# Severn Sound

*Environmental Association*

## Mapping, Evaluating and Predicting Changes in Coastal Margin Aquatic Habitat in Severn Sound and Southeastern Georgian Bay: Synthesis report

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**Mapping, Evaluating and Predicting Changes in Coastal Margin Aquatic Habitat in Severn Sound and Southeastern Georgian Bay: Synthesis report**

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## Table of Contents

## List of Tables and Figures

## Abstract

The mapping of nearshore habitat in the coastal margins of the Severn Sound area is a collaborative project involving SSEA, the University of Windsor, Environment Canada and Climate Change, Fisheries and Oceans Canada, the Ministry of Natural Resources and Forestry, with assistance from Parks Canada, NR Canada, Huronia Community Foundation and RBC Securities Foundation. The project used sophisticated sonar equipment and recent underwater and aerial images to map the coastal areas of Severn Sound and determine the habitat suitability for the fish community of the area.

The project used a combination of University of Windsor's Remotely Operated Vehicle for Scientific Research (ROVER) sonar, Habitat Solutions North America's tow fish sonar and SSEA's boat-mounted sonar to assess the lake bottom habitat. The analysis covered from the shoreline to a distance of up to 100 metres from shore along selected sections of coastline in Severn Sound.

We mapped bathymetry, substrate texture, and aquatic plant distribution. Water levels were incorporated into a digital elevation model converting all relative depths to meters above sea level elevations using the Midland water level gauge (operated by CHS).

In selected areas, Submerged Aquatic Vegetation (SAV) coverage and other metrics, were estimated using the downscan profile information from ROVER and SSEA sonar. The sonar downscan data was augmented by interpretation of the Habitat Solutions NA data, 2013 ortho images, SSEA underwater images and interpretation of other air photo and site observations. Using the same information, enhanced with surficial sediment sampling, substrate was interpreted. Selected sonar and underwater imaging transects out from shore to approximately 10 m depth were completed to determine the approximate depth limit of SAV.

In selected areas, a 10 m resolution bathymetric model was derived from several data sources of depth and elevation including: the South Central Ontario Ortho-photo Project 2013 point cloud elevations, U. of Windsor ROVER soundings, DFO bio-acoustic soundings, CHS Navigation Chart Field Sheet points, County of Simcoe 2012 DEM (South Shore) and MNRF Provincial DEM (North shore). The integrated elevation model covers land and lake bottom portions of the area.

Downscan profile information was used to measure and output water depth, Submerged Aquatic Vegetation (SAV) depth and height, and substrate texture. Both U. of Windsor ROVER and SSEA's sonar equipment were used to collect this type of data in selected areas. Habitat Solutions NA's side scan sonar (Klein System) tow fish results in a mosaic image of the bottom data that covers a much larger area. All systems along with aerial, surface and underwater imagery were used to facilitate the interpretation of nearshore habitats in selected areas with special emphasis on Penetang Harbour.

A habitat suitability model was used to score fish habitat quality of the selected nearshore areas. Nearshore habitat mapping will provide planners and agency staff with a scientifically defensible tool to manage the nearshore habitat.

# 1. Introduction

## 1.1 Nearshore Habitat Modelling

The coastal margin is perhaps the most visible and ecologically significant zone of lake ecosystems. This is especially true of areas that have complex shorelines and high recreational and thus economic value. Human activities and development have major impacts on the margin, necessitating planning and protection. In addition, changes in shoreline condition and location as manifested by the effects of water level change, algal blooms, fish kills and other biological signals are highly visible and elicit strong responses from the public. Land use planning requires detailed knowledge of the structure and biological quality of the nearshore and coastal margins to understand how human activity will impact the biological components of these habitats. Coastal areas are also important habitats for a variety of aquatic organisms including fishes, and changes in shoreline and coastal areas can affect species composition, distribution, and abundance (Jude & Pappas 1992, Uzarski et al. 2005, Brazner & Beals 1997). Technology is well developed to assess and interpret both shoreline structures and the bathymetry and bottom characteristics of deeper waters, however, the area most subject to change – the zone extending from the land-water margin to depths of 1-2 m within 100 m of shore – are relatively inaccessible in undeveloped areas from both land and water and therefore are poorly known.

Severn Sound and southern Georgian Bay have among the most complex and biodiverse shoreline features in the Great Lakes. Despite the widely-recognized importance and value of the nearshore area, the bathymetry and bottom features of large stretches of the coastal margin are poorly known. Extensive efforts were made in the 1990s to manually map and georeference Severn Sound (Minns et al. 1999). Maps were created by field crews on foot from which the quality of fish habitat was derived. This information was compiled, assessed in terms of value as fish habitat, and gave rise to a classification of the Severn Sound shoreline according to Fish Habitat Suitability (Minns et al. 1999). Despite the level of effort (data collection over the period 1989-1994), the resulting classification of habitat suitability was limited by depth and resolution.

The basis of the shoreline habitat classification is that all fish species have some degree of dependence on the lake nearshore (including tributary mouths) at some stage in their life cycle (Lane et al. 1996a, b, c). The nearshore is particularly critical for the first year of fish life after eggs hatch (Minns et al. 1996, Minns 2003, Minns, 2005). Most extinctions of freshwater fishes have been caused by habitat alteration and destruction (50%), followed by exotic species introductions (37%) and overexploitation by humans (8%) (Thomas 1994). Habitat is the essential foundation upon which fish populations thrive and fisheries prosper (Minns, et al.1996). Since habitat inventories and fish community studies of the early 1990’s in Severn Sound (SSRAP 2002, Minns, et al. 1999, Randall et al. 1998, Leslie and Timmins 1992, OMNRF Trapnet Surveys (prior to 2000, unpublished)), several significant changes have occurred that may have altered habitat conditions and influenced the Severn Sound fish community and habitat conditions.

1. Fishing pressure for Walleye (*Sander vitreus*) and other predator species has apparently increased in Georgian Bay especially in Severn Sound since the early 1990's (OMNRF Creel Surveys, , Gonder 2003)
2. The increase in the Double-crested Cormorant (*Phalacrocorax auritus*) population in Georgian Bay may be having a negative impact on the fish community of Georgian Bay including Severn Sound (Weseloh 2003, MNR study)
3. The introduced exotic, invasive species: Zebra mussel (*Dreissena polymorpha*) and Quagga mussel (*Dreissena bugensis*) has infested Severn Sound since 1994-95 and has contributed to changes in open water clarity and nearshore habitat conditions (SSRAP 2002, general refs). The newly introduced Round goby (*Neogobius melanostomus*), and to a lesser extent Tubernose goby (*Proterorhinus semilunaris*) may also be adversely influencing fish community (e.g. Tran 2007).
4. The trophic status of Severn Sound has changed due to phosphorus control (possibly in conjunction with the effects of Dreissenid spp.) with decreases in phosphorus concentration, phytoplankton and zooplankton biomass and increases in water clarity in open waters (SSRAP 2002).
5. Lake Huron-Georgian Bay water levels decreased starting in 1999, to record lows (see historical graph of CHS water level website), adversely influencing nearshore spawning and nursery areas and resulting in alteration of shoreline substrate conditions and shifting plant communities. In recent years (2014 to present) water levels in Georgian Bay have dramatically increased, highlighting the need for a nearshore habitat mapping system that incorporates water level fluctuation.

With these ecosystem changes, there is also increasing pressure for shoreline development, especially along the coast of Severn Sound (including the coastline of the Township of Tiny). Shoreline management decisions must be based on more detailed habitat mapping and classification, based on sound defensible methods. The Interim Severn Sound Fish Habitat Management Plan (SSRAP 1993) was developed as a guidance tool for resource agency and municipal planning staff as an early indicator of constraints for proposed marine construction and shoreline development proposals as well as for the targeting of opportunities for habitat enhancement. This early plan lacked spatial detail in shoreline mapping and a defensible method of relating the shoreline habitat rating to the productive capacity of the Severn Sound nearshore. To improve on the spatial detail of the nearshore habitat mapping, an inventory of shore features, substrate and vegetation was conducted over the period 1989 to 1994 (Portt et al. 1990, unpublished; Minns et al. 1999). The resulting GIS database from the inventory was used with the Defensible Methods model (Minns et al. 1995) to develop a scientifically defensible approach and methodology for classifying discrete areas of fish habitat into one of three classes (Red, Yellow or Green) ranging in habitat suitability (Minns et al. 1999). Unfortunately, the habitat inventory for this work was carried out during a high-water level phase in Georgian Bay, recording relative depths. To provide a current management framework for the area, an inventory of nearshore habitat that updates the shoreline conditions under fluctuating water level conditions is required.

Although the area is currently delisted, the SSEA and other resource agencies monitor habitat within the Severn Sound area. Despite the importance of nearshore habitat for fish, invertebrate and plants, there is relatively little known about the shallow, vegetated areas within Penetang

Harbour, and other areas of Severn Sound. Previous work in the 1990's assessed nearshore fish habitat, however, falling water levels, increased shoreline development and climate change factors have limited the interpolative power of these maps. High resolution, updated maps will not only accurately map the influence of changing conditions in the area but will also inform the SSEA, municipal partners and resource agencies with far better coastal habitat information for management decisions.

## 1.2 Remote Sensing

Hydro acoustic mapping is becoming more common in aquatic mapping efforts (Lefebvre et al 2009, Warren & Petterson 2007, Baily et al. 2002). This technique involves the production of sound waves in the water column at regular intervals (pings). When a sound wave meets an object that is of a different density than its current medium (water) some of the energy is reflected towards the sounder (backscatter), and some sound continues through the new medium. The amount of time it takes for the wave to be sent and returned to the sounder is used to calculate the distance from the source to the object and the backscatter intensity can be used to infer what kind of object the sound wave encountered. Backscatter intensity is highest when the sound waves meet sediment, or objects in the water column such as fishes and macrophytes (Lefebvre et al. 2009, Komatsu et al. 2003, Paul M. et al. 2011).

Hydro acoustic techniques have been employed to map out various bathymetric characteristics in aquatic ecosystems such as macrophyte abundance and sediment composition. (Stolt et al. 2011, Oakley et al. 2012). Habitat maps can be created by plotting and extrapolating data using GPS coordinates that are collected concurrently with other variables such as: depth of the water column, vegetation height, and back scatter intensity (Warren & Peterson 2007). These maps can then be used in combination with other data (such as water quality parameters) to evaluate habitats for different species of invertebrates and fishes (Brown et al. 2000, Yeung & McConnaughey 2008). Hydro acoustics are not affected significantly by water turbidity and surveying is relatively quick which allows for the acquisition of more detailed data from larger swathes of habitat with minimal effort. The acoustic transducer can be attached to the hull of a boat and can cover any area the boat can pass over; however, this technique is limited to areas that are accessible by boat. Other studies have used autonomous underwater vehicles (AUV) in passive and active bathymetric surveys in areas that may be inaccessible by boat (Henthorn et al. 2006), but these devices can be extremely costly and impractical for extended use.

To apply these habitat mapping techniques to coastal margins, access to shallow water (1 – 2 m) is needed. In the case of Severn Sound, any sonar used must operate in a variety of shoreline types with highly variable changes in aquatic vegetation and substrate type.

## 1.3 ROVER

The University of Windsor developed the Remote Operated Vehicle for Environmental Research (ROVER) to collect information on bathymetry and substrate characteristics (macrophyte distribution, sediment characterization) in aquatic habitats that are not amenable to surveys by conventional water-craft and remote sensing technology (shallow, vegetated areas). ROVER is an inflatable one-person boat equipped with a remote-controlled trolling motor, and two sonar units. The vessel can collect high-resolution (HR) bathymetric data and assess submerged aquatic vegetation (SAV) distribution and height. ROVER uses real-time differential GPS (transmitted via a wireless broadcast signal permitting the vessel's progress to be tracked from shore), a recording depth sounder (Lowrance HD5 fishfinder), and shallow-water scanning sonar to collect real-time, geo-referenced bathymetric and epibenthic information. Data are recorded digitally onboard the vessel, and processed after the survey. Due to ROVER's small size and weight it sits high in the water and can access heavily vegetated, shallow areas (< 1 m). This autonomous vehicle is also easier to repair and maintain than other AVs as most parts are commercially available at local outdoors shops, and is suited for detailed mapping of larger areas of shoreline cost effectively.

Originally, a large portion of ROVER field work was conducted in Penetang Harbour, Severn Sound, where it was deployed to collect bathymetry data and vegetation cover to classify habitats. The application of ROVER sampling was expanded to sample across the whole of Severn Sound after showing initial success in Penetang Harbour.

### 1.4 Objectives and Approach

The objectives of this project were to:

- *map and evaluate selected areas of the coastal margins of Severn Sound, classify the habitat on the basis of depth, substrate characteristics, and macrophyte distribution,*
- *produce digital maps delineating the distribution of fish habitat and its quality*
- *assess the condition of fish communities using electrofishing and fyke netting techniques, and collaborate with OMNRF in the interpretation of trap net data*
- *assess the relative importance of habitat quality, water quality and contributing watershed quality in determining fish community condition (assessed by various capture methods) at a site*

Using a combination of a remotely operated raft (ROVER) and boat-mounted side-scan sonar recording, we assessed bottom habitat from the shoreline (30 cm depth) to a distance of up to 100 m from shore along selected sections of coastline in Severn Sound. The data were then be used to create maps of depth, substrate texture, and aquatic plant distribution (verified with video imagery) for selected areas of Severn Sound.

Habitat suitability models to score habitat suitability were evaluated for selected coastal areas. We also incorporated "expert" data of known highly suitable habitat into the mapping to enhance the fidelity of the modelled results. Survey data was compared with fish community data from electrofishing transects carried out by the Department of Fisheries and Oceans (DFO) and historical data from the Ontario Ministry of Natural Resources and Forestry (OMNRF) to evaluate the habitat classification mapping in relation to fish community. Nearshore habitat mapping will provide planners and agency staff with a scientifically defensible tool to manage the nearshore habitat.

Data layers were converted to digital maps for Penetang Harbour, a "data rich" area of Severn Sound, in order to evaluate habitat suitability models and to document coastal habitat suitability for future management (protection/restoration potential). The project mapping will also allow comparisons to be made, in future projects, of changes in coastal habitat distribution and the potential for changes in distribution of wetland and submergent vegetation areas relative to earlier surveys (Minns et al. 1999). Mapped habitat suitability will be compared with fish community data to verify habitat classification in light of other environmental stressors.

The University of Windsor ROVER and other data acquisition systems linking positioning systems to sonar data collection (Habitat Solutions NA, SSEA) automates surveys, providing georeferenced, point-specific real-time signals, which are processed to provide detailed records of depth, substrate (texture, and depth of organic sediment layers), and macrophyte density, cover and biomass, when combined with video and still images.

Predictions of habitat suitability (original and revised models) were compared and validated using existing OMNRF, University of Windsor and DFO data of fish communities across a range of habitat index values. Resulting mapping and survey data were also compared to other habitat assessment programs or indices (e.g. the Great Lakes Environmental Indicator program (Danz et al. 2007; Niemi et al. 2009), the Great Lakes Coastal Wetland Monitoring Program (Burton et al. 2008; Uzarski et al. 2010), and the Fish Quality Index (Seilheimer et al. 1996). These latter measures are calibrated against assessments of water quality (Seilheimer et al. 1996) and adjacent land use condition (Uzarski et al. 2010). Consequently, a harmonization of assessment techniques will allow us to assess anticipated changes in fish communities under various land use development scenarios and anticipated risks of climate change mediated through effects on contributing watersheds (Ciborowski et al. 2009, Ciborowski et al. 2012). Using these measures together will make it possible to diagnose whether fish communities can best be protected by maintaining water quality (reducing phosphorus point sources), improving habitat condition, or managing patterns of land use (limiting nonpoint run-off) in the contributing watershed.

## 1.5 Collaborators

Keith Sherman (SSEA) was responsible for overall project coordination and coordination of field logistics, providing liaison between the project members and Severn Sound stakeholders and agencies. SSEA GIS staff and other GIS and data compilation staff worked to integrate raw data into a common geospatial database using existing digital structures housed at SSEA.

Jan J.H. Ciborowski (University of Windsor UWIN) was responsible for coordination of the scientific aspects of the project, execution, synthesis and reporting; his expertise in experimental design and indicator theory development will guide the development of sampling regimes, data interpretation and overall assessments.

Scudder Mackey (Habitat Solutions NA) provided training of SSEA and University of Windsor personnel and oversaw nearshore sidescan data collection, processing and data interpreting to aid in interpretation of substrate type.

Susan Doka (DFO) was responsible for overseeing habitat data integration for the derivation of updated habitat classification models and their assessment.

Christine Boston is the lead DFO biologist for fish community assessments (by way of electro-fishing). Working with Robert Randall, she oversaw the electrofishing work carried out during 2016 and collaborated on the development and assessment of fish Indices of Biological Integrity (IBI) and new habitat models. She also compared earlier electrofishing data from sites in Severn Sound to assess changes in fish community.

University of Windsor partnership with Lucinda Johnson performed comparison of biological conditions of coastal margin areas with the type and amount of human disturbance (agriculture, non-natural land, density, number of roads, point source pollution) in watersheds draining into the study area (The GLEI composite stressor index; Ciborowski et al. 2011). In future projects, she will assess the effect of climate change on coastal habitat and fish communities based on empirical observation derived from patterns observed in the GLEI data (Ciborowski et al. 2012).

Kemal Tepe (UWIN) was responsible for developing the signaling technology that allows ROVER to operate remotely and transmit data signals to recording computers.

Lex McPhail was responsible for ROVER data QA/QC. He was responsible for overseeing the collection of SSEA sonar data and imagery from the study area. He also worked with the MNRF SCOOP2013 data for the Severn Sound area in conjunction with other depth and elevation data collected and available to produce digital elevation models of selected areas of Severn Sound. He was responsible for preparing data layers for mapping in cooperation with UWIN and DFO staff. Lex has been the SSEA GIS lead, maintaining data, overseeing the write-up of data-processing procedures and producing data layers from collected data.

Li Wang (UWIN) was responsible for ROVER data QA/QC as well as preparing data layers for mapping. Li was the University of Windsor GIS lead, creating data layers from collected data.

Justin Landry was the University of Windsor field technician for habitat surveys, report writer, data processor and lead for substrate particle size analysis.

Jon Midwood was the lead DFO biologist for habitat assessment (hydroacoustic surveys). Jon collected and interpret environmental data to characterize habitat in Severn Sound in a concurrent SGBLSCUF funded Project by DFO.

Dave Reddick was the field lead for the DFO. Working with Christine Boston, Dave was responsible for the collection of fish, logger and habitat data in Severn Sound area.

Jesse Gardner Costa (UWIN) was the University of Windsor field lead responsible for deploying and operating ROVER units to assess conditions at the coastal margin. Jesse also coordinated with partners, arranging meetings, and coordinated the write-up of ROVER data QA/QC as well as preparing data layers for mapping.

Stephen Goudey – as the designer of the original ROVER units, Stephen was be responsible for technical refinement and signal interpretation technology and development

## 2. Methods and Materials

### 2.1 Study Site: Severn Sound

The project is located in the Severn Sound area of southeastern Georgian Bay (Figure 2.1) and adjacent coastlines. The area includes the Township of Tiny, the Towns of Penetanguishene and Midland, the Township of Tay, the Township of Severn and the Township of Georgian Bay. Severn Sound area has a shoreline length of approximately 250 km (from the southern boundary of the Township of Tiny around to Main Channel north of Beausoleil Island). The Sound has a surface area of approximately 127 $km^2$. This area is located on the contact between the sedimentary shoreline of Simcoe County and the Precambrian Shield in Muskoka District.

Due to time and resource limitations, only selected areas of Severn Sound could be surveyed during the project. Despite this limitation, we exceeded the shoreline length and nearshore area originally proposed (150Km and 1500 ha) for survey data collection (see Attached Performance Indicators Chart). Processing and interpretation focused on Penetang Harbour as the survey data provided the best opportunity to demonstrate the methods developed as part of the project in a definable unit of Severn Sound. This approach provided scientifically-defensible predictions that can be used in future work throughout Severn Sound and other nearshore areas of Georgian Bay. Sampling across a broader area requires increasing interpolation, (causing greater uncertainty overall).

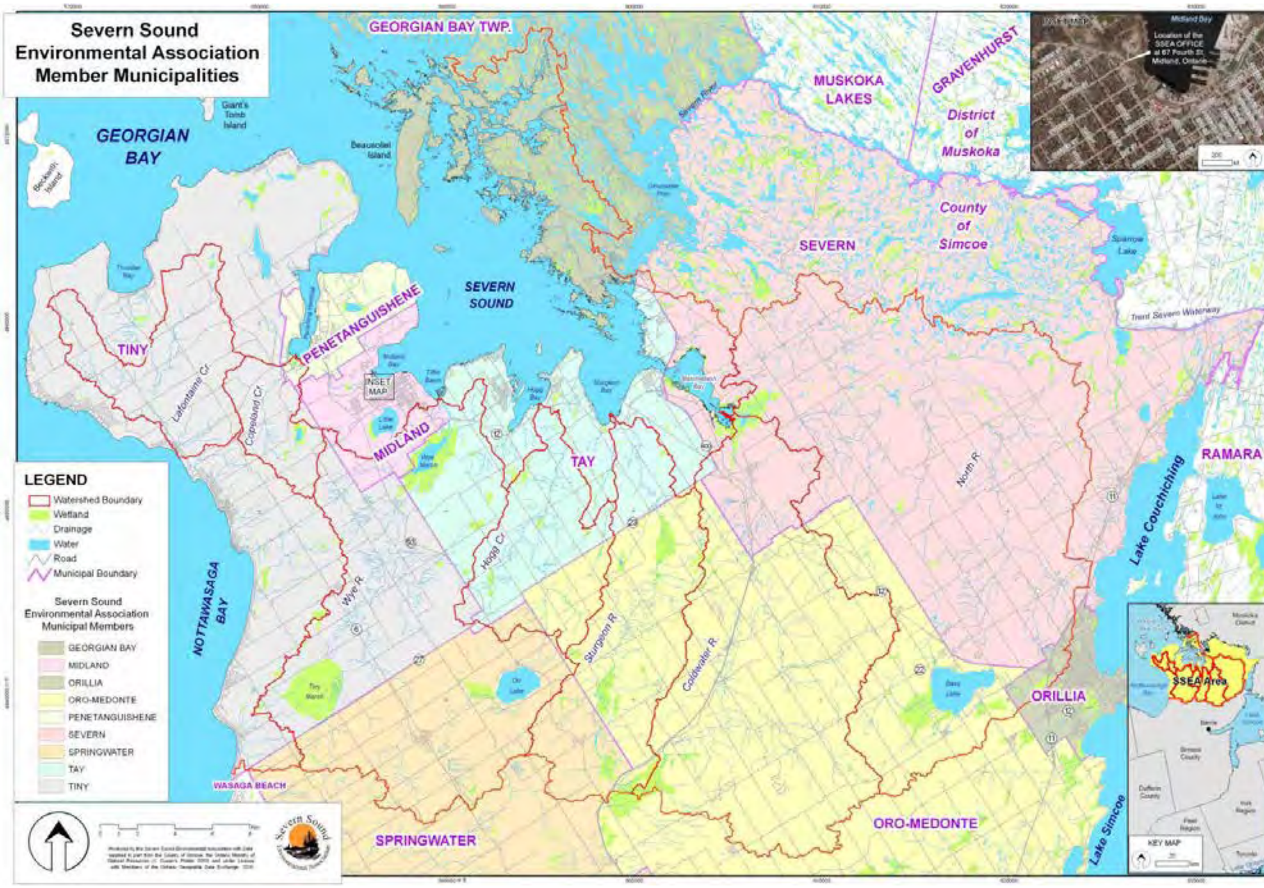



Figure 2.1. Watershed map of Severn Sound, Georgian Bay, ON.

*2.1.1 Site selection*

Hydroacoustic sonar (DFO) – As part of a parallel project in collaboration with this project, the Department of Fisheries and Oceans designed a survey using a hydroacoustic technology (Biosonics R) which provided an interpretation of substrate conditions and submerged aquatic plants at 20 sites in Severn Sound (see Appendix_B1-A and Appendix_A5).

ROVER Sonar survey site selection (UWIN) - 40 sites were selected (~20 per year, see Appendix_B1-B). University of Windsor used a stratified-random design, blocking 20 sampling areas across the entire Severn Sound watershed; this ensured equal representation of shoreline across Severn Sound. Each area was divided into 2 parts and random sites were chosen within each half along the shoreline. Blocks and sub-blocks were approximately 12.5 km and 6.25 km in length, respectively. At a site, approximately 1.5 km of shoreline was covered by ROVER surveys per day. Where possible, sonar sites would coincide with historical fish survey sites from the available DFO and OMNRF data.

Underwater video surveys (SSEA) – Underwater video surveys by SSEA followed the University of Windsor's study design for later validation on remote-sensing data. Transects parallel and perpendicular to shore were taken to capture gradients of substrate and submerged aquatic vegetation (see Appendix_B1-C). In addition, surface imagery was captured to provide enhanced detail for interpretation of water/land transition features such as EAV and shoreline substrate (Appendix_B1-C).

Sidescan Surveys (Habitat Solutions NA) – Given the wide swath of coverage of the Klein sidescan sonar equipment, extensive coastal areas of Severn Sound were surveyed during 2015 and interpreted during late 2015 and 2016. Gaps in coverage were a result of not risking equipment in shallow waters with uncertain obstructions to towing the equipment (see Appendix_B1-D).

Fish and Habitat survey site selection (DFO) – Electrofishing sites were chosen based on historical DFO fishing sites from King and Portt 1989 and Minns et al. 1999. Additional fishing sites and habitat survey sites were chosen to complement the University of Windsor study design to fill in gaps in coverage. For more details on the DFO sites and methods see sections 2.2.3 and 2.5 (see also Appendix_B1-E).

Monitoring sites (SSEA/UWIN/DFO) In order to supplement the interpretation of substrate conditions along the coastal margin of Severn Sound, a series of 100 ponar grab samples and 31 "spot" observations of substrate conditions were collected by UWIN in 2016 and combined with samples collected previously by UWIN for SSEA in 2007 and 2008 (see Appendix_B1-F). The seismic survey conducted by GSC Atlantic in cooperation with the Severn Sound RAP (1995-1997) was also used to support the interpretation of open water substrate conditions in selected areas of Severn Sound (Appendix_B1-G).

Open water quality monitoring during the ice-free period of the year was conducted by SSEA at 14 sites throughout Severn Sound during the project as a parallel project (Appendix_B1-F). DFO selected ten sites for temperature/dissolved oxygen loggers and SSEA selected an additional three sites for temperature loggers to collect hourly temperature during 2016 (Appendix_B1-F). One of the SSEA sites (at Port Severn) has been a long-term ice-free hourly monitoring site (2002-present).

## 2.2 Bathymetry Layer (Digital Elevation Model and shoreline)(SSEA)

A disadvantage of past fish habitat mapping has been the collection of data using relative depths which, for the day, month or year of data collection, could vary with water level conditions on Georgian Bay. Fluctuations in Georgian Bay water levels can have an effect on the reliability of the resulting geospatial models used for the assessment if relative depth used in most models is not corrected for changes in water level elevations. These changes can occur hourly, within a day or from year to year. Data from the Canadian Hydrographic Service Water Level Gauge at Midland Harbour (gauge 11445, approximate location at E:588021; N:4956105 http://www.tides-marees.gc.ca/eng/station/Month?sid=11445&tz=EST&pres=2&type=1 ) was used in this study to adjust relative depth data collected to elevation for the time of each survey. Water level phases of Georgian Bay can range from an average of approximately 1.5 m above to 1.5 m below the Chart Datum of 176.0 metres above sea level (CHS Chart 2241). Fluctuation in water level near shore was incorporated by converting collected depth data to elevations in metres above sea level. Elevations were further enhanced by combining the depth elevation data with ground surface elevation data to create a continuous (lake bottom to surface) bathymetric elevation model. By using a continuous elevation model, the lake bottom habitat can be modelled at different water level elevations (see Appendix A1 for full explanation of method using the MNRF 2013SCOOP data for the Severn Sound coastal area).

*2.2.1 ROVER Sonar and Reefmaster procedure (UWIN)*

The Remote Operated Vehicle for Environmental Research (ROVER) is an inflatable one-person boat equipped with a remote-controlled trolling motor, and two sonar units. The vessel is able to collect high-resolution (HR) bathymetric data and assess submerged aquatic vegetation (SAV) distribution and height.

Using a 5.2-m aluminum boat to navigate, we used ROVER to run transect lines at each sampling site to create a grid of depth measurements. Post-processing of the data removed any offset differences of the placement of the sonar units on ROVER and aluminum boat as well as normalized all data to International Great Lakes Datum of 1985 (IGLD85 – 176 m) so we could combine data across years. Using ROVER, parallel transects were spaced approximately 10 m apart in sampling areas.

University of Windsor's sonar data was collected over the summers of 2015 & 2016. Data was collected from July 28, 2015 to October 3, 2015. In 2016 data collection began on June 3rd (verification substrate samples were collected first followed by additional sonar sampling over a similar time frame as in 2015) and finished August 30th.

Sonar (primary) and downscan data were interpreted using ArcGIS (ESRI v 10.1) interpretive GPS software, to map study sites on the lake as well as to trace transects and produce cross-sections of the lake. Depth, and XY coordinates were extracted from the storage medium in the LOWRANCE unit (using LOWRANCE Sonic Log Viewer v.2.1.2.), saved as Comma Separated Value (CSV) files, and imported into Global Mapper© 13 (Blue Marble Geographics). The XY readings were converted to longitude and latitude coordinates and then exported as shapefiles, which were then opened in ArcGIS. Using the Geostatistical Analysis tool (with depth as our z-axis), the data that ROVER sampled was interpolated to generate 10-cm water depth contours.

REEFMASTER® sonar software was used to correct sonar files (remove erroneous data, readjust sediment bottom etc.) as well as calculate % cover and map the submerged aquatic vegetation. For detailed methods on how to use the software and calculate % vegetation cover please refer to Appendix A1 file named,
"APPENDIX_A1__Bathymetric_Mapping_Component_(SSEA)" and Appendix A4a file named,
"APPENDIX_A4a_Estimating_percent_cover_of_SAV_using_sonar_output_from_Reefmaster_software_in_Severn_Sound_(SSEA)"

*2.2.2 Sidescan Sonar collection & interpretation (Habitat Solutions NA)*

Sidescan data from Severn Sound were collected over a period of years. A total of 247.86 shoreline kilometers of sidescan sonar data were collected along survey lines oriented parallel to the shore. Appendix_B1-D shows the location of sidescan sonar surveys collected in nearshore areas of Severn Sound and South Bay. Prior to each survey, preliminary survey tracklines were established in order to ensure adequate coverage and to provide navigation waypoints for the research vessel.

The sidescan sonar towfish was deployed from Habitat Solutions NA's 5.3-meter (17 foot) power catamaran and a rented aluminum 7 meter (23 foot) center console work boat (see Appendix_A2a). These shallow-draft vessels are ideal for shallow water data collection operations in the nearshore zone. The sidescan sonar data were acquired at boat speeds ranging from 3.0 to 4.5 knots (5.5 to 8.3 km/hr). These slower speeds are optimal for high-quality data collection while providing sufficient coverage to assess nearshore substrate patterns. The equipment and changing water depths are carefully monitored as shallow-water obstructions could severely damage the towfish and/or the research vessel.

The data were typically collected at a 75 m range scale with a line spacing of 112 m. This line spacing provides adequate overlap to eliminate "holidays" (gaps) in data when generating seamless mosaics. The survey lines were oriented parallel to shore in order to maximize time on site and protect the vessel and equipment from submerged hazards (large boulders or other obstructions). The survey would typically start in moderate to deeper water depths and data would be collected progressively landward into shallower water. This provided an opportunity to assess potential shallow-water hazards in advance of the next survey line.

Post-processed sidescan sonar mosaics were generated using Chesapeake Technologies sidescan sonar mosaicking software either during, or shortly after, sonar data collection operations were completed to assist with the identification of lakebed sampling locations. Subsequent to the collection of the sidescan sonar data, additional underwater video data and sediment samples were collected by SSEA in 2016 to validate the interpretation of the acoustic data. For more detailed methods on sidescan surveys please refer to Appendix A2a (file name: "APPENDIX_A2a_Sidescan Sonar_Methods&Processing_(Habitat Solutions NA)") and Appendix A2b for underwater video methods, file name "APPENDIX_A2b_Fish Habitat Imagery Interpretation for Severn Sound_(SSEA)"

*2.2.3 Biosonics collection and interpretation (DFO)*

From 11 July until 27 July 2016, SAV cover and height were assessed in 20 regions throughout Severn Sound, Lake Huron, using hydroacoustic (Biosonics MX with 204.8 kHz and 8.4 °beam width; Figure 2.2.3.1). With this approach, sampling was limited to water depths that were greater than 1-m. The interpretation of the data collected for each hydroacoustic transect was completed in Visual Habitat (Biosonics, Seattle, WA). The first step in the interpretation was establishing the bottom depth and for this the "Rising Edge Threshold", which determines where to assign the bottom echo, was set to -35 dB. This approach was frequently unable to detect the bottom echo due to either dense SAV or unconsolidated sediment therefore in these instances the bottom was manually delineated. After the bottom was determined, a plant detection analysis was completed using the default settings with a "Plant Detection Threshold" of -70 dB, maximum plant depth of 10 m and a plant detection length criterion of 10 cm (minimum height for an echo to be assigned as SAV). The resulting data were then exported for further analysis.

During the hydroacoustic surveys, additional data were collected at key points to 1) characterize local water chemistry, 2) determine the dominant species of SAV at each site, and 3) provide an opportunity to validate the hydroacoustic data. At four points in each of the 20 survey regions water chemistry readings of four parameters (temperature (°C), conductivity (µS/s), dissolved oxygen (mg/L and %), and turbidity (NTU)) were collected using a Sonde EXO multiprobe (YSI, Yellow Springs, OH, USA). Secchi depth was also determined where possible. Generally, these points were situated close to shore in shallow water (<2.0 m, N=2) and in more open and deeper waters (>4.0 m, N=2), although in some locations no deeper sites were present (e.g., Matchedash Bay). Verification points were flagged haphazardly along the hydroacoustics transects and surveyed posthumously using a rake-toss to collect samples of SAV and provide an indication of the dominant species and coverage. Finally, during the hydroacoustic transects the presence, relative cover (sparse [<25% cover], moderate [25-75% cover], dense [>75% cover]) and height (low, mid-depth, high, surface) of SAV were visually estimated and recorded in relation to the hydroacoustic ping number. Since these data were collected concurrently with the hydroacoustic survey, they were used to provide a rough validation of the hydroacoustic output.

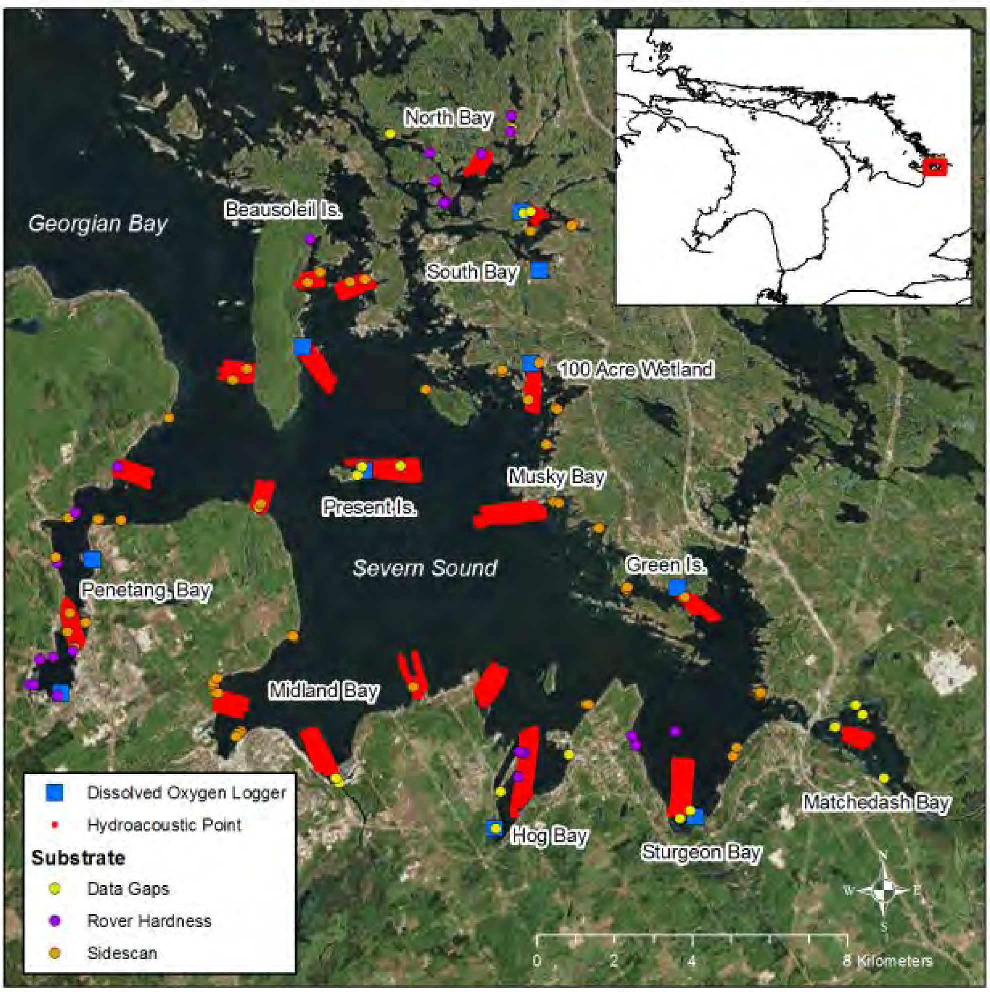



Figure 2.2.3.1: Location of SAV acoustic transects (red lines), dissolved oxygen loggers (blue squares), and substrate samples in Severn Sound. Substrate samples were selected to help fill existing data gaps (yellow circle), to cover a gradient of substrate hardness values (purple circle) and to support the interpretation of sidescan sonar data

Following the interpretation of the hydroacoustic data, results were aggregated by site to provide the proportion of points where SAV were present, and summary details (mean ± standard deviation, quartiles etc.) related to the water depth and percent cover and height of SAV. Percent cover and height of SAV were also plotted against water depth to provide an indication of the depth distribution of SAV. Finally, points were plotted in a GIS to allow for a spatial assessment of SAV height and cover. The effective fetch was also determined for each point and used to calculate an overall mean level of exposure for each survey region. Effective fetch information was extracted from a fetch model run using the proportion of time the wind spent in each of 16 equally spaced compass directions (after Rohweder et al. 2012). These wind data were compiled from the Environment Canada and Climate Change buoy 45143 (southern Georgian Bay) from 2005-2015.

For detailed methods and results related to habitat surveys and collecting environmental data, see the report "APPENDIX_A5_Severn_Sound_Hydroacoustics_Report_(DFO).pdf"

2.3 Dissolved Oxygen, Temperature and water quality

On 8 and 9 June, 2016, ten DO and temperature (DOT) loggers were deployed throughout Severn Sound (Figure 2.2.3.1). DOT loggers were calibrated using a 2-point calibration method using 100% and 0% saturated water. These loggers measure the DO and temperature of the water every 30 minutes for a total of 48 samples per day. The deployment set up consists of an anchor with a rope and float attached. The logger is then hung from secondary float that is suspended 30 cm above the anchor. Deployment locations were selected to explore several disturbance regimes prevalent in Severn Sound including: the influence of sewage plant effluents (Penetang South [adjacent to STP outflow] vs Penetang North [control]), the effect of exposure and connectivity to Georgian Bay (influences water clarity and water chemistry parameters; Present Island [exposed – high connectivity], 100 Acre Wetland [protected wetland – medium connectivity], South Bay South [protected wetland – low connectivity], South Bay North [exposed wetland – low connectivity], and Green Island [protected wetland – high connectivity]), and the influence of inflowing streams (Sturgeon River [in river] vs others; Table 2.3.1). Loggers were retrieved on 12 and 13 October 2016. Following comprehensive QAQC, DO and temperature data from each logger were summarized by month, and the proportion of DO readings each day that fell below 3 mg/L (considered to be anoxic) and between 3-6 mg/L (lower than saturation), temporal trends in DO and temperature, and overall deviance of each DO reading from the daily mean were plotted for each site. This final measure provides an indication of the daily timing of the maximum and minimum DO reading.

SSEA deployed calibrated Hobo® temperature loggers at three locations to supplement the DFO data collected. Loggers were launched to collect temperature every 30 minutes from mid-June to early November 2016 at approximately 0.5 to 1.0 m depth. The Severn River outlet is a long-term site with measurements from March to November for the period 2002 to 2016 (see Table 2.3.1).

At each of the 40 sediment sampling sites (see below), water chemistry (dissolved oxygen (mg/L), temperature ($^{o}$C), pH, ORP (ms) and conductivity (µs) were recorded using a YSI, 1 m below the water surface, general site information (weather, waves, wind) and land use (% development, % shoreline (soft or hard), riparian, etc) were recorded.

Open water quality was collected by SSEA as part of the open water monitoring program at 14 sites throughout Severn Sound during 2015 and 2016. At each site, sampling consisted of: Secchi disc visibility; vertical profiles of temperature, dissolved oxygen, conductivity; and composite samples for chemistry (DOC, Total phosphorus, total nitrogen, TKN, nitrate, ammonia, alkalinity, pH, lab conductivity, major ions and colour).

Table 2.3.1: Summary details for each DFO temperature/dissolved oxygen (DO) logger and SSEA temperature logger sites (+) with coordinates, disturbance category, physiographic region, and mean/max effective fetch.

| **Site Name** | **Easting** | **Northing** | **Disturbance Category** | **Location** | **Physiographic Region** | **Mean Fetch (m)** | **Max Fetch (m)** |
|---|---|---|---|---|---|---|---|
| Inner Penetang | 583625 | 4957650 | Heavy plant growth | Off Beach | Simcoe Upland | 568 ± 18 | 595 |
| Outer Penetang | 584430 | 4961090 | Protected Coast | Coast | Simcoe Upland | 621 ± 18 | 641 |
| Penetang Hbr+ | 583833 | 4958417 | Protected Coast | McGibbon Pt | Simcoe Upland | 125 | 1068 |
| Present Island | 591424 | 4963380 | Exposed Coast | Coast | Simcoe Upland | 2209 ± 263 | 2536 |
| Midland Hbr+ | 587915 | 4956109 | Exposed Coast | Coast | Simcoe Upland | 393 | 2098 |
| Sturgeon River | 599989 | 4954440 | River Outflow | River | Simcoe Upland | 1119 ± 77 | 1214 |
| Hogg Bay* | 594810 | 4954160 | Protected Coast | Wetland | Simcoe Upland | 393 ± 83 | 529 |
| Green Island | 599517 | 4960350 | Protected Coast | Wetland | Georgian Bay Fringe | 625 ± 96 | 784 |
| Severn R + | 601047 | 4961896 | Protected Coast | Dam outlet | Georgian Bay Fringe | 31 | 424 |
| 100 Acre Wetland | 595735 | 4966140 | Protected Coast | Wetland | Georgian Bay Fringe | 166 ± 24 | 198 |
| Beausoleil East* | 589855 | 4966580 | Exposed Coast | Coast | Simcoe Upland | 2295 ± 91 | 2419 |
| South Bay N | 595956 | 4968550 | Exposed Coast | Wetland | Georgian Bay Fringe | 204 ± 10 | 218 |
| South Bay S | 595495 | 4970050 | Protected Coast | Coast | Georgian Bay Fringe | 214 ± 7 | 221 |

“*” Loggers were not included in the analysis of dissolved oxygen profiles because the logger could not be recovered (Beausoleil East) or the logger was partially buried in the sediment (Hogg Bay).

## 2.4 Substrate Layer & particle size analysis

### *2.4.1 Ponar Sampling*

Sediment samples were collected in Severn Sound, Ontario from June 3rd to June 10th, 2016 via petite ponar grabs. Upon arrival, each site was characterized according to % of shoreline make up (beach, rocky, riprap, vegetated bank, etc.) and % of landcover type (low density residential, agricultural, upland forest, etc.). Aquatic vegetation was also characterized by the % of emergent, floating leaf, and submerged vegetation, and the dominant species in each category was noted. Before ponar deployment, water quality readings were taken using a YSI Sonde that measured: water temperature (°C), dissolved oxygen (%), dissolved oxygen (mg/L), conductivity (us/cm), pH, and ORP (mV).

Sediment Samples were collected along a transect perpendicular to shore to catch sediment variation along a depth gradient (deeper, 2 m + to shallower, > 1 m). Two to Five samples were taken along each transect depending on the amount of sediment collected. In areas of bedrock no ponar samples were taken. If ponar sampling yielded no substrate after three attempts no sample was taken. At each sampling location, a GPS point was taken.

Upon retrieval, ponar fullness and sediment composition were recorded (eg: sand, mud, cobble, clay). The ratio of different substrate categories and the presence of vegetation in samples was also recorded. Sediment samples were placed in Ziploc bags with external and internal labels and stored on ice until they were transferred to a freezer (-20 °C).

### *2.4.2 Particle size and Loss on Ignition (LOI) determination*

Substrate samples were thawed at room temperature overnight and then placed in an oven for 4 hours at 30 °C. Samples were then ground up using mortar and pestle until any clumps were gone and the substrate was free flowing and was then placed back in an oven for an additional 24 hours at 106 ° C to drive off any remaining moisture. After cooling to room temperature, samples were sub sampled (~ 3 g for fine sample such as mud and clay, ~ 20 g for samples with rocks, pebbles or large amounts of organic matter). A crucible for each sub sample was weighed, tarred, and then filled with sub sample and weighed again. Weights were recorded in grams onto a worksheet. Sub samples were placed in a muffle furnace for a total of 8 hours to remove any organic matter. The first hour was spent slowly raising the temperature up to 250 ° C. In the second hour, temperature was increased to 500 ° C. The sub samples remained in the furnace at full temperature for 6 hours following the two warm up hours (totaling 8 hours). Following the 8 hours the muffle furnace was turned off and the sub samples were allowed to cool overnight. The following morning the sub samples were weighed and recorded.

The rest of the original sample was filtered through a sieve tower which followed the Wentworth scale (Wentworth, 1922). Remains of the sample in each sieve were weighed on a tarred crucible and recorded in grams. Remaining sediment left in the tray at the bottom of the sieve tower (< 63 um) was weighed and recorded and placed in a scintillation vile with a cap label and internal label and stored at room temperature for further analysis. The tarred crucible, sieves and tray were cleaned between samples. For more detailed methods please refer to Appendix A3 file named “APPENDIX_A3_Substrate Processing_(UWIN)”

## 2.5 Electrofishing Surveys (DFO)

Nearshore electrofishing surveys were conducted at the 1.5 m water depth along transects that were 100 m in length on a seasonal basis (spring, summer, and fall 2016) at 12 different areas in Severn Sound resulting in a total of 197 samples. Sampling occurred at both historical sampling locations (e.g. Penetang Harbour and Hogg Bay) as well as at new sampling locations located in the northern portion of the sound. Survey data from 1990, 1992, 1995, and 2002 were also included for analyses comparing different measures of fish communities (Index of Biological Integrity, Multi-variate Indices, habitat suitability scores). Index of Biotic Integrity (IBI) scores and metrics were generated for each electrofishing sample and average scores per transect ± standard error (SE) by location and year. For more detail please see Appendix B4 entitled "APPENDIX_B4_C_Boston_Nearshore_fish_assemblages_in_Severn_Sound_Summary_(DFO)".

## 2.6 Interpretation of remote-sensing and environmental data

### *2.6.1 Bathymetry*

Using a combination of underwater sonar, imagery and field observations we assessed lake bottom habitat along selected areas of coastline in Severn Sound. All bathymetry data were corrected to Chart datum (176.0 m) to compensate for fluctuation in water levels during surveys. Depth elevation data (sonar bathymetry) were combined with ground surface elevation data to create a continuous (lake-bottom to surface) bathymetric elevation model. By using a continuous elevation model, the lake bottom habitat can be modelled at different water level elevations. For more detailed methods on processing and combining depth and elevation data please refer to Appendix A1, titled "APPENDIX_A1_Bathymetric_Mapping_Component_(SSEA)".

### *2.6.2 Emergent and Submergent Vegetation Interpretation*

Percent vegetation cover is one of three primary input parameters (vegetation, substrate, and depth) used for fish habitat suitability models (such as Habitat/Ecosystem Assessment Tool (HEAT)). Submergent Aquatic Vegetation (SAV) was estimated as presence or absence of SAV at a location and then averaged into a 10 x 10 m grid cell. A percent cover value is applied by comparing the number of point locations where SAV is present with the total number of points that coincide within a 10 m grid cell. The measurement is output as a percent cover value for each cell within a seamless grid of squares for a processing area. Due to the large processing burden, our study areas were subdivided into manageable processing areas, determined prior to the post-processing/modelling step. Penetang Harbour was used to demonstrate methods in a relatively "data rich" area. For more detailed methods on SAV please refer to Appendix A4a,
"APPENDIX_A4a_Estimating_percent_cover_of_SAV_using_sonar_output_from_Reefmaster_software_in_Severn_Sound_(SSEA)

Remotely sensed data, along with surface level and underwater imagery, was used to map and classify submerged aquatic vegetation (SAV) and substrate cover along selected coastal margin areas of Severn Sound. The interpretation was undertaken to provide additional information in areas that were not covered by other sources. Resulting cover information was integrated with the other data sources to facilitate the production of complete layers of substrate and aquatic vegetation that extend from shoreline to a depth of approximately 7m in selected areas. Penetang Harbour, a relatively "data rich" area, was used to demonstrate this method. For more detailed methods on SAV please refer to Appendix A4a, "APPENDIX_A4a_Estimating_percent_cover_of_SAV_using_sonar_output_from_

Reefmaster_software_in_Severn_Sound_(SSEA)" and Appendix A4b, "APPENDIX_A4b_Method_of_Interpreting_Submergent_Aquatic_Vegetation_and_Substrate_in_ Severn_Sound_shoreline_areas _(SSEA)".

Remotely sensed data, and surface level imagery were used to map and classify emergent aquatic vegetation (EAV) and substrate cover along selected shoreline areas of Severn Sound (see APPENDIX_A4c). The interpretation was undertaken to provide additional information in areas that were not covered by survey methods. Resulting cover information was integrated with the other data sources to facilitate the production of complete layers of substrate and aquatic vegetation that extend from underwater up to shore in selected areas. The final layers were applied as inputs to DFO`s Habitat/Ecosystem Assessment Tool (HEAT). For more detailed methods please refer to Appendix A4c, "APPENDIX_A4c_Method_of_Interpreting_Emergent_Aquatic_Vegetation_and_Substrate_in_Severn_ Sound_Coastal_Margin_Areas _(SSEA)".

2.7 Habitat suitability - The Habitat / Ecosystem Assessment Tool (HEAT)

The Habitat / Ecosystem Assessment Tool (HEAT) is an online software tool (http://www.habitatassessment.ca/) that quantifies the suitability of a site or area and the relative habitat supply based on a local or specified fish community and their documented habitat needs or associations across three life stages (spawning, nursery or young-of-the year, and adult) (Doka et al. 2015). Currently the tool uses water depth, substrate type, and vegetation % cover to assess fish habitat.

HEAT is typically used to evaluate pre and post habitat changes (from development, or natural disturbances). In this project, in order to save time, the input data was applied using a fish habitat suitability model adapted from Minns et al. (1999). The model utilized the Composite Habitat Suitability Index values from HEAT to quantify and map fish habitat suitability in Severn Sound. HEAT standardizes habitat evaluation across the Great Lakes. This project used the fish guild selected in the Minns et al. (1999) model with similar weighting used in HEAT. DFO continues to update and refine the HEAT website and model (http://www.habitatassessment.ca/ ).

Data for depth, vegetation cover and substrate from numerous sources were integrated to produce input to the habitat suitability model in a 10 m grid of Penetang Harbour (see APPENDIX_B3a and B3b). The resulting habitat classification provided an example of the use of the HEAT Composite Habitat Suitability Index model in Penetang Harbour (see below). Cut-off values for the generated fish habitat suitability output from Minns et al. (1999) were applied to summarize fish habitat suitability (i.e. LOW=GREEN; MEDIUM=YELLOW; HIGH=RED).

2.8 Relating Stressors and Indices to Fish Communities

We used several variables to evaluate the health of fish communities in Severn Sound. Figure 2.8.1 shows a simplified framework to determine how water quality, watershed quality (stressors), and habitat quantity and quality affect fish communities. Water and habitat quality are derived from the data we collect, watershed quality is determined from the Great Lakes Environmental Indicators (GLEI) project.

The Great Lakes Environmental Indicators (GLEI) project is an international collaboration of researchers with the goal of "developing indicators of ecological condition for the Great Lakes coastal region" (Danz et al. 2005). A focus of the GLEI project has been relating biological condition in wetlands to the amount of human activity in surrounding watershed (i.e. the risk of stress to wetlands). Watershed Quality is one of our main variables influencing the quality of fish communities in Severn

Sound (see discussion, section 4 for a visual representation of our project framework).

We used ordination of collected fish community data (DFO electrofishing, University of Windsor Fyke netting, OMNR trap netting) along an anthropogenic disturbance gradient. A maximum-likelihood analysis was used to generate a 'biotic response function' for each taxa that is observed. Biotic response functions are meant to model the probability of observing a given species at a given point on a disturbance gradient. This approach can be applied to any taxon as long as sampling procedures are standardized between sites used to derive the initial biotic response functions and sites for which condition is being inferred.

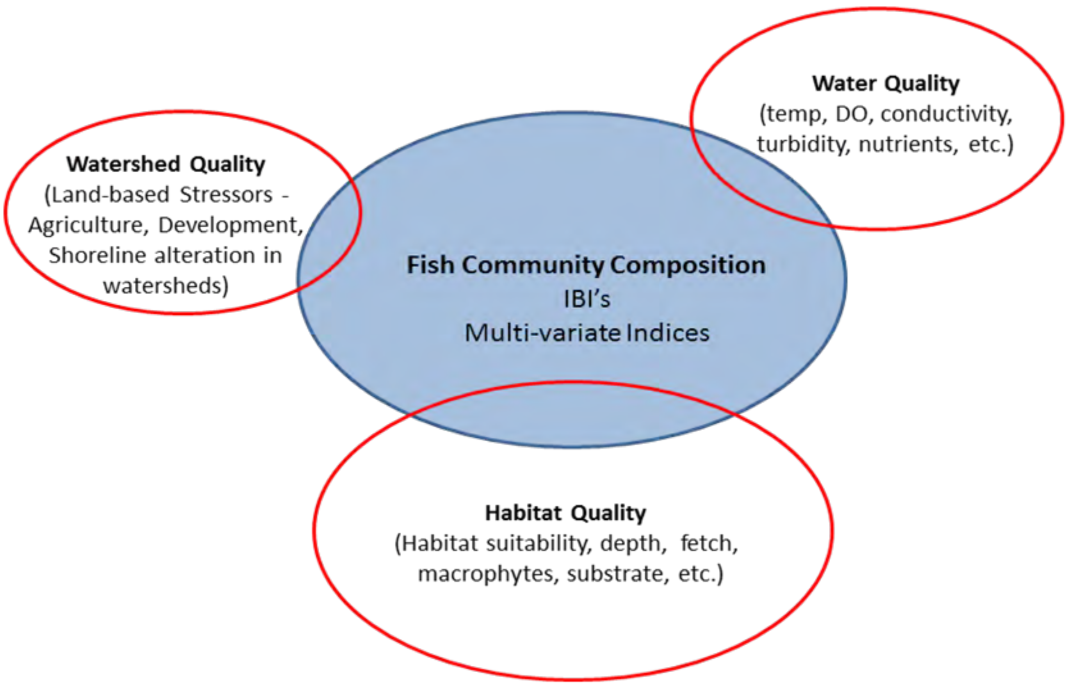



Figure 2.8.1 Simplified Structural Equation Model (SEM) of determining the health and 'quality' of fish communities in Severn Sound.

*2.8.1 Wetland Fish Sampling and Condition*

Information on fish community composition at selected wetlands in Severn Sound was collected between 1998 and 2016 by various groups, including the University of Windsor, and McMaster University (Ciborowski et al. 2015). Coastal Wetland Monitoring Program (CWMP) samples were collected through the Great Lakes Restoration Initiative – funded Great Lakes Coastal Wetland Monitoring program (CWMP, Uzarski et al. 2017; http://www.GreatLakesWetlands.org) and Great Lakes Environmental Indicators (GLEI2) (Johnson et al. 2015). Data for these projects were collected using the same fishing gear but slightly different site selection protocols between 2011 and 2014 For both CWMP and GLEI programs, coastal wetlands (4 ha in area or larger) were selected according to a stratified random design as part of programs to track status and trends in wetland community condition throughout the Great Lakes. McMaster University Wetland Monitoring Initiative data (Chow Fraser et al. 2006;http://www.GreatLakesWetlands.ca) were collected between 1997 and 2012 at wetlands primarily along the eastern Georgian Bay shoreline of Severn Sound (Ciborowski et al. 2015).

Three measures of wetland fish community condition were determined from the data, including

- the CWMP Index of Biotic Integrity (IBI; Cooper et al. 2012), which is calibrated to a combination of in-wetland water quality characteristics and surrounding land use,

- the Wetland Fish Index (Seilheimer et al. 2006), calibrated to the Great Lakes Water Quality Index (Chow Fraser 2006),

- the wetland Fish Assemblage Condition Index (Bhagat et al. *In review*), calibrate to the Great Lakes Environmental Indicators Euclidean Composite stress index (Host et al. 2015), which summarizes the amount of land allocated to agriculture and measures of rural/urban development.

Details of the methods and their relative quality are summarized by Ciborowski et al. (2015)

Fishes were sampled within the dominant vegetation zones of each wetland at sampling depths of between 25 and 100 cm. Vegetation classes included dense and sparse *Schoenoplectus* (>25 vs. $\leq$25 stems/m$^2$, respectively), *Typha, Phragmites,* water lilies, and submerged aquatic vegetation. Fyke nets were set in place overnight for at least 12 h at three sampling points (i.e., replicates; located at least 25 m apart) within each vegetation type. Fishes were collected passively using one of two sizes of fyke nets situated at each sampling point, with the lead extending as far into the vegetation type as possible, perpendicular to the shoreline. Large fyke nets had leads that were 7.62 m long × 0.91 m high and box frames that were 1.22 m wide × 0.91 m high x 1.83 m long. Wings (1.83 m long × 0.91 m height) extended at a 45° angle from the direction of the lead. Small fyke nets were scaled-down versions of the large fyke nets (lead 7.62 m long × 0.46 m high; box frame 0.91 m wide × 0.46 m high x 1.83 m long) All nets were constructed with 4.8 mm mesh. Large and small fyke nets were used to fish vegetation zones with water depths from 0.5 to 1 m and from 0.25 to 0.5 m, respectively.

All fishes >20 mm total length (TL) were identified to species using basin-specific taxonomic keys, examined for deformities and parasites, and a haphazard subsample of the first 25 individuals of each species and size group (small [presumably age 0 or juveniles] and large [presumably at least age 1 or adults]) measured for TL (mm) and released. Selected voucher specimens, photographs of fishes, or fin clips were retained to confirm species identities.

### *2.8.2 Analysis of OMNRF Nearshore Fish Trapping data*

Information on nearshore fish community composition at various locations in Severn Sound was provided by the Upper Great Lakes Management Unit of Ontario Ministry of Natural Resources (A. Liskauskas, OMNRF, *Pers. communication*). In all, 1753 trap-net records, representing collections between 1998 and 2015 were provided. Details of the End-of-Spring Trap Net program for Severn Sound are provided by Liskuaskas (2011; cited in Charlton and Mayne 2012). Each record consisted of a year-of-capture, geospatial coordinates, sampling date and a record of the number of specimens of each species caught. Because metadata and supporting covariate environmental data were not available at the time of writing of this draft, only preliminary assessments could be undertaken.

The land-based stress score for each trap net location was inferred by determining the nearest point of land to a trap, and assigning the GLEI Euclidean Composite stress index score for that point from the online risk map of Host et al. (2015). This provided a relative measure of the combined stress contributed by a combination of agricultural and rural/urban activity in the watershed draining to the shoreline adjacent to the point. The index was scaled to the upper Great Lakes region (Ecoprovince 212), consisting of the watersheds of lakes Superior Huron and Michigan. These lakes have fundamentally different geomorphology and land use than the southern Great Lakes. A score of 0.0 indicates that the amount of anthropogenic activity is the minimum to be found in the region. A score of 1.0 represents the greatest amount of composite stress in the basin.

Initial steps of developing a Fish Assemblage Condition Index (FACI; Bhagat et al. In review) for trap-netted catches were undertaken as follows:

All catch records were converted to relative abundances (percent of catch represented by each species) converted to octaves ($Log_2$[Percentage+1]).

A species abundance curve was generated for the 753 data records provided for the FN125 data set (Figure 3.6.2.1). This analysis indicated that an asymptotic species richness per trap (of approximately 9 species) was reached when a trap captured 20 or more individuals. Consequently, subsequent analyses used the 344 trap records that met the 20-individual criterion.

A total of 34 species was identified in these trap records. Of these, 16 species were caught in 15 or fewer trap sets (4.3% of the total) and judged to be too rare for inclusion in subsequent analyses. Multivariate analyses of the data therefore considered the 18 most frequently occurring species.

The FACI analytical approach entails provisionally identifying the 5% to 10% that are minimally stressed (those with the lowest associated stress score) as being in the ‘reference condition’. Similarly, the 5% to 10% of cases that are maximally stressed are designated as provisionally being in the ‘degraded condition’.

Variation among ‘reference condition’ sites is determined by performing a cluster analysis of the sites (Ward’s method, using Euclidean distances between sites in species space [common species only]). If distinctive clustering is observed, the environmental attributes of the sites that best distinguish the groups are identified using Discriminant Function Analysis. The resulting model is then applied to all non-reference sites to predict the expected species composition of sites in the absence of stress.

Ultimately, a Fish Assemblage Condition Index (FACI) is derived for each cluster of reference sites. This is accomplished by performing Bray-Curtis subjective-end-point ordination on the sites assigned to each cluster group. The ‘reference’ hypothetical endpoint is calculated as the centroid of the reference condition sites forming a cluster (means of each species). The ‘degraded’ hypothetical endpoint is the centroid of the suite of 5% to 10% of sites in the group having the highest stress scores. The ordination then uses the Sorenson index to calculate an index score between a maximum (reference centroid score) and a minimum (degraded centroid score) based on the compositional differences between each sample and the two hypothetical endpoints. Finally, the FACI (dependent variable) is plotted against the stress score (independent variable). The explanatory value of the index is determined by the coefficient of determination of the relationship.

In the absence of environmental information accompanying the trap data, we limited our preliminary analysis to the identification of common species, a cluster analysis of the reference sites, interpretation of the species most important in distinguishing the clusters, and variation in the relative abundances of those species among traps with respect to the GLEI composite stress scores.

## 3. Results

### 3.1 Data collection summary

Appendix B1, "APPENDIX_B1_Progress_Map_Series_(SSEA/UWIN/DFO)" summarizes the collection of the following data: (A)boat mounted sonar collection; (B) ROVER sonar collection: (C), SSEA underwater video survey coverage; (D) sidescan sonar collection; (E) fish community collection sites (fyke netting (UWIN, Coastal Wetland Monitoring project), electrofishing (DFO) and trap-netting (OMNRF) surveys; (F) sediment and temperature logger sample locations (DFO/UWIN/SSEA); (G) historical offshore substrate data (Geological Survey of Canada Atlantic); and (H) shoreline delineation from ortho-photo interpretation and MNRF SCOOP2013 data. These maps show data coverage of the nearshore in Severn Sound collected during this project and other related projects. The data collected from these locations have been processed in selected areas, especially in Penetang Harbour, to interpret environmental variables such as, bathymetry, vegetation cover, substrate, and water quality for further interpretation of the habitat suitability in Severn Sound.

### 3.2 Bathymetry Layer

Bathymetric information input into a Digital Elevation Model (DEM) was derived from elevation/depth data supplied in part from the following data sources: The University of Windsor (ROVER), ECCC, DFO (Bio-acoustics data), Canadian Hydrographic Service (Navigation Chart field sheets), Ontario Ministry of Natural Resources and Forestry (SCOOP 2013 data), and the County of Simcoe (2012 DEM). Figure 3.2.1 gives an example of a bathymetric map created as input to the habitat suitability model. The file is a bathymetry map (in elevation) of Penetang Harbour, in Severn Sound using a 10 x 10 m grid cell for interpolation of depth values. Depth for each grid was calculated using the Chart datum of 176.0 masl.

### 3.3 Substrate Layer & Particle Size Analysis

Ninety-nine (99) ponar samples were selected from over 150 samples collected by the University of Windsor and DFO from across Severn Sound, during the summer of 2016. Of the selected sites, all samples were analyzed for loss on ignition (LOI) and mechanically sieved for grain size classes of gravel, pebbles, sand, silt, and clay. Flow cytometry was used to distinguish between silt and clay size fractions (4 cm – 63 µm).

All sediment samples across Severn Sound were composed mainly of sand (1000 – 63 µm, range = 52.7% to 100%, mean = 95.2% and standard deviation of 12.0). Southern and northern shorelines substrate were not significantly different ($p > 0.5$) from each other, however the differences became more drastic when comparing only coarse sand (500 µm, $p = 0.057$) with larger percentages of coarse sand in samples from the northern shore. The percentage of gravel was also not significantly different between samples collected on the southern and northern shores ($p > 0.8$) however mean % was higher on the southern shore (3.52 %).

