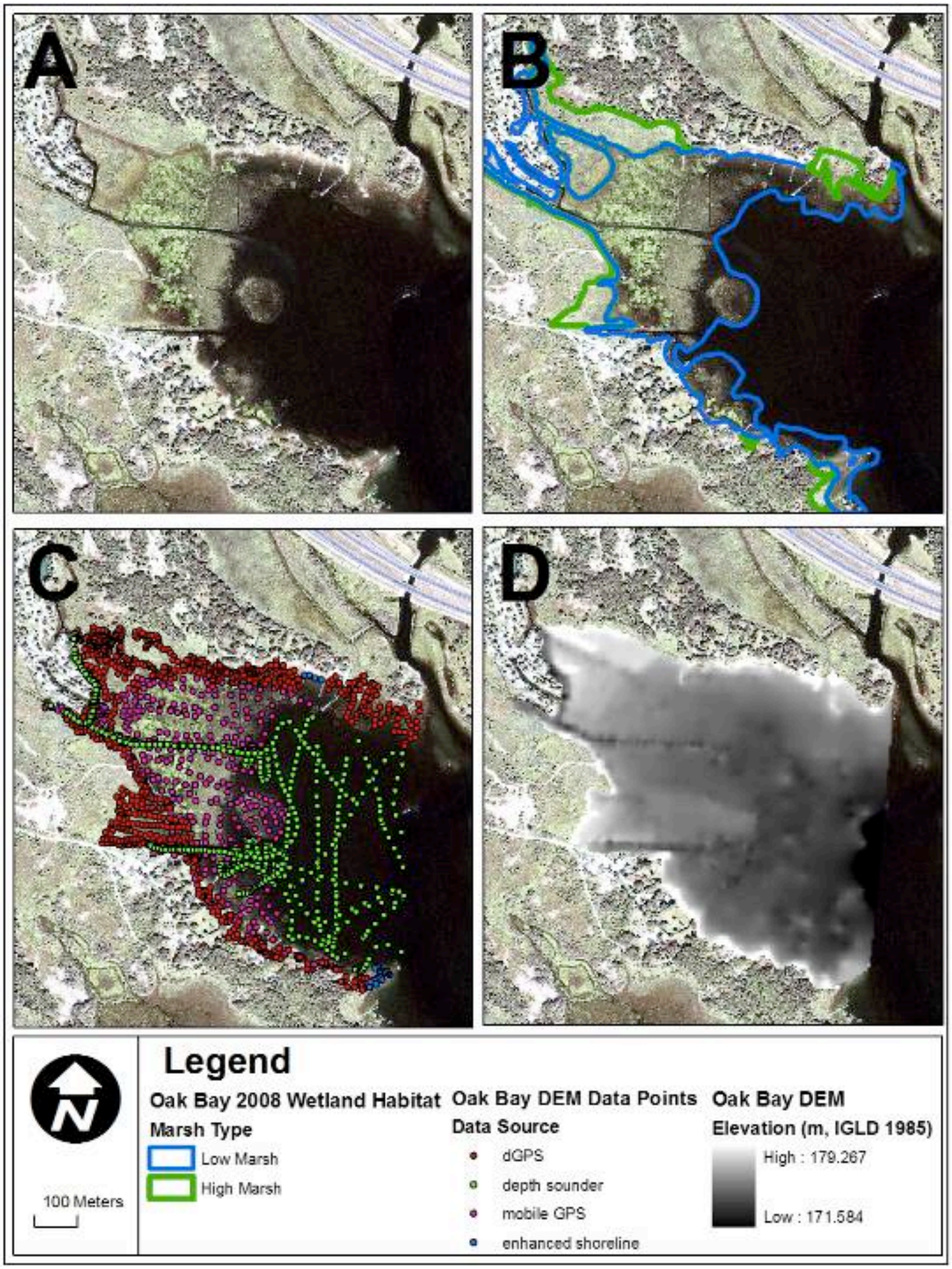


Figure 2: Example of data collected and Digital Elevation Model created for Oak Bay: A) 2008 IKONOS image of Oak Bay, B) distribution of marsh habitat types for the wetland, C) data collected by source for DEM creation, and D) final DEM. Marsh habitat types depicted in B were delineated from the 2008 IKONOS image by expert interpretation. High marsh refers to terrestrial wet meadow habitat and low marsh to permanently inundated habitat. See Figure 1 for the location of Oak Bay in relation to Georgian Bay. Similar figures for each sites can be found in Appendix A.

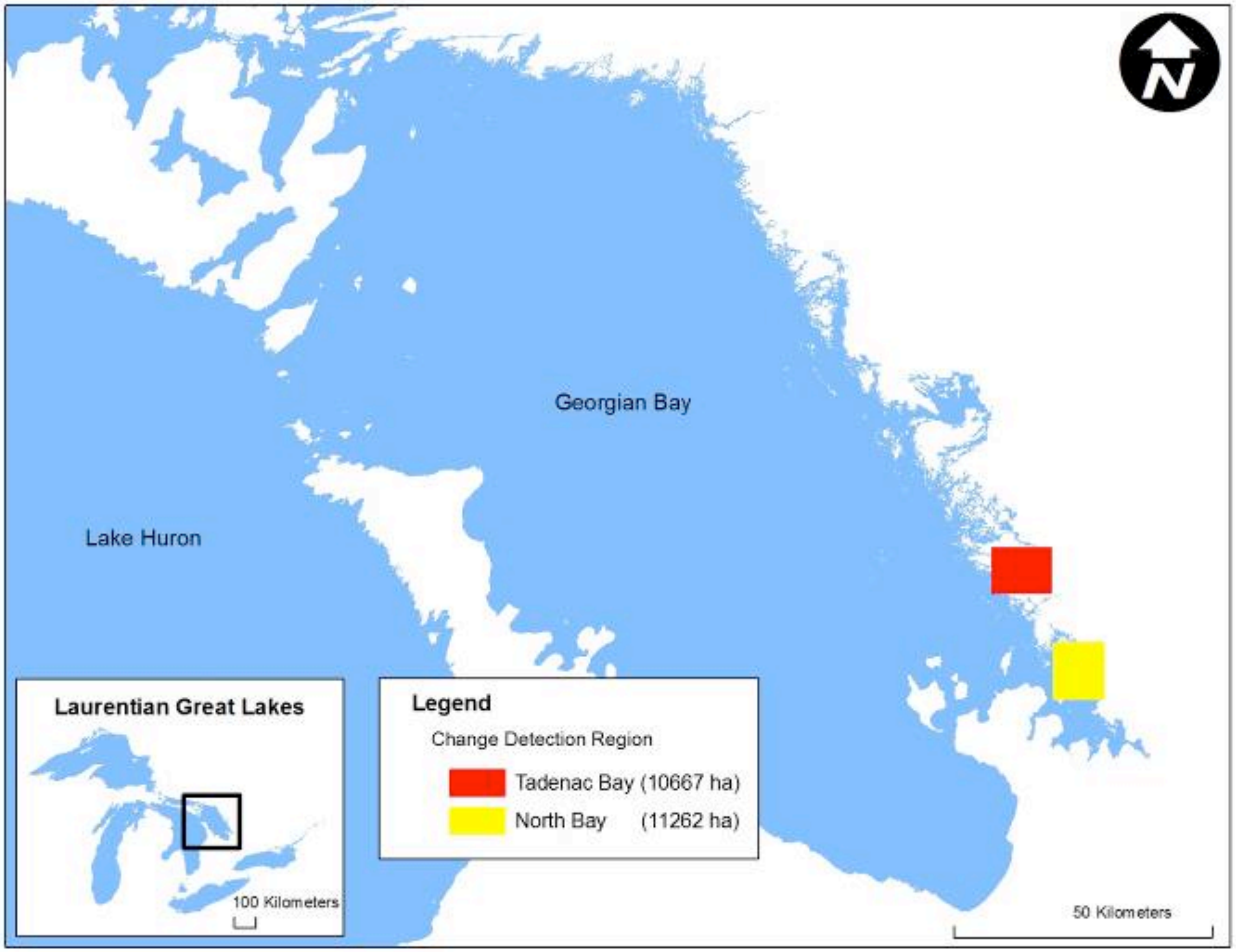


Figure 3: Locations of the 2 study regions (Tadenac Bay and North Bay) used in the vegetation change study.

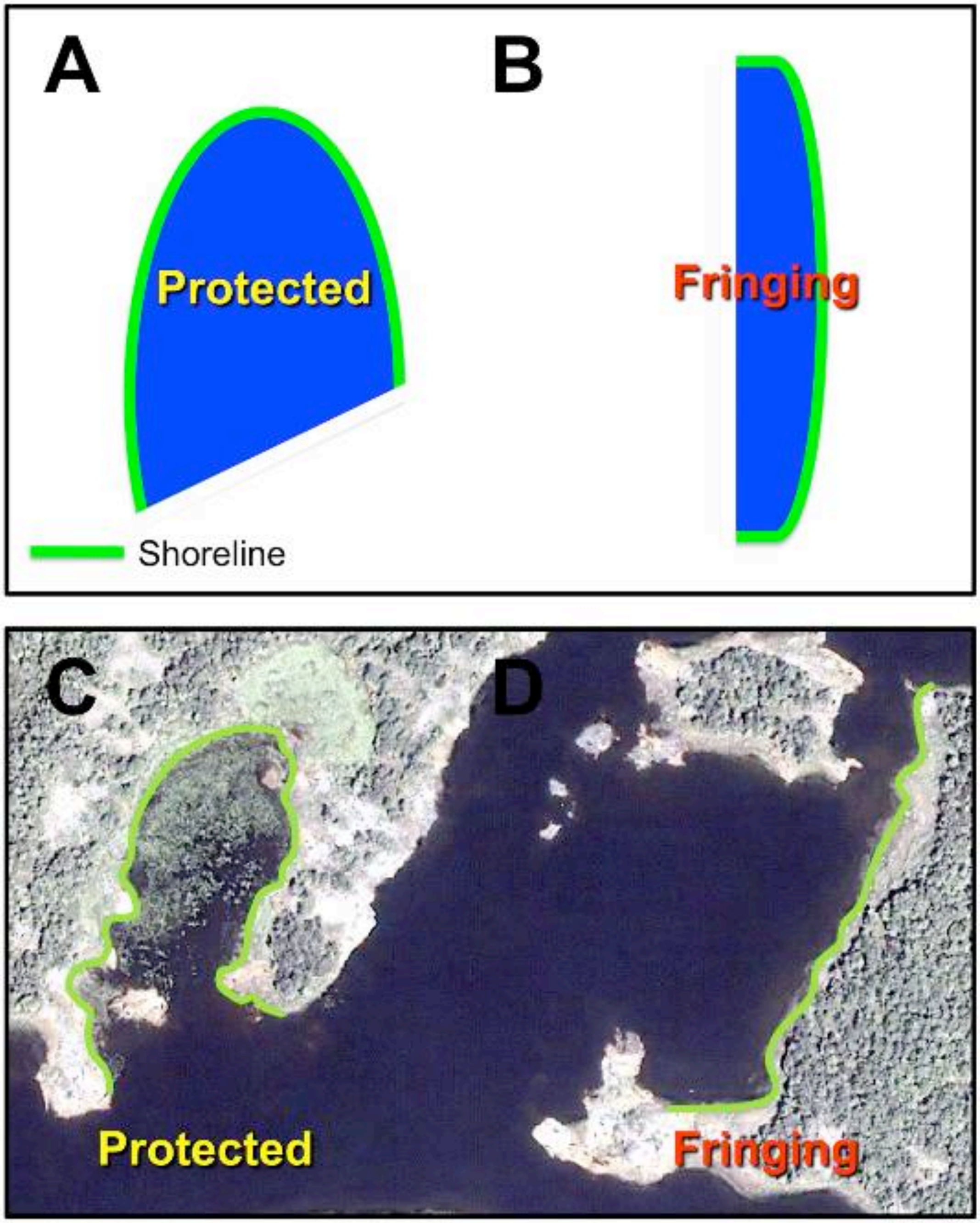


Figure 4: Examples of Protected (A and C) and Fringing (B and D) wetlands classified in the vegetation change study.

