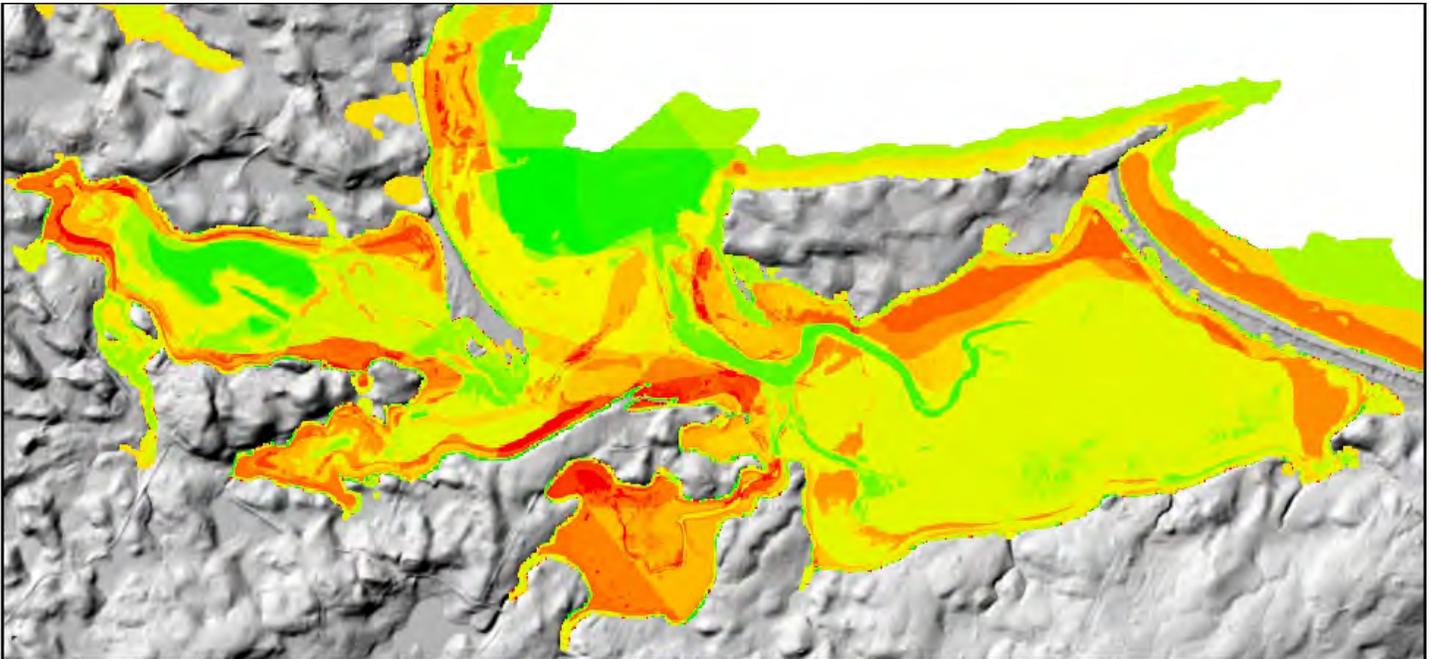


Aquaculture Decision Support Tool Demonstration Project



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Executive Summary

The Nova Scotia Community College's Applied Geomatics Research Group (NSCC AGRG) developed a Visualization platform, Aquaculture Suitability Index and Polygon Statistics Tool to assist Fisheries and Oceans Canada (DFO) with aquaculture development decision-making in Little Harbour, NS. The web-based tool used lidar-derived GIS layers (e.g., depth, intertidal zone, ice-impact zone, eelgrass), aerial imagery, results of a hydrodynamic model (e.g., flushing time, currents, fetch), Traditional Ecological Knowledge (TEK), information on invasive species, shellfish closure information, existing aquaculture lease information, and surrounding land use. A platform was developed to allow users to view the GIS layers using a website, eliminating the requirement for GIS software and therefore increasing accessibility to the GIS layers. The Aquaculture Suitability Index was developed using a GIS fuzzy logic overlay analysis. The analysis used a flexible combination of weighted GIS data layers to result in a map showing the potential usefulness of Little Harbour for aquaculture development. The Suitability Index varies depending on the weighting applied to the input layers; the weights were chosen by DFO. The Polygon Statistics Tool provides statistical information for data layers for a user-defined area. This gives the user quantitative information to assist with decision-making related to aquaculture development. Layers available for statistical analysis were depth, eelgrass, mean monthly currents, and TEK.

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1 Introduction

The Aquaculture Decision Support Tool was developed by the Nova Scotia Community College's (NSCC) Applied Geomatics Research Group (AGRG) for Fisheries and Oceans Canada (DFO), Gulf Region, to assist managers and decision makers in aquaculture site selection. The tool, or web application, is composed of three main components:

1. Visualization,
2. Aquaculture Suitability Index,
3. Polygon Statistics Tool.

Each of these components are combined in a web-based application for visualization and spatial analysis of a wide variety of Geographic Information System (GIS) datasets pertaining to aquaculture suitability, to support informed and efficient decision-making regarding aquaculture development. The Aquaculture Suitability Index was developed for display in the web application based on weights assigned to each data layer by DFO experts. The web application allows users to select different GIS data layers for visualization purposes, and the Polygon Statistics Tool allows users to choose a particular selection of data layers and calculate statistics and spatial analysis on those layers for a small area of their choice. The layers utilized by the application were selected by DFO, provided by both DFO (e.g., fish habitat, traditional ecological knowledge) and AGRG (e.g., depth, eelgrass), and prepared for the tool and web-viewer by AGRG.

The tool was developed as a demonstration project for Little Harbour, Nova Scotia (Figure 1.1). Little Harbour is a small bay along the Northumberland Strait enjoyed by various users, including recreational users like swimmers and boaters, shellfish harvesters, and commercial aquaculture operators. The harbour is habitat to many finfish and shellfish species, invasive species, and contains restrictions on shellfish harvesting. Physical conditions in the harbour are affected by ice, current speed, and flushing rate. Each of these users and conditions has an influence in the development of the aquaculture industry in Little Harbour, and quantitative consideration of these user groups, habitat types, and physical properties was the motivation for the development of this tool.

Little Harbour was chosen because of the existence of a large quantity of data for the area, and because the area has been well-studied by both DFO and AGRG over the past several years (Government of Canada, 2017; Webster et al., 2014, 2016a). AGRG surveyed Little Harbour in 2014 using their topographic-bathymetric aerial lidar sensor, which resulted in high resolution aerial photograph mosaic and a seamless land-sea digital elevation model (DEM). The lidar products were used to derive an eelgrass map and a hydrodynamic model for the harbour. Boat-based measurements of depth, light, temperature and salinity have been collected by AGRG and DFO as part of various studies of Little Harbour, and DFO manages relevant fisheries data.

This project consisted of two main parts: the preparation of the GIS layers for the web-viewer, and the development of the web-based tool. The Methodology section describes the preparation of the layers, construction of the aquaculture

suitability index map, and the development of the web platform. The final data layers used in the viewer and tool are presented in the Results section.

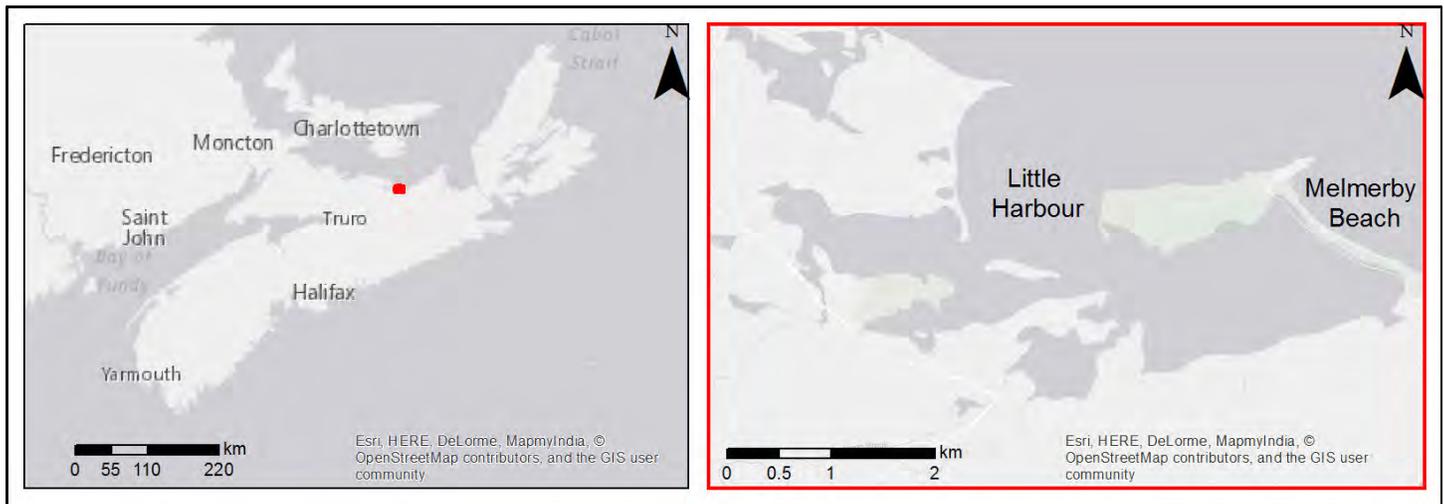


Figure 1.1: Little Harbour, NS, the study area used for the Aquaculture Decision Support Tool Demonstration project.

2 Methods

2.1 GIS Data Layers

Data layers developed for the Web Visualization, the Suitability Index, and the Polygon Statistics Tool were derived from a variety of sources. The layers were processed in ArcMap Desktop version 10.6 using an advanced licence and are projected in Universal Transverse Mercator projection (UTM, Zone 20N), and referenced to the North American Datum-Canadian Spatial Reference System of 1983 (CSRS NAD83) and the Canadian Geodetic Vertical Datum of 1928 (CGVD28). Both raster layers and shapefile layers were produced; in raster layers that are represented by presence/absence a value of one represents presence and a value of zero represents absence. Some layers were developed only for inclusion in the final aquaculture suitability map, while others were generated only for the polygon statistics tool. This section describes the source of each data layer and the methods applied to each layer to prepare it for the project. The layers and their data source are presented in Table 2.1.

Data Source	Data Layer
DEM	Continuous Depth
	Classified Depth
	Intertidal Zone
	Classified Ice Impact-free Depth Map
	Hillshade
	Colour Shaded Relief
	Depth Contour
Orthophoto	Near IR Orthophoto
	RGB Orthophoto
DEM + Orthophoto	Classified Eelgrass Presence
HD Model	Classified Flushing Time
	Classified Mean Monthly Currents
	Classified Max Monthly Currents
	Continuous Flushing Time
	Continuous Mean Monthly Currents
	Continuous Max Monthly Currents
	Classified Channel
	Fetch
DFO Traditional Ecological Knowledge (polygons)	Softshell Clam
	Razor Clam
	Quahog
	Blue Mussel
	Bar Clam
	American Oyster
	Striped Bass
	Sea Trout
	Mackerel
	Capelin
	Atlantic Salmon
	American Smelt
	American Eel
	Alewife
DFO Invasive Species (points)	Violet tunicate
	Vase Tunicate
	Oyster Thief
	Japanese Skeleton Shrimp
	Green Crab
	Golden Star Tunicate
	Coffin Box Bryozoan
	Clubbed Tunicate
DFO (points)	AIS Monitoring Stations
Observed Data (points)	Ground truth
	ADCP Deployments
	Temperature
	Salinity
Canadian Shellfish Sanitation Program	Web Service
Aquaculture Leases	NSFA
Land Use	NSDNR

Table 2.1: Data layers utilized by the Web Application and its components.

2.1.1 DEM

The lidar products were used to generate layers from either direct lidar products (e.g., DEM) or derived products (e.g., eelgrass). The lidar data were processed to 1 m resolution grids and models in 2014, as described in Webster *et al* (2014).

Depth relative to mean sea level (MSL) was generated using ArcMap’s Raster Calculator to nullify any value of the DEM greater than 0 m CGVD28 or MSL and multiply the remaining elevation data by -1; this layer was smoothed using a 3x3 mean filter, resulting in the Continuous Depth layer. This was binned into 0.5 m depth bins resulting in the Classified Depth layer. As requested by DFO, the classes included a 1.8 m bin rather than a 1.5 m bin.

The intertidal zone was derived from the Continuous Depth layer using values of higher astronomical tide (HAT) and lower astronomical tide (LAT) from the Pictou CHS Chart Datum 2000 (CD2000) offsets; a datum conversion value was not available for Little Harbour. The CD2000 values for HAT and LAT were converted to CGVD28 by subtracting 0.92 m, resulting in values of HAT and LAT for Little Harbour of 1.17 m CGVD28 and -0.93 m CGVD28, respectively (Table 2.2). The Intertidal Zone was therefore defined to be elevations between -0.93 m and 1.17 m CGVD28. Values of the Continuous Depth layer outside of the intertidal zone were nullified and values inside of the intertidal zone were set to 1. A majority filter and a boundary clean tool were applied to the Intertidal Zone layer to decrease the speckle.

	CD2000	CD2000 to CGVD28	CGVD28
HAT	2.09	0.92	1.17
LAT	-0.01		-0.93

Table 2.2: Values for vertical datum conversions.

The Ice Impact-free zone was defined as areas deeper than 1 m below LAT. To generate this layer, the DEM was nullified in areas greater than HAT, and the ice impact zone was defined to be the area between 1.17 m (HAT) and -1.93 m. The ice-free zone was defined to be values deeper than -1.93 m, classified into 1 m bins (e.g., -1.93, -2.93 m, -3.93 m, -4.93 m and -5.93 m). A majority filter and a boundary clean tool were then applied to the ice-impact free layer to remove noise.

Hillshade and colour shaded relief (CSR) layers, and 1 m interval depth contours relative to MSL were generated from the DEM.

2.1.2 Orthophoto

The Leica RCD30 60-megapixel camera collected co-aligned RGB+NIR (Red Green Blue + Near-Infrared) motion compensated photographs which were orthorectified and mosaicked into a single multiband image in post-processing. These are displayed in the web application as a NIR image and an RGB image.

2.1.3 Eelgrass

Eelgrass presence/absence was derived from combining the lidar depth, normalized lidar intensity, and RGB orthophoto mosaic as described in Webster *et al* (Webster et al., 2016b).

2.1.4 Hydrodynamic Model

A hydrodynamic (HD) model was developed for Little Harbour using Mike 21 software. The model bathymetry grid was generated entirely from the 2014 topo-bathy lidar survey and was forced at the seaward boundary (Figure 2.1) using predicted tides extracted from WebTide (Dupont et al., 2002). The model simulation period was the same as the deployment period for the ADCP, July 4 – Aug. 3, 2016.

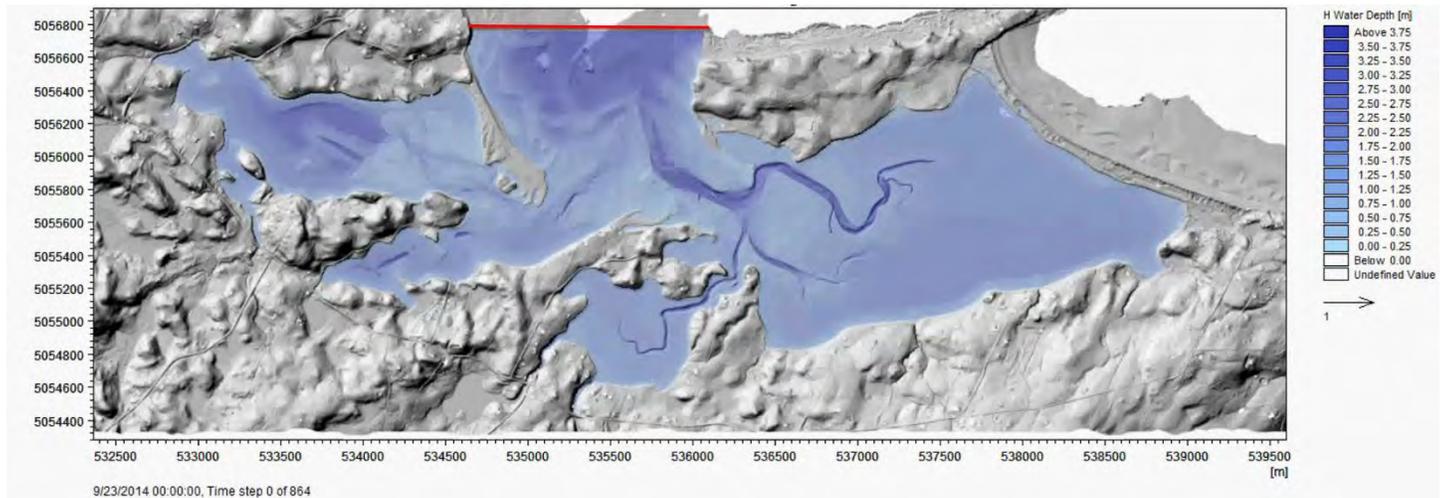


Figure 2.1: The modeled water depth and tidal boundary (red line). The x-axis represents Easting (m) and the y-axis represents Northing (m).

The model was used to produce four layers: flushing time, mean and maximum monthly currents, and fetch. Flushing time was determined using the Advection Dispersion module of Mike 21 to simulate an initial, arbitrary concentration in the harbour, and running the model until the concentration was “flushed out”. More explicitly, the flushing time was defined as the number of days it took for the harbour to be considered flushed such that only $1/e$ of particles present at Day 1 of the simulation remained, where e is Euler’s number, ~ 2.718 . Mean and maximum monthly current magnitudes were calculated directly using Mike 21 based on the July 2016 model simulation. The fetch layer is derived from the wave height resulting from applying a north wind to the model. Wave height was determined to be a suitable proxy for fetch and wave heights were classified as low, moderate, or high fetch.