Samples with grain size smaller than 63 µm were successfully characterized using flow cytometry to analyze grain size from 63 µm – 4 µm. Flow cytometry analysis revealed that the smallest size fraction (< 63 µm) in all samples was mainly composed of clay (< 4 µm), although the percentages of clay and silt varied between samples. The percentage of clay from each sample ranged from 0 % to 86.2 % with a mean of 67.4% and a standard deviation of 14.1. The percentages of clay and silt in samples collected on the southern and northern shores were not significantly different ($p > 0.2$). For figures and details regarding ponar sampling processing, please refer to Appendix A3 entitled “APPENDIX_A3_Substrate Processing_(UWIN)”.

Sidecan surveys covered over 200 km of shoreline in Severn Sound. Mosaics of the data to interpret substrate in selected areas of Severn Sound were produced to augment substrate interpretation. Appendix A2a entitled “APPENDIX_2a_Sidescan_Sonar_methods&processing_(HabitatSolutions NA)” describes the interpretation of substrate using this system.
Combining these data with the ponar information as well as ROVER data, SSEA sonar data and SSEA imagery interpretation (see APPENDIX_A4b&c SAV and substrate interpretation and EAV and substrate interpretation methods) a 10m grid layer of substrate was assembled. Appendix B3a, entitled “APPENDIX_B3a_PenHarb_Substrate_Sources_(HAB_SOL_SSEA_UWIN_DFO)”, shows the substrate sources of data available for Penetang Harbour. To illustrate the method, a map series of substrate categories in Penetang Harbour is provided in Figure 3.3.1a-c as input to the habitat suitability model (see below).

### 3.4 Vegetation layer

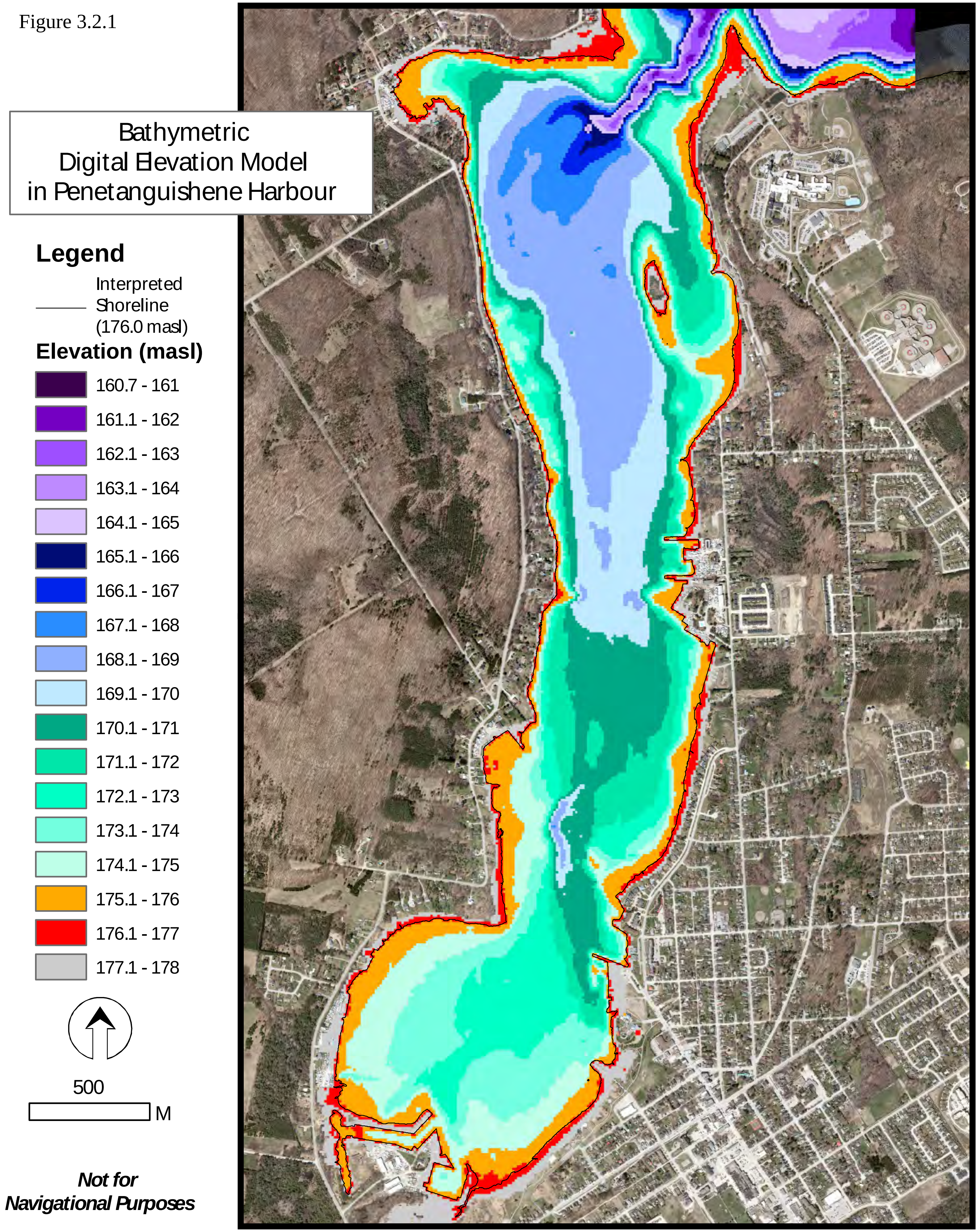
Aquatic Vegetation (EAV&SAV) was estimated as the presence or absence of EAV or SAV at a location and then averaged into a 10 x 10 m grid cell. The data sources used in interpreting EAV and SAV that were available for Penetang Harbour are shown in Appendix B2, entitled “APPENDIX_B2_PenHarb_ROVER_SAV_COVERAGE_2011-2016_(UWIN) and Appendix B3b, entitled “APPENDIX_B3b_PenHarb_Aquatic_Veg_Sources_(UWIN_SSEA_DFO)”. Generally, % SAV cover is denser in protected areas of the harbour – especially the shallow portion of the bay in the south (Figure 3.4.1). There is less SAV near the mouth of the bay, where the shoreline is more exposed and also where depth limits light penetration and plant growth. Sparse vegetation cover in shallow areas, visible in aerial images can convey known shoals and high exposure areas of the bay. The assembled vegetation cover layer was used as input to the habitat suitability model.

### 3.5 Fishing Surveys

Electrofishing surveys took place in the summer and fall. All captured fish were identified by the field crew and individually weighted and measured up to a total of 20 individuals per species before being returned to the water resulting in a total of 7, 412 individual fish records from 2016. In 2016, a total of 38 species of fishes (Table 3.5.1) were caught including a first record in the area for Grass Pickerel (*Esox americanus vermiculatus*) a federally listed Species at Risk.

Index of Biotic Integrity (IBI) scores and metrics were generated for each electrofishing sample and average scores per transect ± standard error (SE) by location and year (see Appendix B4). IBI values at all locations sampled in 2016 fell within the good range (60-80) indicating that the nearshore fish community in Severn Sound is relatively healthy and balanced with a high species diversity. IBI values increased significantly over time at Penetanguishene Harbour; the average IBI score per transect in 2016 was 80 compared to 60 in 1990. The IBI scores at Hogg Bay (67-73) and Green Island (65-66) remained relatively unchanged among sampling years but increased from the earlier surveys at Matchedash Bay (64-70) and Sturgeon Bay (57-63). IBI scores at new sampling locations ranged from 60-77 (see Appendix B4).

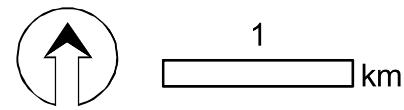
Figure 3.2.1




Produced by the Severn Sound Environmental Association with Elevation/Depth data supplied in part from the University of Windsor (ROVER), Env. Canada - Department of Fisheries and Oceans (Bio-acoustics), Canadian Hydrographic Service (Navigation Chart), Ontario Ministry of Natural Resources and Forestry (SCOOP 2013) and the County of Simcoe (2012 DEM). 2016 Ortho-photo background imagery © County of Simcoe, 2017. While every effort has been made to accurately depict the modelled Bathymetric Elevation data, errors may exist. Any party relying on this information does so at their own risk.

Figure 3.3.1a

# Coverage of Substrate (Clay, Silt and Sand) in Penetang Harbour



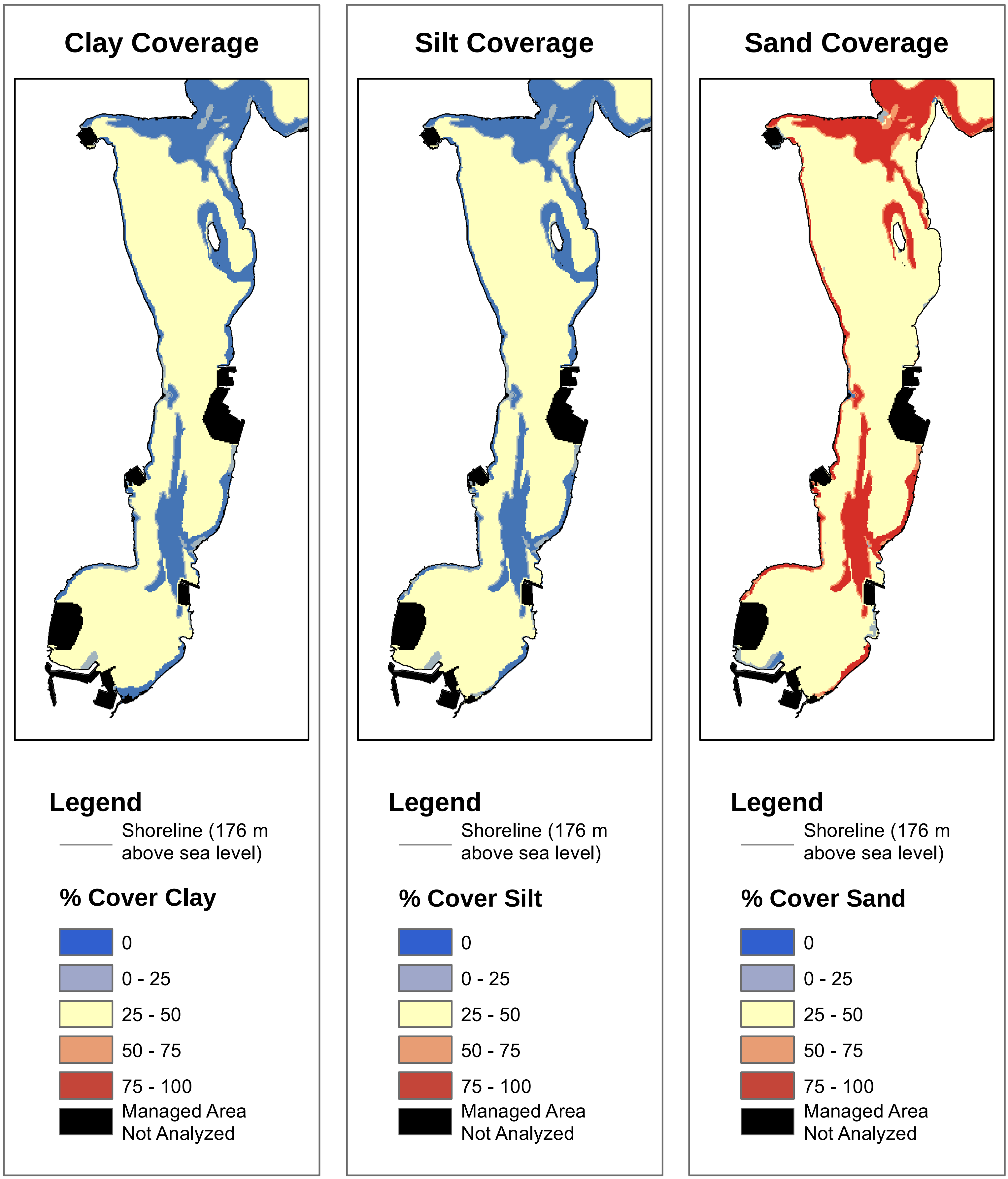
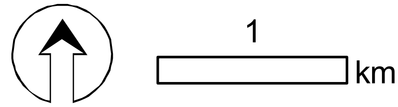
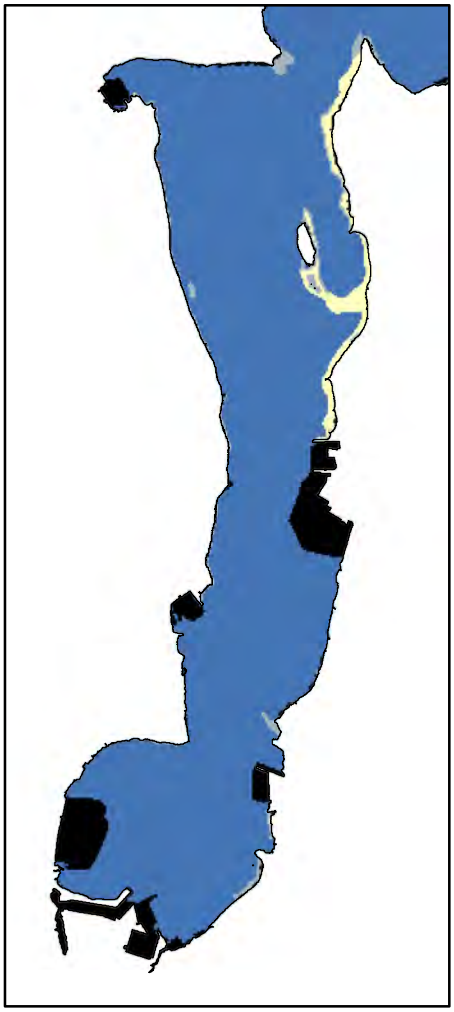



Figure 3.3.1b

# Coverage of Substrate (Gravel, Cobble and Boulder) in Penetang Harbour




## Gravel Coverage



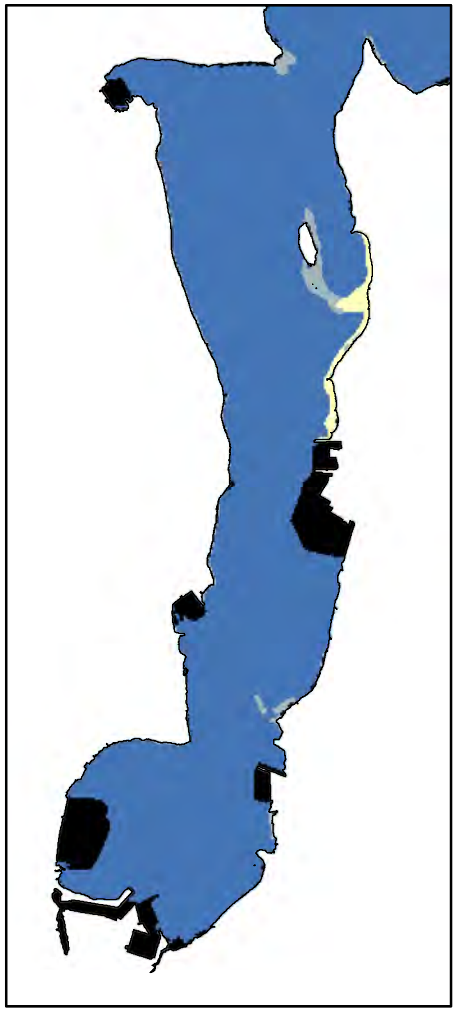
**Legend**

Shoreline (176 m above sea level)

**% Cover Gravel**

- 0
- 0 - 25
- 25 - 50
- 50 - 75
- 75 - 100
- Managed Area Not Analyzed

## Cobble Coverage



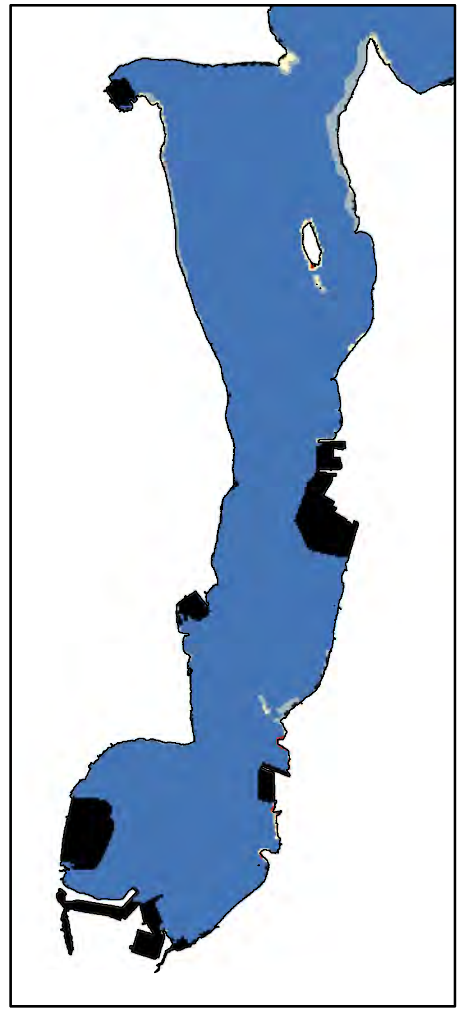
**Legend**

Shoreline (176 m above sea level)

**% Cover Cobble**

- 0
- 0 - 25
- 25 - 50
- 50 - 75
- 75 - 100
- Managed Area Not Analyzed

## Boulder Coverage



**Legend**

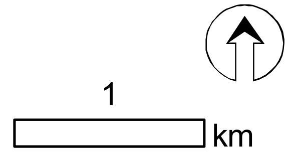
Shoreline (176 m above sea level)

**% Cover Boulder**

- 0
- 0 - 25
- 25 - 50
- 50 - 75
- 75 - 100
- Managed Area Not Analyzed

Figure 3.3.1c

# Coverage of Substrate (Rubble and Bedrock) and Depth Ranges in Penetang Harbour



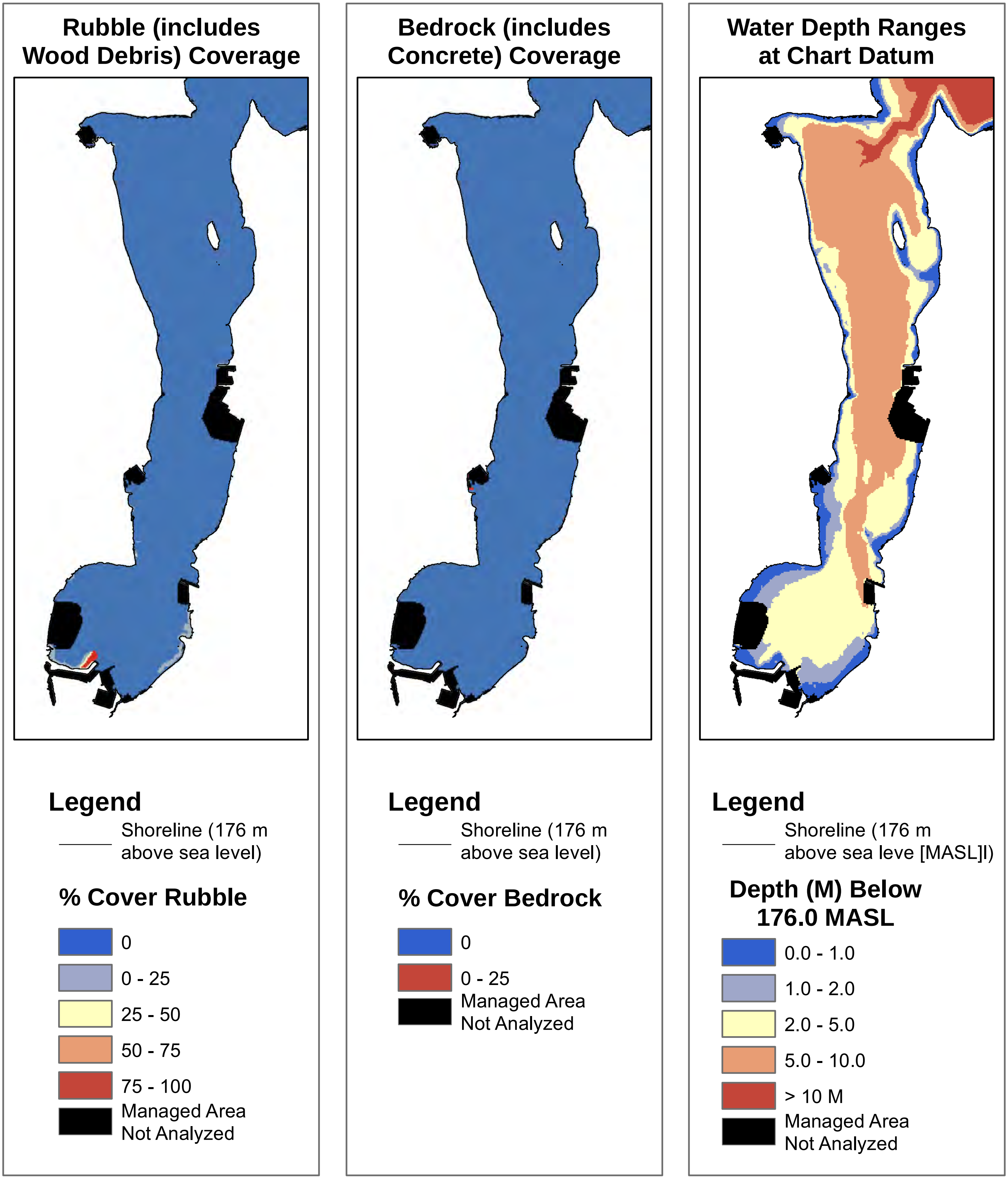
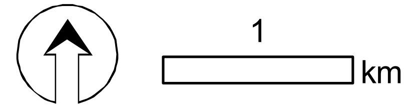



Figure 3.4.1

# Coverage of Aquatic Vegetation in Penetang Harbour



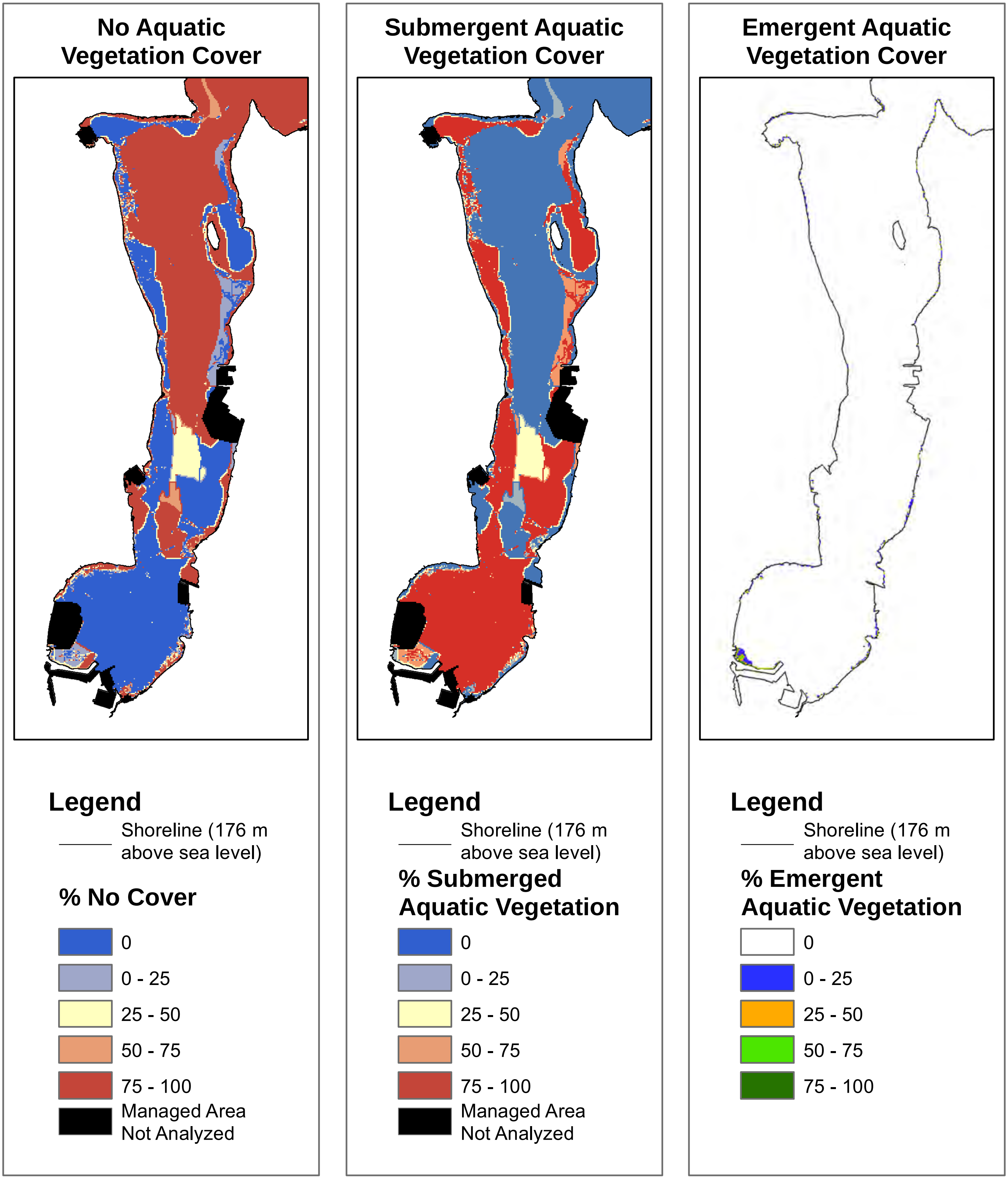



Table 3.5.1. Fish species (common name) caught in electrofishing surveys 1990-2016 in Severn Sound, ON. X denotes that the species was caught that year.

| Common Name | 1990 | 1992 | 1995 | 2002 | 2016 |
|---|---|---|---|---|---|
| Longnose Gar | | | x | x | x |
| Bowfin | x | x | x | x | x |
| Alweife | x | x | x | x | x |
| Gizzard Shad | x | | x | | x |
| Chinook Salmon | x | | | | |
| Rainbow Smelt | | | | | x |
| Northern Pike | x | x | x | x | x |
| Muskellunge | | | | x | |
| Grass Pickerel | | | | | x |
| Central Mudminnow | | | | x | x |
| Quillback | x | | | | |
| White Sucker | x | x | x | x | x |
| Silver Redhorse | | | | x | x |
| Goldfish | x | | | | |
| Common Carp | x | | x | x | x |
| Golden Shiner | x | x | x | x | x |
| Emerald Shiner | x | | | x | x |
| Common Shiner | | | x | | x |
| Blackchin Shiner | x | | x | x | x |
| Blacknose Shiner | | | | x | x |
| Spottail Shiner | x | x | x | x | x |
| Spotfin Shiner | | | | | x |
| Mimic Shiner | | | | | x |
| Bluntnose Minnow | x | | x | x | x |
| Creek Chub | | | | x | |
| Striped Shiner | | | | | x |
| Brown Bullhead | x | x | x | x | x |
| Stonecat | | | | x | |
| Tadpole Madtom | | | | | x |
| Banded Killifish | | | | x | x |
| White Perch | | | x | x | x |
| White Bass | x | | | | |
| Rock Bass | x | x | x | x | x |
| Pumpkinseed | x | x | x | x | x |
| Bluegill | | | | x | x |
| Northern Sunfish | | | | | x |
| Smallmouth Bass | x | x | x | x | x |
| Largemouth Bass | x | x | x | x | x |
| Black Crappie | x | x | x | x | x |
| Yellow Perch | x | x | x | x | x |
| Walleye | x | | x | | x |
| Logperch | x | | x | | x |
| Brook Silverside | x | | x | x | x |
| Round Goby | | | | | x |
| Tubenose Goby | | | | | x |
| **Total** | **25** | **13** | **23** | **28** | **38** |

In-kind data sets from the University of Windsor and OMNRF provided an additional 17 fyke net and 1753 trapnetting sites, respectively, for multiple years. These data will be included in future analyses of fish communities and stressors, and habitat suitability modelling.

3.6 Habitat suitability layer

The habitat suitability classification example for Penetang Harbour provides a demonstration of the methods developed as part of this project. As per Section 2.7 above the grid layers of depth, substrate and vegetation cover have been used to generate a habitat suitability classification of the entire Harbour (Figure 3.6.1). For an explanation of the methods that were used to calculate the habitat suitability index values, see the report " APPENDIX_A6_ Composite_Suitability_Index_Method_(SSEA) "

The highest habitat suitability scores were found in the vicinity of the shallow discharge of Copeland Creek, a cold-cool-water stream located in the south end of Penetang Harbour (maximum HSI of 0.828). The substrate at this location was estimated at 50% sand and 50% silt. The vegetation cover was 100% at this location. Extensive areas of high habitat suitability are located in the shallow south end of the Harbour where extensive plant beds are located.

The lowest HSI was found at the entrance to the Harbour where the depth is greater than 10m, depths below the growth zone of aquatic plants.

The grid approach allows the area (or percent) of habitat of each HSI category to be calculated easily, once the classification has been performed. The summary (Table 3.6.1) indicates that Penetang Harbour has 34 % of the total area, at a water level elevation of 176.0 masl, that has high habitat suitability. The low habitat suitability noted in the Harbour is due to deeper waters where plant growth is light limited (>7m) and near shore areas with coarse substrate along exposed shorelines or shorelines altered during the low water level phase of Georgian Bay (1999-2013) occur. The model can be re-run at a higher water level, such as experienced during 2016 to illustrate the effect of water level fluctuations. This feature was not possible with previous modelling efforts due to relative depth information.

Table 3.6.1 Penetang Harbour - Summary Results for Habitat Suitability Output

| Suitability Classification | Range Min. | Range Max. | Avg. Suitability | Max. Value | Area (km²) | Area % |
|---|---|---|---|---|---|---|
| LOW | 0 | 0.234 | 0.052 | | 2.09 | 54 |
| MEDIUM | 0.234 | 0.523 | 0.38 | | 0.44 | 12 |
| HIGH | 0.523 | 1 | 0.62 | 0.828 | 1.29 | 34 |
| Total | | | | | 3.82 | 100 |
| Note: Does not include Managed Area or Areas above 176 m above sea level. | | | | | | |

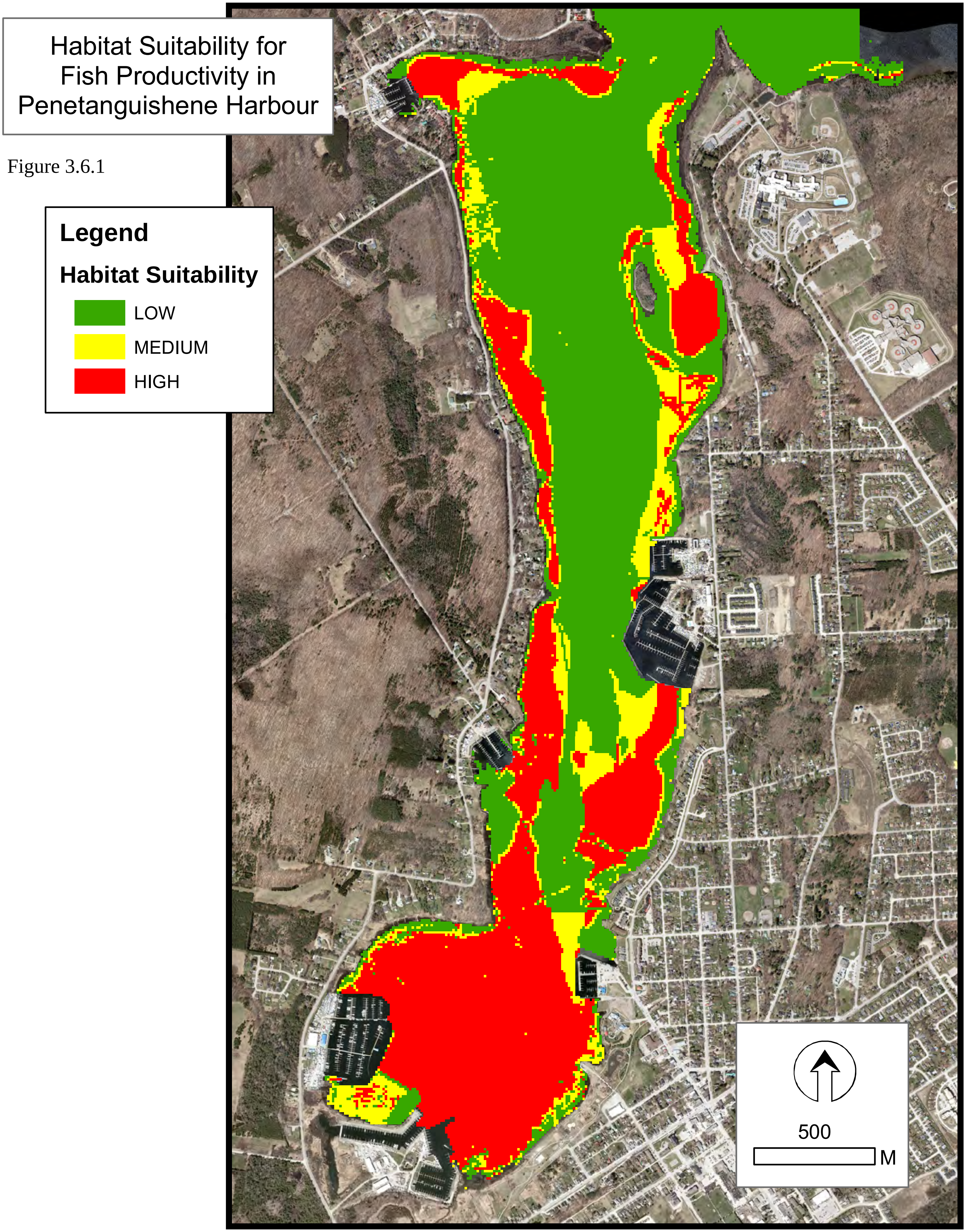



Figure 3.6.1

Produced by the Severn Sound Environmental Association with data supplied in part from the University of Windsor, Habitat Solutions North America, Fisheries and Oceans Canada, Ontario Ministry of Natural Resources and Forestry and the County of Simcoe. 2016 Ortho-photo based data © County of Simcoe, 2017. While every effort has been made to accurately depict the interpreted Substrate/Sediment feature data, errors may exist. Any party relying on this information does so at their own risk.

3.7 Relating stressors (GLEI to habitat suitability) (predicting joint effects)

*3.7.1 Wetland Fish Sampling and Condition*

Ciborowski et al. (2015) compiled and summarized the results of fish wetland surveys carried out by the Great Lakes Environmental Indicators (GLEI), Coastal Wetland Monitoring Program (CWMP) and McMaster University Coastal Wetland Index (MUCWI) project at various periods from the late 1990s to the present. The range scores for fish condition differed, both among Lake Huron regions as a whole and among wetlands with sub-regions. Within Severn Sound, the fish biological index scores were almost uniformly Excellent in areas that were remote from agricultural and development influences. However, the index scores varied greatly among wetlands within the more developed portions of the area, reflecting the local influences of agriculture, land development, water quality, and ecological footprint.

Assessments of biological condition derived from the MUCWI surveys tended to generate higher scores than assessments derived from CWM or GLEI. The CWM assessment scores were intermediate, ranging from Good to Excellent, and the GLEI scores tended to be lowest, often indicating Poor conditions (Fig 3.7.1.1). These differences are largely a reflection of the scale of assessment and intended use of the biological measures. The CWM and MUCWI biological indices are calibrated against stress measured in a wetland at the time of sampling and anthropogenic disturbances that are situated adjacent to wetlands. In contrast, GLEI indices are calibrated against land use stresses in a wetland's contributing watersheds. Furthermore, CWM biological scores are scaled to individual plant zones within wetlands whereas MUCWI and GLEI scores relate to an entire wetland complex.

Because compilation of the in-water habitat condition (HEAT) and local water quality estimates is still in progress, the relative diagnostic value of landscape (GLEI stress), water quality (WQI) and aquatic habitat (HEAT) is still being assessed. Nevertheless, the differences in predictive power of the different measures of fish community condition will be of tremendous value in guiding spatially explicit assessments of the Severn Sound coastal margin. These will help managers determine areas most in need of protection as well as candidate sites that would benefit more from different forms of restoration. The data will be equally useful in creating municipal and regional development and conservation plans.

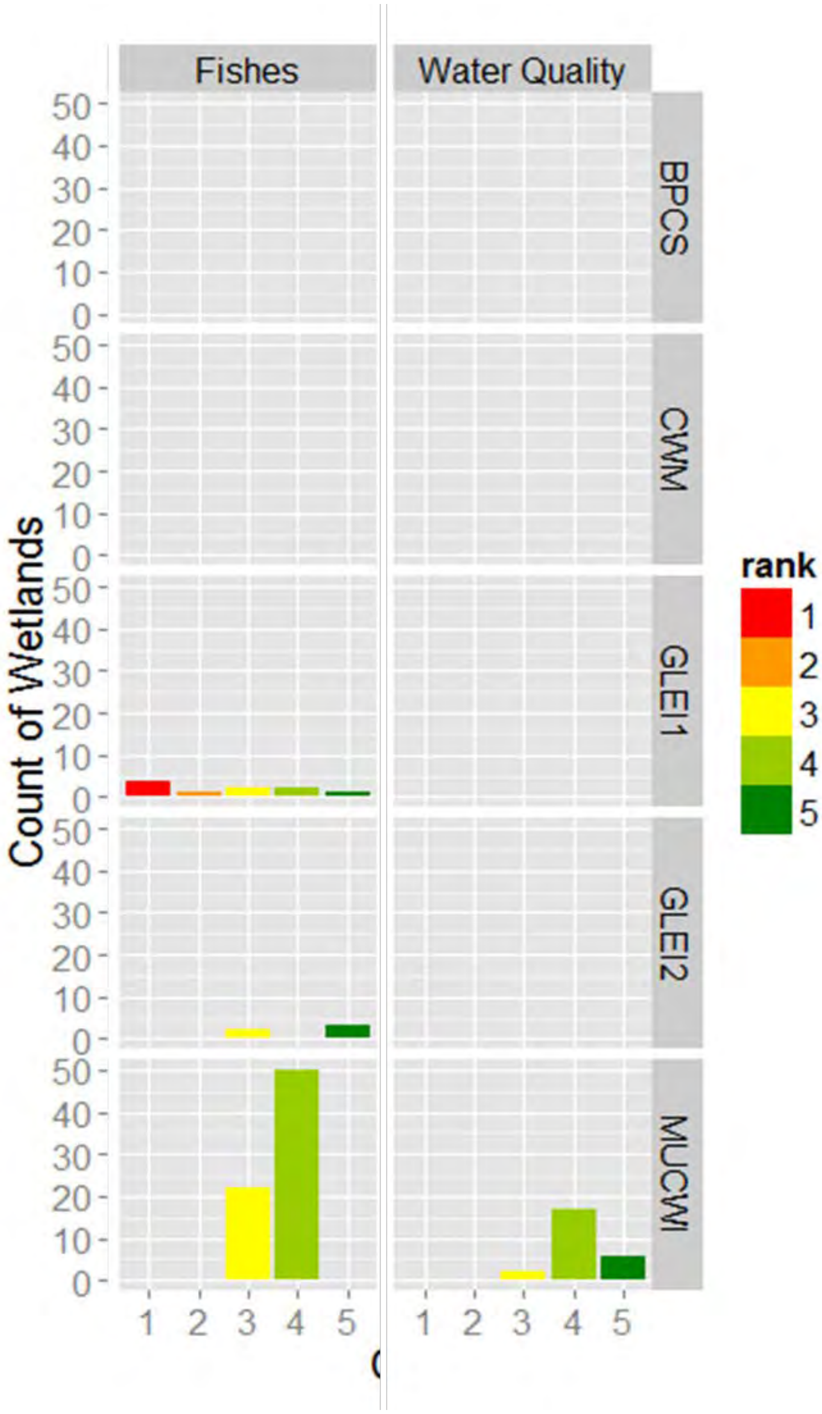



Figure 3.7.1.1. Comparison of fish condition scores for 5 projects for wetlands in Southeastern Georgian Bay. Red=poor, dark green = excellent, x-axis is rank.

*3.7.2 Analysis of OMNR Nearshore Fish Trapping data*

Using trap-net data (from the OMNR) we performed a scatterplot of species abundance and determined species richness plateaued when 20 or more fishes were caught in a sample (Figure 3.7.2.1). This ensured comparable data across sites. Using sites with fish counts of 20 or more, we discarded rare taxa (those present in 15 or fewer of the samples) to prevent any skew in the data. The sites (17) with the lowest stress scores (taken from the GLEI database) were considered as 'reference'.

A cluster analysis of the common species (15 spp.) produced two major clusters (Table 3.7.2.1). Cluster A was dominated by rock bass; cluster B was dominated by largemouth bass, bowfins, and longnose gar. Analyses are incomplete, however, the next steps will be to determine which environmental variables correlate with the two clusters (substrate, temperature, etc.).

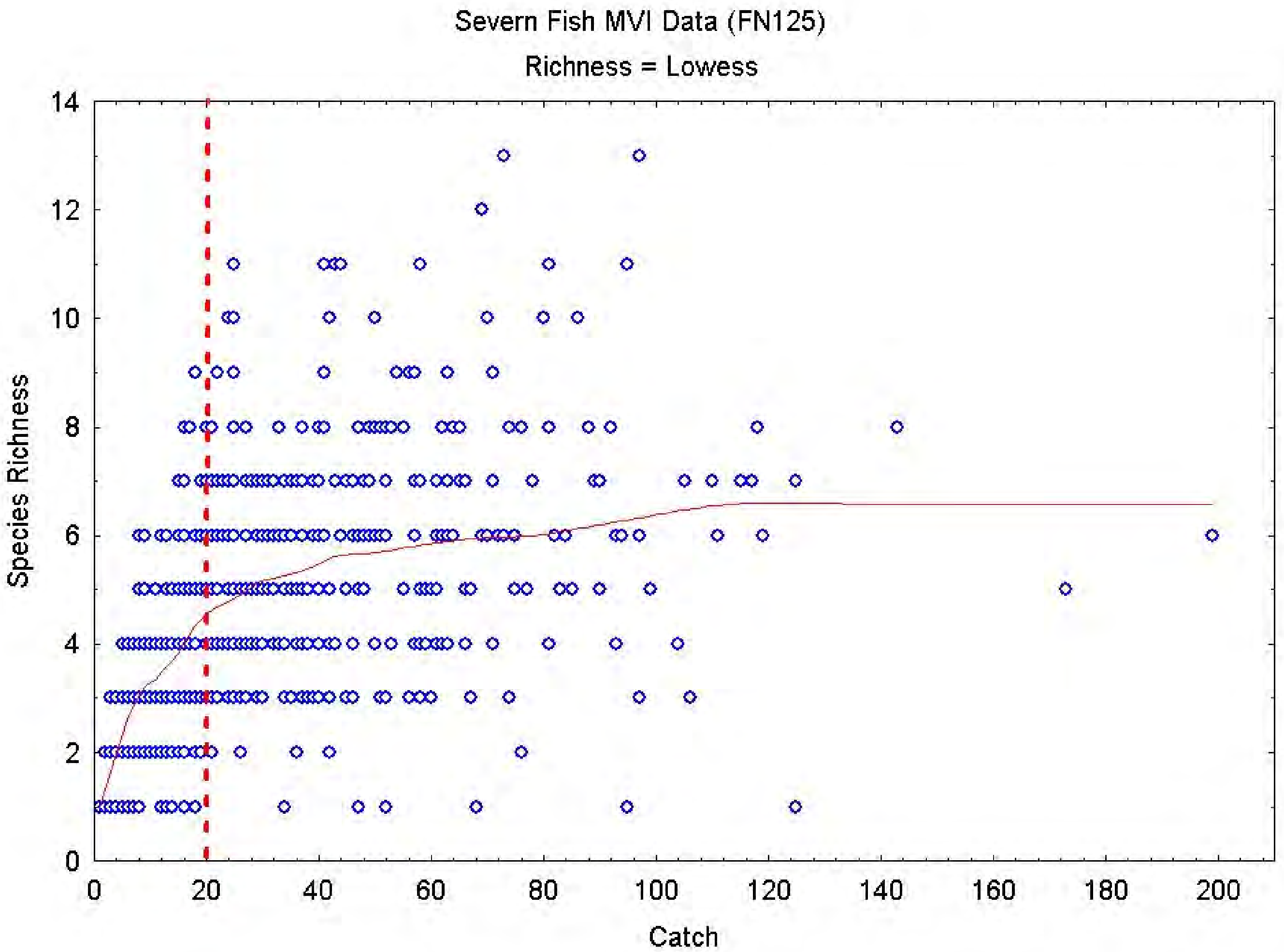



Figure 3.7.2.1. Richness vs Catch. Scatterplot of species richness (y-axis) and fish caught per sample. Data is from the OMNR trap-net dataset (multiple years). Richness plateaus at ~ 9 species after 20 or more fish are caught in a sample.

Table 3.7.2.1. List of common species in trap nets containing 20 or more fishes, their relative frequencies overall and their mean and SE relative abundances (octaves) in groups A and B identified by cluster analysis of catches in reference condition traps. The F-ratio is an indication of the relative between vs. within cluster differences for each species.

| Species | Rel. Freq. (%) | Mean±SE Rel Ab (Octaves). Ref. Cluster A | Mean±SE Rel Ab (Octaves) Ref Cluster B | F-ratio |
|---|---|---|---|---|
| *Esox lucius* | 86 | | | 1.07 |
| *Micropterus dolomieu* | 83 | | | 0.72 |
| ***Micropterus salmoides*** | **72** | **0.523±0.358** | **4.424±0.408** | **48.3** |
| *Sander vitreum* | 66 | | | 0.06 |
| ***Ambloplites rupestris*** | **62** | **5.094±0.36** | **0.632±0.402** | **64.2** |
| *Pomoxis nigromaculatus* | 48 | | | 0.33 |
| *Lepomis gibbosus* | 46 | | | 2.21 |
| *Catostomus commersoni* | 19 | | | 0.74 |
| *Exox masquinongy* | 16 | | | 0.08 |
| ***Amia calva*** | **10** | **0** | **1.08±0.720** | **3.95** |
| *Perca flavescens* | 9.9 | | | -- |
| *Cyprinus carpio* | 9.3 | | | 1.75 |
| ***Lepistosisus osseus*** | **6.5** | **0** | **0.934±0.653** | **3.59** |
| *Morone americana* | 6.5 | | | -- |
| *Amiurus punctatus* | 5.8 | | | -- |

*3.7.3 Analysis of DFO electrofishing data*

IBI analyses of the fish community data collected by the DFO in 2016 are summarized in section 3.4, however, we compared the IBI scores with GLEI stressors (% agriculture, % development, %combined ag and dev). In all 3 comparisons we observed no strong relationship among IBI scores across stressor gradients (Figure 3.7.3.1 for an example).

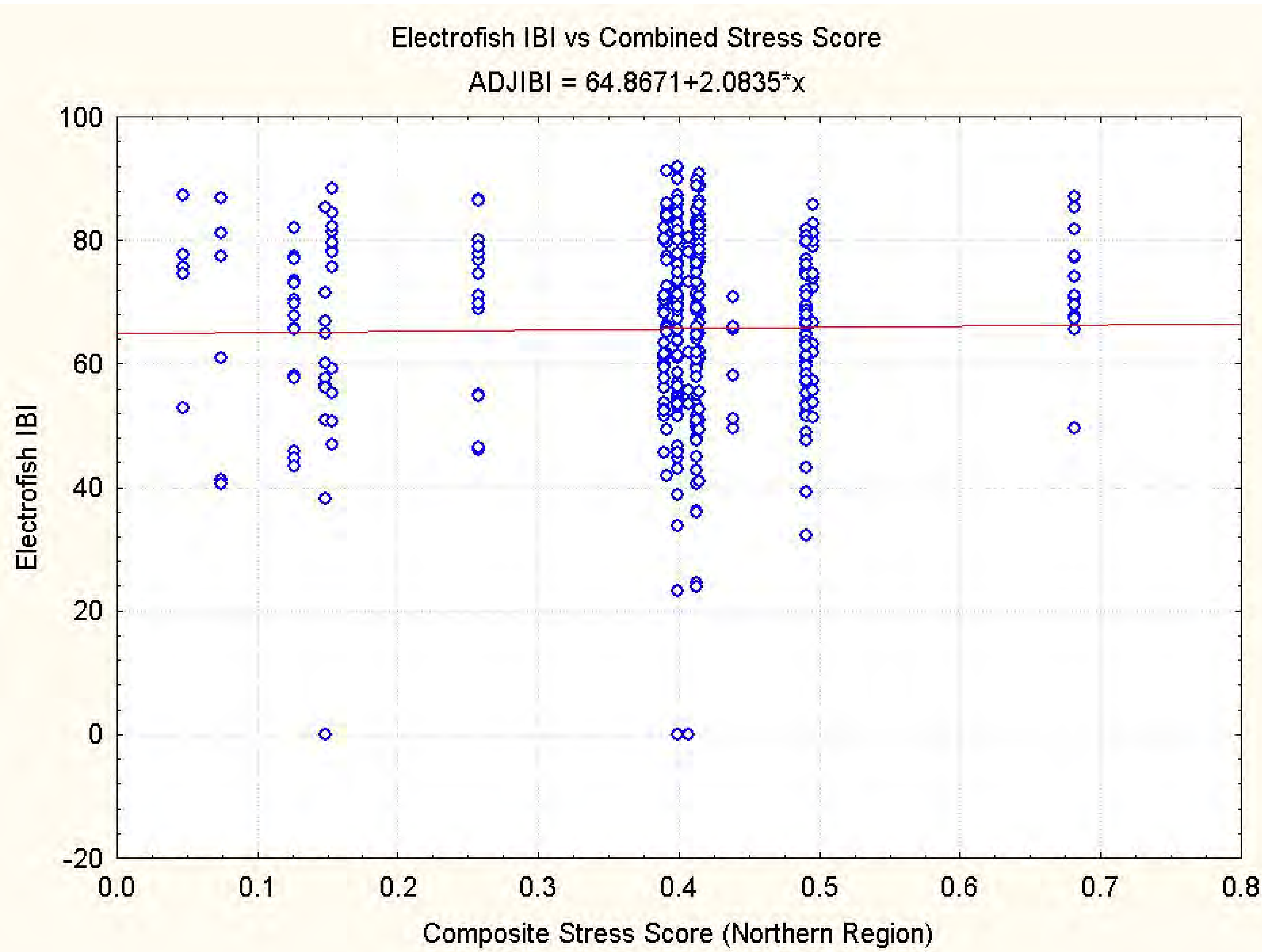



Figure 3.7.3.1. DFO electrofishing IBI vs. Composite stress score (% agriculture & % development) Scatterplot. IBIs score from 100 (excellent) – 0 (very poor).

## 4. Discussion

### 4.1 Fish Communities and Health of the AOC

According to Christine Boston (DFO electofishing project coordinator), Index of Biotic Integrity (IBI) values at all locations sampled in 2016 fell within the good range (60-80) indicating that the nearshore fish community in Severn Sound is relatively healthy and balanced with a high species diversity. IBI values increased significantly over time at Penetanguishene Harbour; the average IBI score per transect in 2016 was 80 compared to 60 in 1990. The IBI scores at Hog Bay (67-73) and Green Island (65-66) remained relatively unchanged among sampling years but increased from the earlier surveys at Matchedash Bay (64-70) and Sturgeon Bay (57-63). IBI scores at the new sampling locations ranged from 60-77.

It is clear from fyke net sampling, conducted through the University of Windsor during 2015 and 2016, that the alien invasive species tubenose goby is present throughout Severn Sound. The impact of this species on the fish community is the subject of research on the Great Lakes in general. The Grass Pickerel (Esox americanus vermiculatus), a federally listed Species at Risk, was noted in Severn Sound for the first time, during DFO electrofishing.

### 4.2 Fish Community Response to Stress

What is the best predictor of a healthy fish community? This was the ultimate question that informed the conceptual framework for this project. Figure 4.2.1 shows our complex Structural Equation Model (SEM) for the project. We collected or measured several environmental and biological variables to calculate measures of habitat, water and watershed quality (large red circles in the SEM). These three aggregate variables will then be compared to see which variable is the greater driver of fish community quality (blue circle in the SEM). To make this comparison we also needed fish community data. We had several sources of data (DFO electrofishing, University of Windsor Fyke netting, OMNR trap netting) but due to an accelerated timeline for the project we had insufficient time to coordinate a workshop among key collaborators and harmonize our datasets to allow comparisons among different methodologies. Once we have harmonized these datasets and their calculated measures of quality (IBI, Multi-variate index, or habitat suitability score) we will compare these values to capture the variability within the system as well determine see which score is best at detecting changes in fish community quality. This section will be updated as we continue analyses.

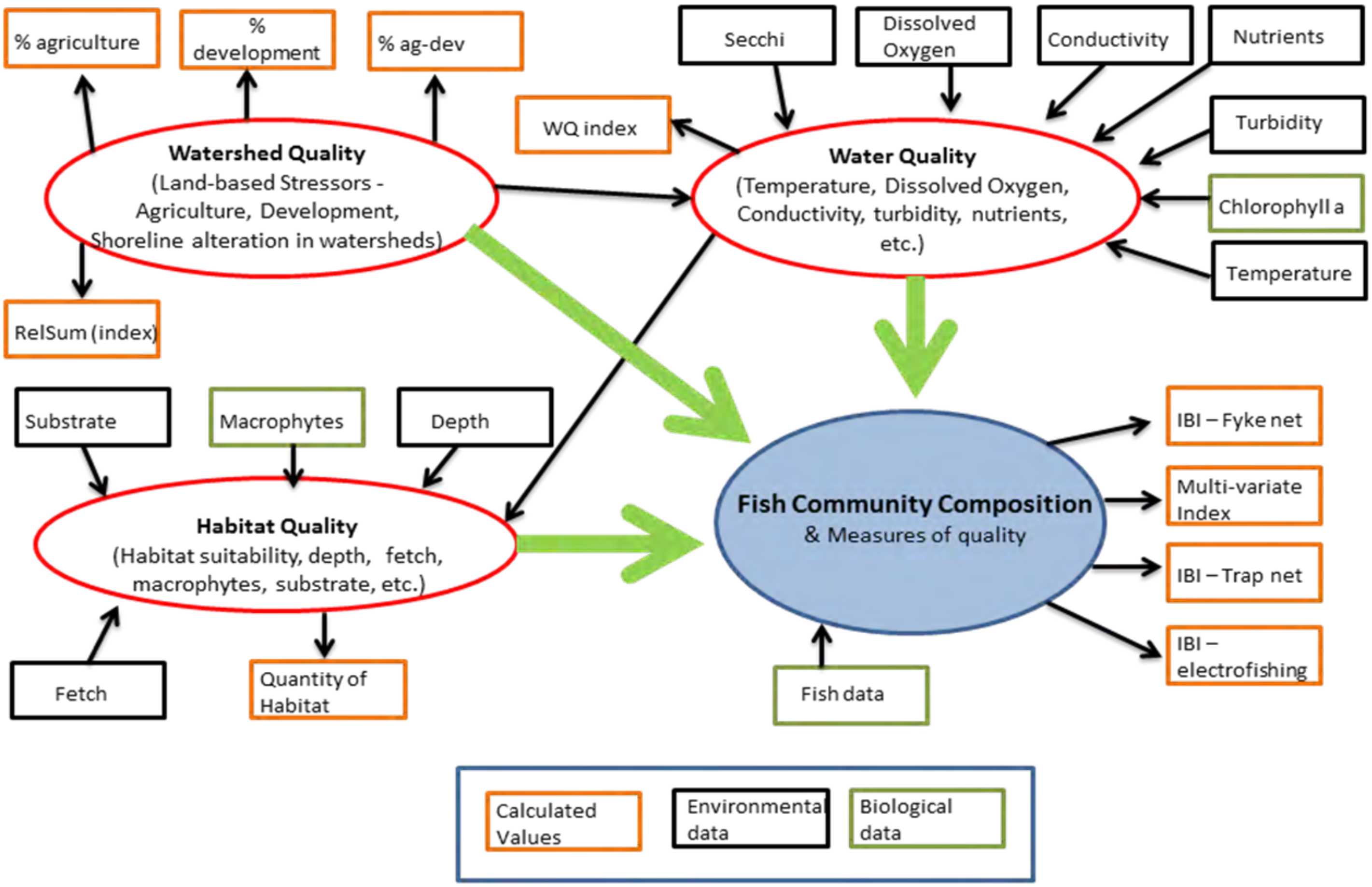



Figure 4.2.1 Complex Structural Equation Model (SEM) of determining the health and 'quality' of fish communities in Severn Sound. This is the conceptual framework for our project.

4.3. Integration into the Baseline Assessment of Nearshore Habitat in the Great Lakes

We collected a suite of environmental variables (Bathymetry, substrate texture, fetch, temperature, etc) and biological data (fish communities, aquatic plant density) to characterize the quantity and quality of habitat in Severn Sound ON. Although data interpretation is ongoing, the use of our data and method of delineating habitat has applications outside of our study area. There are a number of initiatives, such as the Baseline Assessment Task Team, that are looking to inventory and assess nearshore habitat on the Great Lakes.

The Baseline Assessment is a multi-agency collaboration under the Great Lakes Water Quality Agreement (GLWQA) Annex 2 (The commitment to develop a Nearshore Framework under the Lakewide Management Annex) to provide an overall assessment of the state of the nearshore in the Great Lakes.

The goals of this initiative are (draft Baseline Assessment document 2016):

1. Inventory existing surveys of habitats and species.
2. Develop recommendations for assessing net habitat gain based on information in the Biodiversity Conservation Strategies, existing programs, and supporting science.
3. Identify, evaluate, and recommend new approaches for spatial monitoring of habitat extent and condition, including remote-sensing, to conduct baseline surveys

The program will run on a 5-year cycle, delineating and classifying habitat, assessing condition, and ground-truthing with biological surveys. These mirror our initial objectives:

- *map and evaluate the coastal margins of Severn Sound, classify the habitat on the basis of depth, substrate characteristics, and macrophyte distribution,*
- *produce digital maps delineating the distribution of fish habitat and its quality*
- *assess the condition of fish communities using electrofishing and fyke netting techniques, and collaborate with OMNR in the interpretation of trap net data*
- *assess the relative importance of habitat quality, water quality and contributing watershed quality in determining fish community condition (assessed by various capture methods) at a site*

The data collected and analyzed for this project would undoubtedly contribute to the baseline assessment and the methods detailed in this report could be adapted for use.

The scale of the Baseline Assessment is much larger than that of this project and will rely on remote-sensing to cover the entire Great Lakes; however, field-level verification will be required. Severn Sound is ideal because: it's diverse habitat within a small geographical range, it's historical and biological significance (former Area of Concern (AOC) and an excellent case study for changes in quantity and quality of habitat), and with the completion of our field work Severn Sound is data rich for the evaluations the assessment team wishes to make. We are currently engaged with the Baseline Assessment group and hope to share our results and methods guide this initiative.

## 5. Recommendations for future work.

Working with geospatial data is often time consuming. In this project, we collected several environmental variables to create several geospatial data layers. As future project funding allows, these layers will be further processed into new products to answer questions about the driving factors of fish community assemblages in Severn Sound and habitat suitability classification. Data interpretation is time intensive and requires GIS expertise and local knowledge of conditions. Enough data was collected to fuel several years of GIS interpretation, provided project funding can be arranged. Given the short timeframe of the project (just over 1.5 years) we were unable to process all of the collected data. We have worked out the procedures necessary to continue interpreting data and have focused our work on areas of interest (Penetang Harbour), however, more time is needed to interpret our data. Additional work is needed to:

- complete gaps in sonar and imagery of nearshore coastal areas for mapping interpretation
- process seasonal temperature data
- pursue hydrodynamic factors influencing habitat with models
- relate fish habitat metrics to fish community information

Due to the late award of the project, the original intention of interpreting the habitat of extensive sites around Severn Sound was modified to focus on "data rich" areas such as Penetang Harbour where the methods of mapping and evaluating coastal habitat could be demonstrated and improved methods could be worked out for use in future evaluations. As a result of this project, a great deal of data has been collected that will serve future evaluations of Severn Sound nearshore habitat suitability and provides a basis for ongoing fish community evaluations. The success of this project has also relied greatly on the in-kind support of our partners (DFO, SSEA, OMNRF, and University of Windsor). Data sharing has also fostered true collaboration among partners and will facilitate future collaborations. The results of our project will also provide resource agencies and municipalities with an improved basis for management of nearshore areas to protect and enhance fish habitat in future.

### 6. Acknowledgements

We would like to thank SSEA, DFO, ECCC, and the University of Windsor crews for this collaboration. We made excellent connections and hope to continue collaborating on nearshore habitat into the future. We would like to thank the Ontario Ministry of Natural Resources and Forestry (Arunas Liskauskas' lab, Fisheries Biologist with OMNRF Upper Great Lakes Management Unit) for use of their spring trap net data in Severn Sound. We'd like to thank local marinas in the Severn Sound municipalities. Special thanks to Scudder Mackey and Stephen Goudey, our original ROVER collaborators, for help and logistics in getting the ROVER platform where it is today.

ROVER was designed and created by Stephen Goudey, thank you for your training and advice. Scudder Mackey also provided technical and logistical support as well as a number of in-kind services and expenses. ROVER earned its sea-legs in Penetang Harbour; current and future work would not be possible without funding and support from the Severn Sound Environmental Association. Special thanks to Li Wang for manipulating and creating maps with our GIS data.

Lastly, we'd like to thank our sources of funding, the South Georgian Bay Lake Simcoe Cleanup Fund (Environment Canada and Climate Change), DFO, SSEA (and supporting municipalities), NSERC (For initial ROVER development), and the OMNRF. Huronia Community Foundation and RBC Securities Foundation also funded equipment used by SSEA as an in-kind to this project.

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**Appendices**

APPENDIX_A1_Bathymetric_Mapping_Component_(SSEA)
APPENDIX_A2a_Sidescan_Sonar_Methods&Processing_(Habitat Solutions NA)
APPENDIX_A2b_ Fish Habitat Imagery Interpretation for Severn Sound_(SSEA)
APPENDIX_A3_Substrate_Processing_(UWIN)
APPENDIX_A4a_Estimating_percent_cover_of_SAV_using_sonar_output_from_Reefmaster_software_in_Severn_Sound_(SSEA)
APPENDIX_A4b_Method_of_Interpreting_Submergent_Aquatic_Vegetation_and_Substrate_in_Severn_Sound_shoreline_areas _(SSEA) [using aerial and surface level imagery]
APPENDIX_A4c_Method_of_Interpreting_Emergent_Aquatic_Vegetation_and_Substrate_in_Severn_Sound_Coastal_Margin_Areas _(SSEA) [Using Remotely Sensed Data for Areas Requiring Interpretation]
APPENDIX_A5_Severn_Sound_Hydroacoustics_Report_(DFO)
APPENDIX_A6_ Composite_Suitability_Index_Method_(SSEA)
APPENDIX_B1_Progress_Map_Series_(SSEA/UWIN/DFO)
APPENDIX_B2_PenHarb_ROVER_SAV_COVERAGE_2011-2016_(UWIN)
APPENDIX_B3a_ PenHarb_Substrate_Sources_(HAB_SOL_SSEA_UWIN_DFO) [Penetang_Harbour_example]
APPENDIX_B3b_PenHarb_Aquatic_Veg_Sources_(UWIN_SSEA_DFO) [Penetang_Harbour_example]
APPENDIX_B4_C_Boston_Nearshore_fish_assemblages_in_Severn_Sound_Summary_(DFO)

**Mapping, Evaluating, and Predicting Changes in Coastal Margin Aquatic Habitat in Severn Sound and Southeastern Georgian Bay -** Prepared by: Lex McPhail, SSEA

# APPENDIX_A1_Bathymetric_Mapping_Component_(SSEA)

The project uses a combination of underwater sonar, imagery and field verification to assess the lake bottom habitat along selected areas of coastline in Severn Sound and Nottawasaga Bay. Fluctuations in Georgian Bay water levels can have an effect on the reliability of the resulting geospatial models used for the assessment. Water level phases of Georgian Bay range from an average of approximately 1.5 m above to 1.5 m below the Chart Datum of 176.0 metres above sea level. A method to compensate for this fluctuation was implemented by converting and calibrating collected depth data to elevations in metres above sea level. This is further enhanced by combining the depth elevation data with ground surface elevation data to create a continuous (lake bottom to surface) bathymetric elevation model. By using a continuous elevation model, the lake bottom habitat can be modelled at different water level elevations.

In general, the workflow that is required to produce a continuous elevation model is:

- Process the surface elevation point based data
- Calibrate the depth point data with the elevation data
- Integrate the surface and depth elevation data sets
- Create a continuous Digital Elevation Model

The resulting elevation model will facilitate the interpretation of bottom habitat along selected nearshore areas.

## Processing of Surface Elevation Point Based Data

Surface elevation data is available in many forms but for the purpose of this project, the South Central Ontario Ortho-photo Project (SCOOP) 2013 elevation point cloud data was ideal. There are several GIS processing tasks involved when working with the point cloud data. The data has to be imported, classified and filtered before it can be used with the other depth data sets. The steps that were used to process the surface point data have been provided. The tasks were completed manually but automation of some of the redundant routines is possible.

### Elevation Data Based on SCOOP 2013

OMNRF's SCOOP 2013 Semi-Global Matching (SGM) elevation point cloud data and ortho-imagery meets several criteria that make it the best available dataset when compared with other data that is available. The criteria that were used to assess each dataset included: consistent coverage of the study area, year of capture, resolution, scale of analysis and additional processing required for integration with depth. All dataset were available at the time of the project.