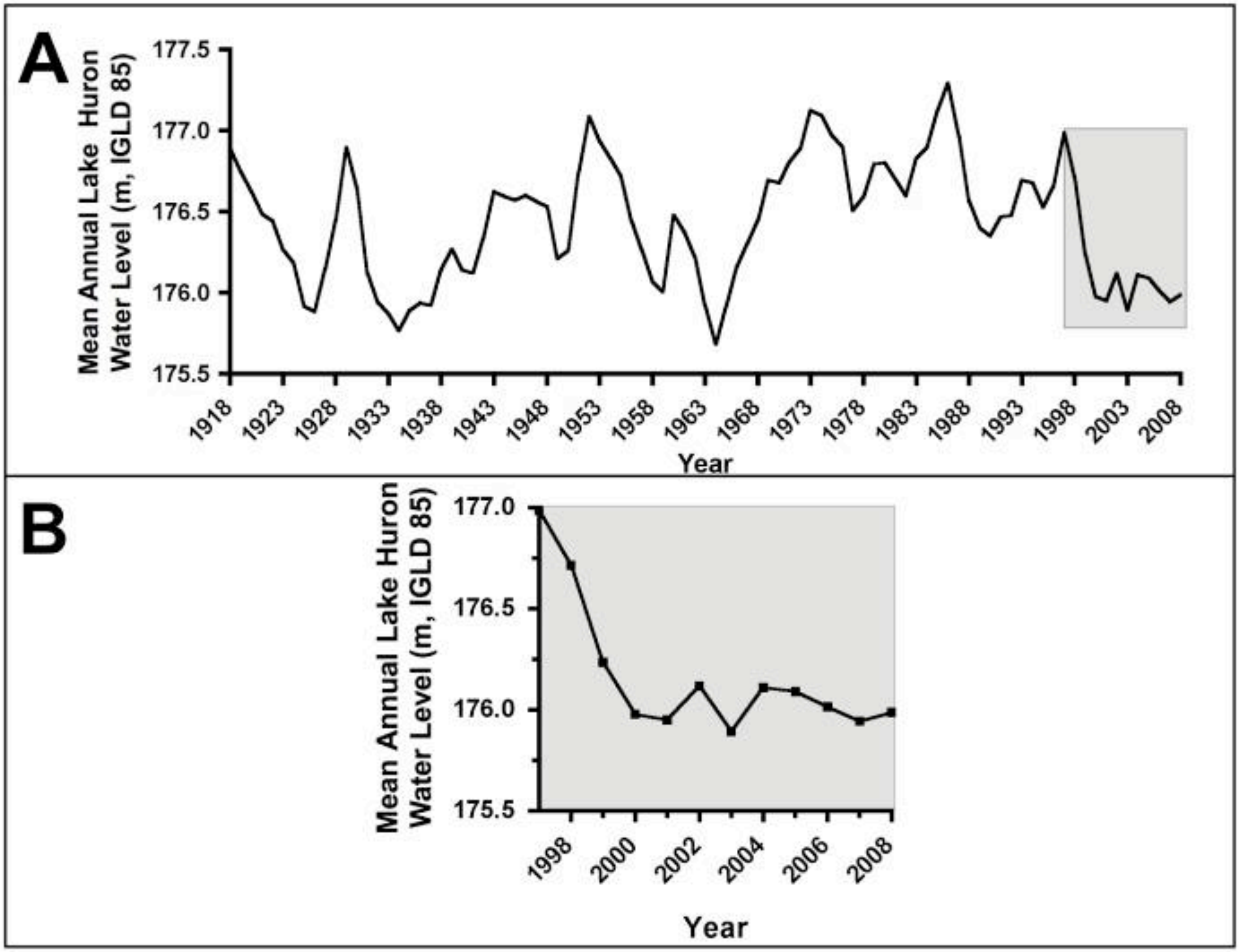


Figure 5: Mean annual Lake Huron water levels. In A we present historic data from 1918 and in B for the time period influencing 2002 and 2008. Data provided by U.S. Army Corps of Engineers (USACE) and Canadian Hydrographic Services (CHS).

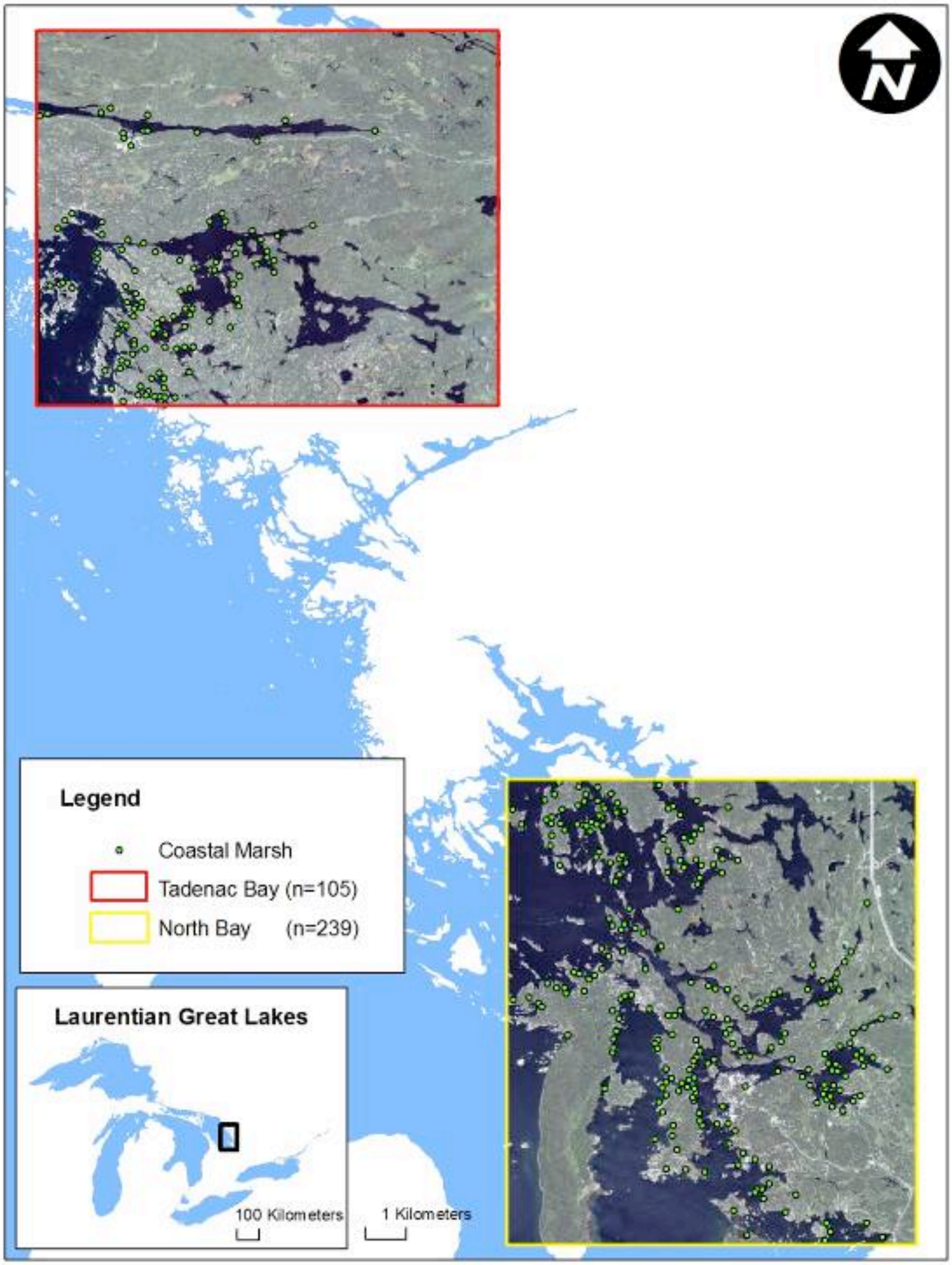


Figure 6: Coastal marshes manually delineated in the vegetation change study. 344 total coastal marshes were identified within the 2 images.

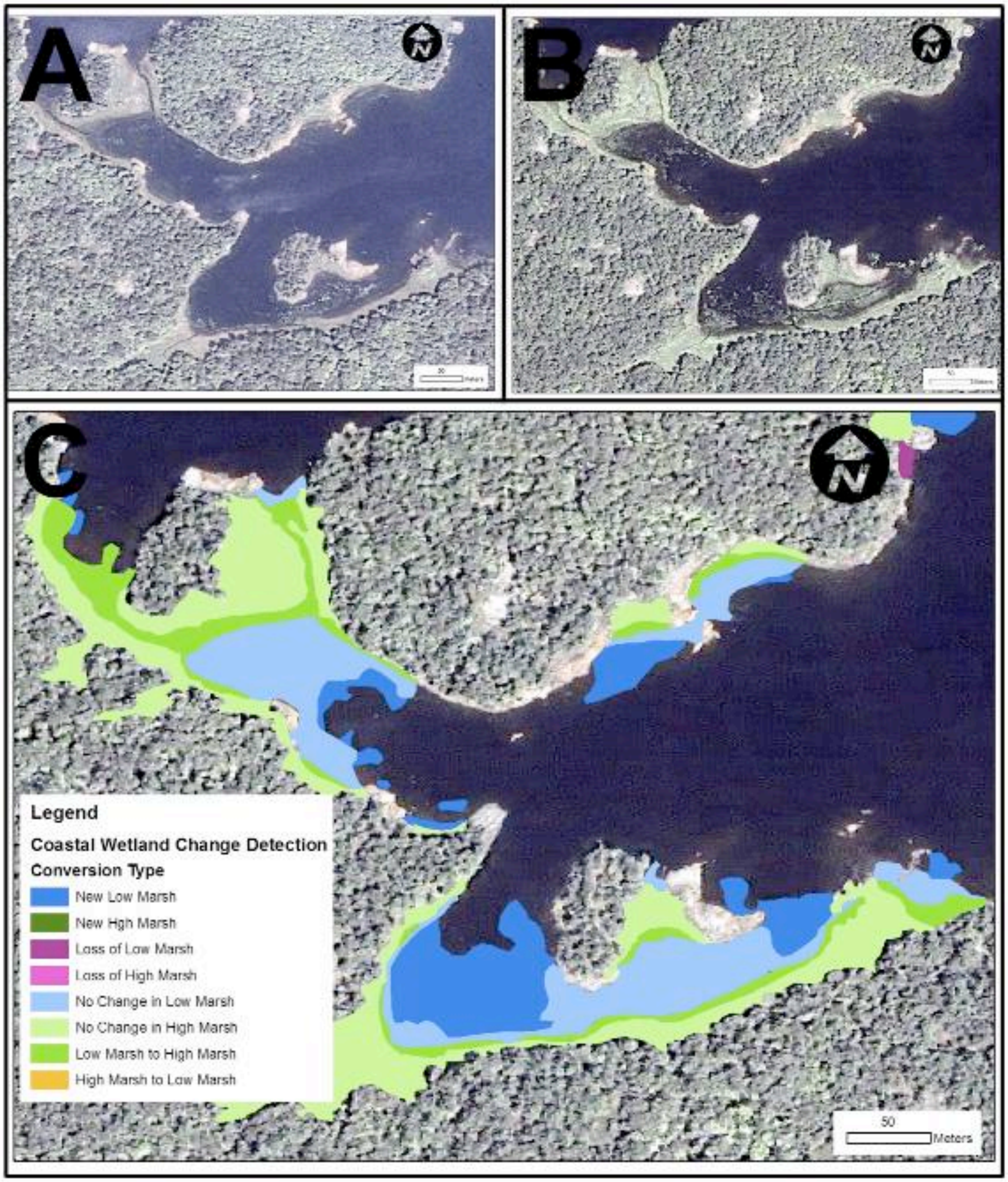


Figure 7: Changes in marsh habitats (low marsh and high marsh) between 2002 (A) and 2008 (B) for a protected eastern Georgian Bay coastal marsh. Habitat delineation and conversion types are presented in C. Panels display 1m resolution IKONOS satellite imagery.

