Fish Habitat Geodatabase and Gap Analysis for Two Binational Areas of Concern in the St. Clair-Detroit River System (SCDRS)

Celeste Y.L. Rémillard , Jacqueline M. Dosen, Jesse Gardner Costa, Jonathan D. Midwood, Kathy E. Leisti, and Susan E. Doka

Fisheries and Oceans Canada
Ontario and Prairie Region
Great Lakes Laboratory for Fisheries and Aquatic Sciences
867 Lakeshore Road
Burlington, Ontario
L7S 1A1

2021

Canadian Technical Report of Fisheries and Aquatic Sciences 3367

Fisheries and Oceans Canada Pêches et Océans Canada

Canada

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.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in the data base *Aquatic Sciences and Fisheries Abstracts*.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page.

Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457-714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715-924 were issued as Department of Fisheries and Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

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. II 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.

Les rapports techniques peuvent être cités comme des publications à part entière. Le titre exact figure au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la base de données *Résumés des sciences aquatiques et halieutiques.*

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 3367

2021

Fish habitat geodatabase and gap analysis for two binational Areas of Concern in the St. Clair–Detroit River System (SCDRS)

by

Celeste Y.L. Rémillard, Jacqueline M. Dosen, Jesse Gardner Costa, Jonathan D. Midwood, Kathy E. Leisti, and Susan E. Doka

Ontario and Prairie Region
Fisheries Ecology Section
Great Lakes Laboratory for Fisheries and Aquatic Sciences
867 Lakeshore Road
Burlington, ON
L7S 1A1

.

Cat. No. Fs97-6/3367E-PDF, ISBN 978-0-660-34539-0, ISSN 1488-5379

Correct citation for this publication:

Rémillard, C.Y.L., Dosen, J.M., Gardner Costa, J., Midwood, J.D., Leisti, K.E., and Doka, S.E. 2021. Fish habitat geodatabase and gap analysis for two binational Areas of Concern in the St. Clair–Detroit River System (SCDRS). Can. Tech. Rep. Fish. Aquat. Sci. 3367: xvi + 103 p.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

Acronym	Description
AOC	Area of Concern
ASL	above sea level
BUI	Beneficial Use Impairment
CHS	Canadian Hydrographic Service
CGVD28	Canadian Geodetic Vertical Datum of 1928
DEM	digital elevation model
DFO	Fisheries and Oceans Canada
EC	Environment Canada (pre 2016)
ECCC	Environment and Climate Change Canada
EV	emergent vegetation
EPA	Environmental Protection Agency (U.S.)
GDB	geodatabase
GLIER	Great Lakes Institute of Environmental Research (University of Windsor)
GLLFAS	Great Lakes Laboratory for Fisheries and Aquatic Sciences (DFO)
HZD	hazard score
HEAT	Habitat / Ecosystem Assessment Tool
IGLD85	International Great Lakes Datum of 1985
IJC	International Joint Commission (US, Canada)
LiDAR	light detection and ranging
LIO	Land Information Ontario
OMNRF	Ontario Ministry of Natural Resources and Forestry (also MNR)
MTRI	Michigan Tech Research Institute
NGS CUSP	National Geodetic Survey Continually Updated Shoreline Product
NOAA	National Oceanic and Atmospheric Administration (U.S.)
OWES	Ontario Wetland Evaluation System
PEC	probable effect concentration
RAP	Remedial Action Plan
RMA2	Resource Management Associates two-dimensional model
SAV	submerged aquatic vegetation
SCDRS	St. Clair–Detroit River System
SEMCOG	Southeast Michigan Council of Governments
SLCC	Sea Lamprey Control Centre (DFO)
TEC	threshold effect concentration
USGS	United States Geological Survey
USACE	United States Army Corps of Engineers
UW	University of Windsor
WIFN	Walpole Island First Nation

ABSTRACT

Rémillard, C.Y.L., Dosen, J.M., Gardner Costa, J., Midwood, J.D., Leisti, K.E., and Doka, S.E. 2021. Fish habitat geodatabase and gap analysis for two binational Areas of Concern in the St. Clair–Detroit River System (SCDRS). Can. Tech. Rep. Fish. Aquat. Sci. 3367: xvi + 103 p.

In this assessment, the St. Clair–Detroit River System (SCDRS: pronounced *scudders*) spans from the source of the St. Clair River at Lake Huron through Lake St. Clair and south to the outflow of the Detroit River at Lake Erie. This restricted SCDRS extent is bordered by one American state (Michigan) and one Canadian province (Ontario) and does not include the western basin of Lake Erie. The SCDRS historically had extensive fish and wildlife habitat, however increased urbanization and pollutants, among other factors, have degraded the system, resulting in the listing of four Great Lakes Areas of Concern within the SCDRS. Extensive temporal and spatial datasets have been collected by several agencies on both sides of the border. Fisheries and Oceans Canada has compiled, organized, and analyzed these datasets into geospatial layers in a geodatabase to generate maps of ecologically important features: elevation, velocity/flow, toxicity, vegetation, and substrate. This report outlines how the data were collected, stored, and summarized into the geodatabase. Data gaps for each layer have been identified. This report has reconciled the data collected; merged the different classification schemes into one spatial layer for each ecological feature assessed; and identified methods that could be applied for any future work. We recommend standardized data collection and classification for the different data layers in the system moving forward. Generally, we recommend consistent, frequent, spatially-representative sampling of features that change often or seasonally, such as vegetation, and less frequent updates for spatial layers such as elevation.

RÉSUMÉ

Rémillard, C.Y.L., Dosen, J.M., Gardner Costa, J., Midwood, J.D., Leisti, K.E., and Doka, S.E. 2021. Fish habitat geodatabase and gap analysis for two binational Areas of Concern in the St. Clair–Detroit River System (SCDRS). Can. Tech. Rep. Fish. Aquat. Sci. 3367: xvi + 103 p.

En cette évaluation, le Réseau des rivières St. Clair et Détroit (RRSCD) s'étend de la source de la rivière St. Clair, au lac Huron, en passant par le lac St. Clair jusqu'à l'embouchure de la rivière Détroit, au lac Érié. En cette région rétracte, le RRSCD touche un état américain (Michigan) et une province canadienne (Ontario) et n'est pas inclus la basin ouest de lac Erie. Par le passé, cette région constituait un vaste habitat pour les poissons et la faune, mais l'augmentation de l'urbanisation et des polluants, entre autres facteurs, ont détérioré le réseau, ce qui a mené à l'établissement de quatre secteurs préoccupants des Grands Lacs dans le RRSCD. De vastes ensembles de données temporelles et spatiales ont été recueillies par plusieurs organismes des deux côtés de la frontière. Le ministère des Pêches et des Océans du Canada a compilé, organisé et analysé ces ensembles de données en couches géospatiales dans une base de données géographiques afin de générer des cartes des caractéristiques écologiques importantes : élévation, débit/vitesse, toxicité, végétation et substrat. Ce rapport décrit la manière dont les données ont été recueillies, stockées et résumées dans la base de données géospatiales. Les lacunes dans les données de chaque couche ont été cernées. Ce rapport met en parallèle les données recueillies, fusionne les différents systèmes de classification en une couche spatiale unique pour chaque caractéristique écologique évaluée et désigne les méthodes qui pourraient être appliquées aux futurs travaux. Nous recommandons de normaliser la collecte et la classification des données des différentes couches de données du réseau. En général, nous recommandons un échantillonnage cohérent et représentatif dans l'espace des caractéristiques qui changent souvent ou de façon saisonnière, comme la végétation, et des mises à jour moins fréquentes des couches comme l'altitude.

INTRODUCTION

The St. Clair–Detroit River System (SCDRS, pronounced scudders; Figure 1) drains from the inflow of the St. Clair River at Lake Huron through Lake St. Clair and the Detroit River, south to the outflow into Lake Erie, and is hydrologically supplied by both Lake Huron and Lake Erie drainage basins (which include Lake St. Clair). The SCDRS has nine tertiary watersheds, ranging in size from approximately 700 km^2 to 31,000 km^2 (LIO 2012) and the main channel has approximately 726 km of shoreline (EC 1994). Home to or used by over 100 different fish species (D. Reddick and S. Doka, unpublished data), the SCDRS has varied aquatic habitat that is important for fish spawning, foraging, and juvenile growth. This document focuses on the main waterbodies of the system and their inflowing rivers and creeks, and not the entire drainage area.

In 1987, under the Great Lakes Water Quality Agreement (GLWQA), the International Joint Commission (IJC) established the Areas of Concern (AOCs) program (IJC 1987). This program identifies “locations where environmental conditions resulting from human activities—officially termed Beneficial Use Impairments (BUIs)—locally prevent certain uses of the lakes” (IJC 2015). If an area was recognized as having one or more of the 14 BUIs (Table 1), it was deemed an AOC and quantitative targets for improvement / recovery of the impaired BUIs were developed through Remedial Action Plans (RAPs) (IJC 2015). The SCDRS was identified by the IJC as containing four AOCs, two shared binationally between Canada and the U.S.—the St. Clair River and the Detroit River—and two AOCs located to the west of Lake St. Clair on the U.S. side of the lake (DRCC 2018) that are not considered here. This report focuses on the two binational AOCs, the connecting channel systems, and Lake St. Clair.

In 1986, initial monitoring of these binational AOCs was conducted, resulting in nine of 14 BUIs in the St. Clair River and 12 of 14 in the Detroit River identified as impaired, including BUI #14, the “loss of fish and wildlife habitat” (GLWQB 1980). Since those assessments, multiple organizations have combined their efforts to remediate the St. Clair River and Detroit River through RAP targets. As of the 2017 reassessment, these RAP efforts have resulted in three of the original nine BUIs in the St. Clair River and six of the 12 BUIs in the Detroit River to be considered unimpaired, with three and one BUI(s) in the St. Clair River and Detroit River systems, respectively, “requiring further assessment” (Table 2). Although progress has been made, the whole system remains influenced by multiple stressors, including contaminants in runoff and wastewater, large-scale shoreline hardening, and urbanization as in other locations in the Great Lakes (Wichert et al. 2004; Chu et al. 2015).

The Fish Habitat Science laboratory (herein referred to as “us,” “we,” “our,” or “Doka Lab”) working under the Great Lakes Laboratory for Fisheries and Aquatic Sciences division of DFO (Fisheries and Oceans Canada) focuses on the status of fish habitat in the Great Lakes. The geodatabase (GDB) we present in this report contains spatial data detailing ecological features of fish habitat within the SCDRS geographical area. To build the GDB, data from various sources, including our own field data (see Table 3 for data sources), were compiled into a geographical information system (GIS). All of the data collected were verified, modified, and merged to create a collection of comprehensive layers to be used to partially assess BUI#14, the loss of fish habitat. These layers establish a collection of maps that spatially characterize the following ecological features in the SCDRS: elevation, water velocity/flow, toxicity, vegetation (emergent/submerged), and substrate type/size composition (Figure 2).

In order to contribute to the BUI #14 assessment, the fish habitat spatial layers in our GDB are to be combined and used to assess and predict habitat suitability over the life cycle of a variety of fishes in the system, considering local ecological drivers, development projects, and conservation and restoration goals. The layers are used in our Habitat Ecosystem Assessment Tool (HEAT), which outputs fish habitat suitability and supply for the identified local or target species over three life stages, considering their guilds (e.g., thermal or feeding guilds) and their predominant associations with a variety of habitat features, such as water depths and types of aquatic vegetation and substrate. For more background and usages of HEAT, refer to Tymoshuk et al (2017) and DFO (2019). HEAT can be applied to the SCDRS now that the main habitat features or layers have been completed and documented here.

In this report we: summarize the spatial data and ecological features used in the GDB to inform fish habitat assessments in the SCDRS; document the protocols established to develop or update georeferenced layers; and identify data gaps within the layers, along with recommendations to improve the GDB in the future. The focus is on fish use of these habitat features and not assessing aquatic mammals, birds, herptiles, or mussels, although others could use this information to do so.

SPATIAL FRAMEWORK FOR A FISH HABITAT GEODATABASE

Creating a GDB framework for fish habitat data provides the capacity to store, assimilate, and analyze data gathered from multiple sources. The SCDRS GDB was modelled after the Hamilton Harbour AOC spatial framework (Doolittle et al. 2010), and we consider the following components necessary to build a spatial GDB:

- ✓ Data organization (how data is collected and compiled by the developer/partners)
- ✓ Data use (by those who receive the data/how it can be used by others)
- ✓ Data gaps (presence/absence of data in AOCs)
- ✓ Data integration and standardization (creating a platform for all AOCs and beyond)
- ✓ Data sharing (providing a system that is easy to access, share, or retrieve data).

Our SCDRS GDB stores all relevant geographic, ecological, and spatial information related to the St. Clair River and Detroit River AOCs and Lake St. Clair fish habitat assessment (note: western Lake Erie is not included) (for data sources and application in layers, see Table 3 and Figure 2, respectively). The GDB incorporates: shapefiles containing point, line, and polygon data; tables containing attributes used for mapping and extracting detailed information such as coordinates; and raster images, which can be integrated with multi-platform data (ESRI 2018a). Creating a GDB provides the ability to make changes 'on-the-fly'—allowing for easier updating and the flexibility to manage different data formats—and improves file compression and information management to enable users to transfer data between programs or other users with ease (ESRI 2018a).

There are three stages to producing a fish habitat GDB: 1) understanding the type of information that has been collected; 2) organizing and displaying the information spatially, including updating or developing metadata; and 3) analyzing or testing the outcomes (Doolittle et al. 2010).

In the first stage, comprehending the data types and collection methods is essential. Often, multiple types of similar data are collected, leaving the developer to understand how the data is organized and spatially referenced, as well as what is needed to create the final output, which is typically either a shapefile or a raster file (ESRI 2018a). Each shapefile layer consists of four main files: .dbf, which contains the tabular data; .prj, the geographic projection of the layer; .shp the type of shapefile (point, line, or polygon); and .shx, which contains the spatial information of the layer. All file types are created at the time of layer development in geoprocessing software (ESRI 2018b, ESRI 2018c). Raster data are also commonly represented as three outputs: 1) as a dataset, which has a predefined output such as bands and columns; 2) as a product that specifies the ways data were collected; and 3) as a type, which enables raster data to be added from other rasters (ESRI 2016a). Spatial files are stored together and accessed as a single unit to display in the appropriate format while stored in a GDB.

Stage two in GDB development involves creating a system that optimizes data input, management, and layer creation. This system defines naming conventions, data storage locations, and projection and is stored as metadata. Quality assurance and quality control of data also occur at this stage. Therefore, extensive knowledge of data and data collection methods, data use, and system management is needed. The final spatial layers can be displayed such that potential data gaps can be identified and thus help define the final stage of GDB development (Doolittle et al. 2010).

In the final stage, gap analyses are performed to determine what data and/or areas need to be updated or corrected and which areas, if any, require more attention. Such analyses are necessary and may need to be repeated to identify missing information for producing reliable scientific assessments. The spatial framework that was developed specifically for the SCDRS is described in this report and includes a description of data collection and map development methods, and also identifies data gaps for the SCDRS spatial information as of 2017.

DATA AND SITE DESCRIPTIONS

Fish habitat and water quality data in the SCDRS were collected by the authors (sometimes in partnership, including with Walpole Island First Nation), multiple federal, provincial, and municipal agencies, academia, and other Canadian/U.S. environmental organizations (Table 2). We compiled and organized the data, which were provided in multiple formats, including bathymetric, light detection and ranging (LiDAR) and multi-beam backscatter classified outputs, sediment toxicity point samples, and hydroacoustic sampling, among others (Appendix A). Processed field data were compiled using Microsoft Excel (Microsoft Corporation 2016), R software (R Foundation for Statistical Computing, Vienna, Austria), as well as ESRI's ArcGIS 10.4.1 (ESRI 2018b), ESRI's ArcGIS 10.7.1 (ESRI 2018c) and ESRI's ArcGIS Pro 2.4.2 (ESRI 2019a). The final base maps and spatial layers represent three locations within the SCDRS: the St. Clair River, the Detroit River, and Lake St. Clair (Figure 1). Although data were collected for both sides of the border, primarily data from Canadian sources were used to interpret gaps, if present.