Table 1 - Comparison of elevation datasets considered for integration with depth data

| Dataset | Coverage | Year | Resolution | Scale | Additional Processing |
|---|---|---|---|---|---|
| Provincial DEM V3.0 | Entire Area | Updated to 2013 | 30 m DEM | Provincial | Correction of Shoreline |
| FRI Point Cloud | North Portion | 2007 | 60 cm Point Cloud<br>5 m DSM raster | Local | DEM and Digitize Shoreline |
| SCOOP 2013 | Entire Area | 2013 | 40 cm Point Cloud | Local | DSM, DEM and Digitize Shoreline |
| County of Simcoe Terrain Dataset | South Portion | 2002 enhanced to 2012 | 20 m DTM<br>5 m DEM | Local to Regional | Calibration with DTM and breakline |
| Provincial DEM V2.0 | Entire Area | Enhanced in 2002 | 60 m DTM<br>10 m DEM | Regional to Provincial | Correction of Shoreline |

In the Severn Sound area, there is a physiographic divide between the Canadian Shield in the North and the Lower Great Lakes – St. Lawrence Lowlands in the South. This divide has had an influence on the types and quantity of geographic data that have been collected in the past. Contrasts between the Severn Sound North and South Watersheds include land cover, population and government jurisdictions and have resulted in different priorities and opportunities for collecting Ortho-photo based data. SCOOP 2013 data provides consistent coverage for the entire Severn Sound and Nottawasaga Bay Study area.

Another dataset that was looked at and encompasses the entire Severn Sound area is the Provincial Digital Elevation Model (PDEM). The PDEM Version 1.0 and 2.0 is a 10 m resolution grid and was originally derived from a 60 m resolution Digital Terrain Model. The PDEM Version 3.0 is the current version and is available at 30m. The scale of these Provincial data sets is too small for meaningful local scale analysis.

Other elevation datasets that were assessed were similar to SCOOP 2013 in that they were based on Ortho-photos. Prior to 2013, in the County of Simcoe (South Shore), “leaf off” Ortho-photos were collected in 2002 and 2008 by OMNRF and County of Simcoe. The County of Simcoe also captured Ortho-photos in 2012. Products of the

2002 and 2012 projects included terrain based datasets including breaklines, a Triangulated Irregular Network model, a 5 m resolution Digital Elevation Model and Digital Terrain Model elevation point data.

On the District of Muskoka shore of Severn Sound, Ortho-photos were captured in 2007, 2008 and 2012. The 2007 photos are near infra-red ortho-photos and were taken for Forest Resource Inventory (FRI) mapping purposes by OMNRF. Part of the FRI initiative involved the production of a 60 cm resolution SGM elevation point cloud dataset. The FRI data was not available in the South and has not resulted in the production of a DEM or breakline type data.

The SCOOP 2013 elevation data was selected as the base for elevation modelling along the coastal margin of Severn Sound for several reasons.

- Consistent SCOOP 2013 data is available across the entire study area.
- It is the most recent aerial photo and elevation dataset available at the time of the study.
- Detailed point cloud data can be used to create a Digital Surface Model and with some processing, a DEM which will facilitate integration with depth point data.
- Resolution is adequate for local scale analysis

Additional benefits of using the SCOOP 2013 data are:

- GIS analysis tools are available which enhance the capabilities of existing ArcGIS software to work with the elevation point cloud data. Other, more costly software solutions are also available but require additional resources and were not used for this project.
- During 2013 Georgian Bay was at a low water level phase. SCOOP 2013 elevation points that were captured along the shoreline would most likely be underwater during high water periods. This helps with calibrating the numerous elevation and depth datasets. When depth survey data was collected during high water periods, depth elevation points may coincide with the SCOOP 2013 (low water period) elevation points.
- Additional surface information can be interpreted from the point cloud including areas of emergent vegetation.

## LAS Tile Processing

The SGM point cloud data was received in the LAS file format. The LAS file format was developed to handle LIDAR data but supports the exchange of any 3-dimensional data. The extent of each SCOOP 2013 LAS tile is approximately 1.5 km in length by 2.0 km in width and covers an area of 3.0 km². With an elevation point ground sample distance of approximately 40 cm, one tile can consist of over 10 million points. This type of data provides a large amount of detail but requires computer resources with adequate processing power and storage capacity. Large data files take more time to process.

For this project, the focus of analysis was on the Georgian Bay shoreline. Inland areas were not modelled. The portions of the Severn Sound and Nottawasaga Bay shoreline areas were subdivided into sections of a manageable size. The selection of areas was based on the availability of sonar, underwater imagery and fish survey data. After a section of nearshore was selected, LAS file processing was completed for the area. Working with between two and four LAS tiles at one time provides an acceptable amount of coverage while not straining computer resources.

LAS files were processed using ESRI's ArcMAP 10.2.2 with the 3D and Spatial Analyst extensions. In ArcMap, background processing was disabled to alleviate errors that occurred with the tools that were used during the processing steps. Additional tools that were used are components of LAS tools (the same tools are available in the 3D Sample Tools toolbox) and Lidar Tools for ArcMAP 10.2. Lidar Tools for ArcMap 10.3 is also available.

There are several steps involved when working with the LAS data.

**Setup and Importing**

- Identify area of interest (AOI) and find the LAS files that cover the AOI using the SCOOP 2013 index
- Create a folder to hold all processing data (processing folder). Note: the name should be representative of the area being worked on.
- Copy the individual LAS files into the folder
- Create a "back up" subfolder in the processing folder and back up the LAS files
- Create a LAS Dataset using ArcCatalog (right click on the processing folder and select new|LAS Dataset)
- Add the individual LAS files to the LAS Dataset
- Add the LAS Dataset to ArcMAP|Data View

**Limiting the Extent of a LAS Dataset and Removing Overlap**

Each SCOOP 2013 LAS file covers an area of approximately 3.5 km² and contains approximately 14 million elevation points. The large size of LAS data has an effect on computer resources and time required to process the data. For this study, it is recommended that an area of interest, with a limited extent, be established early in the process. This will reduce the time it takes to process an area by reducing the number of points in the LAS dataset.

In addition to limiting the LAS extent, overlapping areas between flight lines were removed. SCOOP 2013 LAS data was captured in flight lines that run in a North/South direction. Each flight line overlaps the adjacent flight line by approximately 15 %. The area that is removed is the outside half of the overlapped area from the East and West sides of each LAS tile.

To reduce the extent of the LAS dataset and the overlapping area between flight lines, polygon rectangles can be used to reassign the class codes of points that fall within the polygon. The codes are then filtered to remove the reassigned class codes.

The method used to limit the LAS extent is as follows:

- Create a polygon shapefile that consists of rectangle masks of the area to be removed (reclassified) for each flight line.
- Digitize the rectangles creating masks that cover the outside half of the overlapped area from the East and West sides of each LAS tile.
- Make a backup of the LAS files before reclassifying the class codes of the overlapping areas.
- Using the 3D Analyst|Data Management|LAS Dataset|Set LAS Class Codes Using Features tool, all elevation points that coincide with the overlap mask rectangles will be reassigned a code value of 7 (noise).
- Convert the LAS Dataset to a LAS file using the Lidar Tools|Manage|LAS To LAS tool. This enables processing by LAS Tools.
- Using LAS Tools|las2las(filter) select the LAS file that was created in the previous step. Note: LAS file can only be selected using the browser button provided.
    - Set “filter by classification or return” to “drop classification”
    - Set “coordinate or return number(s)” to “7” (noise)
    - Input the required file and folder name and run the tool.
- Create a new LAS Dataset and add the LAS file (no overlapping data)

## Classification of Ground and Non-Ground Features

To produce a bare earth elevation model, a classification of the point cloud digital surface model data is required. The non-ground points are included in the production of a DSM raster but will be eliminated from the DEM. Lidar Tools was used for this procedure. Georgian Bay open water is classified and removed after the Ground Classification process has been completed.

- Classify ground using Lidar tools|Classify|Ground.
- There is a limit to the number of points that can be processed. The display can be set to reduce the number of points that are processed by performing the analysis only on the extent of the display. During testing, the display was set to a scale of 1:2000. This may vary depending on monitor/window size.
- Set the scale to an appropriate value
- Run the Ground tool.
    - o Check the “Limit display extent” check box.
    - o The parameters that were used are Ground Sample Distance = 25 m (slightly larger than largest building) and z threshold = 0.25 m (maximum vertical difference allowed between neighboring ground points)
    - o If the time to process takes more 10 minutes, reduce the size of the display extent.
- For the first area (display extent), confirm that the LAS file Ground classifications are satisfactory before completing the entire LAS Dataset.
    - o Symbolize the LAS Dataset by classification code
    - o Ensure the majority of tree canopy and building points remain unclassified.
    - o Check that the coverage of ground points is sufficient enough to yield a reasonable DEM. Ground point coverage in wooded areas with dense canopy will be low. In some circumstances, emergent vegetation and low lying shrubs may be classified as ground. Georgian Bay open water may be classified as ground but it will be addressed later.
    - o If there is a substantial error with the classification, remove the LAS file from the LAS Dataset and replace with the backed up LAS file (original).
    - o Adjust the threshold values.
    - o If there are minor discrepancies, the point classes can be changed manually by using the Edit|Change Class Code and Flags dialog in the LAS Dataset Profile Viewer.
- Pan to another area ensuring the extent scale remains constant then run the Ground tool again. Pan and run the Ground tool through the remainder of the LAS dataset.

*Notes*

- If the Ground tool does not classify ground points (all points remain non-ground) then close and restart ArcMAP and start the process again.
- There is a possibility of overwriting the Ground classification to the LAS file. Back up the LAS files regularly.

## Infilling No-data Areas with Other Elevation Sources

In areas where there is a lack of ground elevation points, additional points can be appended to the LAS Dataset from other data sources. The no-data areas normally occur where points have been reclassified in forested areas where there is a thick tree canopy or around buildings. The data that was used to infill the no-data areas was: along the South shore, in the County of Simcoe (COS), the COS 2012 DEM converted to points at a 5 m resolution; and along the North shore, in the District of Muskoka, the OMNRF's Provincial DEM converted to points at a 10 m resolution. The process that was used to infill no-data areas is as follows:

- Ensure all LAS files are within the same folder. If required, copy the LAS files to a new folder and create a new LAS Dataset using the copied LAS files as the inputs.
- Convert the LAS files to a multipoint shapefile using 3D Analysis Tools|Conversion|From Files|LAS to Multipoint
- Convert the Multipoint shapefile to a 10 m resolution raster grid using Conversion Tools|To Raster|Point to Raster
- Convert the raster grid to a polygon shapefile using Conversion Tools|From Raster|Raster to Polygon. Leave the Simplify Polygon checkbox unchecked.
- Select features from CHS/PDEM or COS elevation points layer(s) that intersect with the point cloud 10 m polygon coverage. From the attributes table, switch the selection.
- Export the selected point into a new shapefile.
- Convert the shapefile to a 3D feature shapefile
- Convert the 3D feature shapefile to a text file
- Convert the text file to a LAS file
- import the LAS file into the LAS Dataset

## Removal of Georgian Bay Open Water

Georgian Bay open water may meet the criteria for ground due to its lack of vertical relief. The SGM method does not reliably penetrate water and water elevations should be eliminated from the analysis. Open water points will be replaced with calibrated depth elevation points or where there is inadequate coverage, Canadian Hydrographic Service depth sounding elevation points.

Eliminating open water elevation points from the LAS Dataset requires a shoreline polygon layer that is consistent with the SCOOP 2013 Ortho-photo data. Initially, other shoreline data including the 2002 and 2012 breakline data, and the NRVIS Ontario Hydrographic Network waterbodies layer were considered for this purpose. These datasets were not utilised primarily because they are based on data that was collected at different water levels than the SCOOP 2013 data. The main focus of this project component is to produce a flexible model based on water levels and there is no alternative dataset. It was necessary to create a new shoreline polygon layer derived from the SCOOP 2013 Ortho-photos and elevation point cloud. There were several steps that enhanced the digitizing process which was based on standard aerial photo interpretation techniques.

- Point cloud data was symbolized in separate category ranges at 0.2 m above and below the estimated water level.
- All other elevation symbols were set to null colour.
- A scale of greater than 1:250 was used for digitizing.
- The Shoreline polygon layer was digitized following what was interpreted as shoreline from the SCOOP 2013 Ortho-photo. The elevation points were used as a guide especially in gradually sloped and emergent vegetation areas.
- In cases where emergent vegetation plants (cattails) registered an elevation that is more than the shoreline elevation, the shoreline was digitized to not include the emergent plants. This information could be used to identify emergent plant areas inundated by water at a later stage.

To remove the Georgian Bay open water from the complete ground classified LAS Dataset the following procedure was followed:

- Make a backup of the LAS files before reclassifying the open water class codes
- Using the 3D Analyst|Data Management|LAS Dataset|Set LAS Class Codes Using Features tool, all elevation points that coincide with the open water polygon layer will be reassigned a code value of 9 (water).
- Convert the LAS Dataset to a LAS file using the Lidar Tools|Manage|LAS To LAS tool. This enables processing by LAS Tools.
- Using LAS Tools|las2las(filter) select the LAS file that was created in the previous step. Note: LAS file can only be selected using the browser button provided.
    - Set “filter by classification or return” to “keep classification”
    - Set “coordinate or return number(s)” to “2” (ground)
    - Input the required file and folder name.
- Create a new LAS Dataset and add the LAS file (no open water)

### Visual Inspection

With a complete ground classified LAS Dataset with no Open Water, a visual inspection will identify discrepancies that may require manual classification.

- Symbolize the LAS Dataset by classification code
- With the LAS Dataset layer on top of the 2013 Ortho-photos, look for features that should be classified as ground but were not.
    - Feature examples include islands, depressions, clearings and steep embankments (marinas, pits and quarries).
    - Also look for features that should not be classified as ground such as buildings.

Reclassify manually with the Edit|Change Class Code and Flags dialog in the LAS Dataset Profile Viewer if necessary.

The resulting LAS Dataset can be used with the depth elevation data as a guide to help calibrate the depth data and also as part of the continuous elevation model.

## Calibrate the depth point data with the elevation data

Prior to the integration of bottom elevation and ground surface elevation, a number of steps are required to convert the sonar depth datasets to elevation. This process was applied to the ROVER and SSEA Sonar data collected during 2015 and 2016 using sonar processing and visualization software (Reefmaster).

### Reefmaster Procedure

For selected areas, each ROVER/SS_Sonar Track (SL2) was processed and corrected using the edit function of the Reefmaster software. The manual procedure to process the data is interpretive in nature and produces four distinct layers of point data. In addition to the raw, uncorrected data, the datasets that were created using depth in metres are Corrected Bottom Depth and Depth to Submerged Aquatic Vegetation (SAV) Canopy. Two qualitative datasets, Underwater Feature Flag and Data Error Flag were interpreted on for a small number of transects to enhance the output.

### Reefmaster Processing Steps

Create a folder structure that will hold all datasets. A copy of each Track will be housed in its own Track folder. Create a subfolder to house the output datasets (csv files) that will be exported.

In Reefmaster, for each Track, create a new workspace that will be saved to the corresponding Track folder on the hard drive.

For the current Track add the SL2 five times by importing GPS Assets. This may seem redundant but prevents overwriting previous edits in Reefmaster.  Tracks cannot be renamed in Reefmaster so using a consistent order for the output layers will facilitate the process. The recommended order is as follows:

1. Raw data (doesn`t get changed)
2. Corrected Bottom Depth
3. Depth to SAV Canopy
4. Underwater Feature Flag
5. Data Error Flag

An alternative option is to make five copies of the same SL2 Track on the hard drive and rename them appropriately. The five track copies would import into Reefmaster and would be easier to organize. The drawback is there will be five copies of the same SL2 file using up memory on the hard drive.

To edit a track, double click the track or right click|select edit. Turn on the sonar data view (Show Sonar) and show the track points. The track points will be adjusted manually using the Edit tool. Note: When editing, the original SL2 data is not altered or overwritten. All changes take place in Reefmaster and can be saved only by exporting the data (csv). Changes made are kept intact when the project is opened.

To edit the track points, where a depth correction or flag is required, either play the Sonar Track or use the scroll bar to advance the track and drag the tool cursor along the corrected path. Track points will snap to the cursor location along the Z axis. Note: editing Track points does not alter the point`s X and Y coordinates.

**Corrected Bottom Depth**

In dense areas of SAV, interference with the sonar reaching the bottom may result in erroneous depth readings. Corrections can be made to points that don`t coincide with the interpreted bottom.

**Depth to SAV Canopy**

SAV Canopy is interpreted to mark the estimated top of SAV. All track points are moved with the exception of points that don`t coincide with vegetation.

**Underwater Feature Flag**

Underwater features including large rocks, boulders, logs, bedrock and manmade features (eg. rock crib) that can be interpreted are flagged to facilitate transfer to GIS. Track points that correspond to any features are set to a depth of zero or moved to a depth that can be readily identified in the exported data string. Where available, the side scan data can also be used to help with the interpretation. The method requires taking notes on the feature and the order that the feature occurs in the data string. The resulting feature flag file (csv) is edited in MS Excel to append the feature description.

### Data Error Flag

On occasion, erroneous track data is recorded introducing errors into the data string. Identifying track points that are based on incorrect data may help with the QA/QC process resulting in enhanced correction or removal of the affected points. Examples of erroneous data include:

- Loss of GPS signal – Track point coverage becomes sporadic or point locations are incorrect. This is caused by line of sight interference with satellite coverage (bridges, adjacent tree cover, buildings and thick cloud cover).
- Wave Action – Sonar data appears rippled. Track point depths fluctuate and in large wave conditions (boat passing by) can cause errors in the depth readings to the point where they are unusable. Small fluctuations (ripples) can be corrected during the Bottom Depth and Depth to SAV processes and don't need to be flagged.
- Transducer/Chart Plotter Malfunction – Sonar profile is unusable. Track points are sporadic/incomplete coverage. Interference (AV tangling around transducer, propeller wash from boat motor or incorrect transducer alignment) with the transducer reduces the ability to capture correct data. Chart Plotter malfunctions include incorrect bottom lock settings and cable connectivity issues.

Data error flagging is completed using a similar to the method used for identifying Underwater Features. Track points that correspond to any errors are set to a depth of zero so they can be readily identified in the exported data string. The method requires recording the order that the error occurs in the data string. The resulting data error flag file (csv) is edited in MS Excel to append the error occurrence information. It is not necessary to identify the type of error.

In cases where sonar coverage is complete but there are gaps in the track point data or point locations are incorrect (shifted), enhanced corrections can be made. To correct the data, Latitude and Longitude coordinates are acquired using the Waypoint tool (Drop Pin). Several waypoints with user assigned ID numbers can be created and later exported to a csv file. Depth values can be measured using the measure distance tool but must be recorded separately, outside Reefmaster. The depths are appended to the csv file afterwards using the ID number as the link. The enhanced corrections can be appended to the track point data in Excel. This process can be cumbersome but does provide the ability to fill in gaps in priority areas.

## Data Export

After the data correction process is complete, the output data is exported to csv file by right clicking the target track and selecting "Write to File". Select CSV Format and then save the data to the appropriate folder. The filenames to use should correspond with the Track Name and the type of correction (Raw data, Depth to Bottom, SAV Canopy, Feature Flag or Error Flag).

All data is merged into one MS Excel file. The initial file to use for merging the data is the Raw Data file. Open the Raw data csv in Excel. Copy the data string from each relevant data type into the Raw Data file. Ensure the Raw Data file is saved as an excel file (xlsx). It is important to copy the data from each data type csv in the same record order as it originated from Reefmaster. In addition, do not sort any of the data until after processing is complete. The data being appended has a one to one relationship with the Raw data file. If there are additional records in any of the files, then an error has occurred and troubleshooting the data merging process is required.

Additional calculations using Excel should be completed prior to converting the data to a GIS layer. Corrections for transducer depth should be applied. Depth to bottom should be converted to Bottom Elevation by determining the average water elevation at the time of the survey. Water level data for the Midland water level gauge can be acquired online from Canadian Hydrographic Service (http://www.isdm-gdsi.gc.ca/isdm-gdsi/twl-mne/inventory-inventaire/interval-intervalle-eng.asp?user=isdm-gdsi&region=CA&tst=1&no=11445). Depth to SAV Canopy is converted to SAV Height by subtracting the Depth to SAV Canopy from Bottom Depth.

Bottom elevation is calculated by subtracting the total bottom depth from the water level elevation. The transducer (depth [TD]) is situated below the water surface by 0.07 metres for the ROVER and 0.10 metres for the SSEA Sonar. The distance between the transducer and the bottom (depth [BD]) plus the transducer depth equals the total bottom depth. CHS water level (WLCD) at the time of the survey is provided as a value relative to chart datum (CD). The water level value can be above (positive), at (equal to) or below (negative) chart datum. The CD for Lake Huron/ Georgian Bay is 176.0 metres above sea level. The formula to determine bottom elevation is applied to each point as follows:

$$(CD + WLCD) - (BD + TD) = BE$$

Where: CD = Chart Datum

WLCD = Water Level Chart Datum

BD = Bottom Depth

TD = Transducer Depth

BE = Bottom Elevation

The Track Point correction/alteration process that is completed for each sonar track will result in an excel spreadsheet consisting of fields for each data type. The spreadsheet can be exported to a shapefile or similar point based GIS layer.

## Integration of Depth Data with Elevation Data

Integrating the depth data with the elevation data creates a bathymetric elevation model that provides the capabilities to model fish habitat suitability at different water levels. Bottom depth that has been converted to elevation is appended to the final LAS Dataset that was completed during the LAS processing step. The bottom depth to elevation conversion was completed for the U. of Windsor's ROVER and Fisheries and Oceans Canada's (DFO's) BioAcoustics sonar track data. The sonar track data does not normally result in a complete coverage which can be problematic for modelling when developing an elevation model. For this analysis, additional bottom elevation data, based on Canadian Hydrographic Service depth sounding data, was added to the model in areas where there are gaps in data coverage.

After the depth and elevation data is appended to the final LAS dataset, a triangulated irregular network (TIN) is created using the 176.0 m above sea level shoreline as a breakline to help conform the model to the shoreline. The resulting TIN is then converted to a 10 metre elevation grid which is transferred to the corresponding vector grid mesh. The elevation data is later converted to depths at a predetermined water elevation and is used as one of the input parameters to generate a habitat suitability map using DFO's Habitat/Ecosystem Assessment Tool.

# References

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SCOOP 2013 Digital Elevation Model User Guide. 2015. Spatial Data Infrastructure Mapping and Information Resources Branch Corporate Management and Information Division Ministry of Natural Resources and Forestry

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APPENDIX_A2a_ Sidescan Sonar_Methods&Processing_(HabitatSolutionsNA)

## Sidescan Sonar – General Concepts

Sidescan sonar emits a narrow fan-shaped acoustic pulse that extends outward 90 degrees from the long axis of the towfish. Some of the sound that is emitted by sidescan sonar is absorbed by the lakebed; the rest is reflected off the lakebed. The amount of acoustic energy reflected off the lakebed is related to the relative hardness and texture of the lakebed. Generally, harder materials (bedrock, sand, metal) will give a stronger acoustic return than softer materials (silt, clay, or mud). Sound that is reflected back toward the towfish is called acoustic backscatter. The acoustic backscatter provides a detailed image of a narrow strip directly below and to either side of the towfish (Figure 1).

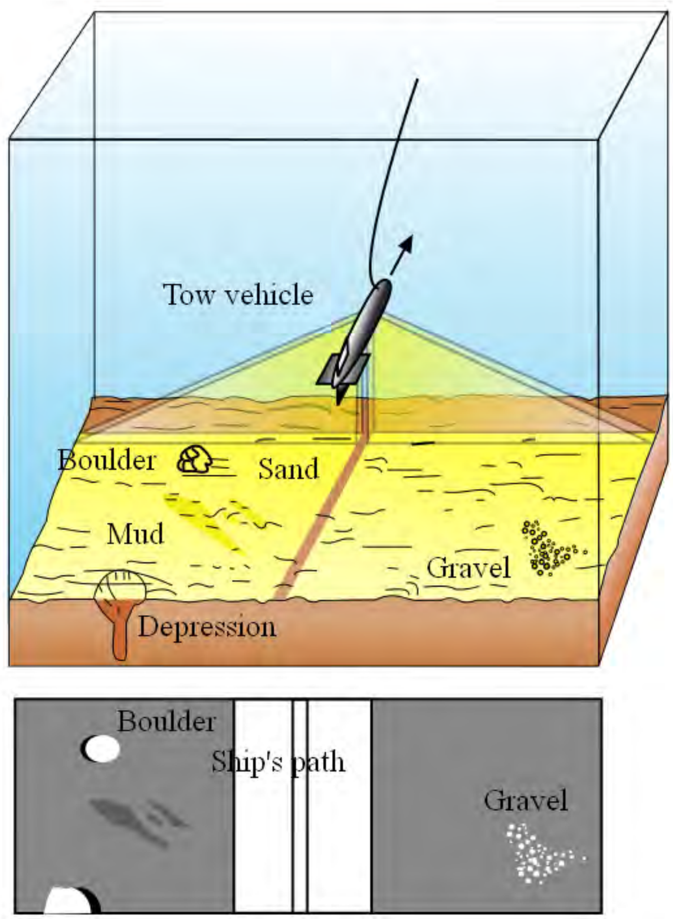


Figure 1. The yellow fan-shaped area illustrates the geometry of the acoustic pulse generated by the sidescan sonar towfish. Sound reflected off the bottom and received by the towfish (acoustic backscatter) produces a detailed acoustic image of the lakebed. These images are shown as a continuous waterfall display which is shown as a grey area, with corresponding bottom features depicted on the resulting image. http://woodshole.er.usgs.gov/operations/sfmapping

Sidescan sonar measures and records the backscatter characteristics (intensity, texture, pattern, and distribution) of lakebed deposits or other features on the bottom. These reflections are amplified, processed and displayed as a continuous set of images (called a waterfall display) as the sidescan sonar is towed along the survey trackline. Different backscatter responses are then interpreted to represent a particular substrate type or feature. Direct sampling or visual confirmation is usually needed to identify and verify the physical characteristics of the material providing the specific backscatter response. Given the ability of sidescan sonar to cover relatively wide swaths of the lakebed fairly quickly, it is an efficient tool that can be used to map substrate characteristic and features on the lakebed of interest (targets).
In many respects, sidescan sonar data are similar to aerial photographs taken of the earth's surface. The only difference is that the images are produced with reflected sound rather than reflected light. In areas where multiple survey

tracklines are run, the sidescan sonar data can be processed and merged together to form a seamless image of the lakebed. These integrated images are called sidescan sonar mosaics, and are analogous to air photo mosaics where aerial photography is pieced together to form a seamless image of the earth's surface.

Sidescan sonar mosaics typically have spatial coordinates (i.e. are georeferenced) and can be integrated with existing base maps, bathymetry (water depth data), and/or sampling data. Because the sidescan sonar data are georeferenced, it is possible to quantify substrate area and the geographic distribution of features of interest on the lakebed.

**Sidescan Sonar - Equipment**

Equipment used in this study included a Klein Marine System 3000 Dual Frequency Digital Sidescan Sonar (Figure 2) coupled with Klein Marine Sonar Pro® data acquisition software, a Trimble Model DSM 212H Digital Geographic Positioning System (DGPS) operating at a 1 Hz sampling rate, and Chesapeake Technologies SonarWiz.Map data processing and mosaicking software. The L3-Klein System 3000 is an integrated, 100% digital sidescan sonar system consisting of a stainless steel towfish that is towed behind or alongside the survey vessel, a Topside Processing Unit (TPU), and a PC Laptop running the Sonar Pro® sidescan sonar data collection software.

Figure 2. Image of L3-Klein System 3000 Towfish (courtesy Klein Marine, Inc.) Towfish resting in transport cradle ready for deployment during the Severn Sound study (photo Severn Sound Survey 2015)

Acoustic data are collected digitally by the sidescan sonar towfish and transmitted via coaxial cable to the TPU. The TPU is connected via a standard CAT-5 Local Area Network (LAN) to a Windows-based PC running the Sonar Pro® data collection software. The Sonar Pro® software integrates acoustic and navigation data and generates a real time center-out waterfall display of the sidescan sonar data as it is being collected (Figure 3).

The software provides the capability to identify, capture, locate, and save targets of interest "on-the-fly" as the sidescan sonar data are collected. The software also monitors towfish altitude off the bottom, produces real-time navigation plots, and provides digital readouts of critical data collection parameters as the survey progresses. All data is saved for later post-processing and analysis. For the Severn Sound surveys, digital navigation charts were loaded into the Sonar Pro® software to display the real time location of the vessel/towfish and swath width of the sidescan data collected. Digital navigation charts were also loaded into a laptop running Blue Marble Global Mapper® software which has real time navigation and trackline plotting capabilities. Navigation data were also recorded and saved on the navigation laptop.

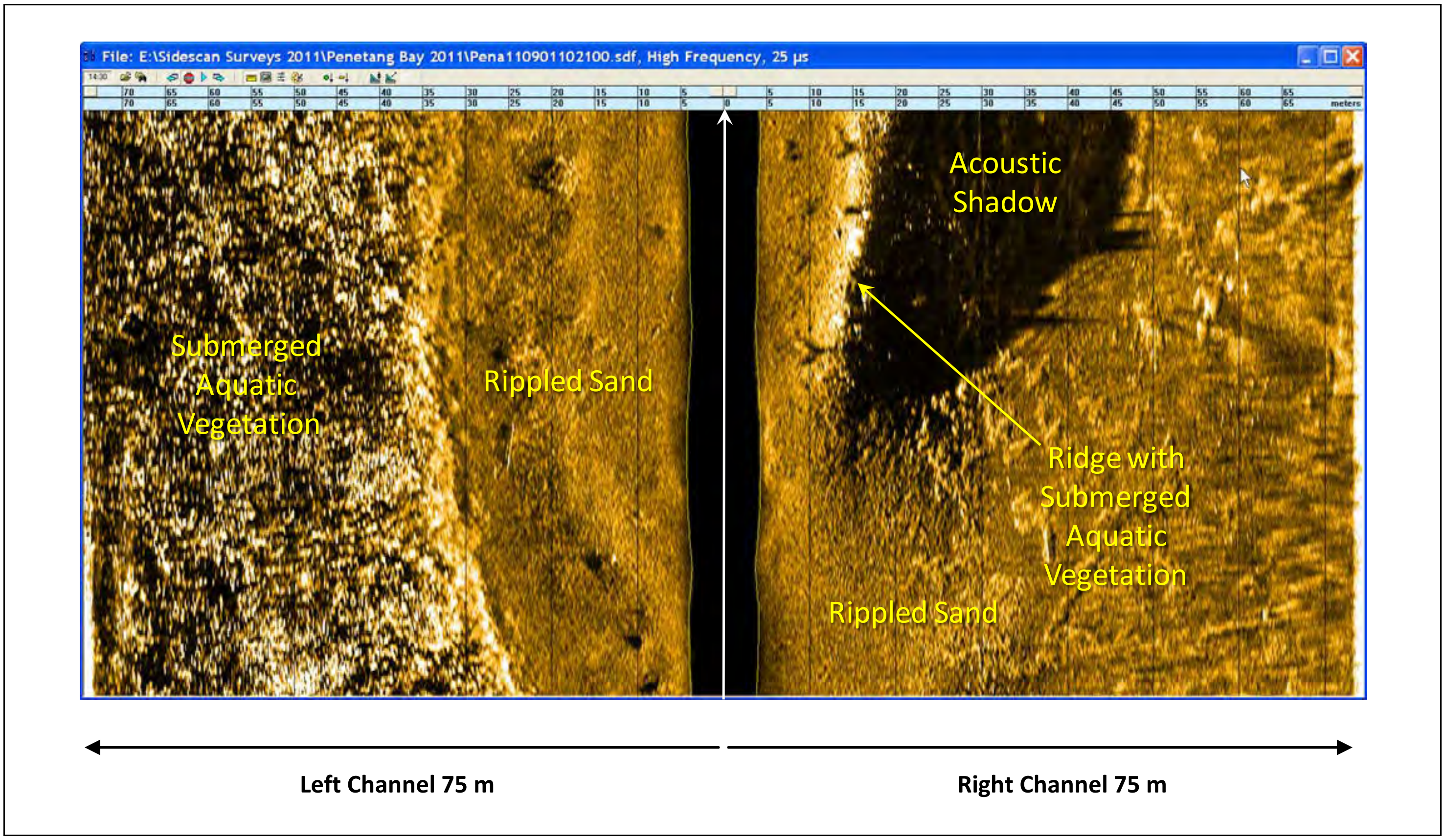


Figure 3. Typical Sonar Pro® center-out waterfall display. Sidescan sonar image scrolls downward as a function of vessel speed. Range setting is 75 m yielding a total swath width of 150 m. Range lines are spaced at 10 m intervals measured from the center of the display. White arrow indicates direction of vessel movement with current towfish position at the top the waterfall display.

A Trimble DSM 212H DGPS receiver operating at a 1 Hz sample rate was used to provide positional data for the sidescan sonar. Positional data are electronically fed directly from the DGPS receiver into the Klein Sonar Pro® data acquisition software to provide instantaneous real-time geo-referencing of the sidescan sonar data. Differential positioning error is less than 1 meter horizontal RMS.

## Methodology

### Sidescan Deployment and Data Management

The sidescan sonar towfish was deployed from Habitat Solutions NA's 5.3 meter (17 foot) power catamaran and a rented aluminum 7 meter (23 foot) center console work boat (Figures 4 and 5). These shallow-draft vessels are ideal for shallow water data collection operations in the nearshore zone. A portable Honda generator was used to provide AC power to the sidescan sonar TPU and data acquisition computers. The towfish was typically deployed off the left (port) side of the vessel using a lightweight Kevlar reinforced tow cable and held in place by a Klein cable grip. Offset measurements were measured between the GPS antenna and cable grip and entered into the Sonar Pro® software for automatic layback calculation. Cable out measurements combined with the offset measurements allows the software to accurately calculate layback distance which is used to determine the precise location of the towfish in the water.

Figure 4. Habitat Solutions 5.3 meter (17 foot) power catamaran used to collect sidescan sonar data for the Severn Sound Nearshore Assessment project (photo South Bay Survey 2015).

Figure 5. Aluminum rental boat used to collect sidescan sonar data for the Severn Sound Nearshore Assessment project (photo Penetang Survey 2012)

Upon completion of the field work, sidescan and navigational data were then transferred to a workstation for post-processing. Post-processed sidescan sonar mosaics were generated using Chesapeake Technologies sidescan sonar mosaicking software either during, or shortly after, sonar data collection operations were completed to assist with the identification of lakebed sampling locations as well. Records from both the 100 kHz and 500 kHz datasets were used to interpret the sidescan sonar data. Subsequent to the collection of the sidescan sonar data, additional underwater video data and sediment samples were collected to validate the interpretation of the acoustic data.

Post-processed digital data were archived on multiple hard drives and/or DVD's. Archived digital data include: 1) processed navigation and sidescan sonar acoustic backscatter data, 2) screen captures from individual sidescan sonar tracklines and, 3) screen captures of sidescan sonar mosaics. Digital data include navigation data (location, bearing, speed), raw acoustic backscatter data collected by the sidescan sonar (SDF files), and processed data generated by the Chesapeake mosaicking software (CSF, GeoTIFF, and JPEG2000 files). Digital copies of these files have been provided to the project team for incorporation into the project database.

**Sidescan Sonar Data Collection**

Sidescan data from Severn Sound were collected over a period of years. A total of approximately 247.86 shoreline kilometers of sidescan sonar data were collected along survey lines oriented parallel to the shore. Table 1 summarizes line km collected each year. Figure 6 shows the location of sidescan sonar surveys collected in nearshore areas of Severn Sound and South Bay. Prior to each survey, preliminary survey tracklines were established in order to ensure adequate coverage and to provide navigation waypoints for the research vessel.

The data were typically collected at a 75 m range scale with a line spacing of 112 m. This line spacing provides adequate overlap to eliminate holidays (gaps) in data when generating seamless mosaics. The survey lines were oriented parallel to shore in order to maximize time on site and protect the vessel and equipment from submerged hazards (large boulders or other obstructions). The survey would typically start in moderate to deeper water depths and data would be collected progressively landward into shallower water. This provided an opportunity to assess potential shallow-water hazards in advance of the next survey line.

Table 1. Summary of line kilometers collected and survey dates for the Severn Sound Nearshore Assessment project.

| Date | Area | Shoreline Km | Line Km$^2$ |
|---|---|---|---|
| August 2011 | Penetang Bay | 22.6 | 4.2 |
| April 2012 | Penetang Bay | 18.39 | 2.6 |
| July 2014 | Severn Sound, Beausoleil Island | 47.25 | 14.8 |
| August 2015 | Severn Sound, South Bay | 159.6 | 20.7 |
| | Total: | 247.86 | 42.3 |

The sidescan sonar data were acquired at boat speeds ranging from 3.0 to 4.5 knots (nautical miles per hour). These slower speeds are optimal for high-quality data collection while providing sufficient coverage to assess nearshore substrate patterns. The equipment and changing water depths are carefully monitored as shallow-water obstructions could severely damage the towfish and/or the research vessel.

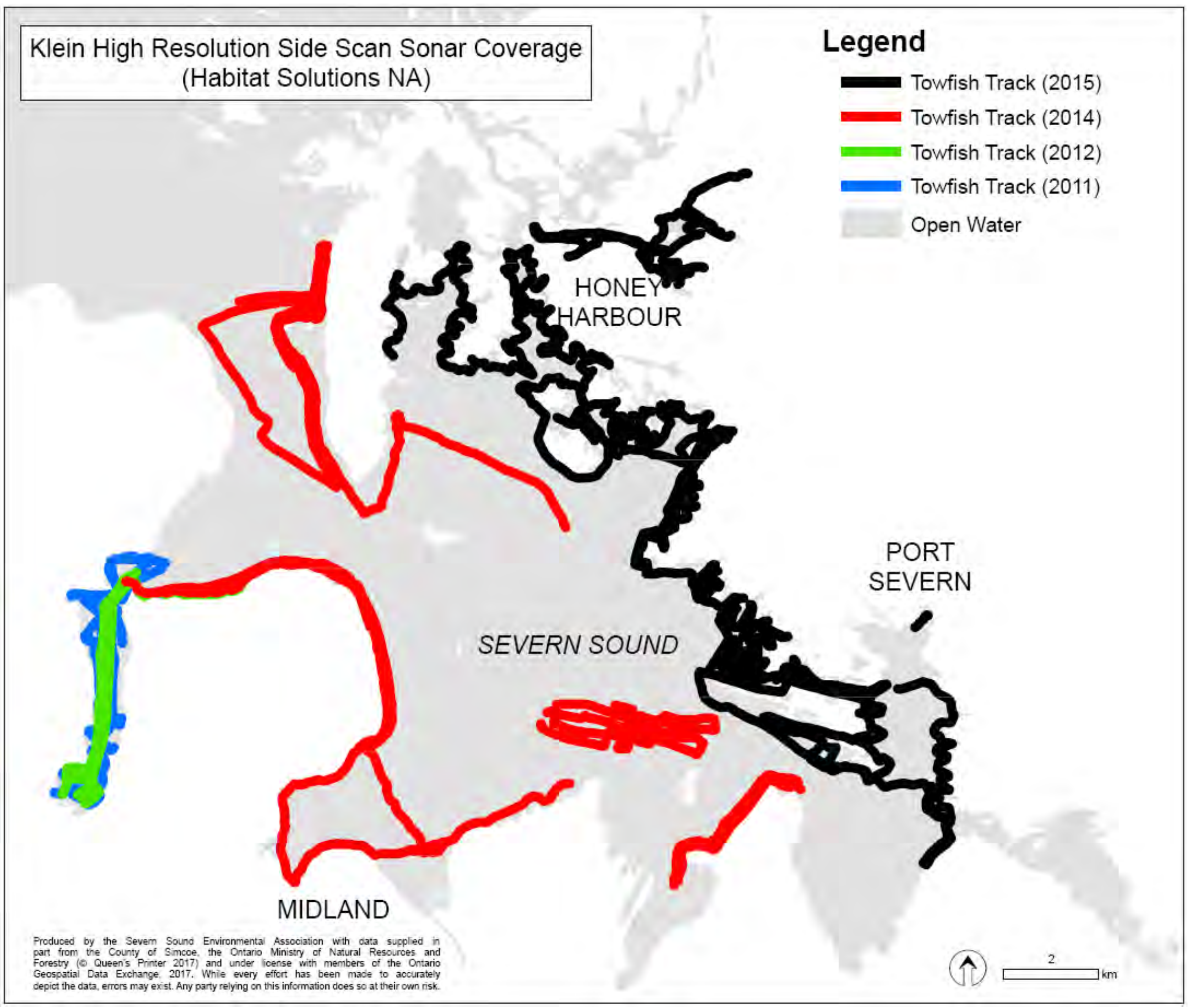


Figure 6. Map of Severn Sound and South Bay showing sidescan sonar survey coverage areas.

Potential sampling sites and/or targets of interest were identified as the surveys progressed. Typically, the data would undergo preliminary processing to determine potential sample and/or underwater video data locations to verify the backscatter response of specific lakebed materials.

**Sidescan Sonar Processing**

For each site, raw SDF files were played back and reviewed using the Sonar Pro® software. This ensures that the data were recorded properly and that coverages are complete. Features of interest are noted for each survey line.

The Chesapeake SonarWiz Map® mosaicking software was then configured for the appropriate map projection (UTM Zone 17N, WGS 1984, meters) and a test line was imported into the mosaicking software to adjust initial gain and intensity settings. Once suitable contrast and brightness are attained, the remaining raw SDF files are imported and batch processed by the software. The software uses the raw SDF files to create an initial georeferenced image (or tile) for each individual trackline. The individual tiles are merged and displayed together to create a preliminary sidescan sonar mosaic of the entire survey area. Individual trackline coverages can be selected, trimmed, and adjusted to meet the specific needs of the survey. For example, it is possible to trim the ends of the tracklines where the vessel is turning sharply to begin the next adjacent trackline. These data at the end of the tracklines are typically smeared and distorted due to rapidly changing aspect ratios as the vessel changes direction and position.

Each edited trackline is then manually bottom-tracked in order to measure water depths below the fish. This is critical when calculating slant range corrections (process by which the water column is removed from the center of the record). Slant range correction removes near-field distortion (compression) and improves positional accuracy if the data. Once the lines have been bottom tracked and slant-range corrected, gain settings were then adjusted to yield similar contrast and brightness across the image. These gain settings are stored in a library that can be recalled and used at any time. Other image processing tools are available to improve image quality and were applied as appropriate.

The data from individual sidescan sonar tracklines were processed by the SonarWizMap mosaicking software and merged together to form a seamless mosaic of the entire survey sites. The mosaic software creates processed images (or tiles) made up of individual survey lines that are then digitally stitched together to create a final sidescan sonar mosaic. The tiles and the mosaic are georeferenced and can be exported as high-resolution Geotiff or JPEG2000 files suitable for importation into GIS software (ArcGIS, Global Mapper, or equivalent). For this project, the Geotiff images were generally exported at a 20 to 35 cm resolution. Digitally, each sidescan sonar mosaics, in uncompressed GeoTIFF format, resulted in a large file size. The equivalent JPEG2000 mosaics are much smaller in size and were used to create the base layer(s) for interpretation due to the reduced file size and ease of manipulation.

## Interpretation

The acoustic response is dependent on the texture (grain size), composition (hard or soft), and roughness (smooth or rough) of the lakebed material. An initial interpretation of backscatter polygons (acoustic response) is made on the processed tiles and/or the mosaic. The original waterfall displays are also reviewed to assist with substrate identification. Sample and video transect locations were plotted on work copies of the mosaics in order to integrate ground-truth data with the acoustic data. In general, areas of similar acoustic response can be reliably interpreted as the same type of substrate material.

Waterfall displays provide the highest resolution and detail of the lakebed. Waterfall displays are typically used in conjunction with sidescan sonar mosaics when interpreting features on the lakebed. In general, harder materials with higher acoustic reflectivity will show up as “bright” patterns on the sidescan sonar. Softer materials with lower acoustic reflectivity will show as “dark” patterns on the sidescan sonar. Areas with relief above the lakebed will typically cast an “acoustic shadow” which will show up as a black area on the waterfall display (see Figure 3). Elongated bright areas may represent changes in lakebed slope where low-angle acoustic energy is reflected off more steeply inclined slopes such as a sharp drop off at the edge of a shallow shelf area adjacent and parallel to the shoreline.

Severn Sound

Environmental Association

# APPENDIX A2b Fish Habitat Imagery Interpretation for Severn Sound (SSEA)

March 2017

# Methodology of the Consolidation and Refinement of Fish Habitat Data Collected in Severn Sound

## March 2017

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# FOREWORD

This document explains the methods used for consolidation and refinement of Severn Sound Environmental Association (SSEA) fish habitat data collected in 2016.

This report received technical review prior to its publication. This does not necessarily signify that the contents reflect the views and policies of individual member municipalities of the SSEA. Mention of any trade names, programs, or commercial products does not constitute endorsement or recommendation for use.

## ACKNOWLEDGEMENTS

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## TRADEMARKS

ArcGIS products are registered trademarks of Environmental Systems Research Institute. VLC is a trademark internationally registered by the VideoLAN non-profit organization. Windows Movie Maker and Microsoft Excel is a registered trademark of Microsoft. GoPro is a registered trademark of GoPro, Inc. SplashCam is a registered trademark of Ocean Systems Inc.. Sony Handycam is a registered trademark of Sony Electronics, Inc. L.P.. Sea-Trak is a registered trademark of Seaviewer Cameras, Inc..

## DISCLAIMER

While efforts have been made to ensure that the supplied information is accurate and up-to-date, complete accuracy cannot be guaranteed. The methods described in this report relate to the tools (equipment and software) that were available and chosen to implement the study. Although there may be other tools that could be used to produce similar results, this method may not be applicable.

## SUMMARY

This report will provide the methodology used to consolidate, and refine fish habitat using underwater and surface imagery, video, and data. The report will function as a step-by-step guide to facilitate the completion of the tasks using a consistent methodology and rationale by explaining the organization and interpretation of fish habitat data.

# TABLE OF CONTENTS

## BACKGROUND

Severn Sound is a group of bays located in Southeastern Georgian Bay. Severn Sound Environmental Association (SSEA) was originally founded in 1997 as a partnership between local stakeholders, and the federal, provincial and municipal governments to help support the completion of the Severn Sound Remedial Action Plan (SSRAP). Severn Sound was 1 of 17 places listed as an Areas of Concern (AOC) because of degraded water quality. It was removed from the AOC list on January 22, 2003 after restoration was achieved or targets were met. SSEA's mission is to sustain environmental quality and to ensure continued protection through implementing a legacy of wise stewardship of Severn Sound and its tributaries.


**Figure 1: Location of the Severn Sound Watershed (Source: Great Lakes MODIS Imagery, 2009)**

As part of the SSRAP delisting strategy, Severn Sound fish habitat targets were met however ongoing implementation is required. The fish community in Georgian Bay is of great importance to the public because of the popularity of recreational fishing in the area. Furthermore the fish community contributes to the overall health of the watershed, which must be maintained for clean drinking water and other recreational uses.

Recently, fluctuating water levels, climate change and shoreline development are applying stress on the Great Lakes and more specifically Georgian Bay (Midwood, 2012). Cvetkovic et al. (2010) suggested that fish community changes are impacted more by vegetation changes than the effects of low water. Fish utilize aquatic vegetation for a range of purposes including spawning and nursery habitat, shelter from predators, shade and cooler temperatures, and as a source of food.

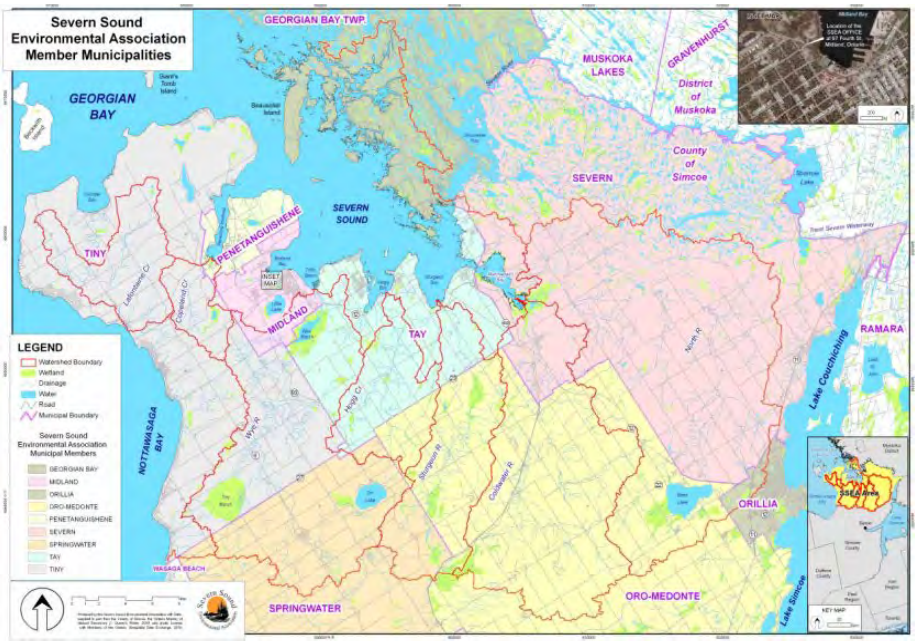



**Figure 2: Map of the Severn Sound Watershed and Subwatersheds**

## PROJECT OVERVIEW

The consolidation and  refinement of the SSEA fish habitat data supports SSEA's future work to identify areas that are highly suitable and productive fish habitat. The methodology outlined here supports a wider initiative which involves multiple stakeholders and contributors. Additional data has been collected from these partners and is available to SSEA for verification or supplementation purposes.

For the purpose of simplicity, this methodology will focus solely on data collected by SSEA and the processes used to collect, organize, manipulate and analyze the data.

The Methodology can be broken down into three categories: Data Collection, Data Storage, and Data Processing. Ultimately these steps are building to a final goal of Data Interpretation. Data Interpretation has not been included in this report, since it is a subjective method whereas, data collection, storage and processing methods are all objective. Data collection involves the physical gathering of fish habitat data through scientific instruments. The Data Collection section includes a brief summary of past data collection methods in contrast with current collection methods and an explanation on why this methodology was updated. The section also explains what type of data was collected and what equipment was utilized.

The Data Storage section outlines how the data is organized and the filing structure used for each step in the Data Processing section which is broken down into four steps; Video Conversion, Image Processing, Pairing Process and Hyperlink Process. The section provides instructions on how to best organize the data created at each step.

The Data processing section details consolidation and refinement of the data. In this section data is manipulated into formats that best suited the needs of the project. During data processing the data is cleaned up by checking for errors and removing irrelevant data.

Data Processing has four steps:

Video Conversion – Video was uploaded from tape to digital format. Video was *'clipped'* to ensure no extra footage from past projects was included at either the beginning or end of the tape. Video was then converted from .avi to .wmv format to save space on computer hard drives.

Pairing Process- GoPro images and video snapshots which contained GPS coordinates were paired and placed in folders. Metadata for each pair was recorded in an excel spreadsheet with unique values for each pair.

Hyperlink Process- GPS coordinates and the additional metadata from the excel spread sheets were georeferenced in mapping software for each GoPro image location. The points on the map were then hyperlinked to the appropriate image. From each point on the map an image of the immediate area can easily be referred to.

Image Processing- Photo processing was completed on some of the images to provide a digitally enhanced version of the image. Enhancements to image clarity and quality were made in photo editing software. The enhancements were intended to help with interpretation with the next steps of the overall coastal mapping project.

# DATA COLLECTION

## Data Collection Summary

In the past SSEA collected fish habitat data along many of the shorelines in Severn Sound. As the years have progressed many of the procedures, equipment, and methods used to collect and store the data have changed, primarily due to the improvement of technology. Since this data was collected over a range of years, the data storage media was not consistent (e.g. CD, paper, tape, DVD-R, and Digital). The changes to the data collection methods and lack of uniform data storage required the development of a system to organize all the Fish Habitat Data.

In recent years use of a high resolution digital camera (GoPro Hero 3) has provided better quality imagery, in comparison with traditional video camera footage. The GoPro is set up to capture an image every five seconds above and below the water surface. The resulting imagery data along with location are later used for the interpretation of habitat features.

The GoPro camera does not have Global Positioning System (GPS) functionality, and the geographic coordinates of the imagery are required to accurately define image locations during the interpretation process. GPSs use satellite signals to determine a fixed position on the globe; the technology does not work underwater since the signal does not adequately penetrate the water's surface. To provide coordinate data, a method of coupling a GPS unit, situated above the surface of the water, with the camera system was utilized. As part of the camera system, a second video camera (SplashCam) was required to enable the tracking of the GPS coordinates on the video imagery. The SplashCam was operated in tandem with the GoPro. A process of matching the GoPro images with the corresponding SplashCam footage is required to obtain the best quality images and the most accurate GPS coordinates.

Below and above water surface imagery along with GPS data was collected, during the Summer and Fall of 2015 and 2016, to create a georeferenced photo archive of images in the coastal margins of Severn Sound. The photo archive was hyperlinked using geographic coordinates that were mapped using Environmental Science and Research Institute's (ESRI) ArcMap GIS software, to create shapefiles that were interpreted with a visual assessment of aquatic vegetation, percent cover, substrate and depth. The imagery was also used to validate the classification of underwater sonar datasets.

Depth, aquatic vegetation and sediment data from previous years was combined with the interpreted imagery to enhance the underwater imagery coverage. This data has also been georeferenced, analysis will also be completed in ArcMap and the results will be available for areas not covered in the 2015 and 2016 datasets.

# Equipment

## Imagery

### *Splashcam Deep Blue Underwater Video Camera System*

The Splashcam Deep Blue underwater video camera uses a cable to relay a video feed to the operator in the boat. The video feed is recorded to a tape using a Sony Handycam. It can be equipped with 2 LED waterproof flashlights to provide light at greater depths. When paired with a Sea-Trak GPS the GPS coordinates can be displayed on the video track (Figure 3).

### *GoPro Hero3-Black Edition*

A GoPro Hero (Hero3-Black Edition) was also mounted to the frame of the Splashcam to capture high quality pictures taken in 5 second intervals. In the past only the aforementioned video camera system was used to collect imagery, however the GoPro offers an expanded view with its fish eye lens and a clearer picture, especially underwater.

**Figure 2: GoPro (Right) Mounted with the Splashcam (Left)**

## GPS

### *Sea-Trak by SeaViewer*

Sea-Trak™ along with a DVR provides permanent (recorded) documentation with Lat/Lon embedded. Requires external GPS to show coordinates (figure 4).

"This device is specifically designed for ANALOG camera systems. The SeaTrak is a video overlay device designed to take information (longitude / latitude coordinates) from GPS and record them on the underwater video feed. These coordinates are also displayed live on the monitor at the same time." (SeaViewer Underwater Video Systems, www.seaviewer.com)


**Figure 3: Sea-Trak and Trimble GPS Units**

### *Trimble GeoXT 2005*

The Trimble GeoXT 2005 hand held is used in conjunction with the Sea-Trak to record GPS coordinates using EVEREST™ multipath rejection technology to provide submeter accuracy. (GeoExplorer 2005 Series Getting started Guide, 2005)

### *Lowrance HDS7 Chart Plotter*

The Lowrance HDS7 Chart Plotter supports the sonar transducer with a built in broadband sounder and GPS. The device displays data in high definition mapping on the LED screen, which can be exported to mapping software for refinement and interpretation. (HDS-7 Gen2 fishfinder/chartplotter, www.lowrance.com)

## SONAR

### *SSEA Boat Mounted Sonar*

Sonar depth data was also collected by SSEA at the same time as the imagery using a boat mounted Lowrance HDS7 Chart Plotter. The depth data was primarily acquired to provide down scan profiles and side scan mosaics of the bottom and Submerged Aquatic Vegetation (SAV) coverage. The Sonar GPS track datasets were used as a supplement in areas where GPS location data was missing or was sparse due to technological or human errors in the collection process. Some accuracy is lost when the 'Sonar Track Method' was applied and it is a slower process, however it is a viable alternative for locating images while achieving similar results in areas where the sonar data is available.

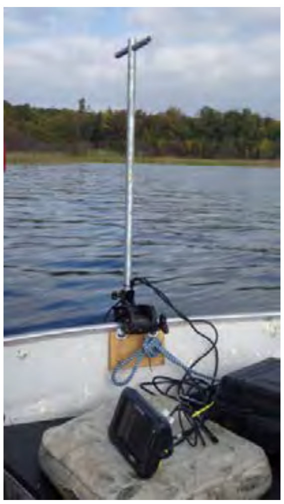


**Figure 5: Boat Mounted Transducer (bottom submerged)**

The SSEA boat mounted sonar transducer sends out sound waves and receives the echoes which are interpreted by the chart plotter to show sediment and depth below the water's surface. The transducer is mounted to the side of the boat and kept underwater when in use.

**Figure 6: Front view of bottom of transducer**

**Figure 4: Back view of bottom of transducer**

# DATA STORAGE

## Storage Framework

Fish habitat data is stored on the local D drive with a backup copy stored on a 4.45 TB external hard drive *Seagate Expansion Drive*. The final data is stored on an 8TB Hard drive *LaCie* and only includes the complete data which is one or more shapefiles and one or more folders of images, where the shapefiles are hyperlinked to GoPro or Video Snapshot Images.

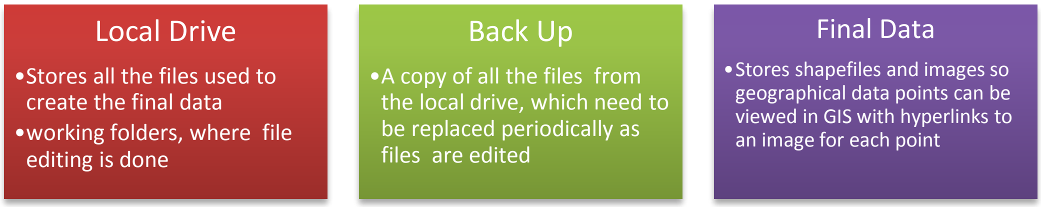



**Figure 7: Diagram of Storage on Drives**

There is a folder dedicated to each step required to refine the fish habitat data including; Video Conversion, Image Processing, Video GoPro Pairing and Hyperlinking. The structure for each folder is explained in further detail below.

## Video Conversion

Within the Video_Conversion folder there are folders for each location and date a video was collected. Each of these folders contains an .avi file and a converted .wmv file for each video tape that was collected for that date and location.

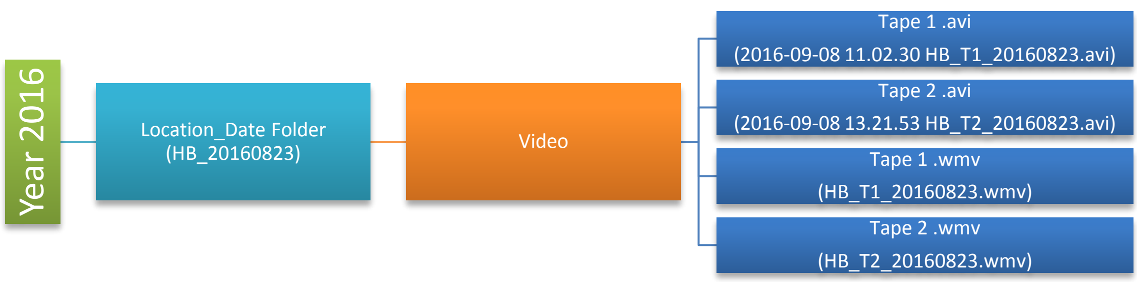



**Figure 8: Diagram of Video Conversion File Structure**

## Image Processing

The Image_Processing folder is where the GoPro Images are downloaded to be stored in dated folders. Each date that GoPro images were captured gets its own folder. The Image processing folder is also where any processed images are stored. Processed images are images that have been altered to enhance the image for interpretation and should be saved in a separate folder and named accordingly.

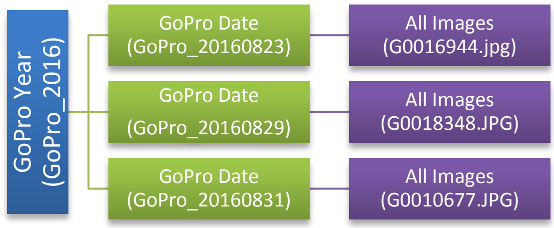



**Figure 9: Diagram of Image Processing File Structure**

## Pairing Process

Within the Video_GoPro_Pairing folder there is a folder which contains a sample folder structure, of blank folders to set up the pairing process, and a sample pairing spreadsheet. This folder can be copied to save time setting up paring folders.

There is also a folder for video snapshots this is where snapshots from VLC media player should be saved to, which can be left empty and a folder for the converted videos in .wmv format. A folder labeled with the year stores all the pairs for each date in dated folders is where the majority of pairing work will take place.

Within the dated folders (in the year folder) there is a folder for shapefiles. This folder is where the hyperlinked shapefiles for the specific date are kept. There may be multiple versions of shapefiles in this folder, they should be named using a version numbering system, with the highest number denoting the most recent and accurate shapefile.

There is also a folder for the GoPro images captured for the specific date. If any splash cam video is missing then an additional folder is created with the same name plus '_Missing_Video' added to the end, to organize the pictures that fall between missing video times.

Finally, the Pairs folder is where the majority of work is done; it is broken down into folders named after the video tapes. Within the tape folders there are a number of segment folders which hold the pairs. The pairs are in individually numbered folders within the segment folders. The excel file which houses the metadata for each pair is also found in the Pairs folder.

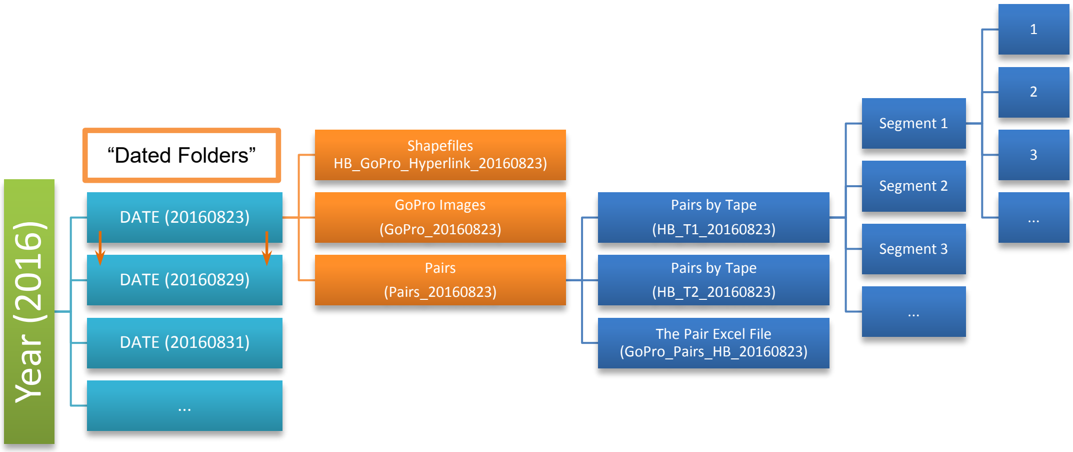



**Figure 10: Diagram of Pairing Process Dated File Structure**

A sample folder structure with blank folders has been created to save time with creating the last half of this tree in the future.

## Hyperlink Process

The GoPro_Hyperlink folder is the folder where all the hyperlink processing is done. It is where all the images and hyperlinked shapefiles are stored, which is the final data, which will be copied to the 8TB HD LaCie. The MXD is also stored in this folder.

If video is missing and the 'Sonar Track' methodology needs to be applied then there will be a folder for this process which will contain batch files for copying paired sonar images, and Excel spread sheets which will be used to create the batch files text.

Additionally, if there is any data that needs to be pulled to be shared with another organization that data and any other files created to obtain that data should go in a separate folder within the Hyperlink folder.

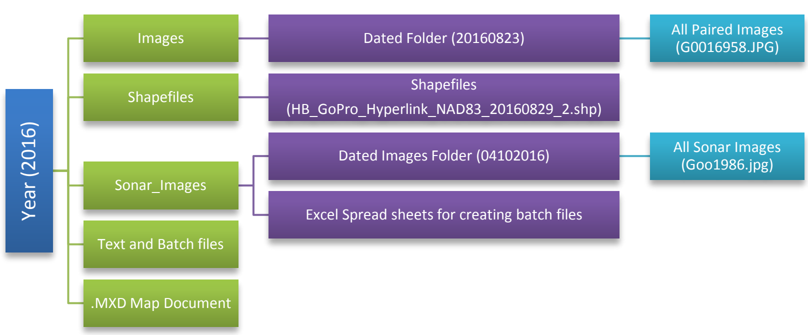



**Figure 11: Hyperlink File Structure**

# DATA PROCESSING

## Video Conversion

Video that was collected at each location on each date will be separated by tapes. Tapes hold roughly an hour worth of video, so some locations may have multiple tapes. These tapes need to be uploaded to the computer for use in the pairing process.

### Transferring Sony Handycam Tape to Digital Format:

1. Plug in Sony Digital Handycam to power source. Plug the power adaptor into an outlet and into the DC port on the camera (located on bottom of device, under the battery pack "DC In").
2. Plug in the cable for transfer. Plug the fire wire cable into the PC (located at back of PC tower) and the DV In/Out port on the camera (located on front right side).
3. Place the tape in the camera. (Open flap at top of camera, press blue eject button, tape roll faces inward, push gently to close, close flap)
4. Turn on the camera. (Push small green button located at front of camera beside the record button and flick up one notch to the VTR setting)
5. Import Video. (Windows pop up will appear and prompt to import video, select yes and name the video)
6. Name the video. Use the predetermined naming convention as follows:
    - AREASHORTFORM_TAPENUMBER_DATE
    - Example: BS_T1_20161006 would stand for Beausoliel area, first tape of the day, October 6th 2016
7. Video transfer. After the video has been named the transferring will automatically begin. A new screen will open; the tape will rewind then start playing from the beginning. Transferring happens in real/recorded time, for instance if there is 1 hour of footage the transfer will take 1 hour.