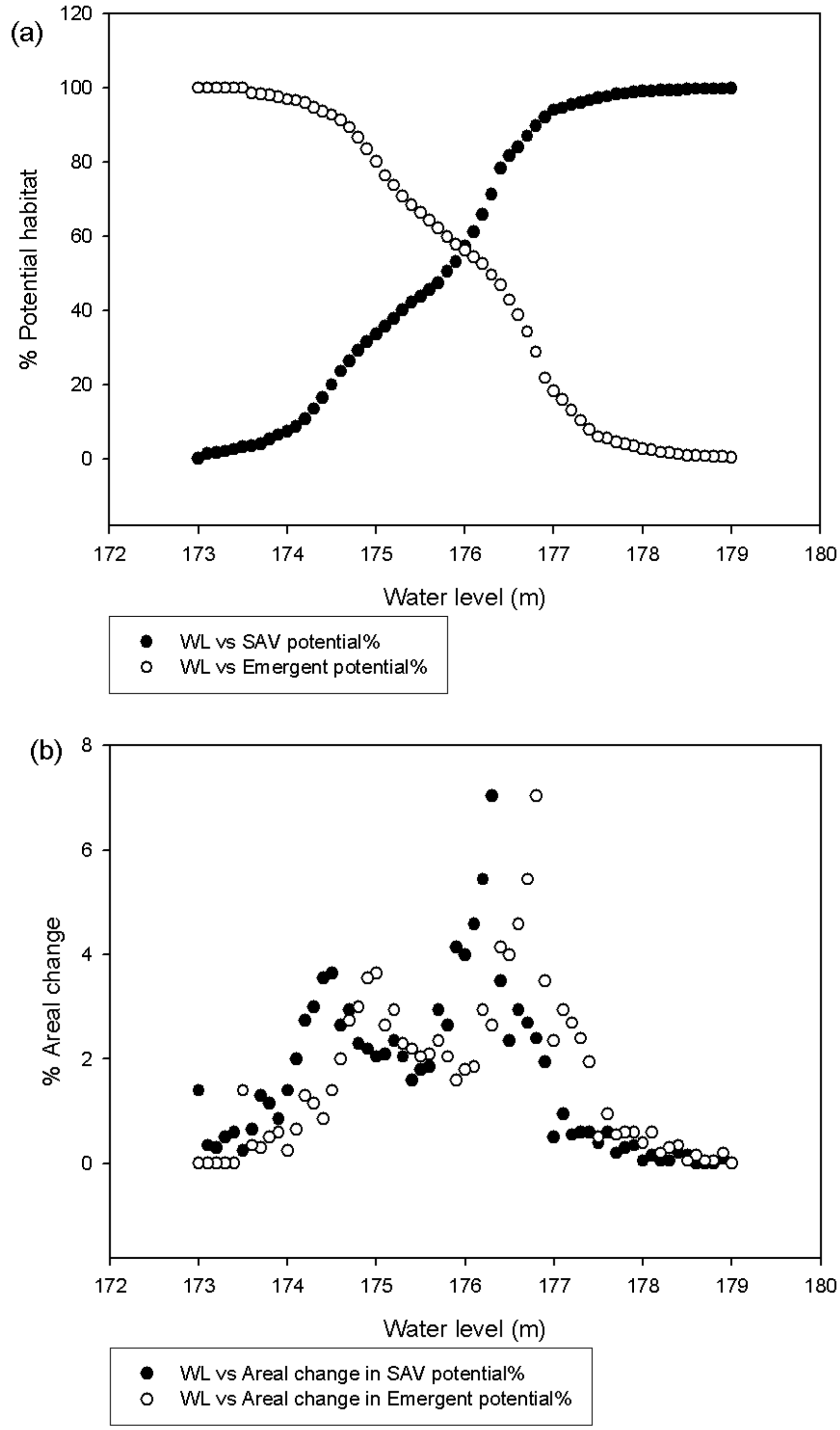
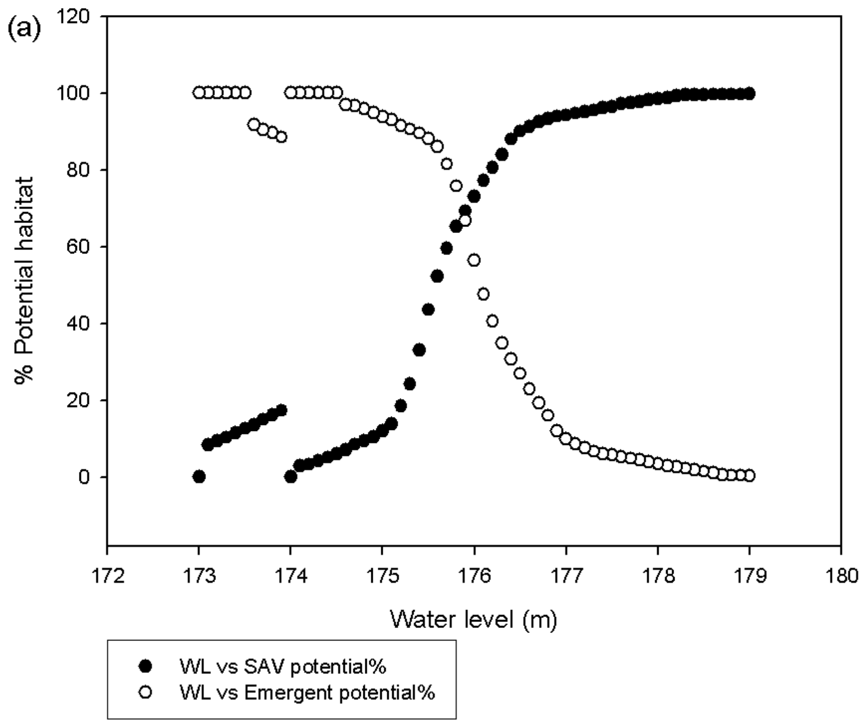


Figure 8 Alexander Bay (a) response curves (b) % areal change between two intervals of water level



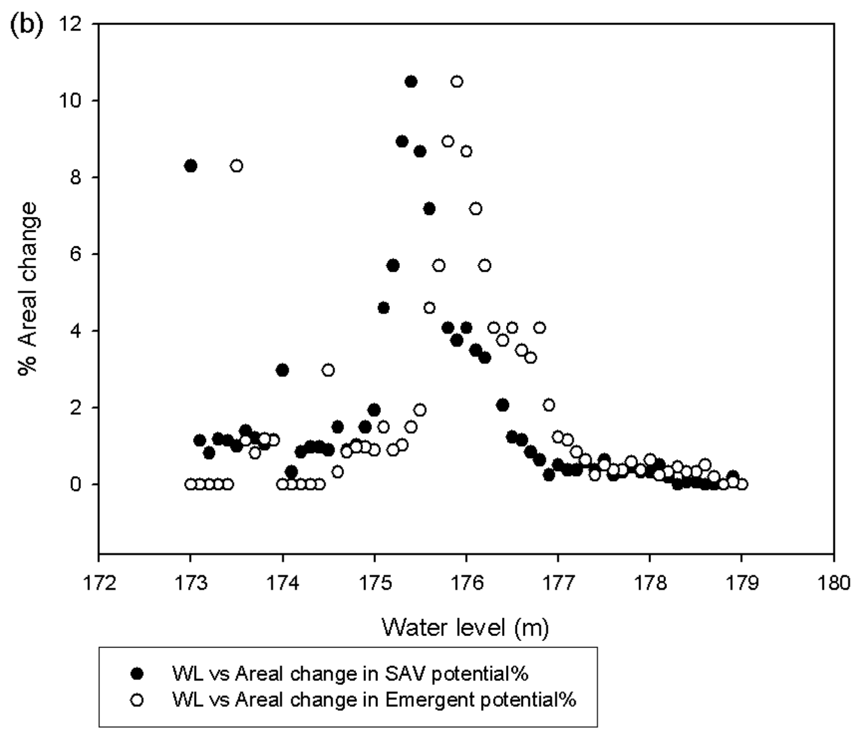


Figure 9 Coffin Rock (a) response curves (b) % areal change between two intervals of water level

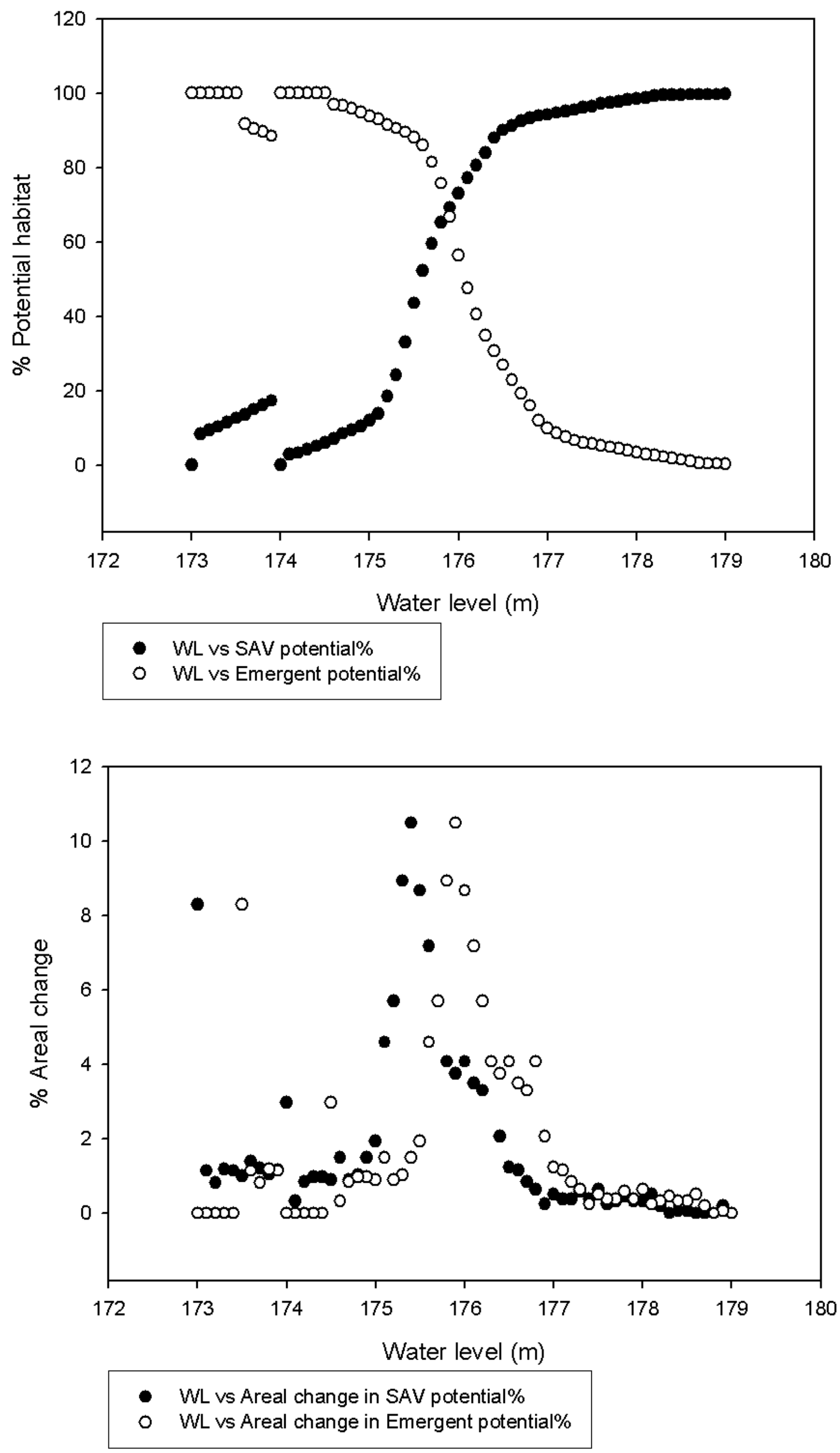


Figure 10 Miner's Creek (a) response curves (b) % areal change between two intervals of water level