ST. CLAIR RIVER

The St. Clair River has a maximum depth of 21 m in the shipping channel, measures between 0.5 to 1.5 km in width at datum, and is roughly 64 km in length from its source at Lake Huron downstream to where it splits into a delta system—including the North and South Channels—that drains into Lake St. Clair. The North Channel is on the U.S. side of the St. Clair River delta and is close to Harsens Island, a wetland comprising important fish and wildlife habitat (DNRM 2017). The Canadian side is defined by the international border through the centre of the main river and South Channel. Located east of the river and South Channel is the Walpole Island First Nation (WIFN; unceded territory), which has many wetlands for fish and wildlife habitat with many dykes and berms, somewhat typical of other wetland areas in the system (J. Gardner Costa, S.M. Larocque, D. Reddick, M. Croft-White, E. Budgell, C. Jacobs, S.E. Doka, J.D. Midwood, unpublished data). The main St. Clair River channel is used by large shipping freighters and pleasure craft (Appendix A), and has multiple land uses on either shore and on the many islands in the system (e.g., urban, agricultural, industrial). Much of the system has been channelized with vertical seawalls. Many people, fishes, and wildlife are directly or indirectly affected by the human-influenced land and water uses occurring here (GLWQB 1980; DNRM 2017).

LAKE ST. CLAIR

Although not an AOC itself, Lake St. Clair connects the St. Clair River and Detroit River AOCs. The lake is approximately 1,100 km^2 in area with a maximum depth of 8.2 m in the dredged shipping channel, and an average depth of 3.4 m. The Canada-U.S. border separates the lake on a southwest angle from the shipping channel of the St. Clair River to Lake St. Clair's confluence at the Detroit River inflow. In Lake St. Clair, the distribution of spatial samples collected and compiled for layers is not as dense as in either river. However, since the St. Clair River and Detroit River AOCs are hydrologically connected through Lake St. Clair, environmental factors at one location in the system may affect fish and wildlife habitat in areas downstream. Therefore, Lake St. Clair is included in the analysis of the SCDRS as a whole for a more complete and binational spatial perspective.

DETROIT RIVER

The Detroit River measures 52 km in length with a maximum depth of 15 m and is on average 2.6 km in width (EC 1994; USACE 2019). This connecting channel extends from its source at Lake St. Clair to its mouth at Lake Erie. Like the St. Clair River, the Detroit River is also a major shipping route that has routine dredging (Appendix A).

Although both rivers' characteristics have been captured through many spatial data sources, the Detroit River is more data-rich than the St. Clair River, especially for elevation, flow/velocity, and toxicity data.

ECOLOGICAL FEATURES

The SCDRS is comprised of many ecologically important areas for fish, including the St. Clair River delta, as well as multiple islands and many coastal wetlands located within the Detroit and St. Clair rivers and Lake St. Clair. Here we present information for the ecological features used in our fish habitat assessment of the corridor.

ELEVATION

Elevation typically describes the height of a feature relative to mean sea level. Elevation information is necessary when describing topography and sea or lake levels, and can be especially critical in defining watersheds. Land and seabed elevations and bathymetric data (water depth) are used with water level elevations to predict the distribution of wetted area and create a baseline that defines the extent of aquatic habitats. Elevations are important because water depth interacts with many other habitat variables (e.g., velocity/flow, vegetation, substrate) to influence overall habitat suitability (NOAA 2017). Often, bare-earth elevations are used to create digital elevation models (DEMs; ESRI 2020), which interpolate elevation data over evenly spaced grid cells or lattices using GIS or similar software.

To create a DEM, elevation values must be referenced using a standardized vertical datum. A vertical datum is a reference point from which to report elevations or to standardize bathymetry (NOAA 2018). Historically, mean sea level was most commonly used as the zero elevation reference point (Mahoney 2008). However, as technology developed, more accurate local datums were derived and now there are multiple universal datums used. The U.S. typically applies the North American Vertical Datum of 1988 (NAVD88; NRCAN 2016) as their standard reference frame, while Canada uses the International Great Lakes Datum of 1985 (IGLD85; NRCAN 2019) or the Canadian Geodetic Vertical Datum of 1928 (CGVD28; NRCAN 2019). The SCDRS is a unique region as it is not only binational, but geographically it also covers multiple local, vertical datums, (NOAA 2018), herein referred to as "vertical step planes." These are particularly important for greater accuracy in adjusting water levels and calculating flooding in DEMs.

To create a DEM that covered the entire geographical area of the SCDRS, LiDAR and bathymetry data spanning several years were collected from several sources. Multiple steps were required to merge all of the LiDAR and bathymetry data and produce a seamless final DEM layer (for data sources and application in the DEM layer, see Table 3 and Figure 2 [digital elevation model]).

First, we needed to piece together all of the datasets and ensure no overlap between the LiDAR and bathymetry data were present; in our past experience, this has introduced errors because each dataset extrapolates their respective data differently. Therefore, we created two extents of the system using a shoreline shapefile (NOAA and NGS 2019). The shoreline shapefile was converted to a polygon layer (ESRI 2016b) and used to represent the aquatic extent of the system. The same shoreline layer was then buffered using a 1-km buffer distance (ESRI 2016c) as the upland boundary of the extent, excluding the wetted areas. We clipped the LiDAR datasets to the upland boundary layer so that it covered only the land portion. Likewise, the bathymetry datasets were clipped to the aquatic layer to ensure no overlap with the LiDAR data.

Next, it was important to ensure all datasets referenced the same vertical datum. We used IGLD85 as our standard because the SCDRS is connected to two North American Great Lakes and the IGLD85 is a common standard in Canada. Also, the DEM will be used to inform Canadian and First Nations decision makers on how to manage and restore aquatic habitat in the system, but is easily convertible for U.S. partners. LiDAR data collected from United States Geological Survey (USGS) and Land Information Ontario (LIO) were referenced to other datums (NAVD88 and CGVD28, respectively) and therefore were adjusted to reference IGLD85 instead. We used selected benchmark locations on the U.S. and Canadian sides of Lake Erie, where elevations were collected using multiple vertical reference datums (Zhou 2005). The difference between NAVD88 and IGLD85, as well as CGVD28 and IGLD85, were averaged and used as our adjustment factor. The USGS LiDAR data were standardized by subtracting

0.06 m from all NAVD88 elevation data. The LIO LiDAR data were standardized by subtracting 0.102 m from all CGVD28. The bathymetry datasets we received from the USGS, National Oceanic and Atmospheric Administration (NOAA), and United States Army Corps of Engineers (USACE), were already referenced to IGLD85. We then projected all of the datasets to the North American Datum of 1983 (NAD83) Universal Transverse Mercator Zone 17N coordinate system (NRCAN 2016).

Subsequently, we converted the bathymetry, or water depth data, into elevations using the vertical step plane datums. To do this, we used a polygon shapefile of the vertical step planes developed by NOAA specifically for the area (ECCC, Environment and Climate Change Canada, Burlington, Ontario, personal communication, 2012; NOAA, National Oceanographic and Atmospheric Administration, Germantown, Maryland, 2012, personal communication, 2012; USACE, United States Army Corps of Engineers, Detroit, Michigan, personal communication, 2012; Figure 3). The polygon shapefile contained the range of vertical datums from Lake Huron (176.0 m ASL) to Lake Erie (173.3 m ASL), divided into 30-cm increments. Using the raster calculator tool in ArcGIS 10.7.1 (ESRI 2016d), we converted the bathymetric depth values (always provided at low water datum) to lake-floor elevations, where elevation at bottom was computed as elevation = water depth + vertical step plane datum. (Note: water depth is measured as a negative number from 0 at datum).

Elevation data were sparse in some areas of the SCDRS, such as the southern St. Clair River where distributary channels form the delta. In this region, one DFO field dataset was used in part to produce the DEM (see Appendix A for details) for Lake St. Clair. We collected bathymetry data while sampling for aquatic vegetation using hydroacoustics during two field seasons in 2015 and 2017. The resolution of the sample data were quite coarse with distances of up to 100 m between transects. As well, some areas such as Goose Lake were registering returns of 0-m depth. To account for the large space between the transects and inaccurate data samples, we removed samples with 0-m depths. When this data were corrected and merged with other layers, it appeared distorted. Thus, we decided to interpolate the field points to create a finer resolution raster layer first, before merging with other elevation layers. We performed a natural neighbour analysis (ESRI 2016e) and created a 10 x 10-m bathymetry raster that filled the gaps and smoothed the transition between samples, similar to the resolution of other data sources. This method filled the gaps between the 100-m samples and created a more seamless bathymetry layer. However, there are areas that—due to the relatively large resolution of the interpolated raster layer (10 x 10-m grid)—have been exaggerated and may not accurately represent the finer bathymetric / elevation sources, such as with CHS (Canadian Hydrographic Service)/NOAA and LIO LiDAR information (Table 4), especially along the shoreline.

The wetlands and island area of the delta presented particular challenges for obtaining sufficient bare-earth elevation data. Therefore, multiple sources were required and more steps were taken to ensure accuracy in this lowland area. For the WIFN area only, we used the upland extent to extract relevant data points from the elevation datasets and point cloud data in the area. LIO-processed, point-cloud data were classified using LiDAR returns; the data were provided as landscape tiles, which are easier for data management (i.e., file sizes are very large). We extracted the point data using the "LAS to dataset" tool (ESRI 2019b), then evaluated the points by their numerical return class (ESRI 2019c). For example, a classification value of "2" signified a ground response, and "5" represented a high-vegetation return. Values classified as "ground" were selected and processed using a point to raster method (ESRI 2019c).

The resulting raster showed that interpolations along the shoreline of wetlands in the area typically exceeded ground elevations for the entire area, suggesting the presence of dense vegetation and not bare earth; this is likely influenced by the invasive species *Phragmites australis*, which grows in dense stands. The vegetation elevations were then compared with imagery from the Southwestern Ontario Orthophotography Project (LIO 2015)—a 50-cm high-resolution satellite imagery collection—and with Google Earth (2016) Landsat data, and analyzed using a normalized difference vegetation index (ESRI 2019d) for validation of vegetation presence. Using this method, we determined that elevations of ~180 m ASL were associated with dense-vegetation reflections and not geological or human structures in the St. Clair River delta.

To support our theory of vegetation interference in LiDAR returns in the area, we compared the emergent vegetation dataset from the Michigan Tech Research Institute (MTRI; Bourgeau-Chavez et al. 2015) for confirmation. The MTRI product has recent *Phragmites australis* spp. distributions; the coverage confirmed dense vegetation in the WIFN area, likely affecting elevation values requiring correction to bare-earth elevations (although, in likely flooded wetland areas). These erroneous high elevation values were removed from the point cloud layer before interpolation between elevation points, with higher confidence of being bare-earth measurements.

Once all elevation datasets had been corrected to the same vertical datum and projection, and error checked, we converted them to point layers using the "point to raster" tool (ESRI 2019e). Lastly, we input all of the point layers into the "topo to raster" tool (ESRI 2018d) in ESRI ArcGIS Pro for final digital elevation modelling (ESRI 2018c). Our final 10 x 10-m resolution DEM raster is used as a model for continuous land and sea elevations and produces a more accurate bathymetry in coastal areas.

Data gaps

In the early stages of developing the SCDRS GDB, we created a DEM at a 30 x 30-m resolution. At this coarse resolution, some wetland and shoreline areas were distorted, leading to unrealistic anomalies during water level modelling. To improve the elevation model, we determined which spatial anomalies required further investigation, gathered more recent data, and updated all spatial layers. Although the final output is geographically more precise, additional surveys would improve the model at a smaller grid size, with more detailed bathymetric data in data-sparse or older point locations such the St. Clair River delta and surrounding wetlands.

To account for the continuous spread of *Phragmites spp.* in wetlands, ground-truthed elevation data should be collected more frequently and matched with remote sensing imagery for correction. With densities of up to 200 stems per square metre (GLANSIS 2016; Wynia 2019), this tall vegetation can be impenetrable to LiDAR, resulting in responses classified as high elevation values (Lantz 2012) which are not bare-earth. To correct for this error, several methods were used to correct the elevations, especially in the St. Clair River delta. We recognize the correction factor we used may not apply to all wetlands in the system. Therefore, for greater accuracy in aquatic habitat mapping, especially when creating a DEM for a wetland of such large geographical size, and abundant natural littoral zone, we recommend a strategic approach with regular ground-truthing.

Also, inconsistencies were found in the City of Grosse Pointe Park, Michigan. In this particular area only one elevation dataset was available, at a 90 x 90-m grid resolution. Interpolated values in this urban area were higher than the surrounding terrain. Using Google Earth (2016) and re-analyzing the original raster, there was no explanation (including invasive vegetation) for the heightened elevation found in this area, although it could be from uncorrected structures in the area. Large trees were present but not considered further as a source of error because of their small canopy size. For a more accurate DEM of this location, we recommend using more precise and recent data surveyed from Grosse Pointe Park, Michigan.

When the resolution was coarse or when data were sparse in the channel, it resulted in distorted and uneven raster layers. We used a natural neighbour (ESRI 2016e) analysis to fill the gaps and smooth the elevation data. Although this method did help with the final output, it may not be an accurate representation of the distributary channel depths throughout the delta. It would be beneficial to process the DEM again with multiple new sources of bathymetry data to ensure accuracy and precision in future.

The final DEM is a 10 x 10-m grid. This grid size is another contributing factor in the precision of the elevation layer in the SCDRS GDB. At this resolution, many of the features may be over- or under-represented locally, such as vertical sea walls. However, the underlying data were not collected at a 10-m resolution and has been interpolated to create uniformity across attributes. In particular, shoreline attributes, coarse-grain substrates types (e.g., shoals), and small submerged aquatic vegetation patches may be lost at the 10-m resolution, were not detected by survey equipment, or cannot be predicted by generic models. Due to the system’s size, the underlying resolution and accuracy of the base spatial data, and the computational power required to process data at higher resolution, we believe that a 10-m grid is the most reasonable representation of the system for habitat modelling purposes, currently. As such, no layer should be used for flood mapping (except crudely) or navigational purposes.

Many features would be better represented at a finer scale, but there is also the resolution of fish usage of habitat features which must be considered. We recommend that the next iteration of the DEM be at a finer resolution (i.e., 5 x 5 m) to minimize spatial exaggeration or interpolation errors, or that another spatial method be used to represent discreet features (e.g., polygons to represent edge features better, if that is desired). We also recommend more ground-truthing and sampling in the coastal areas (especially by seawalls), deltas, island areas, and surrounding channels for better elevation accuracy in these important fish habitat areas. Also, increased knowledge of the height, density, and distribution of dense plant species in these areas, in addition to proper land / topographic surveys, will help improve the accuracy of the DEM and allow for higher-resolution habitat modelling and restoration project planning, among many other uses. For example, elevation data in both rivers was more extensive than in Lake St. Clair for navigational reasons; and the area had the oldest (1948) bathymetric data (Table 3) that may have changed significantly given development and land use pressures as well as natural erosion and depositional processes.

VELOCITY AND FLOW DIRECTION

Water velocity is an important ecological factor and is defined as the distance water moves over time, and is often expressed in meters per second (m/s). River velocities can affect plant and wildlife distributions, organic and sediment distributions, fish habitat usage, and lake and river shorelines (through erosion and deposition) (Green 2003; Ford et al. 2008; USGS 2019). The direction of water flow, as distributional gradients, is also important to know in ecological systems, streams and rivers in particular. Both can help predict how sediments move and where sedimentation may occur, and how animals and nutrients are distributed. Often, water flowing from the surrounding watershed brings excess nutrients and pollutants, depending on land cover. Knowing the directionality of flow can help predict where particles will move and what habitats may be affected. And, fish have been shown to avoid certain flows and velocities (Trigal and Degerman 2015).