    The recording can be stopped at any time using the stop button. (Example: if you are transferring from a tape that has been overwritten and the last few minutes of the tape contain old material, you can press stop and save some time. Alternatively, you can edit the file in Movie Maker to cut out parts that are unnecessary, once the transfer is complete.)
8. Transfer complete. The .avi file type (default) will be saved on the local drive (C: >Users>yourname>My Videos) unless otherwise specified. Save the video to the appropriate folder within the Video_Conversion folder (see Storage Framework). The

.avi file will be named by the start date and **time** of the transfer followed by the *name that was specified in step 6*.
(Example: 2016-12-14 **13.08.41** *BS_T1_20161006*)

9. Creating a backup. The .avi will need to be moved to the appropriate folder (see Storage Framework) and a backup copy will need to be saved on an external hard drive (Drag and drop to appropriate folders).

10. Export to .wmv. Once the file has been backed up, the .avi can be converted to a .wmv to conserve space. (Example .avi = 12.4 GB and .wmv = 8.9 GB) Open the .avi with windows movie maker (right click file > Open with > Windows Movie Maker) inspect frames and clip out any unwanted parts, if there are any. (Drag and drop cursor to appropriate point in video right click>split, right click on split portion> remove)

11. Save the movie. (File>Save Movie>for high definition display give appropriate name, location and file type; Windows Media Video file.) Saving as .wmv does not happen in real/recorded time but will still take some time for conversion (20-30 minutes for an hour worth of tape).

    The Video_Conversion folder will contain both an .avi and .wmv file of the same footage less what was edited out of the .wmv in Movie Maker. The .avi will have the transfer date before the given name, while the .wmv should just have the given name.

# PAIRING PROCESS

Pairing images is required to find the coordinate location of the GoPro images. The GoPro is programed to take high quality pictures every 5 seconds. The SplashCam video recording is of lower quality but records GPS coordinates on the lower left hand corner of the screen when paired with the SeaTrak GPS. The GPS displays the Longitude, Latitude, Time (24hr), Direction (NW), Speed (1 KPH), and Date (mm-dd-yy).

Both the GoPro and the Splashcam are mounted beside each other at the end of a cable, then are lowered into the water while the boat drives along transects of shoreline. The collected media is then refined and interpreted to figure out the suitability for fish habitat.

## Setup

### *Filing Structure*

1. Set up the filing structure by creating a folder for the year with subsequent folders for each date data was collected, name the folders the date of data collection, following this format: YYYYMMDD.
2. In each of these folders there will be two folders 1. For the GoPro images (Named: GoPro_date) 2. For the Pairs (Named: Pairs_date).
3. Fill folder 1 with corresponding images.

4. To fill folder 2, the Pairs folder, copy and paste the folder structure from D:\Sample Folder Structure for Fish Habitat, changing the names of the first two folders to fit the corresponding video. Start a second folder when starting a second tape.

   The excel spreadsheet, is where metadata for each pair is recorded, it is stored in the dated pairs folder. A new spreadsheet is used for each location. There is an example/starter spread sheet in the Sample Folder Structure entitled GoPro_Pairs_Sample_Date, the name must be changed to correspond with the video/s.

   Under the folder named after the video there are multiple segment folders numbered from 1 to 20, more may need to be added or less used depending on how many segments the video has. Within each segment folder there is a numbered folder for each individual pair, again more may need to be created or less used, empty folders that don't get used should be deleted.

## VLC Media Player

1. Set up VLC media Player with helpful buttons in the tool bar. Click tools on the toolbar then Customize Interface. Click and drag buttons from toolbar elements to the first and second line on the toolbar. Chose 'snapshot', 'frame by frame', 'faster' and 'slower' if not already on toolbar. Stop, Play and Pause will already show on toolbar. Close when finished.

   Example of what tool bar will look like: 

2. Set up the snap shot preferences in VLC Media Player. Click tools on the toolbar then Preferences>Video. Under video snapshots direct where the image should be placed D:\VLC_Snaps, Prefix the name of the images with "vlcsnap-" then the short form for the video location then the tape number followed by "-00"

   Example: vlcsnap-BS_T1-00.

   Check the box for sequential numbering. Ensure the format is jpg. Save preferences. Keep the VLC_Snaps folder open on second screen for easy drag and drop into the segment folders in the pairing steps.

## Excel Spreadsheet

To set up the excel spread sheet open the sample spreadsheet and examine the columns. (See Appendix 1)

- Pair_ID, LAT_DEG, LON_DEG, have already been populated. The date needs to be changed to the corresponding date of the video, this date will not change in the sheet so it can be copied to the bottom. The video will stay the same for a number of segments so it can also be copied far down, but remember to change the tape number if there are second or third tapes for the date.

- Segment_ID always starts at 1 and always starts with an underwater pair, it will need to be populated for each pair as will UW_AW (Underwater or Above Water). The coordinates will also need to be populated for each pair; this information is on the snapshot from the video in the bottom left corner.

- LAT_DEG and LON_DEG have a formula to automatically convert Degrees Minutes Seconds to Decimal Degrees.

- The first Video_Time and GoPro_Time will have to be inputted manually, video time is located at the bottom left on snapshot. To find the GoPro_time left click the image>Properties>Details and look under *date taken*.

- VLC_Image will be named with sequential numbers; there is a formula that adds the number from VCL_Image_Count which can be populated from 001 to 100 or any indefinite amount. If an image is not right and gets deleted remember to change the count number. Remember every time VLC media player closes sequential numbering will start over. VLC_Image follows a similar formula and uses the last three digits from the GoPro_Image_# column to name the video. Attention needs to be paid to the formula in this column as zeros will have to be taken away every time a single digit number turns to a double digit and double to triple etc.

- GoPro_Image_# is linked with formulas to the time columns Video_Time and GoPro_Time, this allows for input for the last three digits from the GoPro photo to dictate the time based on how many photos were skipped in between, since a photo is taken every 5 seconds, it will add 5 seconds for every photo skipped.

- Notes can be recorded in the last column, noteworthy items would be large rocks, fish or anything unusual. In some instances the GPS loses its signal (satellite blinks on video screen) causing a point or a group of points to be non-accurate. When this happens it should be distinguished in the notes column.

- Method is where the three possible methods that can be used in the pairing process are recoded. The first method is "Image Pairing" which is what will be used for the majority of pairs, however if there are GoPro Images missing then the "Video Shapshot" method is used, or if video is missing then the "Sonar Track" method is used (see Using Sonar Data and Oblique Imagery to Predict Image Location When Video is Missing).

Watch all automated columns to ensure the right information is being recorded; some tweaking to formulas may need to be done from time to time to ensure the correct information is being recorded.

## Computer Screen

Set up computer screen with excel, Windows Photo Viewer for GoPro images, VLC media player for .wmv video and a window open to the pairing segments for the corresponding video.

Example:

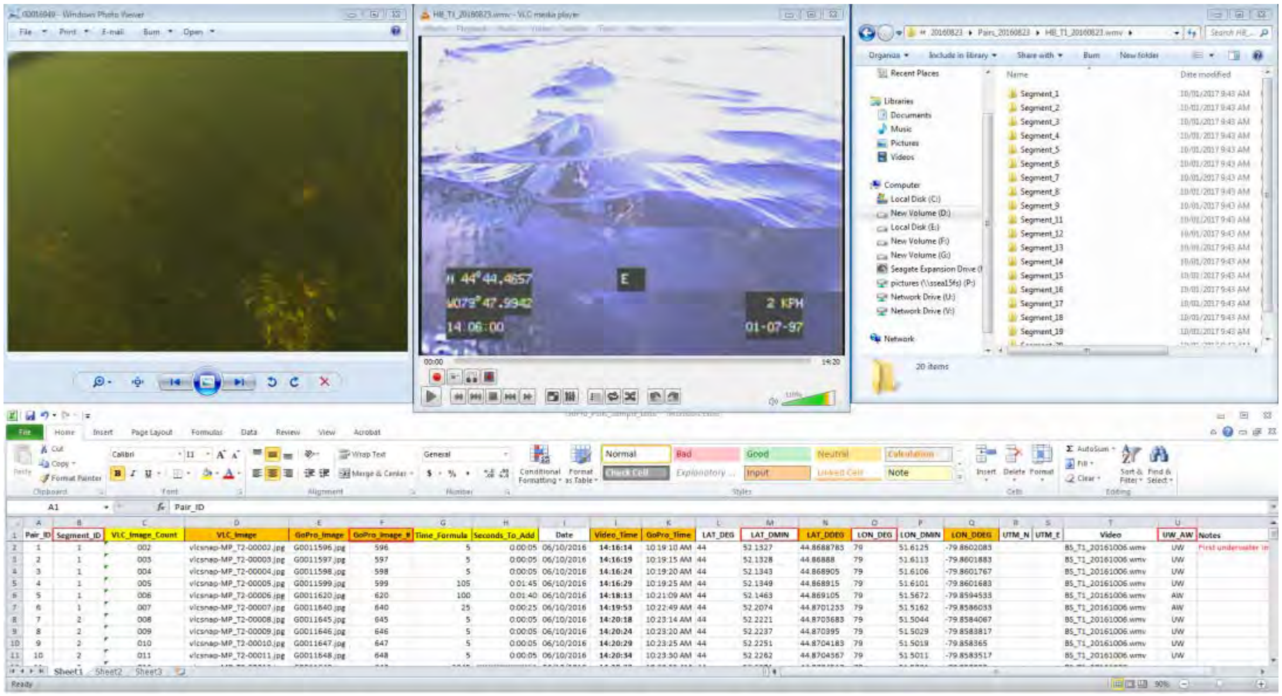



**Figure 12: Pairing Process Computer Screen Setup**

## Matching Pairs

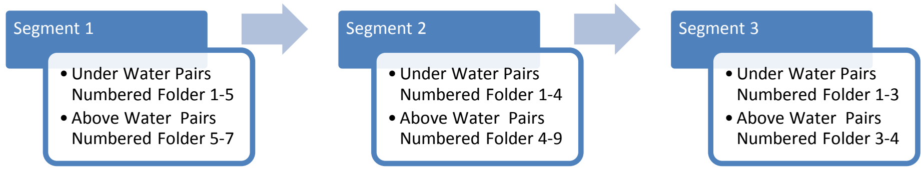
### *Pairing GoPro Images with Slash Cam Video:*

1. Find the first pair by matching the video to the first underwater image, so that the image in the video is a replica of the image in the photo. Pick defining features that appear in both images and triangulate them with other features so that they appear exactly the same in both images. Use the ‘slower’ button to slow how many frames per second the video plays, this will help get a more accurate result.

2. Once a match is made take a snapshot in VLC media player by pressing the camera button. The image will appear in the VLC_Snapshot folder, drag and drop the .jpg to the folder numbered 1 within the Segment_1 folder.
3. Copy and paste the GoPro image to this folder as well. There will be two images in every numbered folder that is needed for a particular segment.

   Some segments may have a small amount of numbered folders and some may have a large amount depending on the amount of matches in one segment. Segments always start underwater and finish above water. A segment is a series of pairs under and above water. A new segment starts at the first pair under water after the last pair above water.

   Example:




4. Fill in the spreadsheet with the appropriate information in each row and column. Filling in the spreadsheet can be automated using formulas, so that only a couple fields need to be filled for each pair, this will significantly cut down on the time it takes to complete each tape (see Setup: Excel Spreadsheet for more details about each column, where to find the sample spreadsheet and formulas to automate the process).

5. Underwater matches should be made for each GoPro image where the waterbody bottom is visible. If the GoPro image only shows water or the top of some lake weed, these images do not need to be included in the pairs. However in any GoPro image where the sediment of the waterbody floor is visible, or is not visible because of dense vegetation, a match should be made.

6. The next pair can be found by playing the video and pausing at the calculated time. The calculated time is to give a possible timeframe of the pair. Within the calculated second the pair can be found by using the 'frame by frame' button. There are 32 frames per second in the video. Continue following this process for the rest of the pictures.

7. Above Water, GoPro images do not need a match for each photo, rather a match can be made whenever the view along the shoreline changes. The best way to estimate this is to pick a defining feature in the image on the far right had side of the picture, then click through the next pictures in photo viewer until the feature has moved across the image to the right hand side of the image.

8. Continue to match pairs and fill the folders for the duration of the video, when one video is finished the next video can be recorded in the same spreadsheet, however it will need a new video folder and new set of segments.

## Missing Photos or Video

### *Missing Photos*

If there are GoPro Images missing between video segments follow a similar process as above using only the video. This could occur if the video recorder has been turned on but the GoPro has not. In this case the snapshot of the video can be used for the hyperlinked shapefile however the image quality will be reduced. Take a snapshot every 5 seconds underwater and every time there is a new view above water. Copy the snapshot images to the numbered folder in the segment folder the same as a regular pair but also make a copy of each snapshot and place in a separate folder using the naming convention; Snapshot_Date within the dated folder.

### *Missing Video*

In some instances the memory on the Splashcam becomes full and recording stops; however the GoPro does not stop capturing images. These images that have missing video cannot be added with the others because the location is not known. In order to find an approximate location of these images the sonar track method must be used (See Using Sonar Data and Oblique Imagery to Predict Image Location When Video is Missing below).

# HYPERLINK PROCESS

## Importing Fish Habitat Data to Arcmap

### *Preparing Excel Data for Exporting to ArcMap Steps:*

In order for time values to be properly converted into ArcMap they must be reformatted in excel since ArcMap stores time values as dates in the attribute table. One way to do this is to convert the date and time columns to text formatting.

1. Insert a new column after Date, Video_Time and GoPro_Time, give the colomn the same name but add "_Text" after it. Example "Date_Text"

2. In the first cell in the Date_Text column use the formula =TEXT(I2,"yyyymmdd") where I2 is the first cell in the Date column. Copy formula for all cells in the column. This formula removes the backslashes from the date, which is beneficial since the dated folders that contain the GoPro images are also named this way.

3. Use the same method to fill the Video_Time and GoPro_Time columns but use the formula =TEXT(K2,"hh:mm:ss AM/PM") instead.

### *Exporting Excel Data to ArcMap Steps:*

1. Open Arcmap> Add Data> find spreadsheet> select proper sheet

2. Right click sheet on TOC and go to Display XY Data.  Specify the X and Y fields (X=LON_DDEG and Y=LAT_DDEG) right click on the Sheet Event and Zoom to layer.

   Ensure data looks correct and that there are no outliers. If there are any outliers select the point and examine Pair_Id number in the attribute table or use the identify tool. Double check the Pair_ID in the corresponding excel spread sheet and make any necessary corrections. Remove the sheet so that edits can be made in excel. Once the edits have been made add the data back again.

3. Right click the Sheet Event in the TOC and export to shapefile (Data > Export Data) Put the output feature class in the appropriate dated folder under Video_GoPro_Pairing. Name the shapefile SHORTFORM_GoPro_Hyperlink_DATE

4. Add the shapefile and define the projection for it (ArcToolbox >Data Management > Projections and Transformations > Define Projection) Set geographic coordinate system to GCS_North_American_1983.

5. Project the shapefile (ArcToolbox >Data Management > Projections and Transformations > Project) Set the projected Coordinate system to NAD_1983_UTM_Zone_17N. Name the shapefile SHORTFORM_GoPro_Hyperlink_NAD83_DATE, put in the appropriate dated folder with the un-projected shapefile.

6. Repeat process for all spreadsheet dates. Once the shapefiles have been created and projected, add aerial imagery and further examine the points to ensure data is correct.

## Hyperlinking to Gopro Images

### *Creating Hyperlinked Shapefiles Steps:*

1. To hyperlink the shapefile with the GoPro images, first a new column in the attribute table must be created. Left click on the shapefile and open attribute table under table options choose add field. Name the new field Hyperlink, set as text, precision 60. Repeat for all shapefiles.

2. Create a new folder called GoPro_Hyperlink, fill this folder with folders for each date of data collection plus a folder called Shapefiles. Fill each dated folder with the GoPro images that were paired by *copying* (do not drag and drop, do not cut and paste) them from their respective folders.

   To find all the GoPro images type G in the search bar for the dated Pairs folder, it will list all the paired images, since they all begin with G. Copy these images to the new dated folders within the GoPro_Hyperlink folder.

3. In Arcmap click on the editor toolbar and select start editing. Open the attribute table on the first shapefile and scroll to the new field use right click and open field calculator. Under hyperlink= : type "\"& then double click [GoPro_Imag] from the list of fields.

   Between the quotations is where the path to the images goes. Copy the address from the corresponding dated folder in the GoPro_Hyperlink folder.

   Example: "D:\GoPro_Hyperlink\20160823\"&[GoPro_Imag]

   Press OK.

4. The column will populate. Close the attribute table left click on the shapefile in the TOC and select Properties>Display turn on support hyperlinks and use the Hyperlink field. Press ok.

5. Click the hyperlink button on the Tools toolbar (lightning bolt symbol) and the points in the shapefile should change to blue dots, this means the hyperlinks have been activated, click on a point to display the image.

## Hyperlinking to Video Snapshots:

If any pairs were missing GoPro images and only video snapshots were used, these will also need to be hyperlinked.

1. Open the attribute table double click the 'Method' Column to organize by method. Scroll to the Video Snapshot method data and select only those entries.

2. In an edit session, use the field calculator to populate the hyperlink column with the correct path for the snapshot images, following a similar method as above.

# Sonar Track Method

### *Using Sonar Data and Oblique Imagery to Predict Image Location When Video Data Is Missing:*

1. Open ArcMap and bring any Hyperlinked Shapefiles that have been completed into project. Bring in aerial imagery for reference. Gaps in the hyperlinked shapefiles along the shoreline show areas that are missing data. These gaps should correspond to GoPro images missing video data, which should be filed separately in a separate folder, as noted previously.

2. Bring Oblique Imagery into the project and hyperlink it to the according folder. Bring in Sonar shapefiles for the areas missing video data.

3. Create a new shapefile from a pre-existing point from a completed hyperlink shapefile so the attributes stay the same (select the point>left click the shapefile in TOC>Data>Export Data). Follow the same naming format but add _sonar to the end.

   Example: MP_GoPro_Hyperlink_20161004_Sonar

   Store it in the same location as the previous shapefiles, in the corresponding dated folder.

   Example: D:\Video_GoPro_Pairing\2016\20161004

   Delete point, since it does not belong to the sonar data set.

4. Start an edit session on the newly created shapefile. Image points will be placed along the sonar track, using aerial and oblique imagery for reference. Make the sonar shapefile the only selectable layer. (Left click in TOC>Selection>Make This the Only Selectable Layer.) Pin 'Create Feature' and 'Attributes' windows to the side of screen for easy editing.

5. The sonar track is made up of multiple points; each point is an average of a number of pings the sonar sends out. Along the trail there are breaks, these are where the sonar equipment goes underwater, therefore these spaces are where the underwater imagery points will be located.

   The above water images will fall somewhere along the sonar trail.

   Open the file which contains the GoPro images missing video and find the first above water image. Since supporting oblique imagery is needed to locate the AW points, always start with the first AW image.

**Figure 13: Gaps in Sonar Track**

6. On the first image, zoom to the centre of the image, look at the shoreline and pick a defining feature. Then click the oblique hyperlink for the nearest oblique image and examine for the same feature. Find the same feature on the aerial imagery of the shoreline then select the closest sonar point.

   For buildings, the oblique imagery, which was taken on an angle, lets you see both the front façade of the building and the roof. The oblique imagery is very helpful since the aerial imagery does not show very much of the front of the building and mostly shows the roof, whereas the GoPro image shows mostly the front of the building.

7. Copy the sonar point to the shapefile (right click copy, right click paste > chose new shapefile in drop down list) and fill in attributes. Continue this for each AW image that shows a new view of shoreline, just like the pairing process.

8. The attributes that need to be filled are Segment_ID, Date, GoPro_Time, GoPro_Imag, and AW_UW. Most of the other attribute data will be missing using this process however LAT_DDEG and LON_DDEG can be calculated upon completion. Date and Method will stay the same for the shapefile so that it can also be left for the end. The most important field to fill out is GoPro_Imag.

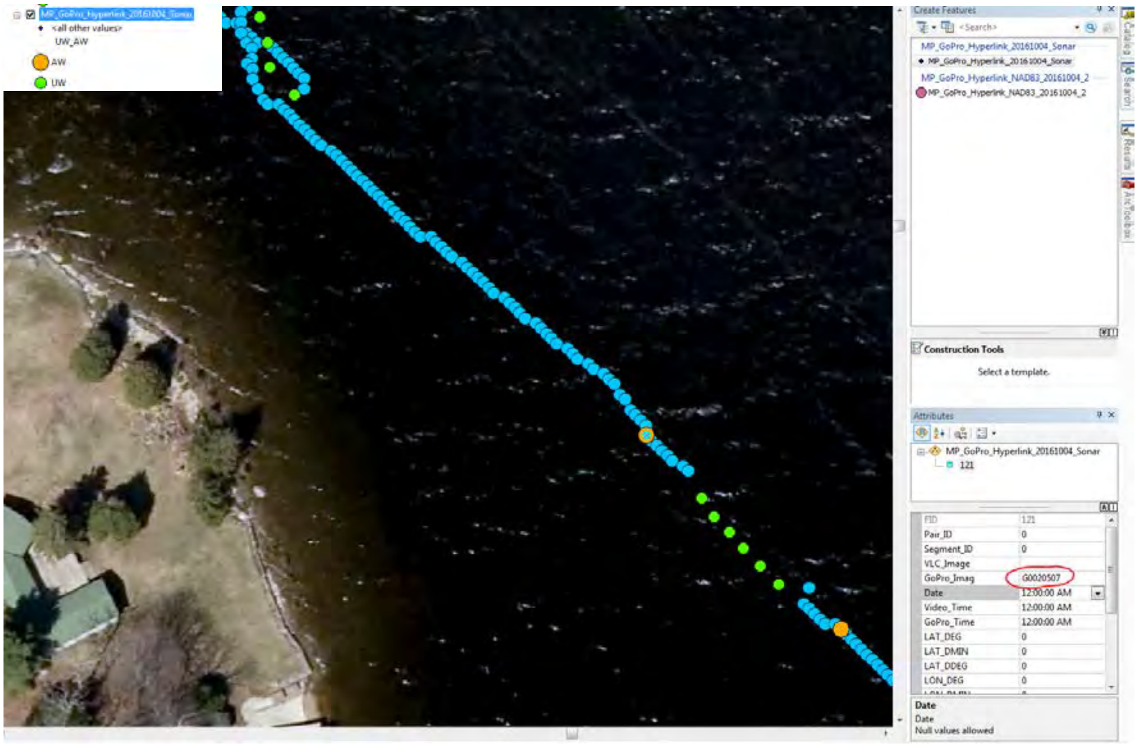


**Figure 14: Inputting Attributes**

9. After the AW segment has been done move on to the UW segment, there are no points for the UW segment so points need to be created in the gaps in the sonar trail. Fill out the attributes the same as before.

10. Follow this process until all the images have been gone through. Repeat for all missing data, then back-up newly created shapefiles.

11. In an edit session, open the attribute table and use the field calculator to add the date for all the points under the Date column (#mm-dd-2016#). Use the field calculator to add text "Sonar Track" for all the points under Method. Finally, calculate the Hyperlink path for each point using the same method as described in Hyperlinking GoPro Images. The hyperlinks will not work, since the sonar images have not been brought into the corresponding dated folder in the Hyperlink folder (see Using DOS Commands to Copy Specific Images to New Folders).

12. Use Calculate Geometry to add Decimal Degree coordinates to LAT_DDEG and LON_DDEG columns. In the same edit session in the attribute table, right click LAT_DDEG> Calculate Geometry. In the Calculate geometry pop up, select Y coordinate of point, Use the same coordinate system of the data source; PCS: NAD 1983 UTM Zone 17N and select Decimal Degrees from the unit drop down list. Press Ok. Do the same for LON_DDEG but select X for the coordinate of point instead.

## Using DOS Commands to Copy Specific Images to New Folders:

In order to bring the images that were used in the sonar track methodology to the hyperlink folder, a DOS *COPY* command prompt needs to be utilized.

1. Create a new folder called Sonar_Images in the GoPro_Hyperlink folder for this process.

2. Set up the text file which will be used to batch copy all the images. The list of images needs to be exported from the attribute table of the dated sonar shapefile. Open the attribute table and select all records (Table Options>Select All) Then right click on the left hand side of the table before the first column and Copy Selected.

3. Open an Excel spread sheet and paste table. Delete all columns that are irrelevant, keep only GoPro_Imag and Date. Save the file in Sonar_Images folder and name it following this format: Shortform_DATE_Sonar_Images

   Example: MP_20161004_Sonar_Images.xlsx

4. Next set up a table like the one below. Using excel to create the strings of text needed for every copy in a batch file is much faster than typing it out.

| Copy From: | | | | | Copy To: | | Final Text |
|---|---|---|---|---|---|---|---|
| Copy | Path | GoPro_Imag | .jpg | Concatenated | Path | Concatenated | Concatenated & Contatenated |
| Copy | D:\Video_ | G0019986 | .jpg | Copy D:\Video_ | D:\GoPro_ | D:\GoPro_Hyperlink | Copy D:\Video_GoPro_Pairing\20 |
| Copy | D:\Video_ | G0019989 | .jpg | Copy D:\Video_ | D:\GoPro_ | D:\GoPro_Hyperlink | Copy D:\Video_GoPro_Pairing\20 |
| Copy | D:\Video_ | G0020001 | .jpg | Copy D:\Video_ | D:\GoPro_ | D:\GoPro_Hyperlink | Copy D:\Video_GoPro_Pairing\20 |
| Copy | D:\Video_ | G0020009 | .jpg | Copy D:\Video_ | D:\GoPro_ | D:\GoPro_Hyperlink | Copy D:\Video_GoPro_Pairing\20 |
| Copy | D:\Video_ | G0020050 | .jpg | Copy D:\Video_ | D:\GoPro_ | D:\GoPro_Hyperlink | Copy D:\Video_GoPro_Pairing\20 |
| Copy | D:\Video_ | G0020051 | .jpg | Copy D:\Video_ | D:\GoPro_ | D:\GoPro_Hyperlink | Copy D:\Video_GoPro_Pairing\20 |
| Copy | D:\Video_ | G0020052 | .jpg | Copy D:\Video_ | D:\GoPro_ | D:\GoPro_Hyperlink | Copy D:\Video_GoPro_Pairing\20 |
| Copy | D:\Video_ | G0020053 | .jpg | Copy D:\Video_ | D:\GoPro_ | D:\GoPro_Hyperlink | Copy D:\Video_GoPro_Pairing\20 |
| Copy | D:\Video_ | G0020054 | .jpg | Copy D:\Video_ | D:\GoPro_ | D:\GoPro_Hyperlink | Copy D:\Video_GoPro_Pairing\20 |
| Copy | D:\Video_ | G0020055 | .jpg | Copy D:\Video_ | D:\GoPro_ | D:\GoPro_Hyperlink | Copy D:\Video_GoPro_Pairing\20 |
| Copy | D:\Video_ | G0020015 | .jpg | Copy D:\Video_ | D:\GoPro_ | D:\GoPro_Hyperlink | Copy D:\Video_GoPro_Pairing\20 |
| Copy | D:\Video_ | G0020016 | .jpg | Copy D:\Video_ | D:\GoPro_ | D:\GoPro_Hyperlink | Copy D:\Video_GoPro_Pairing\20 |
| Copy | D:\Video_ | G0020017 | .jpg | Copy D:\Video_ | D:\GoPro_ | D:\GoPro_Hyperlink | Copy D:\Video_GoPro_Pairing\20 |

**Figure 15**

5. Populate the GoPro_Imag column with all of the image names.

6. In the first coloum, type “Copy ” with space after it and copy the text down to the bottom of the GoPro_Image names (double click on bottom right hand of cell). Do the same for .jpg.

7. In the computer explorer window find the folder where the images are stored, in the dated folder, with the Pairs folder. Left click the address bar at the top of the window> copy address. Paste the address in the first excel cell under the Path column. Add a backslash to the end of the address. Copy the path down to the bottom of the GoPro_Image names.

8. Concatenate all the columns to create the *Copy From* text string. (in the first cell =concatenate(C3,D3,E3,F3).

9. Repeat a similar process for the *Copy To* side of the table beside the *Copy From* side but use the path for the newly created Sonar_Images folder instead. Create folders within Sonar_Images folder for each date the sonar process was used; include that file name in the path (Remember the backslash). Concatenate the path with GoPro_Imag to give the copied files the same name.

10. Finally, concatenate both strings of text with a space between them in the 'Final Text' column.

Example:

Copy D:\Video_GoPro_Pairing\2016\20160831\GoPro_20160831\G0011446.jpg D:\GoPro_Hyperlink\Sonar_Images\31082016\G0011446.jpg

Fill all the other cells similarly. Then copy all the final text cells.

11. Open notepad and paste the text. Save as a .txt file to the appropriate folder, then save as a .bat file (file>save as> leave name the same but change .txt to .bat save as type: all files).
12. Open folder where .bat file was saved and double click to run it. This should fill the empty dated folder with all the sonar images.
13. Hyperlink the new hyperlink_sonar shapefile to the new dated folder that only contains sonar track method images.

## Merging Shapefiles:

Before merging the shapefiles, UTM_N and UTM_E fields need to be calculated. The shapefiles should also be backed up before merging, to ensure a completed version is saved in another location.

1. Calculate UTM_N and UTM_E. Follow a process similar to calculating LON_DDEG and LAT_DDEG (See Using Sonar Data and Oblique Imagery to Predict Image Location When Video Data Is Missing Step 12) only select meters as the unit in the Field Calculator. UTM_E = X and UTM_N = Y.

2. Merge Shapefiles. To merge the sonar shapefile with the hyperlink shapefile open Geoprocessing>Merge. Drag both shapefiles into the 'input datasets' drop down, then name the 'output dataset' with the same name as the original hyperlink shapefile but add _Merged_ and the version number to the end. Save in the same location as original hyperlink shapefile.

Example: MP_GoPro_Hyperlink_NAD83_20161004_Merged_3

3. Once the merged shapefile has been created the attribute table may need to be cleaned up, any information that is missing needs to be filled in and any unnecessary fields can be deleted.
4. Next all the hyperlinked shapefiles can be

# IMAGE PROCESSING

Before Image Interpretation, editing may need to be performed on images in Photoshop to ensure the content of the picture (vegetation or sediment) is clear and easily identifiable.

Although both above and below water images may be used for interpretation, the underwater images are the most detailed for interpreting Submerged Aquatic Vegetation (SAV), Sediment and substrate. Underwater images are also not as clear because of cloudy or murky water, less sunlight and underwater haze. Editing will focus on the underwater images for these reasons.

In most cases adjustments to sharpness, contrast and colour will make a great difference in the overall clarity of an image. Applying adjustments to all the images may be necessary to improve clarity for interpretation. Occasionally, further editing may need to be done on specific images which are still unclear.

## Use Dos Commands to Copy Underwater Images

1. Follow a similar method as *Using DOS Commands to Copy Specific Images to New Folders:* to copy the underwater (UW) images to a new folder called "UW" within the dated images folder.
2. Select all the UW images from the attribute table of the merged shapefile and export to excel, or copy and paste from the original into a new spreadsheet.
3. Create a table similar to the one created for the sonar images and fill cells appropriately. Add the date_folder field to the concatenation to pull the images out of their respective dated folders.
4. Concatenate columns to create a final string of text
5. Open notepad and past all the text, save as a batch file
6. Run the batch file and ensure the images are saved correctly.

## Batch Editing in Photoshop

There are two editing processes that can be used to enhance image clarity in Photoshop. The first is editing in Camera Raw the second is editing in Photoshop.

### *Editing in Camera Raw:*

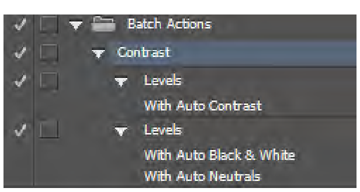
1. Open Photoshop then click File>Browse in Bridge, next navigate to the newly created folder with only the underwater images.

2. Select all images in the folder under the Content tab left click> Open in Camera Raw…
3. On the top left hand side above the `Film Strip` (view of all images open) click Select All then click Synchronize, this applies all adjustments made to the selected image to all images.
4. Under the Basic adjustments tab slide the clarity slider all the way to the right for maximum clarity.
5. Under the Detail adjustment tab slide the sharpness slider all the way to the right for maximum sharpness.
6. Save Images. Create a new folder within the underwater images folder and name it 'Edited.' Save the edited raw image as a .jpg with the same name in this folder.
7. Press done to return the bridge.
8. Continue this process for all the dated folders of images.

## Editing in Photoshop using Batch Actions:

1. Open Photoshop and connect to the 'Mini Bridge'. Navigate to the first edited image folder. Alternatively, if there were no edits done to the Raw image select the underwater images folder instead.
2. Open the first image in the bridge. Right click > Open with Photoshop.
3. Open the actions window. Click Window>Actions
4. Create a new set of actions. Click button with grey folder symbol on bottom right hand side of window.
5. Name the set. "Batch Actions"
6. Create a new action. Name the action "Contrast and Colour" select Batch Actions as the set in the drop down bar, click record. When recording every action taken such as opening and closing images, any adjustments or any processing will be scripted to the action.
7. Auto Contrast. Click Image>Auto Contrast
8. Auto Colour. Follow similar steps for Auto Colour.
9. Stop recording. Click the grey square at the bottom right hand corner of the actions window to stop recording actions.

   Contrast and Colour action should look like the following:

   If there are any additional actions they can be deleted using the button with the grey garbage can symbol.

10. Select all the images in the mini bridge. Click+Shift the first image to the last image.

11. Process images. Left click image Photoshop>Image Processor, leave the defaults for #1, Save to the same location for #2, leave the defaults for #3, Select run action, Batch Action, Contrast and Colour for #4. Click run.
12. A new folder called JPEG will be created within the underwater edited folder. This is where the batched auto contrast and auto colour images will be saved.

    It is important to set up the action the correct way before applying it to multiple images. Do a test run on a sample image first and ensure the outcome looks correct, that it was saved to the right location and that the action completed without any glitches. There may be glitches if too many images get opened in Photoshop. This will occur if the action has an open command scripted. If open is a part of the action delete it.

## Refining Edited Images That Are Still Unclear

Some images may still be unclear after batch editing. They may appear dark, dull or hazy. These images can be further refined in Photoshop. However images that are blurry from motion can only be corrected to a certain extent. It is recommended to skip motion blurred photos and concentrate on images that are dark dull or hazy.

Browse through batch edited images. Make note of any images that look dark, dull or hazy.

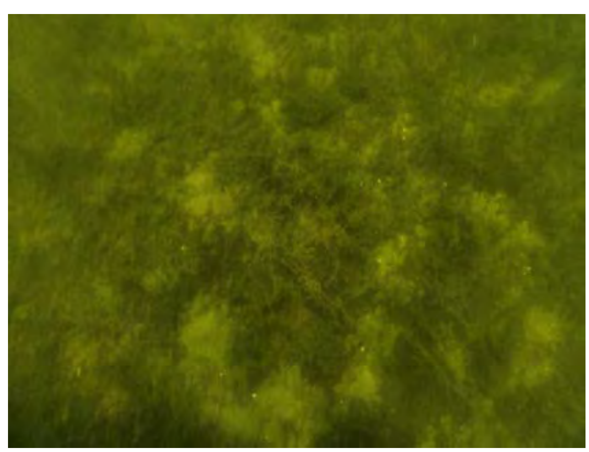
### *Refining Dull and Hazy Photos:*

1. Open image in Photoshop
2. Click Image>Adjustments> HDR Toning
3. View default adjustment if that does not look right try Surrealistic from the drop down menu.

### *Lightening Dark Photos:*

1. Open in Photoshop
2. Click Image>Adjustments>Equalize
3. Or Try Image>Adjustments>Brightness/Contrast and slide the slider to determine the best results.

G0013149 Before Refining



G0013149 After Refining with HDR Toning Adjustment

## Create a New Shapefile for Enhanced Images

Rather than rewriting over the unenhanced images with the enhanced images, it is easiest to create a new shapefile with hyperlinks specifically to the folder with the enhanced photos.

1. Create a new folder in the hyperlink folder for the enhanced images and call it UW_Enhanced. Copy all the JPEGS and edited photos to this folder so that there is only one version for each enhanced image.
2. Export only the underwater points to create a new shapefile name it "Merged_Enhanced_UW_FH_Hyperlink_Points_YEAR" and assign coordinate system.
3. Follow steps similar to *Hyperlinking to GoPro Images* only use the UW_Enhanced image folder in the field calculator to create the file path. Enable hyperlinks and use in in conjunction with the regular AW and UW images in interpretation.

After completion of the Image Processing a final copy of the image archives and hyperlink shapefiles for both regular and enhanced images should be saved on the LaCie external hard drive in the Severn_Sound_Coastal_Mapping_Data folder. The enhanced UW image archive should be separated from the AW & UW image archive, by year.

# CONCLUSION

To maintain the initiatives set forth by the SSRAP as part of the delisting strategy, ongoing fish habitat monitoring is required by SSEA. SSEA recognizes the impact that fish habitat degradation has on the surrounding communities, as it is a major draw as a recreational activity and contributes to the overall health of the watersheds within the municipal partner's jurisdiction. Therefore it is necessary to ensure that the data collected to monitor fish habitat is collected, stored and processed in an efficient and organized manor, to achieve precise results.

Once the Video Conversion, Pairing Process, Hyperlink Process and Image Processing steps have been completed the data will be well organized and a refined version of it will be available for the next phase of data interpretation. The shapefile and file archive of photos can easily be manipulated in mapping software to show location specific imagery which can aid in determining suitable fish habitat. By using images in remote sensing methodology the shoreline can be digitized to represent percentage of vegetation and substrate which can both be seen in above and underwater imagery.

# ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| AW | Above water |
| CHS | Canadian Hydrographic Service |
| DFO | Department of Fisheries and Oceans |
| FH | Fish Habitat |
| LED | Light-emitting Diode |
| N/A | Not Applicable |
| ROVER | Remotely Operated Vehicle for Environmental Research |
| SAV | Submerged Aquatic Vegetation |
| SSEA | Severn Sound Environmental Association |
| SSRAP | Severn Sound Remedial Action Plan |
| UTM | Universal Transverse Mercator |
| UW | Underwater |

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# APPENDIX1: Example Spreadsheet for Data Processing


Orange columns contain equations to automate data entry and speed up process.

Red boarder columns are the only columns that need to be filled manually after set up.

Yellow columns can be hidden after set up to save space.

UTM_N and UTM_E will be auto filled in ArcMap later.

**APPENDIX_A3_Substrate_Processing_(UWIN)**

# Using Grain Size Analysis to Categorize Substrate Type in Nearshore Fish Habitat in Severn Sound, ON

**March 2017**

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## Table of Contents

**List of Tables**



**List of Figures**

## Introduction

Coastal areas, including wetlands are important habitats for fishes because they act as nurseries and spawning areas for more pelagic species, and provide shelter and food sources for more littoral species (Jude & Pappas 1992, Brazner & Beals 1997). Changes in shoreline structure can have impacts on the abundance and distribution of several species, and human activity can alter the species composition of these areas (Uzarski et al. 2005, Jenkins & Sutherland 1997). Coastal habitats are necessary for maintaining healthy populations of fishes, which in turn support recreational and commercial fisheries.

The structure of nearshore habitat can be characterized by a wide range of variables including: macrophyte density, depth, and sediment type, creating diverse areas along a shoreline influencing the species composition of fish found in each area (Keast et al. 1978). The association between habitat and fish species can be modelled and used for conservation efforts, such as developing indexes of biotic integrity (IBI) (Brousseau et al. 2004). To develop habitat models, environmental variables are needed to correlate with the biota. In this report, we detail the collection and processing of substrate samples, a component needed for modeling of fish habitat.

The Habitat Ecosystem Assessment Tool (HEAT, http://habitatassessment.ca/) is a model developed by the Department of Fisheries and Oceans Canada (DFO) to examine the relationships between nearshore habitats and fish community composition in the Laurentian Great Lakes. Collaborating with the DFO, the University of Windsor and Severn Sound Environment Association (SSEA) have collected remote-sensing data in Severn Sound, ON in 2015 and 2016 to input data into the HEAT model. HEAT requires fish community data, % vegetation (emergent and submergent) cover, depth and substrate (clay, silt, sand etc.). We've collected all four of these variables, however, this report details the collection of substrate. Substrate can influence the growth of different kinds of macrophytes (Palmer et al. 2004) and influence invertebrate communities (Williams and Mundy 1978) which helps to shape overall habitat. Different fishes may associate with different habitat when searching for prey (Webster & Hart 2004), and when seeking shelter (Gotceitas & Brown 1993), highlighting the importance of substrate assessment when conducting habitat modeling.

Substrate is typically categorized using grain size to place the sample into different groups based on the Wentworth scale (Cummins 1962). This approach is more objective and allows for the quantification of samples as opposed to trying to categorize a sample visually. Samples are taken with a ponar grab or sediment core to collect multiple inches of sediment and then dried out to remove water from the sample. Samples are then broken into different size fractions using mechanical sieving (filtering a sample through increasingly smaller meshes) and the weight of each fraction recorded as a percentage of the overall sample. Sample composition can then be defined as the percentage of different substrate groups (silt, clay, sand) that were inferred from the percentages of different grain size fractions that make up the total sample.

Some studies may call for grain size analysis that is too small for mechanical sieving, in such cases further processing of the sample is needed. Laser diffractometry is a modern method employed for analyzing fine particle sizes including sediments (Sperazza et al. 2004) that uses light passed around a particle to determine its size. The objective of this study was to make use of mechanical sieving and flow cytometry to analyze sediment samples collected from Severn Sound, ON down to a particle size of 4 µm. The amount of time necessary to process a large number of samples and all necessary steps were recorded to develop a series of protocols for future research and to determine the viability of this approach. The substrate data obtained from this analysis will in turn be used in the HEAT model for a project in Severn Sound, ON.

## Methods

### Study Site

Severn Sound is located on the eastern side of Georgian Bay, Lake Huron (44.799618, -79.819877). The shoreline of Severn Sound is diverse, ranging from sand beaches, rock, wetland and developed areas consisting of commercial and residential land use. As a result, there are a wide array of nearshore sediment types associated with different habitats across the study site. Severn Sound was delisted as an area of concern in 2003 (https://www.ec.gc.ca/raps-pas/default.asp?lang=En&n=6CF1B88D-1) due to improved water quality and habitat management, however, there is still interest from local and federal bodies about the recovery of different areas and any changes in community composition over the years.

### Field Sampling

Sediment samples were collected in Severn Sound, Ontario from June 3rd to June 10th 2016 via petite ponar grabs. Upon arrival, each site was characterized according to % of shoreline make up (beach, rocky, riprap, vegetated bank, etc.) and % of landcover type (low density residential, agricultural, upland forest, etc.). Aquatic vegetation was also characterized by the % of emergent, floating leaf, and submerged vegetation, and the dominant species in each category was noted. Before ponar deployment, water quality readings were taken using a YSI Sonde that measured: water temperature (°C), dissolved oxygen (%), dissolved oxygen (mg/L), conductivity (µs/cm), pH, and ORP.

Sediment samples were collected along a transect perpendicular to shore to catch sediment variation along a depth gradient (deeper, 2 m + to shallower, > 1 m). Two to Five samples were taken along each transect depending on the amount of sediment collected; in areas of bedrock, no ponar samples were taken. If ponar sampling yielded no substrate after three attempts, no sample was taken. At each sampling location, a GPS point was taken.

Upon retrieval, ponar fullness and sediment composition were recorded (sand, mud, cobble, clay). The ratio of different substrate categories and the presence of vegetation in samples was also recorded. Sediment samples were placed in Ziploc bags with external and internal labels and stored on ice until they were transferred to a freezer (-20 °C).

### Sediment Processing

Of the 150 substrate samples collected, only 99 were processed with available funds. Substrate samples were selected in 3 ways. Priority 1 selected samples that overlapped with previous sidescan sonar surveys. Substrate samples will be used to validate sidescan data and estimate substrate of the Severn Sound Nearshore. Priority 2 had sites selected in a stratified random fashion. Based on remote sensing secondary echoes (E1 & E2 values) we classified sites as soft, medium or hard substrate. We randomly chose substrate samples that overlapped with E1 & E2 values, blocked by substrate type (soft, medium, and hard – with similar sample sizes for each class). Priority 3 chose samples to ensure representation around Severn Sound; we used these samples to fill in any gaps that the previous selection processes may have missed.

Substrate samples were thawed at room temperature overnight and then placed in an oven for 4 hours at 30 °C. Samples were then ground up using mortar and pestle until any clumps were broken up and the substrate was free flowing and was then placed back in an oven for an additional 24 hours at 106 ° C to drive off any remaining moisture. After cooling to room temperature, samples were sub-sampled (~ 3 g for fine sample such as mud and clay, ~ 20 g for samples with rocks, pebbles or large amounts of organic matter). A crucible for each sub sample was weighed, tared, and then filled with subsample and weighed (g) again. This was done following the Doka lab protocols.

Sub samples were placed in a muffle furnace for a total of 8 hours to burn off any organic matter to determine % carbon or Loss on Ignition. The first hour was spent slowly raising the temperature up to 250 ° C. In the second hour, temperature was increased to 500 ° C. The subsamples remained in the furnace at full temperature for 6 hours following the two warm up hours (totaling 8 hours). After 8 hours, the muffle furnace was turned off and the sub-samples were allowed to cool overnight. The following morning the sub-samples were weighed and recorded and then subtracted from the pre-burn weight to determine % carbon.

The rest of the original sample was filtered through a sieve tower which followed a classified Wentworth scale (clay [<3.9 µm], silt [3.9-6.25 µm], sand [6.25µm-2 mm], gravel [2-16 mm], pebble [16-64 mm], cobble [64-256 mm], boulder [>256 mm]) (Wentworth, 1922: Table 1). Remains of the sample in each sieve were weighed on a tared crucible and recorded in grams. Remaining sediment left in the tray at the bottom of the sieve tower (< 63 µm) was weighed and recorded and placed in a scintillation vile with a cap label and internal label and stored at room temperature for flow cytometry analysis (See below). The tared crucible, sieves and tray were cleaned between samples.

Flow Cytometry

Samples were prepared 24 hours before running to ensure particles did not clump before processing. Samples were taken from the scintillation vials using a scoopula, 0.05 g from each sample was mixed into a solution of 500 µm of Fluorescent-Activated Cell Sorting (FACS) fluid in a weighing dish and wetted by mixing with a rubberized probe. This solution was then washed into a plastic 15 ml vial using 10 ml distilled water. All plastic vials were labelled externally following the codes on the scintillation vials.

The flow cytometer was calibrated with micro beads of 4 known sizes (2 µm, 3.4 µm, 7.4 µm and 14.7 µm). The beads were run through the flow cytometer and their size distributions were plotted onto a scatter-plot using Becton, Dickson and Company Fluorescent-Activated Cell

Sorting Diva (BD FACS Diva) software. A 4 µm threshold was set to distinguish between silt (63 µm - 4 µm) and clay (<4 µm) (< 4 µm described samples composed of clay, and > 4 µm described samples composed of silt as per DFO protocols, Table 2).

In preparation for analysis, samples were agitated by shaking to re-suspend sediment particles into the solution; a ~ 2 ml of sample solution was transferred from its plastic vial into a glass test tube. The sample was then placed in the flow cytometer. Each sample was run as a separate tube in BD FACS Diva under the same parameters – Forward Scattered light (FSC, x axis) was set to 88 volts, and Side Scattered light (SSC, y axis) was set to 110 volts. Samples were run for 10,000 events in BD FACS Diva unless data acquisition was significantly slower due to a more dilute sample, in which case samples were analyzed for 5000 or 1000 events. Samples ran for an average of 1-2 minutes. All data output was exported as a pdf file (3 files in total).

Data output for each sample consisted of a scatter-plot showing size fraction of calibration beads, a frequency histogram for each plot and a graph displaying relative percentage of particle size along a 4 µm threshold. These percentages were then used to extrapolate the overall composition (% of silt and clay) of the sediment samples collected in each scintillation vial.

**Preliminary Results**

In total, 99 ponar samples were selected from over 150 samples collected by the University of Windsor and DFO from across Severn Sound, during the summer of 2016. Of the selected sites, all samples were analyzed for loss on ignition (LOI) and mechanically sieved over a period of 2 weeks with access to 3 ovens for drying, one muffle furnace for burning off organic carbon and one sieve tower. Samples were composed of different types of substrate that was initially qualified visually (mud, clay, sand, rock). After mechanical sieving and flow cytometry substrate samples fell into several categories based on grain size including: sand, silt, clay, and pebbles. Samples were successfully characterized using mechanical sieving grain size from 4 cm – 63 µm.

From initial visual surveys sediment samples appeared to mainly consist of mud and silt, however mechanical sieving revealed that all but one sample (consisting entirely of gravel, 4 - 2 mm) were composed mainly of sand (1000 – 63 µm, range = 52.7% to 100%, mean = 95.2% and standard deviation of 12.0). When compared between southern and northern shorelines the percentage of sand in each sample was not significantly different ($p > 0.5$) however the differences became more drastic when comparing only coarse sand (500 µm, $p = 0.057$) with larger percentages of coarse sand in samples from the northern shore. The percentage of gravel was also not significantly different between samples collected on the southern and northern shores ($p > 0.8$) however mean % was higher on the southern shore (3.52 %).

Samples with grain size smaller than 63 µm were successfully characterized using flow cytometry to analyze grain size from 63 µm – 4 µm. Sample preparation time for the flow cytometer was approximately 45 mins per 10 samples. Sample run times using the flow cytometer was approximately 2 hours for 44 samples. All samples were run in 4 sessions (4 days) including one initial session to calibrate bead sizes for our study. Flow cytometry analysis revealed that the smallest size fraction (< 63 µm) in all samples was mainly composed of clay (< 4 µm), although the percentages of clay and silt varied between samples (Figure 1). The percentage of clay from each sample ranged from 0 % to 86.2 % with a mean of 67.4% and a standard deviation of 14.1. The percentages of clay and silt in samples collected on the southern and northern shores were not significantly different ($p > 0.2$).

## Summary

Substrate samples from nearshore habitats were successfully characterized using standardized grain size fractions. Size fractions that were too small to analyze with mechanical sieving were analyzed with flow cytometry; this proved to be an efficient method for dealing with many samples. Overall, this methodology proved to be a quick, cost effective way of analyzing sediment and grain size down to a very fine scale.

The data collected show substrate around Severn Sound is predominantly sand, despite observations from the field. These data will now be mapped using Geographic Information Systems (GIS) software and combined into a geo-referenced grid with depth, % vegetation cover and fish community these substrate samples will be used to quantify fish habitat within Severn Sound, ON.

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**Tables**

Table 1: Wentworth Scale (Wentworth, CK. 1922)

| Diameter (mm) | Diameter (phi) | | Wentworth Size Class |
|---|---|---|---|
| 4096 | -12 | | |
| | | | Boulder |
| 256 | -8 | | |
| | | Gravel | Cobble |
| 64 | -6 | | |
| | | | Pebble |
| 4 | -2 | | |
| | | | Granule |
| 2 | -1 | | |
| | | | Very Coarse Sand |
| 1 | 0 | | |
| | | | Coarse Sand |
| 0.5 | 1 | Sand | |
| | | | Medium Sand |
| 0.25 | 2 | | |
| | | | Fine Sand |
| 0.125 | 3 | | |
| | | | Very Fine Sand |
| 0.0625 | 4 | | |
| | | | Coarse Silt |
| 0.0313 | 5 | | |
| | | | Medium Silt |
| 0.0156 | 6 | Silt | |
| | | | Fine Silt |
| 0.0078 | 7 | | |
| | | | Very Fine Silt |
| 0.0039 | 8 | | |
| | | Mud | Clay |
| 0.00006 | 14 | | |

Table 2: Modified Wentworth scale used in HEAT model (Sue Doka, DFO).

| Substrate Class | Grain Size (cm) | Notes on Texture or Familiar Size Examples | Ball Squeeze Test | Ribbon Test |
|---|---|---|---|---|
| Bedrock | | | | |
| Hardpan Clay | | very dense layer of clay that is difficult to penetrate | | |
| Clay | <0.0004 | feels smooth and sticky | resists breaking | Ribbon forms which is > 5 cm before breaking |
| Silt | 0.0004-0.0062 | feels floury, finer than sand with organic component | stays together but changes shape easily | Ribbon forms between 2 – 5 cm before breaking |
| Sand | 0.0062-0.2 | feels gritty | breaks with slight pressure | Weak ribbon forms which is less than 2 cm before breaking |
| Gravel | 0.2 – 6.4 | golf ball diameter is ~ 4 cm | | |
| Rubble | 6.4 – 17 | baseball diameter is ~ 7 cm<br>volleyball diameter is ~ 21 cm | | |
| Cobble | 17 – 25 | basketball diameter is ~ 24 cm | | |
| Boulder | > 25 | bigger than a basketball | | |

## Figures

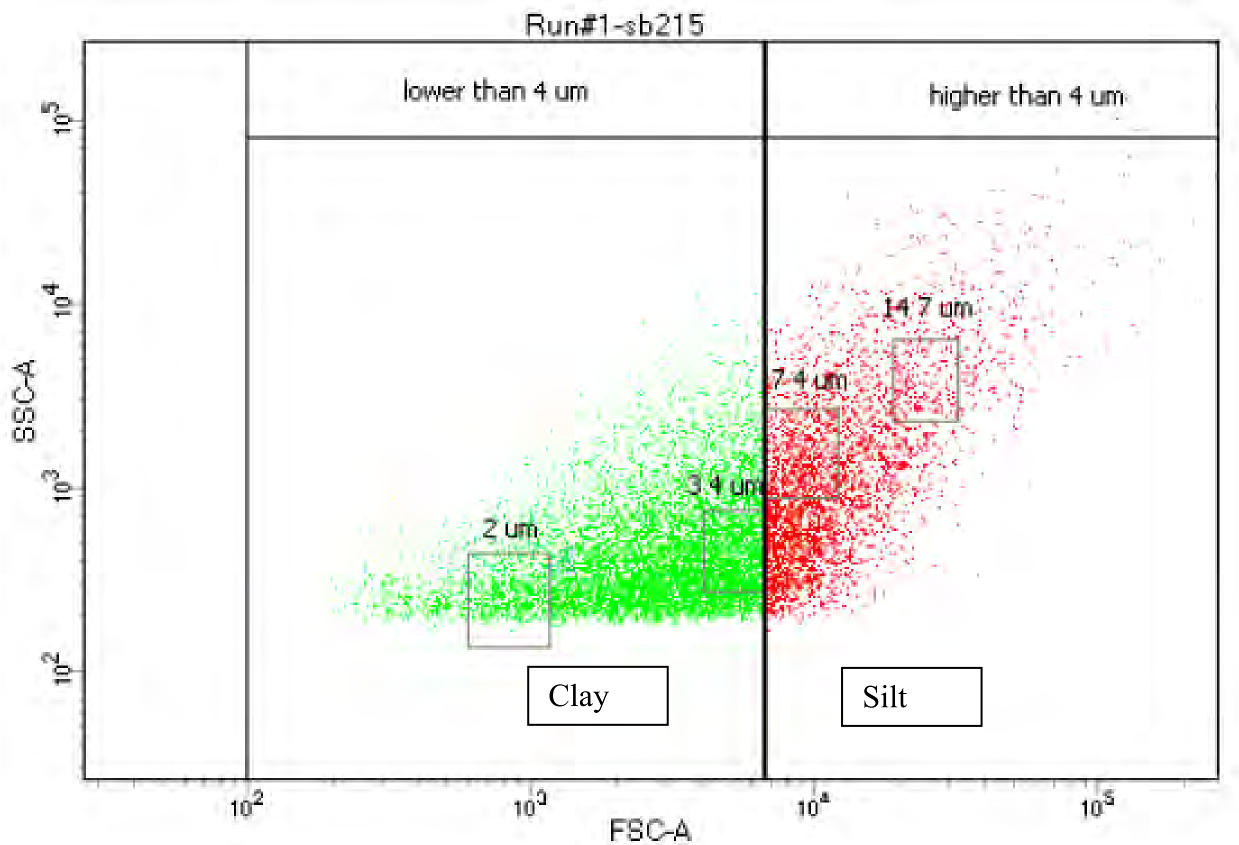



Figure 1: Log scale dot plot exported from BD FACS Diva. Both axes represent unit less values

Tube: sb215

| Population | #Events | %Parent | %Total |
|---|---|---|---|
| All Events | 10,000 | #### | 100.0 |
| 2 um | 560 | 5.6 | 5.6 |
| 3 4 um | 1,328 | 13.3 | 13.3 |
| 7 4 um | 652 | 6.5 | 6.5 |
| 14 7 um | 171 | 1.7 | 1.7 |
| lower than 4 um | 6,706 | 67.1 | 67.1 |
| higher than 4 um | 3,222 | 32.2 | 32.2 |

Figure 2: Summarizes the number of events (particles scanned) and total percentages of particles in each area from Figure 1. The last two rows were used for the 2 substrate categories (Silt (>4µm vs. Clay <4µm).

APPENDIX_A4a_Estimating_percent_cover_of_SAV_using_sonar_output_from_Reefmaster_Software_in_Severn_Sound_(SSEA)

# Description of procedures to estimate percent cover of Submerged Aquatic Vegetation (SAV) using sonar output from Reefmaster Software in Severn Sound

**Lex McPhail, Severn Sound Environmental Association**

**2/17/2017**

After the Sonar correction process using Reefmaster is complete, a method of estimating SAV Percent Cover was applied to the data. SAV Percent Cover is one of three primary input parameters used for fish habitat suitability models such as the Habitat/Ecosystem Assessment Tool (HEAT).

The method used to estimate SAV is based on the presence or absence of SAV at a location. A percent cover value is applied by comparing the number of point locations where SAV is present with the total number of points that coincide with a 10 m grid cell. The measurement is output as a percent cover value for each cell within a seamless grid of squares for a processing area. The Severn Sound study area is too large to process as one area. The study area was subdivided into manageable processing areas which were determined prior to the post-processing/modelling step.

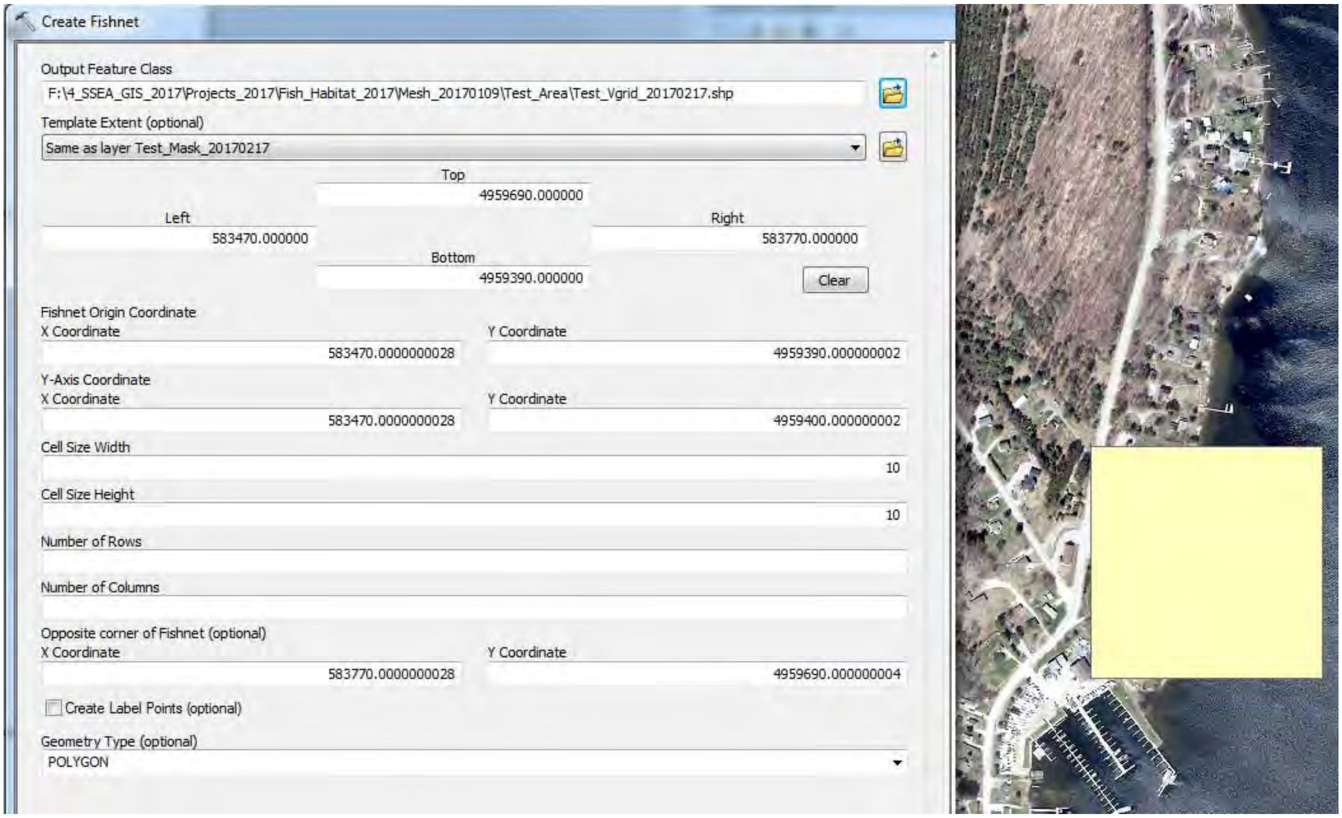
Processing areas range in size from 43 km² for the priority area of Penetang Harbour to smaller 300 m² areas covering the areas around DFO electro fishing sites. A 10m² grid was created for each processing area. The type of grid used for this study is a Vector Grid also known as a fishnet mesh created using ArcMap. Vector grids were used rather than raster grids in order to utilize the attribute capabilities associated with vector based models which are different from the raster format. One limitation to using a vector grid is the higher the resolution and larger the coverage area, the larger the file size which affects computer processing speed. When the calculation of SAV Percent Cover is complete for a processing area, the Vector grid is exported to a raster grid which is then used in HEAT.

The work flow for this component of the analysis is as follows:

1. Process the SAV Depth and Bottom Depth comma separated values files (Sonar files output from Reefmaster) to convert depth to metres above sea level and calculate presence/absence of SAV. (Described in “procedures to use Reefmaster Software for processing Sonar data” use ROVER_Sonar_Data_Processing_Template_20170109.xlsx as a template)
2. Import the Sonar track point spreadsheet into ArcMap as a shapefile
3. Create a 10m² Vector grid that covers the process area and will house all analysis data
4. Join the Vector grid to the sonar track point layer to transfer the vector grid ID to each point
5. Summarize the sonar track point data by the vector grid ID to output counts of SAV, Total point count and SAV Percent Cover per grid square and save as a separate spreadsheet
6. Join the summarized SAV Cover data with the vector grid using the vector grid ID and transfer the SAV Percent Cover and average elevation to the grid.
7. Export the vector grid to a raster

## Creation of the vector grid

For this study, vector grids were created using the “Create Fishnet” tool in ArcMap. A vector grid is generated by inputting the required parameters including the cell size and layer extent, and running the tool.




**1: Example of ArcMap's "Create Fishnet" dialog**

To facilitate future analysis by providing the capability to combine vector grids without shifting grid coordinates, it is recommended that vector grids originate at the nearest 10 m coordinate as demonstrated in figure 1 (Template Extent) and are oriented in the North/South direction (not rotated) . This can be accomplished by first establishing the processing area extent using the graphic rectangle tool in ArcMap. The yellow square in Figure 1 covers an area of 300 by 300 metres. By editing the graphic properties of the square, the lower left corner can be shifted to the nearest 10 m coordinate. The graphic square was converted to a shapefile which was used for the Template Extent in the “Create Fishnet” dialog. The projection used for the analysis is Universal Transverse Mercator NAD83 Zone 17.

### Summarizing the sonar track point data

After joining the vector grid to the point shapefile the vector grid ID is transferred to the point shapefile attribute table. The attribute table data is summarized by Grid ID using Microsoft Excel to output counts of SAV (present), Total point count and SAV Percent Cover ([Count of SAV Present/Total Point Count]*100) per grid square. Corrected bottom elevation can be transferred at the same time. For this study, a pivot table was set up in excel to facilitate the data summary process.

The summary table is joined to the vector grid using the grid ID to transfer the SAV Percent Cover and Bottom Elevation to the grid.

## APPENDIX_A4b_Method_of_Interpreting_Submergent _Aquatic_Vegetation_and_Substrate_in_Severn_Sound _shoreline_areas _(SSEA)

# Method of Interpreting Submerged Aquatic Vegetation (SAV) and Substrate in Severn Sound Coastal Margin Areas Using Remotely Sensed Data for Areas Requiring Interpretation

**Prepared by: Justine Lunt, Risk Management/ Data Management Technician and Lex McPhail, Severn Sound Environmental Association**

**5/2/2017**

# SUMMARY

Remotely sensed data, along with surface level imagery, was used to map and classify submerged aquatic vegetation (SAV) and substrate cover along selected coastal margin areas of Severn Sound. The interpretation was undertaken to provide additional information in areas that were not covered by other sources. Resulting cover information was integrated with the other sources to facilitate the production of complete layers of substrate and aquatic vegetation that extend from the underwater up onto nearshore in selected areas. The final layers will be applied as inputs to DFO`s Habitat Evaluation and Assessment Tool (HEAT). This step-by-step guide will facilitate the completion of imagery interpretation using a consistent methodology and rationale.