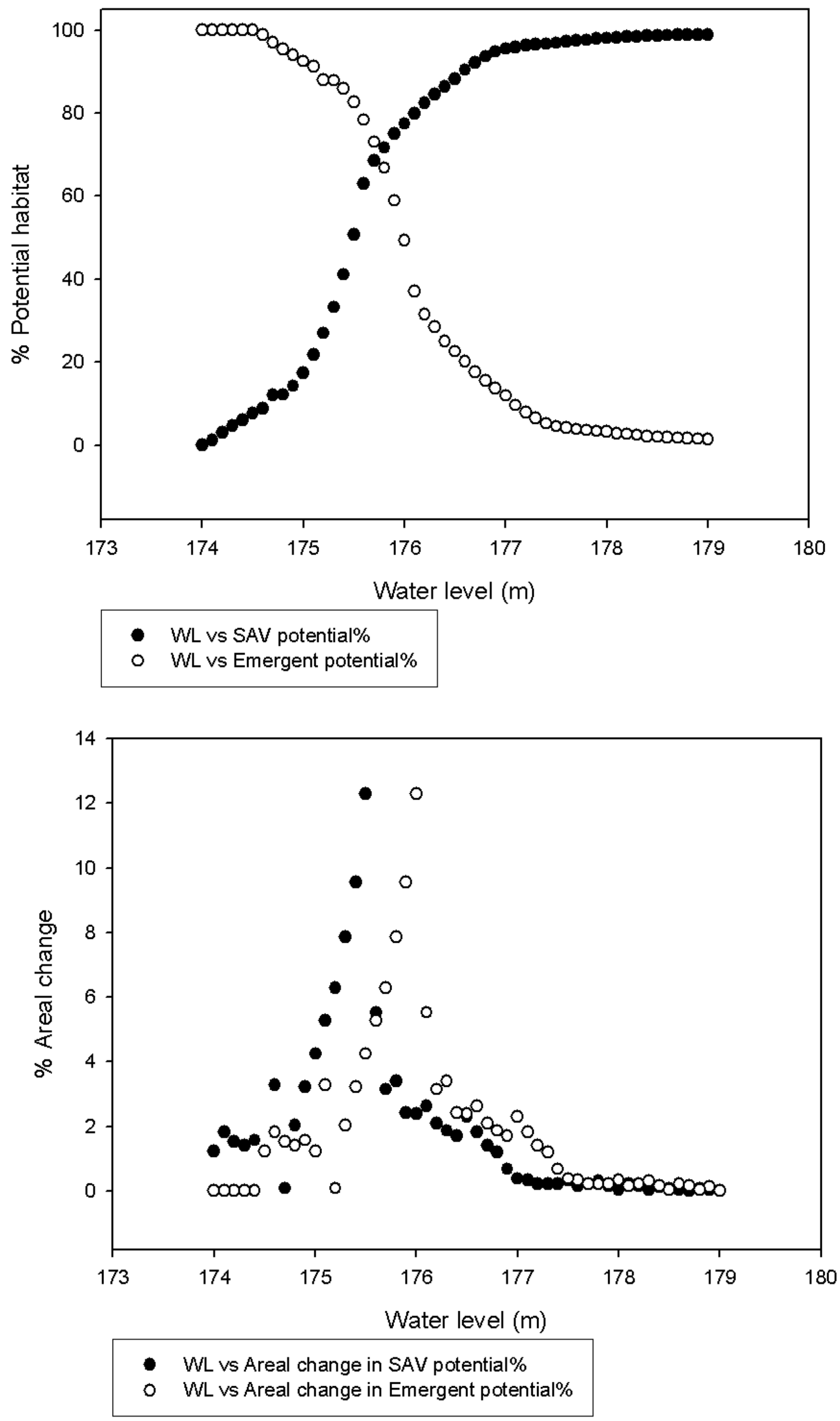


Figure 11 North Bay 1(a) response curves (b) % areal change between two intervals of water level

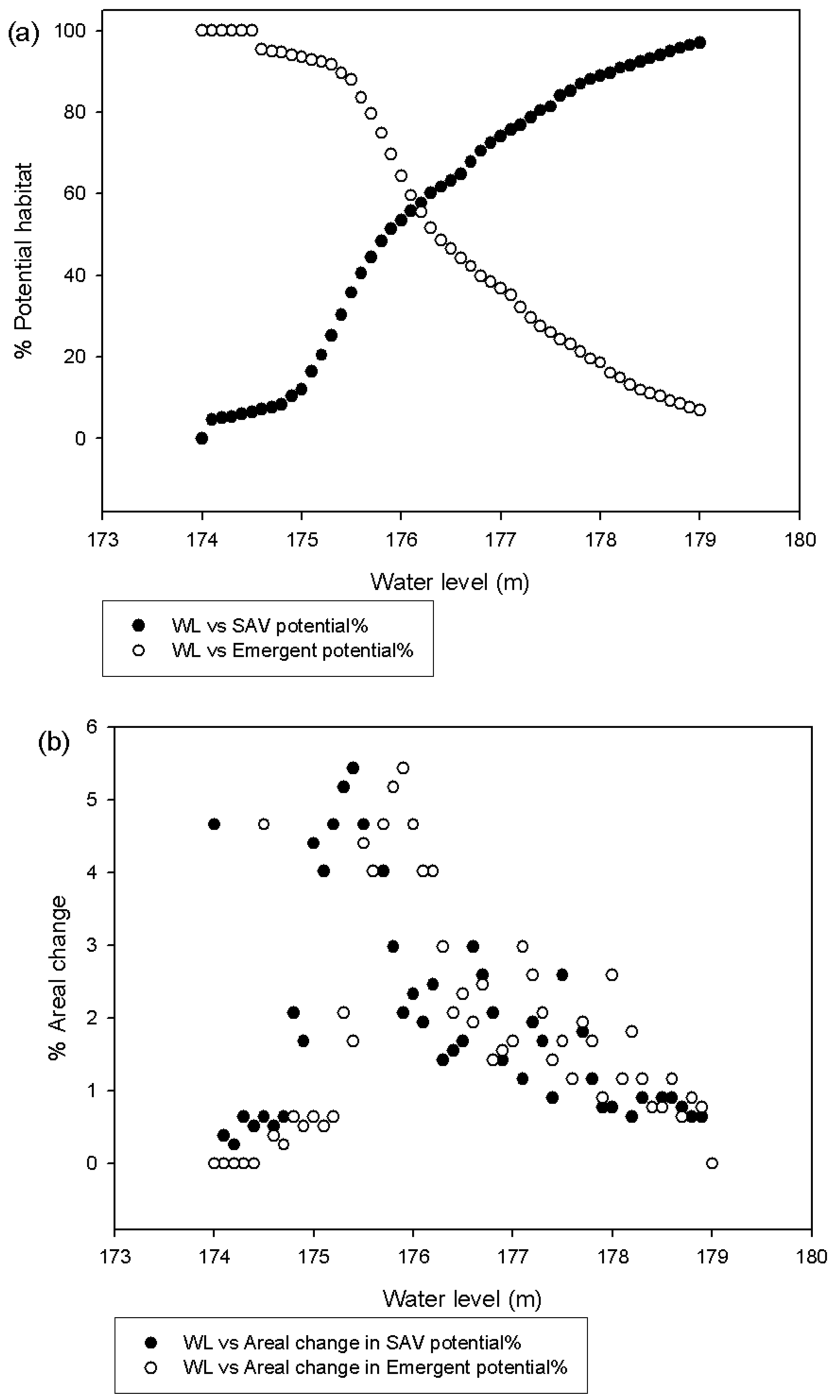


Figure 12 North Bay 5 (a) response curves (b) % areal change between two intervals of water level

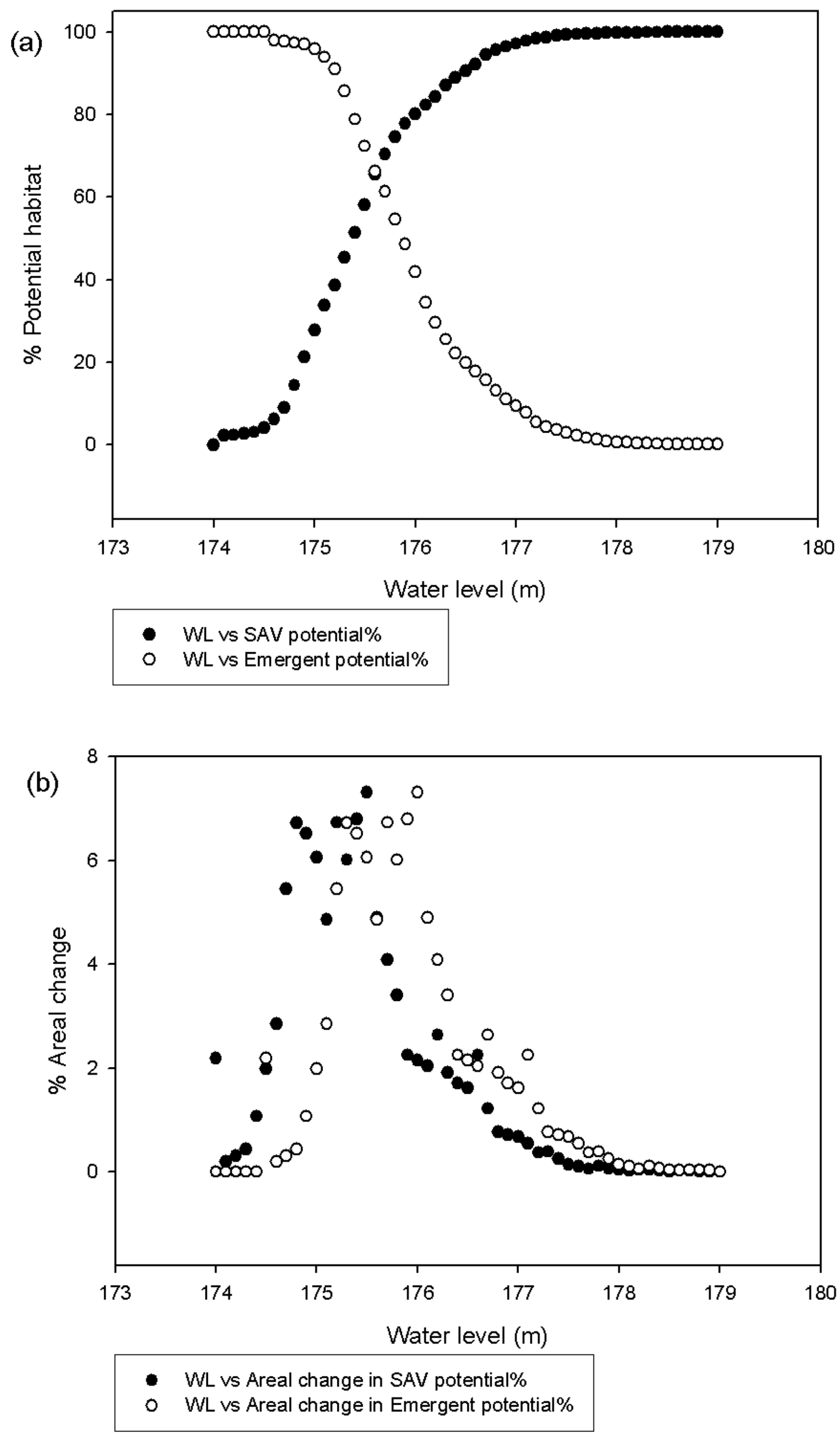
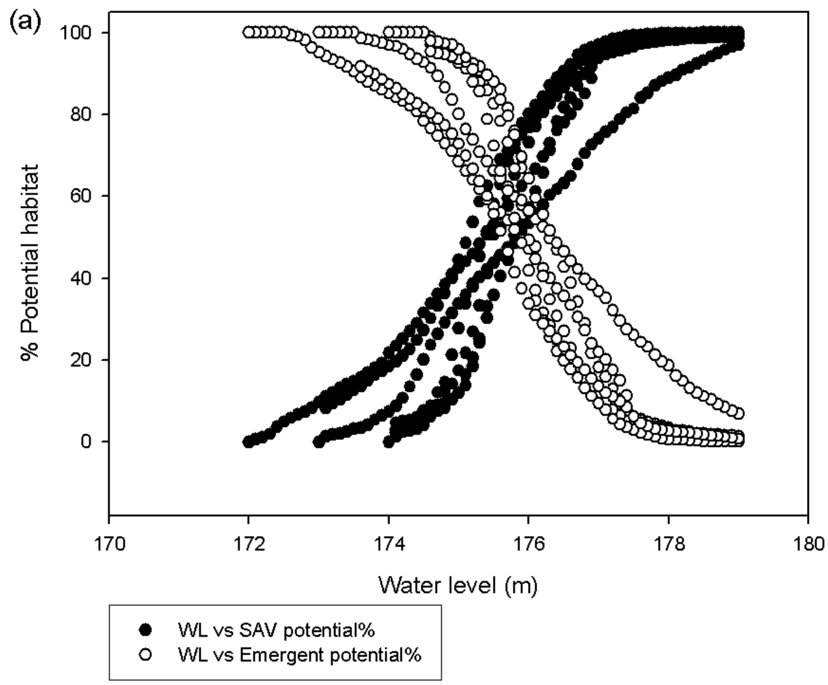