Flow direction and average velocity in the SCDRS was modelled using an Resource Management Associates, two-dimensional hydrodynamic model (RMA2, ECCC 2019) as a joint project between USACE and USGS (Holtschlag and Koschik 2002). Using water depth, this two-dimensional model was used by Environment Canada (2008) to compute water flow direction, and depth-averaged velocities at a total of 42,936 nodes in the SCDRS, with the St. Clair River and Detroit River data computed at a 5-second timestep. In particular, the velocity data were modelled using specified boundary conditions for water (EC 2008). Inputs included the average monthly outflow from Lake

Huron (5,200 m^3/s) from 1918 to 2010. A downstream water-level boundary condition was the average water level for Lake Erie from 1918 to 2010, equal to 174.14 m (EC 2008). The model's primary calibration parameters were roughness values, established from water level observations, and measurements of instream velocity using acoustic Doppler current profiler data from 1999 to 2001 (Holtschlag and Koschik 2002). The RMA2 model operated under the hydrostatic assumption that accelerations in the vertical direction were unimportant.

The model output was provided as a points layer for the SCDRS extent (Figure 5; for data sources and application of this layer, see Table 3 and Figure 2 [velocity/water direction], respectively). Approximately 71.5% of the samples from the RMA2 model flowed in a southwest direction at an angle of 225°, and the average velocity for the system was calculated as 0.425 m/s. We used a minimum curvature spline technique (ESRI 2016f) in ArcGIS 10.4.1 (ESRI 2018b) to interpolate the velocities to our SCDRS boundary extent at a 10 x 10-m resolution. Additionally, we created a flow direction layer, simply by symbolizing the angle degree assigned to each point as an variably sized arrow. We reduced the number of arrows for better visualization; the water direction arrows were overlain on the velocity layer (Figures 5–7).

<u>Data gaps</u>

Velocities were based on the long-term average water level of 174.14 m for Lake Erie, and the long-term average outflow of 5,200 m^3/s from Lake Huron (Holtschlag and Koschik 2002). In reality, velocity is dynamic and changes not only seasonally, but daily (NOAA 2019a). Therefore, to accurately predict the impact that changing flows, velocity, and water levels have on the ecosystem, it is recommended that seasonal and temporal variations be modelled daily or seasonally to predict range and variability. Changing water levels of recent years or for decadal periods would increase accuracy or allow for trend calculations. Flow specificity would enable detailed modelling of interannual sediment (Mackey et al. 2006) and vegetation dynamics, which are two habitat variables that can provide feedback on velocity and flow redistributions within hydrodynamic systems.

Future modelling could also consider expanding Doppler collection points to include areas experiencing erosion (Nairn 2005). Localized data would allow more accurate predictions of changes to channels and lakes bed. Lastly, it should be noted that wind-driven processes were not considered and can significantly change habitats during extreme events and temporarily affect fish distributions.

TOXICITY

Pollutants enter the aquatic system through multiple avenues, including atmospheric pollution, watershed runoff, and industrial and municipal inputs, as well as through sediment dynamics. These dynamics can hold (concentrate) toxins in the sediment as well as release them into the aquatic environment, depending on concentrations and environmental conditions (Kalff 2002). Fish and other wildlife are both directly and indirectly impacted by pollutants in the ecosystem. Moreover, toxicity is known to have negative impacts on submerged aquatic vegetation growth (MacDonald et al. 2000; Doolittle et al. 2010) and benthic invertebrates (Lotufo et al. 2014; McPhedran et al. 2017). Thus, sediment toxicity sampling and mapping is important to identify contaminant hotspots in the system. This often requires multi-year monitoring and sampling to assess changes in toxicity over time as well as collecting enough spatial samples to determine the threshold concentrations that may have detrimental effects on benthic invertebrates, fish, and wildlife populations (Baudo et al. 1990).

In the SCDRS, sediment toxicity samples were collected from 1999 to 2014 by Dr. Ken Drouillard (University of Windsor [UW], Great Lakes Institute of Environmental Research [GLIER]) and colleagues (Drouillard et al. 2016, 2020; K. Drouillard, UW, GLIER, Windsor, Ontario, personal communication, 2017; Table 5). These data were interpolated into a system-wide map by the Doka Lab. Sediment were sampled at random locations throughout the SCDRS, using Ponar grabs (Drouillard et al. 2020, Figure 8). Additional samples were retrieved from the St. Clair River delta using a probability sampling design which focused on locations believed to have high toxicity in proximity to historical industrial inputs or high levels of urbanization (Drouillard et al. 2020).

Drouillard et al. (2020) analyzed the Ponar sediment samples for potential toxicity by comparing contaminant concentrations, using the consensus based sediment quality guidelines described in MacDonald et al. (2000), as well as the Ontario sediment quality guidelines (Fletcher et al. 2008). The consensus-based guidelines define the threshold effect concentration (TEC: the highest chemical concentration in sediment before toxic effects in benthic invertebrates are likely) and probable effect concentration (PEC: the lowest chemical concentration in sediment where toxic effects for benthic invertebrates are likely) of 28 chemicals of concern commonly found in freshwater sediments (MacDonald et al. 2000; Table 6). The Ontario sediment quality guidelines were used to assess two chemicals (iron and hexachlorobenzene) that were not assigned TEC and PEC values in the sediment quality guidelines described by MacDonald et al. (2000). The Ontario sediment quality guidelines define a low effect level (LEL: a chemical concentration threshold for toxic effects in sensitive benthic invertebrates only) and a severe effect level (SEL: a chemical concentration threshold for toxic effects in most benthic invertebrates); both were considered comparable to TEC and PEC, and interpreted as such in the data provided.

The consensus based sediment quality guidelines were used to determine the overall toxicity of each sample site by computing each site’s hazard score (HZD) (introduced in McPhedran et al. 2017; K. Drouillard, UW, GLIER, Windsor, Ontario, personal communication, 2017; Table 7). TEC and PEC values were used to compute doseresponse toxicity curves that determined chemical-specific anticipated toxicity or “Effect(%)” (i.e., the toxicity value of a chemical, ranging between 0% and 100%; McPhedran et al. 2017). Any chemical with a concentration lower than the TEC was assigned an anticipated toxicity / Effect(%) value of 0%. The HZD for each sample-site was then computed by summing each chemical’s anticipated toxicity / Effect(%), and ranged from 0% to >100%. For further details on how the HZD was computed see McPhedran et al. (2017). They then took the HZD values and divided them into five bins or “HZD categories,” with 5 being the most toxic (K. Drouillard, UW, GLIER, Windsor, Ontario, personal communication, 2017; Table 7).

We were provided the 1999 to 2014 toxicity dataset that was collected and processed at UW, GLIER (K. Drouillard, UW, GLIER, Windsor, Ontario, personal communication, 2017). In total, the dataset consisted of 662 samples (Figure 8) with the associated HZD and HZD category assignments. We used the HZD category data from all years to create our toxicity spatial layer. We interpolated the HZD categories across the entire SCDRS using Thiessen polygons, a method that uses the value of the sample and the distances to the next points (ESRI 2018e, Figure 9). Additionally, values were interpolated across the system using inverse distance weighted smoothing (ESRI 2016g) to create a continuous raster layer in a 10 x 10-m grid representing the relative toxicity of sediments throughout the SCDRS (Figures 10–13).

Data gaps

Given the large size of the SCDRS and the high resolution for mapping we chose, sediment samples for the toxicity layer are comparatively sparse, specifically in ecologically significant areas such as the binational delta wetlands and some areas where toxicity was expected to be high (i.e., near Sarnia, Ontario, as well as additional U.S. AOCs on the St. Clair River and the Detroit River, especially near Detroit, Michigan). Upstream, connected areas with known toxicity issues are likely to have an effect on toxicity levels downstream. For example, the Clinton River (Michigan) and Rouge River (Michigan) U.S. AOCs are watersheds—represented as polygons by the Environmental Protection Agency (EPA 2019a, 2019b, Figure 14)—flowing into the SCDRS and are likely to have areas with toxicity issues. However, the closest samples for the main channel toxicity assessment were approximately 3.0 km (Clinton River into Lake St. Clair, Figure 15) and 100 m (Rouge River into Detroit River, Figure 16) from the rivermouths to the sample site. Therefore, an increased sampling effort in closer proximity to the potentially hazardous inflow regions is recommended to capture any gradients from those sources.

Additionally, the data samples were taken from 1999 to 2014. Up-to-date toxicity data can track remediation efforts and account for natural processes (such as sedimentation or water flow and velocity in the region) that may alter or redistribute pollutants over time. When separated into two time stanzas (1999–2008 and 2009–2014), the change in toxicity levels between stanzas is evident (Figures 17–20). Thus, lumping the results together over time to create a complete spatial picture of the system can distort the output by including older and more toxic samples, and lead to misrepresentation of toxicity hazard locally, such as near the main outflow to Lake St. Clair in the delta. These time stanzas will be used as toxicity scenarios in future fish habitat modelling.

VEGETATION

For the vegetation layers, we used data from multiple agencies on both sides of the border to map the presence of emergent vegetation (EV) and submerged aquatic vegetation (SAV) in the SCDRS. EV is rooted at the bottom of a water body with stems and leaves extending above the water surface, and is typically found in wetlands and within the littoral zone, usually within 5 m of the shoreline (Wetzel 2001), depending on wave protection. SAV grows at-bottom and within the water column but does not break the water's surface (Wetzel 2001). Both EV and SAV provide food and habitat for wildlife and aquatic species, depending on the life stage of the organism (Carpenter and Lodge 1986; Wetzel 2001). We acknowledge that floating-leafed vegetation also exists in EV and SAV areas, but we do not map or model that vegetation type, specifically. Knowledge of the presence and potential for vegetation within a system is necessary for ecosystem condition assessments and habitat suitability mapping for biota (ENVIRON 2009).

Emergent vegetation

EV provides habitat for fish and other wildlife and can be used by various species of fish at different life stages (Carpenter and Lodge 1986; Portt et al. 1988, 1999). The data used to create our system-wide EV layer were originally processed by Southeast Michigan Council of Governments (SEMCOG), MTRI, and LIO (for data sources and their application into layers, see Tables 3 and 8 and Figure 2 [emergent vegetation]). SEMCOG (2004) describes wetlands as locations where water is present above a natural land mass for three seasons and contributes to varying levels of vegetation growth (Lusch and Goodwin 2012). SEMCOG identified EV and wetland locations in the U.S. by analyzing three sets of data: the National Wetlands Inventory, soils data, and land-use data (Lusch and Goodwin 2012). Once wetland areas were confirmed, SEMCOG categorized the data into six classes: aquatic bed, beach/bar, emergent, forested, open water, and scrub shrub, plus unconsolidated.

MTRI has developed a wetland and land-use layer that encompasses the entire Great Lakes basin and uses satellite imagery from multiple sources. They used a hybrid method of the Anderson Level 1 and National Wetlands Inventory classification systems (Bourgeau-Chavez et al. 2015) to identify wetlands and other vegetative cover. The wetland and cover data were input into a random forest classifier and resulted in 24 vegetation classes that we reinterpreted.

LIO defined wetlands as areas with variable water levels, with certain soil conditions, and a “growing system” suitable for specific plants (LIO 2017). LIO has identified and mapped the wetlands in Ontario using the Ontario Wetland Evaluation System (OWES). To fill in the gaps, LIO collected additional wetland data from Wetland Interim, Forest Resource Inventory, Southern Ontario Land Resource Inventory System, and Ontario Ministry of Natural Resources and Forestry (OMNRF) district data. All data sources were joined to create the OWES map layer. LIO defined EV more broadly in six classifications: open water, bog, fen, marsh, swamp, and unknown.

To compile this data into one comprehensive EV layer for the SCDRS, only classes of EV were selected and merged into our final layer. From the SEMCOG data, we used the “emergent” class. Six out of the 24 MTRI land-use descriptors included EV, including wetland, *Schoenoplectus* spp., *Typha* spp., *Phragmites* spp., wetland shrub, and forested wetland. Finally, from the LIO (2017) data, we used the marsh and swamp wetland classes only; bog and fen are typically upland features. All data layers were merged into a single polygon layer and were classed as EV only. Thus, the SCDRS had an EV coverage of 233.4 km^2 within a 1-km distance from the main channel shoreline across the region (Figures 21–24, Table 8). Scenarios of pre and post *Phragmites* invasion and its inferred suitability (Wynia 2019) will be compared.

<u>Submerged aquatic vegetation</u>

SAV is used as food and foraging habitat for many fish and wildlife species, and its presence has been identified as an indicator of aquatic ecosystem health (LSRCA 2011). We collected SAV data through hydroacoustic and quadrat sampling between 2007 and 2017 (for data sources and application of this layer, see Table 3 and Figure 2 [submerged aquatic vegetation]; (Appendix A, Tables A1–A4, Figures A1–A7; see also Midwood 2020). In total, 81,868 georeferenced samples were collected throughout the Canadian side of the system and evaluated for SAV presence–absence (Figures 25–28, Table 9).

The sample data for the rivers only (*n* = 54,671) were divided so that 75% of the data were used as model input (to train the model), and the other 25% were used to validate the model. These data, along with distance to shipping channel and water depth, were used to develop a random forest SAV model, specific to the SCDRS, that can predict SAV cover throughout the connecting channels (Appendix A). The final model predicts SAV with 94% accuracy (compared to the validation dataset). Our final raster SAV layer presents a prediction of SAV presence by cell based on the input variable for the model, displayed as percent cover (ESRI 2016a) (Figure 29). In general, the model output predicted that SAV is relatively dense in the nearshore, protected areas, and absent beyond a depth of 10 m (inferred from best water transparency values) (Appendix A).

Data gaps

There were a few spatial data gaps identified in the EV layer. In particular, we found classification methods and sampling frequency were not consistent from year to year or group to group. Differences in the classification schemes used by the three sources created challenges in accurately identifying and merging vegetation types for our purposes. As such, we assumed classes must be similar if their descriptions were similar among the various naming conventions. We accept that this may result in the over- or under-representation of EV in the system. Additionally, the distribution of EV alters as conditions such as water levels (DFO 2018) or growth of invasive species changes.

As for the SAV layer, training and validation data were primarily collected on the Canadian side of the river, but efforts were made to cover a suite of habitat conditions potentially relevant to SAV distribution. More data could be collected on both sides of the river, but for now the model is sufficient for future scenario comparisons. Of note, the SAV model output represents a system with good water clarity and as such, potential future conditions. That future desired state can be compared with periods of reduced water clarity, current conditions, or prior vegetation surveys. Therefore scenario analysis would compare before and after water quality improvements, or zonal adjustments for currently turbid rivermouths.

With increasing urbanization in the SCDRS and climate change (Watson et al. 1998), we recommend increased monitoring and modelling of EV and SAV, using a standardized classification scheme more frequently. This would not only track the spread of invasive plants and their effect on available habitat (Wynia 2019) but also seemingly more frequent algal blooms (some harmful) that affect SAV distributions.

SUBSTRATE

Different substrate types are used by many taxa for spawning, refugia, and burrowing habitats, and provide a medium for plant growth if composition is suitable (Bain et al. 1985; J. Gardner Costa, S.M. Larocque, D. Reddick, M. Croft-White, E. Budgell, C. Jacobs, S.E. Doka, J.D. Midwood, unpublished data). Thus, substrate analysis and a consistent classification scheme for substrate are important for habitat suitability analyses for fish species (Chu et al. 2015). Between 1994 and 2015, substrate data for the SCDRS region was collected by multiple groups, including GLIER (K. Drouillard, UW, GLIER, Windsor, Ontario, personal communication, 2017; J. Ciborowski, UW, GLIER, Windsor, Ontario, personal communication, 2017), and those discussed below (for data sources and application in this layer, see Table 3 and Figure 2 [substrate], respectively).