# PROJECT OVERVIEW

The interpretation of fish habitat data supports SSEA's future work to identify areas that are highly suitable and productive fish habitat. This report is one of several components used in the Mapping, Evaluating, and Predicting Changes in Coastal Margin Aquatic Habitat in Severn Sound and Southeastern Georgian project; a collaboration between University of Windsor, Department of Fisheries and Oceans, Ontario Ministry of Natural Resources and Forestry, and Severn Sound Environmental Association (SSEA). Additional data has been collected and interpreted for the lake bottom using other methods. Integration of the interpreted layers with the lake bottom layers was completed in selected areas to enhance the coverage area to include shoreline areas.

This methodology will focus on the interpretation process used to digitize and classify percent cover of SAV and substrate in areas that are visible by using available remotely sensed data.

Interpretation of imagery is subjective to the interpreter and results can vary from person to person. Following a consistent interpretation and digitizing methodology will increase the reliability of the interpreted data. The data sources, identifying the some of the challenges of interpretation, and outlining data interpretation process have been described in the following sections.

The methodology of data interpretation for fish habitat is described in three sections; interpretation set up, interpretation of SAV percent cover and interpretation of substrate percent cover. Interpretation of SAV percent cover and substrate percent cover both outline the steps and rules that were applied for digitizing specific to each type of cover as well as the attributes that were used to describe each feature.

It is assumed that the user of this method has a general understanding of GIS principles and techniques. The GIS software that was used to complete this component is ArcGIS Basic although other similar software packages could be used.

Surface imagery data was consolidated and refined using the *Methodology of the Consolidation and Refinement of Fish Habitat Data Collected in Severn Sound.* Supporting data is listed with a brief description in the Data Sources section below.

## DATA SOURCES

The following data sets were used throughout the interpretation process.

| Dataset | Type | Data Source | Year | Study Area Coverage |
|---|---|---|---|---|
| South Central Ontario Ortho-photo Project (SCOOP) | Orthographic Imagery Tiles (.TIF) | OMNRF | Spring 2013 | Entire Area |
| Simcoe County Ortho-photos | Orthographic **Imagery Mosaic** | County of Simcoe | Spring 2016 | South Shore |
| Severn Sound Oblique Imagery | Oblique imagery (.JPG) captured by a SSEA staff | SSEA | Sept. 2015 | Select Areas of South and North Shore |
| South Georgian Bay Oblique Aerial Imagery Project | Oblique aerial imagery (.JPG) Hyperlinked point shapefile<br>- First flight line | OMNRF/ Environment Canada | Nov. 2014 | South Shore |
| South Georgian Bay Oblique Aerial Imagery Project | Oblique aerial imagery (.JPG) Hyperlinked point shapefile<br>- Second flight line | OMNRF/ Environment Canada | Dec. 2014 | Selected areas of South Shore |
| Georgian Bay Shoreline Features | Shoreline classification system to monitor the change in natural/altered shoreline over time. | Provincial Geomatics Service Centre - OMNRF/ Environment Canada | 2016 | South shore (Georgian Bay) |
| SSEA Surface Shoreline Imagery | Surface level imagery (.JPG) Hyperlinked point shapefile | SSEA | Summer/ Fall 2015 and 2016 | Selected Areas |
| Bathymetry Mesh | Polygon Mesh | SSEA | 2017 | Selected Areas |
| SAV percent cover mesh | Polygon Mesh | SSEA / University of Windsor and County of | 2016 | Selected Areas |

| | | | | |
|---|---|---|---|---|
| | | Simcoe | | |
| Sidescan Sonar | Polygon Shapefile (.SHP) | Habitat Solutions NA | 2012 | Selected Areas |
| Underwater Geology | Polygon shapefile (.SHP) | Geological Survey of Canada | 1995-1997 | Selected Areas |
| Windsor Ponar | Point Shapefile (.SHP) | University of Windsor | 2016 | Selected Areas |
| SAV DFO BioAcoustics | Point Shapefile (.SHP) | Department of Fisheries and Oceans | 2016-2017 | Selected Areas |

Note: Where appropriate, all data including newly created layers was projected to Universal Transverse Mercator – North American Datum 1983 – Zone 17.

## INTERPRETATION CHALLENGES

The interpretation methodology has some limitations. Interpretation is subjective to the interpreter. Limits observed for determining percent cover SAV include cases where submerged vegetation cannot be identified due to a lack of supporting imagery and remote sensing data because data was not collected in that area, or in areas where there were un-uniform distributions of percent coverages and no other accompanying data to assist with further interpretation.

Determining the fine substrate types along the near shore areas can be difficult. Bedrock and boulders are easily identifiable since they are the largest and usually the most distinguishable types of substrate. Areas with sand are also easily identifiable in the majority of areas based on mega ripples visible in ortho photographs and sidescan sonar. It is more challenging to interpret the size of the finer substrates such as sand and gravel, from the surface, oblique and ortho-photo images. The imagery is taken at distances far enough away that identifying grain sizes can't be accomplished with confidence. The underwater images assisted with interpretation of substrate condition identification, where the images were taken in the relevant near shore areas. Grain size analysis helps with assigning the substrate material into the HEAT substrate categories. Additional field data and expert knowledge was used for enhancing the coverage of the nearshore and coastal margin area substrate.

Boundary delineation of near shore and coastal margin areas for both substrate and SAV can be subjective and relies on the interpreter's abilities to estimate percent cover and identify contiguous areas using the various sources of information. It is not always easy to identify where boundaries of polygons should be drawn as vegetation and sediment outcroppings form inconsistent patterns and are not always neatly grouped. These limitations are mitigated by following the digitizing rules and understanding the attribute descriptions wherever possible. It is important for the interpreter to be consistent with the interpretation process. After the process has been completed the resulting data will be an input to a HEAT model.

# DATA INTERPRETATION

## Interpretation Setup

1. Start a new .mxd and name it interpretation.
2. Add data listed in the data sources section for the appropriate areas.
3. Connect shapefiles that support hyperlinks to the appropriate image folder.

Note: Use 2013 County orthographic images as a base for digitizing and use the 2016 County orthographic images for reference, since the 2013 imagery has a lower water level it is easier to distinguish submerged vegetation and sediment.

## INTERPRETATION OF SUBSTRATE PERCENT COVER

Shoreline area substrate was interpreted and combined with estimated underwater substrate cover in selected areas. The attribute data was formatted in a similar way to HEAT input data requirements.

### Digitizing Percent Cover Substrate Steps:

A new polygon substrate layer was created by following a similar process as prescribed in the steps for interpreting percent cover for vegetation.
Fields were added to the attribute table for each substrate type listed below (similar to HEAT):

- **Bedrock**
- **Boulder** (25 cm and above)
- **Cobble** (17 to 25 cm)
- **Rubble** (6.4 to 17 cm) – note: wood waste was considered rubble in some areas
- **Gravel** (0.2 to 6.4 cm)
- **Sand** (<0.2 cm)
- **Silt**
- **Clay**
- **Hardpan**

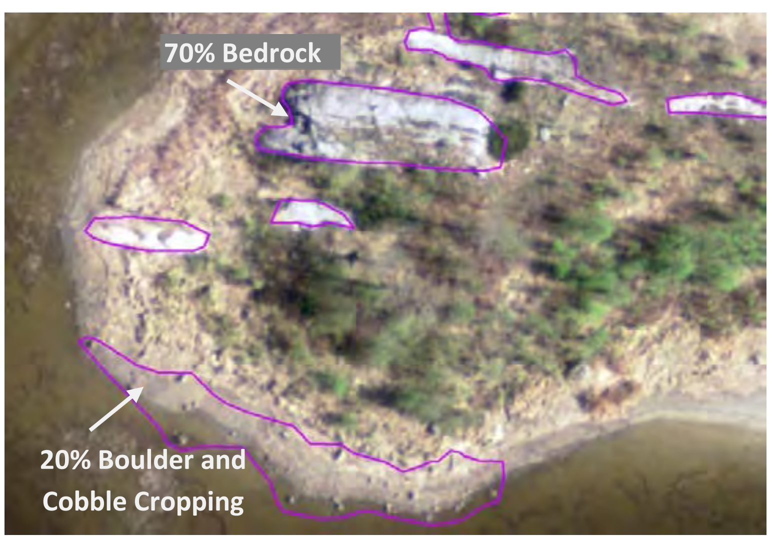
The ‘Percent Cover’ attributed to each substrate field was one of the following values: 10, 20, 30, 40, 50, 60, 70, 80, 90, or 100 with 10 percent being a small amount of sediment and 100 percent being completely covered by substrate. Leave unknown substrate amounts at 0.

An additional field for total substrate percent cover named “TOT” was also appended to the attribute table. The total was used to keep track of polygons that did not add up to 100 percent. Percent cover was assumed in cases where substrate and imagery information was lacking.

The Substrate Percent Cover layer was edited using standard digitizing techniques. The following is a description of the process that was used:

1. Select an area on the map to begin digitizing.
2. Begin where there is an identifiable cluster of similar substrate.
3. Examine the supporting imagery to decide where best to digitize the border.
4. Digitize substrate polygons by following this set of rules:
    a. Digitize at a 1:500 map scale or smaller
    b. Digitize polygons no smaller than 10 $m^2$
    c. Not all polygons will be contiguous. Some areas may consist of several smaller patches that should be merged.
    d. Not all substrate types can be identified if there is not enough supporting imagery. Therefore any substrate that cannot be accurately identified should be recorded as 0. When possible, an assumed substrate percent cover is assigned based on the information from adjacent substrate areas.
    e. Group substrate types or classifications together as much as possible, in some cases other substrate types may be scattered within the polygon.
    f. Do not count vegetation in substrate percentages. Example 1 shows shrubs or moss growing on top of bedrock should not be digitized.
    g. For areas where vegetation is scattered throughout the substrate and cannot be digitized separately, do not include vegetation in the substrate percentage.
    h. Where possible, accompanying underwater imagery and sidescan sonar data should be used to assist with definition of SAV polygon boundaries as well as interpretation of ortho images where water clarity allowed Example 2 shows in water substrate where visible in ortho photo and underwater images.
5. Assign values to the fields of substrate that are present within the polygon using the attribute values defined previously.

Example 1:



Example 2:

## Interpretation of Vegetation Percent Cover

### Digitizing Percent Cover for Submerged Aquatic Vegetation Steps:

A copy was made of the substrate layer previously digitized and this new polygon layer was renamed to house the SAV Percent Cover information. All fields, with the exception of the object ID, the shape, the shape length and the shape area, were deleted. The following fields (field names as bold) were added to the attribute table:

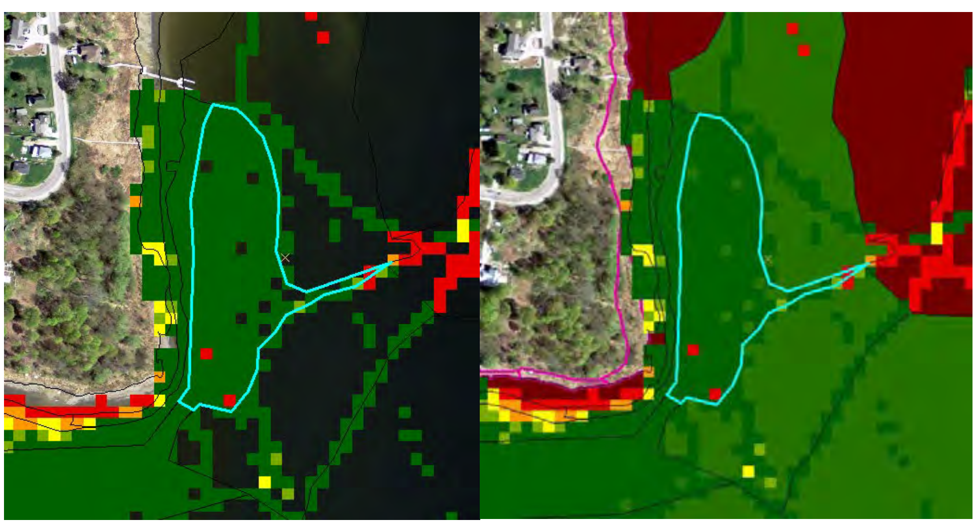
- **SAV_P_C -** The percent coverage attributed to each polygon can be only one of the following values: 0,25,50,75, or 100 with 0 being no cover and 100 being full cover. A value of 999 was input for areas that were considered "managed areas", so that they could be discounted from calculations.
- **NO_COV-** The percent of no coverage attributed to each polygon can be only one of the following values: 0,25,50,75, or 100 with 0 indicating full cover and 100 being no cover. A value of 999 was input for areas that were considered "managed areas", so that they could be discounted from calculations.
- **ADD_DESC -** A description of the polygon was only used to include a description for the polygons that had values of '999' in "SAV_P_C" and "NO_COV", in which case "Managed Area" was entered as the description. Managed areas refer to marinas that

impact the presence and distribution of SAV within their areas, and therefore cannot be accurately estimated based on these anthropogenic activities.

The SAV Percent Cover layer was edited using standard digitizing techniques. The following is a description of the process that was used:

1) Import the completed nearshore substrate layer previously completed.
2) Where substrate polygons are identified as being 100% sand, they should be likewise identified as 100% no cover for SAV.
3) Where substrate polygons are identified as being 100% boulder, they should be likewise identified as 100% no cover for SAV.
4) Examine the supporting imagery and remote sensing data to decide where best to digitize the borders.
5) Start digitizing
   a) Begin in areas where there is a nearly complete area of SAV coverage based on SAV percent cover mesh. Fill in these areas with polygons that are closest to the average of the percent coverage already estimated; Example 3 shows an area with majority SAV percent cover mesh at a value of 100% coverage, and the right-side image is the complimentary polygon drawn to fill in the gaps in data with 100% coverage.
   b) Elevation data was broken down into greater than 7 m of depth and between 7-4 m of depth. SAV should be interpreted as being 100% no cover for areas greater than 7 m of depth and 25% cover and 75% no cover for areas between 7 and 4 m of depth where there is no accompanying imagery or other remote sensing data available for further analysis.

Example 3:



# CONCLUSION

As part of the Severn Sound Remedial Action Plan delisting strategy, ongoing fish habitat monitoring is required by SSEA. SSEA recognizes the impact that fish habitat degradation has on the surrounding communities, as it is a major draw for recreational activities and contributes to the overall health of Severn Sound. It is important that the interpretation of fish habitat data follows an organized approach, to achieve accurate results.

As part of the Mapping, Evaluating, and Predicting Changes in Coastal Margin Aquatic Habitat in Severn Sound and Southeastern Georgian project the shoreline area substrate and EAV data will be combined with depth, submerged aquatic vegetation and underwater substrate data to provide an enhanced set of layers that cover selected areas of Severn Sound. The combined data will be used as an input to DFO's Habitat Assessment and Evaluation Tool, which is used for modelling fish habitat quality of extensive coastline areas in Severn Sound. Once complete, nearshore habitat mapping will serve as a scientifically defensible tool for planners and agency staff to manage nearshore habitat in the future.

## REFRENCES


Provincial Geomatics Service Centre. (2016) *Proposed Shoreline Mapping Best Practices, Lake Simcoe and the Great Lakes.*

Wentworth, C. K. (1922). *A scale of grade and class terms for clastic sediments*. Journal of Geology.

APPENDIX_A4c_Method_of_Interpreting_Emergent_Aquatic_Vegetation_and_Substrate_in_Severn_Sound_Coastal_Margin_Areas _(SSEA)

# Method of Interpreting Emergent Aquatic Vegetation and Substrate in Severn Sound Shoreline Areas Using Aerial and Surface Level Imagery

**Prepared by: Lauren Millar, Aquatic Habitat Intern and Lex McPhail, Severn Sound Environmental Association**

**4/18/2017**

## SUMMARY

Remotely sensed data, along with surface level imagery, was used to map and classify emergent aquatic vegetation (EAV) and substrate cover along selected shoreline areas of Severn Sound. The interpretation was undertaken to provide additional information in areas that were not covered by other data sources. Resulting cover information was integrated with the other sources to facilitate the production of complete layers of substrate and aquatic vegetation that extend from the lake bottom up to the high water elevation (177.0 metres above sea level) in selected areas. The final layers will be applied as inputs to DFO`s Habitat Evaluation and Assessment Tool (HEAT). This step-by-step guide will facilitate the completion of imagery interpretation using a consistent methodology and rationale.

## PROJECT OVERVIEW

The interpretation of fish habitat data supports SSEA's future work to identify areas that are highly suitable and productive fish habitat. This report is one of several components used in the Mapping, Evaluating, and Predicting Changes in Coastal Margin Aquatic Habitat in Severn Sound and Southeastern Georgian project; a collaboration between University of Windsor, Department of Fisheries and Oceans, Ontario Ministry of Natural Resources and Forestry, and Severn Sound Environmental Association (SSEA). Additional data has been collected and interpreted for the lake bottom using other methods. Integration of the interpreted layers with the lake bottom layers was completed in selected areas to enhance the coverage area to include shoreline areas.

This methodology will focus on the interpretation process used to digitize and classify percent cover of EAV and substrate in areas that are visible by using available aerial photos and surface imagery and are not obscured by water.

Interpretation of imagery is subjective to the interpreter and results can vary from person to person. Following a consistent interpretation and digitizing methodology will increase the reliability of the interpreted data. The data sources, identifying the some of the challenges of interpretation, and outlining data interpretation process have been described in the following sections.

The methodology of data interpretation for fish habitat is described in three sections; interpretation set up, interpretation of EAV percent cover and interpretation of substrate percent cover. Set up applies to both interpretations since much of the supporting imagery and data is the same. Interpretation of EAV percent cover and substrate percent cover both outline the steps and rules that were applied for digitizing specific to each type of cover as well as the attributes that were used to describe each feature.

It is assumed that the user of this method has a general understanding of GIS principles and techniques. The GIS software that was used to complete this component is ArcGIS Basic although other similar software packages could be used.

Surface imagery data was consolidated and refined using the *Methodology of the Consolidation and Refinement of Fish Habitat Data Collected in Severn Sound.* Supporting data is listed with a brief description in the Data Sources section below.

## DATA SOURCES

The following data sets were used throughout the interpretation process.

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| Severn Sound Oblique Imagery | Oblique imagery (.JPG) captured by a SSEA staff | SSEA | Sept. 2015 | Select Areas of South and North Shore |
| South Georgian Bay Oblique Aerial Imagery Project | Oblique aerial imagery (.JPG) Hyperlinked point shapefile<br>- First flight line | OMNRF/ Environment Canada | Nov. 2014 | South Shore |
| South Georgian Bay Oblique Aerial Imagery Project | Oblique aerial imagery (.JPG) Hyperlinked point shapefile<br>- Second flight line | OMNRF/ Environment Canada | Dec. 2014 | Selected areas of South Shore |
| Georgian Bay Shoreline Features | Shoreline classification system to monitor the change in natural/altered shoreline over time. | Provincial Geomatics Service Centre - OMNRF/ Environment Canada | 2016 | South shore (Georgian Bay) |
| SSEA Surface Shoreline Imagery | Surface level imagery (.JPG) Hyperlinked point shapefile | SSEA | Summer/ Fall 2015 and 2016 | Selected Areas |
| Rotary Park Images | Images (.JPG) of the shoreline at Rotary Park in Penetanguishene. | SSEA | Sept. 2015 | Rotary Park |

Note: Where appropriate, all data including newly created layers was projected to Universal Transverse Mercator – North American Datum 1983 – Zone 17.

## INTERPRETATION CHALLENGES

The interpretation methodology has some limitations. Interpretation is subjective to the interpreter. Limits observed for determining vegetation type include cases where vegetation cannot be identified for reasons such as; the surface image was taken too far from the shoreline so the vegetation in the image is too small to identify, or not having any supporting imagery available because data was not collected in that area, or where vegetation is dense, it is too difficult to verify what vegetation types are present.

Determining percent cover of vegetation can pose as a challenge. The density of vegetation is reflected in the colour and texture displayed in the ortho-photos, surface images and oblique aerial images. Each imagery type has its limitations. The available Ortho-photos were captured during the leaf off/spring period which helps with reducing the effect of the tree canopy on ground visibility but also has an effect on the visibility of EAV cover; some plants are dormant making interpretation difficult. Surface imagery, which was usually captured during the period between late spring and early fall, can be misleading in some cases where tall vegetation in the foreground obscures the visibility of features behind it. The oblique imagery is very helpful in such cases, however similar to the Ortho-photos, interpreting EAV cover using images taken during winter conditions is hindered by the fact that most plants are dormant. Conversely, oblique imagery that was captured during the late spring to early fall period, when leaves are visible, can still reduce visibility of features behind the plants and canopy. Using all sources of available imagery, in tandem, has greatly enhanced the interpretation process by providing multiple vantage points of each area.

Determining the fine substrate types along the shoreline areas can be difficult. Bedrock and boulders are easily identifiable since they are the largest and usually the most distinguishable types of substrate. It is more challenging to interpret the size of the finer substrates such as sand and gravel, from the surface, oblique and ortho-photo images. The imagery is taken at distances far enough away that identifying grain sizes can't be accomplished with confidence. Identifying grain size helps with assigning the substrate material into the HEAT substrate categories. Additional field data and expert knowledge was used for enhancing the coverage of the shoreline area substrate.

Boundary delineation of shoreline areas for both substrate and EAV can be subjective and relies on the interpreter's abilities to estimate percent cover and identify contiguous areas using the various sources of information. It is not always easy to identify where boundaries of polygons should be drawn as vegetation and sediment outcroppings form inconsistent patterns and are not always neatly grouped. These limitations are mitigated by following the digitizing rules and understanding the attribute descriptions wherever possible. It is important for the interpreter to be consistent with the interpretation process. After the process has been completed the resulting data will be an input to a HEAT model.

# DATA INTERPRETATION

## Interpretation Setup

1. Start a new .mxd and name it interpretation.
2. Add data listed in the data sources section for the appropriate areas.
3. Connect shapefiles that support hyperlinks to the appropriate image folder.

Note: Use 2013 County orthographic images as a base for digitizing and use the 2016 County orthographic images for reference, since the 2013 imagery has a lower water level it is easier to distinguish emergent vegetation and sediment.

## Interpretation of Vegetation Percent Cover

### Digitizing Percent Cover for Vegetation Steps:

A new polygon layer was created to house the EAV Percent Cover information. The following fields (field names as bold) were added to the attribute table:

- **PercentCov -** The percent coverage attributed to each polygon can be only one of the following values: 0,25,50,75, or 100 with 0 being no cover and 100 being full cover.
- **Descr -** A description of the vegetation within the polygon is also a required attribute. Vegetation is broken down into the following categories and listed in order of abundance:
  - No Cover- For percent values of 0 only.
  - h- Deciduous Trees (ex. Willow tree > 6m tall)
  - c- Coniferous Trees (ex. Pine tree > 6m tall)
  - ne- Narrow-leaved Emergents
  - re- Robust Emergents
  - be- Broad-leaved Emergents
  - f- Floating Plants (rooted)
  - ts- Tall Shrub
  - ls- Low Shrub
  - ml- Manicured Lawn

  Note:Dead vegetation was not accounted for.

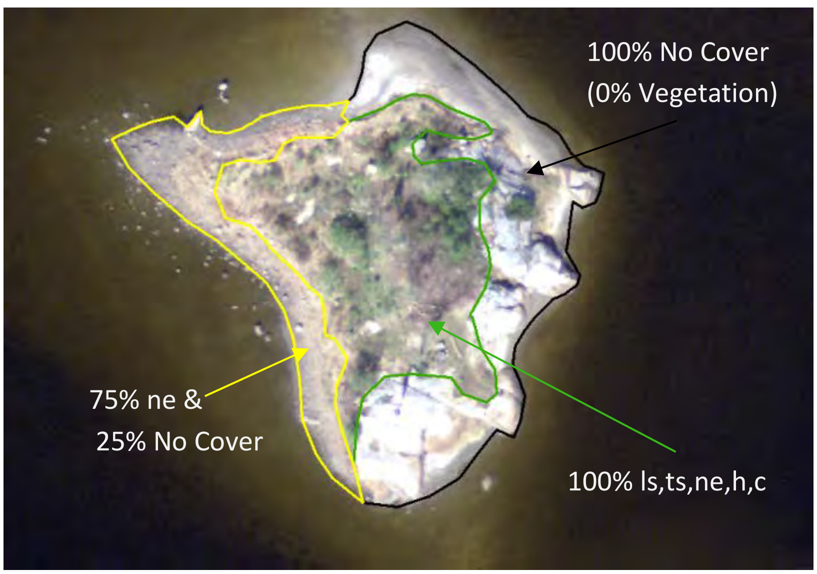
The categories were modified from the Ontario Wetland Evaluation System. For further details on description, and examples of species which fall into each category see pg. 62-63: https://dr6j45jk9xcmk.cloudfront.net/documents/2685/stdprod-103924.pdf

- **Invasives** - If an invasive plant is easily identifiable within the image then the image name (ex. G003417.jpg) is entered in the 'Invasives' field for review by a biologist at a later date. Phragmites is an example of an invasive plant that may be identifiable from an image.

The EAV Percent Cover layer was edited using standard digitizing techniques. The following is a description of the process that was used:

1. Select an area on the map to begin digitizing.
2. Begin where there is a cluster of similar vegetation.
3. Examine the supporting imagery to decide where best to digitize the border.
4. Start digitizing the interpreted area by following this set of rules:
    a. Group similar vegetation together as much as possible.
    b. In some cases hardwood or coniferous trees may be scattered amongst other vegetative areas.
    c. Digitize polygons no smaller than 150 $m^2$
    d. Not all polygons will be contiguous. Some areas may consist of several smaller patches polygons that should be merged.
    e. Digitize at a 1:500 map scale or smaller.
    f. Continue digitizing the polygon until the area is adequately represented.
    g. Digitize areas of substrate (Example 1 - sand beach, bedrock or very shallow areas) as "No Cover". Similarly if there is an area of bedrock with some scattered vegetation, estimate the percentage of the vegetation and do not include the substrate in the estimate.
    h. Ensure that the attributes are populated for the corresponding area.
    i. Move on to the next area and repeat the process until all shoreline areas that can be interpreted are complete for the study area.

Example 1:



# INTERPRETATION OF SUBSTRATE PERCENT COVER

Shoreline area substrate was interpreted and combined with estimated underwater substrate cover in selected areas. The attribute data was formatted in a similar way to HEAT input data requirements.

## Digitizing Percent Cover Substrate Steps:

A new polygon substrate layer was created by following a similar process as prescribed in the steps for interpreting percent cover for vegetation.
Fields were added to the attribute table for each substrate type listed below (similar to HEAT):

- **Bedrock**
- **Boulder** (25 cm and above)
- **Cobble** (17 to 25 cm)
- **Rubble** (6.4 to 17 cm)
- **Gravel** (0.2 to 6.4 cm)
- **Sand** (<0.2 cm)
- **Silt**
- **Clay**
- **Hardpan**

The 'Percent Cover' attributed to each substrate field was one of the following values: 10, 20, 30, 40, 50, 60, 70, 80, 90, or 100 with 10 percent being a small amount of sediment and 100 percent being completely covered by substrate. Leave unknown substrate amounts at 0.

An additional field for total substrate percent cover named "TOT" was also appended to the attribute table. The total was used to keep track of polygons that did not add up to 100 percent. Percent cover was assumed in cases where substrate and imagery information was lacking.

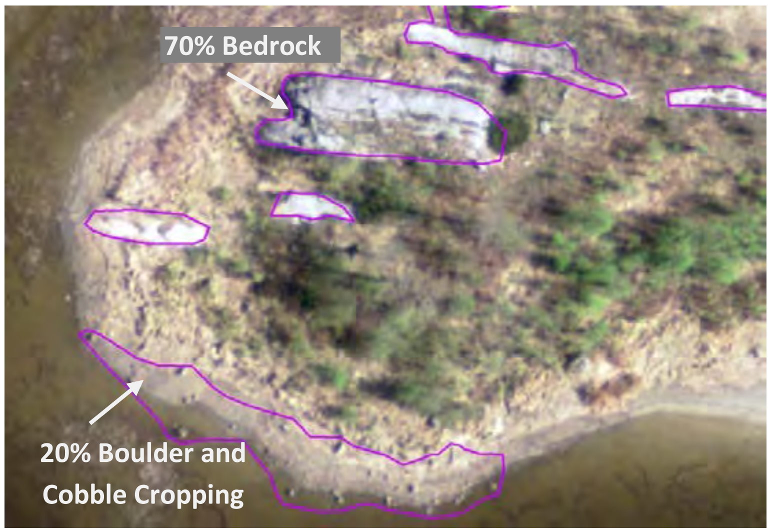
The Substrate Percent Cover layer was edited using standard digitizing techniques. The following is a description of the process that was used:

1. Select an area on the map to begin digitizing.
2. Begin where there is an identifiable cluster of similar substrate.
3. Examine the supporting imagery to decide where best to digitize the border.
4. Digitize substrate polygons by following this set of rules:
    a. Digitize at a 1:500 map scale or smaller
    b. Digitize polygons no smaller than 10 $m^2$
    c. Not all polygons will be contiguous. Some areas may consist of several smaller patches that should be merged.
    d. Not all substrate types can be identified if there is not enough supporting imagery. Therefore any substrate that cannot be accurately identified should be recorded as 0. When possible, an assumed substrate percent cover is assigned based on the information from adjacent substrate areas.
    e. Group substrate types or classifications together as much as possible, in some cases other substrate types may be scattered within the polygon.

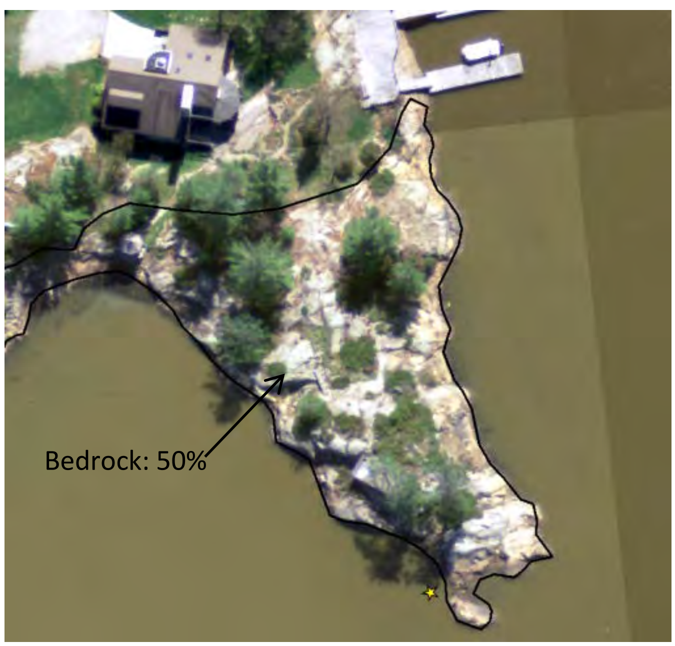
f. Do not count vegetation in substrate percentages. Example 2 and 3 shows shrubs or moss growing on top of bedrock should not be digitized.
g. For areas where vegetation is scattered throughout the substrate and cannot be digitized separately, do not include vegetation in the substrate percentage.
h. Underwater nearshore areas are also interpreted where the bottom was clearly visible, usually in a depth of less than 3 M.

5. Assign values to the fields of substrate that are present within the polygon using the attribute values defined previously.

Example 2:




Example 3:



# CONCLUSION

As part of the Severn Sound Remedial Action Plan delisting strategy, ongoing fish habitat monitoring is required by SSEA. SSEA recognizes the impact that fish habitat degradation has on the surrounding communities, as it is a major draw for recreational activities and contributes to the overall health of Severn Sound. It is important that the interpretation of fish habitat data follows an organized approach, to achieve accurate results.

As part of the Mapping, Evaluating, and Predicting Changes in Coastal Margin Aquatic Habitat in Severn Sound and Southeastern Georgian project the shoreline area substrate and EAV data will be combined with depth, submerged aquatic vegetation and underwater substrate data to provide an enhanced set of layers that cover selected areas of Severn Sound. The combined data will be used as an input to DFO's Habitat Assessment and Evaluation Tool, which is used for modelling fish habitat quality of extensive coastline areas in Severn Sound. Once complete, nearshore habitat mapping will serve as a scientifically defensible tool for planners and agency staff to manage nearshore habitat in the future.

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APPENDIX_A5_Severn_Sound_Hydroacoustics_Report_(DFO)

# Mapping and Assessing Coastal-Margin Aquatic Habitats in Severn Sound, Lake Huron

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2018

**Canadian Technical Report of**
**Fisheries and Aquatic Sciences 3284**

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## Canadian Technical Report of Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of Fisheries and Oceans Canada, namely, fisheries and aquatic sciences.

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## Rapport technique canadien des sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques de Pêches et Océans Canada, c'est-à-dire les sciences halieutiques et aquatiques.

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Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les numéros 1 à 456 de cette série ont été publiés à titre de Rapports techniques de l'Office des recherches sur les pêcheries du Canada.

Les numéros 457 à 714 sont parus à titre de Rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de Rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Canadian Technical Report of
Fisheries and Aquatic Sciences 3284

2018

# MAPPING AND ASSESSING COASTAL-MARGIN AQUATIC HABITATS IN SEVERN SOUND, LAKE HURON

by

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## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

## ABSTRACT

The coastal margin of Severn Sound, Georgian Bay has the most complex shoreline in the Great Lakes region and provides important habitat for a wide variety of species. Presently much of the shoreline is natural, but the coastal margin is increasingly affected by human development, water level fluctuations, and gradual warming of the air and water. To better assess the status of aquatic habitat in the coastal margin of this diverse region we: 1) mapped the extent of submerged aquatic vegetation (SAV) across a range of habitat conditions; 2) collected substrate samples to verify existing side-scan sonar; and 3) tracked dissolved oxygen (DO) and temperature dynamics in key regions. Results suggest that while much of the diversity in aquatic habitat conditions in Severn Sound is largely driven by natural factors, some regions exhibit some detrimental effects from human activities. SAV was abundant across much of the Sound with cover and depth distribution primarily restricted by exposure to wind and wave action (restricts distribution in shallow waters) and natural variation in water clarity due to dissolved organic carbon (primarily restricts the maximum depth of colonization). Sand dominated the majority of substrate samples, except in more protected areas that had higher organic content. Finally, DO profiles were also affected by the level of exposure with more stable DO levels at exposed sites and increasing hourly and daily variability in more protected areas. Extended periods of anoxia were not prevalent, but daily periods of anoxia were common at two of the more protected wetland areas suggesting these events were primarily driven by diurnal cycles in primary production. The results presented in this report can be combined with ongoing efforts by the Severn Sound Environmental Association and University of Windsor to help develop a complete fish habitat suitability model for the coastal margin of Severn Sound.

## RÉSUMÉ

La marge côtière de la baie Severn, dans la baie Georgienne, possède la ligne de côte la plus complexe de la région des Grands Lacs et constitue un habitat important pour les espèces aquatiques. À l’heure actuelle, une grande partie du littoral est naturelle, mais la marge côtière est de plus en plus touchée par le développement humain, les fluctuations des niveaux d’eau et le réchauffement graduel de l’air et de l’eau. Pour mieux évaluer l’état de l’habitat aquatique dans la marge côtière de cette région diversifiée, nous avons 1) cartographié l’étendue de la végétation aquatique submergée dans diverses conditions d’habitat, 2) recueilli des échantillons de substrat pour vérifier le sonar à balayage latéral existant, et 3) effectué un suivi de la dynamique de l’oxygène dissous (OD) et des températures dans des régions clés. Les résultats donnent à penser que, bien qu’une grande partie de la diversité des conditions de l’habitat aquatique dans la baie Severn soit en grande partie attribuable à des facteurs naturels, certaines régions présentent certains effets néfastes découlant des activités humaines. La végétation aquatique submergée était abondante dans la majeure partie de la baie, la couverture et la répartition en fonction de la profondeur étant principalement limitées par l’exposition au vent et à l’action des vagues (limite la répartition dans les eaux peu profondes) et par les variations naturelles de la limpidité de l’eau dues au carbone organique dissous (limite principalement la profondeur maximale de la colonisation). Le sable dominait la majorité des échantillons de substrat, sauf dans les zones plus protégées où la teneur en matières organiques était plus

élevée. Enfin, les profils d’oxygène dissous étaient également influencés par le niveau d’exposition avec des niveaux d’oxygène dissous plus stables aux sites exposés et une variabilité horaire et quotidienne croissante dans les zones plus protégées. Les périodes prolongées d’anoxie n’étaient pas fréquentes, mais les périodes quotidiennes d’anoxie étaient courantes dans deux des zones de milieux humides les plus protégées, ce qui donne à penser que ces événements étaient principalement dus aux cycles diurnes de la production primaire. Les résultats présentés dans ce rapport peuvent être combinés aux efforts continus de la Severn Sound Environmental Association et de l’Université de Windsor pour aider à élaborer un modèle complet d’habitat propice du poisson pour la marge côtière de la baie Severn.

# 1.0 INTRODUCTION

The coastal margin is perhaps the most visible and ecologically significant zone of lake ecosystems. This is especially true of areas that have complex shorelines and high recreational use and thus economic value. The coastal margin of south-eastern Georgian Bay, Severn Sound in particular, has the most complex shoreline in the Great Lakes region and provides spawning, nursery, refugia and foraging habitats for fishes, birds, amphibians, and reptiles. This region was formerly a Great Lakes Area of Concern (AOC), but was delisted in 2003 following improvements to water quality. While presently much of this shoreline is natural, this zone is increasingly affected by landscape alterations for human development, gradual warming of the air and water, and marked fluctuations in water levels. Despite high levels of biodiversity, depth profiles and habitat features of much of the coastal margin of Severn Sound are poorly understood. Surveys of the coastal margin and nearshore of the Severn Sound region paired with classifications of habitat suitability are required in order to identify areas most in need of protection from water and land-based stresses and the best candidates for conservation and restoration efforts. Within the coastal margin, submerged aquatic vegetation (SAV) provides important habitat for the majority of freshwater fishes at all stages of their life-history. Consequently, SAV coverage is a strong predictor of the productivity of a freshwater ecosystem (Randall et al. 1996). Hydroacoustic technology allows for the assessment of the height and cover of SAV across a larger spatial scale than more typical transect- or quadrat-based assessments. Given the range of coastal margin types (exposed vs protected), which may influence the minimum depth of SAV colonization, as well as natural variability in water clarity (clear water vs dystrophic water), which may affect the maximum depth of SAV colonization, Severn Sound provides an excellent location to evaluate the various natural factors that influence the extent and cover of SAV in freshwater ecosystems.

Dissolved oxygen (DO) is an indicator of ecosystem productivity and also a critical limiting factor in aquatic ecosystems. Coastal areas that have high levels of human disturbance, via shoreline modification, agricultural run-off or municipal waste inflows, may experience eutrophication, leading to the development of harmful algal blooms and ultimately anoxia or supersaturation (DO levels exceeding the saturation threshold for a given atmospheric pressure and water temperature). The DO profile in coastal areas is therefore a limiting factor in the distribution of aquatic biota. Severn Sound provides an ideal opportunity to compare the DO dynamics of coastal areas across a range of natural (connectivity and exposure) and anthropogenic (sewage outflow) disturbances. A more detailed understanding of the factors that influence temporal and spatial differences in DO will help refine habitat suitability estimates in the coastal margins of Severn Sound. Since DO loggers also measures temperature simultaneously, these loggers also provide vital temperature information that is helpful in modelling thermal habitat supply for biota and its dynamics in the area.

Given the unique environmental conditions in Severn Sound and the long-term goal of re-evaluating habitat suitability in this region, the objectives of the present report are to: 1) map the extent of SAV cover and height in representative portions (range of exposure, depths, and water clarity) of the coastal margin of Severn Sound; 2) verify substrate composition in existing side-scan sonar data with 99 validation samples; and 3) document the DO and temperature dynamics in key areas and provide a high-level comparison of these patterns across the range of environmental conditions present in Severn Sound.

## 2.0 METHODS

### 2.1 SAV SURVEYS

From 11 July until 27 July 2016, SAV cover and height were assessed in 20 regions throughout Severn Sound, Lake Huron, using hydroacoustic (Biosonics MX with 204.8 kHz and 8.4 °beam width; Figure 1). With this approach, sampling was limited to water depths that were greater than 1-m. The interpretation of the data collected for each hydroacoustic transect was completed in Visual Habitat (Biosonics, Seattle, WA). The first step in the interpretation was establishing the bottom depth and for this the “Rising Edge Threshold”, which determines where to assign the bottom echo, was set to -35 dB. This approach was frequently unable to detect the bottom echo due to either dense SAV or unconsolidated sediment; therefore, in these instances the bottom was manually delineated. After the bottom was determined, a plant detection analysis was completed using the default settings with a “Plant Detection Threshold” of -70 dB, maximum plant depth of 10 m and a plant detection length criterion of 10 cm (minimum height for an echo to be assigned as SAV). The resulting data were then exported for further analysis.

During the hydroacoustic surveys, additional data were collected at key points to 1) characterize local water chemistry, 2) determine the dominant species of SAV at each site, and 3) provide an opportunity to validate the hydroacoustic data. At four points in each of the 20 survey regions water chemistry readings of four parameters (temperature (°C), conductivity (μS/s), dissolved oxygen (mg/L and %), and turbidity (NTU)) were collected using a Sonde EXO multiprobe (YSI, Yellow Springs, OH, USA). Secchi depth was also determined where possible. Generally, these points were situated close to shore in shallow water (<2.0 m, N=2) and in more open and deeper waters (>4.0 m, N=2), although in some locations no deeper sites were present (e.g., Matchedash Bay). Verification points were flagged haphazardly along the hydroacoustics transects and surveyed posthumously using a rake-toss to collect samples of SAV and provide an indication of the dominant species and coverage. Finally, during the hydroacoustic transects the presence, relative cover (sparse [<25%

cover], moderate [25-75% cover], dense [>75% cover]) and height (low, mid-depth, high, surface) of SAV were visually estimated and recorded in relation to the hydroacoustic ping number. Since these data were collected concurrently with the hydroacoustic survey, they were used to provide a rough validation of the hydroacoustic output.

Following the interpretation of the hydroacoustic data, results were aggregated by site to provide the proportion of points where SAV were present, and summary details (mean ± standard deviation, quartiles etc.) related to the water depth and percent cover and height of SAV. Percent cover and height of SAV were also plotted against water depth to provide an indication of the depth distribution of SAV. Finally, points were plotted in a GIS to allow for a spatial assessment of SAV height and cover. The effective fetch was also determined for each point and used to calculate an overall mean level of exposure for each survey region. Effective fetch information was extracted from a fetch model run using the proportion of time the wind spent in each of 16 equally spaced compass directions (after Rohweder et al. 2012). These wind data were compiled from the Environment Canada and Climate Change buoy 45143 (southern Georgian Bay) from 2005-2015.

### 2.2 DISSOLVED OXYGEN AND TEMPERATURE

On 8 and 9 June, 2016, ten DO and temperature (DOT) loggers were deployed throughout Severn Sound (Figure 1). DOT loggers were calibrated using a 2-point calibration method using 100% and 0% saturated water. These loggers measure the DO and temperature of the water every 30 minutes for a total of 48 samples per day. The deployment set up consists of an anchor with a rope and float attached. The logger is then hung from secondary float that is suspended 30 cm above the anchor. Deployment locations were selected to explore several disturbance regimes prevalent in Severn Sound including: the influence of sewage plant effluents (Inner Penetang [proximate to STP outflow] vs Outer Penetang [control]), the effect of exposure and connectivity to Georgian Bay (influences water clarity and water chemistry parameters; Present Island [exposed – high connectivity], 100 Acre Wetland [protected wetland – medium connectivity], South Bay South [protected wetland – low connectivity], South Bay North [exposed wetland – low connectivity], and Green Island [protected wetland – high connectivity]), and the influence of inflowing streams (Sturgeon River [in river] vs others; Table 1). Loggers were retrieved on 12 and 13 October, 2016. Following comprehensive QAQC (outlined below), DO and temperature data from each logger were summarized by month, and the proportion of DO readings each day that fell below 3 mg/L (considered to be anoxic) and between 3-6 mg/L (lower than saturation), temporal trends in DO and temperature, and overall deviance of each DO reading from the daily mean were plotted for each site. This final measure provides an indication of the daily timing of the maximum and minimum DO reading.

### 2.3 SUBSTRATE

Sediment samples were collected at 99 sites spread throughout Severn Sound using a petit ponar (Figure 1). A 250 mL representative sample of material from the ponar was collected, frozen and later analyzed for composition and loss on ignition (organic content) following standardized protocols. Frozen samples were thawed at room temperature overnight and then placed in an oven for 4 hours at 30°C. Samples were then ground using a mortar and pestle until any clumps were broken up and the substrate was free flowing. It was then placed back in an oven for an additional 24 hours at 106°C to remove any remaining moisture. After cooling to room temperature, samples were sub-sampled (~ 3 g for fine sample such as mud and clay, ~ 20 g for samples with rocks, pebbles or large amounts of organic matter). A crucible for each subsample was weighed, tared, and then filled with the subsample and weighed (g) again. Subsamples were then placed in a muffle furnace for a total of 8 hours to burn off organic matter and determine the Loss on Ignition (LOI). The first hour was spent slowly raising the temperature up to 250°C. In the second hour, temperature was increased to 500°C. The subsamples remained in the furnace at full temperature for 6 hours. After 8 hours the muffle furnace was turned off and the subsamples were allowed to cool overnight. The following morning the subsamples were weighed and recorded and then subtracted from the pre-burn weight to determine LOI. The remaining material was further sieved to assign an overall composition based on the Wentworth scale (clay [<3.9 μm], silt [3.9-6.25 μm], sand [6.25μm-2 mm], gravel [2-16 mm], pebble [16-64 mm], cobble [64-256 mm], boulder [>256 mm]). Sediment left in the tray at the bottom of the sieve tower (< 63 μm) was weighed and recorded and placed in a scintillation vile with a cap and internal label and stored at room temperature for flow cytometry analysis.

Samples were prepared 24 hours before running to ensure particles did not clump before being run. Samples were taken from the scintillation vials using a scoopula, 0.05 g from each sample was mixed into a solution of 500 μm of Fluorescent-Activated Cell Sorting (FACS) fluid in a weighing dish and wetted by mixing with a rubberized probe. This solution was then washed into a plastic 15 ml vial using 10 ml distilled water. The flow cytometer was calibrated with micro beads of 4 known sizes (2 μm, 3.4 μm, 7.4 μm and 14.7 μm). The beads were run through the flow cytometer and their size distributions were plotted onto a scatter-plot using Becton, Dickson and Company Fluorescent-Activated Cell Sorting Diva (BD FACS Diva) software. A 4 μm threshold was set to distinguish between silt (63 μm - 4 μm) and clay (<4 μm).

In preparation for analysis, samples were agitated by shaking to re-suspend sediment particles into the solution; a ~ 2 ml of sample solution was transferred from its plastic vial into a glass test tube. The sample was then placed in the flow cytometer. Each sample was run as a separate tube in BD FACS Diva under the same parameters

– Forward Scattered light (FSC, x axis) was set to 88 volts, and Side Scattered light (SSC, y axis) was set to 110 volts. Samples were run for 10,000 events in BD FACS Diva unless data acquisition was significantly slower due to a more dilute sample, in which case samples were analyzed for 5000 or 1000 events. Samples ran for an average of 1-2 minutes. Data output for each sample consisted of a scatter-plot showing size fraction of calibration beads, a frequency histogram for each plot and a graph displaying relative percentage of particle size along a 4 μm threshold. These percentages were then used to extrapolate the overall composition (% of silt and clay) of the sediment samples collected in each scintillation vial.

# 3.0 RESULTS

## 3.1 SAV SURVEYS

### *3.1.1 Water Chemistry*

Water chemistry parameters showed only limited variability within a site; however, among sites there were clear differences that were largely driven by the level of influence of Georgian Bay waters and exposure to wind and wave action. Not surprisingly, water temperatures were generally higher (~25ºC) in more protected regions compared with more exposed sites (Table 2). In terms of conductivity, Beausoleil West and Present Island provided a good reference for conditions in Georgian Bay (~180 μS/s), while the North Bay and South Bay sites were influenced by dystrophic (soft) water coming off the Georgian Bay Fringe (114-159 μS/s). Sites with conductivity readings well above those found in Georgian Bay likely reflect some measure of anthropogenic disturbance (i.e., Matchedash Bay – 330 μS/s or Midland Bay East - 205 μS/s; Table 2). While DO (both % and mg/L) were collected and are provided (Table 2), the DOT loggers likely provide a better measure of site variability since probe readings were collected during the day when DO levels are at their peak (see below). Finally, for many sites turbidity could not be estimated since the probe was not able to reliably measure turbidity levels less than 0.05 NTU. Where available, turbidity levels were generally low (mean across sites = 0.13 ± 0.32 NTU), therefore in Severn Sound turbidity is likely not a limiting factor in the establishment of SAV.

Secchi depth readings ranged from a low of approximately 3.0 m in South Bay and North Bay to a high of over 5.0 m outside in Penetanguishene Bay and around Beausoleil and Robert's Islands (Table 3). Similar to the conductivity measurements discussed above, lower secchi depths in South Bay and North Bay are likely driven by dystrophic water from their watersheds (high humic content and naturally brown-coloured waters).

### *3.1.2 Hydroacoustics*

In each of the 20 regions, four transects were run perpendicular from shore either starting in or ending in approximately 1-m of depth and progressing beyond the edge of the SAV bed to a maximum depth of 13 m (Figure 1). This type of transect was not possible in all regions due to depth limitations. For example, surveys in Matchedash Bay and Sturgeon Bay were restricted to depth intervals between 1.32-1.83 m and 1.27-3.13 m, respectively, thereby preventing an assessment of the maximum depth of SAV colonization at these sites (Table 4). Similarly, while a wider range of depths were surveyed at several other stations, the maximum depth of SAV was often quite similar to the maximum depth surveyed (i.e., South Shore of Severn Sound – SAV Present = 1.16-9.86 m and SAV Absent = 1.08-9.83 m; Table 5). Bearing these caveats, across all regions the maximum depth at which SAV was detected was 10.49 m (Sucker Creek), with a considerably lower mean depth of SAV occurrence ranging from a low of 1.63 m (Matchedash Bay) to a high of 5.98 m (Midland West; Table 5; Figures 2 and 3). The proportion of each surveyed area that was covered in SAV was highly variable, from a low of 0.2 or less at sites that were generally more exposed to wind and wave action (i.e., Beausoleil Island West) to those where the entire survey area was covered in SAV (i.e., Matchedash Bay; Table 5).

The highest mean SAV percent cover was found in regions where SAV occurred at virtually all sampled positions; these areas also tended to have restricted sampling depths (see comment above; Table 5; Figures 4 and 5). Three distinct patterns in the distribution of SAV percent cover across depths were evident among sampling regions and differences were largely driven by variations in cover in shallow depths (<3 m; Figures 6, 7 and 8). The first group represented sites that generally had low levels of exposure (mean fetch <1200 m; Table 5) and consequently SAV percent cover was close to 100% down to the shallowest depth interval sampled (1-2 m). This group included many sites that were in or adjacent to coastal wetlands (e.g., 100 Acre Wetland, Green Island, Inner Hog Bay, etc.; Figures 6, 7 and 8) and the relationship between SAV percent cover and depth can best be described as logistic, with deep water limitations likely driven by water clarity. The next group represented exposed regions (mean fetch >3000 m; Table 5) and SAV percent cover was supressed at these sites in shallow water (<3 m), peaking instead between 3-5 m (e.g., Outer Penetang, Beausoleil West, etc.; Figures 6, 7 and 8). The result is a relationship between SAV percent cover and depth that is more unimodal. The final group was intermediate between the exposed and protected sites (mean fetch = 1800 m; Table 5) with SAV percent cover being supressed at depths less than 2-m and peaking in a similar depth range as the more exposed regions (e.g., Midland Bay East, Inner Penetang, etc.; Figure 6, 7 and 8). Two sites had more limited depth ranges (North Bay and South Bay), with SAV percent cover declining around 4-5 as opposed to 5-7 m. Increased light attenuation, as documented with lower Secchi depths, was likely the causal factor behind the narrower extent of SAV beds at these sites as well as their shallower mean depth of occurrence of SAV.

Not surprisingly, the regions with the highest mean SAV height were typically similar to those with the greatest SAV percent cover (Table 5). The three exposure groups outlined above were also generally consistent for SAV height with more exposed sites typically having shorter SAV and a peak shifted into deeper waters than more protected areas (Figures 9, 10 and 11). With only a few exceptions (e.g., North Bay, Beausoleil West), the relationship between SAV height and depth was quasi-unimodal generally peaking between 3-4 m at protected sites or sites with intermediate levels of exposure and between 4-5 m at exposed sites (Figures 9, 10 and 11).

#### *3.1.3 Hydroacoustic Validation*

Visual assessments were completed at 252 points and these were then linked to ping numbers from the hydroacoustic survey. Consistent with our past experience with validation of hydroacoustic data, density and height estimates from the hydroacoustics and field surveys did not match exactly, but rather showed similar trends. This is partly the result of how the hydroacoustic data are aggregated during interpretation wherein a single output data point is actually comprised of 10 “pings”. Furthermore, since the swath of the hydroacoustic beam covers a larger area than the visual point sampling, a lack of concordance between these two datasets is not surprising. As a result, the cover and height predictions from the hydroacoustic surveys tended to be of a higher magnitude than the actual observed values (Table 6); however, there was still a consistent relationship between the visual estimates of density and SAV height and those predicted by the hydroacoustics (i.e., highest cover values for the “dense” category and lowest for the “sparse” category; Table 6). In terms of predicting whether SAV were present or not, the visual assessment data suggested that the hydroacoustics were 83.3% accurate, with the majority of the errors those of commission (13.5%; SAV present when the visual assessment did not record SAV). For the majority of these sites (20/34), SAV cover was predicted to be less than 30%. For the few occasions where the hydroacoustics omitted SAV, the visual estimates primarily categorized the site as having either short or sparse SAV.

#### *3.1.4 Dominant SAV*

Data from 133 verification points were collected with SAV present at 103 of these points. In total 32 species were identified, with *Vallisneria americana* as the most common species (present at 50% of the points). Other common species included *Elodea canadensis* (41%), *Ceratophyllum demersum* (33%), *Najas flexilis* (33%), *Chara* spp (31% - technically a green algae, but structurally similar to SAV), and *Myriophyllum spicatum* (29%; Table 7). Across Severn Sound, species richness was quite variable ranging from a low of 3 (Outer Penetang) to a high of 14 (Green Island and Robert's Island; Table 3).

### 3.2 DOT LOGGERS

The majority of the loggers (9/10) were successfully retrieved in the fall of 2016; however, the logger placed along the eastern shore of Beausoleil Island could not be located. At the time of writing this logger has not been located, despite expanded surveys by Fisheries and Oceans Canada and Parks Canada staff. For the remaining loggers, data were QAQC'd following the standard operating procedure for the Fish Habitat Lab with the Great Lakes Laboratory for Fisheries and Aquatic Sciences at DFO. This includes the application of a biofouling correction, where appropriate, which can compensate for errors in recorded DO caused by the accumulation of biological material during deployment. This correction was applied to four loggers (Inner and Outer Penetang, Sturgeon River, and South Bay North). Also during the QAQC phase, the DO profiles for each logger were evaluated to determine whether the sensor had become submerged in substrate (a common occurrence in nearshore areas with soft substrates). Through this process, data from the logger deployed in Hog Bay were determined to be of questionable value due to a high probability of submergence in substrate (which artificially decreases DO measurements). Therefore, this logger was excluded and results are presented for the eight remaining loggers.

Water temperatures across sites generally showed a consistent pattern, increasing through the summer, peaking in August and declining into the fall (Table 8; Figure 12). There were two exceptions to this pattern, the Sturgeon River and Inner Penetang, which both had cooler and more stable temperatures across the sampling period. In the former case, ground water supplies into the Sturgeon River likely act to buffer warming from higher air temperatures and increased solar radiation. Similarly, for Inner Penetang, we hypothesize that cooler water temperatures were driven by the proximity of this station to Copeland Creek, a cold water stream that flows into southern Penetanguishene Bay.

We explored DO profile patterns several different ways to assess the influence of 1) sewage plant effluents, 2) exposure and connectivity to the Bay, and 3) the input of an agricultural stream. First, Inner Penetang (proximate to the STP) was compared with Outer Penetang since they occur in the same physiographic region (Simcoe Upland) and have similar levels of exposure. Across the sampling period it was clear that DO was more variable at Inner Penetang; indeed, Inner Penetang had the greatest range in DO values at any site sampled in Severn Sound and frequently reported DO levels at supersaturation (Table 8; Figure 13). DO levels at Outer Penetang only fell below 6 mg/L on two occasions, in contrast, starting in late June, DO levels at Inner Penetang were typically below this threshold for between 6-12 hours each day and in several instances fell below 3 mg/L (Figure 13). The dynamic nature of Inner Penetang was most apparent on an hourly basis, peaking on average 7 mg/L above the daily mean between 14:00-16:00 and declining through the night and into the early morning (Figures 14 and 15). While peak DO at Outer Penetang occurred during the same time period, mean, minimum and maximum readings were considerably less variable, typically changing by only ±2 mg/L within a 24-hr period (Figures 14 and 15).

The DOT logger at Present Island served as a control location for Severn Sound since it was exposed and, based on water chemistry data presented above, representative of waters in Georgian Bay proper. It is therefore likely indicative of the DOT profile for Bay waters, with DO rarely falling below 6 mg/L and fluctuations being primarily influenced by shifts in temperature and the corresponding change in saturation capacity (Table 8; Figure 13). Daily peaks in DO were still evident between 14:00-19:00, with slight declines (2-3 mg/L) to a low between 03:00-08:00 (Figures 14 and 15). A similar pattern (albeit larger magnitude) was also evident in three of the four wetland areas (South Bay North, South Bay South, and Green Island), with the sole exception being 100 Acre Wetland where DO levels peaked earlier in the day (10:00-14:00). This site also recorded consistently low DO levels throughout the study period and had the greatest number of records where DO was below both 6 and 3 mg/L. While the other three wetland sites did see DO levels below 3 mg/L, these were typically less frequent and of a shorter duration.

The two sites in South Bay were selected to reflect wetlands that were more influenced by their watersheds than the Bay (as indicated by their lower conductivity readings relative to Present Island) and allow a comparison between DO profiles in a fringing wetland (South Bay North) and more protected embayment (South Bay South). Despite apparent differences in geomorphology, DO profiles at these sites were quite similar with only slightly more DO readings below 6 mg/L at South Bay South (Figure 13). In contrast, both the 100 Acre Wetland site and Green Island were thought to be more influenced by water from the Bay, but this influence seems to have been mitigated by other conditions at these sites that appear to have facilitated declines in DO (discussed below).

The final area of interest was the Sturgeon River, which drains an area of 98.3 $km^2$ and, while it has considerable natural cover in this watershed, mixed-use agriculture is also present. We found no evidence that waters entering Severn Sound from the Sturgeon River had a DO profile different from those observed at our control site at Present Island (Figure 12 and Figure 13).

### 3.3 SUBSTRATE

Substrate composition from the 99 samples collected throughout Severn Sound suggested that sand (6.25 μm-2 mm) was by far the most dominant component, comprising an average of 95.2% of the overall sample (Table 9). There were a few samples where sand was less dominant, notably single samples in Honey Harbour (#3), 100 Acre Wetland (#1), Midland Bay (#10), Robert's Inlet (#3), and Beausoleil West (#2) where gravel (2-16 mm) comprised over 20% of the sample. Silt and clay rarely comprised more than 5% of the overall sample and no larger material (cobble [64-256 mm], boulder [>256 mm]) was found; however, this is likely more a function of sampling limitations with petit ponar than the absence of these substrate types in Severn Sound. Finally, loss on ignition (organic content) was low when averaged across all samples (6.5%); however, there were some regions that had greater than 10% organics across all samples including: North Bay (34.6%), South Bay (16.9%), Matchedash Bay (12.5%), Hog Bay (12.2%), and Green Island (10.7%); all areas that were categorized as being protected.

## 4.0 DISCUSSION

This report outlines a comprehensive spatial survey of submerged aquatic vegetation, substrate composition and dissolved oxygen profiles in Severn Sound, Lake Huron. In 2003, this region was delisted as a Great Lakes AOC, but ongoing monitoring of environmental conditions in the Sound is critical to ensure aquatic conditions remain unimpaired. A major ongoing component of this is the completion of a fish habitat suitability assessment for Severn Sound and the work presented here will support these efforts by 1) mapping SAV cover across a range of water depths and environmental gradients to contribute to the development of a regionally derived spatial SAV model, 2) aid in the interpretation of substrate composition from side-scan sonar data by providing field validation samples, and 3) assess dissolved oxygen variability by comparing dissolved oxygen profiles in regions influenced by sewage treatment plant outflows, across a range of exposure, and in a tributary.

Based on SAV surveys in 20 regions of Severn Sound it is clear, although not surprising, that the cover and depth distribution of SAV are heavily influenced by exposure to wind and wave action and water clarity (dystrophic vs non-dystrophic in particular). The primary literature strongly supports these results (reviewed in Lacoul and Freedman 2006) with exposure largely dictating the minimum depth of SAV establishment (largely driven by the removal of propagules by waves or ice scour; Stewart and Freedman 1989) and water clarity dictating the maximum depth of SAV establishment (based on the rate of attenuation of photosynthetically active solar radiation; Chambers and Prepas 1988). In the exposed regions surveyed for the present report, it was evident that SAV was largely absent in water depths less than 3 m, particularly as the mean effective fetch for the survey region surpassed 3 km. SAV was still present at many of these more exposed sites, but the peak in cover and SAV height were shifted into deeper water, relative to more protected areas. This shift likely influences our ability to accurately assess the fish community assemblage in more exposed areas since many commonly used fish sampling methods are not effective past depths of 2-3 m (i.e., electrofishing or fyke nets), while other gear cannot be deployed along exposed coastlines (trap nets). Invariably, fish are using these deeper beds of SAV, so alternative sampling methods (e.g., gill nets) may be required to assess their contribution as fish habitat to Severn Sound, especially given the abundance of exposed coastal shorelines in the Sound.

In contrast to many nearshore areas of the lower Great Lakes, turbidity was comparatively low in all surveyed areas in Severn Sound (Chow-Fraser 2006). This likely contributed to the generally high Secchi depth readings and establishment of SAV at water depths exceeding 7-m in many regions. The maximum depth of SAV colonization was only notably shallower at two sites (North Bay and South Bay), where water colour was more dystrophic due to watershed inputs draining off of granitic formations in the Georgian Bay Fringe. Past SAV surveys along the eastern coast of Georgian Bay have documented a similar trend of reduced maximum depth of SAV colonization in more dystrophic waters (Midwood 2012). It is important to note that this variability in water colour is natural; therefore, SAV modelling efforts in Severn Sound will need to incorporate a measure of water colour or, alternatively, an estimate of the relative influences to water chemistry of the local watershed and Georgian Bay waters.

The data presented in the current report will be critical in the development and validation of a SAV model for Severn Sound. A two-stage model will likely be the most appropriate with the first step outlining where SAV are likely to be present and the second step applying either a unimodal distribution of SAV height/cover (for more exposed sites) or a logistic distribution of SAV height/cover (for protected sites). Several spatial layers that will be necessary for this modelling exercise have already been compiled (i.e., effective fetch and a digital elevation model); however, additional layers will need to be developed to incorporate variability in water colour and connectivity to Georgian Bay.

Similar to SAV, there were clear differences in DO profiles along a gradient of exposure, with relatively stable DO levels at the more exposed sites and increasing hourly and daily variability at more protected sites. With a few exceptions (100 Acre Wetland in particular), most protected areas did not experience extended periods of anoxia, suggesting that low DO is not a recurring issue in Severn Sound. That being said, the two regions where the lowest DO levels were recorded were coastal wetland sites, therefore a more detailed assessment of the spatial and temporal variability of DO in these types of systems is likely warranted. Identifying the driving factor behind the observed anoxic periods in coastal wetlands will help to establish whether this is largely a natural phenomenon and, if so, DO targets in wetlands currently undergoing remediation in other AOCs can be adjusted to account of this natural variability. There are several potential reasons why low DO may occur in a seemingly healthy coastal wetland. First, high productivity in coastal wetlands often results in the development of sediments with a considerable amount of organic material undergoing decay. The breakdown of this material consumes oxygen and, depending on where in the water column the DOT logger is situated, may result in an apparent decline in DO levels. Our loggers were only situated 30 cm off the bottom of the substrate, therefore, if decomposition rates are high, oxygen may be consumed from this depth stratum. An alternate hypothesis for the observed low DO levels is that of a shading effect from floating vegetation (i.e., pond or water lilies). This may be particularly true for the 100 Acre Wetland DOT logger, which was deployed in a stand of *Nuphar variegata* that had almost completely covered the surface of the water at the time of retrieval. This covering may limit photosynthesis by SAV and phytoplankton growing underneath the floating vegetation thereby reducing DO levels (as has been observed in *Eichhornia crassipes*, Rai and Datta Munshi 1979 and *Trapa natans*, Caraco and Cole 2002). The documented shift in the timing of peak DO levels to earlier in the day at this site may further corroborate this hypothesis since this is the window when the sun would be close to its zenith and therefore the angle of light would also be at its lowest value allowing for maximum light penetration into the water column. Further exploration of the cause of low DO in coastal wetlands is warranted and Severn Sound presents an ideal location to explore various mechanisms, while controlling for many of the anthropogenic influences prevalent in other Great Lakes ecosystems.