Figure 13 Oak Bay (a) response curves (b) % areal change between two intervals of water level



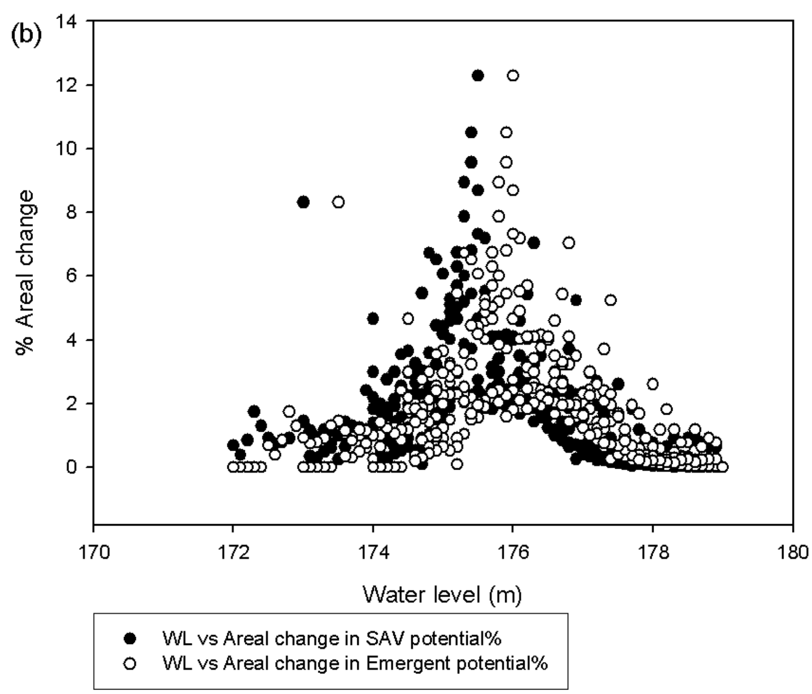


Figure 14 Treasure Bay (a) response curves (b) % areal change between two intervals of water level

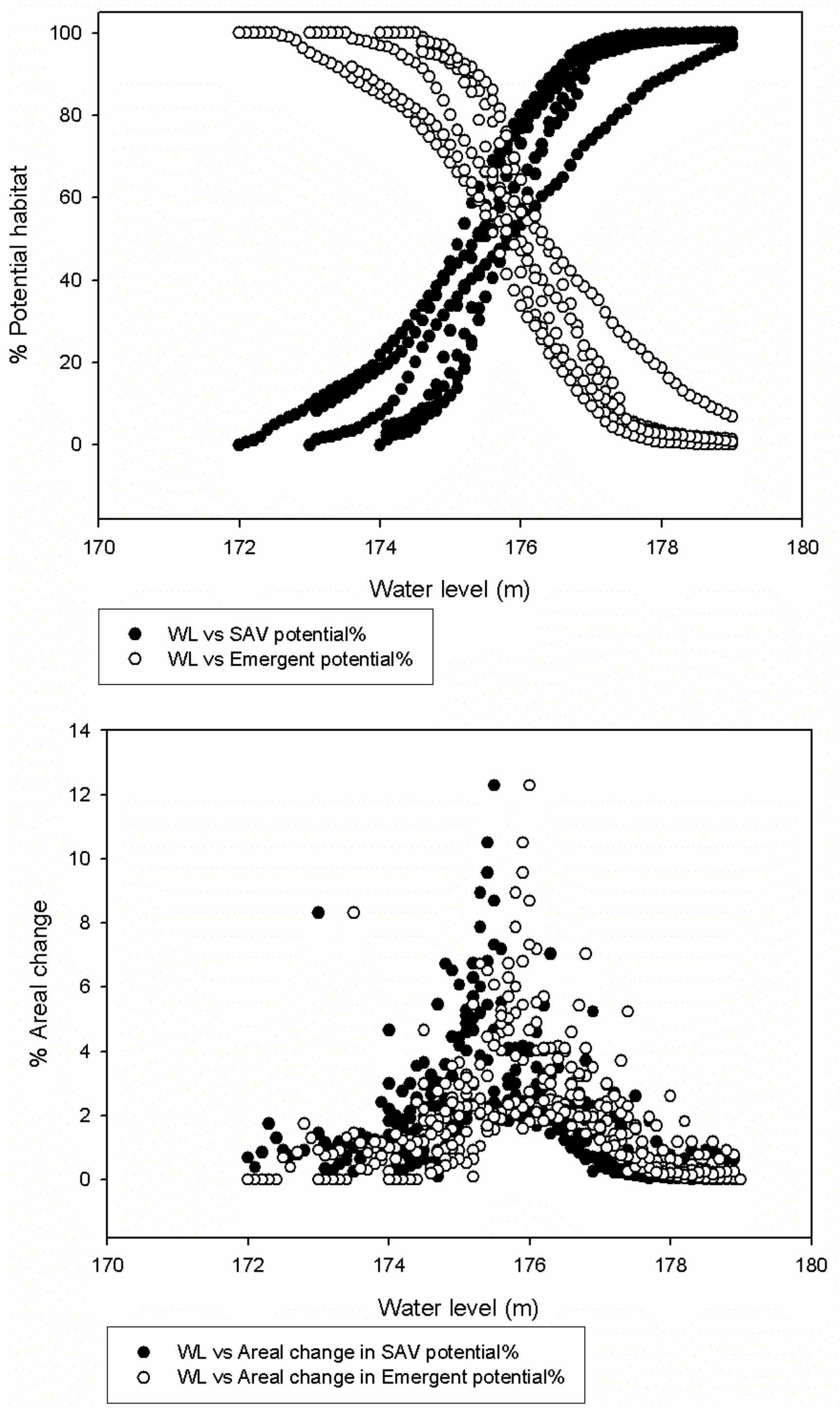


Figure 15 All sites (a) response curves (b) % areal change between two intervals of water level