Samples were collected using Ponar grab samples at point locations and RoxAnn hydroacoustic surveys (Rukavina 2003; K. Tallon, Sea Lamprey Control Centre, Sault

Ste. Marie, Ontario, personal communication, 2013; Table 10). Although sample data collection spanned multiple decades, we assumed that over this period the bottom composition of the SCDRS would have minimal change. We acknowledge that erosion and sedimentation occur over time with varying flows (USGS 2013), and shoreline development and restoration actions may have changed substrate types locally during and after the periods the data were collected.

Ponar grab sampling

Ponar grab sampling occurred from 2003 to 2015, resulting in 1,300 soft sediment samples being collected. Ponar samples were collected by lowering the instrument into the water to substrate depth, where the grabber is activated by the operator and closes to collect the sample (ANAMAR 2015). Once at the surface, sediment was visually evaluated for substrate composition by field crews, photographs were taken, and subsamples removed (Appendix A). The subsamples were then quantitatively processed by Environment and Climate Change Canada's (ECCC's) sediment lab using laboratory methods similar to those described in Gardner Costa et al. (2020) and Leisti et al. (2020), and classified using a modified Wentworth grain size classification scheme (Wentworth 1922; MacDonald et al. 2000). All of the data used for mapping were based on Wentworth classes as sediment percent composition. Additionally, organic content was determined by loss on ignition, but has not yet been used in substrate mapping (Figures 30–33).

RoxAnn sampling

The RoxAnn hydroacoustic method (Rukavina 2003) uses sonar echoes to detect SAV, substrate, and water depth as the sampling vessel moves through a transect. A RoxAnn system was used by data providers to discriminate between the hardness and roughness of the lake bottom, which is interpreted by an echo reader (Caddel 1998; Rukavina 2003). For substrate, two echoes were measured to determine the roughness and hardness of the lake bottom. These echoes were then plotted and analyzed to verify substrate classification. From 1994 to 2000, 443,669 data points were collected using the RoxAnn hydroacoustic method in the SCDRS: 271,115 points were received from the Sea Lamprey Control Centre (SLCC) (K. Tallon, SLCC, Sault Ste. Marie, Ontario, personal communication, 2013) and 172,554 points from Environment Canada (EC [now ECCC]) (N. Rukavina and H. Biberhofer, EC, National Water Research Institute, Burlington, Ontario, personal communication, 2003).

RoxAnn substrate data provided by K. Tallon (SLCC, Sault Ste. Marie, Ontario, personal communication, 2013) came classified as Type 1, 2, or 3 based on their grain sizes (Table 11). We reclassified those substrate types into Wentworth classifications (Wentworth 1922) and percent compositions based on class descriptions and expert opinion (Table 12).

Data from EC (N. Rukavina and H. Biberhofer, EC, National Water Research Institute, Burlington, Ontario, personal communication 2003) had been plotted by roughness and hardness values using a Cartesian chart. The data came grouped into 15 classes, eight of which translated to substrate types (Table 13). We reclassified these eight RoxAnn classification types into a Wentworth classification (Wentworth 1922) percent composition based on the class descriptors. For example, RoxAnn classes named “mud” or “soft” were translated into the Wentworth classes described as clay, silt, and sand. As well, we reclassified the “hard” classes into combinations of cobble, rubble, boulder, and gravel percent compositions, based on the class descriptor as well as expert opinion of the area. Of note, bedrock and hardpan clay likely do not occur in the system, but would also be classified as hard.

Once we modified all the available RoxAnn data, we compiled it into one database along with the Ponar sample data. We quality assessed the data so each sample was a percent composition of each of the seven possible Wentworth classification substrate types (boulder, rubble, cobble, gravel, sand, silt, and clay). For every substrate sample, percent composition was computed and adjusted so that the total percent of the sample summed to 100% (e.g., 25% sand, 75% silt). It is important to note that RoxAnn outputs are broad compared with Wentworth classifications (MacDonald et al. 2000), and therefore less accurate in our conversions. However, with this method data can be easily collected and processed across large swaths, and contribute to a large proportion of the spatial substrate data for the system, based on validation sampling with both Ponar and video.

Due to disparities between collection types, we developed three methods for spatially merging all substrate data. Regardless of collection technique, a natural neighbour interpolation (ESRI 2016e) was performed. This algorithm gathers its information from surrounding data at a central point and interpolates the surroundings based on that dataset (Sibson 1981). Our first method created an interpolated layer of all the substrate data (Ponar and RoxAnn) for the entire system. The second method separated and interpolated the Ponar data only, using the natural neighbour process. Lastly, the third method clipped the Ponar interpolation to 250 m around each grab sample. The remainder of the extent was filled with the complete substrate data interpolation (i.e., the layer created using the first method).

Using these three methods for all substrate types, individual spatial layers representing each substrate class’s percent composition were generated. Figures 34–39 represent the three approaches used, and display sand percent composition. Although a raster layer of percent composition for each substrate type was created, we show sand percent composition because it had the most ubiquitous distribution throughout the system and has gradient properties. All substrate class data were output to a 10-m grid for system-wide analysis. Final maps will need to be vetted with experts, but we will use method #3 maps for spatial analysis of habitat, as this method accounts for deficiencies across collection types.

Data gaps

As indicated, one of the significant issues with the substrate data for the SCDRS is that the majority of data collected are RoxAnn data. Taking the RoxAnn output and delineating it further into specific Wentworth classes requires a great deal of assumption and inference (Cholwek et al. 2000), as most acoustics substrate methods are only able to distinguish hard from soft. Alternatively, Ponar grab samples provide accurate accounts of substrate type at localized sample points, but for soft sediments only. However, Ponar sampling requires much more effort to collect and generally results in reliable information on finer substrate types (i.e., smaller than cobble size), but does not resolve beyond "hard" when samples cannot be obtained by other means (e.g., underwater camera, providing water clarity allows).

Moreover, substrate composition (especially hard types) can differ dramatically throughout a system based on many factors. Thus it can be misleading to interpolate any type of substrate data beyond a short distance, although some spatial gradients are apparent with fines (i.e., gradients of percent sand/silt/clay), especially in deltas. With these concerns in mind, the development of three potential substrate layers for the entire SCDRS was necessary and should be considered theoretical until extensive validation is undertaken. As well, coarse substrate types, especially constructed shoals such as isolated islands, should be mapped with more precision. Specific project information is not included here yet as we focused on the whole system base layer first.

Another zone of substrate diversity and manipulation is the shoreline. Shoreline substrate attributes have not been included in the development of these substrate layers yet, either. Shoreline surveys had been performed by NOAA, conservation authorities, and others, but the data were very coarse (e.g. >1-km reaches). Additionally, the methods used to identify shoreline types differed by agency and in descriptive detail. Therefore it was not possible to convert shoreline classifications to Wentworth classes in most cases. Hence, additional information and validation data are needed; satellite imagery or air photo interpretation could be helpful.

Having a complete and comprehensive shoreline layer with more specificity would be beneficial since shoreline substrate is often very different from offshore substrate types, and it could be used to fill data gaps within the coastal zone, a potentially highly suitable fish habitat locale. To aid in future habitat modelling and restoration planning, it is recommended that a shoreline survey along a smaller reach size be undertaken, based on current shoreline classes that focus on nearshore or coastal substrate composition in water immediately next to shore features.

Finally, since sampling occurred over decades, it is possible the distribution of finer grain sizes like clay, silt, and sand may have been redistributed by velocity, flow, and sedimentation changes in the systems under differing water levels, as discussed in Nairn (2005). In the 2000's, the system experienced a period of below average water levels (but not as low as the 1920s and 1930s); and recently, in 2019 to 2020, levels were record highs. This would be especially impactful at rivermouths and at the sources of the main rivers, changing high- and low-flow portions of the connecting channels, and affecting the distributary channels of the delta. To capture this potential variability in substrate composition, more frequent Ponar sampling and acoustic mapping in areas with known high deposition and erosion rates should be collected, especially in areas targeted for restoration, as has been surveyed in the Fighting Island reef zone. The focus on gap-filling identified in this report would help reduce spatial interpolation errors and account for time trends in high variability zones.

CONCLUSIONS

The SCDRS gap analysis and GDB report presents data collected by multiple agencies, including our laboratory and DFO. This spatially referenced GDB of features that contribute to aquatic habitat is now available for future modelling analyses. Note that the focus is on fish use of these habitat features and not assessing aquatic mammals, birds, herptiles, or mussels although others could use this information to do so. Our group will be undertaking a fish habitat assessment using this GDB. The data collection and compilation was completed as of 2017, after which full system maps where created. We have identified several gaps to improve upon the spatial information for future assessments.

There were two consistent issues that became evident while compiling the different layers. The first was the age of the data, in many cases. Although some spatial characteristics will not change over decades—such as the bulk of land and sea elevations, average flow and velocity characteristics, and substrate types (in certain areas such as in the main channels and at the centre of Lake St. Clair). Other components are continuously transforming or variable, such as SAV or toxicity of contaminant distributions. The results of toxicity mapping definitely changed over time (Drouillard et al. 2020). Because toxicity levels can have a detrimental impact on fish health and decrease habitat suitability, water quality was initially one of the main reasons for establishing AOCs. Thus, it is imperative to continue to monitor trends and use current data, whether changes in toxicity are achieved through remediation actions or natural processes.

Furthermore, bathymetric features, especially in important habitats such as wetlands, are sampled very infrequently, with some points dating to the mid 20th century. These same areas have high error associated with remote techniques for measuring elevations, so ground-truthing and validating more frequently is important, but difficult because of accessibility. Nonetheless, the compilation of the layers presented here is the most comprehensive for the system that we know.

In addition, invasive EV species, such as *Phragmites australis spp,* are known to spread more quickly and cause changes in vegetation communities more rapidly (Wynia 2019). This invasive EV tends to grow in much denser stands than native vegetation species. Wynia (2019) found that stands with densities of greater than 100 stems per square metre, regardless of type, were impenetrable to many fish, thereby indirectly creating a loss of fish habitat through various mechanisms, even though flooded invasive vegetation was still used as habitat. Additionally, alterations to wetlands due to urbanization and other human-influenced activities created changes over time that should be tracked more frequently to target problem areas (such as major vegetation changes or inaccessibility to fish) and thus obtain a proper time-trend analysis to gauge overall system suitability and health.

Substrate composition is another layer that definitely required concerted effort to update, especially in coastal areas that are urbanized and shallow (Lapointe et al. 2010). Coarse substrates used for shoreline protection are not captured well by hydroacoustics shallower than 1-m depth, or by shoreline surveys that do not record in-water substrate type next to features. Although large-scale substrate redistributions are unlikely to occur in low-flow areas like the middle of Lake St. Clair (outside the shipping channel), the relative proportion of fines in coastal, sheltered areas, and at rivermouths or dredged areas may change over time and should be updated more frequently. There is a general lack of knowledge of hard or large substrate type distributions and their specific locations in the SCDRS.

The second major gap identified in the GDB is the low resolution of sample distributions or data to create maps for the full system extent. All of the layers require more spatially representative sampling, and better, accurate documentation for specific subsets can translate into habitat characteristics. For example, shoreline type and composition could be loosely translated into broad Wentworth classes. But sampling at the bottom of seawalls (which are predominate in the channels) would be needed. LiDAR and satellite imagery are becoming increasingly available and widespread, making data for elevation models more accessible. However, the purpose of the survey directly influences the data collected. In particular, the existing bathymetric data collected in the St. Clair River delta was primarily for mapping the navigational channels. This resulted in less accurate elevation data in the shallow nearshore areas, which also tend to be fish nurseries and serve other important habitat functions, yet are subjected to multiple human impacts more so than the shipping lanes. More targeted sampling in these shallow, mostly vegetated areas would greatly improve spatial accuracy, especially the DEM, which is used as the basis for other modelled layers and analyses (e.g., coastal, warmwater, sheltered habitat calculations).

As noted previously, the modelled velocity layer was comprehensive, although certain areas were not captured well, including areas with back eddies or areas where water flow is altered at shoreline obstructions and behind berms. Performing field validation surveys of velocities in these data-poor or high-error regions would help improve our confidence in the model output and improve future hydrodynamic model iterations, especially if adequate SAV maps can be provided. However, the same issues hold true for the SAV layer. Generally, areas that we feel may lack accurate model output include embayments and coastal areas. When completing more detailed and site-specific analyses, accurate SAV data in these areas will be necessary for model calibration and validation over time, especially as a water clarity layer has proved elusive and thus we cannot include that driver in model development or use it to track SAV improvements in the system.

Lastly, the substrate layer is a relatively comprehensive dataset, however the majority of these data are from RoxAnn surveys. As discussed, RoxAnn outputs are less accurate than actual grab samples because they only capture the hardness and smoothness of the lake bottom, and translate that backscatter into substrate type bins based on acoustic return distributions. Thus, we have lower confidence in substrate typing where no Ponar, camera, or other validation data exists. Future work should include not only a validation of RoxAnn backscatter interpretation, but also video confirmation, particularly in areas with coarser substrate sizes above gravel, and identification of any areas of bedrock or hardpan clay if they exist. Of note, vertical seawalls and smooth concrete or similar features are interpreted as bedrock features in habitat models.

The layers presented in this document use data collected from 1948 to 2017, and should be updated at a predetermined interval (perhaps every 5 years depending on the dataset and new data availability) to keep the data layers relevant as well as to provide information on changes in the system. Spatial and other data gaps identified here should be considered for future sampling efforts relevant to each layer. However, we firmly believe these ecological layers are now ready to be used for habitat assessments to quantify the amount of suitable habitat for fish species and their life stages by relevant condition or guild, as appropriate (e.g., vegetation, substrate, depth, or temperature guilds). We can now evaluate the loss or gain of habitat for these fish groups/stages, identify areas of high suitability within the SCDRS, aid in future project site selection given the consolidated spatial information, as well as run scenarios of different past, current, and future states for different habitat variables. These analyses will be paired with pre- and post-project comparisons of specific habitat projects, that could be informed by the existing layers we have finalized.

ACKNOWLEDGEMENTS

We would like to thank the many contributors to this project, starting with ECCC who funded this baseline geodatabase compilation through the Great Lakes Action Plan (GLAP). We would also like to thank our Canadian and First Nations data providers: the fish habitat Walpole crew for coordinated field data collection and the Walpole Island First Nations people for their input, guidance, and support in the joint delta surveys project, especially Clint Jacobs for a thorough review of this report; the many DFO crews and personnel over the years who collected and compiled vegetation, substrate, depth, water quality, sediment, and fish community information; the Ontario Ministry of Natural Resources and Forestry, especially contacts Craig Onafrychuk and Adam Hogg at Land Information Ontario; the University of Windsor (in particular Drs. Jan Ciborowski, Nick Lapointe, and Ken Drouillard) for the toxicity and some sediment data supplied for the area; ECCC, particularly Aaron Thompson (for his communications with the vertical step plane and flow/velocity modelling), and Hans Biberhofer of the Sediment Laboratory at the Canada Centre for Inland Waters; Kevin Tallon of DFO for providing and helping interpret the Sea Lamprey Control Centre's Roxann data). We also thank data providers/sources from the U.S., including: MTRI and SEMCOG (EV); USGS, USACE, and NOAA (substrate surveys, bathymetry, and/or land elevations); and of course, the many agency members of the SCDRS Initiative who were very helpful in tracking down and providing data for our layers from various sources.

Our work could not have been completed without the help of Canadian RAP coordinators, including Sandra Kok and April White from ECCC, and those at conservation authorities, including Erin Carroll and Donna Blue (nee Strang) from the St. Clair Region Conservation Authority, and Clair Saunders, Gina Pannuzio, and Jacqueline Serran of the Essex Region Conservation Authority. With great appreciation, we would like to particularly thank Rex Tang for his continuous support on the project, including training the many students who worked with us in our Fish Habitat Lab group; we also gratefully acknowledge these many students for their role in assisting with data collection and ground-truthing along the shores of this "corridor." Finally, we acknowledge GIS specialists Andrew Doolittle, Jody MacEachern, David McNiece, and Andrew Lewin for their contributions to early data collection and compilation of spatial layers.