The model results were also used to assist in classifying the channel. The Classified Channel layer was derived from the continuous depth layer and the mean monthly currents layer. The depth layer had a focal flow analysis tool run with a threshold of five and a mask to remove the shoreline edges. The resulting layer was then added to the mean monthly currents layer using the raster calculator and then a threshold of one was applied to that layer. The layer was then reclassified to presence/absence and a majority filter and boundary clean tool were run to remove noise. For future study areas that include navigational buoys, electronic charts in addition to the above methodology would be used to derive the channel.

2.1.5 Traditional Ecological Knowledge

DFO provided Traditional Ecological Knowledge (TEK) datasets representing the habitat of migratory fish species (striped bass, sea trout, mackerel, capelin, Atlantic salmon, American smelt, American eel, and alewife) and molluscs (softshell clam, razor clam, quahog, blue mussel, bar clam, and American oyster). The mollusc data layers were converted from polygons to binary presence/absence rasters.

2.1.6 Invasive Species

DFO provided point data indicating the known presence of Aquatic Invasive Species (AIS) (violet tunicate, vase tunicate, oyster thief, Japanese skeleton shrimp, green crab, golden star tunicate, coffin box bryozoan, and clubbed tunicate).

2.1.7 Supporting Data

Environment and Climate Change Canada (ECCC) has been collecting temperature and salinity data at 20 stations in Little Harbour as part of the Canadian Shellfish Sanitation Program (CSSP) since 1990; ECCC shared these data for use in this project. The data are represented as mean temperature and salinity values (1990-2016) at each station.

The ground truth validation data collected in Little Harbour by AGRG in 2014 are presented here as a point dataset. The points are coloured by eelgrass presence and include popup windows displaying metadata and any underwater imagery collected at that point.

An Acoustic Doppler Current Profiler (ADCP) was deployed in Little Harbour in 2016 to assist with validation of the hydrodynamic model; the location of the ADCP is shown on the map.

Information on currently issued aquaculture leases in Little Harbour is available from the NS Fisheries and Aquaculture (NSFA) website (<https://novascotia.ca/fish/aquaculture/site-mapping-tool/>). Both shellfish and finfish, as well as issued and proposed, lease information is available, but for the Little Harbour web visualization only the issued leases are displayed.

2.1.8 Web Service Data

CSSP provides a web-service showing current shellfish harvesting closures (<http://www.dfo-mpo.gc.ca/shellfish-mollusques/cssp-map-eng.htm>) which is linked to the Little Harbour web visualization application, showing live updates to closures.

2.1.9 Land Use

The Nova Scotia Department of Natural Resources provides a data layer on land use for all of Nova Scotia called the Forest Resource Inventory. The layer is derived from aerial photographs and includes information on how land is being used, e.g., agriculture, forestry, urban. For Pictou County, the layer was updated most recently in 2007. To prepare and simplify the data for the web visualization application, several codes of non-forested land (FORNON) were merged, and layers not

relevant to Little Harbour or aquaculture were removed. The final classes represented in the web application are defined in Table 2.3.

Merged Class	FORNON Code(s)
Agriculture	86, 91
Barren	84, 85
Beach	94
Cliffs/dunes/coastal rocks	76
Forest	0, 1, 3, 5, 6, 7, 8, 9, 12, 20, 33, 38, 39
Forest harvest	60, 61
Infrastructure	92, 95, 96, 97, 98, 99
Lakes	77
Oceans	78
Urban	87
Wetland	72, 73, 74, 75

Table 2.3: NSDNR Land Use layer definitions.

2.2 Web Visualization

The Web Visualization component gives the user the ability to select from this list of layers, change their transparency, and overlay various datasets to examine overlapping areas and data trends. The user is also able to click on a data layer to display a popup with the data value from the selected cell. A user can click on any layer and a summary of the data layer properties, source, and other metadata will be displayed.

The web-based component of the project leverages the ArcGIS API for JavaScript with the Dojo toolkit. Once published, the ArcGIS Server is responsible for converting the spatial data into images and formats supported by modern web browsers. It provides methods to access values and properties unique to each dataset type and design. Representational state transfer (REST) or RESTful web services application program interface (API) are how this is done by the server. ArcGIS Server creates and manages the REST API that the web map application accesses to utilize the data. Some of the highlights of this process are access controls, caching, tiling of images, and file size optimizations.

2.3 Aquaculture Suitability Index

2.3.1 Fuzzy Logic

Suitability modelling, also known as site selection or overlay analysis, involves the combination of spatial data from diverse sources which satisfy a set of criteria to produce an output map of potential (Bonham-Carter, 1994). Suitability models identify the best location for specific phenomena; in this case, the most ideal locations for aquaculture development in Nova Scotia coastal waters. In raster overlay analysis, each cell or pixel of each input layer references the same geographic location, which makes combining characteristics of numerous layers into a single output map appropriate (ESRI, 2017). Numeric values, or weights, are assigned to each characteristic or variable, allowing the user to mathematically combine the layers and assign a new value to each cell in the output layer.

Different types of suitability models exist including simple Boolean logic, Weighted Index Overlay, and Fuzzy Logic. For this project, a Fuzzy Logic approach was employed, as the Boolean Logic and Weighted Index Overlay models were deemed inappropriate for the input layers of this project. Many phenomena show a degree of uncertainty which cannot be properly expressed with crisp sets of class boundaries, as with simple Boolean logic, where a binary output map is produced with pixels having a value of either 0 or 1, signifying that a pixel is either suitable (1) or it is not suitable (0) and there is no in-between (Bonham-Carter, 1994). The Weighted Index Overlay approach is also based on crisp sets where each pixel is either in a class or not. Map classes occurring on each input map are assigned different scores or weights, as well as the maps themselves, and these input maps are then added together and divided by the sum of their weights (Bonham-Carter, 1994). Due to the additive nature of this approach, the resulting output map is often very liberal and abundant in “suitable” areas.

Fuzzy Logic suitability analysis allows for more flexible combinations of weighted maps with the rules or weights of fuzzy membership being assigned subjectively (based on expert opinion or knowledge) to estimate the relative significance of the input maps (Bonham-Carter, 1994). Whether a data layer belongs to a class or not is subjective; class boundaries can be “fuzzy”, and fuzzy logic performs overlay analyses more like natural human thinking (ESRI, 2017). Using linguistic modifiers to describe how a certain variable belongs to a class is difficult to translate computationally, as it is very difficult for computers to work with vague concepts, which are easily comprehended by humans (Yanar and Akyürek, 2006). For example, to numerically represent the depth of the harbour by the label “shallow”, it is necessary to define the meaning of the term “shallow.” Once these criteria are defined, this approach then involves assigning membership values to a fuzzy set (input map) on a continuous scale from 0 (no membership) to 1 (full membership) (Bonham-Carter, 1994). A fuzzy membership value of 0.5, for example, implies that the original phenomenon may or may not be a member of the fuzzy set. As the membership value migrates below or above 0.5, is it less likely or more likely, respectively, that the phenomenon is a member of the fuzzy set (ESRI, 2017).

To determine locations which have a high likelihood of membership in all sets, or in the context of this project, the geographic locations which are most suitable for aquaculture development, several different fuzzy operators, or mathematical functions are available. The Fuzzy Algebraic Sum operator was selected as the operator for the aquaculture suitability modelling for this project, as described in Table 2.4 (Bonham-Carter, 1994).

Fuzzy Operator	Description	Formula
Fuzzy AND	The minimum of the fuzzy memberships from the input rasters	$\mu_{combination} = MIN(\mu_A, \mu_B, \mu_C, \dots)$ <p>Where μ_A is the membership value for map A at a particular location, and so on</p>
Fuzzy OR	The maximum of the fuzzy memberships from the input rasters	$\mu_{combination} = MAX(\mu_A, \mu_B, \mu_C, \dots)$ <p>Where μ_A is the membership value for map A at a particular location, and so on</p>
Fuzzy Algebraic Product	The multiplication of input maps producing a "decreasing" output	$\mu_{combination} = \prod_{i=1}^n \mu_i$ <p>Where μ_i is the fuzzy membership function for the i-th map and $i=1, 2, \dots, n$ maps are to be combined</p>
Fuzzy Algebraic Sum	Complementary to the fuzzy algebraic product resulting in an "increasing" output	$\mu_{combination} = 1 - \prod_{i=1}^n (1 - \mu_i)$ <p>Where μ_i is the fuzzy membership function for the i-th map and $i=1, 2, \dots, n$ maps are to be combined</p>
Fuzzy Gamma	The algebraic product of the fuzzy sum and fuzzy product, both raised to the power of gamma (γ)	$\mu_{combination} = (Fuzzy\ algebraic\ sum)^\gamma * (Fuzzy\ Algebraic\ product)^{1-\gamma}$ <p>γ is a parameter chosen by the user</p>

Table 2.4: Description of the fuzzy operators. Adapted from Bonham-Carter (1994).

2.3.2 Fuzzy Logic Model Parameter Weighting

A subset of the GIS Data Layers discussed in Section 2.1 was selected by DFO to be used in the Fuzzy Logic Model (Table 2.5). Each layer was assigned a weight, and each class was assigned a score, as defined by DFO. Weighted layers and scored classes were combined using the fuzzy logic algebraic sum to produce the final Aquaculture Suitability Index, which indicates areas most and least suitable for suspended oyster aquaculture development.

Layer	Layer Weight	Class	Class Rank
Depth (m)	7	0 - 0.5	0
		0.5 - 1	0
		1 - 1.8	0
		1.8 - 2	1
		2 - 2.5	1
		2.5 - 3	1
		3 - 3.5	1
		3.5 - 4	1
		4 - 4.5	1
		4.5 - 5	1
		5 - 5.5	1
		5.5 - 6	1
Ice impact-free depth map	20	Ice Impact Zone	0
		Ice Free Zone 1 m	0.5
		Ice Free Zone 2 m	1
		Ice Free Zone 3m	1
		Ice Free Zone 4 m	1
Eelgrass	20	Presence	0
		Absence	1
CSSP Classification	10	Open	1
		Closed	0
TEK - Molluscs -Softshell Clam	10	Presence	0
		Absence	1
TEK - Molluscs - Razor Clam	10	Presence	0
		Absence	1
TEK - Molluscs - Quahog	10	Presence	0
		Absence	1
TEK - Molluscs - Blue Mussel	10	Presence	0
		Absence	1
TEK - Molluscs - Bar Clam	10	Presence	0
		Absence	1
TEK - Molluscs - American Oyster	10	Presence	0
		Absence	1
Average Monthly Current (m/s)	5	0 - 0.5	1
		0.5 - 1	0.4
		>1	0
Max Current Speed (m/s)	5	0 - 0.5	0.6
		0.5 - 1	0.2
		>1	0
Flushing Time	5	<5 days	1
		5-20 days	1
		>20 days	0.6
Exposure/Fetch	5	Fetch high and /or wave height >1m	0
		Fetch moderate and/or wave height 0.5 - 1m	0.3
		Fetch low and/or wave height <0.5m	1
Channel	10	Presence	0
		Absence	1

Table 2.5: Data layers used to inform the Aquaculture Suitability Map.

2.4 Polygon Statistics Tool

The Polygon Statistics Tool was developed to provide the user specific statistics for a user-defined area. The user can draw a shape anywhere on the map, and the tool will use information from the layers defined in Table 2.6 to populate a table with the statistics shown in Table 2.7, giving the user quantitative information to assist with decision-making related to aquaculture development. The statistics tool uses JavaScript logic to select an area of interest, the geometry of the area is then sent to the server as input and triggers a Python geoprocessing tool, geoprocessing results are then returned to user.

Data Source	Data Layer
DEM	Continuous Depth
DEM + Orthophoto	Classified Eelgrass Presence
HD Model	Classified Mean Monthly Currents
Traditional Ecological Knowledge	Softshell Clam
	Razor Clam
	Quahog
	Blue Mussel
	Bar Clam
	American Oyster
	Striped Bass
	Sea Trout
	Mackerel
	Capelin
	Atlantic Salmon
	American Smelt
	American Eel
Alewife	

Table 2.6: List of layers utilized by the Polygon Statistics Tool.

Layer	Statistic
Polygon	Area (m ²)
	Perimeter (m)
Eelgrass	% Eelgrass Coverage within the Polygon Area (%)
	% Eelgrass within the Bay (%)
	Total Eelgrass Area in the Polygon (m ²)
	Total Eelgrass Area in the Bay (m ²)
Depth	Average (m)
	Minimum (m)
	Maximum (m)
	Standard Deviation (m)
Current	Average (m/s)
	Minimum (m/s)
	Maximum (m/s)
	Standard Deviation (m/s)
Species	Lists species present in the TEK Habitat layer

Table 2.7: Statistics calculated by the Polygon Statistics Tool.

3 Results

3.1 GIS Data Layers

The GIS Data Layers for Little Harbour are displayed in this section exactly as they appear in the Web Visualization application.

3.1.1 DEM

The maximum depth in Little Harbour is ~6 m below MSL, and the deepest areas are located at the mouth of the harbour and in the channel (Figure 3.1, Figure 3.2, Figure 3.3). Outside of the channels, the harbour is quite shallow (<1.5 m in most areas) and flat, and therefore included in the intertidal zone (Figure 3.4). There are several areas that have elevations above MSL, including the southward-pointing migrating sandbar near the mouth of the harbour. The ice-impact zone, defined as extending 1 m deeper than the lower limit of the intertidal zone, extends over almost the entire harbour, with the channels, a small area of the western bay, and the mouth of the harbour excluded (Figure 3.5). A histogram of the bathymetry provides insight into the distribution of bathymetry, and shows that over 50% of the DEM (which includes the areas surveyed outside of the harbour, e.g., Melmerby Beach and the small portion of Chance Harbour to the North) lies within the intertidal zone, and ~70% of the DEM is considered impacted by ice (Figure 3.6).

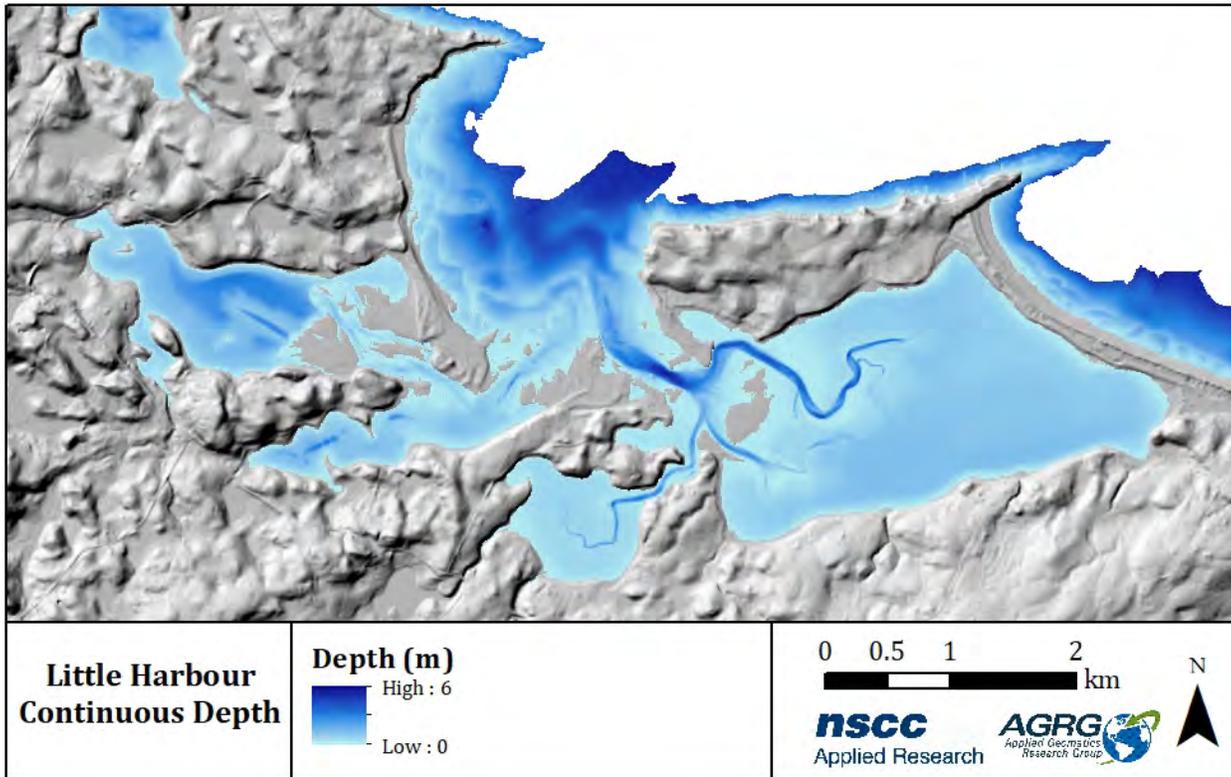


Figure 3.1: Continuous Depth Model, with depth relative to Mean Sea Level.