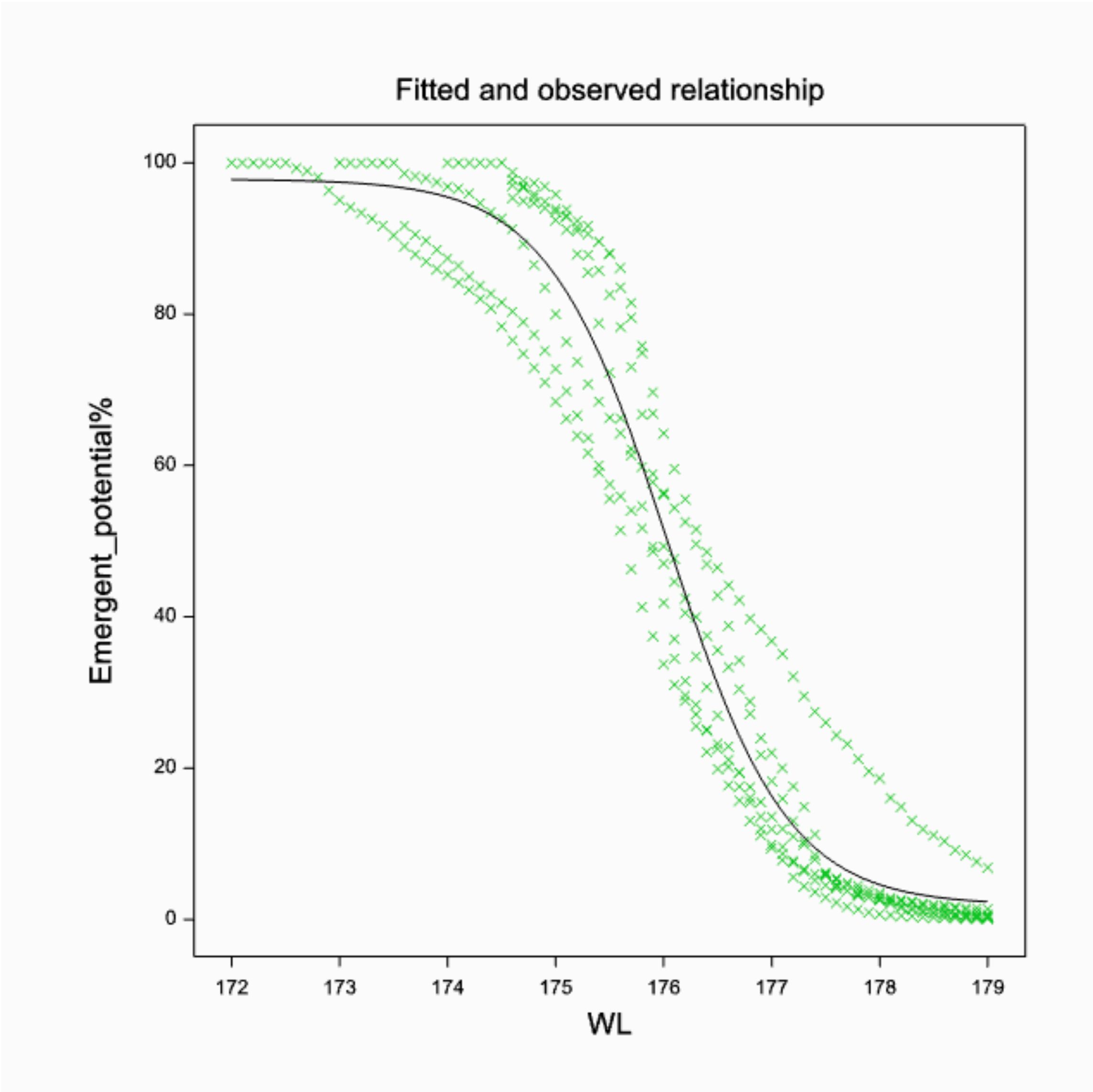


Figure 16 Fitted emergent response curve to changes in water level

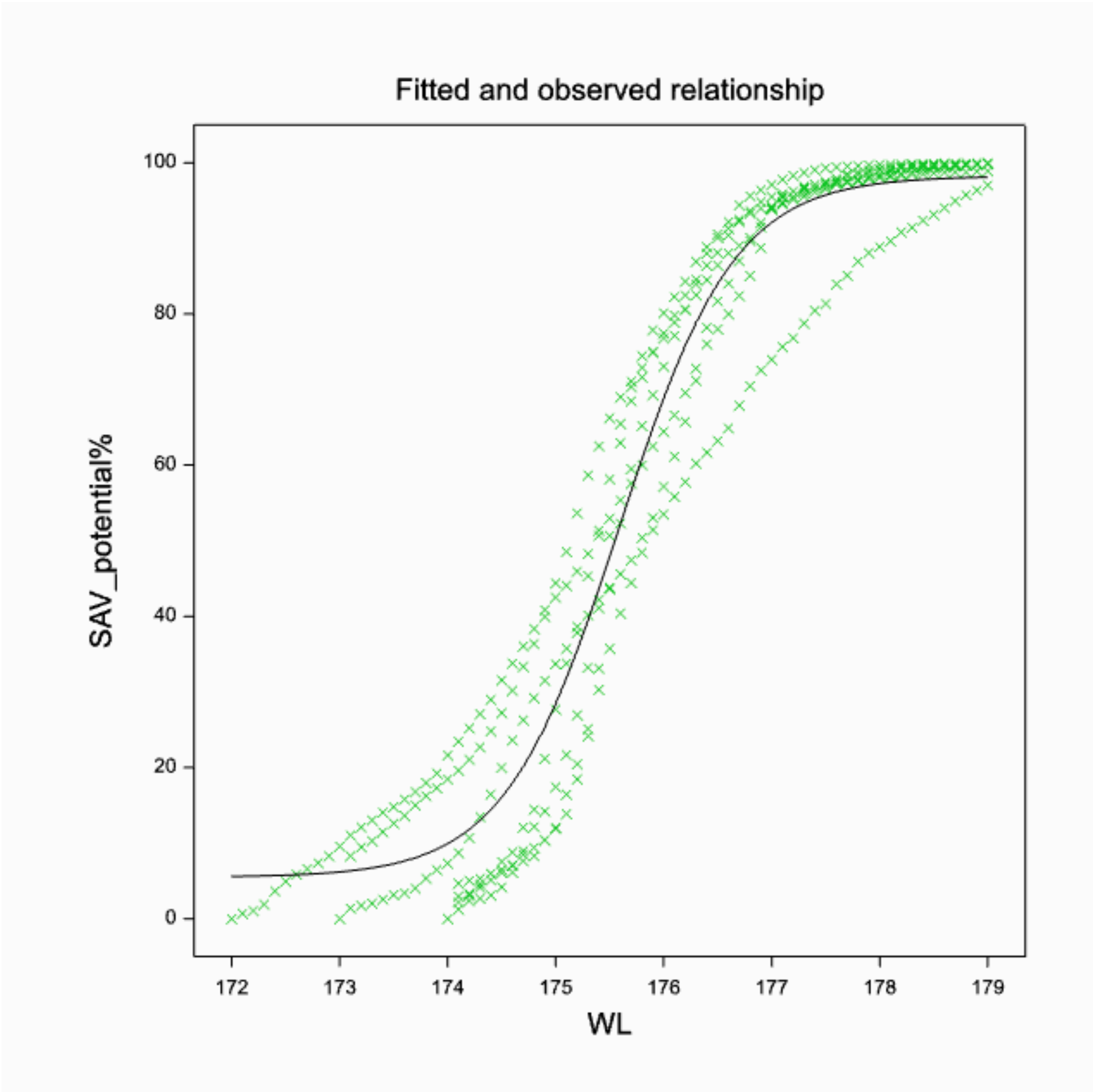


Figure 17 Fitted submergent response curve to changes in water level

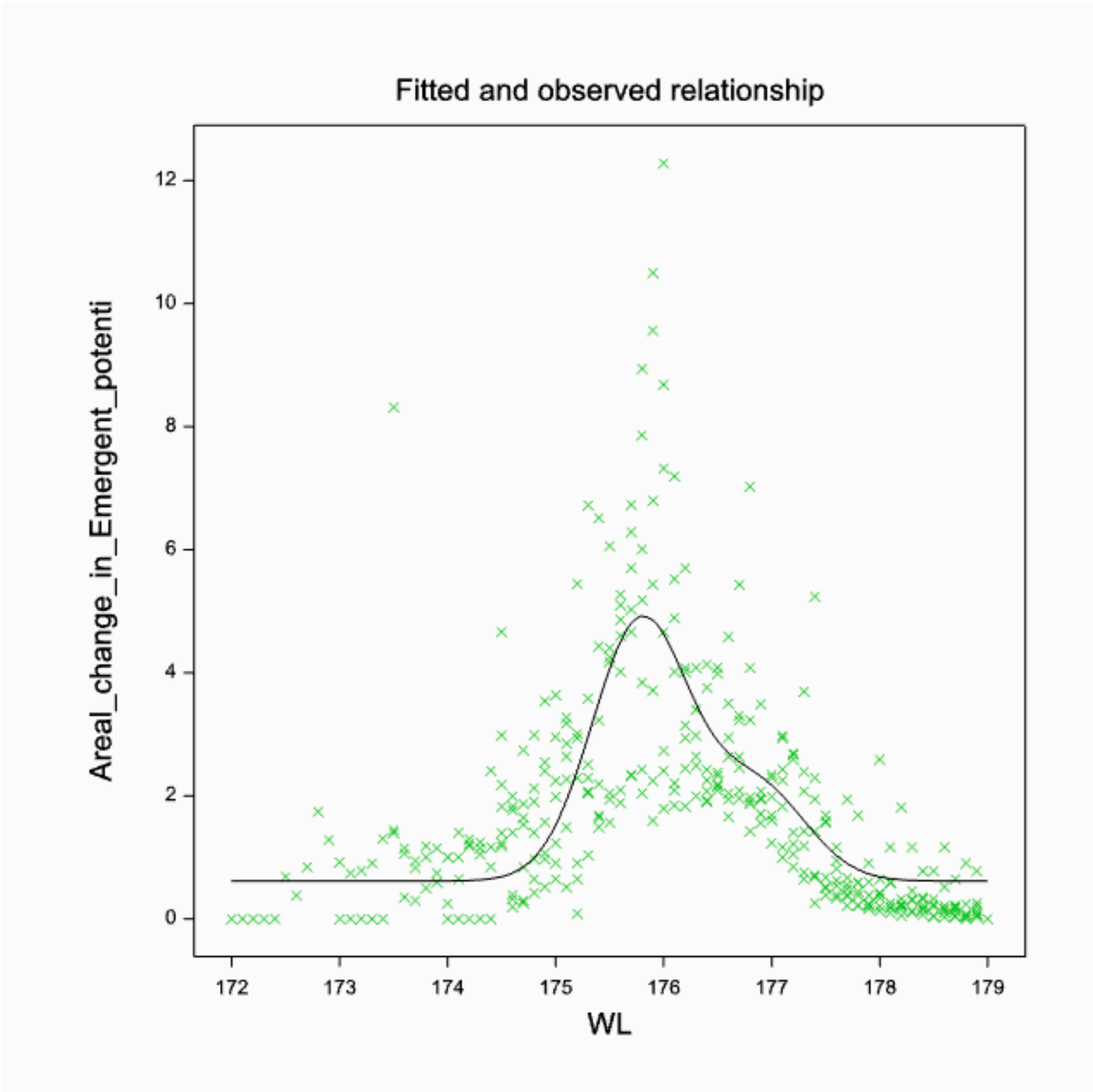


Figure 18 Fitted curve of the percent areal change in emergent and water level interval

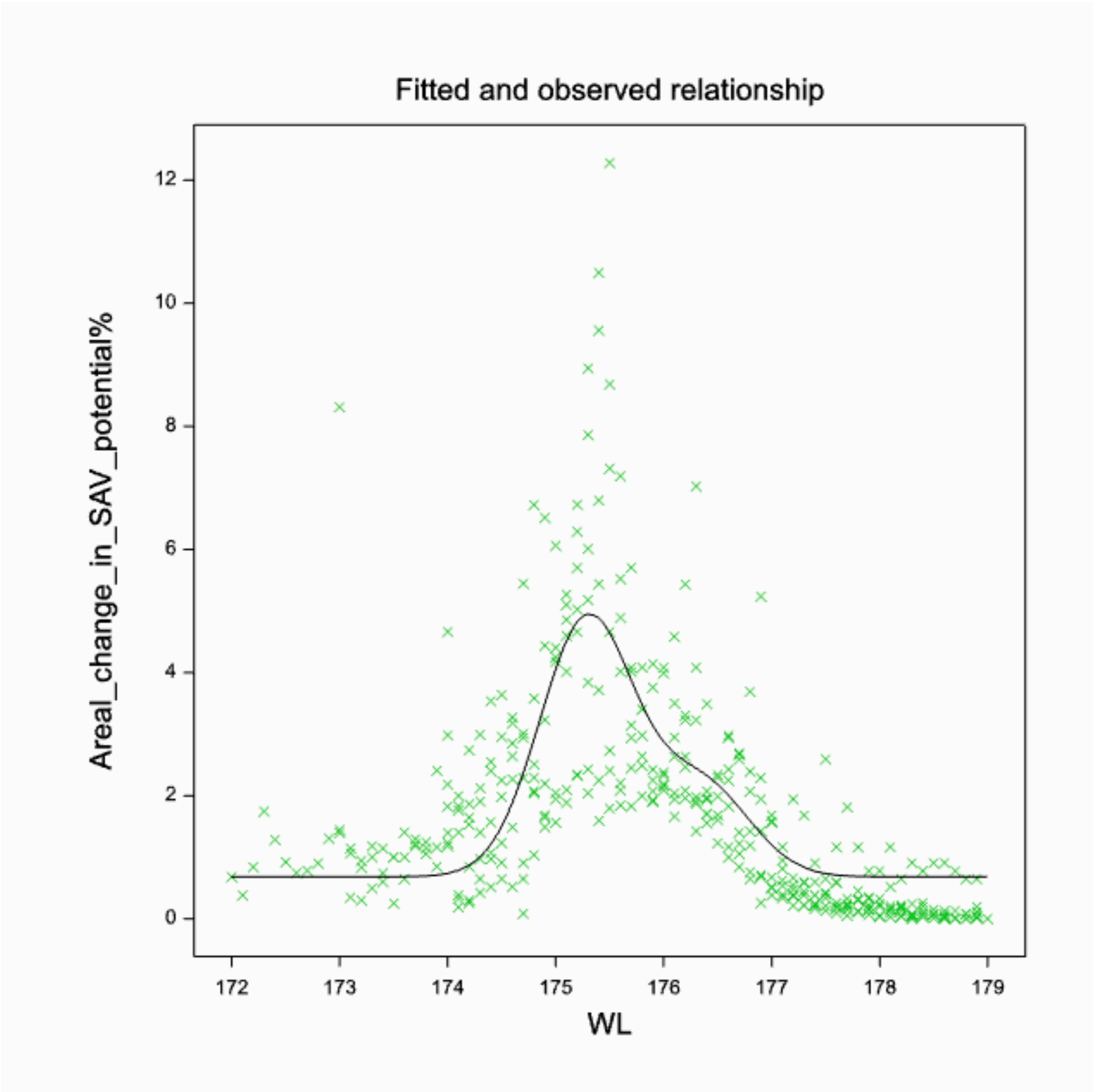


Figure 19 Fitted curve of the percent areal change in submergent and water level interval

Appendix A

Eastern Georgian Bay coastal wetland Digital Elevation Model examples

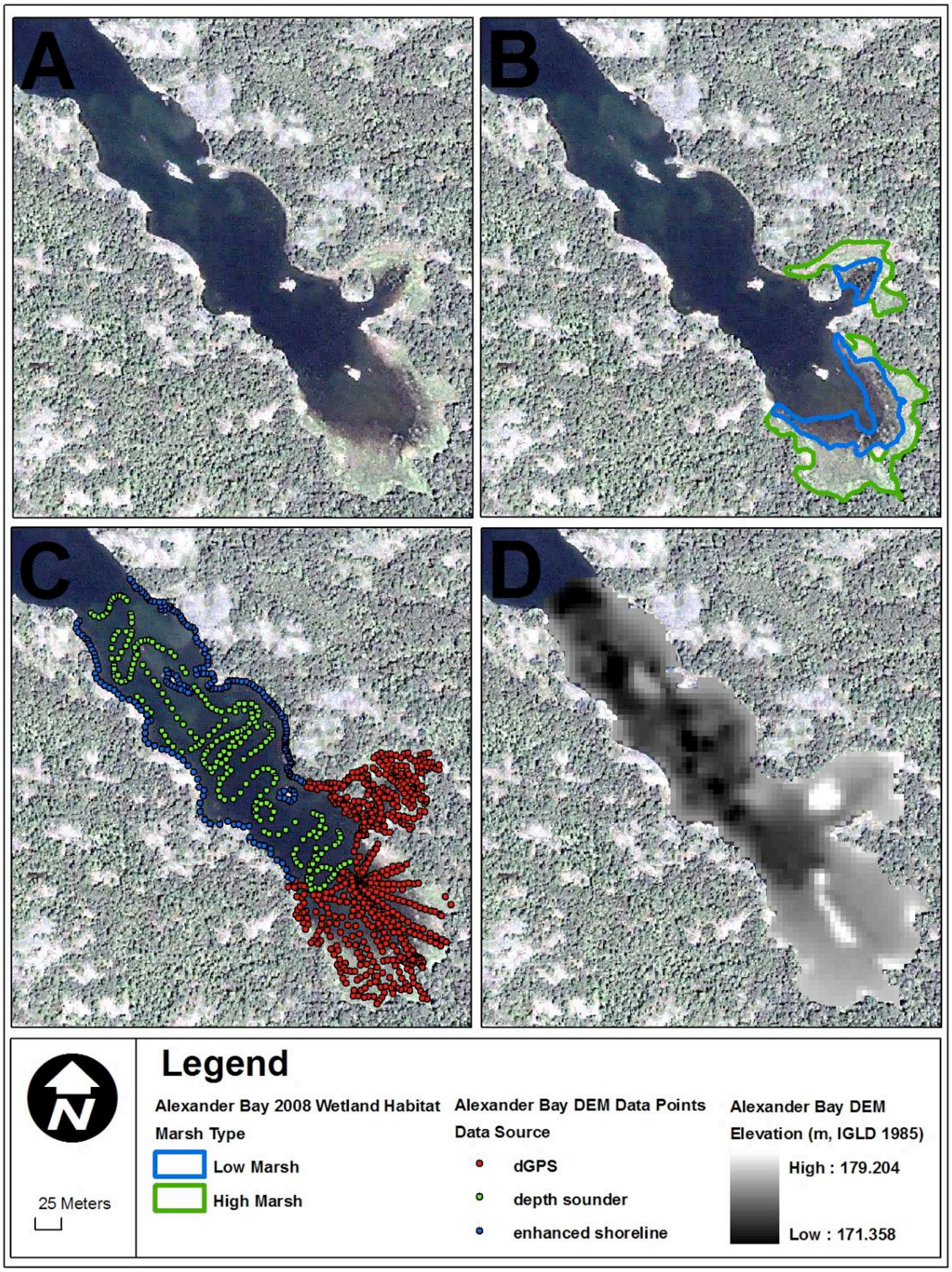


Figure A1: A) 2008 IKONOS image of Alexander Bay, B) 2008 marsh habitat delineation, C) DEM data points by type, D) Final Digital Elevation Model