REFERENCES

ANAMAR (ANAMAR Environmental Consulting Inc). 2015. Sediment Sampling: What is a PONAR Grab Sampler [online]. Available from https://www.anamarinc.com/blog-frontpage/entry/sediment-sampling-what-is-a-Ponar-grab-sampler (accessed March 2018).

Baudo, R., Giesy, J., and Muntau, H. (*Editors*) 1990. Sediments: chemistry and toxicity of in place pollutants. Lewis Publishers, Inc. Chelsea, Mich.

Bain, M.B., Finn, J.T., and Booke, H.E. 1985. Quantifying Stream Substrate for habitat Analysis Studies. N. Am. J. Fish. Manag. 5(3B): 499–500.

Bourgeau-Chavez, L., Endres, S., Battaglia, M., Miller, M.E., Banda, E., Laubach, Z., Higman, P., Chow-Fraser, P., and Marcaccio, J. 2015. Development of a Bi-National Great Lakes Coastal Wetland and Land Use Map Using Three-Season PALSAR and Landsat Imagery. Remote Sens. 7I: 8655–8682. doi: 10.3390/rs70708655.

Caddel, S.E.1998. Application of an acoustic sea floor classification system for benthic habitat assessment. J. Shellfish Res. 17(5): 1459–1461.

Carpenter, S.R., and Lodge, D.M. 1986. Effects of Submerged macrophytes on ecosystem processes. Aquat. Bot. 26: 341–370.

Cholwek, G., Bonde, J., Li, X., Richards, C., and Yin, K. 2000. Processing RoxAnn sonar data to improve its categorization of lake bed surficial substrates. Mar. Geo. Res. 21**:** 409–421.

Chu**,** C., Minns, C.K., Lester, N.P., and Mandrak, N.E. 2015. An updated assessment of human activities, the environment and freshwater fish biodiversity in Canada. Can. J. Fish. Aquat. Sci. 72:135–148.

DFO (Department of Fisheries and Oceans Canada). 2018. Historical Monthly Mean Water Levels from the Coordinated network for each of the Great Lakes [online]. Available from http://www.tides.gc.ca/C&A/network_means-eng.html (accessed June 2018).

DFO (Department of Fisheries and Oceans Canada). 2019. Development and evaluation of the Habitat Ecosystem Assessment Tool (HEAT). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2019/046. 14 p.

DRCC (Detroit River Canadian Cleanup). 2017. Pathway to Delisting: Detroit River Canadian AOC Delisting Strategy 2013 – 2019 [online]. Available from http://detroitriver.ca/wp-content/uploads/2019/06/Detroit-River-Canadian-Delisting-Plan_June2019.pdf (accessed September 2019).

DRCC (Detroit River Canadian Cleanup). 2018. What is an Area of Concern? [online]. Available from http://detroitriver.ca/area-of-concern/ (accessed September 2018).

DNRM (Department of Natural Resources Michigan). 2017. 2017 St. Clair Flats Wildlife Area Annual Report [online]. Available from https://www.michigan.gov/documents/dnr/SCFWA_Annual_Report_435404_7.pdf (accessed September 2018).

Doolittle, A., Bakelaar, C.N., and Doka, S.E. 2010. Spatial framework for storage and analyses of fish habitat data in Great Lakes' Area of Concern: Hamilton Harbour geodatabase case study. Can. Tech. Rep. Fish. Aquat. Sci. 2879: xi + 68 p.

Drouillard, K.G., Tomczak, M., Reitsma, S., Haffner, G.D. 2006. A river-wide survey of polychlorinated biphenyls (PCB)s, polycylic aromatic hydrocarbons (PAHs), and selected organochlorine pesticide residues in sediments of the Detroit River—1999. J. Great Lakes Res. 32(2): 209–226.

Drouillard, K.G., Lafontaine, J., Grgicak-Mannion, A., McPhedran, K., and Szalińska, E.E. 2020. Spatial and temporal trends of metal and organic contaminants in the Huron-Erie corridor – 1999–2014. *In* Contaminants of the Great Lakes. The handbook of environmental chemistry, vol 30. *Edited by* J. Crossman and C. Weisener. Springer International Publishing. pp. 49–83. doi:10.1007/698_2020_489.

EC (Environment Canada). 1994. Environmental Sensitivity Atlas for the St. Clair River, Lake St. Clair and Detroit River Shorelines. Environment Canada – Environmental Protection Branch, Ontario Region, Canadian Coast Guard, 79 p.

EC (Environment Canada). 2008. St. Clair River hydrodynamic modelling using RMA2 Phase 1 report [online]. Accessed from http://www.iugls.org/DocStore/ProjectArchive/HDR_StClairHydraulics/HDR02_Bruxer_2DRMA2Modelling/Reports/HDR02-R1_BruxerThompson.pdf#page=16&zoom=100,0,0 (accessed August 20, 2020).

ECCC (Environment and Climate Change Canada). 2019. Resource Management Associates 2-D. [Computer software] for modelling the St. Clair – Detroit River system. Burlington, Ontario.

ENVIRON (ENVIRON International Corporation). 2009. Final Project Report for Applying the COA Framework to the St. Clair River Area of Concern [online]. Available from https://friendsofstclair.ca/wp-content/uploads/2019/05/Final-Project-Report-for-Applying-the-COA-Framework-to-the-St-Clair-River-AOC-2009.pdf (accessed September 2019).

EPA (United States Environmental Protection Agency). 2019a. Clinton River AOC Boundary Map (Vector: Polygon) [online]. Available from https://www.epa.gov/great-lakes-aocs/clinton-river-aoc-boundary-map (accessed March 2019).

EPA (United States Environmental Protection Agency). 2019b. Rouge River AOC Boundary Map (Vector: Polygon) [online]. Available from https://www.epa.gov/great-lakes-aocs/rouge-river-aoc-boundary-map (accessed September 2019).

ESRI (Environmental Systems Research Institute). 2016a. What is raster data? [online]. Available from https://desktop.arcgis.com/en/arcmap/10.3/manage-data/raster-and-images/what-is-raster-data.htm#:~:text=In%20its%20simplest%20form%2C%20a,pictures%2C%20or%20even%20scanned%20maps (accessed May 2019).

ESRI (Environmental Systems Research Institute). 2016b. Polygon [online]. Available from https://desktop.arcgis.com/en/arcmap/10.3/analyze/arcpy-classes/polygon.htm (accessed March 2019).

ESRI (Environmental Systems Research Institute). 2016c. Buffer [online]. Available from https://desktop.arcgis.com/en/arcmap/10.3/tools/analysis-toolbox/buffer.htm (accessed May 2019).

ESRI (Environmental Systems Research Institute). 2016d. Raster calculator. Available from https://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/raster-calculator.htm (accessed June 2020).

ESRI (Environmental Systems Research Institute). 2016e. Natural Neighbour [online]. Available from http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/natural-neighbor.htm (accessed May 2019)

ESRI (Environmental Systems Research Institute). 2016f. Spline [online]. Available from http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/spline.htm (accessed April 2019).

ESRI (Environmental Systems Research Institute). 2016g. How IDW works [online]. Available from http://desktop.arcgis.com/en/arcmap/10.3/tools/3d-analyst-toolbox/how-idw-works.htm (accessed April 2019).

ESRI (Environmental Systems Research Institute (ESRI). 2018a. Geodatabase Design Steps. [online]. Available from http://desktop.arcgis.com/en/arcmap/10.3/manage-data/geodatabases/geodatabase-design-steps.htm (accessed May 2018).

ESRI (Environmental Systems Research Institute). 2018b. ArcGIS™ 10.4.1 [Computer software]. Redlands, California.

ESRI (Environmental Systems Research Institute). 2018c. ArcPRO™ 2.4.2. [Computer software]. Redlands, California.

ESRI (Environmental Systems Research Institute). 2018d. How Topo to Raster Works [online]. Available from https://pro.arcgis.com/en/pro-app/tool-reference/3d-analyst/how-topo-to-raster-works.htm (accessed October 28 2019).

ESRI (Environmental Systems Research Institute). 2018e. Create Thiessen Polygons (Analysis) (ArcInfo only) [online]. Available from http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?pid=1272&topicname=Create_Thiessen Polygons_(Analysis) (accessed May 2018).

ESRI (Environmental Systems Research Institute). 2019a. What is a geodatabase? [online]. Available from https://desktop.arcgis.com/en/arcmap/10.3/manage-data/geodatabases/what-is-a-geodatabase.htm#:~:text=At%20its%20most%20basic%20level%2C%20an%20ArcGIS%20geodatabase,Microsoft%20SQL%20Server%2C%20PostgreSQL%2C%20Informix%2C%20or%20IBM%20DB2%29 (accessed January 2020).

ESRI (Environmental Systems Research Institute). 2019b. What is a LAS dataset? [online]. Available from https://desktop.arcgis.com/en/arcmap/10.3/manage-data/las-dataset/what-is-a-las-dataset-.htm (accessed June 10, 2019).

ESRI (Environmental Systems Research Institute). 2019c. Lidar point classification [online]. Available from https://desktop.arcgis.com/en/arcmap/10.3/manage-data/las-dataset/lidar-point-classification.htm#:~:text=Lidar%20points%20can%20be%20classified,codes%20in%20the%20LAS%20files (accessed June 10, 2019).

ESRI (Environmental Systems Research Institute). 2019d. NDVI Function [online]. Available from http://desktop.arcgis.com/en/arcmap/10.3/manage-data/raster-and-images/ndvi-function.htm (accessed May 2019).

ESRI (Environmental Systems Research Institute). 2019e. Point to raster [online]. Available from https://desktop.arcgis.com/en/arcmap/latest/tools/conversion-toolbox/point-to-raster.htm (accessed June 2019).

ESRI (Environmental System Research Institute). 2020. Digital elevation models [online]. Available from https://learn.arcgis.com/en/related-concepts/digital-elevation-models.htm (accessed Jan 2021).

Fletcher, R., Welsh, P., and Fletcher, T. (2008) Guidelines for identifying, assessing and managing contaminated sediments in Ontario. Ontario Ministry of Environment, Queens Printer for Ontario, Toronto, ON

Ford, D., Pingel, N., and DeVries, J.J. 2008. Hydrologic Modeling System HECHMS: Applications Guide. US Army Corps of Engineers, Institute for Water Resources Hydrologic Engineering Center. Davis, CA 1:118 [online]. Available from https://www.hec.usace.army.mil/software/hec-hms/documentation/HEC-HMS_Applications_Guide_March2008.pdf (accessed May 2019).

Gardner Costa, J., Rémillard, C.Y.L., Doolittle, A., and Doka, S.E. 2020. Hamilton Harbour shoreline survey — 2006. Can. Tech. Rep. Fish. Aquatic. Sci. 3381: vii + 37 p.

GC (Government of Canada). 2019a. Detroit River: Area of Concern [online]. Available from https://www.canada.ca/en/environment-climate-change/services/great-lakes-protection/areas-concern/detroit-river.html (accessed July 2019).

GC (Government of Canada). 2019b. St. Clair River: Area of Concern [online]. Available from https://www.canada.ca/en/environment-climate-change/services/great-lakes-protection/areas-concern/st-clair-river.html (accessed July 2019).

GLANSIS (Great Lakes Aquatic Nonindigenous Species Information System). 2016. *Phragmites australis australis* (Cav.) Trin. ex Steud. [online]. U.S. Geological Survey, Nonindigenous Aquatic Species Database, Gainesville, Fla., and NOAA Great Lakes Aquatic Nonindigenous Species Information System, Ann Arbor, Mich. Available from https://nas.er.usgs.gov/queries/greatlakes/FactSheet.aspx?SpeciesID=2937&Potential=N&Type=0&HUCNumber=DHuron (accessed April 2019).

GLWQB (Great Lakes Water Quality Board. 1980. Report on Great Lakes Water Quality [online]. Available from https://ijc.org/sites/default/files/D9.pdf (accessed August 2018).

Google Earth (2016). Lake St. Clair, Ontario, Canada.42˚ 33’ 12.83”N, 82˚ 30’ 51.45”W, Eye alt 19.60 mi., Landsat/Copernicus 2016, version 7.3.2.5576 [online]. Available from https://www.google.com/maps/@42.55356,-82.51429,31159m/data=!3m1!1e3 (accessed April 30, 2019).

Green, J. 2003. Velocity and turbulence distribution around lotic macrophytes. Aquat. Ecol. 39: 1–10. doi: 10.1007/s10452-004-1913-0.

Holtschlag, D.J., and Koschik, J.A. 2002. A Two-Dimensional Hydrodynamic Model of the St. Clair-Detroit River Waterway in the Great Lakes Basin. U.S. Army Corps of Engineers, Water-Resources Investigations. Lansing, Mich.

IJC (International Joint Commission). 1987. Protocol Amending the Agreement between Canada and the United States of American on Great Lakes Water Quality, 1978, as Amended on October 16, 1983 and on November 18, 1987.

IJC (International Joint Commission). 2015. AOC Stands for Areas of Concern, and Great Lakes Progress [online]. Available from https://www.ijc.org/en/aoc-stands-areas-concern-and-great-lakes-progress (accessed August 2018).

IJC (International Joint Commission). 2019. Annex 1 – Areas of Concern. [online]. Available from https://ijc.org/en/who/mission/glwqa/annex1 (accessed September 2019).

Kalff, J. 2002. Particle sedimentation and sediments. *In* Limnology. *Edited by* T. Ryu. Prentice Hall Inc., Upper Saddle River, N.J., pp. 292–308.

Lantz, N. 2012. Detection and mapping of *Phragmites australis* using high resolution multispectral an hyperspectral satellite imagery. M.Sc. thesis, Department of Geography, The University of Western Ontario, London, Ont. Available from https://ir.lib.uwo.ca/etd/1012 (accessed February 2019).

Lapointe, N.W.R., Corkum, L.D., and Mandrak, N.E. 2010. Macrohabitat associations of fishes in shallow waters of the Detroit River. J. Fish Biol. 76:446–466.

Leisti, K.E., Gardner Costa, J., MacEachern, J.T, Gertzen, E.L., and Doka, S.E. 2020. Toronto Harbour 2012 shoreline, substrate, and submerged aquatic vegetation survey. Can. Tech. Rep. Fish. Aquat. Sci. 3379: viii + 47 p.

LIO (Land Information Ontario). 2012. Land Information Ontario Data Description: Watershed, Tertiary. Queens Printer for Ontario. Peterborough, Ontario. [online]. https://geohub.lio.gov.on.ca/datasets/mnrf::watershed-tertiary (accessed July 2019).

LIO (Land Information Ontario) 2015. Southwestern Ontario Orthoimagery Project. Southwestern Ontario Orthophotography (SWOOP) 2015 [online]. Available from https://geohub.lio.gov.on.ca/datasets/62d2c0ed59954290b35900b9e1fd8d44 (accessed March 21, 2019).

LIO (Land Information Ontario). 2017. Land Information Ontario Data Description: Wetland. Queens Printer for Ontario. Peterborough, Ontario. Available from https://www.sse.gov.on.ca/sites/mnr-publicdocs/en/cmid/wetland%20-%20data%20description.pdf (accessed March 7, 2019).

LIO (Land Information Ontario). 2019. Ontario Classified Point Cloud (Lidar-Derived). (Vector: Points) [online]. Available from https://geohub.lio.gov.on.ca/datasets/adf19376eecd4440a4579a73abe490f5?geometry=-84.917%2C42.090%2C-79.691%2C42.799 (accessed April 10, 2019).