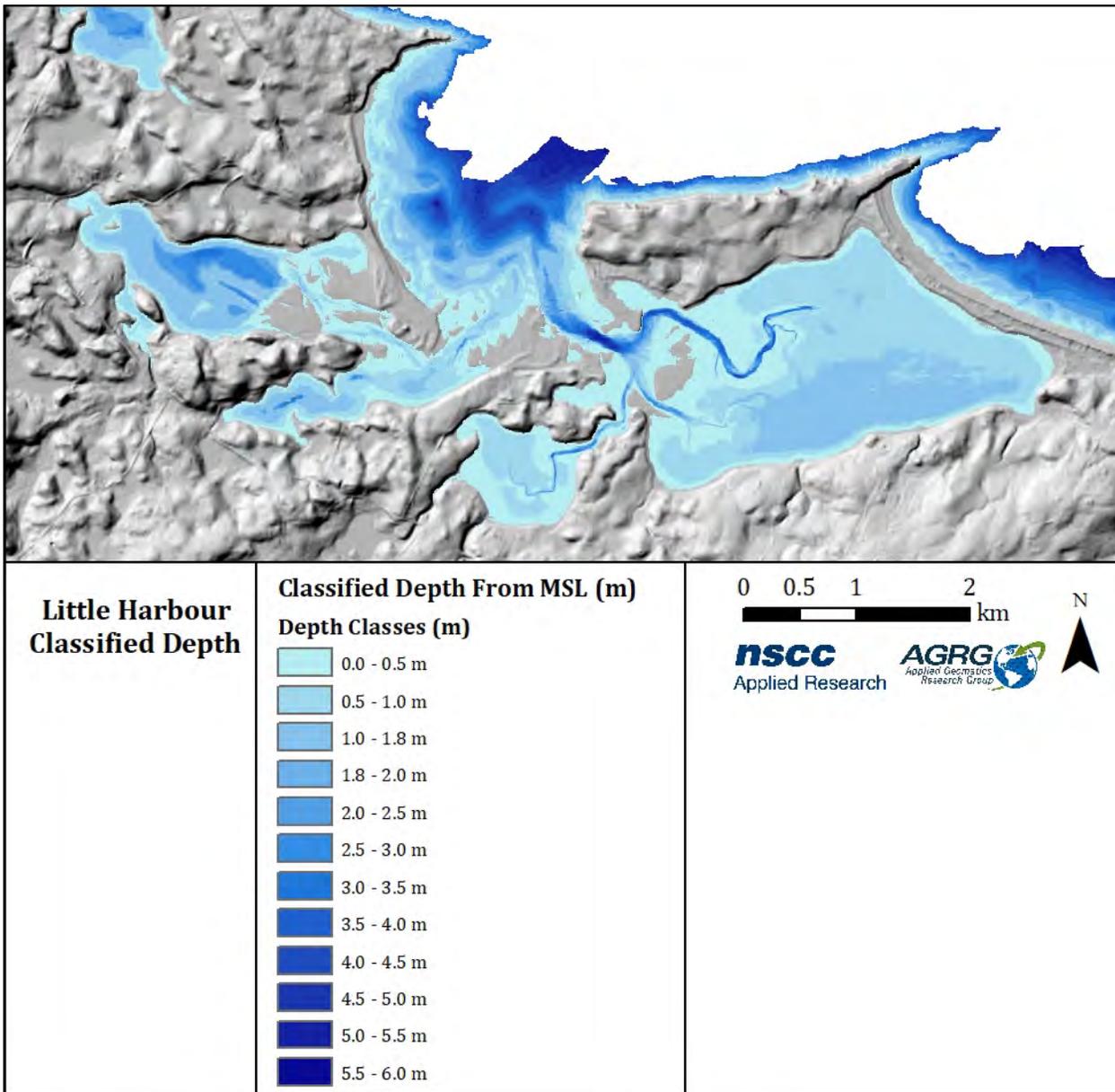


Figure 3.2: Classified Depth Model, with depth relative to Mean Sea Level. Note the 1.8 m class between 1.0 m and 2.0 m.

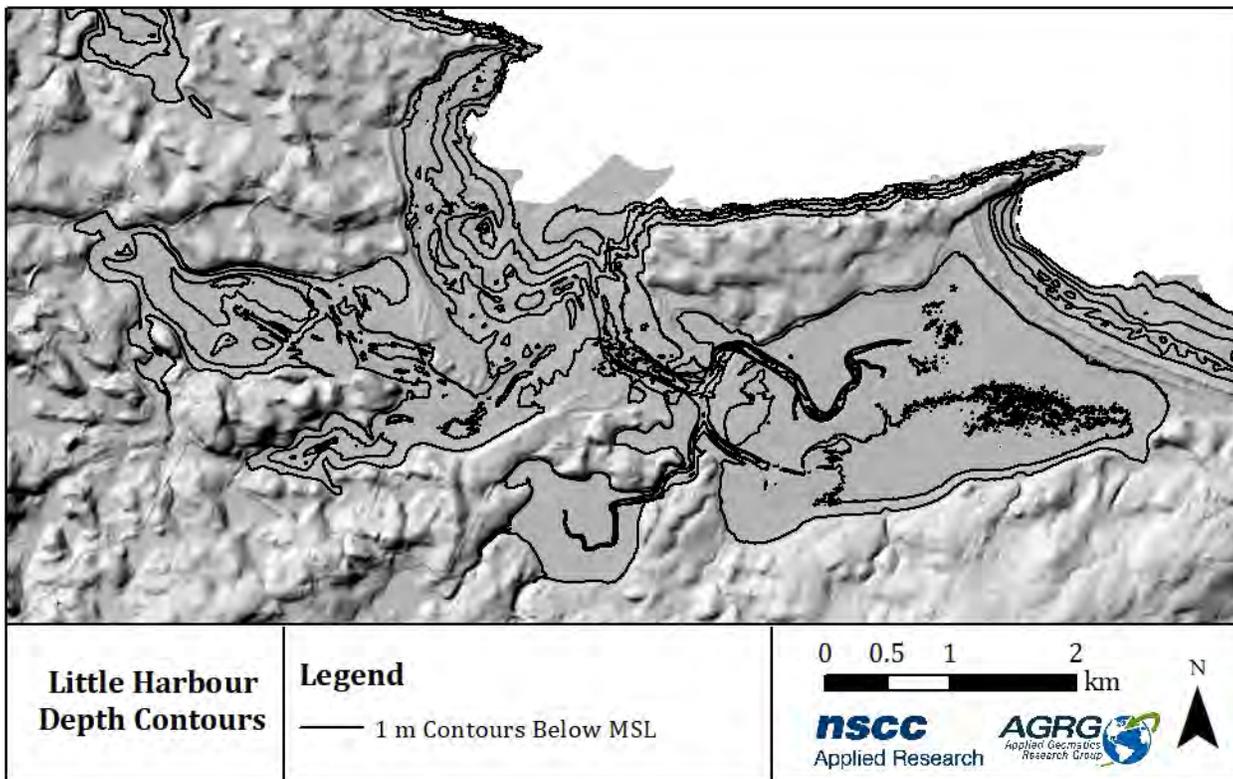


Figure 3.3: 1 meter depth contours starting at mean sea level, created using a lidar-based elevation model.

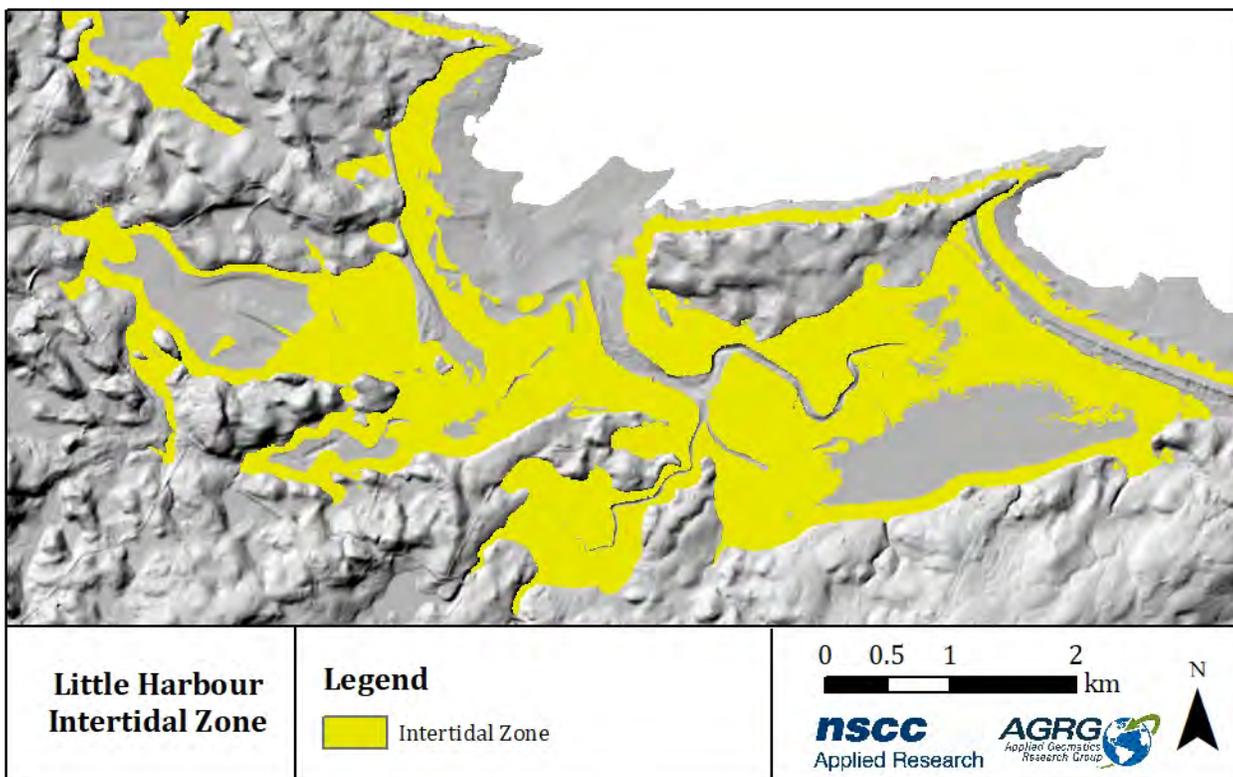


Figure 3.4: The intertidal zone, defined as the region on the elevation model between -0.93 m (Lower Astronomical Tide) and 1.17 m (Higher Astronomical Tide).

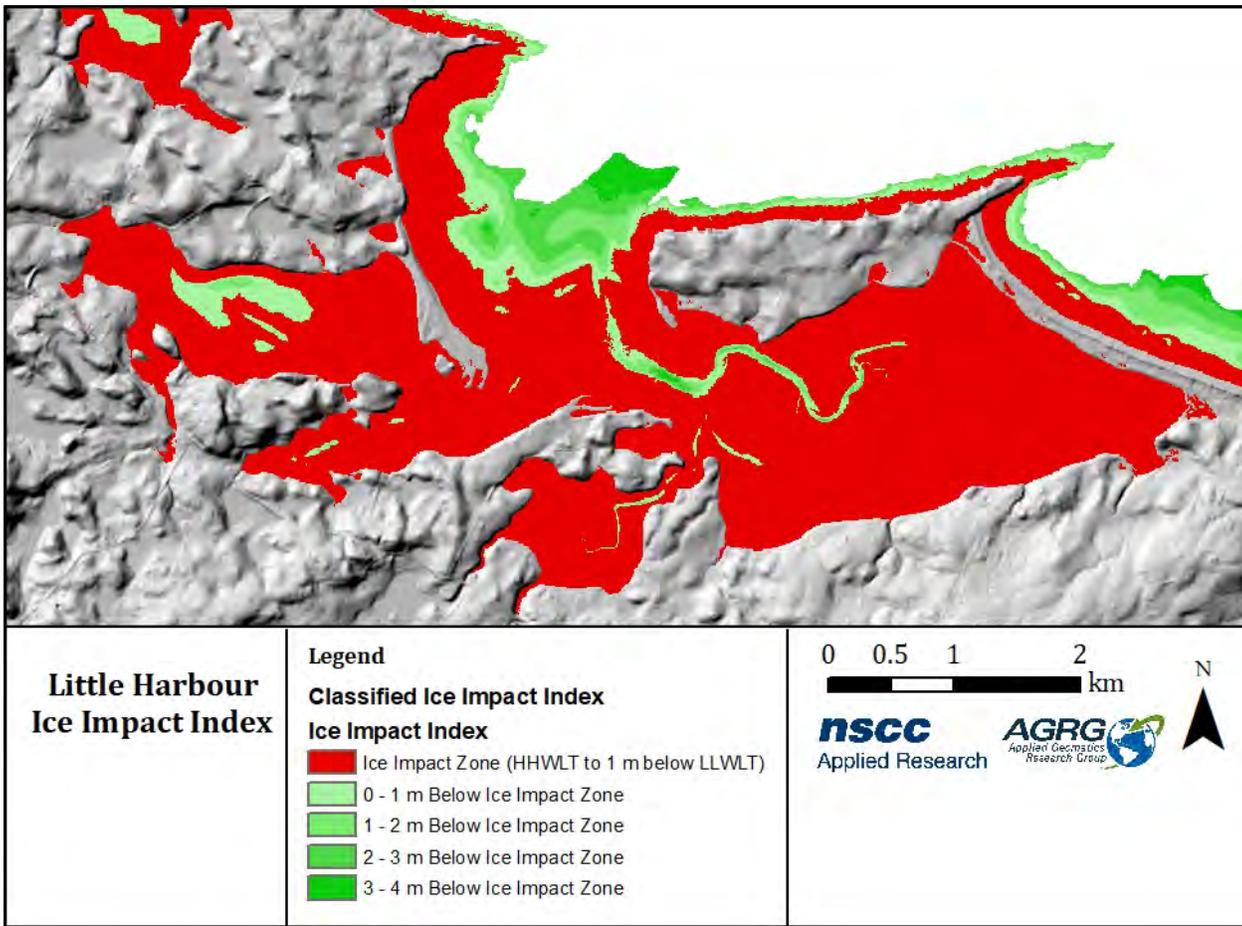


Figure 3.5: The ice Impact zone is defined as the level of Higher Astronomical Tide (HAT) to one meter below Lower Astronomical Tide (LAT), with the ice impact-free zone divided into 1 meter increments below the impact zone.

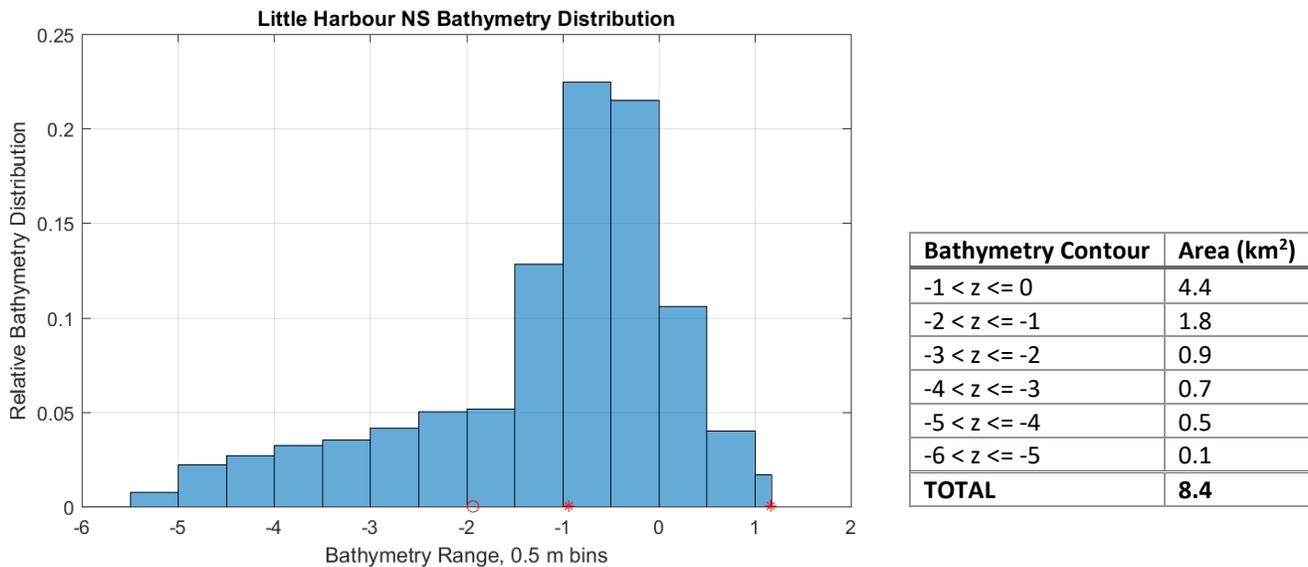


Figure 3.6: Bathymetry histogram for Little Harbour in 0.5 m bins showing the relative distribution of each contour. Note that the intertidal zone is between -0.93 m and 1.17 m, as indicated by the red asterisks, and the ice-impact zone is between -1.93 m (red circle) and 1.17 m. The table shows the distribution by area for 1 m contours (km²).

The fetch layer was derived from significant wave height (H_{sig}) resulting from the application of a strong north wind to the study area (Figure 3.7). Model cells with $H_{sig} > 1$ m were classified as having high fetch, H_{sig} between 0.5 and 1.0 m was assigned a classification of moderate fetch, and H_{sig} less than 0.5 m was assigned a classification of low fetch.

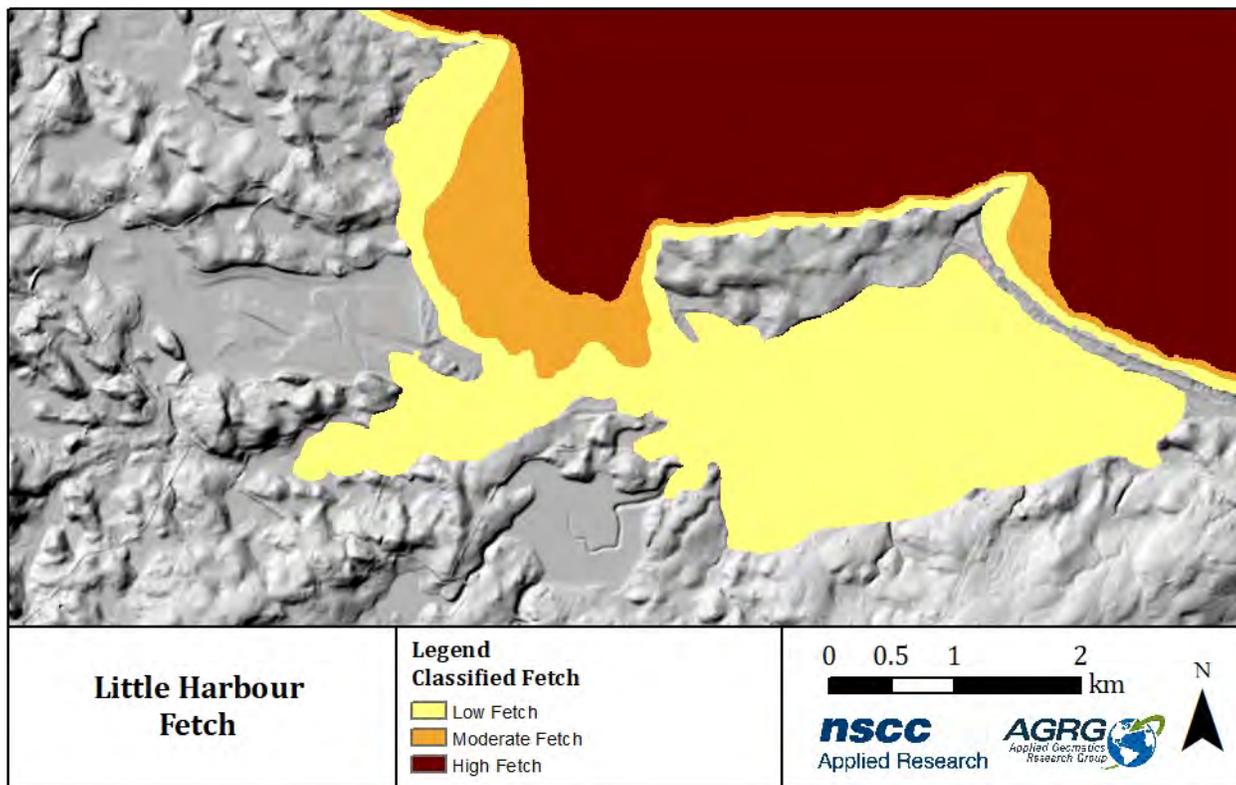


Figure 3.7: The fetch layer was derived from significant wave heights resulting from modelled exposure to a north wind.