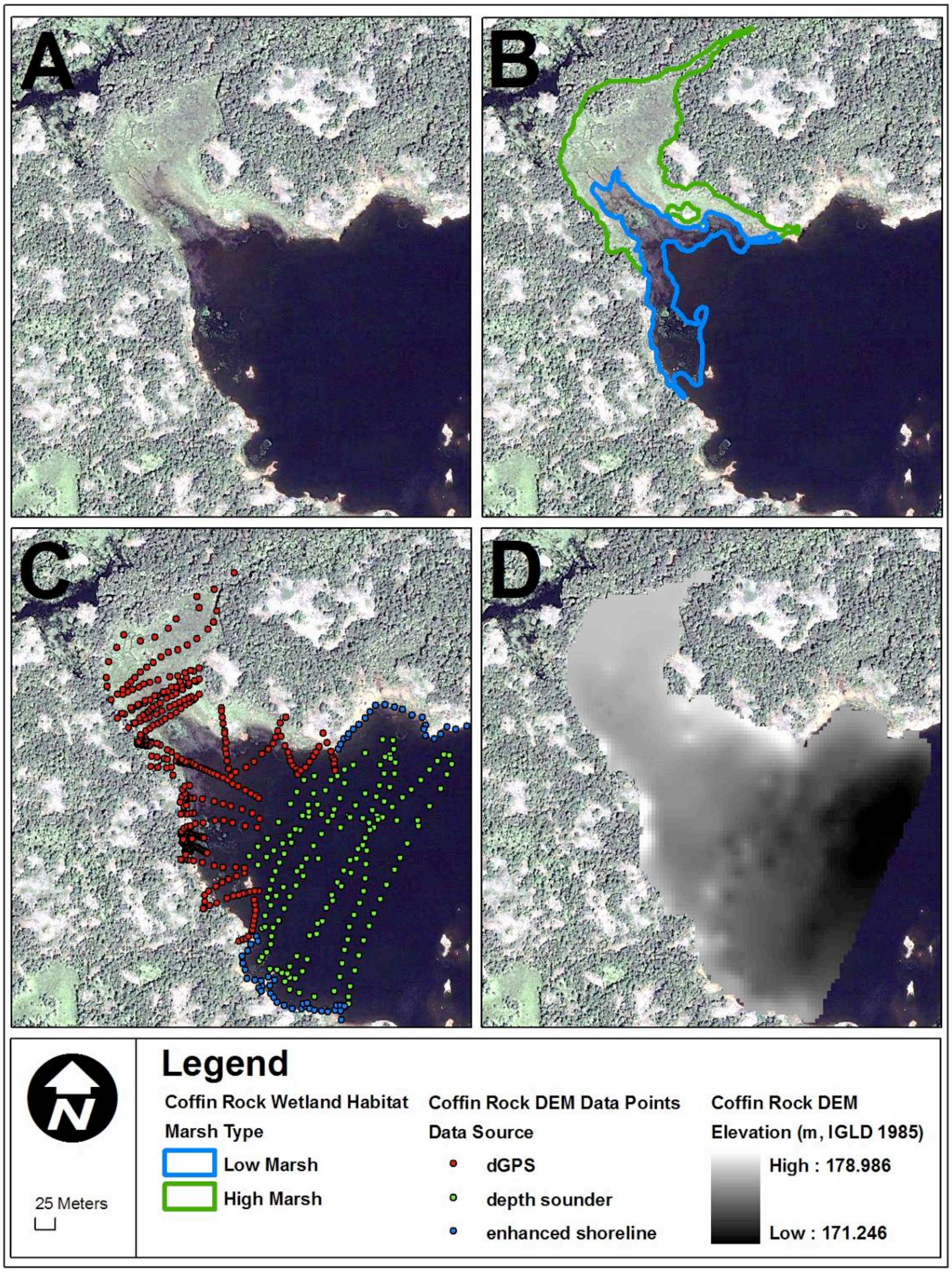


Figure A2: A) 2008 IKONOS image of Coffin Rock, B) 2008 marsh habitat delineation, C) DEM data points by type, D) Final Digital Elevation Model

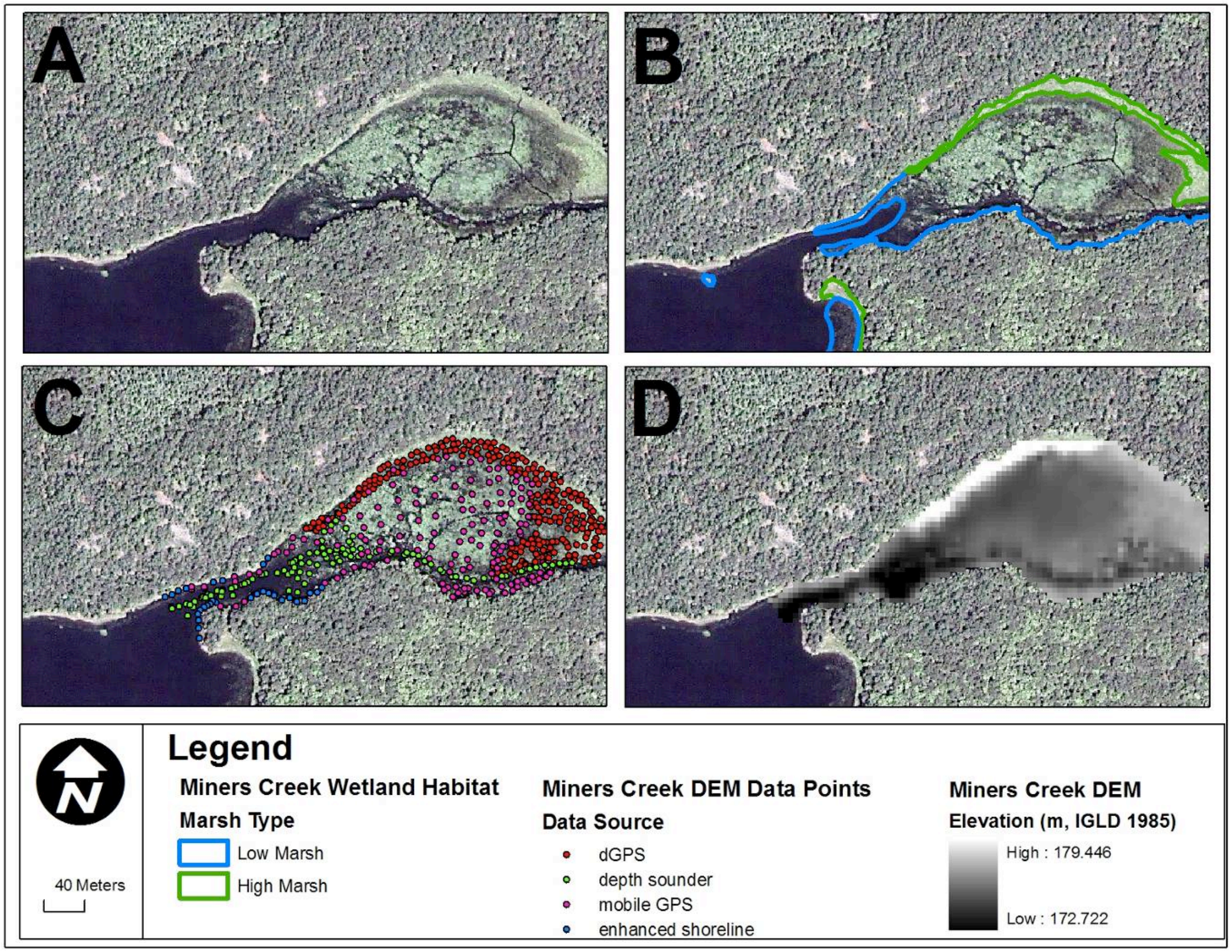


Figure A3: A) 2008 IKONOS image of Miner's Creek, B) 2008 marsh habitat delineation, C) DEM data points by type, D) Final Digital Elevation Model

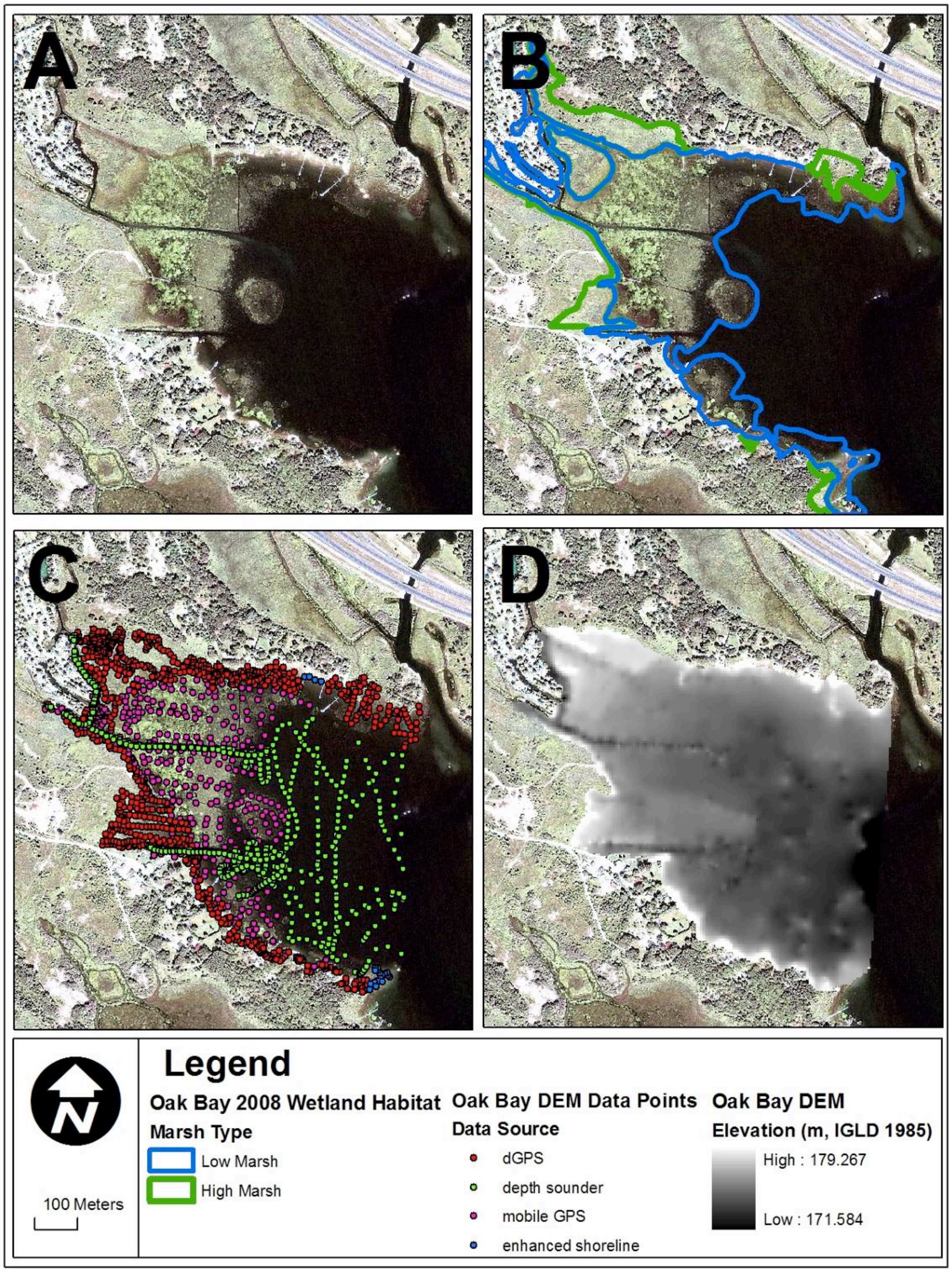


Figure A4: A) 2008 IKONOS image of Oak Bay, B) 2008 marsh habitat delineation, C) DEM data points by type, D) Final Digital Elevation Model