Lotufo, G.R., Burton, G.A., Rosen, G., and Fleeger, J.W. 2014. Assessing Biological Effects. *In* Processes, Assessment and Remediation of Contaminated Sediments. *Edited by* Danny D. Reible. The University of Texas at Austin, Austin, Tex. pp. 131–175.

LSRCA (Lake Simcoe Region Conservation Authority). 2011. Aquatic Plants in Lake Simcoe: Distribution, Environmental Controls and Utility as Ecological Indicators. Technical Progress Series in Lake Monitoring: Report No. 1 [online]. Available from https://www.lsrca.on.ca/Shared%20Documents/reports/aquatic-plants-tech-report.pdf (accessed March 2019).

Lusch, D., and Goodwin, R. 2012. Michigan Land Cover / Use Classification System. Remote Sensing and GIS Research and Outreach Services, Department of Geography, Michigan State University. East Lansing, Mich.

MacDonald, D.D., Ingersoll, C.G., and Berger, T.A. 2000. Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems. Arch. Environ. Contam. Toxicol. 39(1):20–31. doi: 10.1007/s002440010075

Mahoney, M.J. 2008. A discussion of various measures of altitude [online]. Available from https://wahiduddin.net/calc/refs/measures_of_altitude_mahoney.html (accessed 31 March 2010).

Mackey, S.D., Reutter, J.M., Ciborowski, J.J.H., Haas, R.C., Charlton, M.N., and Kreis Jr., R.J. 2006. Huron-Erie Corridor System Habitat Assessment – Changing water Levels and Effects of Global Climate Change. *In* HEC Project Completion Report, USFWS Restoration Act Sponsored Research Agreement # 30181- 4- J259. 47 p.

McPhedran, K.N., Grgicak-Mannion, A., Paterson, G., Briggs, T., Ciborowski, J.J.H., Haffner, G.D., and Drouillard, K.G. 2017. Assessment of hazard metrics for predicting field benthic invertebrate toxicity in the Detroit River, Ontario, Canada. Integr. Environ. Assess. Manag. 13(2): 410–422. doi:10.1002/ieam.1785.

Microsoft Corporation. 2016. Microsoft Excel: Microsoft Office Professional Plus 2016, Version 16.0.4927.1000. [Computer software]. Redmond, Wash.

Midwood, J.D. 2020. Development of a submerged aquatic vegetation model for the St. Clair and Detroit Rivers. Can. Tech. Rep. Fish. Aquat. Sci. 3399: v + 13 p.

MTRI (Michigan Technical Research Institute). 2020. Wetland Map: GL coastal/MI interior (Vector: Raster) [online]. Available from https://geodjango.mtri.org/coastal-wetlands/ (accessed May 2019).

Nairn, R. 2005. Modeling Physical Processes for the Huron – Erie Corridor [online]. Baird & Associates, Oakville, Ontario. Available from www.lemn.org/ResearchNeedsWorkshop303_files/PDF presentations/Nairn,R.pdf (accessed December 12, 2019).

NOAA (National Oceanic and Atmospheric Administration). 2017. Understanding Essential Fish Habitat [online]. Available from https://www.fisheries.noaa.gov/insight/understanding-essential-fish-habitat (accessed March 11 2020).

NOAA (National Oceanic and Atmospheric Administration). 2018. National Geodetic Survey: Vertical Datums [online]. Available from https://www.ngs.noaa.gov/datums/vertical/ (accessed August 2019).

NOAA (National Oceanic and Atmospheric Administration). 2019a. Great Lakes Water Levels [online]. Available from https://www.glerl.noaa.gov/data/wlevels/ (accessed March 11 2020).

NOAA (National Oceanic and Atmospheric Administration). 2019b. NOAA Bathymetric Data Viewer – Maps and Geospatial [online]. Accessed from https://maps.ngdc.noaa.gov/viewers/bathymetry/ (accessed January 2019); Available from https://www.ngdc.noaa.gov/mgg/greatlakes/erie.html (accessed July 2021).

NOAA and NGS (National Oceanic and Atmospheric Administration and National Geodetic Survey). 2019. NOAA Continually Updated Shoreline Product. Shoreline for Huron – Erie Corridor [online]. Available from https://shoreline.noaa.gov/data/datasheets/cusp.html (accessed September 12, 2019).

NRCAN (Natural Resources Canada). 2016. The UTM Grid – Universal Transverse Mercator Projection [online]. Available from https://www.nrcan.gc.ca/earth-sciences/geography/topographic-information/maps/utm-grid-map-projections/utm-grid-universal-transverse-mercator-projection/9779 https://www.nrcan.gc.ca/earth-sciences/geography/topographic-information/maps/utm-grid-map-projections/utm-grid-universal-transverse-mercator-projection/9779%20 (accessed March 2020).

NRCAN (Natural Resources Canada). 2019. Height Reference System Modernization [online]. Available from https://www.nrcan.gc.ca/height-reference-system-modernization/9054 (accessed August 2019).

Portt, C.B., Coker, G., and Minns, C.K. 1999. Riverine habitat characteristics of fishes of the Great Lakes watershed. Can. Manuscr. Rep. Fish. Aquat. Sci. 2481: vi + 62 p. Available from https://waves-vagues.dfo-mpo.gc.ca/Library/235354_pt1.pdf [accessed 9 June 2021].

Portt, C.B., Minns, C.K., and King, S.W. 1988. Morphological and ecological characteristics of common fishes in Ontario lakes. Can. Manuscr. Rep. Fish. Aquat. Sci. 1991: vi + 37 p. Available from https://waves-vagues.dfo-mpo.gc.ca/Library/40651149.pdf [accessed 9 June 2021].

SEMCOG (Southeast Michigan Council of Government). 2004. Southeast Michigan Wetland Indicator. http://www-personal.umich.edu/~sarhaus/Land90.pdf. (accessed August 2018).

Sibson, R. 1981. A brief description of natural neighbor interpolation. *In* Interpolating Multivariate Data. *Edited by* V. Barnett. John Wiley & Sons, New York, N.Y. pp. 21–36.

Rukavina, N.A. 2003. Roxann Surveys of Northern Lake Michigan Shoal Sediments. National Water Research Institute, Burlington, Ont. NWRI contribution No. 02-220. 34 pp. Available from http://publications.gc.ca/collections/collection_2019/eccc/en13-5/En13-5-03-220-eng.pdf (accessed December 2019).

Trigal, C. and E. Degerman. 2015. Multiple factors and thresholds explaining fish species distributions in lowland streams. Global Ecology and Conservation 4: 589-601.

Tymoshuk, J., Abdel-Fattah, S., Gertzen, E., and Doka, S.E. 2017. Habitat ecosystem assessment survey results. Can. Tech. Rep. Fish. Aquat. Sci. 3214: 25p.

USACE (United States Army Corps of Engineers). 2019. Detroit River [online]. Available from https://www.lre.usace.army.mil/Missions/Great-Lakes-Information/Outflows/Discharge-Measurements/Detroit-River (accessed January 2019).

USGS (United States Geological Survey). 2013. Nomenclature [online]. Available from https://pubs.usgs.gov/of/2006/1195/htmldocs/nomenclature.htm (accessed March 2019).

USGS (United States Geological Survey). 2019. How Streamflow is Measured [online]. Available from https://water.usgs.gov/edu/streamflow2.html (accessed April 2018).

Wentworth, C. K. 1922. A scale of grade and class terms for clastic sediments. Available from http://www.journals.uchicago.edu/doi/pdf/10.1086/622910 (accessed March 2021).

Watson, R.T., Zinyowera, M.C., Moss, R.H., and Dokken, D.J. 1998. *In* The Regional Impacts of Climate Change: An Assessment of Vulnerability. *Edited by* R.T.Watson, M.C.Zinyowera, R.H.Moss IPCC, Geneva, Switzerland. Available from https://archive.ipcc.ch/ipccreports/sres/regional/index.php?idp=0 (accessed August 2018).

Wetzel, R.G. 2001. Limnology: Lake and River Ecosystems, 3rd Edition. Academic Press, San Diego, Calif.

Wichert, G.A., Mackenzie, J.S. and Staples, P. 2004. Aquatic ecosystem classification for the Great Lakes Watershed in Ontario. Nature Conservancy of Canada.

Wynia, A. 2019. Fish and invertebrate use of invasive Phragmites in a Great Lakes freshwater delta. M.Sc. thesis, Environmental and Life Sciences, Trent University, Peterbourough, Ont. Available from https://digitalcollections.trentu.ca/islandora/search/Wynia?type=dismax (accessed May 2019).

Zhou, Feng. 2005. Vertical datum conversion in the Lake Erie coastal area. *In* Proceedings of the 2005 National Conference on Digital Government Research. *Edited by* L.M.L. Delcambre and G. Giuliano. Digital Government Research Center, Atlanta, Ga. pp. 321–325.

TABLES AND FIGURES

Table 1. List of 14 Beneficial Use Impairments (BUIs) identified by the International Joint Commission. At least one of the BUIs must be present for an area to be classified as an Area of Concern. BUIs are not listed in order of priority as per source: IJC (2019).

No.	Beneficial Use Impairment
1.	Restrictions on fish and wildlife consumption
2.	Tainting of fish and Wildlife Flavour
3.	Degraded fish and wildlife populations
4.	Fish tumours or other deformities
5.	Bird or animal deformities or reproductive problems
6.	Degradation of benthos
7.	Restrictions on dredging activities
8.	Eutrophication or undesirable algae
9.	Restrictions on drinking water consumption or taste and odor problems
10.	Beach closings
11.	Degradation of aesthetics
12.	Added costs to agriculture or industry
13.	Degradation of phytoplankton and zooplankton populations
14.	Loss of fish and wildlife habitat

Table 2. List of Beneficial Use Impairments (BUIs) for the Canadian Areas of Concern (AOCs) in the St. Clair–Detroit River System. As of 2017, the St. Clair River had six impairments remaining, with BUIs continuing to be listed as "no longer meets the impaired criteria" and three BUIs requiring further assessment. The Detroit River had seven remaining impairments, one that requires further assessment (RFA) and six BUIs that are no longer impaired. Sources: DRCC (2017); GC (2019a, 2019b).

AOC	**Beneficial Use Impairment**	**Status** [a] **(2017)**
St. Clair River	#1 Restrictions on fish and wildlife consumption	Impaired
	#2 Tainting of fish and wildlife flavour	Not Impaired
	#3 Degraded fish and wildlife populations [b]	RFA
	#4 Fish tumours or other deformities	RFA
	#5 Bird or Animal deformities or reproductive problems	RFA
	#6 Degradation of benthos	Impaired
	#7 Restrictions on dredging activities	Impaired
	#8 Eutrophication or undesirable algae	Not Impaired
	#9 Restrictions on drinking water consumption or taste & odour problems	Impaired
	#10 Beach closings	Impaired
	#11 Degradation of aesthetics	Not Impaired
	#12 Added costs to agriculture or industry	Not Impaired
	#13 Degradation of phytoplankton and zooplankton populations	Not Impaired
	#14 Loss of fish and wildlife habitat	Impaired
Detroit River	#1 Restrictions on fish and wildlife consumption	Impaired
	#2 Tainting of fish and wildlife flavour	Not Impaired
	#3 Degraded fish and wildlife populations	Impaired
	#4 Fish tumours or other deformities	Impaired
	#5 Bird or Animal deformities or reproductive problems	Impaired
	#6 Degradation of benthos	Impaired
	#7 Restrictions on dredging activities	Impaired
	#8 Eutrophication or undesirable algae	Not Impaired
	#9 Restrictions on drinking water consumption or taste & odour problems	Not Impaired
	#10 Beach closings	Not Impaired
	#11 Degradation of aesthetics	Not Impaired
	#12 Added costs to agriculture or industry	Not Impaired
	#13 Degradation of phytoplankton and zooplankton populations	RFA
	#14 Loss of fish and wildlife habitat	Impaired

[a] RFA: requires further assessment.

[b] Highlighted and underlined BUIs are the focus of the fish habitat assessment using this geodatabase.

Table 3. List of data sources for the St. Clair–Detroit River System geodatabase. 'Layer' is the final spatial output that the collected data contributed to; 'Vector type' is the type of spatial data we received and interpolated for the purposes of this geodatabase and a future fish habitat assessment; 'Collection Year' is the year of data collection. All layers were created using the data with permission from the data provider, including open data sources. For complete documentation regarding inputs for each spatial layer, please contact the authors.

Layer [a]	Source(s) [b]	Affiliation	Affiliation full name	Spatial or data type [c]	Collection year
DEM		USGS	United States Geological Survey	PTS	2009, 2010
	C. Onafrychuk and A. Hogg [b]	LIO	Land Information Ontario	PTS	2015, 2017
		NOAA/DFO	National Oceanic and Atmospheric Administration	RST	1948–2012
	NOAA 2019b	NOAA/DFO	National Oceanic and Atmospheric Administration	PYLN	2012
		USACE	United States Army Corps of Engineers	PTS	2012
	LIO 2019	LIO	Land Information Ontario	PTS	2012
Velocity	EC 2008	EC	Environment Canada	PTS	2000
Toxicity	Drouillard et al. [b]	UW, GLIER	University of Windsor, Great Lake Institute for Environmental Research	CSV	1999–2014
EV	Bourgeau-Chavez et al. 2015 MTRI 2020	MTRI	Michigan Tech Research Institute	PYG	2015
	LIO 2017	LIO	Land Information Ontario	PYG	2015–2017
		SEMCOG	Southeast Michigan Council of Governments	PYG	2004
SAV	Doka Lab, (Appendix A)	DFO	Fisheries and Oceans Canada	PTS	2007, 2008, 2010, 2017
Substrate	Ciborowski / Drouillard [b]	UW, GLIER	University of Windsor, Great Lake Institute for Environmental Research	PTS	1999–2001
	K. Tallon [b]	SLCC	Sea Lamprey Control Centre, DFO	PTS	2003–2004, 2013–2014
	Doka Lab, (Appendix A)	DFO	Fisheries and Oceans Canada, Fish Habitat Science	PTS	2007, 2008, 2010, 2015
	N. Rukavina [b]	EC	Environment Canada	PTS	1994, 2001
		MNR	Ministry of Natural Resources	PTS	2006, 2015
		USGS	United States Geological Survey	PTS	2008
	H. Biberhofer [b]	EC	Environment Canada	PTS	1999–2000
		NOAA	National Oceanic and Atmospheric Administration	RST	1997–2004

Layer [a]	Source(s) [b]	Affiliation	Affiliation full name	Spatial or data type [c]	Collection year
VSPs		EC	Environment Canada	PYG	2012
		NOAA	National Oceanic and Atmospheric Administration	PYG	2012
	T. Calappi [b]	USACE	U.S. Army Corps of Engineers	PYG	2012
Clinton AOC	EPA 2019a	EPA	Environmental Protection Agency	PYG	2006
Rouge AOC	EPA 2019b	EPA	Environmental Protection Agency	PYG	2006

[a] DEM = digital elevation model; EV = emergent vegetation; SAV = submerged aquatic vegetation; VSPs = vertical step planes; Clinton AOC = Clinton River Area of Concern; Rouge AOC = Rouge River Area of Concern.

[b] Source names with a superscript "*b*" provided unpublished data through personal communication, or is our own unpublished data; data from sources without a name were provided as personal communication by the organization without a contact name and/or no citable reference; data from our laboratory is indicated by Doka Lab (Appendix A); all other sources are in citation format and included in the reference list.

[c] PTS = points; RST = raster; PYLN = polyline; CSV = Comma-separated values; PYG = polygon

Table 4. List of data sources, collection year, and collection method used to compute the digital elevation model for the Saint Clair–Detroit River System. All sources were converted to point files and if necessary adjusted for vertical datum. For data sources and application, see Table 3 and Figure 2 (digital elevation model), respectively.