3.1.2 Orthophotos

The orthophoto layers are invaluable for assisting with the interpretation of the DEM, validating land use, and for use in the derived lidar products, such as eelgrass. The orthophoto true colour mosaic (Figure 3.8) shows areas of sand, vegetation, and identifies the channel; the NIR orthophoto mosaic (Figure 3.9) is helpful in distinguishing between sand or pavement and vegetation on land.

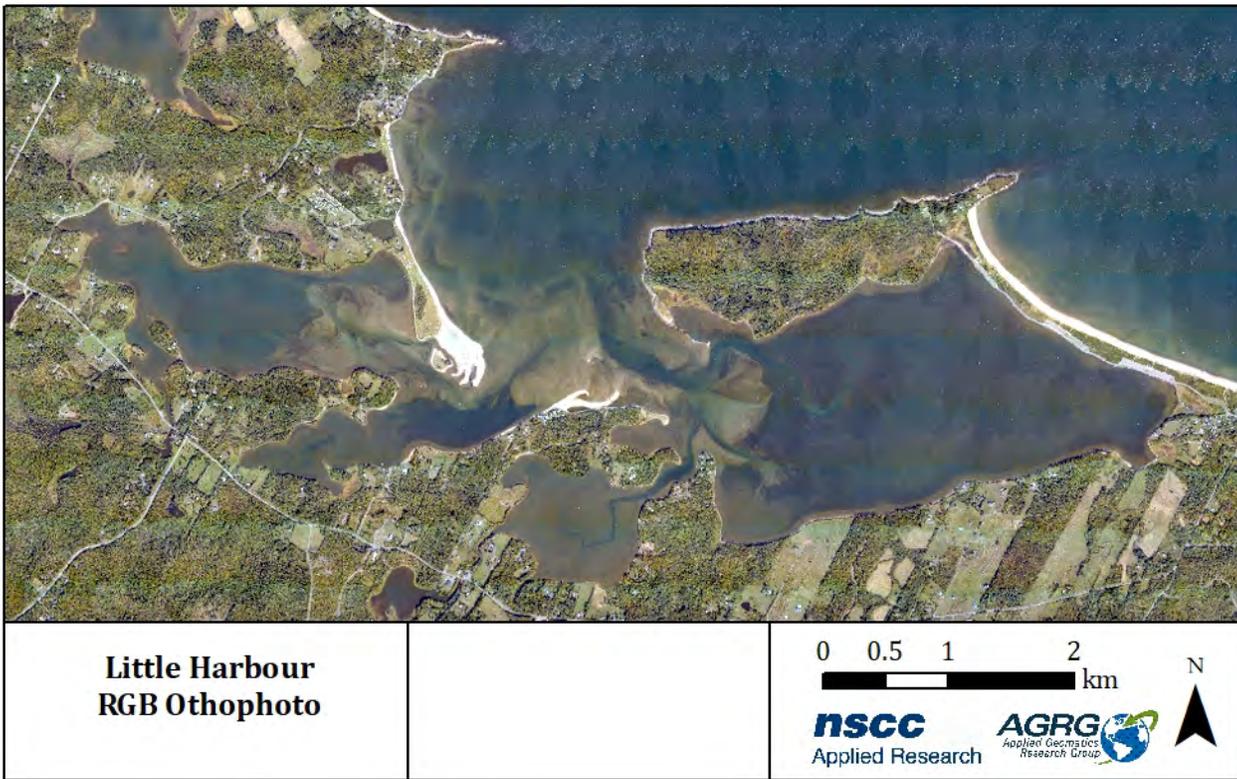


Figure 3.8: True colour image, generated from the RCD30 camera orthophoto mosaic.

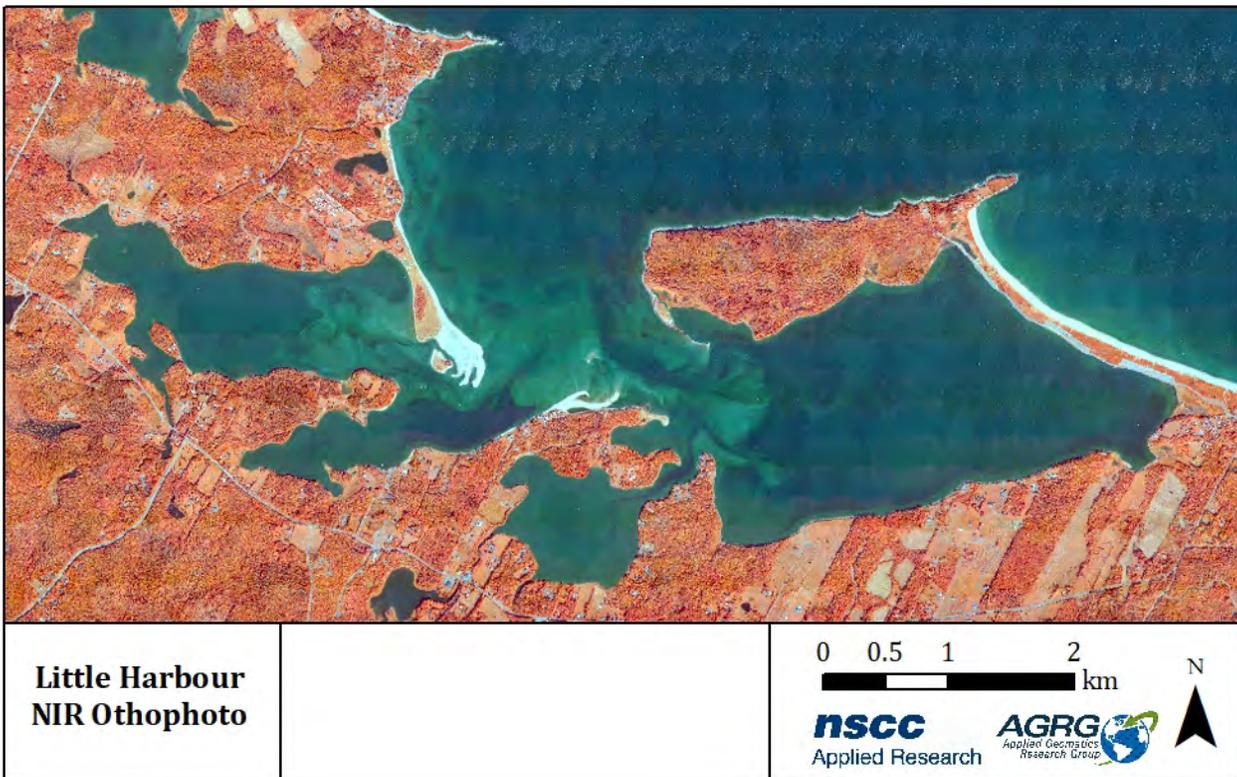


Figure 3.9: RCD30 false colour image with band combination near infrared, green, blue.

3.1.3 Eelgrass

The eelgrass map shows eelgrass presence in Little Harbour and has a 76% agreement with ground truth points. All mismatches were false negatives, where the eelgrass map showed eelgrass absence, but ground truth photos showed presence (Figure 3.10). Further analysis shows the relative and actual distribution of eelgrass throughout the harbour (Figure 3.11). The relative eelgrass area distribution shows that 25% of the total eelgrass is present between -0.8 m and -1.0 m, that eelgrass presence drops off sharply below -1.2 m, and that no eelgrass is present below -1.8 m or above 0.2 m. The distribution of eelgrass area shows that there is 2.16 km² of eelgrass between 0 and -1 m. Since total area of that contour is 4.4 km² (Figure 3.6), the eelgrass histogram indicates that ~50% of that contour has eelgrass presence.

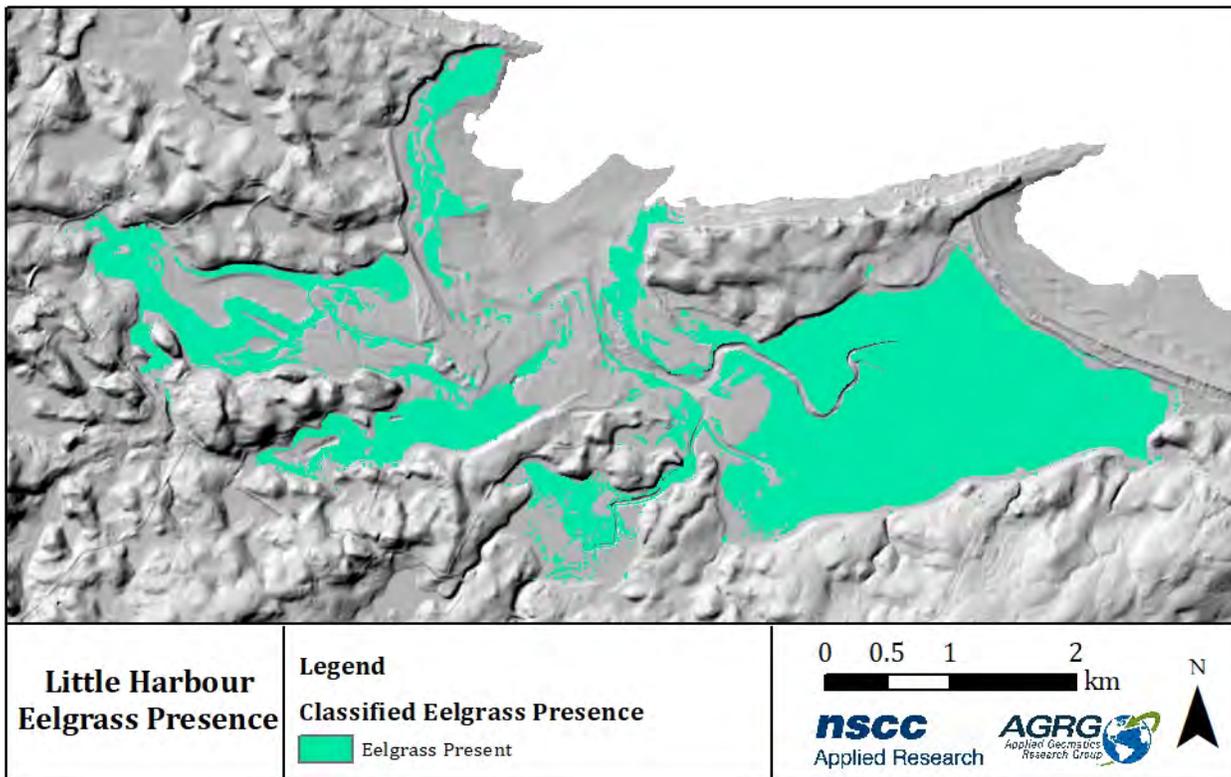
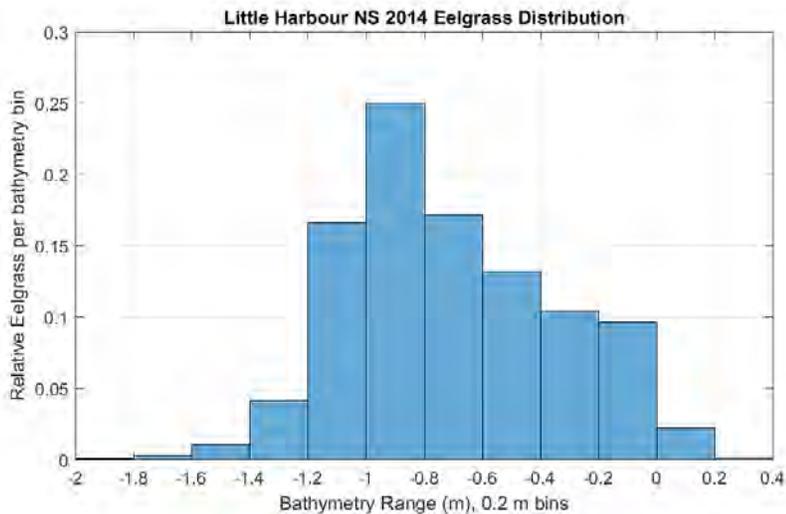


Figure 3.10: Identified areas of eelgrass presence based on a combination of lidar intensity and orthophoto RGB normalization.



Bathymetry Contour	Eelgrass Area (km ²)
0 < z <= 1	0.03
-1 < z <= 0	2.16
-2 < z <= -1	0.67
-3 < z <= -2	0
TOTAL	2.86

Figure 3.11: Relative distribution of eelgrass per depth bin, showing that 25% of the eelgrass is present between -0.8 m and -1.0 m, that eelgrass presence drops off sharply below -1.2 m, and that no eelgrass is present below -1.8 m or above 0.2 m. The table shows the area of eelgrass per contour.

3.1.4 Hydrodynamic Model Products

The classification scheme chosen for the currents shows that mean currents in most of the harbour are less than 0.25 m/s (Figure 3.12). The continuous raster shows the actual values and indicates currents many more complexities and variations in the circulation (Figure 3.13). Maximum currents are between 0 and 0.5 m/s in most of the harbour but faster (0.5 – 1.0 m/s) in parts of the channel (Figure 3.14); the continuous raster shows that the fastest speed simulated was 1.7 m/s and that the current speed varies within each small channel (Figure 3.15). Model results compared to ADCP observations indicates that the model predicts surface elevation and east-west (EW) currents well, under predicts north-south (NS) currents and current magnitude by between 0.1 and 0.2 m/s, and under predicts current direction by ~10-20°.

The flushing time simulation indicated that the mouth of the harbour and the openings to each of the small inlets flushed within 5 days, but that areas farther away from the mouth took longer to flush (Figure 3.17). Given the reduced current speeds in these areas of the harbour, this result is not surprising. There is not a well-defined channel at the mouth of Little Harbour, but two main channels appear just inside the harbour and direct flow to the eastern and western inlets where they divide into several smaller channels (Figure 3.18).

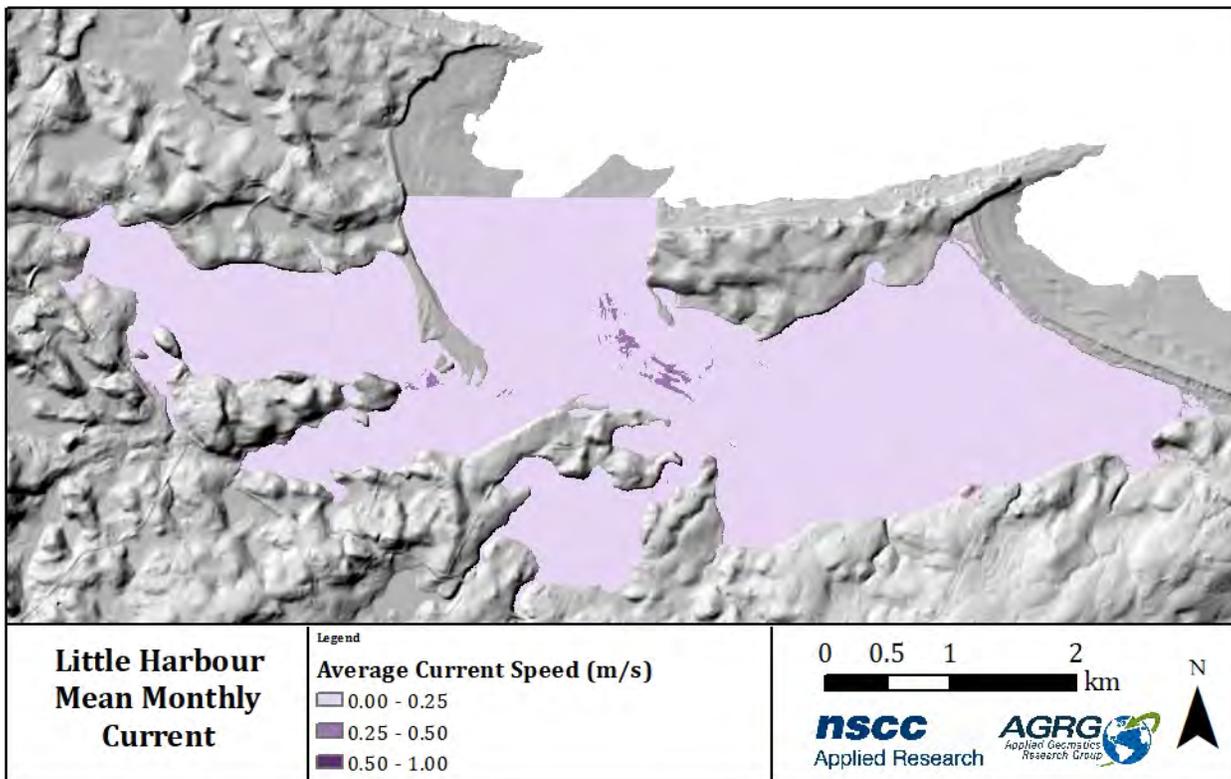


Figure 3.12: Mean of current magnitudes (m/s) during a 1 month simulation of the hydrodynamic model classified into three speed categories.