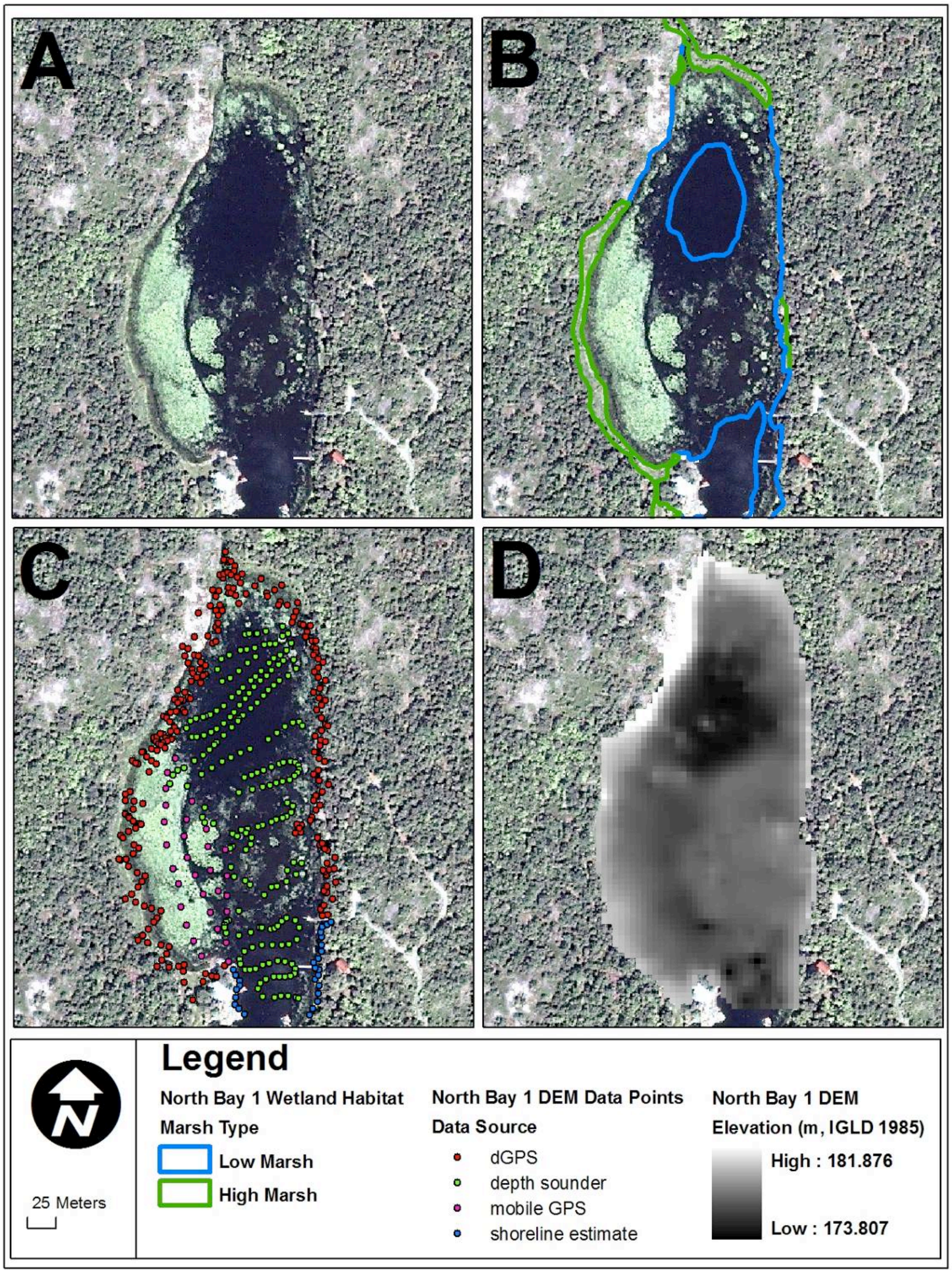


Figure A5: A) 2008 IKONOS image of North Bay 1, B) 2008 marsh habitat delineation, C) DEM data points by type, D) Final Digital Elevation Model

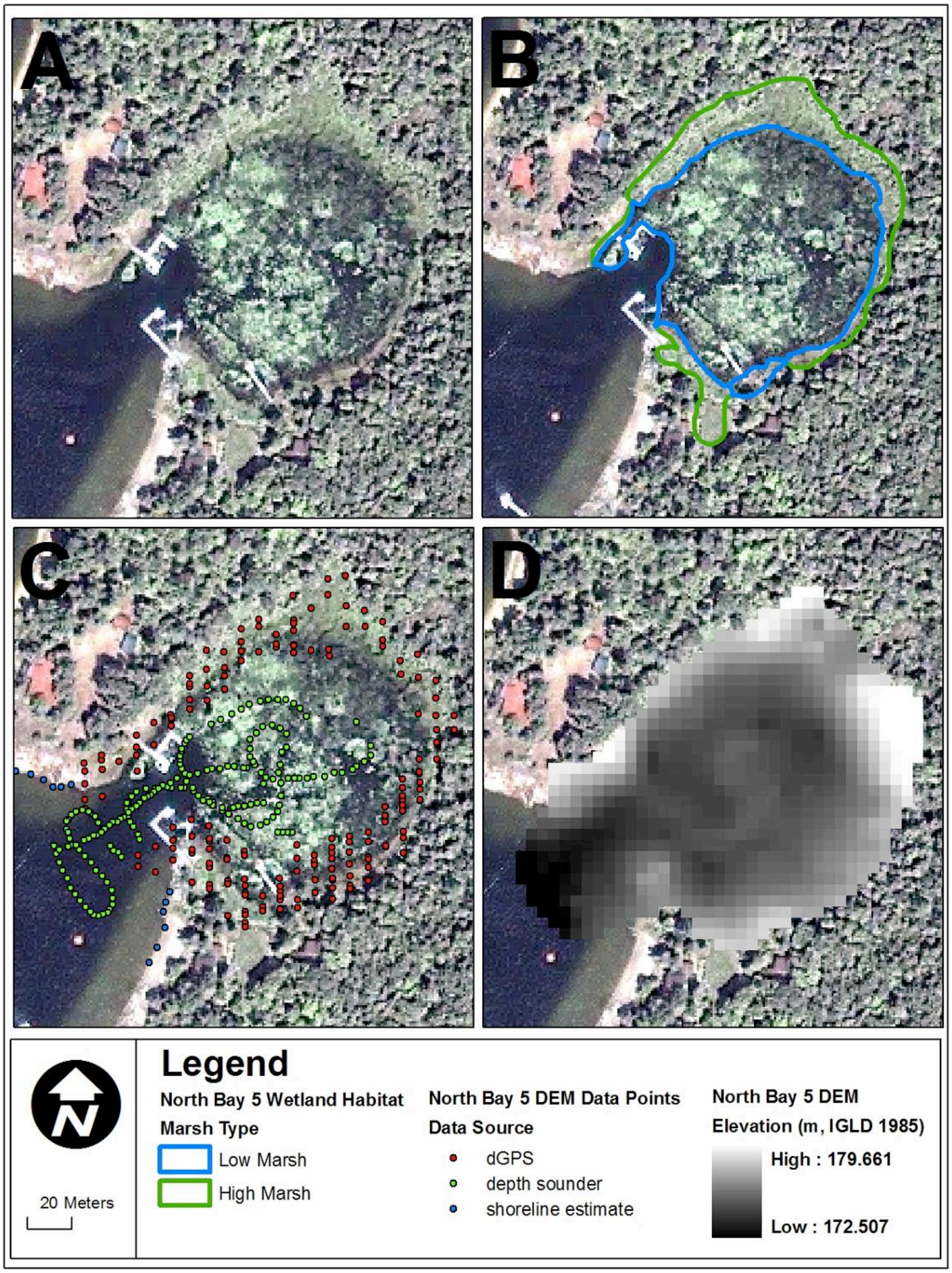


Figure A6: A) 2008 IKONOS image of North Bay 5, B) 2008 marsh habitat delineation, C) DEM data points by type, D) Final Digital Elevation Model

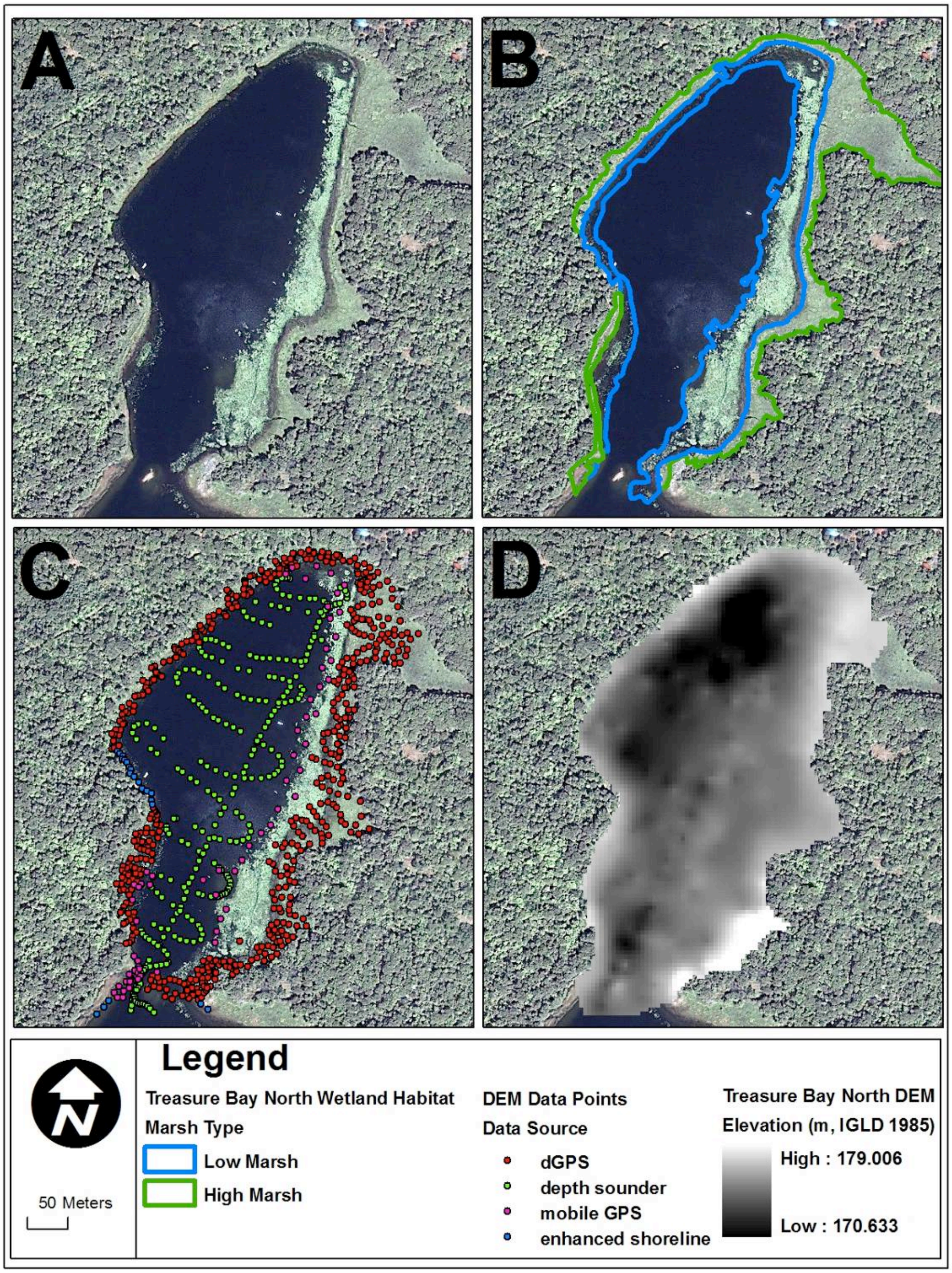


Figure A7: A) 2008 IKONOS image of Treasure Bay, B) 2008 marsh habitat delineation, C) DEM data points by type, D) Final Digital Elevation Model