The lone site where an influence from anthropogenic activity was most acute was Inner Penetang, which is proximate to an STP outflow. While this STP has been recently upgraded to reduce nutrient release into adjacent waters, any additional nutrient input into the typically oligotrophic or mesotrophic waters may be at least partially responsible for the observed large hourly and daily fluctuations in DO. Dense stands of SAV (*Chara* spp. with epiphytic algae) in the area proximate to the logger likely also contributed to the observed high rates of primary productivity during the day. The result is a DO profile that has long been deemed indicative of a eutrophic system (Wetzel 2001). While the hourly cycle peaked during a similar time-window as control sites, the magnitude of the change in DO at Inner Penetang was considerably larger, often reaching supersaturation during peak DO (17-22 mg/L). This level of productivity was unparalleled in the system, and may result in short-term exclusion of some fishes due the potential for the development of gas bubble disease (Weitkamp and Katz 1980; Weitkamp 2007). For fishes this is largely a species-specific response; however, even short durations (hours) of extreme supersaturation (>200%) can cause increased mortality, particularly for small-bodied fishes that cannot easily regulate excess $O_2$ in their swim bladders (Weitkamp and Katz 1980; Weitkamp 2007). That being said, fish community surveys undertaken concurrently with the present work found that southern Penetanguishene Bay was actually one of the most productivity regions in Severn Sound in terms of fish productivity (C. Boston, pers. comm.). This suggests that despite the documented occurrence of supersaturation, there is no clear response in the proximate fish community. The documented supersaturation may therefore affect only a small portion of Penetanguishene Bay (thus fish will use other areas of the Bay with more favourable conditions) or the comparatively short duration of supersaturation may not be of a sufficient duration or rate change to negatively affect fishes. A more in-depth survey of how fish and fish productivity responds to short-term occurrences of supersaturation is therefore warranted to assess the potential influence of STPs. Indeed, a relatively recent review of the subject suggested there had been no population-level evaluations of the effect of supersaturation on fish populations (Weitkamp 2007). This is of particular interest since the majority of studies that have explored negative effects of gas bubble disease are focused on hydro dams and fish passage through supersaturated race-ways (Weitkamp and Katz 1980; Weitkamp 2007). Furthermore, negative effects of supersaturation may represent more of an acute, sub-lethal effect, which may or may not have long-term consequences on affected individuals.

Across virtually all substrate samples, sand was the dominant substrate type. The most apparent differences, from a regional perspective, were associated with the mean loss on ignition or percent organics. The highest measures of organic content tended to be found in areas that were protected from wind and wave action. This finding is to be expected since high wave energy (exposure) has a negative effect on the amount of organic material in the substrate through the erosion of fine organic particles (Madsen et al. 2001). The primary purpose for the collection and analysis of substrate samples was to inform the interpretation of substrate data surveys that have been completed using sidescan sonar and hydroacoustics. These works are ongoing and the 99 samples collected for the present report will be integral to these efforts.

## 5.0 CONCLUSIONS

The results of the 2016 survey clearly show the wide range of habitat conditions present in Severn Sound, Georgian Bay. While currently the major drivers behind site variability appear to be largely natural (exposure), it is evident that some regions are affected by human activities, southern Penetanguishene Bay in particular, but also Matchedash Bay and Midland Bay. By integrating the present work with efforts by the Severn Sound Environmental Association and University of Windsor, a complete fish habitat suitability model for the nearshore environment of Severn Sound can be created.

There were several avenues identified for future research that would benefit both the assessment of Severn Sound and contribute to our overall knowledge of freshwater ecosystems. First, it would be prudent to conduct a more detailed spatial exploration of DO profiles within coastal wetlands to determine the causal mechanism behind extended periods of anoxia in these systems and the extent to which the entire wetland is affected. This has important implications since wetlands are critical spawning and nursery habitat for a majority of fish species, therefore natural periods of low DO may affect both recruitment and growth of dependent fishes. Also, anoxia has been identified as a concern in many Great Lakes AOCs (e.g., Cootes Paradise in Hamilton Harbour), therefore an understanding of natural DO cycles is critical for establishing DO targets for delisting. Next, in the present study we were unable to assess local productivity (based on chlorophyll a for example) in the areas near our DOT loggers. A more thorough assessment of the source of the oxygen that is driving supersaturation is therefore warranted to determine whether harmful algal blooms, which may pose additional ecological concerns, are causing the observed spike in DO. During our brief review of the literature regarding supersaturation, it quickly became apparent that there is limited species-specific information on tolerance levels for the majority of warmwater fishes. A more detailed assessment of the responses of warmwater fishes to supersaturation would help assess whether the levels observed at Inner Penetang and elsewhere pose risks to the growth and survival of local fishes. In addition, a more spatially comprehensive assessment of DO levels in southern Penetanguishene Bay and the identification of potential refugia from supersaturation would help determine the magnitude of the influence from the STP and likelihood of fish exposure to supersaturation. Finally, our SAV surveys identified a habitat zone that is likely under-represented in current fish community sampling efforts, specifically SAV along exposed open coasts. Given the well documented associations between fish and SAV (Randall et al. 1996), this area is likely important habitat for some species yet it is not being incorporated into current assessment programs. This is particularly true during the summer when nearshore areas are too warm for coolwater fishes (e.g., northern pike, *Esox lucius*) and this heterogeneous habitat in deep water may then serve as an important thermal refuge. Future assessments of this habitat zone are therefore warranted; with gill nets, underwater video, or angling providing some strong alternatives.

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**Table 1.** Summary details for each dissolved oxygen (DO) logger site with coordinates, disturbance category, physiographic region, and mean/max effective fetch.

| Site Name | Easting | Northing | Disturbance Category | Location | Physiographic Region | Mean Fetch (m) | Max Fetch (m) |
|---|---|---|---|---|---|---|---|
| Inner Penetang | 583625 | 4957650 | Treatment Plant | STP | Simcoe Upland | 568 ± 18 | 595 |
| Outer Penetang | 584430 | 4961090 | Protected Coast | Coast | Simcoe Upland | 621 ± 18 | 641 |
| Present Island | 591424 | 4963380 | Exposed Coast | Coast | Simcoe Upland | 2209 ± 263 | 2536 |
| Sturgeon River | 599989 | 4954440 | River Outflow | River | Simcoe Upland | 1119 ± 77 | 1214 |
| Hog Bay* | 594810 | 4954160 | Protected Coast | Wetland | Simcoe Upland | 393 ± 83 | 529 |
| Green Island | 599517 | 4960350 | Protected Coast | Wetland | Georgian Bay Fringe | 625 ± 96 | 784 |
| 100 Acre Wetland | 595735 | 4966140 | Protected Coast | Wetland | Georgian Bay Fringe | 166 ± 24 | 198 |
| Beausoleil East* | 589855 | 4966580 | Exposed Coast | Coast | Simcoe Upland | 2295 ± 91 | 2419 |
| South Bay N | 595956 | 4968550 | Exposed Coast | Wetland | Georgian Bay Fringe | 204 ± 10 | 218 |
| South Bay S | 595495 | 4970050 | Protected Coast | Coast | Georgian Bay Fringe | 214 ± 7 | 221 |

"*" Loggers were not included in the analysis of dissolved oxygen profiles because the logger could not be recovered (Beausoleil East) or the logger was partially buried in the sediment (Hog Bay).

**Table 2.** Water chemistry data from probe readings collected during daytime SAV surveys (11 July until 27 July 2016). A malfunction in the turbidity probe early on during the assessment prevented this component from being collected at some locations; however, readings were generally quite low relative to other locations in the Great Lakes suggesting that turbidity is typically not an issue in GB. All values are mean ± standard deviation.

| Site | Date Sampled | Temperature (°C) | Conductivity (µS/s) | Dissolved Oxygen (mg/L) | Dissolved Oxygen (%) | Turbidity (NTU) |
|---|---|---|---|---|---|---|
| 100 Acre South | 27/07/2016 | 25.0±1.1 | 187±1 | 8.54±0.28 | 104±4 | 0.45±0.77 |
| Beausoleil East | 19/07/2016 | 22.3±0.4 | 181±2 | 8.10±0.32 | 93±4 | 0.05±0.03 |
| Beausoleil West | 12/07/2016 | 22.9±0.2 | 183±1 | 9.70±0.12 | 113±2 | |
| Green Island | 13/07/2016 | 25.5±0.3 | 242±1 | 9.47±0.13 | 115±1 | |
| Inner Hog Bay | 27/07/2016 | 25.6±0.5 | 205±6 | 9.06±0.78 | 111±10 | 0.07±0.29 |
| Inner Penetang | 21/07/2016 | 23.4±0.5 | 189±5 | 9.45±0.62 | 111±8 | 0.00±0.05 |
| Matchedash Bay | 13/07/2016 | 26.2±0.2 | 330±9 | 9.86±0.64 | 121±6 | |
| Midland Bay East | 20/07/2016 | 24.1±0.3 | 208±27 | 8.81±0.43 | 105±5 | 0.19±0.08 |
| Midland Bay West | 12/07/2016 | 24.1±0.2 | 189±1 | 9.74±0.05 | 116±1 | |
| Musky Bay | 27/07/2016 | 24.6±0.1 | 191±1 | 8.45±0.10 | 101±1 | 0.40±0.11 |
| North Bay | 14/07/2016 | 26.1±0.2 | 114±1 | 9.19±0.22 | 114±2 | |
| Outer Hog Bay | 11/07/2016 | 24.8±0.9 | 191±1 | 9.75±0.26 | 116±3 | |
| Outer Penetang | 21/07/2016 | 23.4±0.3 | 183±1 | 8.75±0.16 | 103±2 | 0.00±0.03 |
| Present Island | 11/07/2016 | 23.5±0.3 | 179±3 | 10.07±0.38 | 118±5 | |
| Robert's Island | 27/07/2016 | 25.6±0.8 | 189±2 | 8.86±0.36 | 108±5 | 0.26±0.09 |
| South Bay | 14/07/2016 | 26.2±0.0 | 159±2 | 9.19±0.10 | 113±1 | |
| SS South Shore | 20/07/2016 | 24.2±0.5 | 199±7 | 8.65±0.52 | 103±7 | 0.11±0.07 |
| Sturgeon Bay | 13/07/2016 | 26.9±0.7 | 230±19 | 13.31±3.84 | 164±49 | |
| Sucker Creek | 12/07/2016 | 23.0±0.2 | 181±2 | 10.00±0.44 | 116±5 | |
| Treasure Bay | 19/07/2016 | | | | | |
| *Regional Mean* | | 24.6±1.4 | 196±41 | 9.42±1.36 | 113±18 | 0.13±0.32 |
| *Minimum-Maximum* | | 22.3-26.9 | 114-330 | 8.10-13.31 | 93-164 | 0.00-0.45 |

**Table 3.** Secchi depth for each of the submerged aquatic vegetation (SAV) hydroacoustic survey sites. The number of Secchi depth records for each site is also presented and for sites with two or fewer records no standard deviation was calculated. The number of SAV species detected at each site is listed. Finally, the categorical exposure ranking for each site is also provided as well as the mean (with standard deviation) and maximum effective fetch.

| Site Name | # Secchi Records | Mean Secchi (m) | SAV Species Richness | Exposure Category | Effective Fetch (m) | |
|---|---|---|---|---|---|---|
| | | | | | **Mean** ± S.D. | **Maximum** |
| 100 Acre South | 3 | 4.71 ± 0.14 | 12 | Protected | 1702 ± 694 | 2779 |
| Beausoleil East | 3 | 4.35 ± 0.26 | 8 | Exposed | 2883 ± 294 | 3351 |
| Beausoleil West | 5 | 4.81 ± 1.03 | 5 | Exposed | 3425 ± 233 | 3785 |
| Green Island | 2 | 4.31 ± NA | 14 | Protected | 1100 ± 202 | 1475 |
| Inner Hog Bay | 3 | 4.16 ± 0.33 | 12 | Protected | 1492 ± 485 | 2575 |
| Inner Penetang | 3 | 4.93 ± 0.23 | 11 | Intermediate | 735 ± 48 | 796 |
| Matchedash | 2 | 3.95 ± NA | 10 | Protected | 1039 ± 47 | 1112 |
| Midland Bay East | 3 | 4.23 ± 0.15 | 8 | Intermediate | 1816 ± 515 | 2553 |
| Midland West | 3 | 4.37 ± 0.16 | 7 | Intermediate | 1654 ± 202 | 2030 |
| Musky Bay | 3 | 3.90 ± 0.15 | 9 | Exposed | 4647 ± 413 | 5222 |
| North Bay | 6 | 3.10 ± 0.38 | 8 | Protected | 369 ± 47 | 433 |
| Outer Hog Bay | 5 | 3.48 ± 0.31 | 9 | Exposed | 2493 ± 683 | 3742 |
| Outer Penetang | 3 | 5.35 ± 0.08 | 3 | Exposed | 1866 ± 229 | 2308 |
| Present Island | 4 | 4.14 ± 0.73 | 8 | Exposed | 4213 ± 692 | 4811 |
| Robert's Island | 3 | 5.01 ± 0.19 | 14 | Intermediate | 1198 ± 245 | 1664 |
| South Bay | 6 | 2.86 ± 0.25 | 9 | Protected | 353 ± 64 | 438 |
| SS South Shore | 3 | 4.17 ± 0.13 | 8 | Intermediate | 3747 ± 317 | 4226 |
| Sturgeon Bay | 3 | 4.04 ± 0.17 | 10 | Protected | 1530 ± 202 | 1939 |
| Sucker Creek | 5 | 4.38 ± 0.52 | 11 | Exposed | 3513 ± 588 | 4345 |
| Treasure Bay | 1 | 4.61 ± NA | 12 | Protected | 1404 ± 364 | 1832 |

**Table 4.** Results from the hydroacoustic (HA) surveys showing the number of pings where SAV was present (P) or absent (A). The mean, inter-quartile range and min/max depth where SAV were present or absent are also presented.

| Site Name | SAV P/A | # Pings | Mean | 1st –3rd Quartile | Min – Max |
|---|---|---|---|---|---|
| Beausoleil East | P | 544 | 5.73 ± 1.42 | 4.99-6.43 | 1.20-9.44 |
| | A | 971 | 7.21 ± 2.55 | 6.96-9.01 | 1.10-9.64 |
| Beausoleil West | P | 48 | 5.79 ± 3.08 | 2.51-8.46 | 1.52-10.30 |
| | A | 286 | 7.04 ± 4.51 | 2.49-11.42 | 1.87-12.99 |
| Green Island | P | 1013 | 3.63 ± 1.13 | 2.68-4.57 | 1.28-5.95 |
| | A | 12 | 2.04 ± 1.56 | 1.32-1.46 | 1.29-5.50 |
| 100 Acre Wetland | P | 1100 | 5.18 ± 1.64 | 4.14-6.31 | 1.02-9.90 |
| | A | 365 | 8.26 ± 1.20 | 7.57-9.05 | 1.22-9.92 |
| Hogg Bay Inner | P | 2525 | 4.54 ± 1.29 | 3.77-5.65 | 1.02-7.98 |
| | A | 186 | 5.64 ± 2.26 | 6.09-6.56 | 1.14-8.02 |
| Hogg Bay Outer | P | 704 | 3.55 ± 2.06 | 1.75-5.39 | 1.05-8.24 |
| | A | 28 | 5.70 ± 2.80 | 1.81-7.72 | 1.12-8.26 |
| Matchedash Bay | P | 731 | 1.63 ± 0.07 | 1.59-1.68 | 1.32-1.83 |
| | A | 0 | NA | NA | NA |
| Musky Bay | P | 633 | 4.89 ± 1.16 | 3.83-5.38 | 0.99-9.30 |
| | A | 1589 | 8.68 ± 1.83 | 7.92-9.80 | 1.11-10.20 |
| Midland East | P | 631 | 4.24 ± 2.30 | 2.09-6.09 | 1.35-10.42 |
| | A | 1224 | 8.64 ± 3.24 | 7.26-11.39 | 1.38-12.42 |
| Midland West | P | 164 | 5.98 ± 2.43 | 3.67-7.87 | 0.98-9.86 |
| | A | 641 | 9.94 ± 1.22 | 9.24-10.87 | 1.40-12.50 |
| North Bay | P | 559 | 3.16 ± 0.82 | 2.59-3.68 | 0.98-5.53 |
| | A | 74 | 8.14 ± 3.16 | 5.60-11.38 | 1.28-12.58 |
| Inner Penetang | P | 1367 | 5.37 ± 1.30 | 4.94-6.21 | 1.04-8.02 |
| | A | 169 | 6.48 ± 1.89 | 6.57-7.41 | 1.05-8.05 |
| Outer Penetang | P | 129 | 3.78 ± 2.78 | 1.05-5.97 | 0.94-10.47 |
| | A | 1098 | 7.29 ± 3.24 | 7.60-9.20 | 1.02-12.74 |
| Present Island | P | 911 | 4.65 ± 1.83 | 3.96-5.66 | 1.28-9.43 |
| | A | 523 | 5.42 ± 3.36 | 1.58-9.14 | 1.28-9.61 |
| Roberts Island | P | 973 | 5.26 ± 1.90 | 3.78-6.83 | 1.10-8.34 |
| | A | 219 | 5.92 ± 2.87 | 1.76-7.92 | 1.06-8.38 |
| South Bay | P | 158 | 3.88 ± 2.02 | 2.19-5.36 | 1.25-9.03 |
| | A | 334 | 8.68 ± 2.04 | 6.92-10.16 | 1.42-12.77 |
| Sucker Creek | P | 217 | 4.64 ± 2.47 | 2.47-6.77 | 1.29-10.49 |
| | A | 89 | 4.91 ± 3.95 | 2.02-7.94 | 1.29-12.92 |
| Severn South Shore | P | 392 | 3.93 ± 1.76 | 2.22-5.35 | 1.16-9.86 |
| | A | 872 | 8.34 ± 2.19 | 8.36-9.51 | 1.08-9.83 |
| Sturgeon Bay | P | 1471 | 2.39 ± 0.46 | 2.09-2.75 | 1.27-3.13 |
| | A | 0 | NA | NA | NA |
| Treasure Bay | P | 747 | 3.55 ± 1.04 | 2.80-4.17 | 1.64-6.05 |
| | A | 2 | 1.89 ± 0.03 | 1.88-1.90 | 1.86-1.91 |

**Table 5.** Results from the hydroacoustic surveys for SAV. The proportion of hydroacoustic points where SAV was present (Prop. SAV) is shown as are the mean, inter-quartile range and min/max for SAV percent cover and SAV height.

| | | SAV Percent Cover | | | SAV Height (m) | | |
|---|---|---|---|---|---|---|---|
| **Site Code** | **Prop. SAV** | **Mean** | **1st – 3rd Quartile** | **Min – Max** | **Mean** | **1st – 3rd Quartile** | **Min – Max** |
| Beausoleil East | 0.36 | 75.7 ± 32.6 | 50-100 | 10-100 | 0.40 ± 0.31 | 0.16-0.56 | 0.10-1.90 |
| Beausoleil West | 0.14 | 39.4 ± 30.1 | 10-50 | 10-100 | 0.24 ± 0.15 | 0.12-0.32 | 0.10-0.69 |
| Green Island | 0.99 | 96.0 ± 14.2 | 100-100 | 10-100 | 0.78 ± 0.37 | 0.51-1.04 | 0.10-2.07 |
| 100 Acre Wetland | 0.75 | 86.2 ± 25.9 | 80-100 | 10-100 | 0.73 ± 0.41 | 0.42-1.02 | 0.10-2.21 |
| Hogg Bay Inner | 0.93 | 90.6 ± 23.0 | 100-100 | 10-100 | 1.06 ± 0.60 | 0.60-1.49 | 0.10-2.61 |
| Hogg Bay Outer | 0.96 | 50.0 ± 33.9 | 30-100 | 10-100 | 0.33 ± 0.32 | 0.12-0.41 | 0.10-1.86 |
| Matchedash Bay | 1.00 | 99.4 ± 3.7 | 100-100 | 40-100 | 1.07 ± 0.19 | 0.97-1.21 | 0.14-1.44 |
| Musky Bay | 0.28 | 69.3 ± 33.1 | 40-100 | 10-100 | 0.27 ± 0.18 | 0.15-0.31 | 0.10-1.73 |
| Midland East | 0.34 | 72.5 ± 35.6 | 40-100 | 10-100 | 0.42 ± 0.33 | 0.17-0.58 | 0.10-1.72 |
| Midland West | 0.20 | 58.2 ± 35.4 | 20-100 | 10-100 | 0.40 ± 0.44 | 0.12-0.51 | 0.10-1.75 |
| North Bay | 0.88 | 92.4 ± 18.9 | 100-100 | 10-100 | 0.46 ± 0.28 | 0.28-0.54 | 0.12-2.01 |
| Inner Penetang | 0.89 | 93.3 ± 19.9 | 100-100 | 10-100 | 0.90 ± 0.43 | 0.58-1.21 | 0.10-2.36 |
| Outer Penetang | 0.11 | 58.9 ± 38.4 | 20-100 | 10-100 | 0.54 ± 0.32 | 0.20-0.70 | 0.10-1.96 |
| Present Island | 0.64 | 78.2 ± 33.1 | 60-100 | 10-100 | 0.29 ± 0.20 | 0.16-0.34 | 0.10-1.92 |
| Roberts Island | 0.82 | 80.1 ± 30.1 | 60-100 | 10-100 | 0.67 ± 0.48 | 0.20-1.03 | 0.10-2.57 |
| South Bay | 0.32 | 69.5 ± 37.2 | 30-100 | 10-100 | 0.48 ± 0.29 | 0.22-0.70 | 0.10-1.24 |
| Sucker Creek | 0.71 | 56.0 ± 34.5 | 20-100 | 10-100 | 0.29 ± 0.28 | 0.12-0.33 | 0.10-1.80 |
| Severn South Shore | 0.31 | 82.7 ± 29.2 | 77.5-100 | 10-100 | 0.53 ± 0.43 | 0.22-0.62 | 0.10-2.34 |
| Sturgeon Bay | 1.00 | 99.9 ± 1.5 | 100-100 | 70-100 | 1.08 ± 0.41 | 0.74-1.39 | 0.22-2.32 |
| Treasure Bay | 1.00 | 98.1 ± 10.4 | 100-100 | 10-100 | 0.80 ± 0.38 | 0.53-1.04 | 0.10-2.41 |

**Table 6.** Comparison of the mean SAV percent cover and height determined via analysis of hydroacoustic data with the visual assessment categories.

| Visual Categories | # Samples | Hydroacoustic Mean | |
|---|---|---|---|
| | | SAV Cover (%) | SAV Height (m) |
| Surface-Dense | 10 | 100.0 ± 0.0 | 1.08 ± 0.21 |
| Surface-Moderate | 3 | 100.0 ± 0.0 | 0.64 ± 0.03 |
| Surface-Sparse | 4 | 75.0 ± 50.0 | 0.71 ± 0.54 |
| High-Dense | 39 | 99.7 ± 1.62 | 1.19 ± 0.52 |
| High-Moderate | 19 | 96.3 ± 16.1 | 0.94 ± 0.44 |
| High-Sparse | 5 | 82.0 ± 40.2 | 0.74 ± 0.61 |
| Mid-Dense | 36 | 95.8 ± 16.5 | 1.06 ± 0.46 |
| Mid-Moderate | 27 | 92.6 ± 19.9 | 0.84 ± 0.55 |
| Mid-Sparse | 8 | 80.0 ± 38.5 | 0.65 ± 0.51 |
| Low-Dense | 8 | 85.0 ± 35.1 | 0.80 ± 0.64 |
| Low-Moderate | 6 | 60.0 ± 40.5 | 0.66 ± 0.54 |
| Low-Sparse | 8 | 50.0 ± 53.5 | 0.46 ± 0.58 |
| No SAV | 79 | 19.4 ± 32.4 | 0.17 ± 0.28 |
| Overall Means | Dense | 95.1 ± 13.3 | |
| | Moderate | 87.2 ± 19.1 | |
| | Sparse | 71.8 ± 45.6 | |

**Table 7.** List of aquatic macrophyte species and Chara sp. collected at the 133 verification points and their mean coverage at points where they were found to occur.

| Species | Common Name | # of Occurrences | Mean Cover (%) |
|---|---|---|---|
| *Vallisneria americana* | Wild Celery | 51 | 23.7 |
| *Elodea canadensis* | Common Waterweed | 42 | 19.6 |
| *Najas flexilis* | Slender Naiad | 34 | 22.1 |
| *Ceratophyllum demersum* | Coontail | 34 | 37.6 |
| *Chara* spp. | Stonewort | 32 | 56.4 |
| *Myriophyllum spicatum* | Eurasian Milfoil | 30 | 29.8 |
| *Heteranthera dubia* | Water Stargrass | 24 | 18.0 |
| *Potamogeton richardsonii* | Richardson's Pondweed | 20 | 28.8 |
| *Potamogeton robbinsii* | Fern-leaf Pondweed | 19 | 26.9 |
| *Myriophyllum sibiricum* | Northern Milfoil | 16 | 15.6 |
| *Potamogeton zosteriformis* | Flat-Stemmed Pondweed | 12 | 15.8 |
| *Megalodonta beckii* | Beck's Marsh Marigold | 11 | 5.3 |
| *Potamogeton pusillus* | Slender Pondweed | 10 | 39.2 |
| *Potamogeton perfoliatus* | Claspingleaf Pondweed | 7 | 12.7 |
| *Potamogeton amplifolius* | Large-leaf Pondweed | 6 | 12.5 |
| *Utricularia vulgaris* | Common Bladderwort | 6 | 23.5 |
| *Potamogeton* spp. | Pondweed Species | 5 | 25.0 |
| *Nitella* spp. | Brittlewort Species | 4 | 28.0 |
| *Potamogeton crispus* | Curly Pondweed | 3 | 9.0 |
| *Zizania palustris* | Wild Rice | 3 | 8.0 |
| *Potamogeton friesii* | Flat-stalked Pondweed | 3 | 48.3 |
| *Potamogeton gramineus* | Variable-Leaved Pondweed | 2 | 26.5 |
| *Nuphar variegata* | Yellow Pond Lily | 2 | 10.5 |
| *Najas* spp. | Water-nymph Species | 2 | 19.2 |
| *Utricularia minor* | Lesser Bladderwort | 2 | 17.0 |
| *Potamogeton foliosus* | Leafy Pondweed | 1 | 2.0 |
| *Nymphaea odorata* | Fragrant Water Lily | 1 | 96.0 |
| *Ranunculus* spp. | Crowfoot Species | 1 | 2.0 |
| *Sagittaria graminea* | Grassy Arrowhead | 1 | 15.0 |
| *Schoenoplectus acutus* | Hard-stem Bulrush | 1 | 20.0 |

**Table 8.** Summary data from dissolved oxygen (DO) loggers deployed at eight locations throughout Severn Sound. The top group show the range of observed temperatures, the middle group the raw DO readings, and the bottom group the range DO saturation levels corrected for shifting temperatures.

| | Mean ± SD | | | | | Min-Max | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Temperature (°C)** | **June** | **July** | **August** | **September** | **October** | **June** | **July** | **August** | **September** | **October** |
| Green Island | 21.7 ± 2.6 | 24.7 ± 1.3 | 24.4 ± 1.2 | 20.3 ± 2.6 | 16.3 ± 1.6 | 16.0 - 26.3 | 20.6 - 28.1 | 21.5 - 27.5 | 14.7 - 25.4 | 13.2 – 20.0 |
| 100 Acre Wetland | 20.9 ± 2.6 | 24.2 ± 1.3 | 24.6 ± 1.1 | 20.7 ± 2.3 | 16.8 ± 1.4 | 6.1 - 25.1 | 20.5 - 26.7 | 21.0 - 27.2 | 15.5 - 24.9 | 13.4 - 19.5 |
| Present Island | 19.8 ± 2.2 | 23.3 ± 1.4 | 24.3 ± 1.2 | 21.3 ± 1.8 | 17.4 ± 1.1 | 15.0 - 25.3 | 18.8 - 26.6 | 21.3 - 27.9 | 16.5 - 25.8 | 14.5 - 19.5 |
| Outer Penetang | 19.8 ± 2.6 | 23.8 ± 1.1 | 24.9 ± 1.1 | 21.8 ± 1.7 | 17.8 ± 0.8 | 15.0 - 24.8 | 20.6 - 26.4 | 22.3 - 27.5 | 18.2 - 25.5 | 15.6 - 19.5 |
| Inner Penetang | 20.4 ± 3.0 | 19.3 ± 1.6 | 18.5 ± 1.7 | 15.3 ± 1.9 | 12.7 ± 1.3 | 13.6 - 25.7 | 15.7 - 25.8 | 15.0 - 23.6 | 11.5 - 19.8 | 10.4 - 16.7 |
| Sturgeon Bay | 16.5 ± 2.20 | 18.5 ± 1.6 | 18.3 ± 1.2 | 14.5 ± 1.9 | 12.4 ± 2.0 | 11.4 - 20.7 | 14.0 - 23.6 | 15.2 - 21.5 | 10.4 - 19.5 | 7.5 – 15.0 |
| South Bay North | 21.8 ± 2.10 | 24.8 ± 1.1 | 25.3 ± 1.0 | 22.1 ± 1.9 | 17.9 ± 1.0 | 17.6 - 24.9 | 21.9 - 27.7 | 21.2 - 27.6 | 17.7 - 25.4 | 15.8 - 20.7 |
| South Bay South | 22.1 ± 2.50 | 25 ± 1.3 | 24.8 ± 1.3 | 20.9 ± 2.3 | 16.4 ± 1.4 | 16.4 – 26.0 | 20.9 - 27.9 | 21.9 - 28.2 | 15.7 - 26.1 | 13.3 - 19.4 |
| **DO (mg/L)** | **June** | **July** | **August** | **September** | **October** | **June** | **July** | **August** | **September** | **October** |
| Green Island | 8.43 ± 1.48 | 6.94 ± 2.43 | 4.91 ± 2.37 | 5.27 ± 2.17 | 7.14 ± 1.98 | 2.52 - 11.98 | 0.00 - 14.27 | 0.00 - 11.87 | 0.16 - 10.56 | 2.26 - 11.12 |
| 100 Acre Wetland | 8.44 ± 1.58 | 6.73 ± 2.22 | 2.79 ± 2.10 | 2.80 ± 1.85 | 5.26 ± 1.96 | 3.27 - 12.94 | 0.00 - 10.91 | 0.00 - 9.41 | 0.00 - 8.21 | 0.09 - 9.31 |
| Present Island | 9.48 ± 0.85 | 7.83 ± 0.74 | 7.98 ± 0.76 | 8.86 ± 0.64 | 9.40 ± 0.49 | 5.77 - 12.26 | 5.14 - 10.13 | 5.08 - 10.36 | 4.87 - 10.56 | 7.56 - 11.16 |
| Outer Penetang | 9.85 ± 0.91 | 8.69 ± 0.78 | 8.89 ± 1.14 | 9.04 ± 0.71 | 9.29 ± 0.63 | 7.75 - 13.79 | 3.67 - 12.07 | 6.27 - 13.01 | 5.99 - 12.38 | 7.94 - 11.46 |
| Inner Penetang | 11.87 ± 1.40 | 10.87 ± 5.15 | 8.25 ± 4.30 | 8.46 ± 4.55 | 7.88 ± 3.89 | 8.40 - 18.33 | 2.32 - 22.68 | 1.62 - 22.20 | 1.91 - 18.71 | 2.58 - 17.18 |
| Sturgeon Bay | 8.84 ± 1.01 | 8.27 ± 1.32 | 8.14 ± 1.09 | 8.93 ± 1.18 | 9.35 ± 1.23 | 6.42 - 11.17 | 2.58 - 11.51 | 4.10 - 11.43 | 2.17 - 11.92 | 6.01 - 12.86 |
| South Bay North | 8.91 ± 0.63 | 8.07 ± 1.66 | 7.76 ± 2.28 | 8.78 ± 1.98 | 9.75 ± 1.44 | 6.25 - 10.87 | 1.57 - 12.78 | 0.27 - 13.76 | 1.44 - 14.23 | 5.43 - 12.39 |
| South Bay South | 9.58 ± 1.38 | 8.45 ± 2.05 | 6.20 ± 1.38 | 6.15 ± 1.40 | 7.29 ± 1.07 | 5.58 - 13.77 | 3.88 - 14.30 | 0.79 - 10.01 | 0.66 - 9.11 | 3.13 - 9.65 |
| **DO Sat.(%)** | **June** | **July** | **August** | **September** | **October** | **June** | **July** | **August** | **September** | **October** |
| Green Island | 98.0±18.0 | 85.4±29.9 | 60.2±29.4 | 59.6±25.0 | 74.5±21.2 | 29.9-146.4 | 0.0-172.0 | 0.0-144.3 | 1.9-126.3 | 22.2-120.6 |
| 100 Acre Wetland | 96.5±18.3 | 81.9±27.0 | 34.3±26.0 | 31.8±20.8 | 55.7±21.4 | 40.0-129.1 | 0.0-133.9 | 0.0-118.6 | 0.0-90.3 | 0.9-99.5 |
| Present Island | 106.1±9.9 | 94.0±10.4 | 97.6±10.1 | 102.2±8.5 | 100.1±5.7 | 64.9-150.4 | 60.2-126.9 | 60.6-131.2 | 57.5-126.7 | 81.9-119.9 |
| Outer Penetang | 110.3±11.0 | 105.1±10.4 | 109.9±15.6 | 105.2±9.8 | 99.7±7.4 | 88.7-167.1 | 44.3-149.7 | 75.1-164.9 | 72.3-150.8 | 85.0-126.4 |
| Inner Penetang | 134.7±18.7 | 121.2±58.9 | 90.9±49.2 | 86.9±47.8 | 76.4±38.8 | 89.2-222.3 | 25.0-254.8 | 16.9-247.4 | 18.5-197.4 | 23.6-171.9 |
| Sturgeon Bay | 92.2±9.6 | 90.1±14.1 | 88.3±11.7 | 89.3±10.9 | 89.1±9.5 | 70.4-113.8 | 29.0-125.5 | 45.6-122.6 | 22.2-115.5 | 60.0-112.4 |
| South Bay North | 103.6±8.9 | 99.5±21.0 | 96.8±29.3 | 102.7±23.5 | 105.0±16.0 | 76.0-127.1 | 19.7-163.5 | 3.2-176.0 | 16.5-173.0 | 58.9-137.5 |
| South Bay South | 112.5±19.4 | 104.4±25.0 | 76.6±17.9 | 70.4±16.9 | 76.1±11.6 | 66.2-171.2 | 47.6-178.8 | 9.4-129.4 | 7.7-114.6 | 32.9-107.0 |

**Table 9.** Substrate composition at the 99 sites surveyed in 2016. Data points were collected to validate substrate hardness from data collected by the University of Windsor (Rover), validate data collected using sidescan sonar (Sidescan), and to fill gaps in existing substrate data layers (Data Gaps).

| Site | Sample Num. | Collection Purpose | Boulder (+256 mm) | Cobble (64-256 mm) | Pebble (16-64 mm) | Gravel (2-16 mm) | Sand (0.625-2 mm) | Silt (0.0039-0.0625) | Clay (<0.0039) | Loss on Ignition (%) | Latitude | Longitude |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 100 Acre | 1 | Sidescan | 0.0 | 0.0 | 0.0 | 30.9 | 68.9 | 0.1 | 0.2 | 2.56 | 44.83380 | -79.78970 |
| 100 Acre | 2 | Sidescan | 0.0 | 0.0 | 0.0 | 2.0 | 97.9 | 0.0 | 0.1 | 0.38 | 44.84240 | -79.78600 |
| Beausoleil Island | 1 | Rover | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.46 | 44.87171 | -79.86021 |
| Beausoleil West | 1 | Sidescan | 0.0 | 0.0 | 0.0 | 0.1 | 99.9 | 0.0 | 0.0 | 0.49 | 44.84191 | -79.88139 |
| Beausoleil West | 2 | Sidescan | 0.0 | 0.0 | 0.0 | 21.1 | 78.9 | 0.0 | 0.0 | 0.41 | 44.83923 | -79.88604 |
| Green Island | 1 | Sidescan | 0.0 | 0.0 | 0.0 | 0.0 | 98.3 | 0.5 | 1.1 | 9.59 | 44.78938 | -79.75873 |
| Green Island | 2 | Sidescan | 0.0 | 0.0 | 0.0 | 0.0 | 99.5 | 0.1 | 0.3 | 11.27 | 44.78990 | -79.75848 |
| Green Island | 3 | Sidescan | 0.0 | 0.0 | 0.0 | 0.0 | 97.8 | 0.8 | 1.4 | 11.26 | 44.78733 | -79.73972 |
| Hog Bay | 1 | Data Gaps | 0.0 | 0.0 | 0.0 | 0.0 | 99.0 | 0.4 | 0.7 | 21.26 | 44.73426 | -79.80251 |
| Hog Bay | 2 | Data Gaps | 0.0 | 0.0 | 0.0 | 0.0 | 99.0 | 0.3 | 0.7 | 0.96 | 44.74294 | -79.80063 |
| Hog Bay | 3 | Data Gaps | 0.0 | 0.0 | 0.0 | 1.6 | 98.2 | 0.1 | 0.1 | 0.39 | 44.75118 | -79.77820 |
| Hog Bay | 4 | Sidescan | 0.0 | 0.0 | 0.0 | 0.0 | 99.4 | 0.2 | 0.5 | 2.47 | 44.76288 | -79.77227 |
| Hog Bay | 5 | Sidescan | 0.0 | 0.0 | 0.0 | 0.0 | 99.9 | 0.0 | 0.0 | 0.39 | 44.76280 | -79.77152 |
| Hog Bay | 6 | Rover | 0.0 | 0.0 | 0.0 | 0.7 | 96.3 | 0.9 | 2.1 | 5.10 | 44.75182 | -79.79250 |
| Hog Bay | 7 | Rover | 0.0 | 0.0 | 0.0 | 16.5 | 82.6 | 0.2 | 0.7 | 1.57 | 44.75192 | -79.79363 |
| Hog Bay | 8 | Rover | 0.0 | 0.0 | 0.0 | 1.1 | 98.7 | 0.0 | 0.1 | 4.55 | 44.75208 | -79.79447 |
| Hog Bay Inner | 1 | Rover | 0.0 | 0.0 | 0.0 | 0.2 | 99.1 | 0.2 | 0.5 | 12.21 | 44.74620 | -79.79460 |
| Honey Harbour | 1 | Rover | 0.0 | 0.0 | 0.0 | 1.8 | 97.6 | 0.2 | 0.4 | 4.32 | 44.89152 | -79.82083 |
| Honey Harbour | 2 | Data Gaps | 0.0 | 0.0 | 0.0 | 0.0 | 99.9 | 0.0 | 0.0 | 10.30 | 44.89588 | -79.83340 |
| Honey Harbour | 3 | Data Gaps | 0.0 | 0.0 | 0.0 | 47.3 | 52.7 | 0.0 | 0.1 | 0.55 | 44.89607 | -79.83357 |
| Honey Harbour | 4 | Rover | 0.0 | 0.0 | 0.0 | 0.0 | 97.4 | 0.7 | 1.9 | 7.70 | 44.88488 | -79.81900 |
| Honey Harbour | 5 | Rover | 0.0 | 0.0 | 0.0 | 0.0 | 96.4 | 1.5 | 2.1 | 4.83 | 44.88007 | -79.81530 |
| Honey Harbour | 6 | Rover | 0.0 | 0.0 | 0.0 | 0.0 | 99.4 | 0.2 | 0.4 | 1.64 | 44.87975 | -79.81600 |
| Honey Harbour | 7 | Rover | 0.0 | 0.0 | 0.0 | 0.4 | 99.4 | 0.0 | 0.1 | 0.45 | 44.87975 | -79.81628 |
| Matchedash | 1 | Data Gaps | 0.0 | 0.0 | 0.0 | 0.0 | 93.5 | 1.7 | 4.7 | 11.33 | 44.74464 | -79.67573 |
| Matchedash | 2 | Data Gaps | 0.0 | 0.0 | 0.0 | 0.0 | 98.8 | 0.4 | 0.9 | 9.92 | 44.75663 | -79.69146 |
| Matchedash | 3 | Data Gaps | 0.0 | 0.0 | 0.0 | 0.5 | 97.5 | 0.7 | 1.3 | 11.80 | 44.76168 | -79.68464 |
| Matchedash | 4 | Data Gaps | 0.0 | 0.0 | 0.0 | 0.0 | 99.1 | 0.3 | 0.6 | 16.87 | 44.75947 | -79.68247 |
| Midland Bay | 1 | Sidescan | 0.0 | 0.0 | 0.0 | 0.0 | 97.4 | 0.8 | 1.8 | 11.82 | 44.77937 | -79.86750 |
| Midland Bay | 2 | Sidescan | 0.0 | 0.0 | 0.0 | 0.3 | 97.3 | 0.7 | 1.6 | 1.64 | 44.77980 | -79.86757 |
| Midland Bay | 3 | Sidescan | 0.0 | 0.0 | 0.0 | 0.0 | 98.8 | 0.5 | 0.7 | 1.95 | 44.76668 | -79.89308 |
| Midland Bay | 4 | Sidescan | 0.0 | 0.0 | 0.0 | 0.1 | 99.9 | 0.0 | 0.0 | 0.30 | 44.76828 | -79.89345 |
| Midland Bay | 5 | Sidescan | 0.0 | 0.0 | 0.0 | 2.2 | 97.7 | 0.0 | 0.1 | 0.34 | 44.76918 | -79.89387 |
| Midland Bay | 6 | Sidescan | 0.0 | 0.0 | 0.0 | 0.0 | 98.0 | 0.7 | 1.3 | 4.10 | 44.77007 | -79.89248 |
| Midland Bay | 7 | Sidescan | 0.0 | 0.0 | 0.0 | 3.0 | 97.0 | 0.0 | 0.0 | 0.78 | 44.80967 | -79.87802 |
| Midland Bay | 8 | Sidescan | 0.0 | 0.0 | 0.0 | 2.6 | 96.8 | 0.2 | 0.3 | 1.63 | 44.75780 | -79.88498 |
| Midland Bay | 9 | Sidescan | 0.0 | 0.0 | 0.0 | 0.0 | 99.1 | 0.2 | 0.7 | 1.23 | 44.75722 | -79.88583 |
| Midland Bay | 10 | Sidescan | 0.0 | 0.0 | 0.0 | 22.5 | 73.6 | 0.9 | 3.0 | 6.66 | 44.75657 | -79.88660 |
| Midland Bay | 11 | Data Gaps | 0.0 | 0.0 | 0.0 | 0.2 | 95.5 | 1.4 | 2.8 | 4.62 | 44.74548 | -79.85328 |
| Midland Bay | 12 | Data Gaps | 0.0 | 0.0 | 0.0 | 0.0 | 92.9 | 2.1 | 4.9 | 1.61 | 44.74653 | -79.85413 |
| Midland Bay West | 1 | Sidescan | 0.0 | 0.0 | 0.0 | 0.0 | 95.6 | 1.6 | 2.8 | 7.99 | 44.76672 | -79.89222 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Moore Point | 1 | Sidescan | 0.0 | 0.0 | 0.0 | 0.2 | 99.3 | 0.1 | 0.4 | 11.26 | 44.80373 | -79.76733 |
| Moore Point | 2 | Sidescan | 0.0 | 0.0 | 0.0 | 4.4 | 95.6 | 0.0 | 0.0 | 0.60 | 44.82338 | -79.78407 |
| Moore Point | 3 | Sidescan | 0.0 | 0.0 | 0.0 | 3.7 | 96.2 | 0.0 | 0.2 | 1.54 | 44.80992 | -79.78193 |
| Moore Point | 4 | Sidescan | 0.0 | 0.0 | 0.0 | 0.6 | 98.9 | 0.1 | 0.3 | 1.91 | 44.80970 | -79.78025 |
| North Bay | 1 | Rover | 0.0 | 0.0 | 0.0 | 0.0 | 96.5 | 1.3 | 2.3 | 15.69 | 44.89118 | -79.80388 |
| North Bay | 2 | Data Gaps | 0.0 | 0.0 | 0.0 | 0.0 | 99.0 | 0.3 | 0.6 | 28.73 | 44.89692 | -79.79378 |
| North Bay | 3 | Rover | 0.0 | 0.0 | 0.0 | 0.0 | 98.4 | 0.5 | 1.1 | 50.53 | 44.89983 | -79.79380 |
| North Bay | 4 | Rover | 0.0 | 0.0 | 0.0 | 0.0 | 98.1 | 0.7 | 1.2 | 43.59 | 44.89622 | -79.79422 |
| Penetang Inner | 1 | Sidescan | 0.0 | 0.0 | 0.0 | 0.0 | 97.7 | 0.7 | 1.6 | 7.76 | 44.78140 | -79.94100 |
| Penetang Inner | 2 | Sidescan | 0.0 | 0.0 | 0.0 | 0.0 | 99.2 | 0.2 | 0.6 | 7.23 | 44.78580 | -79.94010 |
| Penetang Outer | 1 | Rover | 0.0 | 0.0 | 0.0 | 0.0 | 99.7 | 0.1 | 0.2 | 0.16 | 44.81960 | -79.92390 |
| Penetanguishene | 1 | Sidescan | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.39 | 44.80777 | -79.94025 |
| Penetanguishene | 2 | Rover | 0.0 | 0.0 | 0.0 | 0.0 | 99.9 | 0.0 | 0.1 | 0.33 | 44.80904 | -79.93808 |
| Penetanguishene | 3 | Sidescan | 0.0 | 0.0 | 0.0 | 0.0 | 99.5 | 0.1 | 0.4 | 1.78 | 44.80706 | -79.92305 |
| Penetanguishene | 4 | Sidescan | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | | 44.80738 | -79.93060 |
| Penetanguishene | 5 | Sidescan | 0.0 | 0.0 | 0.0 | 4.9 | 94.7 | 0.1 | 0.3 | 0.50 | 44.78345 | -79.93498 |
| Penetanguishene | 6 | Rover | 0.0 | 0.0 | 0.0 | 0.9 | 96.3 | 1.1 | 1.7 | 1.97 | 44.76653 | -79.94474 |
| Penetanguishene | 7 | Rover | 0.0 | 0.0 | 0.0 | 0.0 | 95.2 | 0.9 | 3.9 | 10.51 | 44.77509 | -79.95012 |
| Penetanguishene | 8 | Rover | 0.0 | 0.0 | 0.0 | 0.0 | 99.6 | 0.1 | 0.3 | 1.27 | 44.77549 | -79.94570 |
| Penetanguishene | 9 | Rover | 0.0 | 0.0 | 0.0 | 0.0 | 88.5 | 5.1 | 6.3 | 19.20 | 44.76925 | -79.95357 |
| Penetanguishene | 10 | Rover | 0.0 | 0.0 | 0.0 | 0.0 | 99.3 | 0.2 | 0.5 | 25.50 | 44.76915 | -79.95217 |
| Penetanguishene | 11 | Sidescan | 0.0 | 0.0 | 0.0 | 0.0 | 97.1 | 1.0 | 1.9 | 9.59 | 44.77785 | -79.93907 |
| Penetanguishene | 12 | Sidescan | 0.0 | 0.0 | 0.0 | 0.0 | 99.9 | 0.0 | 0.1 | 0.00 | 44.77765 | -79.93892 |
| Penetanguishene | 13 | Rover | 0.0 | 0.0 | 0.0 | 0.0 | 99.9 | 0.0 | 0.0 | 0.48 | 44.77697 | -79.93928 |
| Penetanguishene | 14 | Rover | 0.0 | 0.0 | 0.0 | 11.5 | 87.4 | 0.2 | 0.9 | 1.43 | 44.79743 | -79.94418 |
| Penetanguishene | 15 | Sidescan | 0.0 | 0.0 | 0.0 | 0.4 | 97.8 | 0.4 | 1.4 | 20.47 | 44.83080 | -79.90695 |
| Penetanguishene | 16 | Sidescan | 0.0 | 0.0 | 0.0 | 0.0 | 99.3 | 0.2 | 0.5 | 1.47 | 44.80763 | -79.93027 |
| Penetanguishene | 17 | Sidescan | 0.0 | 0.0 | 0.0 | 3.1 | 96.8 | 0.0 | 0.0 | 0.14 | 44.80737 | -79.93057 |
| Penetanguishene | 18 | Sidescan | 0.0 | 0.0 | 0.0 | 0.0 | 24.0 | 0.2 | 0.4 | 2.02 | 44.79868 | -79.94453 |
| Present Island | 1 | Data Gaps | 0.0 | 0.0 | 0.0 | 0.6 | 99.2 | 0.1 | 0.2 | 18.97 | 44.81890 | -79.83164 |
| Present Island | 2 | Data Gaps | 0.0 | 0.0 | 0.0 | 0.4 | 99.5 | 0.0 | 0.1 | 0.88 | 44.81680 | -79.84579 |
| Present Island | 3 | Data Gaps | 0.0 | 0.0 | 0.0 | 1.0 | 98.9 | 0.0 | 0.0 | 0.74 | 44.81873 | -79.84431 |
| Quarry Island | 1 | Sidescan | 0.0 | 0.0 | 0.0 | 0.0 | 98.7 | 0.4 | 0.9 | 4.64 | 44.84020 | -79.79815 |
| Quarry Island | 2 | Sidescan | 0.0 | 0.0 | 0.0 | 0.0 | 98.6 | 0.3 | 1.1 | 3.87 | 44.84073 | -79.79815 |
| Quarry Island | 3 | Sidescan | 0.0 | 0.0 | 0.0 | 1.3 | 98.7 | 0.0 | 0.0 | 0.44 | 44.83654 | -79.82313 |
| Robert's Inlet | 1 | Sidescan | 0.0 | 0.0 | 0.0 | 0.2 | 99.3 | 0.2 | 0.3 | 12.30 | 44.83183 | -79.78097 |
| Robert's Inlet | 2 | Sidescan | 0.0 | 0.0 | 0.0 | 1.2 | 98.7 | 0.0 | 0.0 | 2.04 | 44.83157 | -79.78030 |
| Robert's Inlet | 3 | Sidescan | 0.0 | 0.0 | 0.0 | 21.7 | 77.9 | 0.1 | 0.4 | 2.19 | 44.86180 | -79.84730 |
| Robert's Inlet | 4 | Sidescan | 0.0 | 0.0 | 0.0 | 2.6 | 97.2 | 0.1 | 0.2 | 1.04 | 44.86220 | -79.84230 |
| South Bay | 1 | Sidescan | 0.0 | 0.0 | 0.0 | 0.1 | 98.4 | 0.5 | 1.0 | 10.36 | 44.87288 | -79.78812 |
| South Bay | 2 | Sidescan | 0.0 | 0.0 | 0.0 | 0.0 | 98.1 | 0.6 | 1.3 | 17.47 | 44.87432 | -79.77430 |
| South Bay | 3 | Sidescan | 0.0 | 0.0 | 0.0 | 0.0 | 99.2 | 0.2 | 0.6 | 15.90 | 44.87393 | -79.77472 |
| South Bay | 4 | Data Gaps | 0.0 | 0.0 | 0.0 | 0.0 | 98.5 | 0.6 | 0.9 | 25.75 | 44.87714 | -79.79034 |
| South Bay | 5 | Data Gaps | 0.0 | 0.0 | 0.0 | 1.5 | 97.4 | 0.4 | 0.7 | 14.97 | 44.87739 | -79.78808 |
| SS South Shore | 1 | Sidescan | 0.0 | 0.0 | 0.0 | 3.9 | 95.9 | 0.1 | 0.2 | 0.54 | 44.76750 | -79.82870 |
| Sturgeon Bay | 1 | Sidescan | 0.0 | 0.0 | 0.0 | 1.5 | 97.7 | 0.2 | 0.6 | 2.63 | 44.76425 | -79.71593 |
| Sturgeon Bay | 2 | Sidescan | 0.0 | 0.0 | 0.0 | 0.3 | 99.7 | 0.0 | 0.0 | 0.03 | 44.76457 | -79.71570 |
| Sturgeon Bay | 3 | Sidescan | 0.0 | 0.0 | 0.0 | 4.5 | 95.1 | 0.1 | 0.2 | 0.57 | 44.76505 | -79.71558 |
| Sturgeon Bay | 4 | Rover | 0.0 | 0.0 | 0.0 | 0.0 | 95.8 | 1.3 | 2.8 | 0.87 | 44.75327 | -79.75647 |
| Sturgeon Bay | 5 | Rover | 0.0 | 0.0 | 0.0 | 5.9 | 87.1 | 1.9 | 5.0 | 3.51 | 44.75534 | -79.75761 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sturgeon Bay | 6 | Sidescan | 0.0 | 0.0 | 0.0 | 0.0 | 99.7 | 0.1 | 0.2 | 0.50 | 44.75036 | -79.72484 |
| Sturgeon Bay | 7 | Sidescan | 0.0 | 0.0 | 0.0 | 0.2 | 99.6 | 0.1 | 0.1 | 0.49 | 44.75218 | -79.72351 |
| Sturgeon Bay | 8 | Data Gaps | 0.0 | 0.0 | 0.0 | 0.4 | 95.2 | 1.6 | 2.7 | 2.48 | 44.73788 | -79.73893 |
| Sturgeon Bay | 9 | Data Gaps | 0.0 | 0.0 | 0.0 | 0.0 | 99.7 | 0.1 | 0.2 | 0.86 | 44.73600 | -79.74227 |
| Sturgeon Bay | 10 | Rover | 0.0 | 0.0 | 0.0 | 0.0 | 97.7 | 0.8 | 1.5 | 9.14 | 44.75625 | -79.74350 |
| Sucker Creek | 1 | Sidescan | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.41 | 44.81054 | -79.87722 |
| Treasure Bay | 2 | Sidescan | 0.0 | 0.0 | 0.0 | 0.5 | 97.9 | 0.6 | 1.0 | 9.83 | 44.86180 | -79.86110 |
| Treasure Bay | 3 | Sidescan | 0.0 | 0.0 | 0.0 | 2.5 | 97.4 | 0.0 | 0.1 | 0.00 | 44.86400 | -79.85710 |

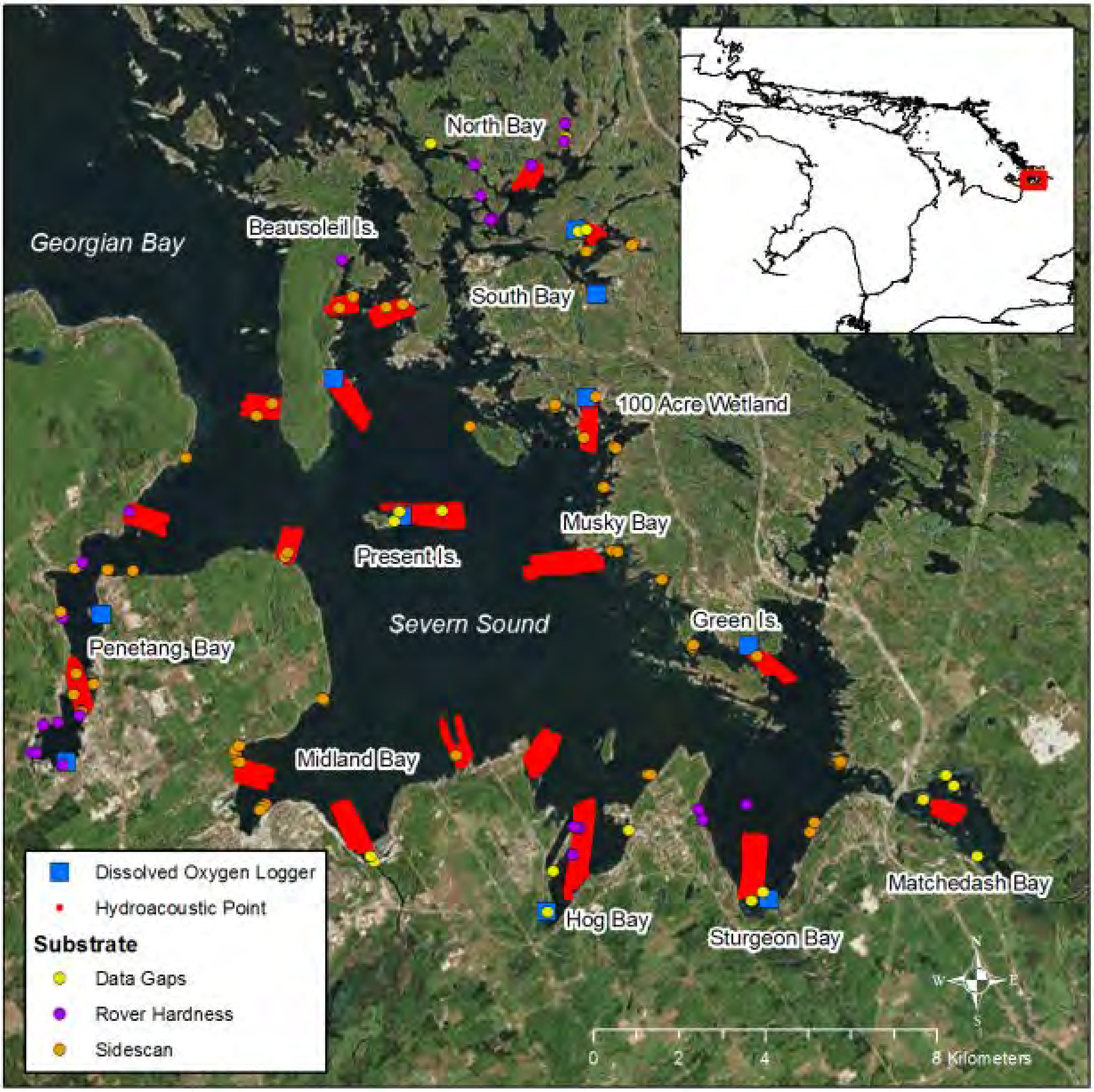



**Figure 1.** Location of SAV acoustic transects (red lines), dissolved oxygen loggers (blue squares), and substrate samples in Severn Sound. Substrate samples were selected to help fill existing data gaps (yellow circle),to cover a gradient of substrate hardness values (purple circle) and to support the interpretation of sidescan sonar data.