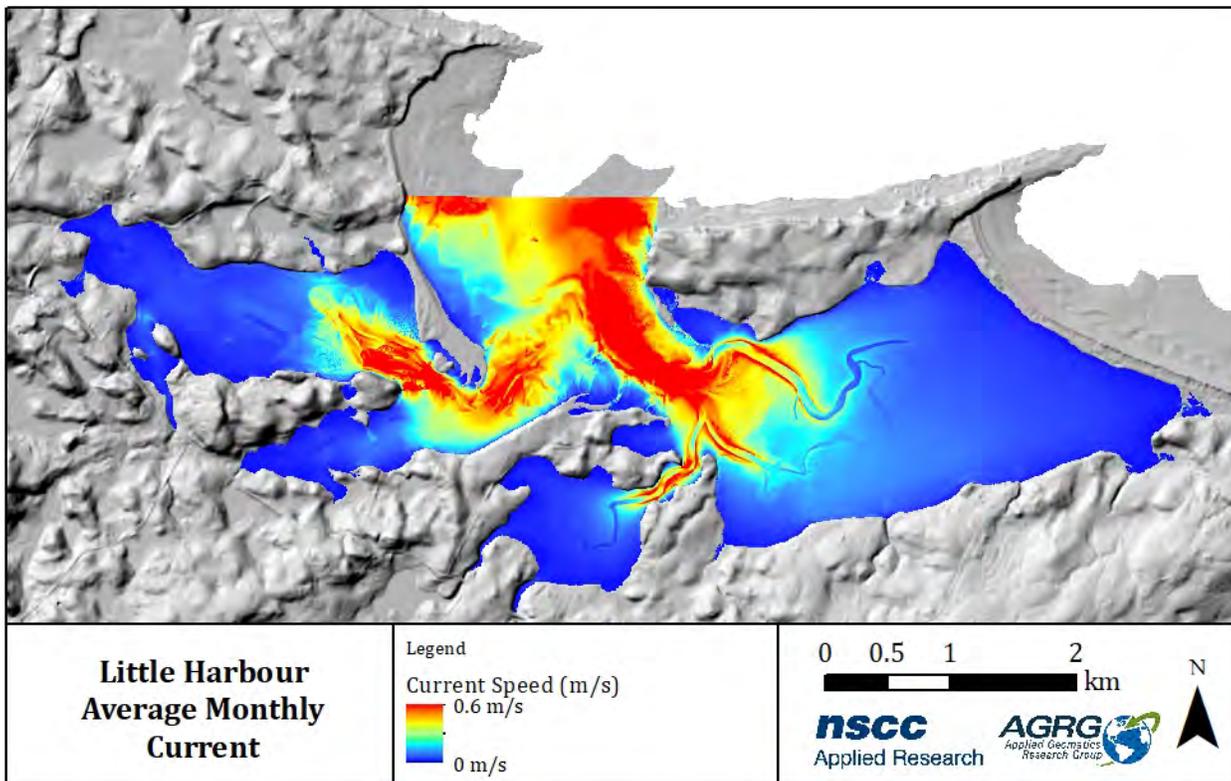


Figure 3.13: Mean of current magnitudes (m/s) during a 1 month simulation of the hydrodynamic model displayed as a continuous raster.

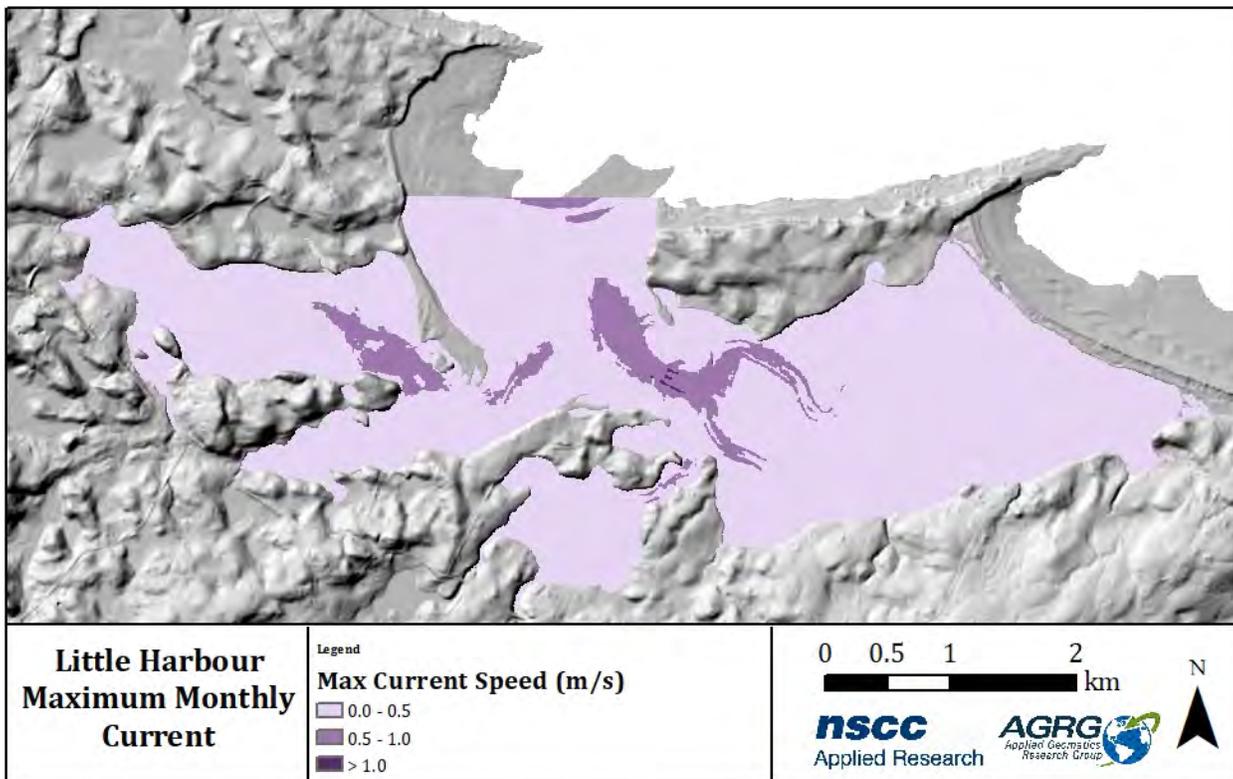


Figure 3.14: Maximum value of current magnitudes in m/s during a 1 month simulation of the hydrodynamic model classified into three speed categories.

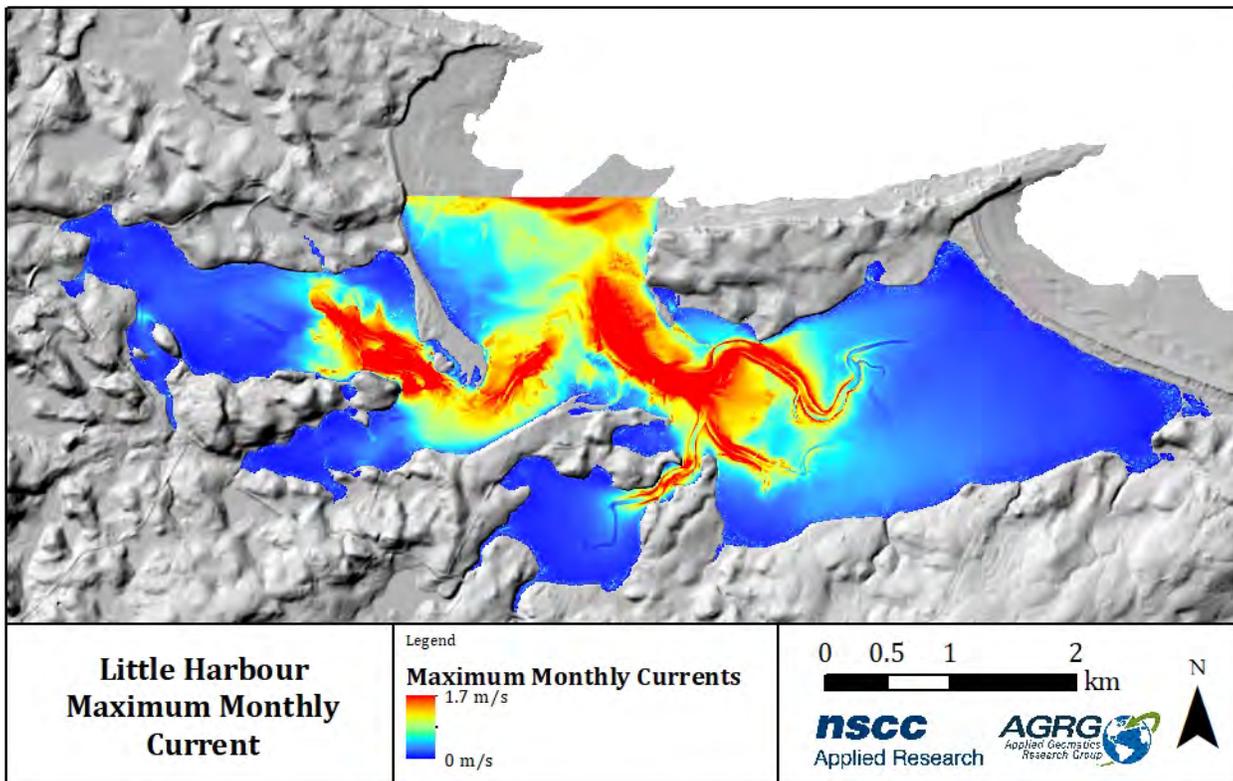


Figure 3.15: Maximum value of current magnitudes in m/s during a 1 month simulation of the hydrodynamic model displayed as a continuous raster.

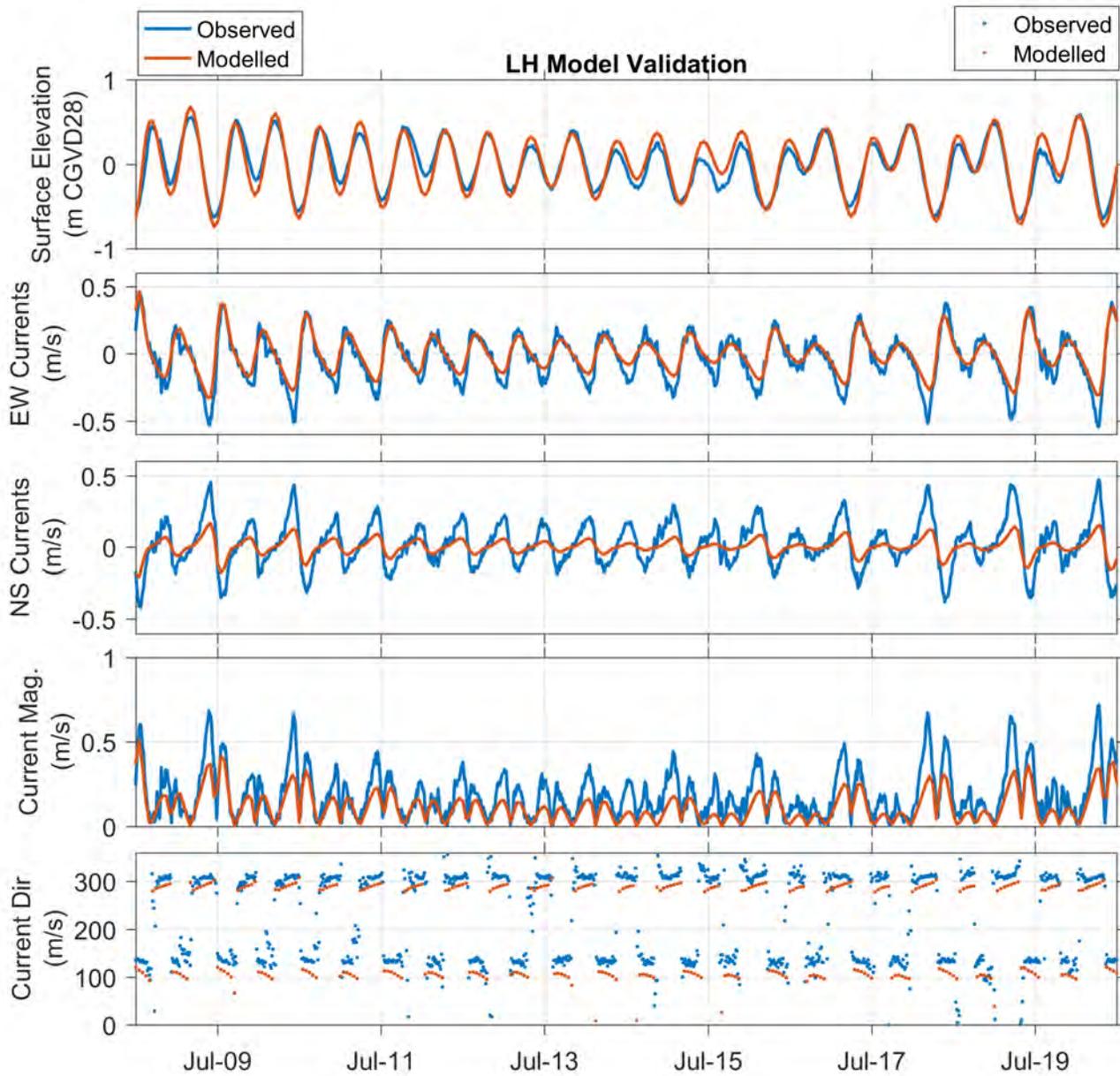


Figure 3.16: Hydrodynamic model results compared to observed ADCP results for July 8 – 20, 2016. The model predicts surface elevation and EW currents well, under predicts NS currents and current magnitude by between 0.1 and 0.2 m/s, and under predicts current direction by ~10-20°.

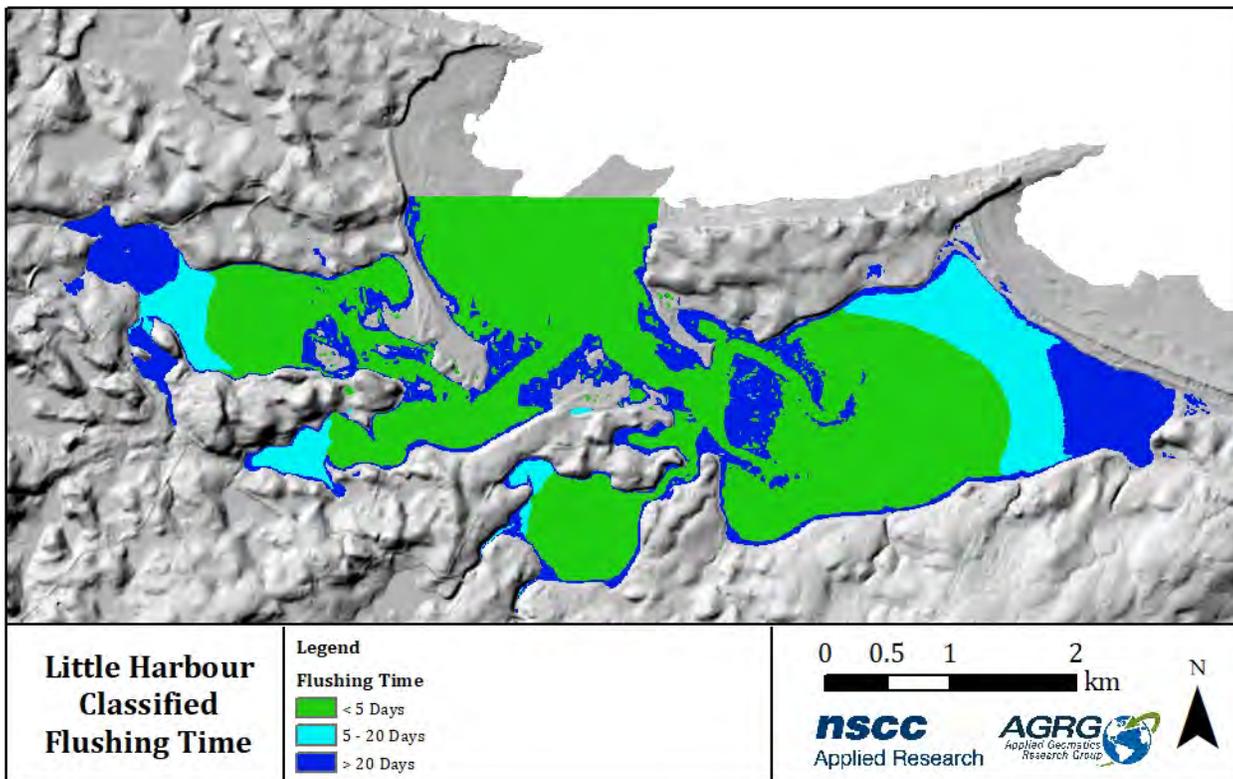


Figure 3.17: The number of days it takes for the harbour to be considered flushed, such that only $1/e$ of particles present at Day 1 of the simulation remain.