Data source [a]	Year(s) collected	Method [b]	Resolution	Vertical datum [c]	Spatial extent [d]
USGS	2009	Lidar	1 m	NAVD88	DR
LIO	2015	Lidar	2 m	CGVD28	DR, SCR, Canadian side of LSC
NOAA	2012	Multibeam survey	1 m	IGLD85	DR
NOAA/DFO	1948–2012	Bathymetry	30 m	IGLD85	Whole system
USGS	2010	LiDAR	2 ft	NAVD88	SCR, U.S. side of LSC
USACE	2012	Multibeam survey	5 m	IGLD85	SCR
LIO	2017	DSM	0.50 cm	CGVD2013	WIFN, St. Clair River delta area

[a] USGS: United States Geological Survey; LIO: Land Information Ontario; NOAA: National Oceanic Atmospheric Administration; USACE: United States Army Corps of Engineers.
[b] Lidar: light detection and ranging surface model points cloud data; DSM: digital surface model.
[c] NAVD88: North American Vertical Datum 1988; CGVD28: Canadian Geodetic Vertical Datum 1928; IGLD85: International Great Lakes Datum 1985; CGVD2013: Canadian Geodetic Vertical Datum 2013.
[d] DR: Detroit River; SCR: St. Clair River; LSC: Lake St. Clair; WIFN: Walpole Island First Nation.

Table 5. Year toxicity samples were collected, number of samples per year, and the cumulative anticipated toxicity [Effect(%)] (HZD: hazard score) min, max and mean for each year. These values are used to provide a range of toxicity present in the St. Clair–Detroit River System for the time of sampling (Source: K. Drouillard, UW, GLIER, Windsor, Ontario, personal communication, 2017).

Year	Samples (*n*)	HZD min (%)	HZD max (%)	HZD mean (%)
1999	147	0	390.44	96.07
2004	104	0	361.38	20.20
2005	36	0	72.80	27.01
2007	6	0	88.76	21.38
2008	32	0	451.31	94.0
2009	35	75.96	516.17	78.23
2012	48	0	67.31	20.19
2013	73	78.61	675.14	66.67
2014	181	82.36	196.34	11.65

Table 6. List of 28 substances that sediment samples were tested against to estimate toxicity. Each substance is processed and evaluated based on the threshold effect concentration (TEC) or probable effect concentration (PEC). TEC represents values below which toxic effects are unlikely, whereas PEC represents values above which will have toxic effects on organisms. Adapted from MacDonald et al. 2000.[a]

Substance	TEC	PEC
Metals	**mg/kg DW**	
Arsenic	9.79	33.0
Cadmium	0.99	4.98
Chromium	43.4	111
Copper	31.6	149
Lead	35.8	128
Mercury	0.18	1.06
Nickel	22.7	48.6
Zinc	121	459
Polycyclic aromatic hydrocarbons	**µg/kg DW**	
Anthracene	57.2	845
Fluorene	77.4	536
Naphthalene	176	561
Phenanthrene	204	1,170
Benz[a]anthracene	108	1,050
Benzo[a]pyrene	150	1,450
Chrysene	166	1,290
Dibenz[a,h]anthracene	33.0	—
Fluoranthene	423	2,230
Pyrene	195	1,520
Polychlorinated biphenyls	**µg/kg DW**	
Total PCBs	59.8	22,800
Organchlorines	**µg/kg DW**	
Chlordane	3.24	17.6
Dieldrin	1.90	61.8
Sum DDD	4.88	28.0
Sum DDE	3.16	31.3
Sum DDT	4.16	62.9
Total DDTs	5.28	572
Endrin	2.22	207
Heptachlor epoxide	2.47	16.0
Lindane (gamma-BHC)	2.37	4.99

[a] DW: diesel water; DDD: dichlorodiphyenyldichloroethane; DDE: dichlorodiphenyldichloroethylene; DDT: dichlorodiphenyltrichloroethane; BHC: benzene hexachloride.

Table 7. Hazard score (HZD) conversion from cumulative Effect(%) (anticipated toxicity) to HZD category. These values are used to map the range of sediment toxicity present in the St. Clair–Detroit River System. From K. Drouillard, UW, GLIER, Windsor, Ontario, personal communication, 2017.

HZD	PEC and TEC classification [a]	HZD Category
0%–25%	Not likely toxic	1
>25%–50%	Not likely toxic - chemicals between TEC and PEC	2
>50%–75%	One or more chemicals above PEC	3
>75%–100%	Multiple chemicals above PEC	4
>100%	Many chemicals above PEC	5

[a] TEC = threshold effect concentration; PEC = probable effect concentration; see toxicity section for details.

Table 8. List of data sources and a summary of information used to create the emergent vegetation spatial layer. Michigan Technical Research Institute (MTRI) coverage included both U.S. and Canadian sides of the St. Clair–Detroit River System. Land Information Ontario (LIO) was available for Ontario only, and the Southeast Michigan Council of Governments (SEMCOG) coverage was available for Michigan only. Further delineation of *Phragmites* and *Typha* spp. was not available within these particular data. SCR = St. Clair River; DR = Detroit River. For data sources and application, see Table 3 and Figure 2 (emergent vegetation), respectively.

Source	Wetland description	Records collected (*n*)	Area (km^2)
MTRI	Forested wetland	1,810	23.60
	Phragmites	4,743	64.00
	Typha	3,783	45.00
	Schoenoplectus	36	0.23
	Shrub wetland	5,874	29.50
	Wetland	2,854	9
LIO	Marsh	863	24.40
	Swamp	68	1
SEMCOG (SCR)	Emergent	1,953	35.10
SEMCOG (DR)	Emergent	330	1.60

Note: These data may not be the most up-to-date. Contact SEMCOG directly to request access to current information.

Table 9. For the St. Clair–Detroit River System analysis, we binned submerged aquatic vegetation (SAV) data (collected by hydroacoustics and converted to points) into 5 quantiles of SAV coverage to identify locations from zero to high SAV density, where '0%' coverage indicates that no SAV was detected. The number of SAV samples (*n*) are shown and represent a 10-m^2 area from the transect ping. For data sources and their application, see Table 3 and Figure 2 (submerged aquatic vegetation), respectively. For locations of sampling for each binned quantile, refer to Appendix A.

SAV coverage (%)	*n*	% of SAV data	Bin minimum value	Bin maximum value	Bin median value
0	39,341	48	0	0	0
>0–25	3,173	4	10	20	14.36
>25–50	3,256	4	30	50	34.96
>50–75	6,407	8	60	70	65.44
>75–100	29,790	36	80	100	96.17
Total	81,967	100			

Table 10. List of all substrate data sources and number of samples collected for substrate analysis. Year of collection was included where available. For data sources and their application, see Table 3 and Figure 2 (substrate), respectively.[a]

Source	Collection method	Year	Samples collected (*n*)
GLIER	Ponar grab samples	1999–2001	165
UW	Ponar grab samples	2003, 2013–2014	284
DFO Doka Lab	Ponar grab samples	2007, 2008, 2010, 2015	248
ECCC	Ponar grab samples	1994, 2001	318
MNR	Ponar grab samples	2006, 2015	157
USGS	Ponar grab samples	2008	13
SLCC	RoxAnn	2013	271,115
ECCC	RoxAnn	1999–2000	172,554
NOAA	Satellite imagery	1997–2004	115
Total			**444,969**

[a] GLIER – Great Lakes Institute of Environmental Research; UW–University of Windsor; DFO – Fisheries and Oceans Canada; ECCC–Environment and Climate Change Canada; MNR –Ministry of Natural Resources; USGS–United States Geological Survey; SLCC–Sea Lamprey Control Centre; NOAA–National Oceanic and Atmospheric Administration;

Table 11. Sea Lamprey Control Centre (SLCC) definitions of their RoxAnn survey output into substrate types (by K. Tallon, Sea Lamprey Control Centre, Sault Ste. Marie, Ontario, personal communication, 2013).

Substrate type	Description
1	Grain size where sand fractions are made up of very fine/fine/medium sands. Coarse sands, gravel, or rubble may be present, however, with minimal contribution to the overall sample. This group of fine substrates are created by the presence of large environmental objects, such as bends in streams or boulder/log deposits with a surface cover generally of woody debris or aquatic macrophysics deposited by changes in water velocity.
2	Sediment that has a greater particle size than Type 1 and is classified as medium, or coarse. In this classification, proportions of silt and detritus decrease, while gravel and rubble make up the majority. This substrate is generally located within areas of lakebed transition, resulting in a decrease of macrophytes and lower organic matter, particularly where water velocity ranges from 5 to 10 cm/s with minimal environmental impediments.
3	Ranges from 6.4 cm and above, containing substrate grains that are commonly found in hydraulic erosional environments, including riffle areas, the thalweg of a stream, or the lowest portion of a valley or river where the velocity of water is >10 cm/s.

Table 12. Sea Lamprey Control Centre (SLCC) classification of their RoxAnn survey outputs into substrate types and assigned Wentworth classes (Wentworth 1922). These were reclassified to percent composition (by K. Tallon, Sea Lamprey Control Centre, Sault Ste. Marie, Ontario, personal communication, 2013).

SLCC classification	Assigned Wentworth classification	% Allocated composition
Type 1 & 2	sand/silt	50% sand, 50% silt
Type 3	gravel/rubble	50% gravel, 50% rubble
Type 2	sand	100% sand
Type 1	silt/sand	75% silt, 25% Sand

Table 13. Collected sediment backscatter classes using RoxAnn survey techniques (N. Rukavina and H. Biberhofer, National Water Research Institute, Environment Canada, Burlington, Ontario, personal communication, 2003). These were classified based on groupings of sonar echoes for roughness, hardness and the associated Wentworth classification system (Wentworth 1922) using MacDonald et al. 2000 methods. Values were redefined into percent (%) composition. For data sources and application, see Table 3 and Figure 2 (substrate), respectively.

RoxAnn classification	Assigned Wentworth classification	% Allocated composition
hard substrate	gravel/rubble	50% gravel, 50% rubble
weeds on soft	sand/silt/clay	33% sand, 33% silt, 33% clay, 1% boulder
mud	sand/silt/clay	40% sand, 30% silt, 30% clay
boulders/hard	boulder/cobble	50% boulder, 50% cobble
coarse sand	sand	100% sand
muddy sand	sand/silt/clay	40% sand, 30% silt, 30% clay
sand	sand	100% sand
gravel	gravel	100% gravel

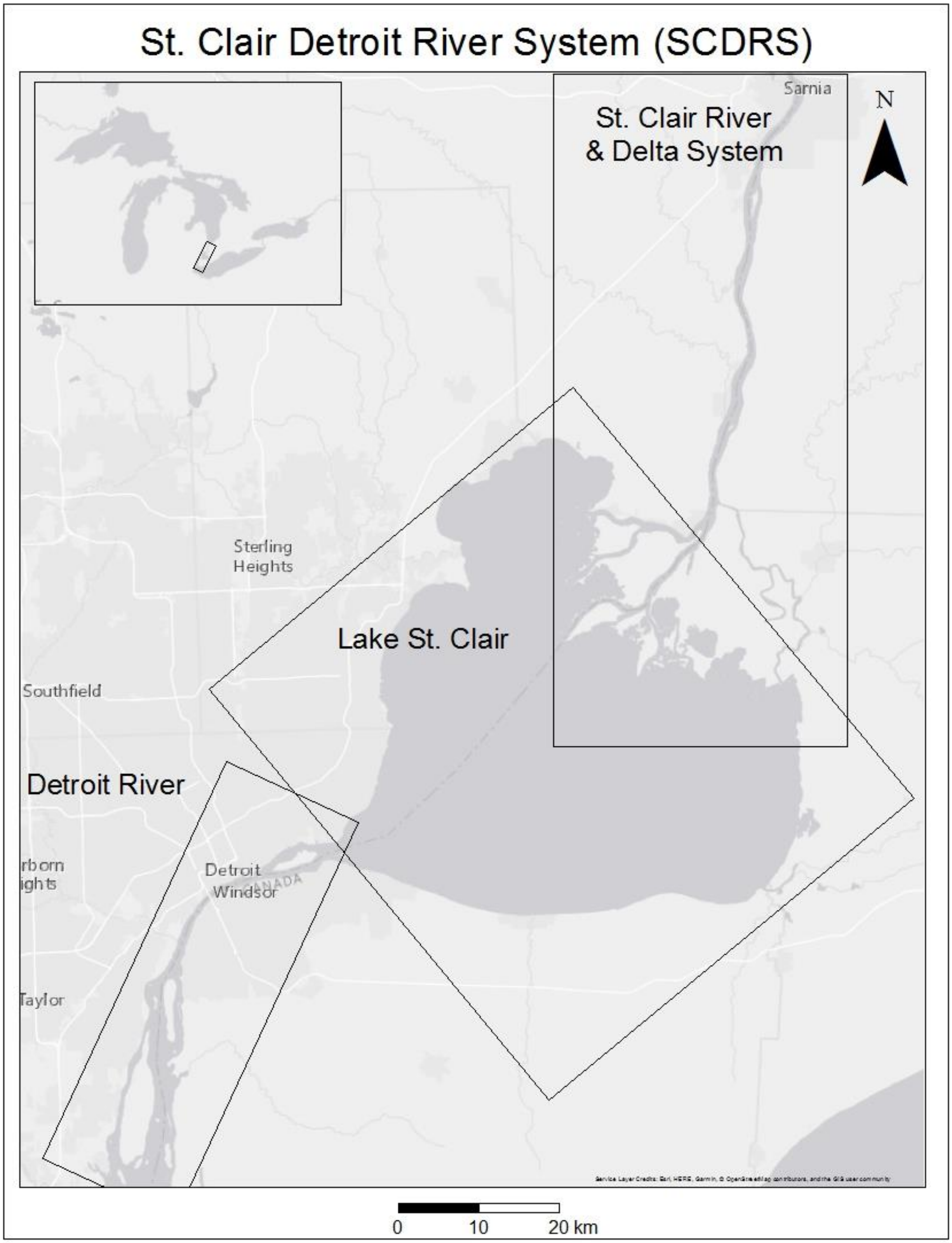
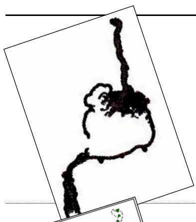
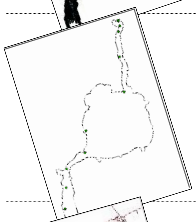


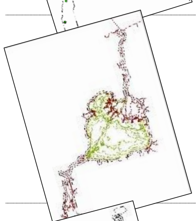
Figure 1. The St. Clair–Detroit River System extent used for mapping and analysis. The St. Clair River, Lake St. Clair, and Detroit River areas are outlined in the rectangular insets above. For the purposes of this report, each subarea was analyzed separately to improve computational time and visibility in printed maps.