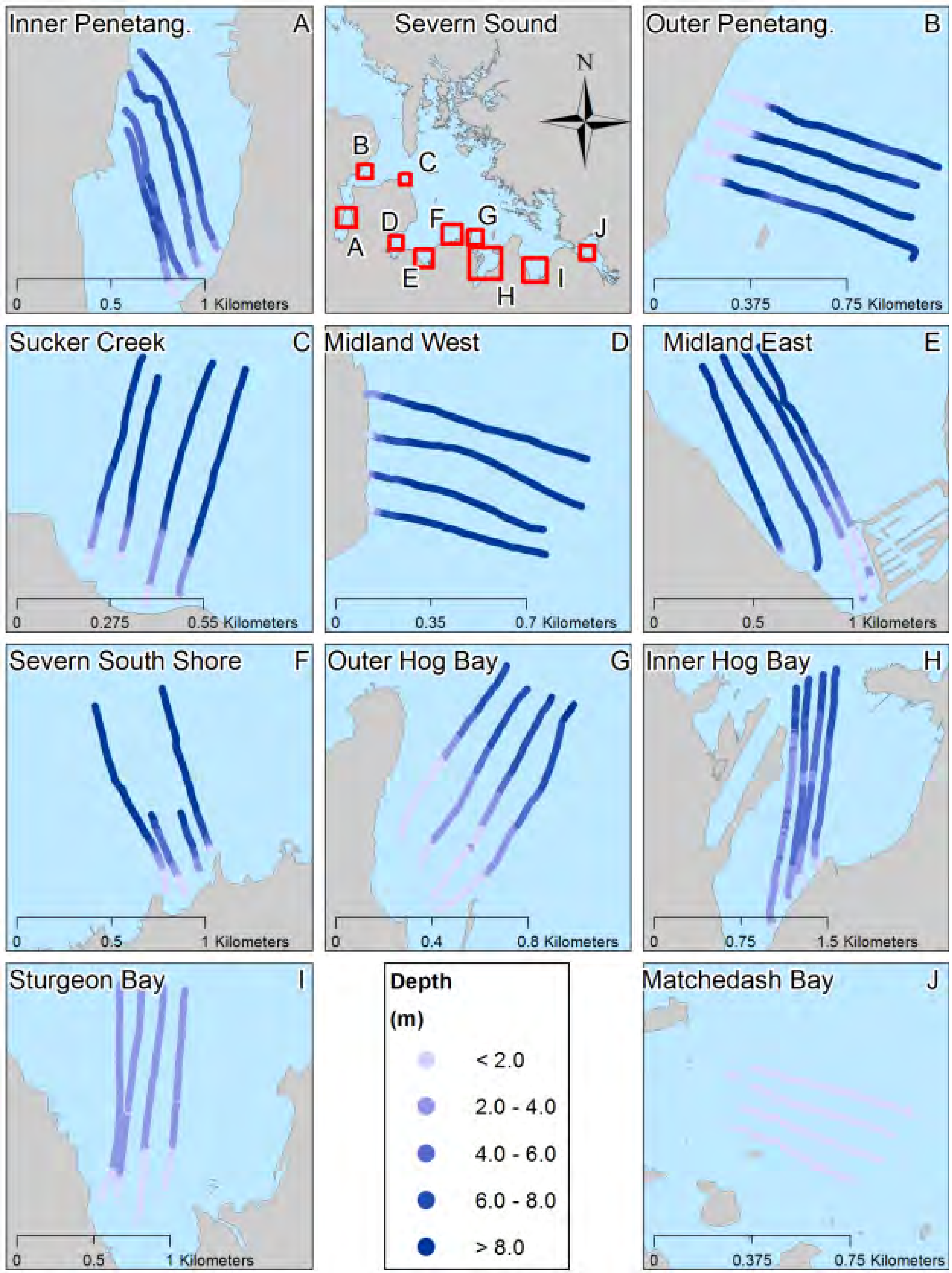



**Figure 2.** Water depth as determined by the hydroacoustic surveys in lower Severn Sound.

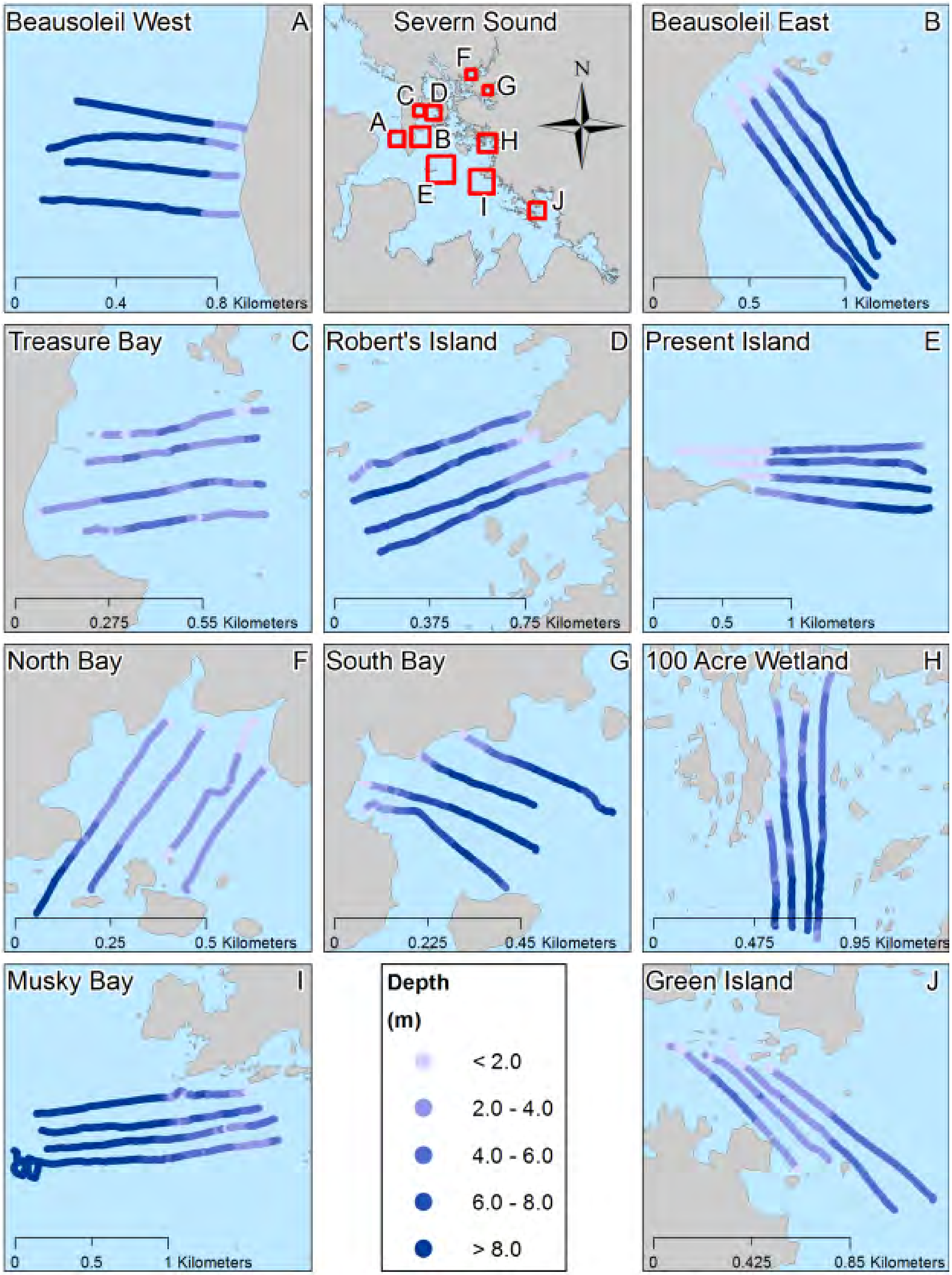



**Figure 3.** Water depth as determined by the hydroacoustic surveys in upper Severn Sound.

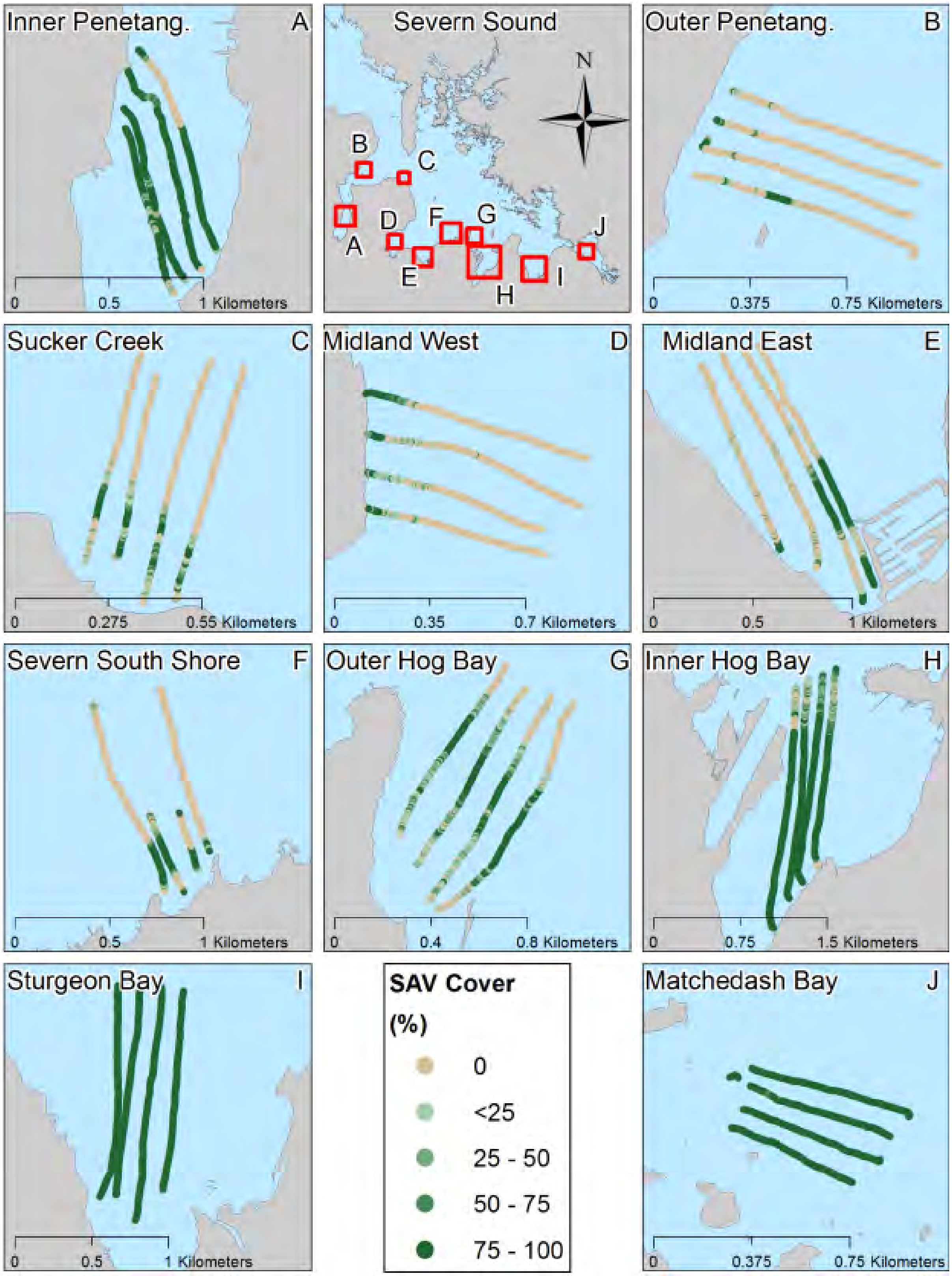



**Figure 4.** SAV percent cover as determined by the hydroacoustic surveys in lower Severn Sound.

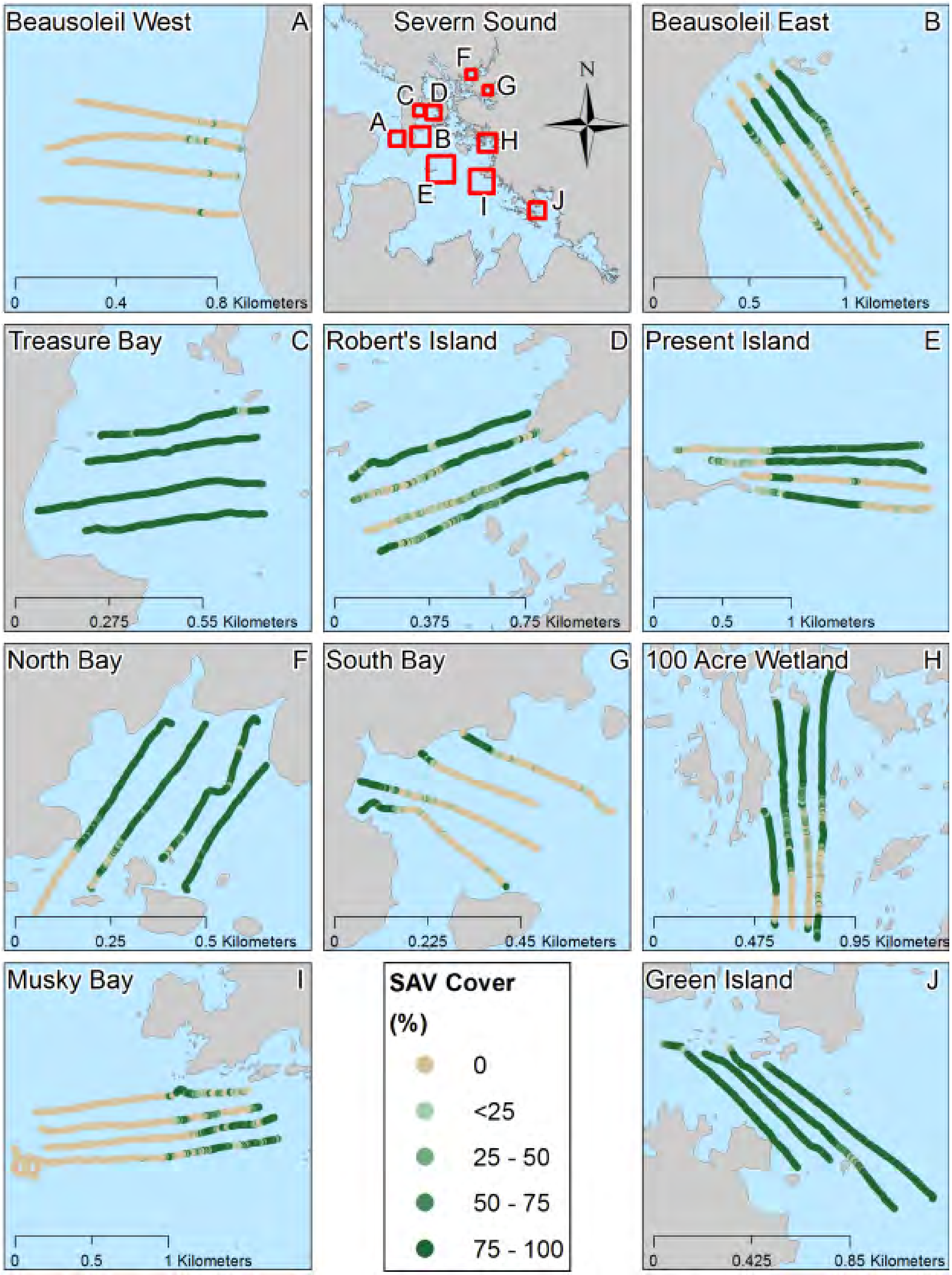



**Figure 5.** SAV percent cover as determined by the hydroacoustic surveys in upper Severn Sound.

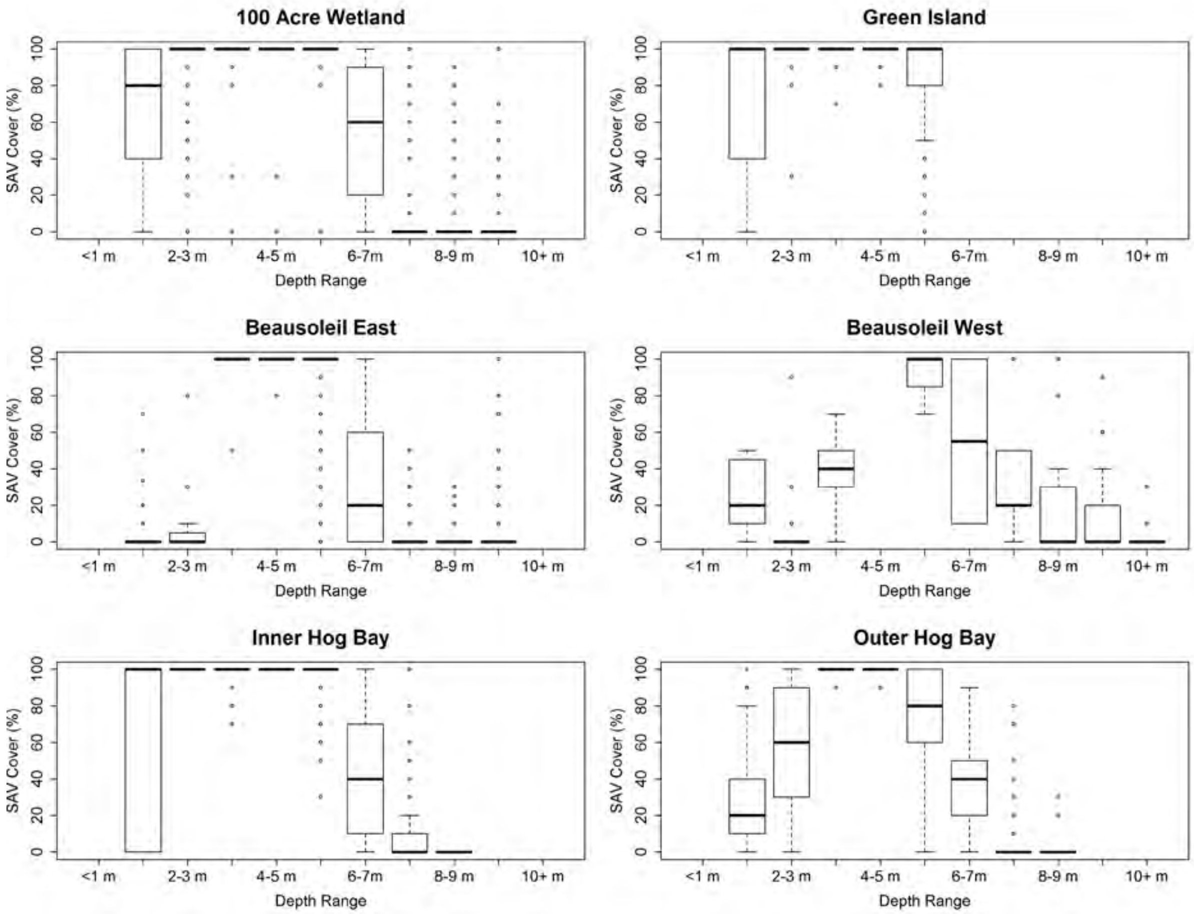



**Figure 6.** SAV percent cover as a function of depth range for a subset of the surveyed regions.

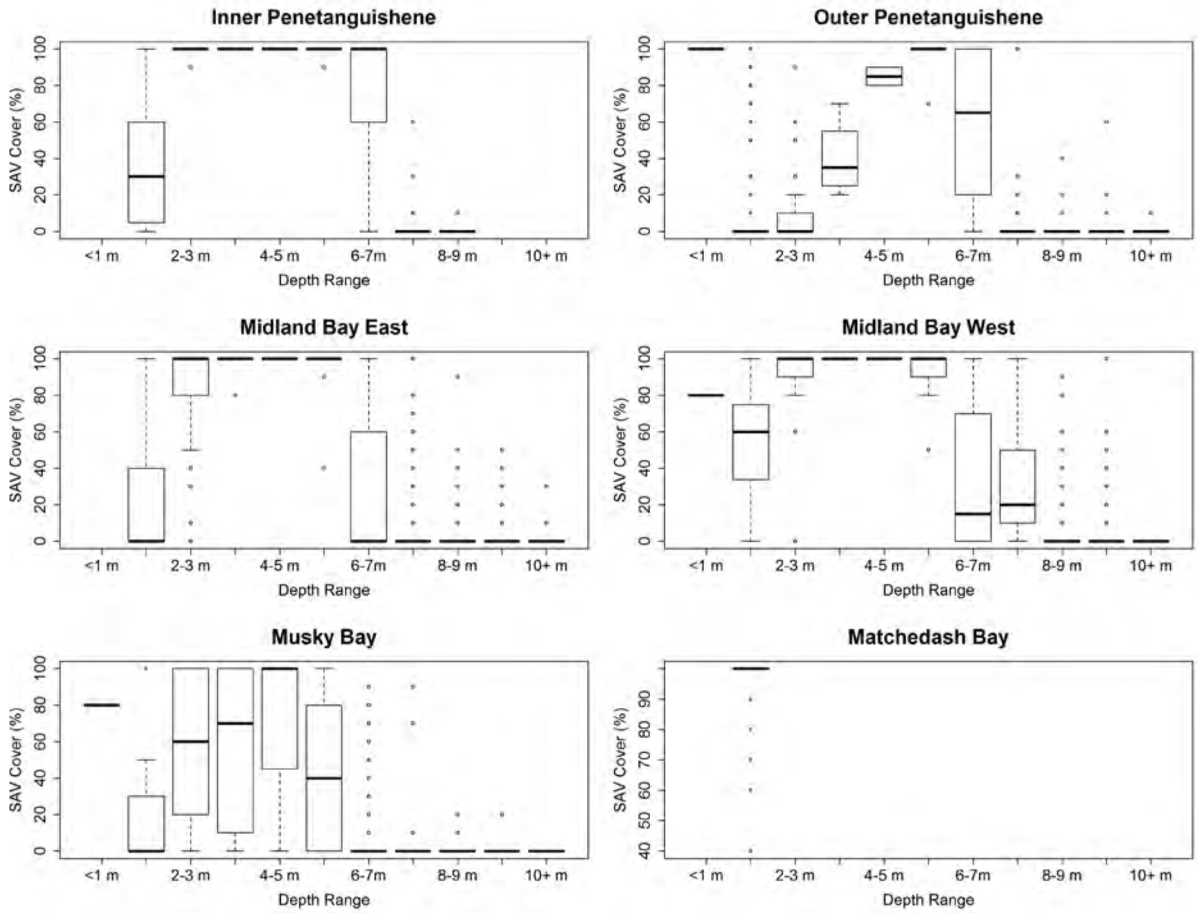



**Figure 7.** SAV percent cover as a function of depth range for a subset of the surveyed regions.

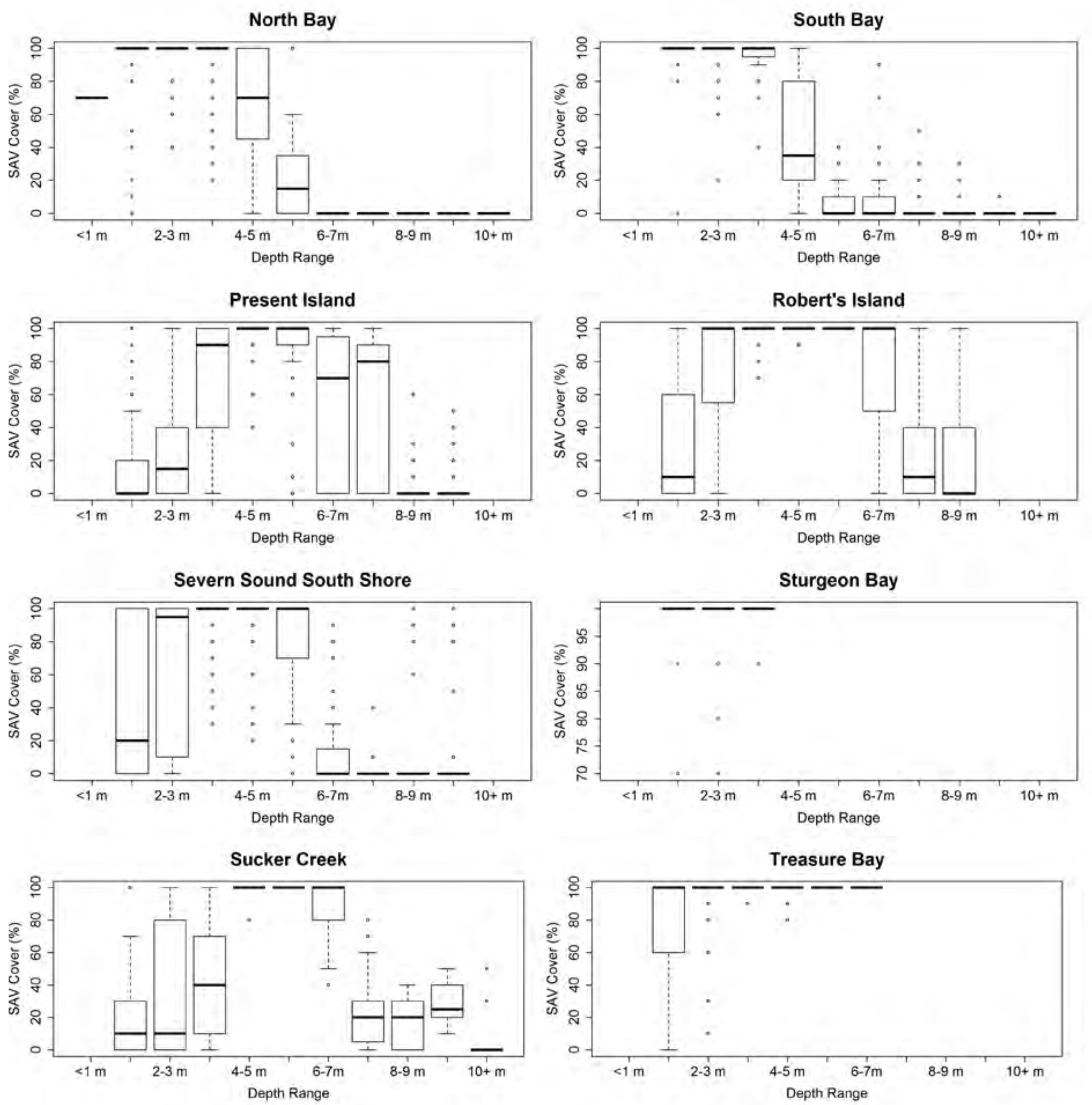



**Figure 8.** SAV percent cover as a function of depth range for a subset of the surveyed regions.

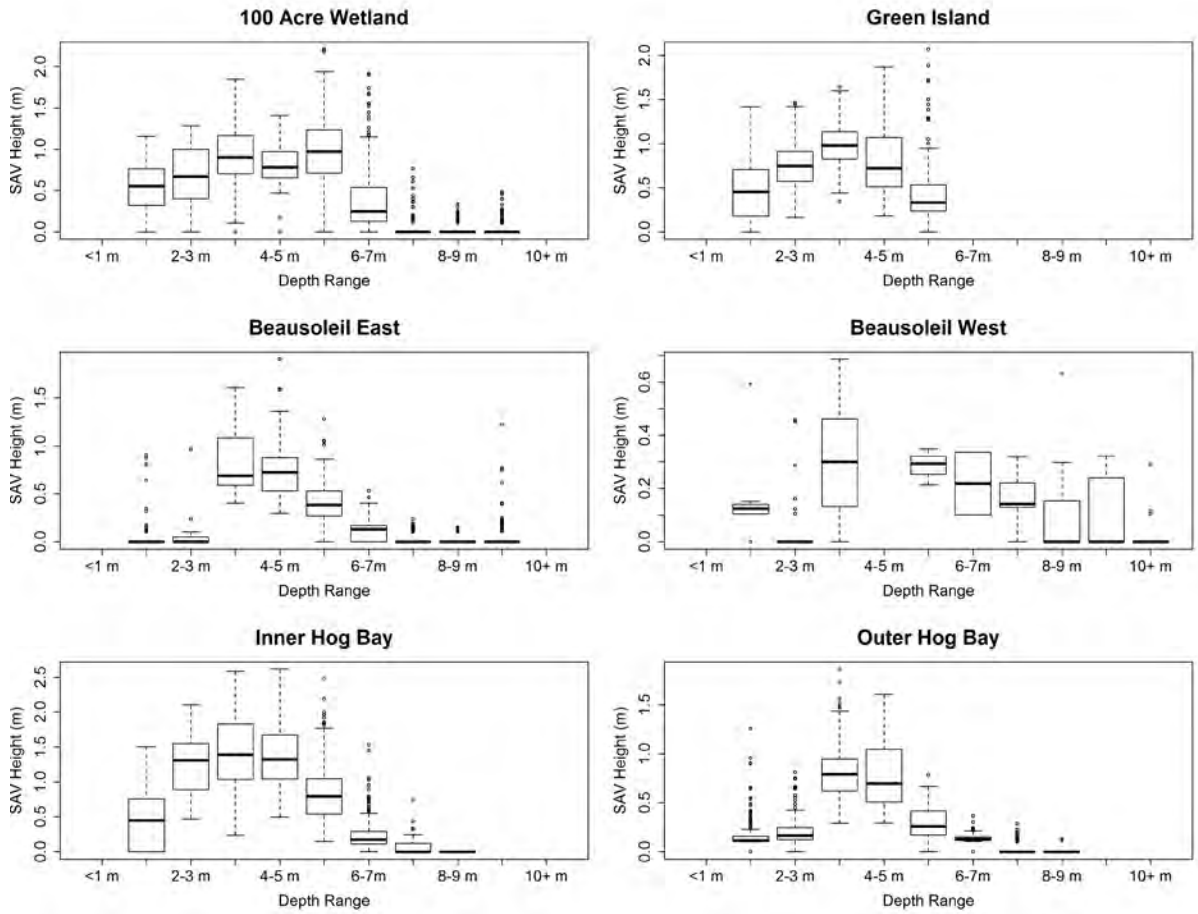



**Figure 9.** SAV height (m) as a function of depth range for a subset of the surveyed regions.

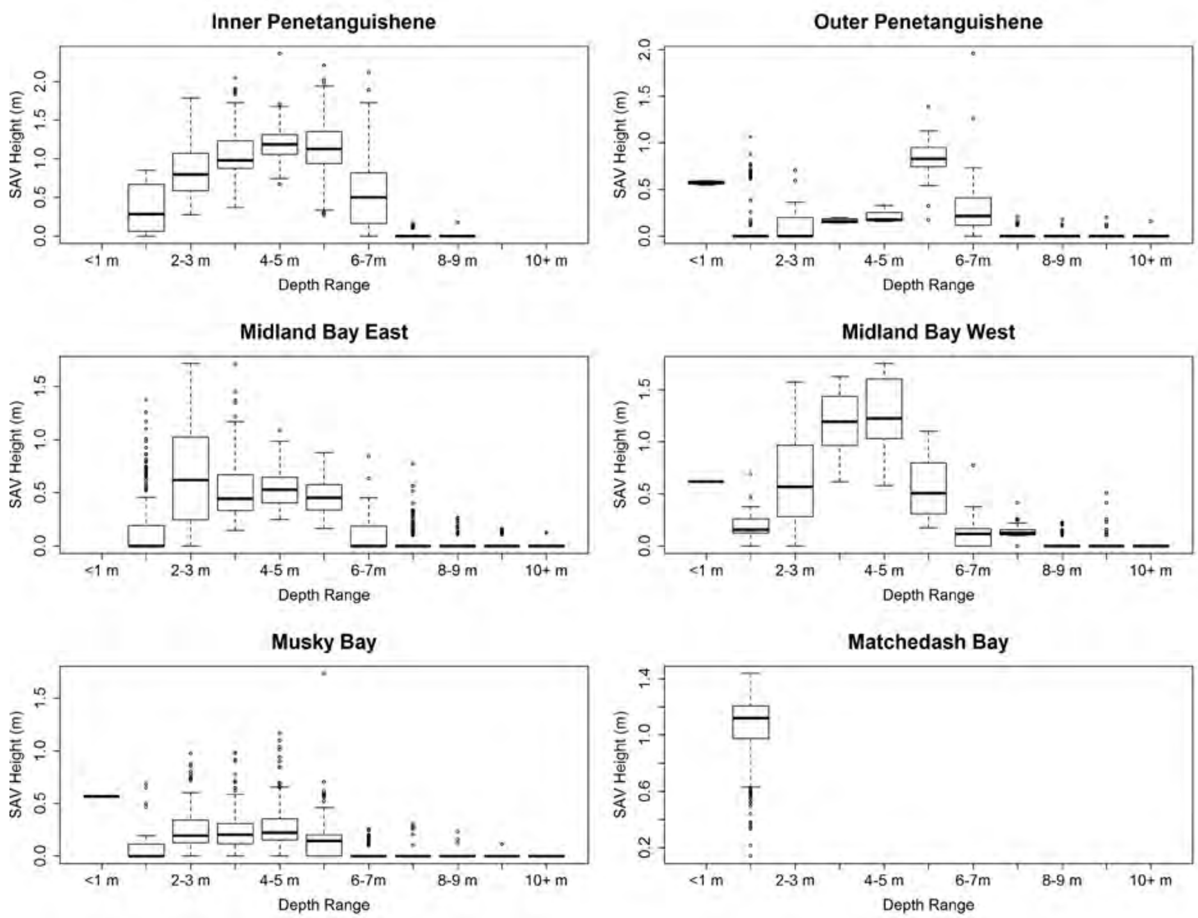



**Figure 10.** SAV height (m) as a function of depth range for a subset of the surveyed regions.

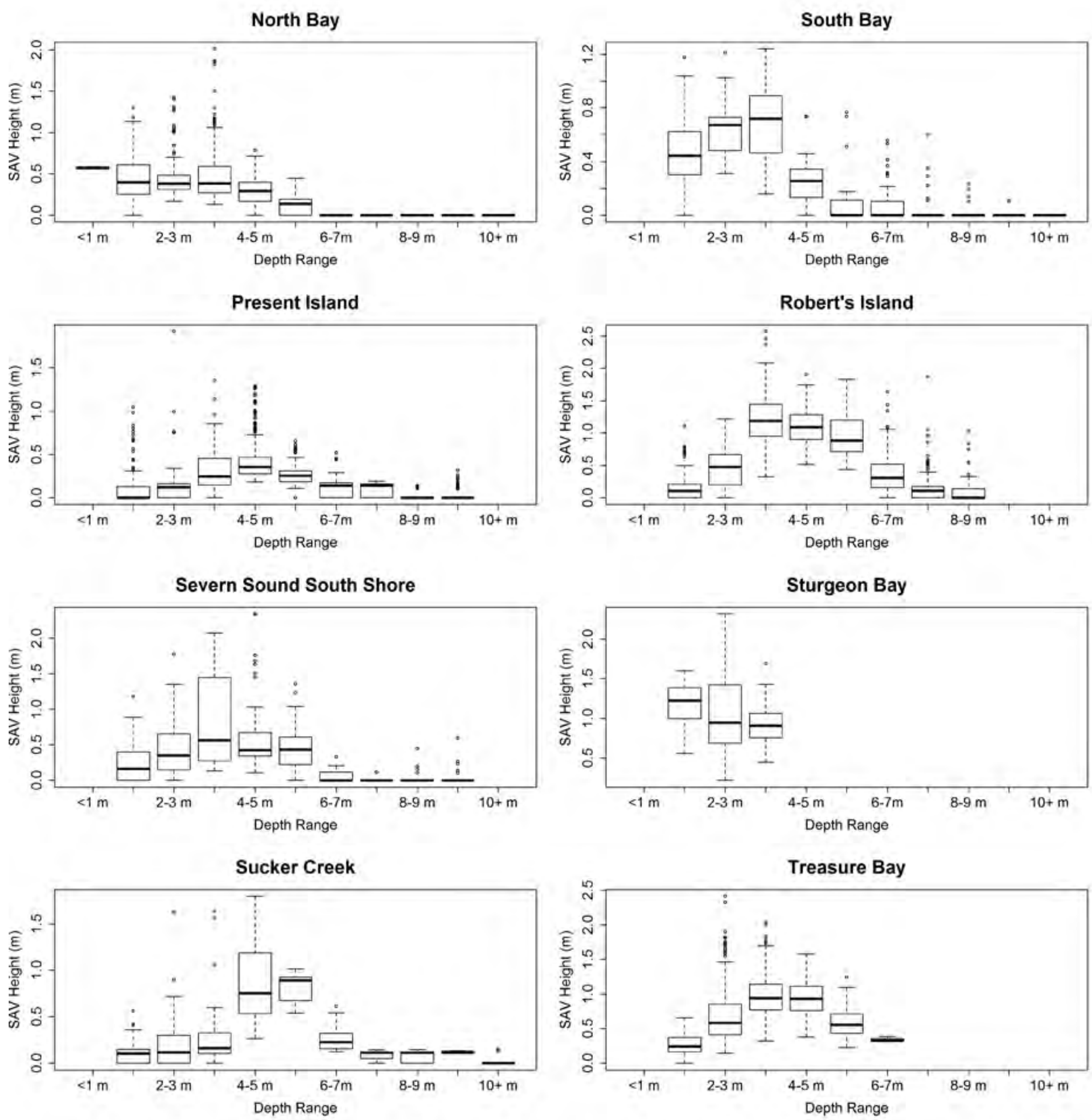



**Figure 11.** SAV height (m) as a function of depth range for a subset of the surveyed regions.

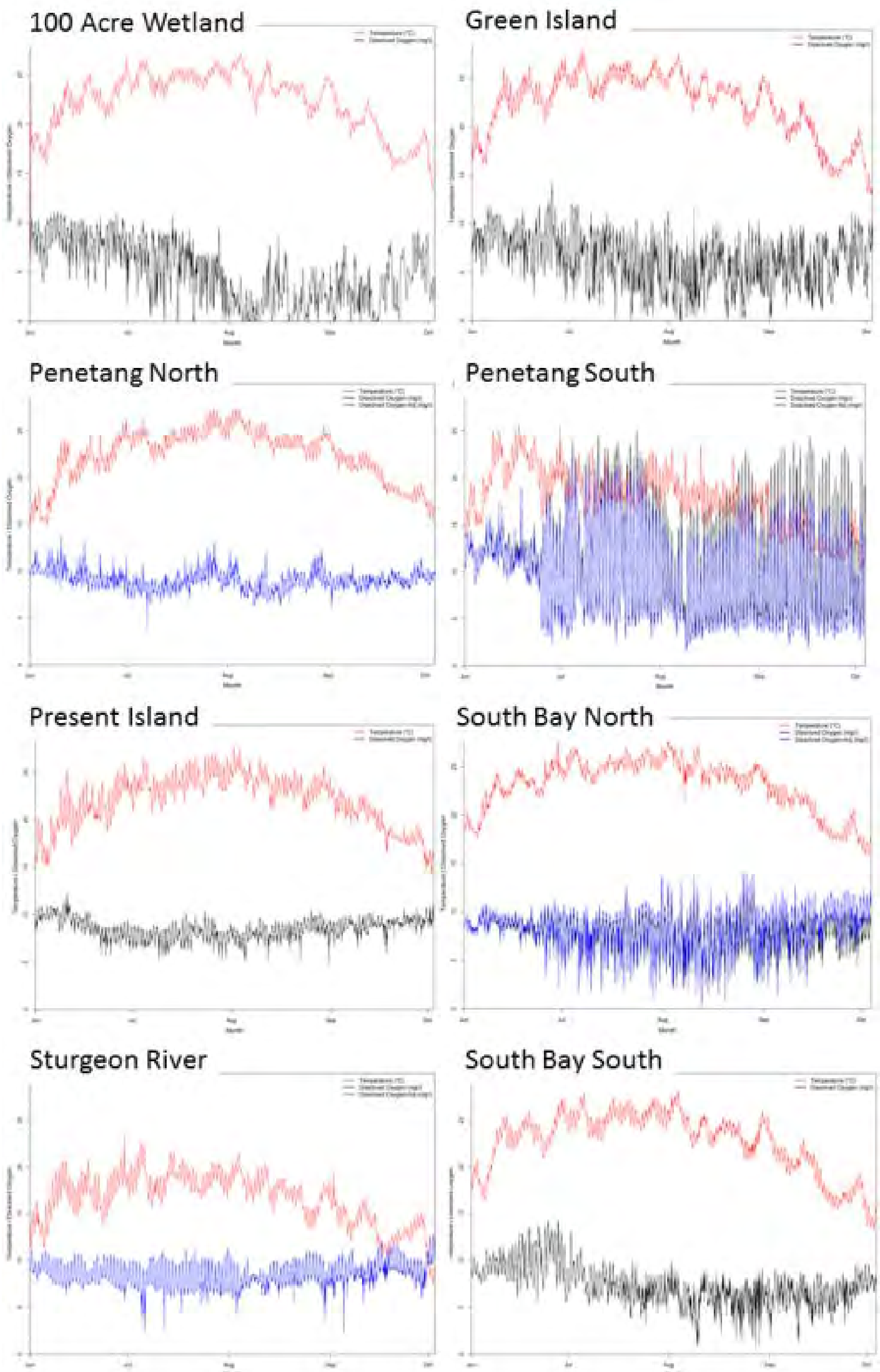



**Figure 12.** Dissolved oxygen (black, blue = corrected raw values) and temperature (red) profiles for loggers deployed at a subset of locations in Severn Sound. Loggers were deployed from 8-9 June, 2016 until 12-13 October 2016. Penetang North = Outer Penetang and Penetang South = Inner Penetang.

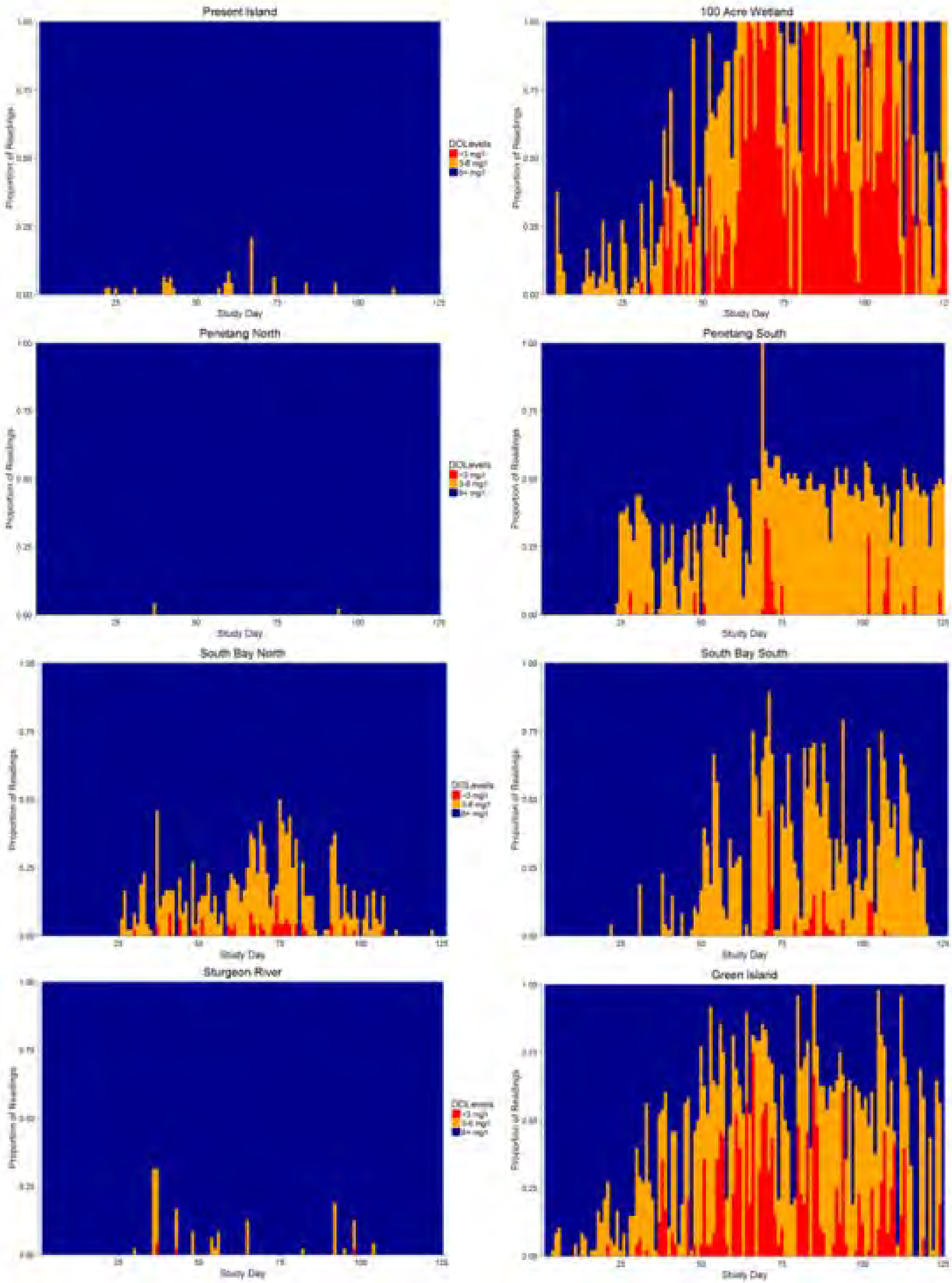



**Figure 13.** Proportion of each 24-hr time period when dissolved oxygen levels (as measured by dissolved oxygen loggers reading every 30 minutes) were greater than 6.0 mg/L (blue), between 3.0-6.0 mg/L (orange) and less than 3.0 mg/L (red). Values less than 3.0 mg/L are generally considered to reflect anoxic conditions. Penetang North = Outer Penetang and Penetang South = Inner Penetang.

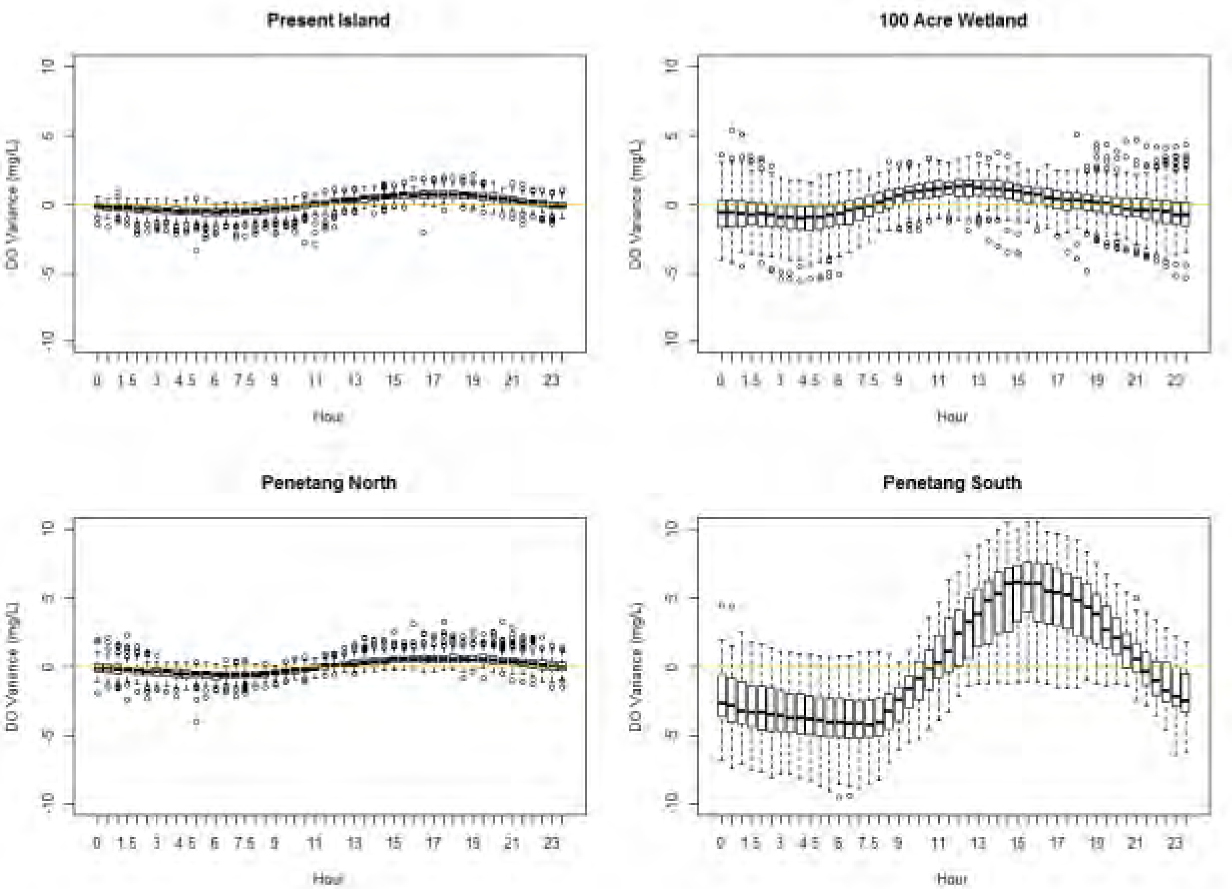



**Figure 14.** Hourly variability in dissolved oxygen (DO) for each logger across the entire sampling period (June – October, 2016). Variance was calculated as the difference between the recorded DO value at each time interval and the daily mean DO associated with that value. Therefore, positive variances indicate DO readings that are higher than the daily mean and negative values those that are lower than the daily mean. Penetang North = Outer Penetang and Penetang South = Inner Penetang.

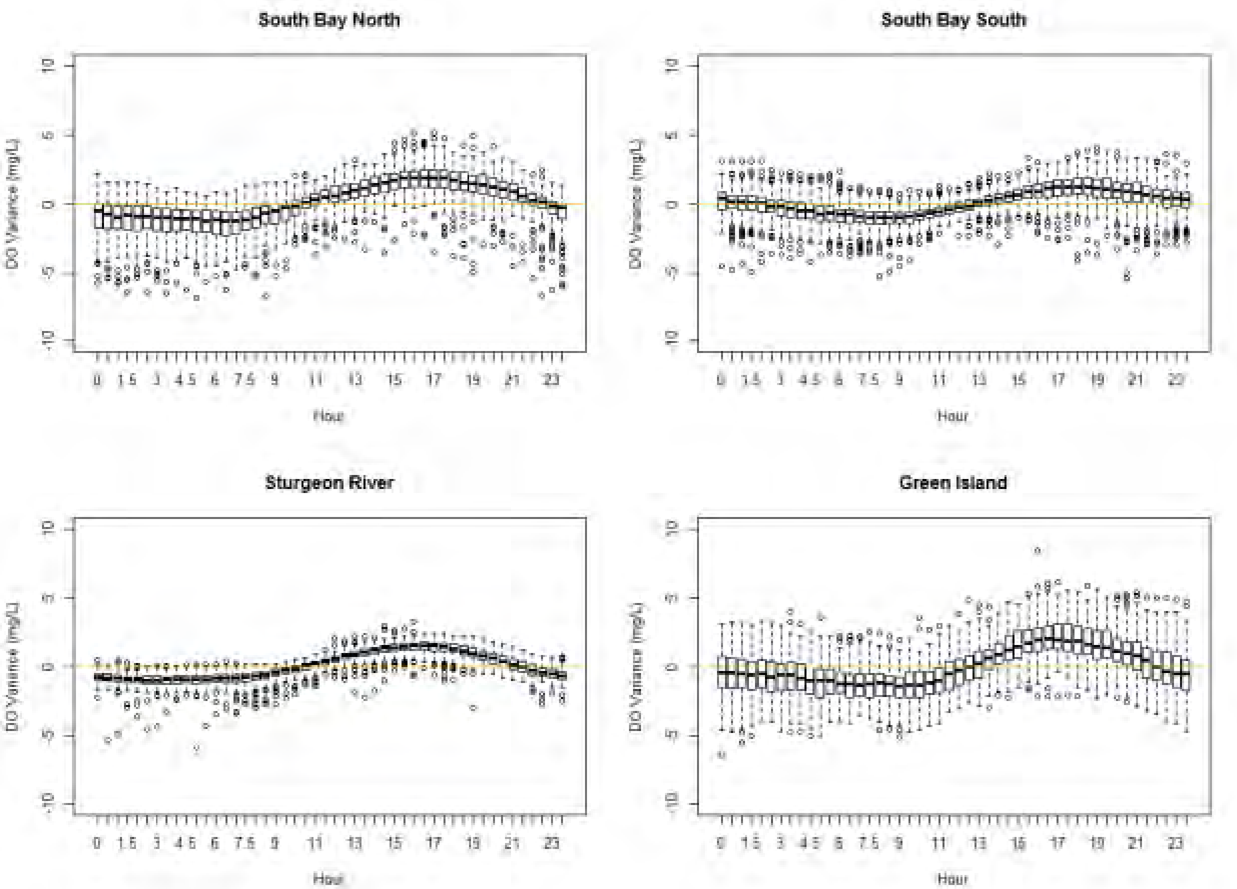



**Figure 15.** Hourly variability in dissolved oxygen (DO) for each logger across the entire sampling period (June – October, 2016). Variance was calculated as the difference between the recorded DO value at each time interval and the daily mean DO associated with that value. Therefore, positive variances indicate DO readings that are higher than the daily mean and negative values those that are lower than the daily mean.

APPENDIX_A6_COMPOSITE_SUITABILITY_INDEX_METHOD_(SSEA)

# Method of Calculating the Composite Fish Habitat Suitability Index Value in Severn Sound

**Prepared by: Lex McPhail, Severn Sound Environmental Association**

**04/27/2017**

## Composite (Fish Habitat) Suitability Index

A method of calculating the Fish Habitat Suitability Index value was adapted from the Development of a Fish Habitat Classification Model for Littoral Areas of Severn Sound, Georgian Bay, A Great Lakes Area of Concern (C.K. Minns, et al, 1999).

Transferring combinations of nearshore depth, aquatic vegetation cover and substrate cover to a composite suitability index (CSI) value relied on a predetermined matrix of composite suitability values (Habitat Suitability Matrix). The CSI value is a number between 0 and 1 that is assigned to each100 percent cover combination of aquatic vegetation cover and substrate cover at each nearshore depth range. The Minns et. Al method focused on water levels of less than 1.5 M in depth. A Habitat Suitability Matrix was derived from Habitat/Ecosystem Assessment Tool (HEAT) that included ranges for deeper water levels.

CSI values were calculated using Microsoft Excel's formula functions. Below are two examples of the calculation method that was applied.

**Example 1**: An area within the 1.0 to 1.5 m depth range, 100% cobble substrate and no vegetation cover (100% No cover) is shown below.

The formula is: (Co_NCSI X Co%) X NC% = CSI Value
Where:

Co_NCSI =Cobble No Cover Suitability Index Value from the Habitat Sutiability Matrix,=
Co% = Cobble (Substrate) Cover Percent as a decimal
NC% = No Vegetation Cover percent as decimal

**Example 2**:A more complex scenario than that found in example 1 is a nearshore area within the 0.0 to 0.5 m depth, with substrate cover of 50% sand, 20% silt and 30% boulder, and aquatic vegetation cover of 50% submergent and 20 % emergent.

The formula is:

((Si_SUBSI X Si%) X SUB%) + ((Si_EMSI X Si%) X EM%) + ((Si_NCSI X Si%) X NC%) + [SAND Version of Formula] + [ Boulder Version of Formula] = CSI Value

Where:

Si_SUBSI = Silt - Submergent Vegetation Suitability Index Value from the Habitat Sutiability Matrix

Si% = Silt (Substrate) Cover Percent as a decimal
SUB% = Submergent Vegetation percent as decimal
Si_EMSI = Silt - Emergent Vegetation Suitability Index Value from the Habitat Sutiability Matrix

EM% = Emergent Vegetation percent as decimal

Si_NCSI = Silt – No Cover Vegetation Suitability Index Value from the Habitat Sutiability Matrix
NC% = No Vegetation Cover percent as decimal

A similar formula is completed for the Sand and Boulder components and all three substrate formulas are added together to output the CSI Value.

The input data is appended to the Excel spreadsheet where preset formulas automatically calculate the CSI value. Each mesh grid cell is calculated individually and the CSI value is later combined with the mesh grid to output a final fish habitat suitability layer.

## References

Minns, C.K., Brunette, P.C.E., Stoneman, M., Sherman, K., Craig. R., Portt C.B., and Randall, R.G. 1999a. Development of a fish habitat classification model for littoral areas of Severn Sound, Georgian Bay, a Great Lakes' Area of Concern. Can. MS. Rpt. Fish. Aquat. Sci. 2490: ix+86p.

2015 to 2017 - Mapping, Evaluating, and Predicting Changes in Coastal Margin Aquatic Habitat in Severn Sound and Southeastern Georgian Bay

# Progress Map Series

## Data Capture and Assembly: 2015, 2016 and Historic Datasets

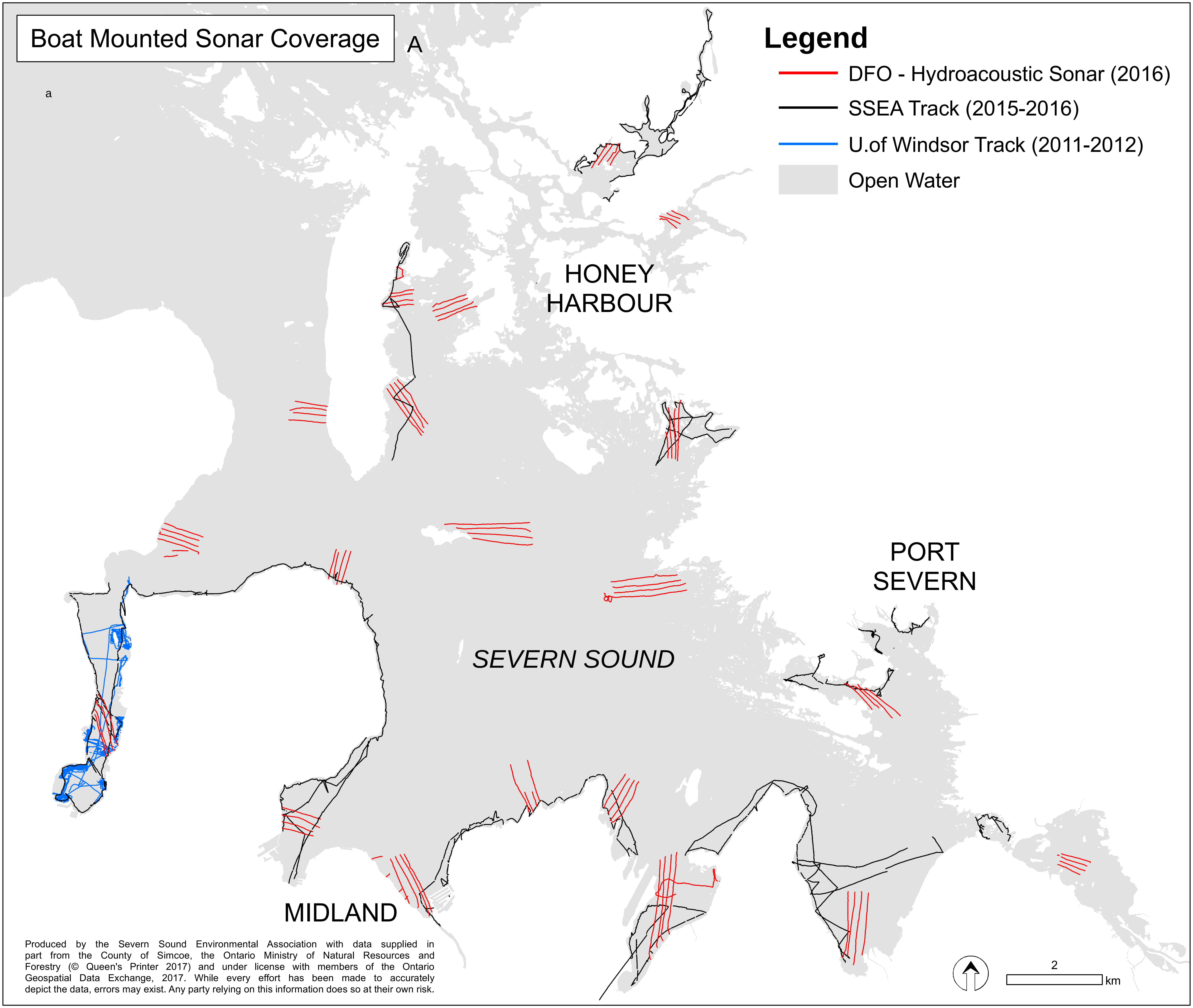
Severn Sound Environmental Association

University of Windsor
thinking forward

This project was undertaken with the financial support of the Government of Canada.
Ce projet a été réalisé avec l'appui financier du gouvernement du Canada.

Canada

Ontario
Ministry of Natural Resources and Forestry



Boat Mounted Sonar Coverage
A
a
Legend
DFO - Hydroacoustic Sonar (2016)
SSEA Track (2015-2016)
U.of Windsor Track (2011-2012)
Open Water
HONEY HARBOUR
PORT SEVERN
SEVERN SOUND
MIDLAND
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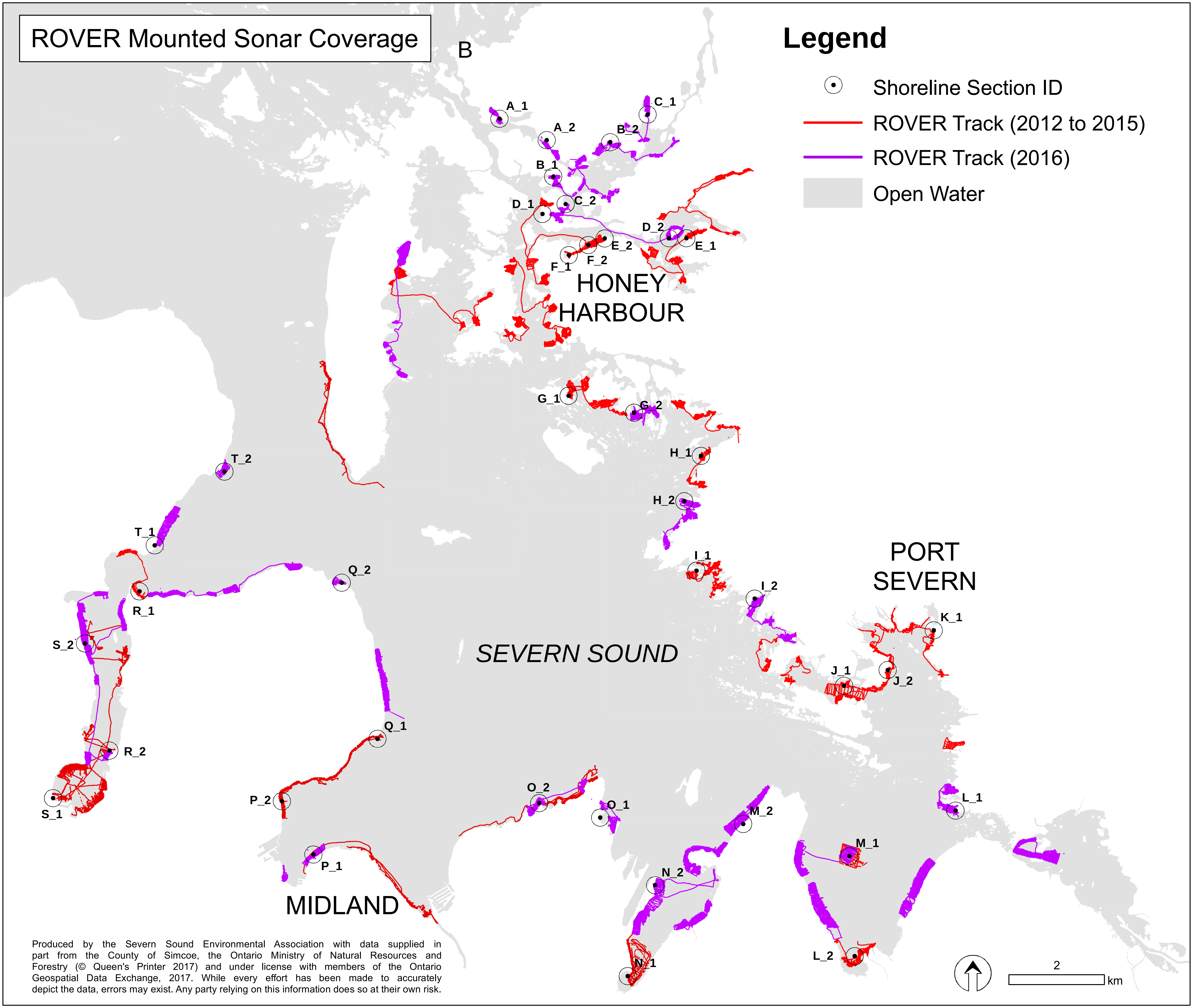
2
km


ROVER Mounted Sonar Coverage
B
Legend
Shoreline Section ID
ROVER Track (2012 to 2015)
ROVER Track (2016)
Open Water
HONEY HARBOUR
PORT SEVERN
SEVERN SOUND
MIDLAND
A_1
A_2
B_1
B_2
C_1
C_2
D_1
D_2
E_1
E_2
F_1
F_2
G_1
G_2
H_1
H_2
I_1
I_2
J_1
J_2
K_1
L_1
L_2
M_1
M_2
N_1
N_2
O_1
O_2
P_1
P_2
Q_1
Q_2
R_1
R_2
S_1
S_2
T_1
T_2
2
km
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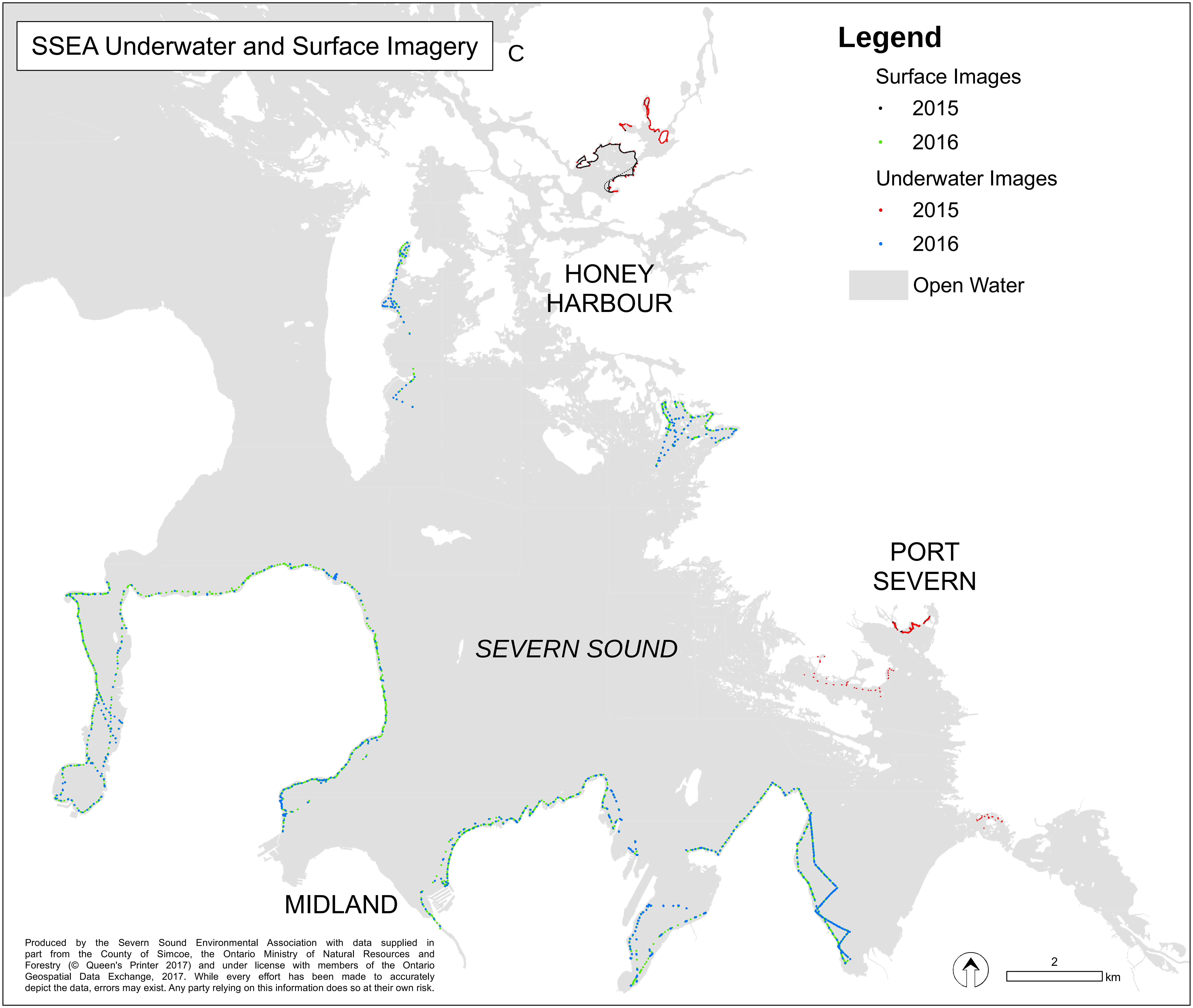
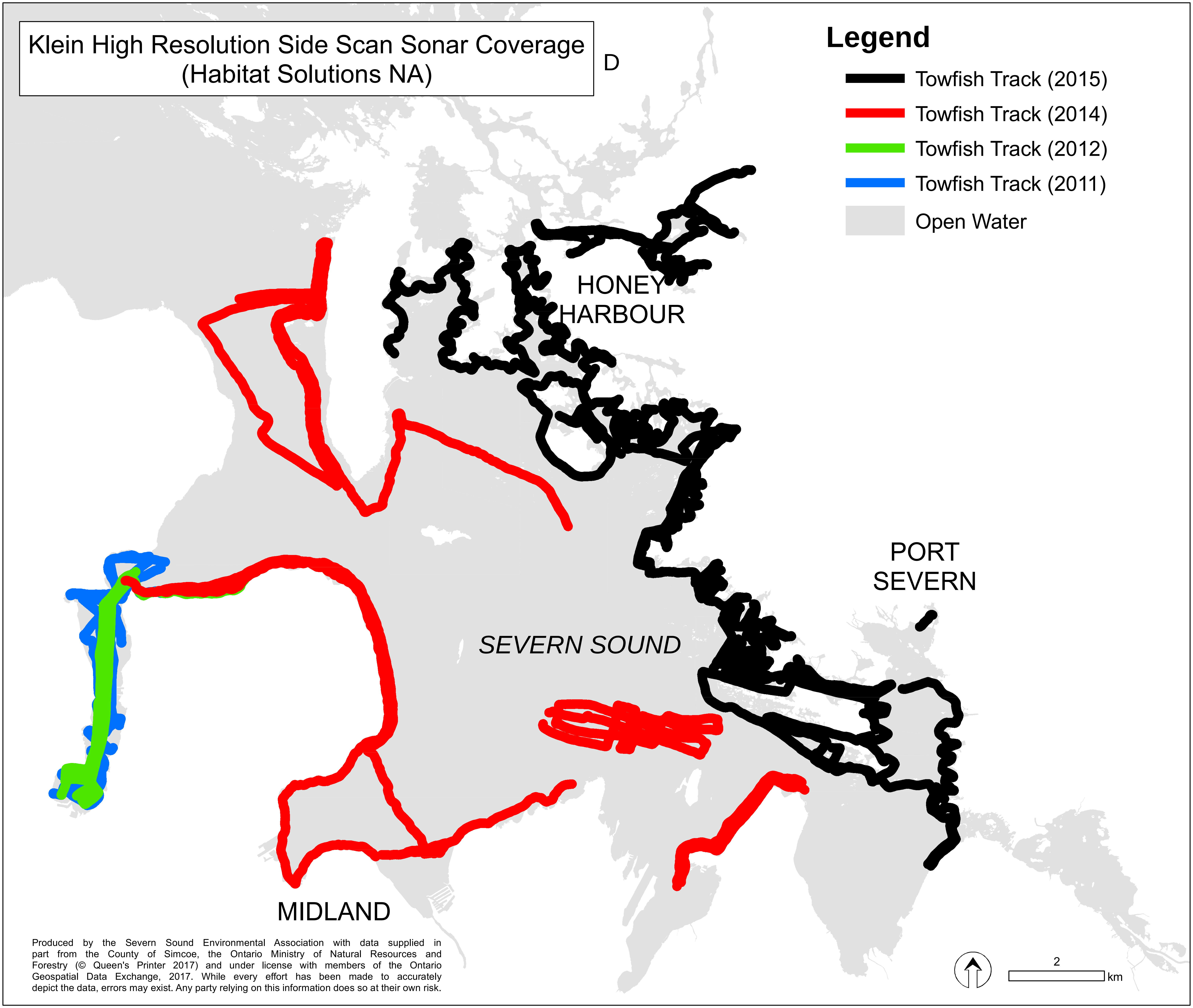

SSEA Underwater and Surface Imagery
C
Legend
Surface Images
2015
2016
Underwater Images
2015
2016
Open Water
HONEY HARBOUR
PORT SEVERN
SEVERN SOUND
MIDLAND
2
km
Produced by the Severn Sound Environmental Association with data supplied in part from the County of Simcoe, the Ontario Ministry of Natural Resources and Forestry (© Queen's Printer 2017) and under license with members of the Ontario Geospatial Data Exchange, 2017. While every effort has been made to accurately depict the data, errors may exist. Any party relying on this information does so at their own risk.