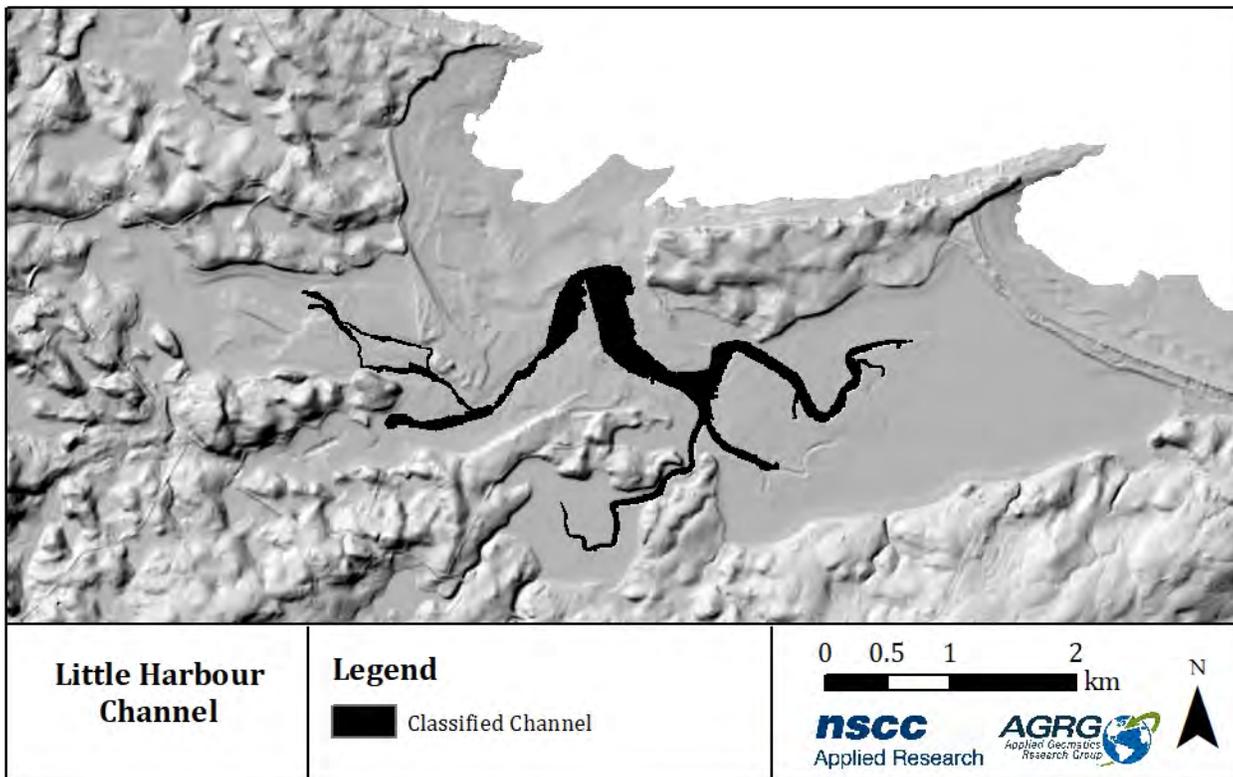


Figure 3.18: AGRG-derived channels based on depth and current flow data.

3.1.5 Traditional Ecological Knowledge

American Smelt and American Eel are the only Migratory Fish habitats present in Little Harbour (Figure 3.19). American Oysters, Bar Clam, Blue Mussel, Quohog, and Softshell Clam species are present in Little Harbour (Figure 3.19).

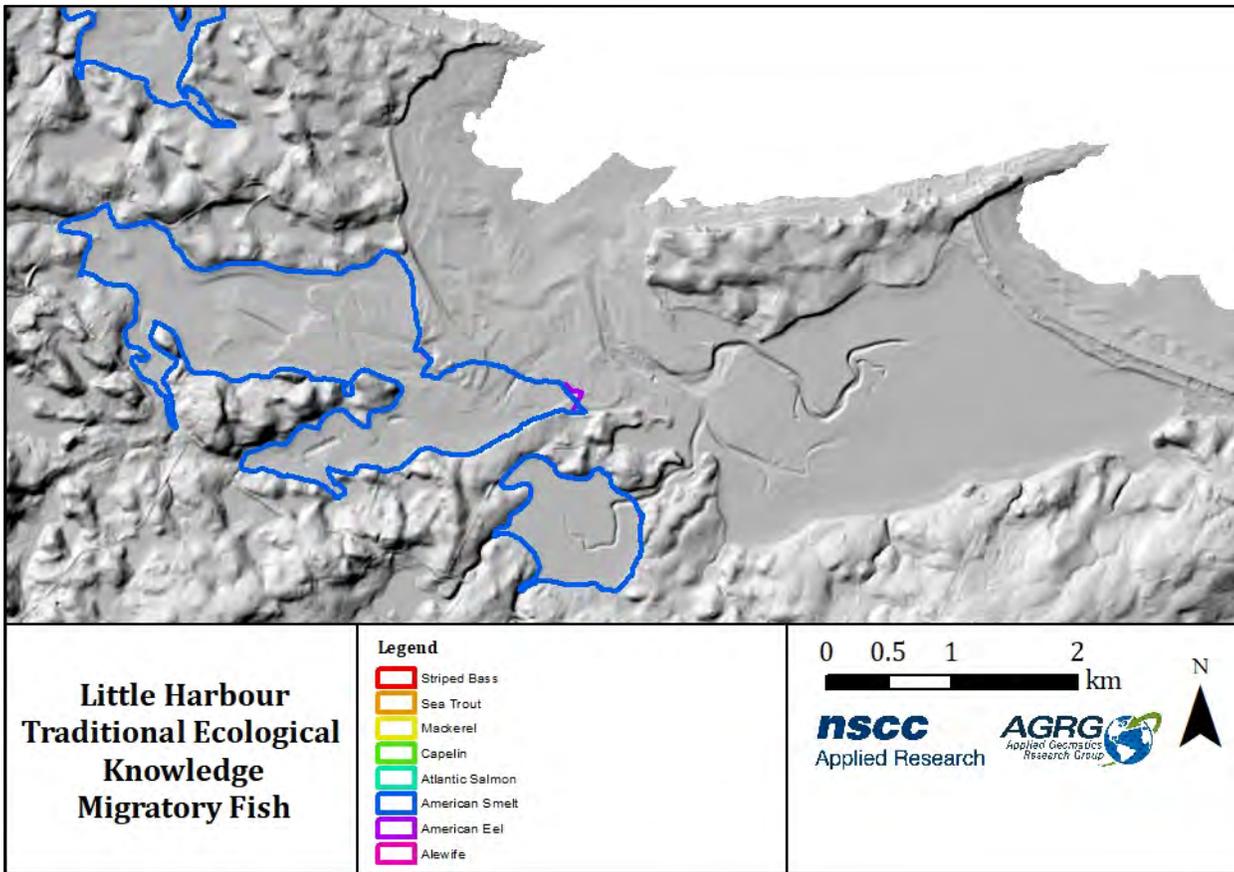


Figure 3.19: Migratory fish presence identified from Traditional Ecological Knowledge.

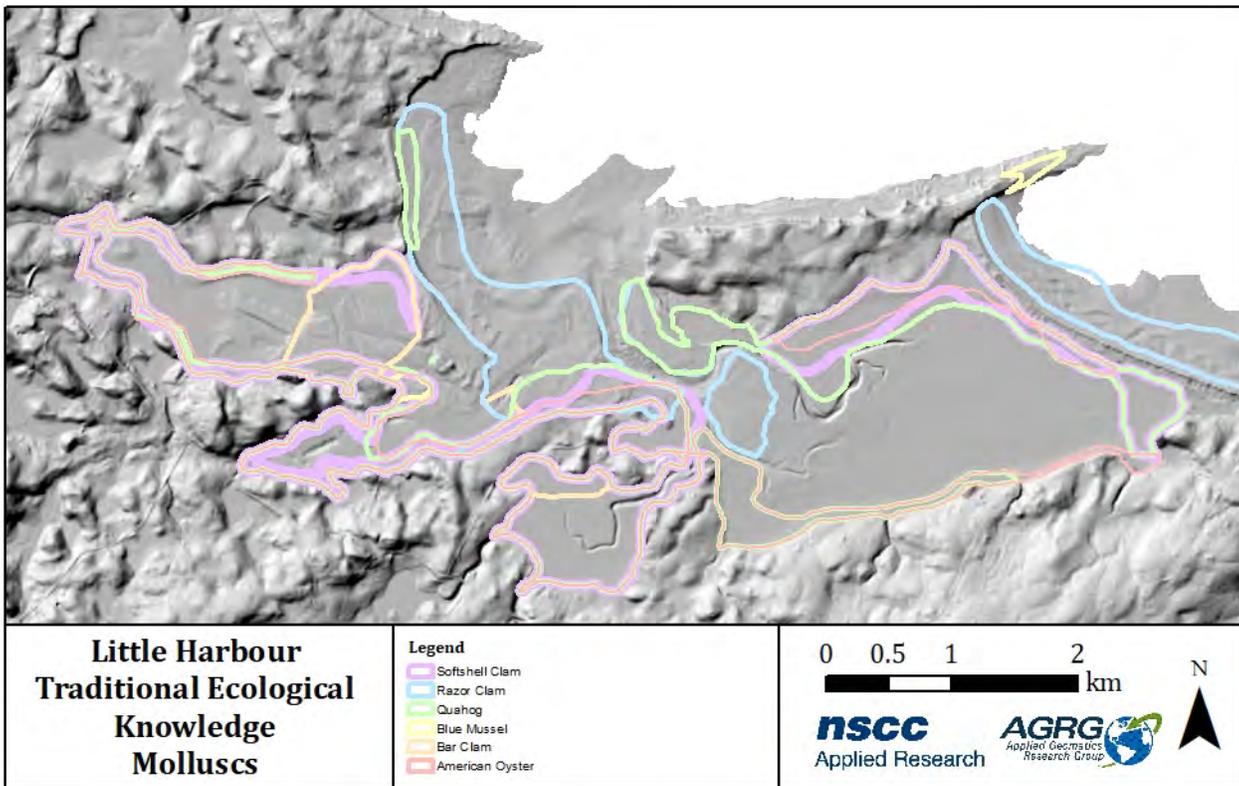


Figure 3.20: Mollusc presence identified from Traditional Ecological Knowledge.

3.1.6 Invasive Species

Violet Tunicate and Green Crab are the only invasive species identified in Little Harbour (Figure 3.21). DFO's Aquatic Invasive Species Monitoring Station is located outside Little Harbour (Figure 3.22).

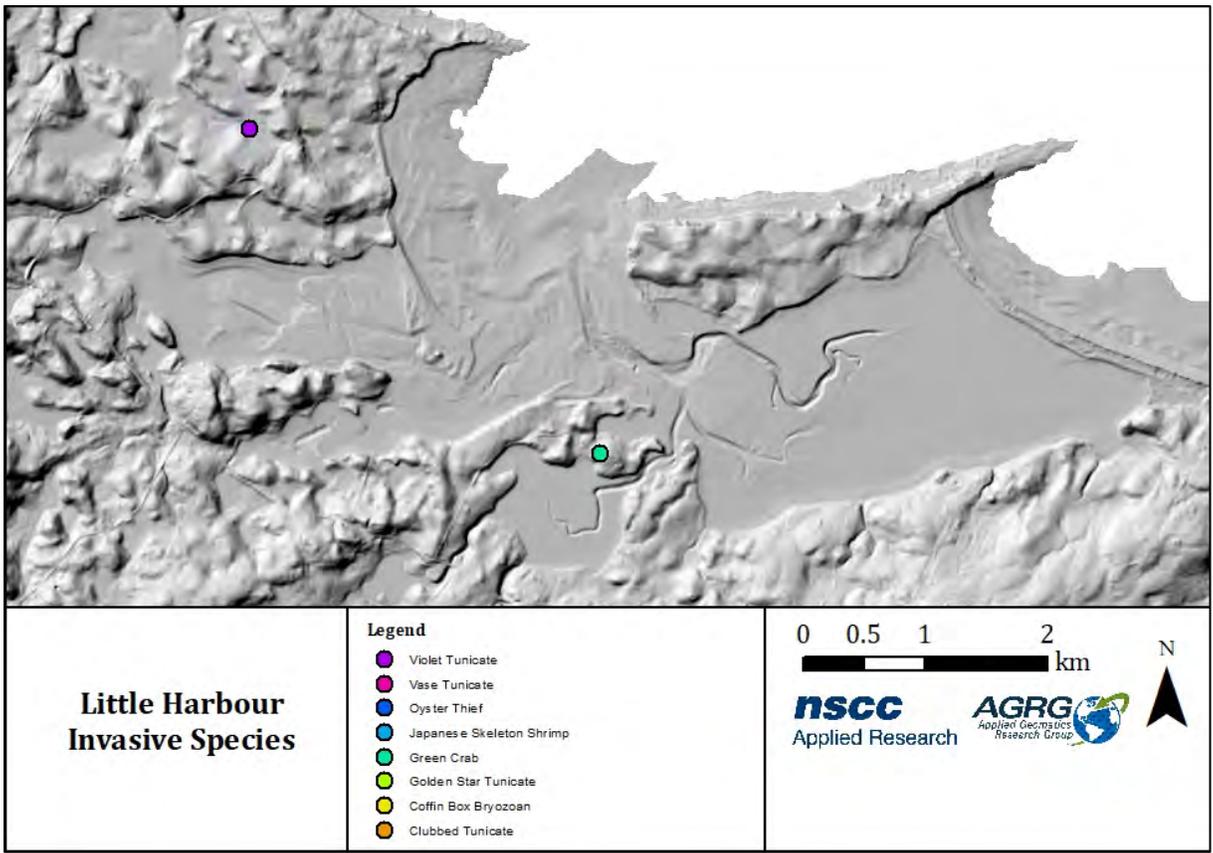


Figure 3.21: Identified presence of aquatic invasive species as reported by DFO.



Figure 3.22: Location of currently existing DFO Aquatic Invasive Species monitoring stations.

3.1.7 Observed Data

Figure 3.23 ground truth observations showed 19/29 sampled sites had eelgrass present; this figure also shows the location of the ADCP deployment in 2016.

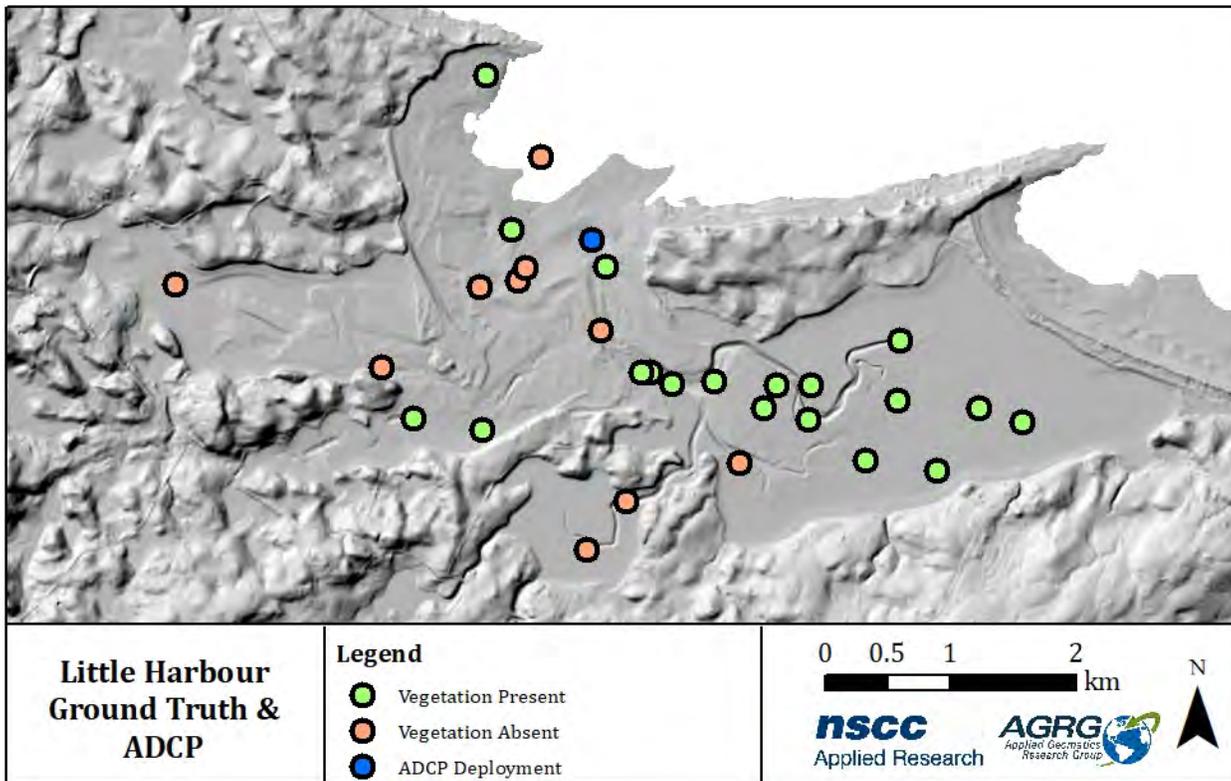


Figure 3.23: Images of bottom type collected with GoPro cameras, used for verification of classified vegetation; position of the ADCP deployment.

3.1.8 Temperature and Salinity Data

Mean temperature from ECCC for 1990-2016 ranges between 17°C and 19.5 °C and salinity data ranges from 26 ppt to 29 ppt. Temperature and salinity do not exhibit spatial correlations (Figure 3.24) or depth correlations (Figure 3.25). The mean and maximum values vary little across the stations, but there is variation in minimum salinity likely due to the locations of the sampling stations near streams, and the CSSP sampling protocol, which requires sampling following heavy rainfall events (Figure 3.26). The sampling program took place between May and November, and other than a few low salinity events, salinity remained between ~25 and ~30 at most stations for most of this season (Figure 3.27). Temperature followed a typical seasonal pattern of warming during the summer months and cooling in the fall but was within ~5-10°C at any station (Figure 3.27).

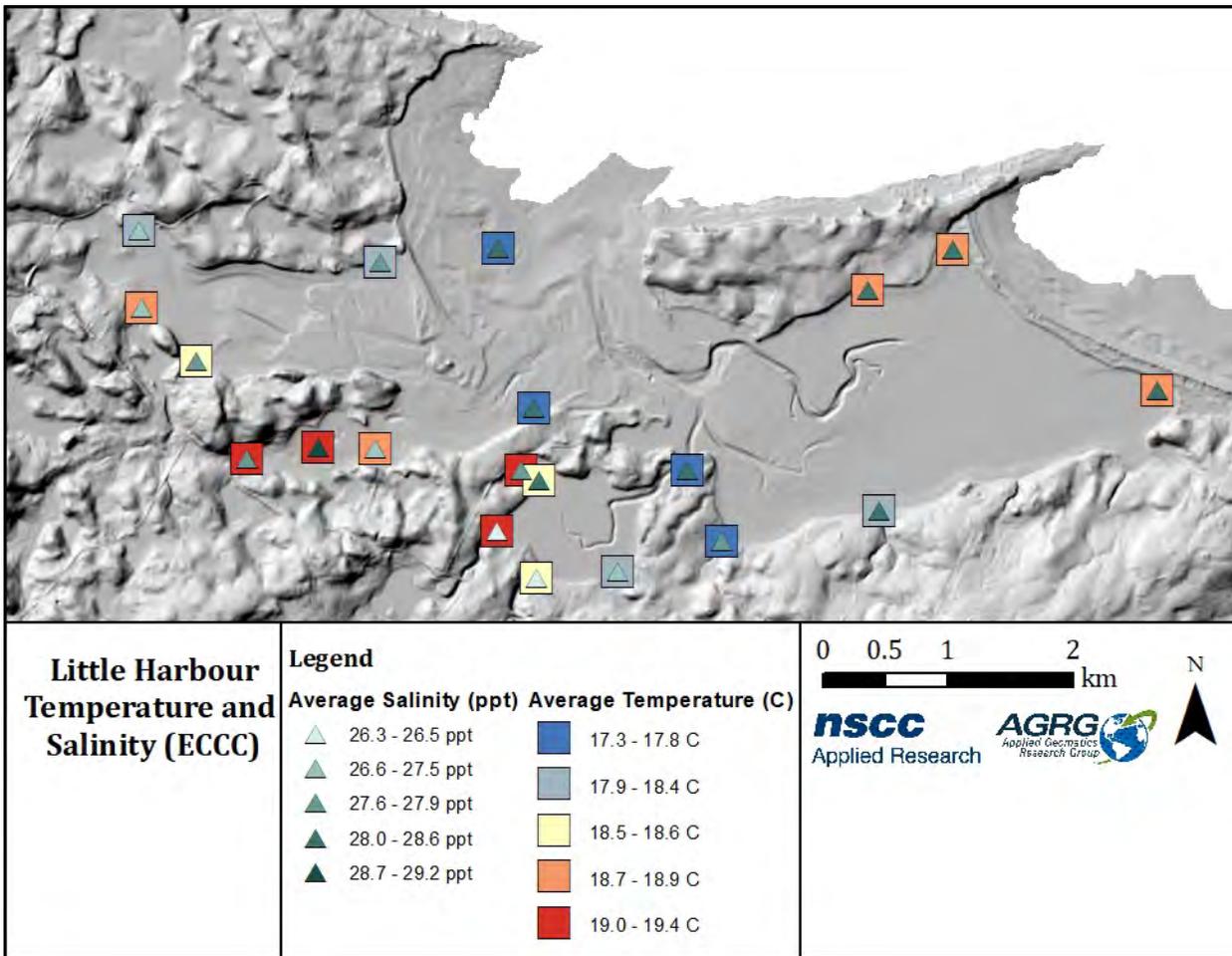


Figure 3.24: Temperature and salinity data from ECCC sampled between 1990 and 2016 as part of the CSSP.

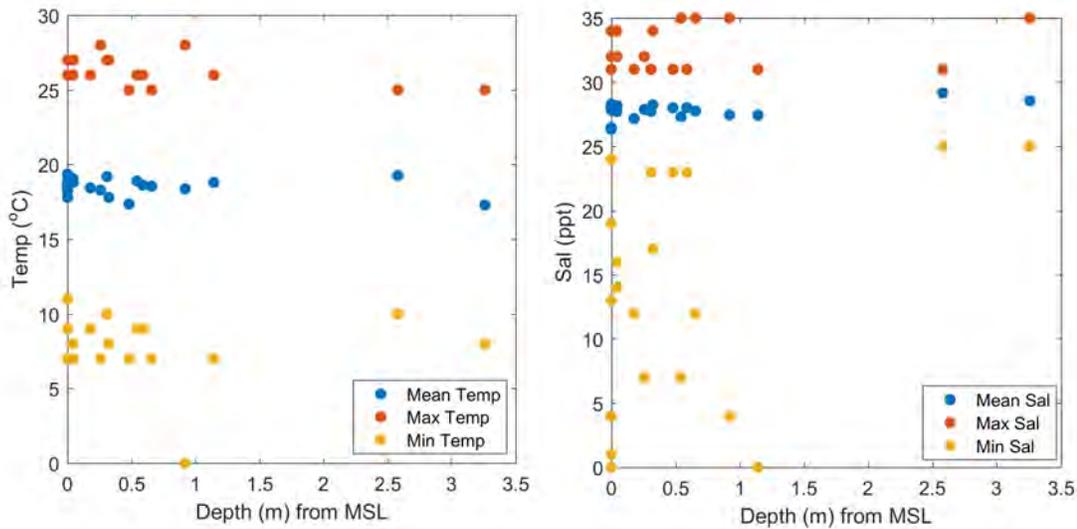


Figure 3.25: Temperature (left) and salinity (right) vs depth (extracted from the Depth layer, relative to MSL).

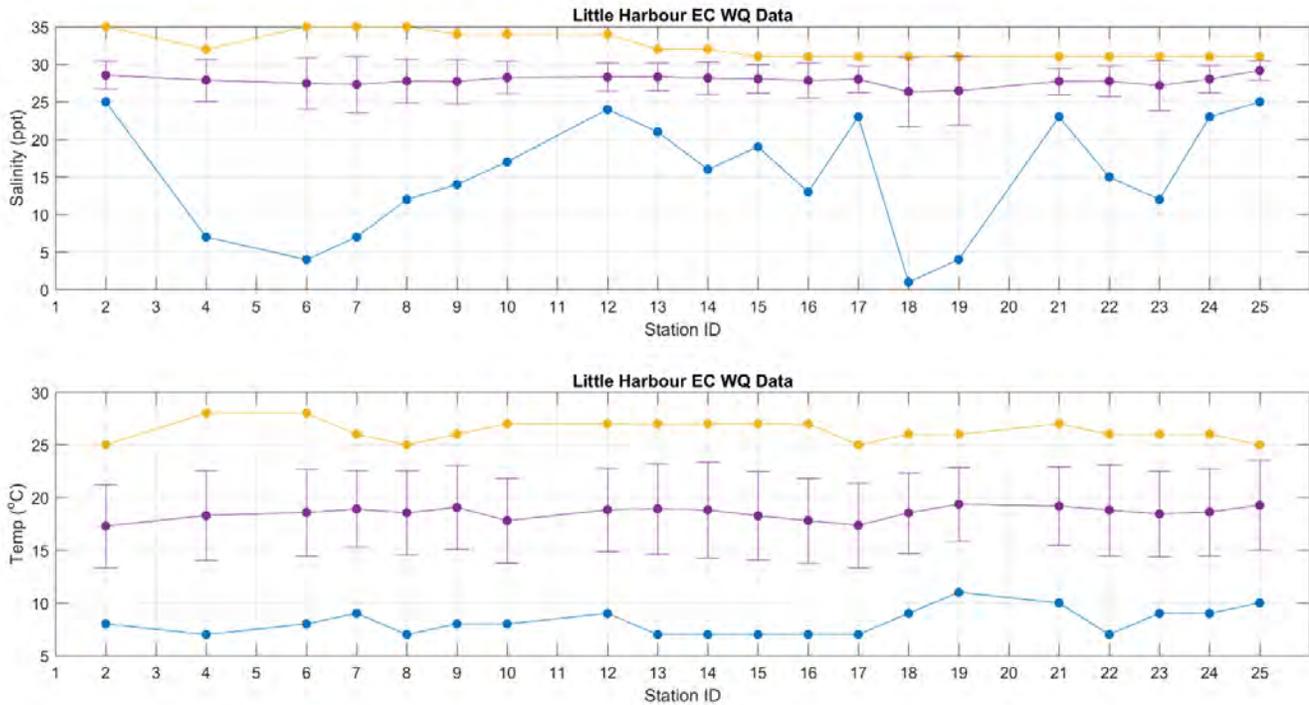


Figure 3.26: Salinity (top) and temperature (bottom) vs sampling station ID. Yellow lines represent the maximum (1990-2016), blue lines represent the minimum, and purple represents the mean plus/minus one standard deviation.

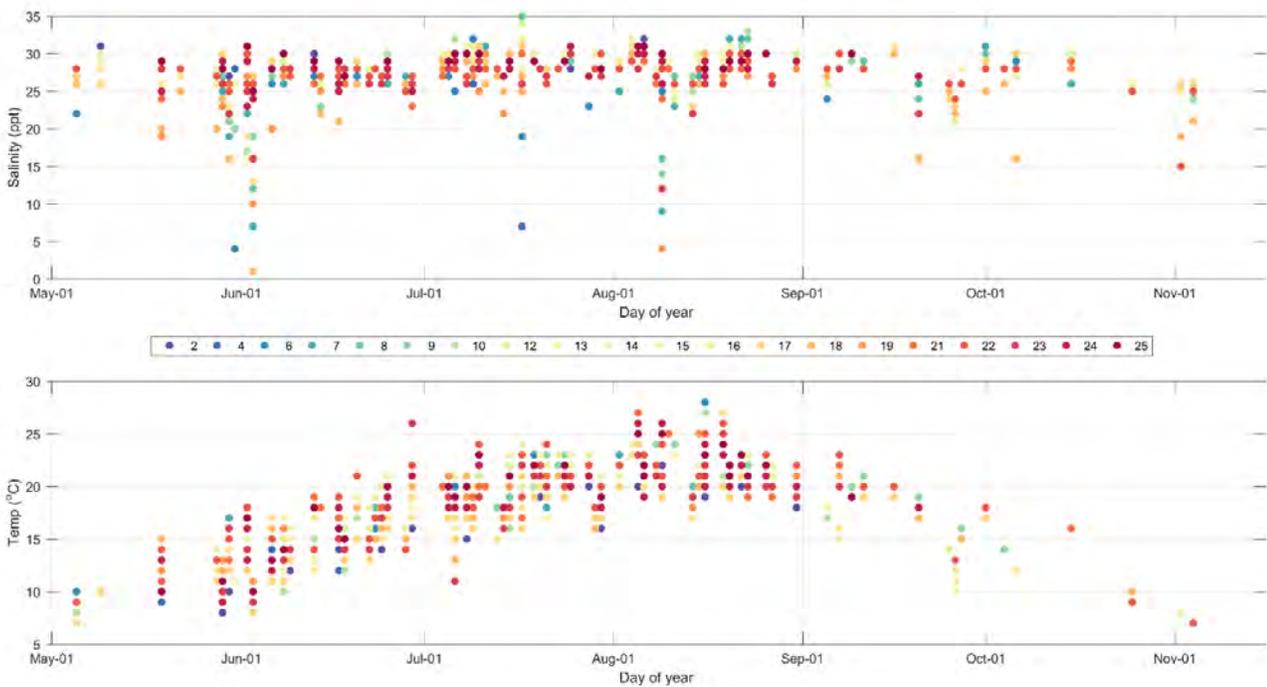


Figure 3.27: Salinity (top) and temperature (bottom) vs day of year and coloured by sampling station.

3.1.9 Web Service Data

The prohibited shellfish closures and aquaculture leases as of March 2018 are shown in Figure 3.28 and Figure 3.29, respectively. More information on closures and leases are available through the web services.

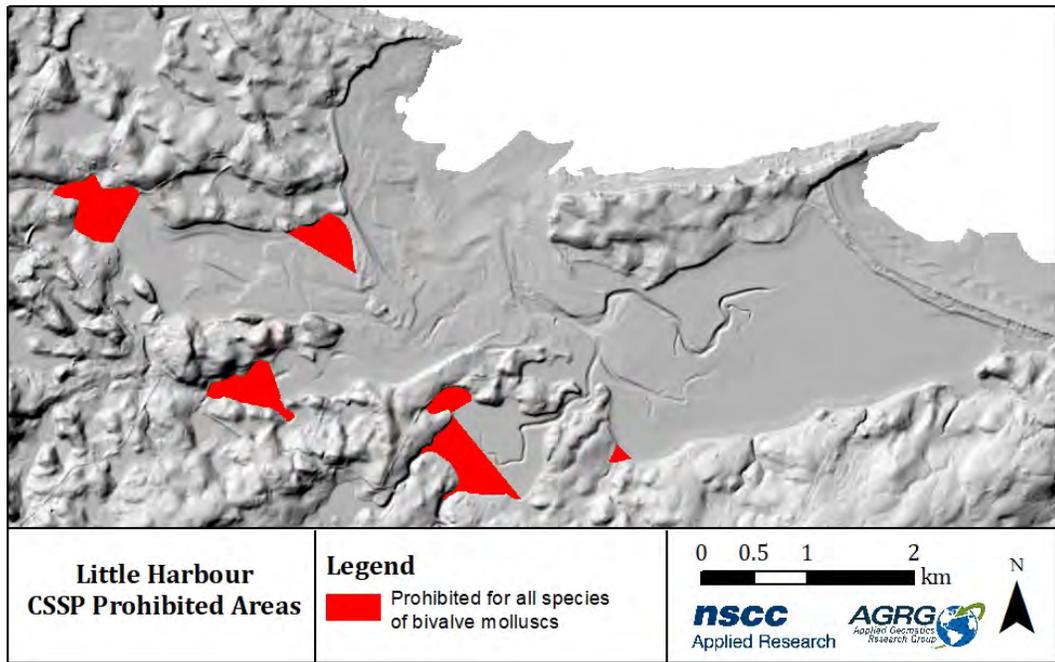


Figure 3.28: Prohibited shellfish areas for Little Harbour as of March 2018. The data for the web tool is accessed as a service from <http://www.dfo-mpo.gc.ca/shellfish-mollusques/cssp-map-eng.htm>.

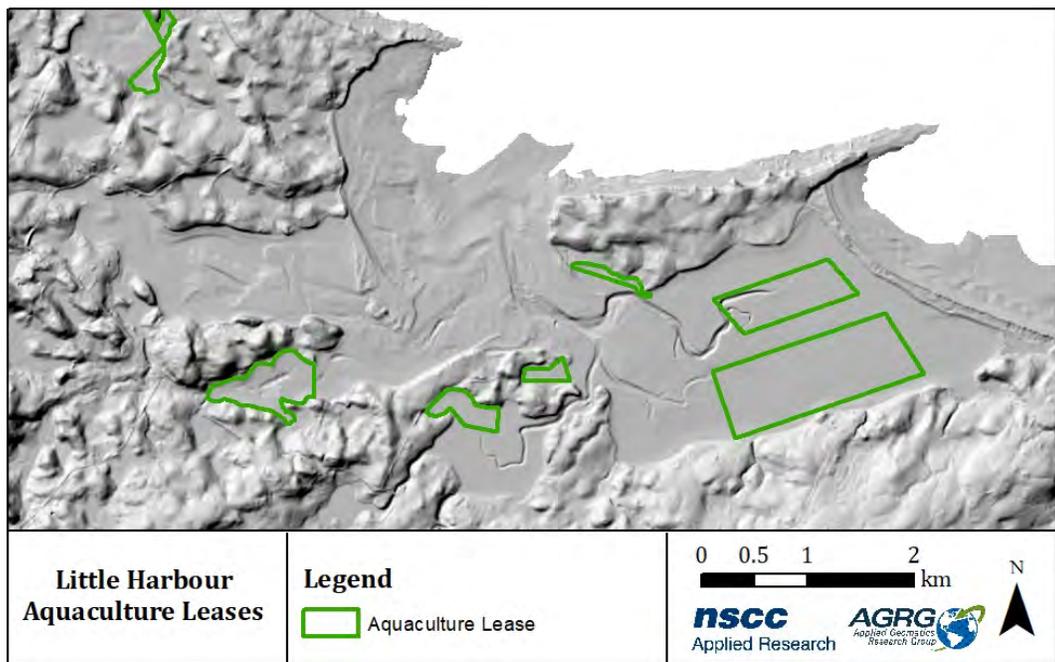


Figure 3.29: Aquaculture leases in Little Harbour. Most recent information is available at <https://novascotia.ca/fish/aquaculture/site-mapping-tool/>

3.1.10 Land Use

The land in the Little Harbour watershed is 70% forested (15 km²), urban/residential land use makes up 13% of overall land use (2.7 km²), while agriculture and clear cut each make up ~8% of overall land use (1.6 km² each) (Figure 3.30).