Klein High Resolution Side Scan Sonar Coverage
(Habitat Solutions NA)
D
Legend
Towfish Track (2015)
Towfish Track (2014)
Towfish Track (2012)
Towfish Track (2011)
Open Water
HONEY
HARBOUR
PORT
SEVERN
SEVERN SOUND
MIDLAND
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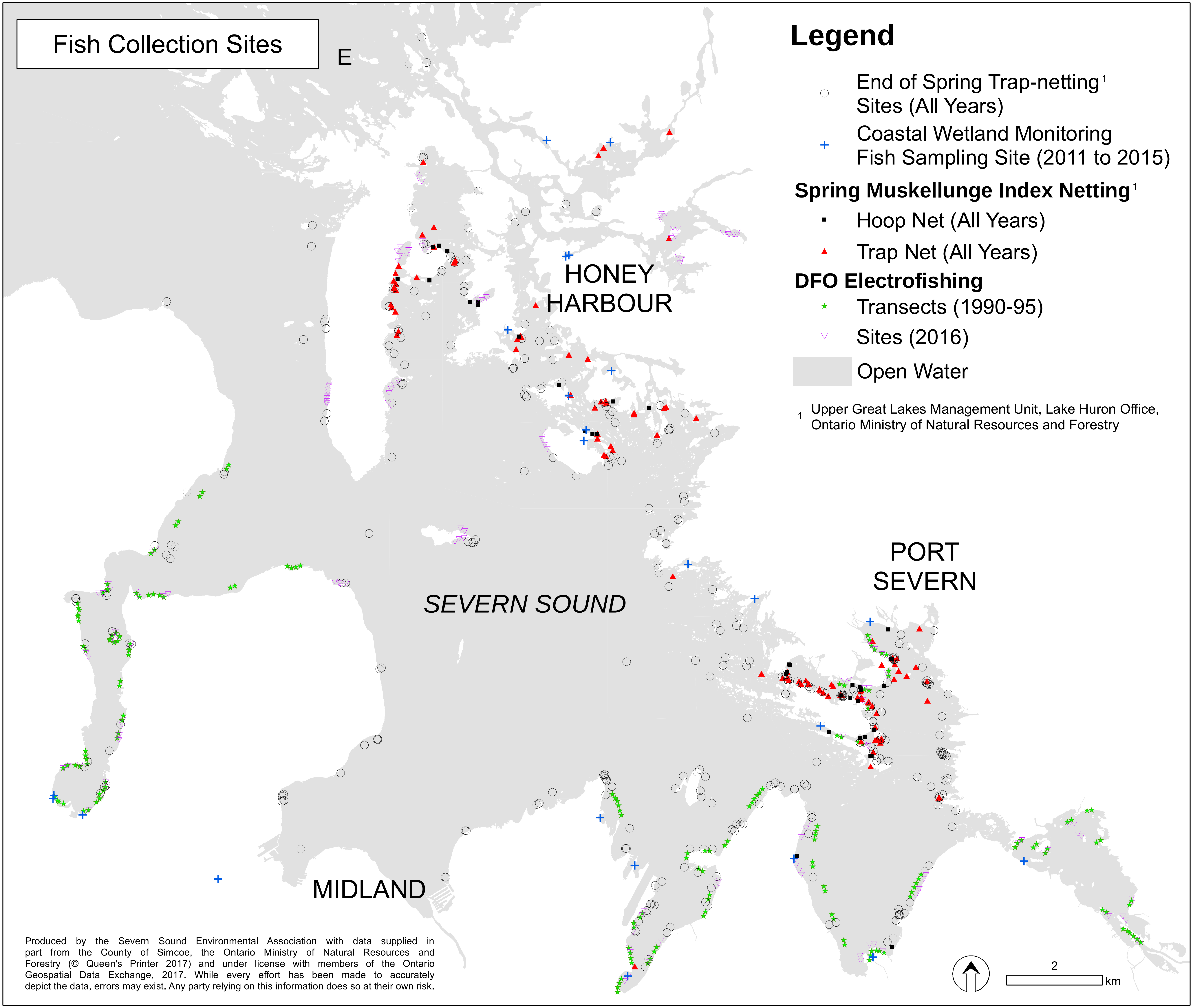
2
km



Fish Collection Sites
E
Legend
End of Spring Trap-netting[1] Sites (All Years)
Coastal Wetland Monitoring Fish Sampling Site (2011 to 2015)
Spring Muskellunge Index Netting[1]
Hoop Net (All Years)
Trap Net (All Years)
DFO Electrofishing
Transects (1990-95)
Sites (2016)
Open Water
1 Upper Great Lakes Management Unit, Lake Huron Office, Ontario Ministry of Natural Resources and Forestry
HONEY HARBOUR
PORT SEVERN
SEVERN SOUND
MIDLAND
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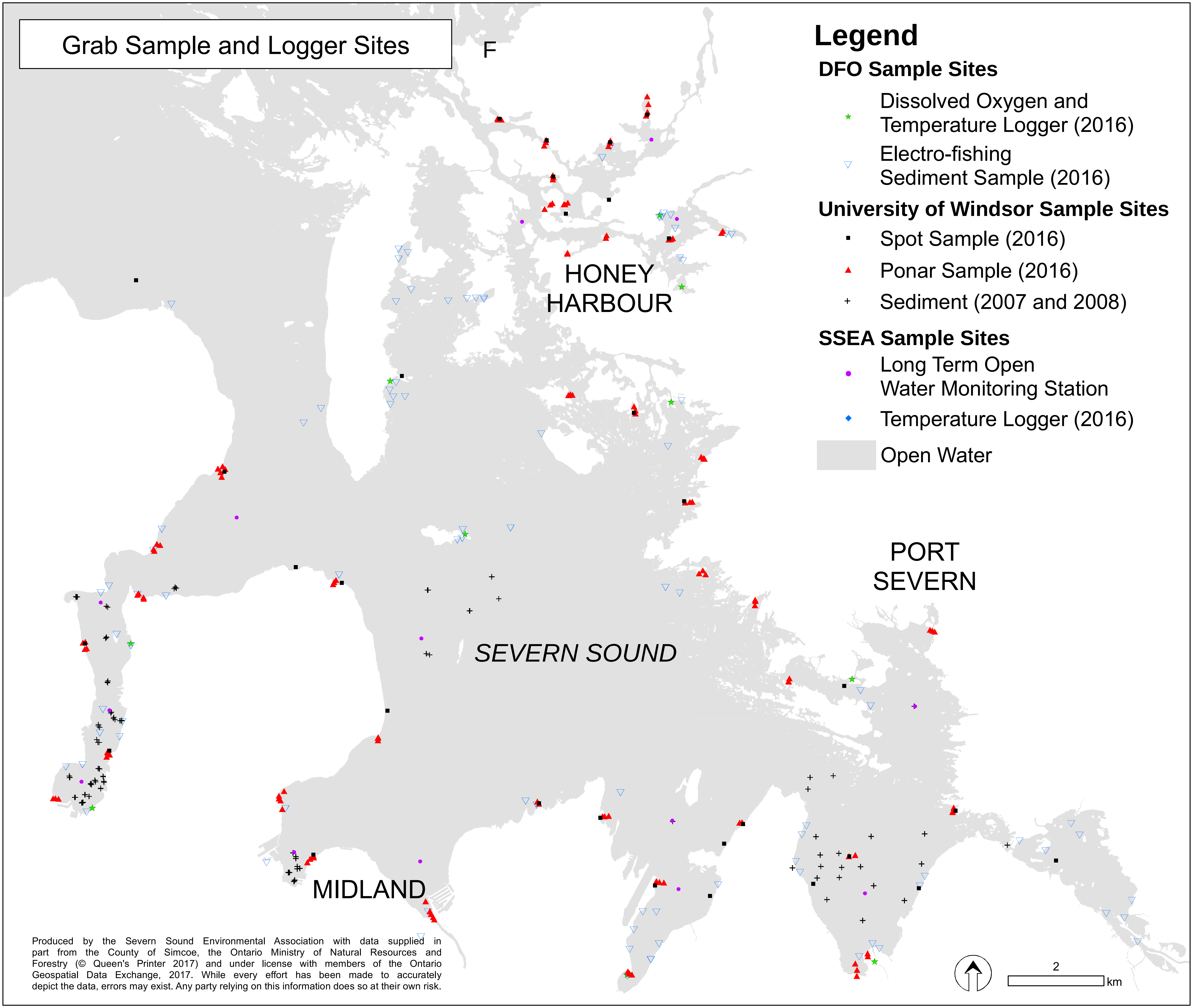
2
km


Grab Sample and Logger Sites
F
Legend
DFO Sample Sites
Dissolved Oxygen and Temperature Logger (2016)
Electro-fishing Sediment Sample (2016)
University of Windsor Sample Sites
Spot Sample (2016)
Ponar Sample (2016)
Sediment (2007 and 2008)
SSEA Sample Sites
Long Term Open Water Monitoring Station
Temperature Logger (2016)
Open Water
HONEY HARBOUR
PORT SEVERN
SEVERN SOUND
MIDLAND
2
km
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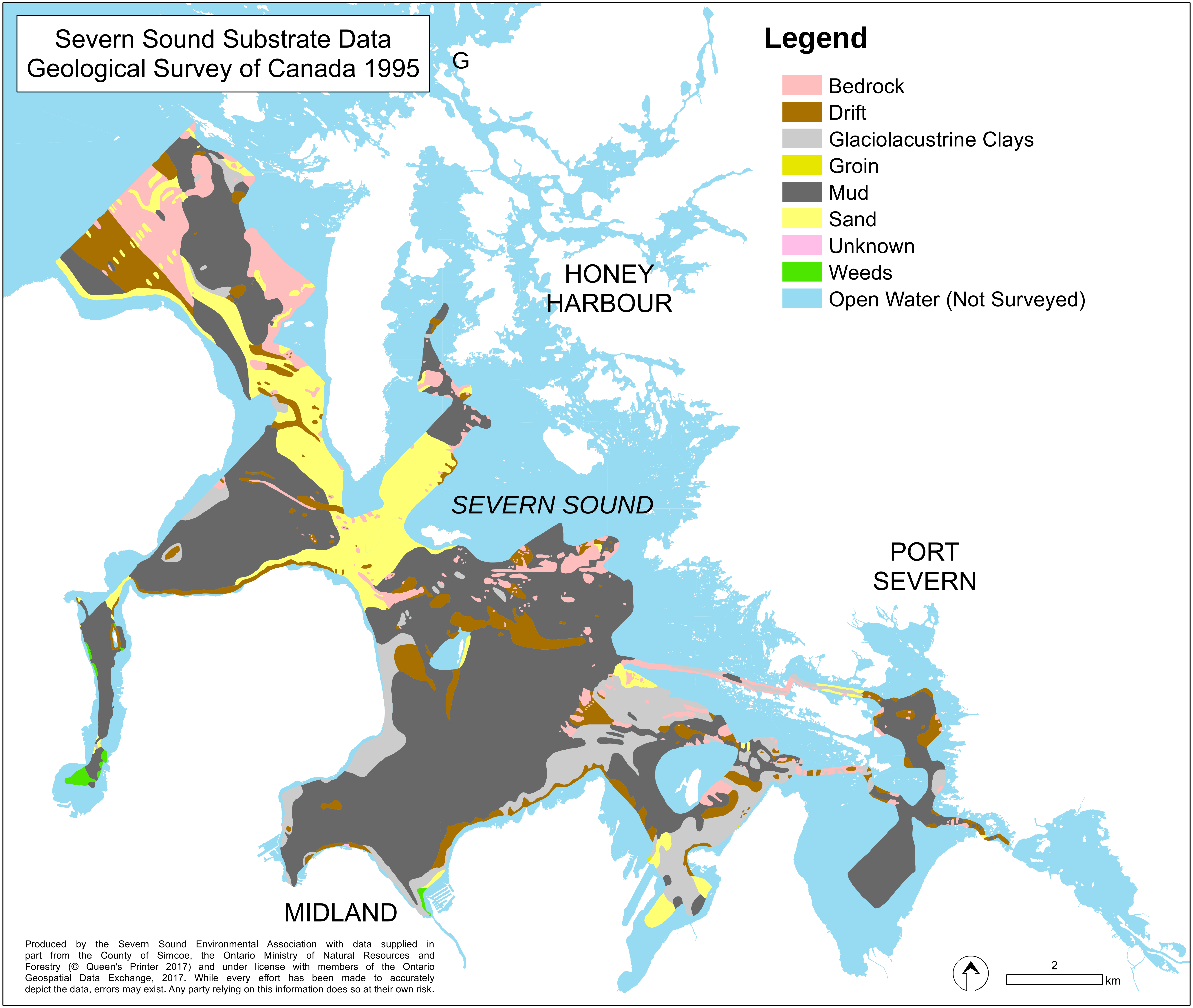

Severn Sound Substrate Data
Geological Survey of Canada 1995
G
Legend
Bedrock
Drift
Glaciolacustrine Clays
Groin
Mud
Sand
Unknown
Weeds
Open Water (Not Surveyed)
HONEY HARBOUR
SEVERN SOUND
PORT SEVERN
MIDLAND
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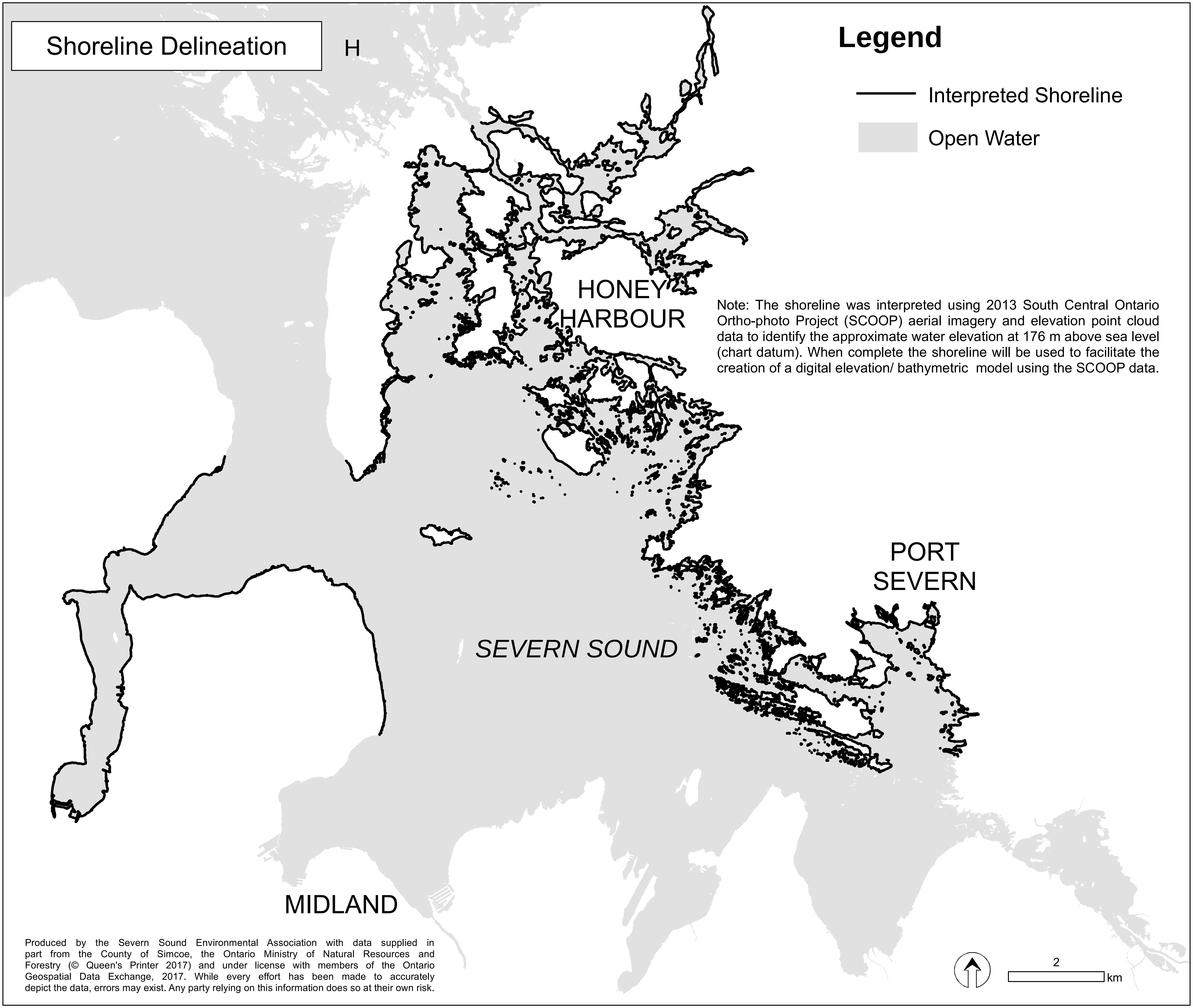
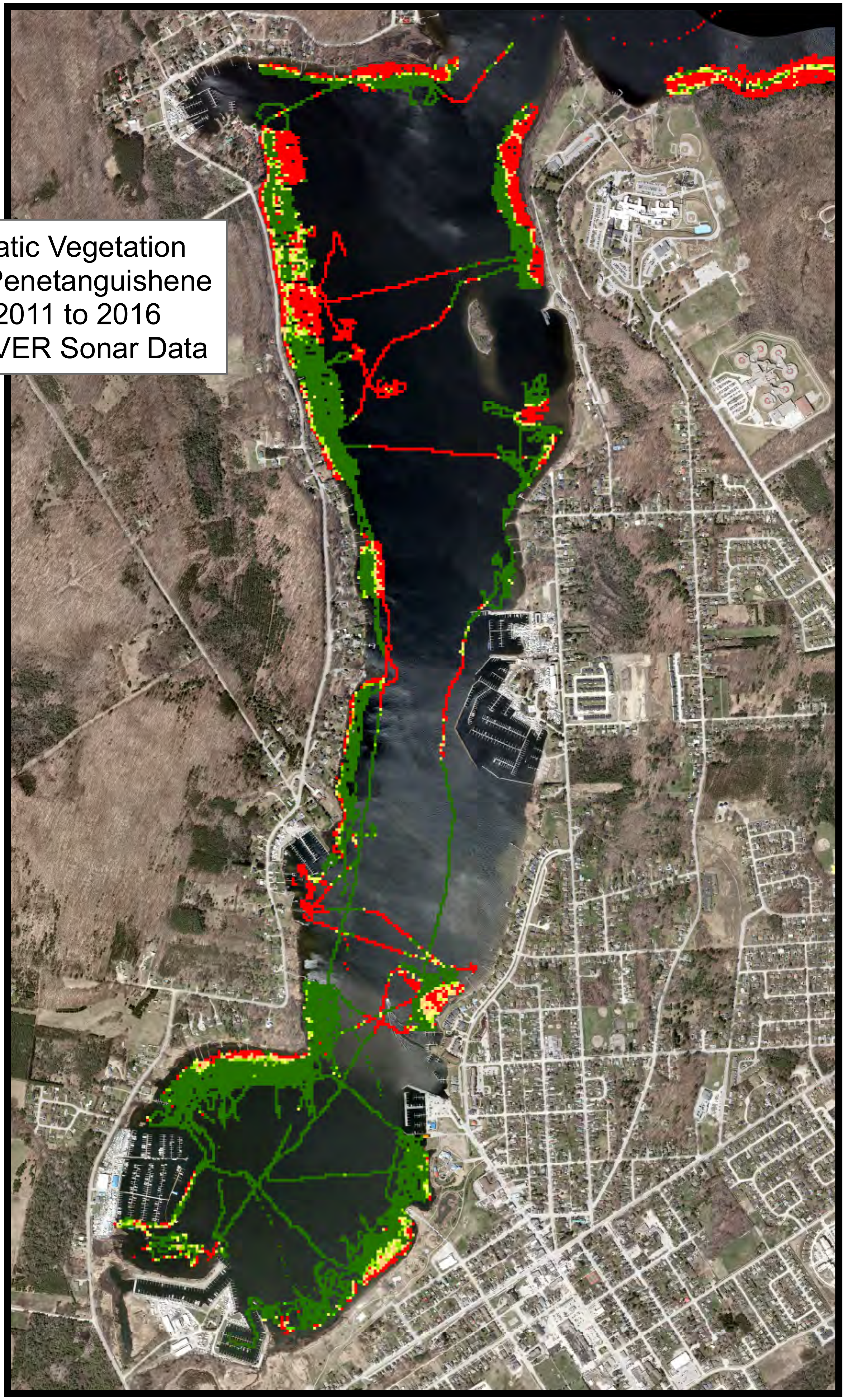
2
km


Shoreline Delineation
H
Legend
Interpreted Shoreline
Open Water
HONEY HARBOUR
Note: The shoreline was interpreted using 2013 South Central Ontario Ortho-photo Project (SCOOP) aerial imagery and elevation point cloud data to identify the approximate water elevation at 176 m above sea level (chart datum). When complete the shoreline will be used to facilitate the creation of a digital elevation/ bathymetric model using the SCOOP data.
PORT SEVERN
SEVERN SOUND
MIDLAND
Produced by the Severn Sound Environmental Association with data supplied in part from the County of Simcoe, the Ontario Ministry of Natural Resources and Forestry (© Queen's Printer 2017) and under license with members of the Ontario Geospatial Data Exchange, 2017. While every effort has been made to accurately depict the data, errors may exist. Any party relying on this information does so at their own risk.
2
km

# APPENDIX B2

## Submerged Aquatic Vegetation Percent Cover in Penetanguishene Harbour using 2011 to 2016 U. of Windsor ROVER Sonar Data



**Legend**

**SAV % Cover**

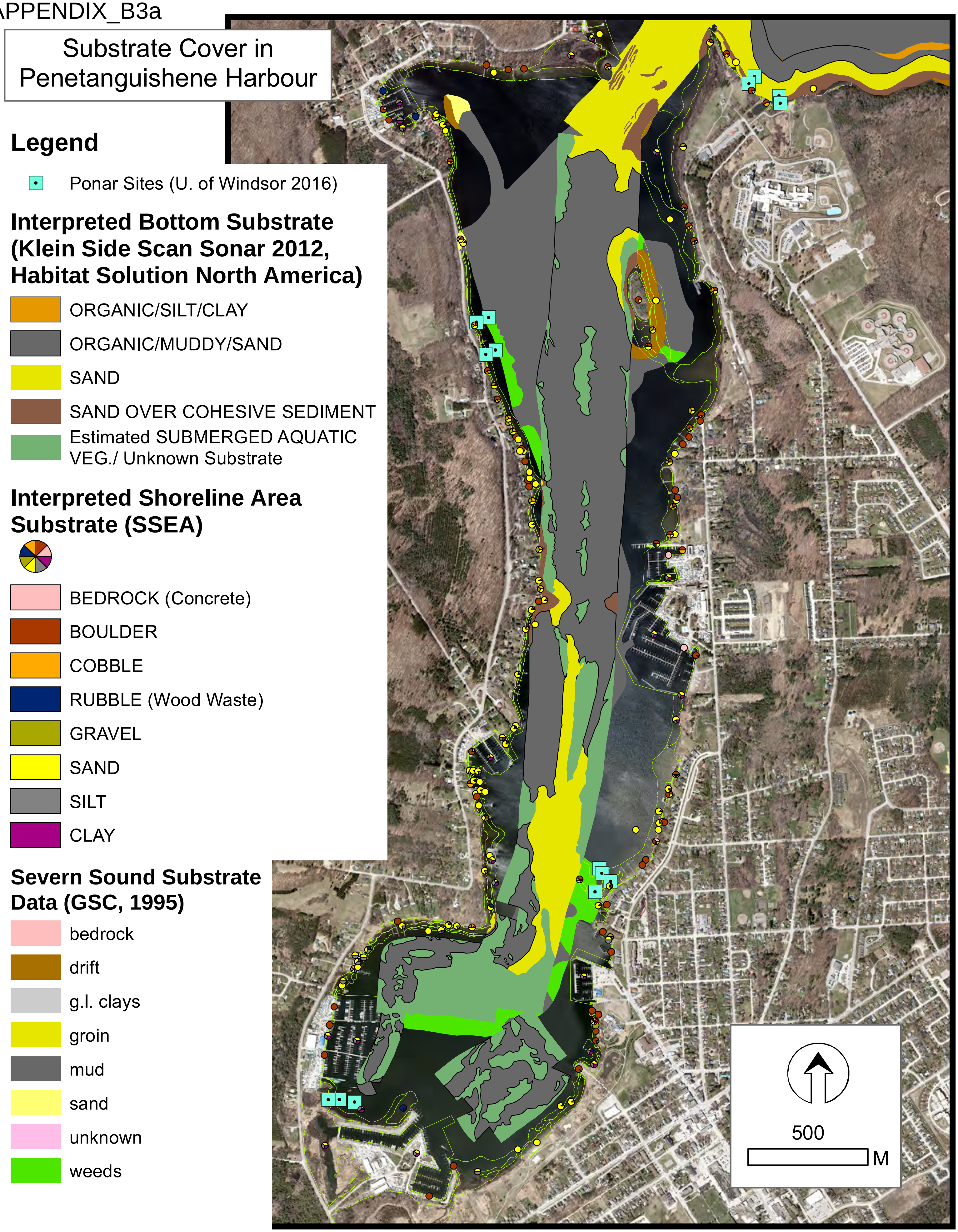
- 0
- 0.5 to 25%
- 25 to 50%
- 50 to 75%
- 75 to 100%

500 M

Produced by the Severn Sound Environmental Association with data supplied in part from the University of Windsor and the County of Simcoe. 2016 Ortho-photo based data © County of Simcoe, 2017. While every effort has been made to accurately depict the modelled Submerged Aquatic Vegetation feature data, errors may exist. Any party relying on this information does so at their own risk.

APPENDIX_B3a

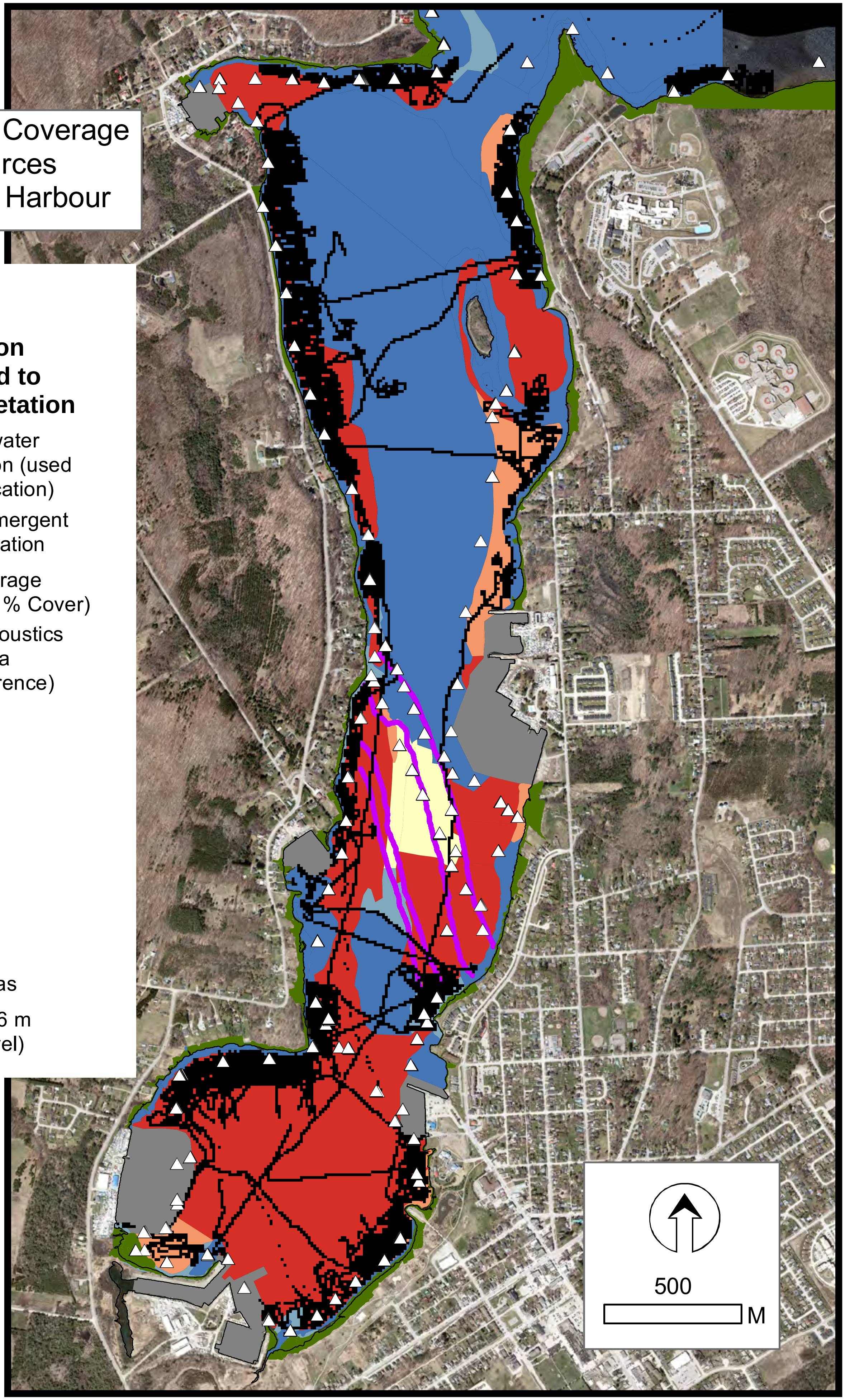
# Substrate Cover in Penetanguishene Harbour




Produced by the Severn Sound Environmental Association with data supplied in part from the University of Windsor,Habitat Solutions North America, Geological Survey of Canada and the County of Simcoe. 2016 Ortho-photo based data © County of Simcoe, 2017. While every effort has been made to accurately depict the interpreted Substrate/Sediment feature data, errors may exist. Any party relying on this information does so at their own risk.

# APPENDIX B3b

## Aquatic Vegetation Coverage and Data Sources Penetanguishene Harbour




Produced by the Severn Sound Environmental Association with data supplied in part from the University of Windsor (ROVER), Env. Canada- Department of Fisheries and Oceans (Bio-acoustics), Ontario Ministry of Natural Resources and Forestry (SCOOP 2013) and the County of Simcoe (2012 DEM). 2016 Ortho-photo background imagery © County of Simcoe, 2017. While every effort has been made to accurately depict the modelled Bathymetric Elevation data, errors may exist. Any party relying on this information does so at their own risk.

# APPENDIX B4

Nearshore fish assemblage surveys in Severn Sound 2016

Christine Boston (Fisheries and Oceans Canada)

In 2016, nearshore electrofishing surveys were conducted at the 1.5 m water depth along transects that were 100 m in length on a seasonal basis (spring, summer, and fall) at 12 different areas in Severn Sound resulting in a total of 197 samples (Table 1.0). Sampling occurred at both historical sampling locations (e.g. Penetang Harbour and Hog Bay) as well as at new sampling locations located in the northern portion of the sound (Table 1.0).

Table 1.0. Electrofishing samples by location and year

| **Location** | **Type** | **1990** | **1992** | **1995** | **2002** | **2016** | **Total** |
|---|---|---|---|---|---|---|---|
| Pentang Harbour | Historical | 43 | | | 28 | 42 | **113** |
| Hog Bay | Historical | 16 | | 14 | 13 | 20 | **63** |
| Sturgeon Bay | Historical | 23 | | | | 28 | **51** |
| Matchedash Bay | Historical | 25 | | | | 20 | **45** |
| Green Island | Historical | | | 27 | | 27 | **54** |
| Sucker Creek | New | | | | | 4 | **4** |
| Beausoleil Bay | New | | | | | 8 | **8** |
| Beausoleil Island | New | | | | | 12 | **12** |
| South Bay | New | | | | | 18 | **18** |
| Quarry Island | New | | | | | 6 | **6** |
| Robert's Island | New | | | | | 6 | **6** |
| Present Island | New | | | | | 6 | **6** |
| **Total** | | **107** | **0** | **41** | **41** | **197** | **386** |

All captured fish were identified by the field crew and individually weighted and measured up to a total of 20 individuals per species before being returned to the water resulting in a total of 7, 412 individual fish records from 2016. In 2016, a total of 38 species of fishes (Table 2.0) were caught including a first record in the area for Grass Pickerel (*Esox americanus vermiculatus*) a federally listed Species at Risk.

Index of Biotic Integrity (IBI) scores and metrics were generated for each electrofishing sample and average scores per transect ± standard error (SE) by location and year are listed in the attached excel spreadsheet (Table 3.0). IBI values at all locations sampled in 2016 fell within the good range (60-80) indicating that the nearshore fish community in Severn Sound is relatively healthy and balanced with a high species diversity. IBI values increased significantly over time at Penetanguishene Harbour; the average IBI score per transect in 2016 was 80 compared to 60 in 1990. The IBI scores at Hog Bay (67-73) and Green Island (65-66) remained relatively unchanged among sampling years but increased from the earlier surveys at Matchedash Bay (64-70) and Sturgeon Bay (57-63). IBI scores at the new sampling locations ranged from 60-77 (Table 3.0).

**Table 2.0**

**Presence/absence of species caught by year in Severn Sound. A total of 45 species were captured between 1990 and 2016.**

| Common Name | 1990 | 1992 | 1995 | 2002 | 2016 |
|---|---|---|---|---|---|
| Longnose Gar | | | x | x | x |
| Bowfin | x | x | x | x | x |
| Alweife | x | x | x | x | x |
| Gizzard Shad | x | | x | | x |
| Chinook Salmon | x | | | | |
| Rainbow Smelt | | | | | x |
| Northern Pike | x | x | x | x | x |
| Muskellunge | | | | x | |
| Grass Pickerel | | | | | x |
| Central Mudminnow | | | | x | x |
| Quillback | x | | | | |
| White Sucker | x | x | x | x | x |
| Silver Redhorse | | | | x | x |
| Goldfish | x | | | | |
| Common Carp | x | | x | x | x |
| Golden Shiner | x | x | x | x | x |
| Emerald Shiner | x | | | x | x |
| Common Shiner | | | x | | x |
| Blackchin Shiner | x | | x | x | x |
| Blacknose Shiner | | | | x | x |
| Spottail Shiner | x | x | x | x | x |
| Spotfin Shiner | | | | | x |
| Mimic Shiner | | | | | x |
| Bluntnose Minnow | x | | x | x | x |
| Creek Chub | | | | x | |
| Striped Shiner | | | | | x |
| Brown Bullhead | x | x | x | x | x |
| Stonecat | | | | x | |
| Tadpole Madtom | | | | | x |
| Banded Killifish | | | | x | x |
| White Perch | | | x | x | x |
| White Bass | x | | | | |
| Rock Bass | x | x | x | x | x |
| Pumpkinseed | x | x | x | x | x |
| Bluegill | | | | x | x |
| Northern Sunfish | | | | | x |
| Smallmouth Bass | x | x | x | x | x |
| Largemouth Bass | x | x | x | x | x |
| Black Crappie | x | x | x | x | x |
| Yellow Perch | x | x | x | x | x |
| Walleye | x | | x | | x |
| Logperch | x | | x | | x |
| Brook Silverside | x | | x | x | x |
| Round Goby | | | | | x |
| Tubenose Goby | | | | | x |
| **Total** | **25** | **13** | **23** | **28** | **38** |

| Table 3.0. Average IBI and metric values | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | Year | Samples | Biomass (kg) | SE | Numbers | SE | NSP | SE | IBI | SE | ADJIBI | SE | HPI | SE | ADJHPI | SE | Native NSP |
| | | | | | | | | | | | | | | | | | |
| Penetang Harbour | 1990 | 30 | 5.12 | 0.9 | 40.80 | 7.1 | 5.43 | 0.5 | 60.08 | 2.9 | 57.00 | 3.3 | 63.27 | 9.6 | 61.72 | 9.5 | 5.03 |
| Penetang Harbour | 2002 | 28 | 1.73 | 0.3 | 32.25 | 4.4 | 5.64 | 0.5 | 66.00 | 3.3 | 64.26 | 3.4 | 28.38 | 3.7 | 27.94 | 3.7 | 5.11 |
| Penetang Harbour | 2016 | 30 | 2.33 | 0.4 | 66.67 | 6.4 | 8.90 | 0.5 | 79.55 | 1.4 | 78.74 | 1.4 | 39.06 | 4.9 | 38.61 | 4.9 | 8.57 |
| | | | | | | | | | | | | | | | | | |
| Hog Bay | 1990 | 16 | 4.90 | 0.8 | 65.38 | 8.9 | 5.81 | 0.3 | 70.32 | 3.9 | 69.63 | 3.9 | 79.13 | 12.3 | 78.53 | 12.2 | 5.56 |
| Hog Bay | 1995 | 7 | 6.65 | 4.7 | 36.43 | 5.9 | 6.57 | 0.6 | 73.03 | 7.3 | 73.03 | 7.3 | 58.37 | 20.9 | 58.37 | 20.9 | 6.43 |
| Hog Bay | 2002 | 13 | 3.93 | 1.0 | 30.08 | 3.6 | 6.92 | 0.4 | 66.56 | 4.4 | 66.46 | 4.4 | 40.62 | 5.9 | 40.60 | 5.9 | 6.46 |
| Hog Bay | 2016 | 13 | 3.81 | 1.0 | 53.46 | 8.9 | 8.00 | 0.6 | 72.56 | 3.5 | 72.37 | 3.5 | 45.78 | 5.5 | 45.63 | 5.4 | 7.62 |
| | | | | | | | | | | | | | | | | | |
| Matchedash Bay | 1990 | 16 | 2.14 | 0.4 | 42.63 | 7.5 | 6.38 | 0.6 | 63.61 | 2.4 | 59.49 | 3.2 | 37.32 | 5.6 | 35.34 | 5.6 | 5.94 |
| Matchedash Bay | 2016 | 13 | 2.68 | 0.6 | 36.85 | 7.0 | 6.92 | 0.5 | 70.30 | 2.4 | 70.30 | 2.4 | 40.05 | 6.1 | 40.05 | 6.1 | 6.92 |
| | | | | | | | | | | | | | | | | | |
| Sturgeon Bay | 1992 | 23 | 1.79 | 0.4 | 17.52 | 3.3 | 4.26 | 0.5 | 56.88 | 4.3 | 56.52 | 4.3 | 24.16 | 4.2 | 24.12 | 4.2 | 4.17 |
| Sturgeon Bay | 2016 | 19 | 2.70 | 0.3 | 48.47 | 9.0 | 8.32 | 0.7 | 72.66 | 2.4 | 71.71 | 2.4 | 40.03 | 4.8 | 39.57 | 4.7 | 8.00 |
| | | | | | | | | | | | | | | | | | |
| Green Island | 1995 | 18 | 2.69 | 0.6 | 48.61 | 9.7 | 6.89 | 0.6 | 64.98 | 4.5 | 61.96 | 5.1 | 39.49 | 5.8 | 38.37 | 5.8 | 6.33 |
| Green Island | 2016 | 18 | 4.05 | 0.8 | 23.56 | 3.0 | 7.56 | 0.6 | 66.42 | 2.5 | 65.77 | 2.4 | 35.99 | 4.4 | 35.83 | 4.4 | 7.17 |
| | | | | | | | | | | | | | | | | | |
| Present Island | 2016 | 6 | 0.22 | 0.1 | 32.00 | 15.7 | 3.67 | 0.6 | 60.12 | 3.5 | 60.12 | 3.5 | 6.29 | 2.0 | 6.29 | 2.0 | 3.67 |
| Quarry Island | 2016 | 6 | 3.27 | 2.7 | 54.50 | 21.5 | 5.33 | 0.9 | 63.50 | 6.8 | 55.99 | 8.0 | 20.78 | 10.0 | 19.31 | 10.1 | 5.00 |
| Robert's Island | 2016 | 6 | 3.15 | 1.9 | 22.83 | 6.2 | 6.67 | 0.9 | 61.99 | 5.3 | 61.99 | 5.3 | 25.22 | 8.7 | 25.22 | 8.7 | 6.50 |
| South Bay | 2016 | 18 | 2.74 | 0.5 | 58.50 | 12.3 | 7.94 | 0.6 | 71.45 | 3.3 | 69.36 | 3.9 | 43.19 | 6.8 | 42.60 | 6.9 | 7.39 |
| Sucker Creek | 2016 | 4 | 3.54 | 2.8 | 26.00 | 6.7 | 5.50 | 1.0 | 65.18 | 8.1 | 62.80 | 7.6 | 22.51 | 10.3 | 22.22 | 10.3 | 5.25 |
| Beausoleil Bay | 2016 | 8 | 1.80 | 0.9 | 84.50 | 11.8 | 9.50 | 0.7 | 76.55 | 3.8 | 76.55 | 3.8 | 29.45 | 4.7 | 29.45 | 4.7 | 8.63 |
| Beausoleil Island | 2016 | 12 | 1.42 | 0.4 | 40.75 | 8.9 | 6.58 | 0.7 | 67.77 | 3.4 | 67.43 | 3.4 | 25.10 | 7.0 | 25.06 | 7.0 | 6.42 |

| Table 3.0. Average I | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | SE | Centrarchid NSP | SE | Turbidity Intolerat NSP | SE | Non-native NSP | SE | Cyprinid NSP | SE | % Piscivore Biomass | SE | % Generalist Biomass | SE | % Specialist Biomass | SE | Native species numbers | SE |
| | | | | | | | | | | | | | | | | | |
| Penetang Harbour | 0.4 | 2.23 | 0.2 | 0.47 | 0.1 | 0.40 | 0.1 | 0.67 | 0.2 | 11.35 | 2.9 | 16.61 | 4.3 | 68.70 | 5.2 | 34.27 | 6.0 |
| Penetang Harbour | 0.4 | 2.39 | 0.2 | 1.14 | 0.2 | 0.43 | 0.1 | 1.32 | 0.2 | 34.03 | 5.8 | 7.37 | 3.4 | 54.89 | 6.0 | 30.57 | 4.2 |
| Penetang Harbour | 0.4 | 2.53 | 0.2 | 2.57 | 0.2 | 0.33 | 0.1 | 3.37 | 0.2 | 32.39 | 6.0 | 8.77 | 2.5 | 58.84 | 5.4 | 66.13 | 6.4 |
| | | | | | | | | | | | | | | | | | |
| Hog Bay | 0.4 | 3.06 | 0.1 | 0.63 | 0.2 | 0.25 | 0.1 | 0.88 | 0.2 | 27.78 | 5.6 | 15.68 | 7.2 | 56.53 | 6.9 | 64.81 | 9.1 |
| Hog Bay | 0.6 | 3.00 | 0.3 | 0.86 | 0.3 | 0.14 | 0.1 | 1.86 | 0.3 | 50.77 | 8.7 | 14.00 | 13.2 | 35.23 | 7.4 | 35.29 | 6.6 |
| Hog Bay | 0.4 | 2.77 | 0.2 | 0.85 | 0.2 | 0.46 | 0.1 | 1.31 | 0.3 | 37.04 | 9.6 | 21.37 | 8.9 | 41.59 | 9.2 | 29.38 | 3.6 |
| Hog Bay | 0.6 | 3.00 | 0.2 | 1.62 | 0.3 | 0.38 | 0.1 | 2.08 | 0.5 | 39.60 | 10.2 | 21.19 | 8.6 | 39.21 | 10.1 | 52.92 | 8.9 |
| | | | | | | | | | | | | | | | | | |
| Matchedash Bay | 0.5 | 2.63 | 0.2 | 0.75 | 0.2 | 0.44 | 0.2 | 0.50 | 0.1 | 16.31 | 5.8 | 23.05 | 5.4 | 60.64 | 6.3 | 36.50 | 6.2 |
| Matchedash Bay | 0.5 | 2.62 | 0.3 | 0.69 | 0.2 | 0.00 | 0.0 | 1.69 | 0.2 | 22.94 | 7.3 | 30.17 | 5.5 | 46.88 | 8.7 | 36.85 | 7.0 |
| | | | | | | | | | | | | | | | | | |
| Sturgeon Bay | 0.5 | 2.26 | 0.2 | 0.43 | 0.1 | 0.09 | 0.1 | 0.48 | 0.2 | 27.26 | 7.3 | 2.87 | 1.7 | 61.18 | 8.0 | 17.35 | 3.3 |
| Sturgeon Bay | 0.6 | 3.00 | 0.3 | 1.47 | 0.2 | 0.32 | 0.1 | 1.58 | 0.3 | 34.13 | 7.5 | 23.09 | 5.1 | 42.78 | 7.3 | 48.00 | 8.9 |
| | | | | | | | | | | | | | | | | | |
| Green Island | 0.6 | 2.83 | 0.3 | 0.89 | 0.2 | 0.56 | 0.2 | 0.78 | 0.2 | 19.83 | 4.8 | 17.76 | 7.0 | 62.41 | 7.2 | 46.06 | 10.1 |
| Green Island | 0.6 | 2.78 | 0.3 | 1.00 | 0.2 | 0.39 | 0.1 | 1.67 | 0.3 | 53.73 | 7.7 | 29.40 | 7.2 | 16.87 | 4.0 | 23.11 | 2.9 |
| | | | | | | | | | | | | | | | | | |
| Present Island | 0.6 | 0.17 | 0.2 | 1.17 | 0.4 | 0.00 | 0.0 | 1.67 | 0.3 | 11.74 | 11.7 | 3.88 | 2.3 | 84.39 | 13.7 | 32.00 | 15.7 |
| Quarry Island | 0.9 | 0.83 | 0.3 | 1.67 | 0.3 | 0.33 | 0.3 | 2.50 | 0.7 | 64.35 | 14.8 | 20.80 | 16.0 | 14.85 | 7.9 | 54.00 | 21.5 |
| Robert's Island | 0.9 | 1.83 | 0.3 | 0.83 | 0.3 | 0.17 | 0.2 | 1.83 | 0.3 | 27.59 | 15.2 | 51.22 | 11.3 | 21.19 | 7.1 | 22.67 | 6.1 |
| South Bay | 0.5 | 3.50 | 0.3 | 1.00 | 0.2 | 0.56 | 0.2 | 1.50 | 0.2 | 46.06 | 6.6 | 15.32 | 6.3 | 38.62 | 6.7 | 56.17 | 12.5 |
| Sucker Creek | 0.9 | 1.25 | 0.5 | 1.75 | 0.3 | 0.25 | 0.3 | 2.25 | 0.3 | 33.16 | 19.2 | 30.05 | 22.8 | 36.79 | 17.3 | 25.75 | 6.7 |
| Beausoleil Bay | 0.8 | 2.75 | 0.4 | 2.38 | 0.3 | 0.88 | 0.2 | 3.50 | 0.6 | 21.90 | 8.9 | 16.48 | 9.6 | 61.62 | 11.7 | 83.25 | 11.9 |
| Beausoleil Island | 0.7 | 1.50 | 0.5 | 1.25 | 0.2 | 0.17 | 0.1 | 2.58 | 0.3 | 9.34 | 3.9 | 33.09 | 8.2 | 57.57 | 9.8 | 40.58 | 8.9 |

| Table 3.0. Average I | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Location | Native species biomass | SE | % Non-native species numbers | SE | % Non-native species biomass | SE | % Offshore numbers | SE | % Offshore biomss | SE |
| | | | | | | | | | | |
| Penetang Harbour | 4.07 | 0.6 | 9.14 | 3.9 | 9.60 | 3.5 | 8.86 | 3.9 | 2.09 | 1.4 |
| Penetang Harbour | 1.58 | 0.3 | 4.29 | 1.6 | 4.32 | 3.2 | 4.19 | 1.6 | 1.25 | 0.9 |
| Penetang Harbour | 2.13 | 0.3 | 0.81 | 0.3 | 2.40 | 2.2 | 0.27 | 0.1 | 1.62 | 0.9 |
| | | | | | | | | | | |
| Hog Bay | 4.11 | 0.8 | 1.99 | 1.6 | 13.24 | 7.2 | 1.43 | 1.4 | 1.03 | 1.0 |
| Hog Bay | 2.01 | 0.3 | 7.14 | 7.1 | 13.33 | 13.3 | 0.00 | 0.0 | 0.00 | 0.0 |
| Hog Bay | 2.62 | 0.7 | 2.82 | 1.1 | 14.79 | 8.4 | 0.27 | 0.3 | 0.01 | 0.0 |
| Hog Bay | 2.59 | 0.6 | 0.90 | 0.4 | 12.79 | 8.5 | 0.48 | 0.3 | 0.14 | 0.1 |
| | | | | | | | | | | |
| Matchedash Bay | 2.12 | 0.4 | 6.74 | 5.1 | 1.13 | 0.9 | 9.49 | 5.3 | 3.98 | 1.8 |
| Matchedash Bay | 2.68 | 0.6 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 |
| | | | | | | | | | | |
| Sturgeon Bay | 1.79 | 0.4 | 1.18 | 1.1 | 0.01 | 0.0 | 1.18 | 1.1 | 0.01 | 0.0 |
| Sturgeon Bay | 2.65 | 0.3 | 0.56 | 0.2 | 1.49 | 1.4 | 2.08 | 0.8 | 0.50 | 0.3 |
| | | | | | | | | | | |
| Green Island | 2.08 | 0.5 | 10.50 | 3.6 | 13.53 | 7.2 | 10.23 | 3.9 | 1.83 | 1.4 |
| Green Island | 2.83 | 0.4 | 2.10 | 0.9 | 14.05 | 6.6 | 1.57 | 0.6 | 0.21 | 0.1 |
| | | | | | | | | | | |
| Present Island | 0.22 | 0.1 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 |
| Quarry Island | 0.52 | 0.2 | 0.89 | 0.9 | 16.57 | 16.6 | 4.34 | 3.2 | 17.37 | 14.2 |
| Robert's Island | 1.44 | 0.3 | 0.37 | 0.4 | 13.70 | 13.7 | 0.00 | 0.0 | 0.00 | 0.0 |
| South Bay | 2.16 | 0.4 | 6.50 | 2.4 | 10.86 | 6.4 | 5.99 | 2.3 | 1.40 | 0.8 |
| Sucker Creek | 0.68 | 0.4 | 0.96 | 1.0 | 24.38 | 24.4 | 5.65 | 4.5 | 1.06 | 1.0 |
| Beausoleil Bay | 0.99 | 0.2 | 1.94 | 0.7 | 11.03 | 9.9 | 0.00 | 0.0 | 0.00 | 0.0 |
| Beausoleil Island | 1.42 | 0.4 | 0.36 | 0.3 | 0.03 | 0.0 | 0.93 | 0.5 | 0.11 | 0.1 |

Table 3.5.2. Average IBI and metric values ± standard error (SE) by location and year

| Location | Year | Samples | Biomass (kg) | SE | Numbers | SE | NSP | SE | IBI | SE | ADJIBI | SE | HPI | SE | ADJHPI | SE | Native NSP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | |
| Penetang Harbour | 1990 | 30 | 5.12 | 0.9 | 40.80 | 7.1 | 5.43 | 0.5 | 60.08 | 2.9 | 57.00 | 3.3 | 63.27 | 9.6 | 61.72 | 9.5 | 5.03 |
| Penetang Harbour | 2002 | 28 | 1.73 | 0.3 | 32.25 | 4.4 | 5.64 | 0.5 | 66.00 | 3.3 | 64.26 | 3.4 | 28.38 | 3.7 | 27.94 | 3.7 | 5.11 |
| Penetang Harbour | 2016 | 30 | 2.33 | 0.4 | 66.67 | 6.4 | 8.90 | 0.5 | 79.55 | 1.4 | 78.74 | 1.4 | 39.06 | 4.9 | 38.61 | 4.9 | 8.57 |
| | | | | | | | | | | | | | | | | | |
| Hog Bay | 1990 | 16 | 4.90 | 0.8 | 65.38 | 8.9 | 5.81 | 0.3 | 70.32 | 3.9 | 69.63 | 3.9 | 79.13 | 12.3 | 78.53 | 12.2 | 5.56 |
| Hog Bay | 1995 | 7 | 6.65 | 4.7 | 36.43 | 5.9 | 6.57 | 0.6 | 73.03 | 7.3 | 73.03 | 7.3 | 58.37 | 20.9 | 58.37 | 20.9 | 6.43 |
| Hog Bay | 2002 | 13 | 3.93 | 1.0 | 30.08 | 3.6 | 6.92 | 0.4 | 66.56 | 4.4 | 66.46 | 4.4 | 40.62 | 5.9 | 40.60 | 5.9 | 6.46 |
| Hog Bay | 2016 | 13 | 3.81 | 1.0 | 53.46 | 8.9 | 8.00 | 0.6 | 72.56 | 3.5 | 72.37 | 3.5 | 45.78 | 5.5 | 45.63 | 5.4 | 7.62 |
| | | | | | | | | | | | | | | | | | |
| Matchedash Bay | 1990 | 16 | 2.14 | 0.4 | 42.63 | 7.5 | 6.38 | 0.6 | 63.61 | 2.4 | 59.49 | 3.2 | 37.32 | 5.6 | 35.34 | 5.6 | 5.94 |
| Matchedash Bay | 2016 | 13 | 2.68 | 0.6 | 36.85 | 7.0 | 6.92 | 0.5 | 70.30 | 2.4 | 70.30 | 2.4 | 40.05 | 6.1 | 40.05 | 6.1 | 6.92 |
| | | | | | | | | | | | | | | | | | |
| Sturgeon Bay | 1992 | 23 | 1.79 | 0.4 | 17.52 | 3.3 | 4.26 | 0.5 | 56.88 | 4.3 | 56.52 | 4.3 | 24.16 | 4.2 | 24.12 | 4.2 | 4.17 |
| Sturgeon Bay | 2016 | 19 | 2.70 | 0.3 | 48.47 | 9.0 | 8.32 | 0.7 | 72.66 | 2.4 | 71.71 | 2.4 | 40.03 | 4.8 | 39.57 | 4.7 | 8.00 |
| | | | | | | | | | | | | | | | | | |
| Green Island | 1995 | 18 | 2.69 | 0.6 | 48.61 | 9.7 | 6.89 | 0.6 | 64.98 | 4.5 | 61.96 | 5.1 | 39.49 | 5.8 | 38.37 | 5.8 | 6.33 |
| Green Island | 2016 | 18 | 4.05 | 0.8 | 23.56 | 3.0 | 7.56 | 0.6 | 66.42 | 2.5 | 65.77 | 2.4 | 35.99 | 4.4 | 35.83 | 4.4 | 7.17 |
| | | | | | | | | | | | | | | | | | |
| Present Island | 2016 | 6 | 0.22 | 0.1 | 32.00 | 15.7 | 3.67 | 0.6 | 60.12 | 3.5 | 60.12 | 3.5 | 6.29 | 2.0 | 6.29 | 2.0 | 3.67 |
| Quarry Island | 2016 | 6 | 3.27 | 2.7 | 54.50 | 21.5 | 5.33 | 0.9 | 63.50 | 6.8 | 55.99 | 8.0 | 20.78 | 10.0 | 19.31 | 10.1 | 5.00 |
| Robert's Island | 2016 | 6 | 3.15 | 1.9 | 22.83 | 6.2 | 6.67 | 0.9 | 61.99 | 5.3 | 61.99 | 5.3 | 25.22 | 8.7 | 25.22 | 8.7 | 6.50 |
| South Bay | 2016 | 18 | 2.74 | 0.5 | 58.50 | 12.3 | 7.94 | 0.6 | 71.45 | 3.3 | 69.36 | 3.9 | 43.19 | 6.8 | 42.60 | 6.9 | 7.39 |
| Sucker Creek | 2016 | 4 | 3.54 | 2.8 | 26.00 | 6.7 | 5.50 | 1.0 | 65.18 | 8.1 | 62.80 | 7.6 | 22.51 | 10.3 | 22.22 | 10.3 | 5.25 |
| Beausoleil Bay | 2016 | 8 | 1.80 | 0.9 | 84.50 | 11.8 | 9.50 | 0.7 | 76.55 | 3.8 | 76.55 | 3.8 | 29.45 | 4.7 | 29.45 | 4.7 | 8.63 |
| Beausoleil Island | 2016 | 12 | 1.42 | 0.4 | 40.75 | 8.9 | 6.58 | 0.7 | 67.77 | 3.4 | 67.43 | 3.4 | 25.10 | 7.0 | 25.06 | 7.0 | 6.42 |

| Table 3.5.2. Average | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | SE | Centrarchid NSP | SE | Turbidity Intolerat NSP | SE | Non-native NSP | SE | Cyprinid NSP | SE | % Piscivore Biomass | SE | % Generalist Biomass | SE | % Specialist Biomass | SE | Native species numbers | SE |
| | | | | | | | | | | | | | | | | | |
| Penetang Harbour | 0.4 | 2.23 | 0.2 | 0.47 | 0.1 | 0.40 | 0.1 | 0.67 | 0.2 | 11.35 | 2.9 | 16.61 | 4.3 | 68.70 | 5.2 | 34.27 | 6.0 |
| Penetang Harbour | 0.4 | 2.39 | 0.2 | 1.14 | 0.2 | 0.43 | 0.1 | 1.32 | 0.2 | 34.03 | 5.8 | 7.37 | 3.4 | 54.89 | 6.0 | 30.57 | 4.2 |
| Penetang Harbour | 0.4 | 2.53 | 0.2 | 2.57 | 0.2 | 0.33 | 0.1 | 3.37 | 0.2 | 32.39 | 6.0 | 8.77 | 2.5 | 58.84 | 5.4 | 66.13 | 6.4 |
| | | | | | | | | | | | | | | | | | |
| Hog Bay | 0.4 | 3.06 | 0.1 | 0.63 | 0.2 | 0.25 | 0.1 | 0.88 | 0.2 | 27.78 | 5.6 | 15.68 | 7.2 | 56.53 | 6.9 | 64.81 | 9.1 |
| Hog Bay | 0.6 | 3.00 | 0.3 | 0.86 | 0.3 | 0.14 | 0.1 | 1.86 | 0.3 | 50.77 | 8.7 | 14.00 | 13.2 | 35.23 | 7.4 | 35.29 | 6.6 |
| Hog Bay | 0.4 | 2.77 | 0.2 | 0.85 | 0.2 | 0.46 | 0.1 | 1.31 | 0.3 | 37.04 | 9.6 | 21.37 | 8.9 | 41.59 | 9.2 | 29.38 | 3.6 |
| Hog Bay | 0.6 | 3.00 | 0.2 | 1.62 | 0.3 | 0.38 | 0.1 | 2.08 | 0.5 | 39.60 | 10.2 | 21.19 | 8.6 | 39.21 | 10.1 | 52.92 | 8.9 |
| | | | | | | | | | | | | | | | | | |
| Matchedash Bay | 0.5 | 2.63 | 0.2 | 0.75 | 0.2 | 0.44 | 0.2 | 0.50 | 0.1 | 16.31 | 5.8 | 23.05 | 5.4 | 60.64 | 6.3 | 36.50 | 6.2 |
| Matchedash Bay | 0.5 | 2.62 | 0.3 | 0.69 | 0.2 | 0.00 | 0.0 | 1.69 | 0.2 | 22.94 | 7.3 | 30.17 | 5.5 | 46.88 | 8.7 | 36.85 | 7.0 |
| | | | | | | | | | | | | | | | | | |
| Sturgeon Bay | 0.5 | 2.26 | 0.2 | 0.43 | 0.1 | 0.09 | 0.1 | 0.48 | 0.2 | 27.26 | 7.3 | 2.87 | 1.7 | 61.18 | 8.0 | 17.35 | 3.3 |
| Sturgeon Bay | 0.6 | 3.00 | 0.3 | 1.47 | 0.2 | 0.32 | 0.1 | 1.58 | 0.3 | 34.13 | 7.5 | 23.09 | 5.1 | 42.78 | 7.3 | 48.00 | 8.9 |
| | | | | | | | | | | | | | | | | | |
| Green Island | 0.6 | 2.83 | 0.3 | 0.89 | 0.2 | 0.56 | 0.2 | 0.78 | 0.2 | 19.83 | 4.8 | 17.76 | 7.0 | 62.41 | 7.2 | 46.06 | 10.1 |
| Green Island | 0.6 | 2.78 | 0.3 | 1.00 | 0.2 | 0.39 | 0.1 | 1.67 | 0.3 | 53.73 | 7.7 | 29.40 | 7.2 | 16.87 | 4.0 | 23.11 | 2.9 |
| | | | | | | | | | | | | | | | | | |
| Present Island | 0.6 | 0.17 | 0.2 | 1.17 | 0.4 | 0.00 | 0.0 | 1.67 | 0.3 | 11.74 | 11.7 | 3.88 | 2.3 | 84.39 | 13.7 | 32.00 | 15.7 |
| Quarry Island | 0.9 | 0.83 | 0.3 | 1.67 | 0.3 | 0.33 | 0.3 | 2.50 | 0.7 | 64.35 | 14.8 | 20.80 | 16.0 | 14.85 | 7.9 | 54.00 | 21.5 |
| Robert's Island | 0.9 | 1.83 | 0.3 | 0.83 | 0.3 | 0.17 | 0.2 | 1.83 | 0.3 | 27.59 | 15.2 | 51.22 | 11.3 | 21.19 | 7.1 | 22.67 | 6.1 |
| South Bay | 0.5 | 3.50 | 0.3 | 1.00 | 0.2 | 0.56 | 0.2 | 1.50 | 0.2 | 46.06 | 6.6 | 15.32 | 6.3 | 38.62 | 6.7 | 56.17 | 12.5 |
| Sucker Creek | 0.9 | 1.25 | 0.5 | 1.75 | 0.3 | 0.25 | 0.3 | 2.25 | 0.3 | 33.16 | 19.2 | 30.05 | 22.8 | 36.79 | 17.3 | 25.75 | 6.7 |
| Beausoleil Bay | 0.8 | 2.75 | 0.4 | 2.38 | 0.3 | 0.88 | 0.2 | 3.50 | 0.6 | 21.90 | 8.9 | 16.48 | 9.6 | 61.62 | 11.7 | 83.25 | 11.9 |
| Beausoleil Island | 0.7 | 1.50 | 0.5 | 1.25 | 0.2 | 0.17 | 0.1 | 2.58 | 0.3 | 9.34 | 3.9 | 33.09 | 8.2 | 57.57 | 9.8 | 40.58 | 8.9 |

| Table 3.5.2. Average | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Location | Native species biomass | SE | % Non-native species numbers | SE | % Non-native species biomass | SE | % Offshore numbers | SE | % Offshore biomss | SE |
| | | | | | | | | | | |
| Penetang Harbour | 4.07 | 0.6 | 9.14 | 3.9 | 9.60 | 3.5 | 8.86 | 3.9 | 2.09 | 1.4 |
| Penetang Harbour | 1.58 | 0.3 | 4.29 | 1.6 | 4.32 | 3.2 | 4.19 | 1.6 | 1.25 | 0.9 |
| Penetang Harbour | 2.13 | 0.3 | 0.81 | 0.3 | 2.40 | 2.2 | 0.27 | 0.1 | 1.62 | 0.9 |
| | | | | | | | | | | |
| Hog Bay | 4.11 | 0.8 | 1.99 | 1.6 | 13.24 | 7.2 | 1.43 | 1.4 | 1.03 | 1.0 |
| Hog Bay | 2.01 | 0.3 | 7.14 | 7.1 | 13.33 | 13.3 | 0.00 | 0.0 | 0.00 | 0.0 |
| Hog Bay | 2.62 | 0.7 | 2.82 | 1.1 | 14.79 | 8.4 | 0.27 | 0.3 | 0.01 | 0.0 |
| Hog Bay | 2.59 | 0.6 | 0.90 | 0.4 | 12.79 | 8.5 | 0.48 | 0.3 | 0.14 | 0.1 |
| | | | | | | | | | | |
| Matchedash Bay | 2.12 | 0.4 | 6.74 | 5.1 | 1.13 | 0.9 | 9.49 | 5.3 | 3.98 | 1.8 |
| Matchedash Bay | 2.68 | 0.6 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 |
| | | | | | | | | | | |
| Sturgeon Bay | 1.79 | 0.4 | 1.18 | 1.1 | 0.01 | 0.0 | 1.18 | 1.1 | 0.01 | 0.0 |
| Sturgeon Bay | 2.65 | 0.3 | 0.56 | 0.2 | 1.49 | 1.4 | 2.08 | 0.8 | 0.50 | 0.3 |
| | | | | | | | | | | |
| Green Island | 2.08 | 0.5 | 10.50 | 3.6 | 13.53 | 7.2 | 10.23 | 3.9 | 1.83 | 1.4 |
| Green Island | 2.83 | 0.4 | 2.10 | 0.9 | 14.05 | 6.6 | 1.57 | 0.6 | 0.21 | 0.1 |
| | | | | | | | | | | |
| Present Island | 0.22 | 0.1 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 |
| Quarry Island | 0.52 | 0.2 | 0.89 | 0.9 | 16.57 | 16.6 | 4.34 | 3.2 | 17.37 | 14.2 |
| Robert's Island | 1.44 | 0.3 | 0.37 | 0.4 | 13.70 | 13.7 | 0.00 | 0.0 | 0.00 | 0.0 |
| South Bay | 2.16 | 0.4 | 6.50 | 2.4 | 10.86 | 6.4 | 5.99 | 2.3 | 1.40 | 0.8 |
| Sucker Creek | 0.68 | 0.4 | 0.96 | 1.0 | 24.38 | 24.4 | 5.65 | 4.5 | 1.06 | 1.0 |
| Beausoleil Bay | 0.99 | 0.2 | 1.94 | 0.7 | 11.03 | 9.9 | 0.00 | 0.0 | 0.00 | 0.0 |
| Beausoleil Island | 1.42 | 0.4 | 0.36 | 0.3 | 0.03 | 0.0 | 0.93 | 0.5 | 0.11 | 0.1 |