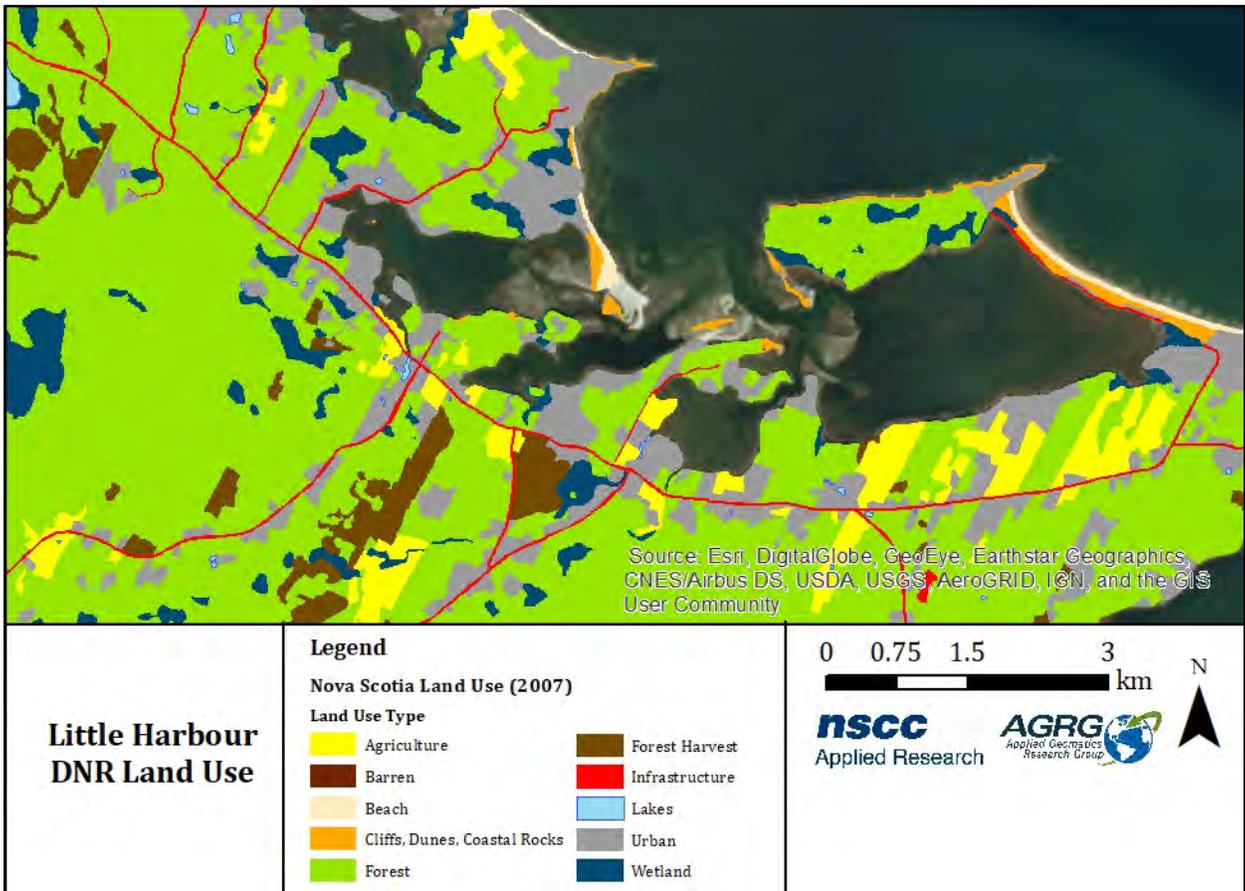


Figure 3.30: The Nova Scotia Forest Resource Inventory land use classification, with reduced categories.

3.2 Aquaculture Suitability Index

The aquaculture suitability index map was created by simplifying input layers into distinct classes, these classes were then attributed suitability weights by experts at DFO. A fuzzy logic routine was run on the weighted layers to produce the final spatial suitability index (Figure 3.31).

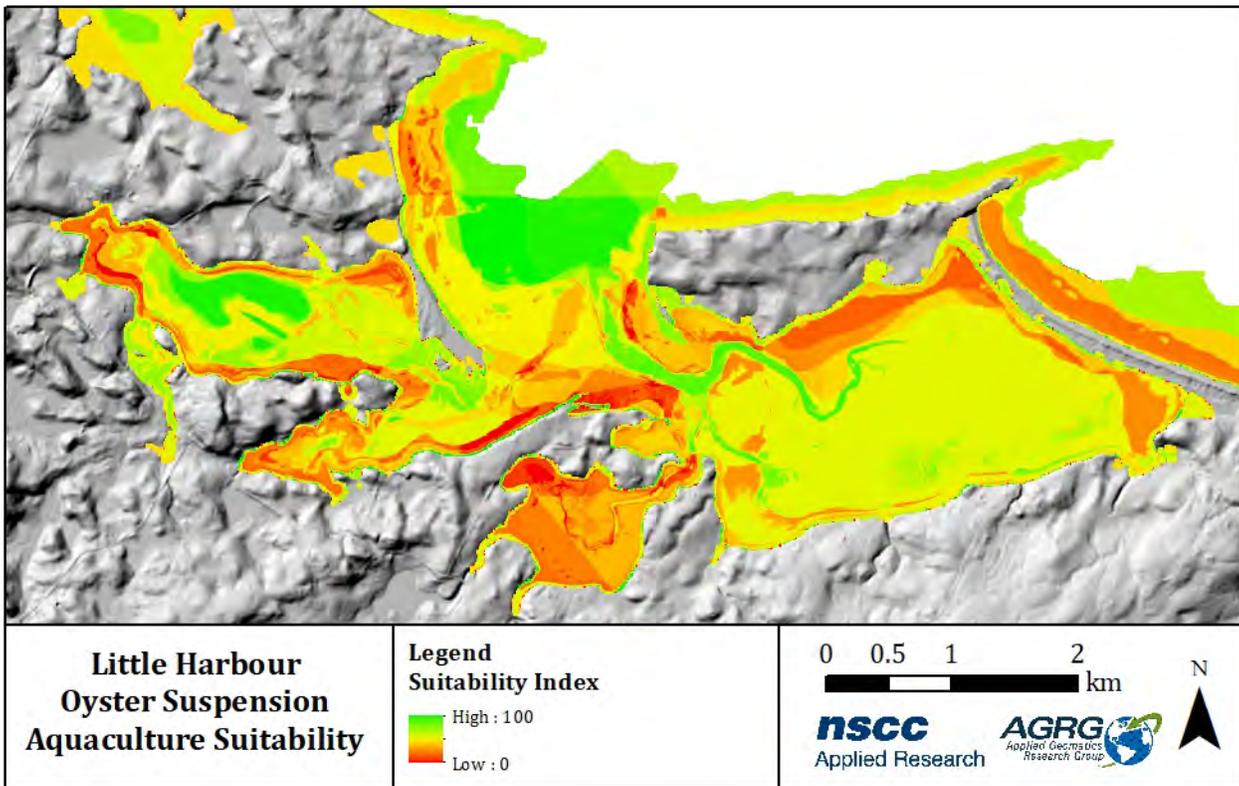


Figure 3.31: Little Harbour Oyster Suspension Aquaculture Suitability map. Areas that are ranked most (least) suitable for aquaculture are shown in green (red).

3.3 Polygon Statistics Tool

The statistics tool allows users to easily obtain metrics on Eelgrass distribution, species presence from traditional ecological knowledge, and water currents and depth by simply drawing a polygon around their area of interest.

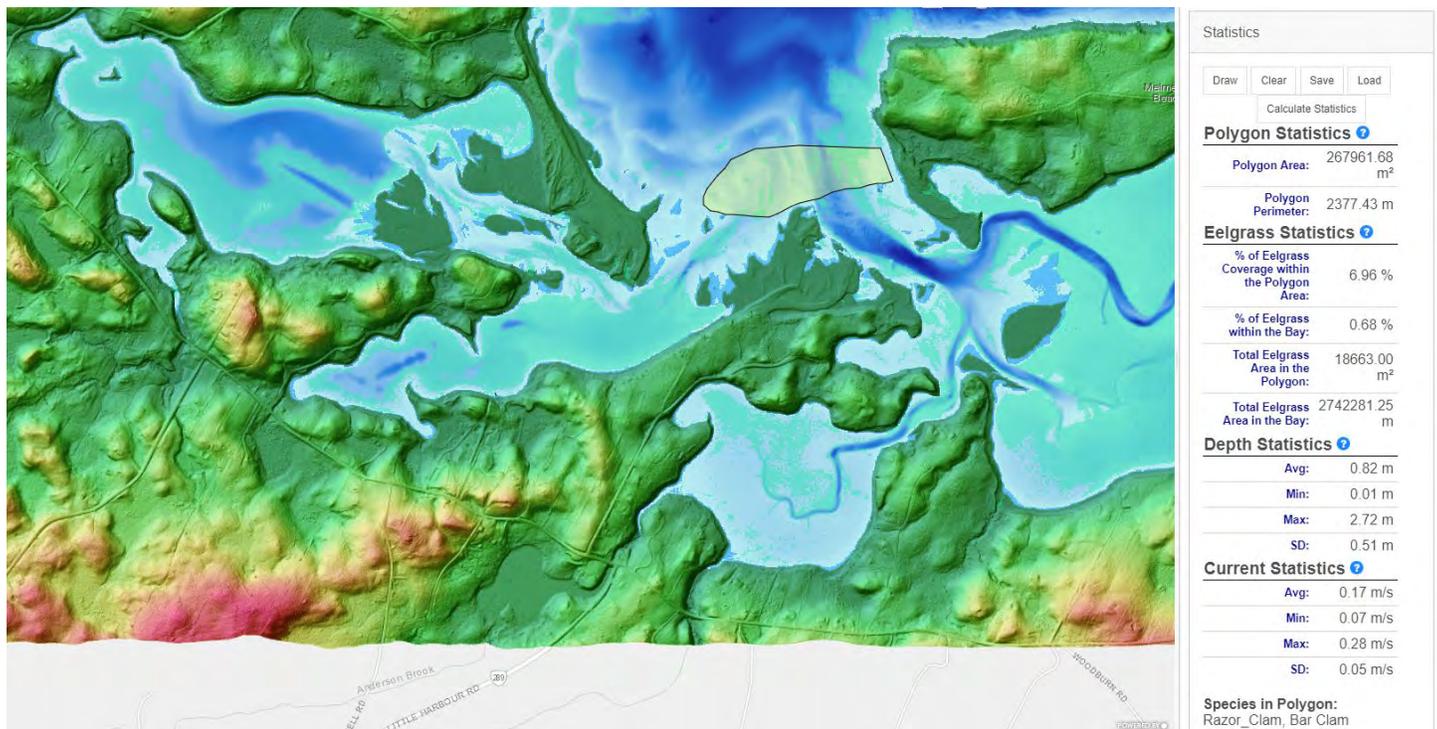


Figure 3.32: Screen shot of output from the statistics web tool.

4 Discussion

The previous study of Little Harbour (Webster et al., 2016a) included an investigation of historic aerial photographs and noted many changes in the coastline over the years that have no doubt been affecting circulation and depth in the harbour, and will continue to do so into the future. The accretion and erosion in this dynamic harbour are important considerations for aquaculture development that have perhaps been overlooked for this study. The 1990 coastline overlaid on the 2014 imagery shows the southward migration of land towards Powell’s Cove across a former channel, and a tiny clump of trees is all that remains of an island that once blocked the mouth of Powell’s Cove (Figure 4.1). The 1990 imagery overlaid with the 2014-derived channel shows how the channel has been re-routed as the land changed (Figure 4.2). It is worth considering the inclusion of the changing coastline, topography, bathymetry, and circulation into future development of the Aquaculture Suitability Map.

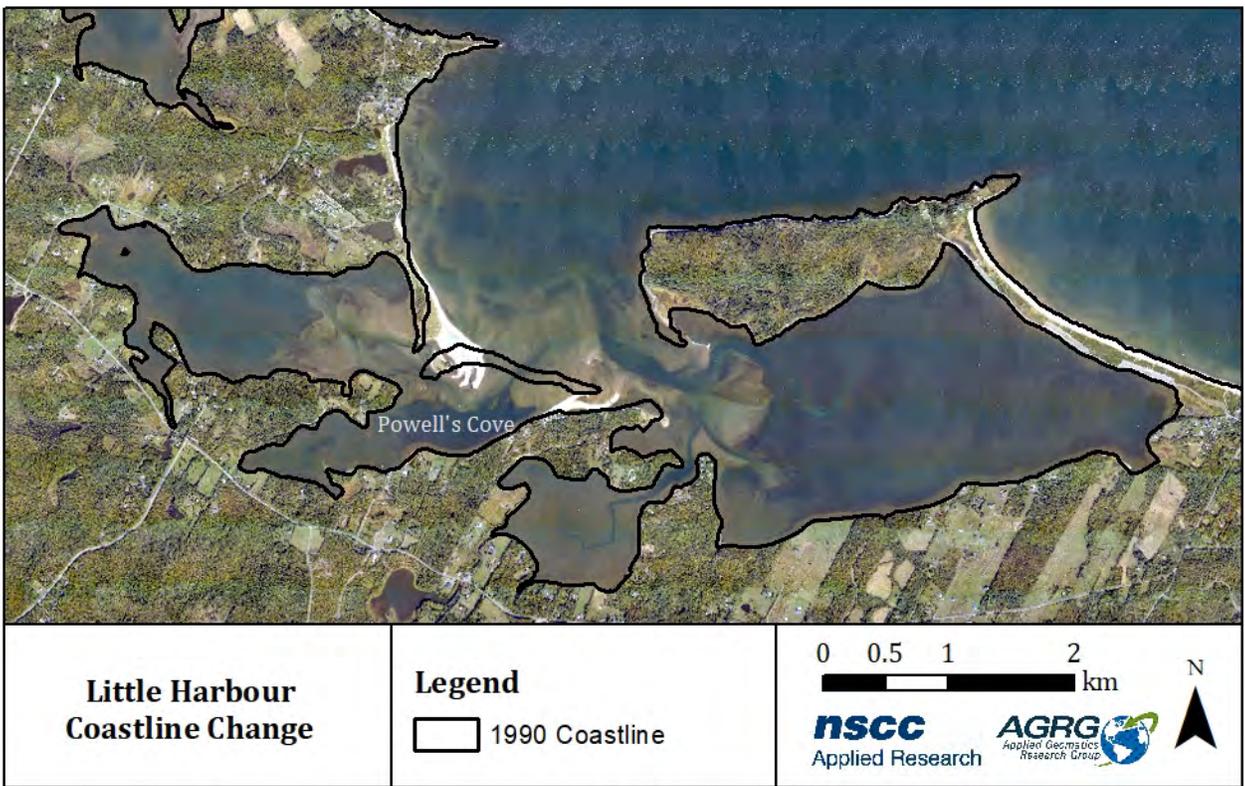


Figure 4.1: The 2014 aerial photograph with the 1990 coastline, showing the changing coastline near Powell's Cove.

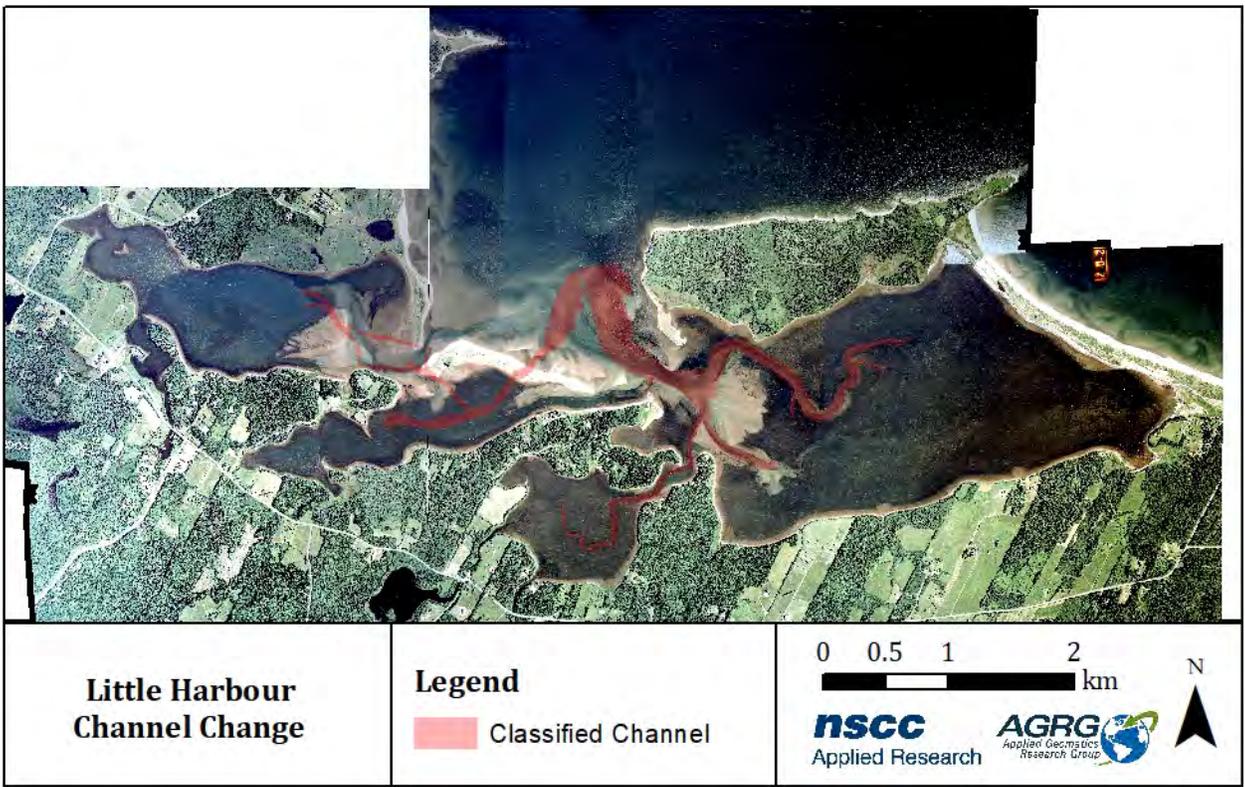


Figure 4.2: The 1990 aerial photograph and the 2014 channel, showing the re-routed channel near Powell's Cove.

5 Conclusions

The Aquaculture Suitability Index and Polygon Statistics Tool were developed for this project. The web-based platform allows users to easily display GIS data layers without using GIS software, and without being tied to a specific computer. This eases access to data and should result in increased utility of the data. The Suitability Index was developed by applying a weight to the input GIS data layers and combining them using a Fuzzy Logic Model. The weights were determined by DFO and resulted in a map of aquaculture suitability that depended on the assigned importance of various inputs. It is anticipated that the index will be a tool to assist decision makers with aquaculture lease site selection. The Polygon Statistics Tool allows users to retrieve information from the GIS data layers without the use of GIS software. The code-based methods developed for this project will transfer easily to a different geographic region. If GIS data layers exist, the exercise of developing a suitability index is trivial due to the work done for this project.

The continued development of this platform might include the addition of other bays and estuaries, adding functionality to allow users to choose the weights of the suitability map and to print a data report.

6 References

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