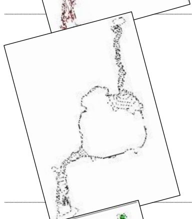
Layer: Digital elevation model
Map use: Elevation, HEAT, SAV models
Data source(s): DFO Doka Lab, LIO, NOAA, USACE, USGS,
Year coverage: 1994–2004
Representation: Points
Spatial relationships: Water and elevation features
Map scale and accuracy: 1:460,000
Symbology and annotation: Blue (light to dark)



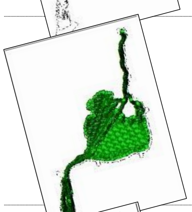
Layer: Digital elevation model
Map use: Water Stations for calculating water level
Data source(s): ECCC, NOAA
Year coverage: 1994–2018
Representation: Point
Spatial relationships: Water and elevation features
Map scale and accuracy: 1: 460,000
Symbology and annotation: Variable



Layer: Digital elevation model
Map use: Elevation, HEAT, SAV models
Data source(s): NOAA
Year coverage: 2011–2012
Representation: Polyline
Spatial relationships: Water and Elevation Features
Map scale and accuracy: 1:460,000
Symbology and annotation: Variable

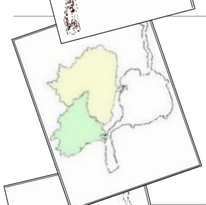


Layer: Vertical step planes
Map use: Offsetting water measurements for bathymetry
Data source(s): NOAA, USACE, USGS
Year coverage: 2012
Representation: Polygons
Spatial relationships: Water and elevation features
Map scale and accuracy: 1:460,000
Symbology and annotation: No colour

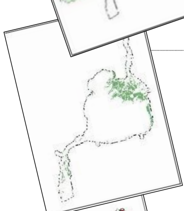


Layer: Velocity/water direction
Map use: HEAT, SAV models
Data source(s): ECCC
Year coverage: 2013
Representation: Points
Spatial relationships: Flow impacts velocity
Map scale and accuracy: 1:460,000
Symbology and annotation: Variable

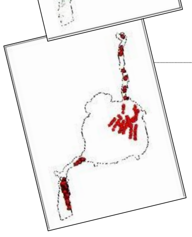
Layer: Toxicity
Map use: Distribution of toxic variables
Data source(s): Drouillard et al. 2020
Year coverage: 1999–2014
Representation: Point
Spatial relationships: Areas of interest
Map scale and accuracy: 1: 460,000
Symbology and annotation: Colour ramp, displayed in 'Categories'



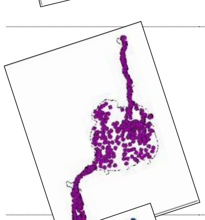
Layer: U.S. AOCs (Clinton AOC, Rouge AOC)
Map use: Identify U.S. AOCs in the SCDRS
Data source(s): EPA
Year coverage: 2019
Representation: Area of Concern
Spatial relationships: Toxicity
Map scale and accuracy: 1: 545,000
Symbology and annotation: Variable



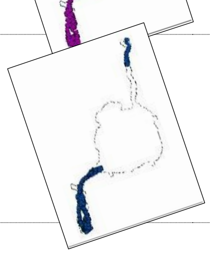
Layer: Emergent vegetation
Map use: HEAT
Data source(s): LIO, MTRI, SEMCOG (DR, SCR only)
Year coverage: 2004–2019
Representation: Polygons
Spatial relationships: Vegetation
Map scale and accuracy: 1:460,000
Symbology and annotation: Olive green



Layer: Submerged aquatic vegetation
Map use: DEM, HEAT, SAV models
Data source(s): DFO Doka Lab
Year coverage: 2008–2017
Representation: Points
Spatial relationships: Vegetation
Map scale and accuracy: 1:460,000
Symbology and annotation: Variable



Layer: Substrate
Map use: HEAT
Data source(s): DFO Doka Lab, EC, GLIER, UW, MNR, USGS
Year coverage: 2003–2001
Representation: Ponar
Spatial relationships: Sediment samples
Map scale and accuracy: 1: 460,000
Symbology and annotation: Output to raster where colour represents grain type



Layer: Substrate
Map use: HEAT
Data source(s): EC, SLCC
Year coverage: 1994–2013
Representation: RoxAnn
Spatial relationships: Sediment samples
Map scale and accuracy: 1: 460,000
Symbology and annotation: Output to raster where colour represents grain type

Figure 2. All contributing data sources and specific layers for the St. Clair–Detroit River System geodatabase and gap analysis report. See Table 3 for data source details. See the List of Acronyms on page ix for definitions.

Figure 3. Locations of vertical step planes in the St. Clair–Detroit River System. There are over 100 step planes used to account for changes to water levels. See Table 3 and Figure 2 (vertical step planes) for data source and application, respectively. Sources: ECCC, Environment and Climate Change Canada, Burlington, Ontario, personal communication, 2012; NOAA, National Oceanographic and Atmospheric Administration, Germantown, Maryland, 2012, personal communication, 2012; USACE, United States Army Corps of Engineers, Detroit, Michigan, personal communication, 2012.

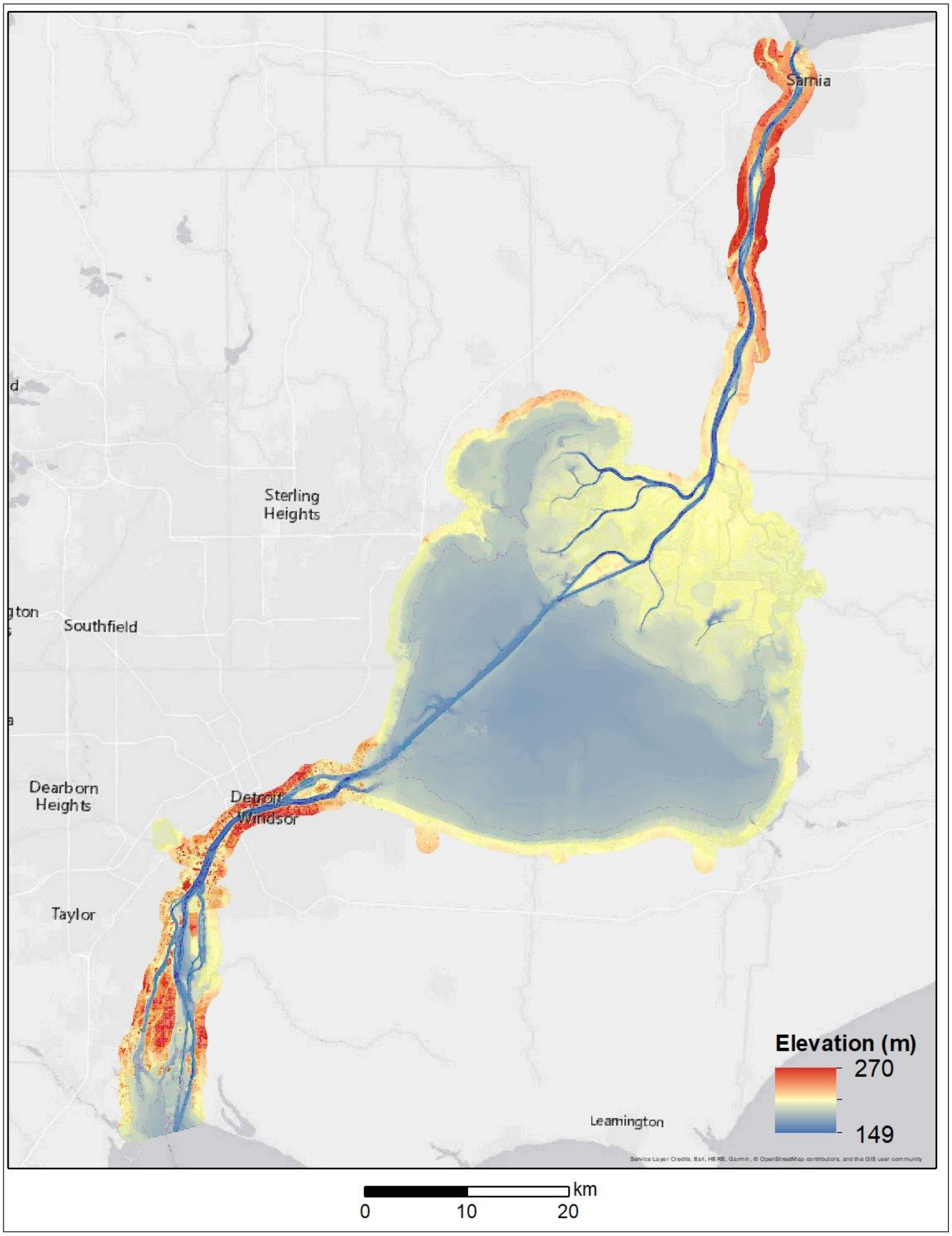


Figure 4. Digital elevation model of the St. Clair–Detroit River System at a 10-m grid resolution. Areas located on the southwest shore of Lake St. Clair near Grosse Pointe, Michigan, appear flooded in this map, however we acknowledge there is a lack of data samples at that location. Information provided herein is up-to-date as of 2017 with consideration that sources are updated at irregular intervals. For data sources and application, see Table 3 and Figure 2 (digital elevation model), respectively.

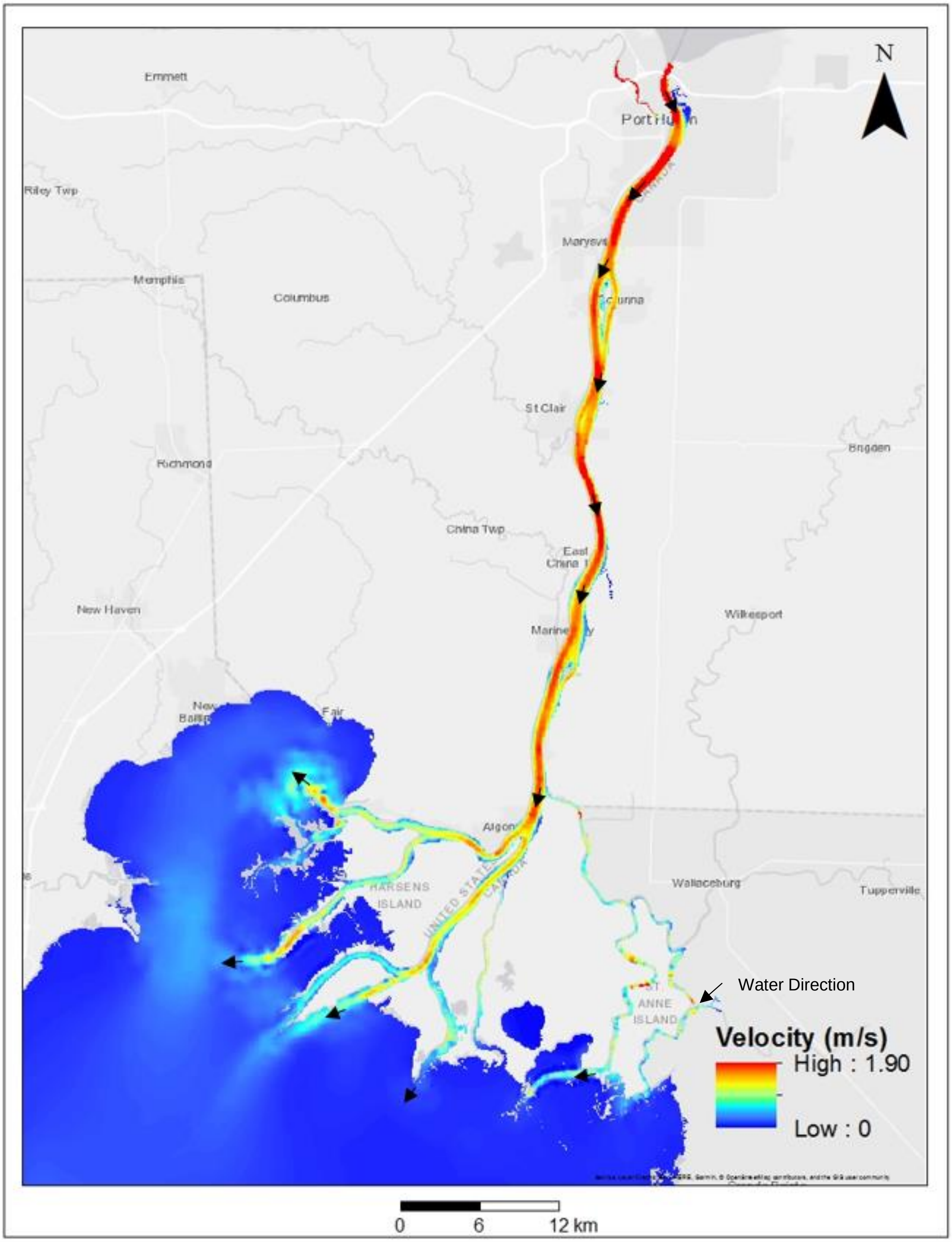


Figure 5. St. Clair River velocity where higher speeds are visualized in red and direction of water flow is displayed by arrows. Velocity was calculated using a Resource Management Associates two-dimensional model (EC 2008). See Table 3 and Figure 2 (velocity/water direction) for data sources and application, respectively.

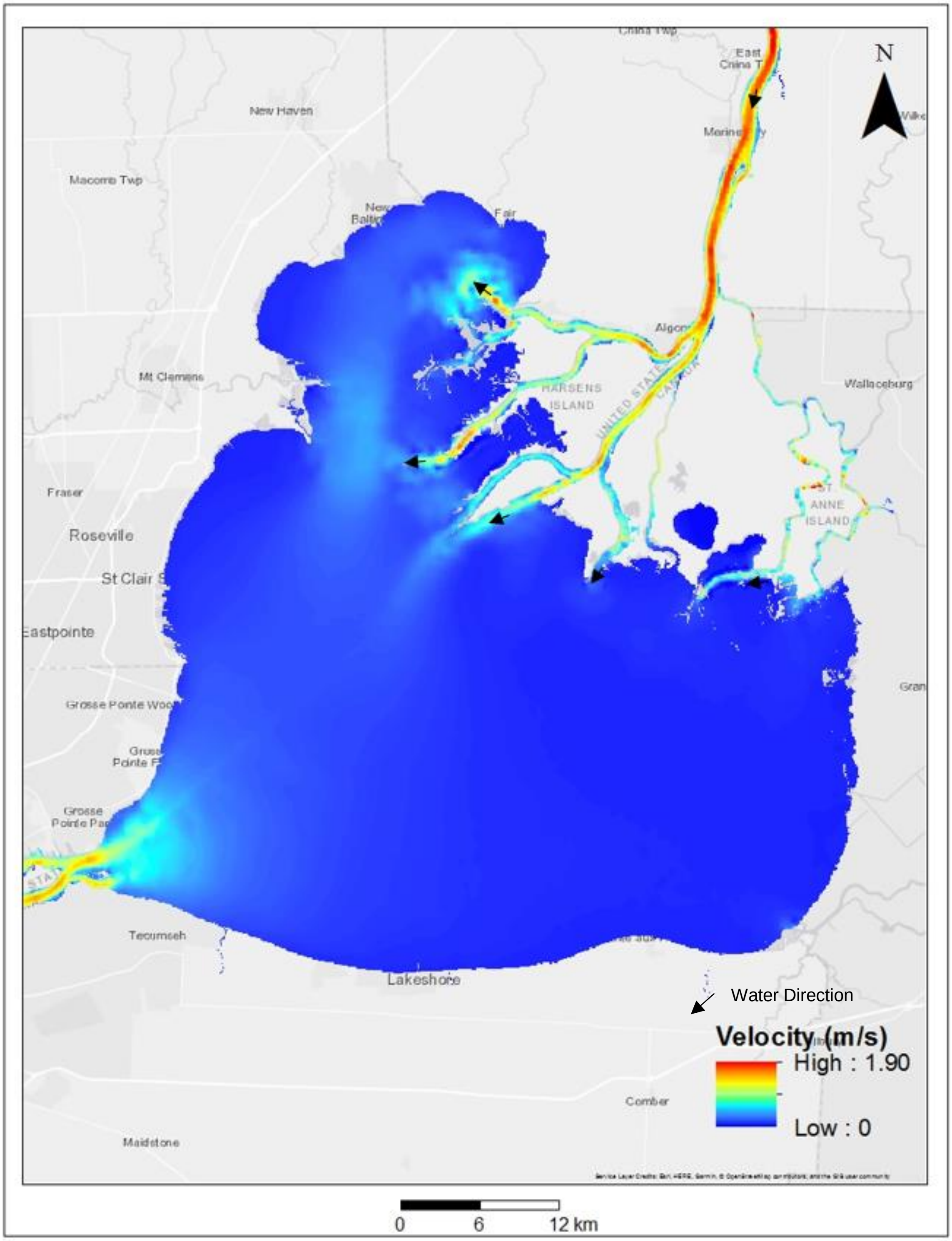


Figure 6. Lake St. Clair velocity where higher speeds are visualized in red and direction of water flow is displayed by arrows. Velocity was calculated using a Resource Management Associates two-dimensional model (EC 2008). See Table 3 and Figure 2 (flow/velocity) for data sources and application, respectively.

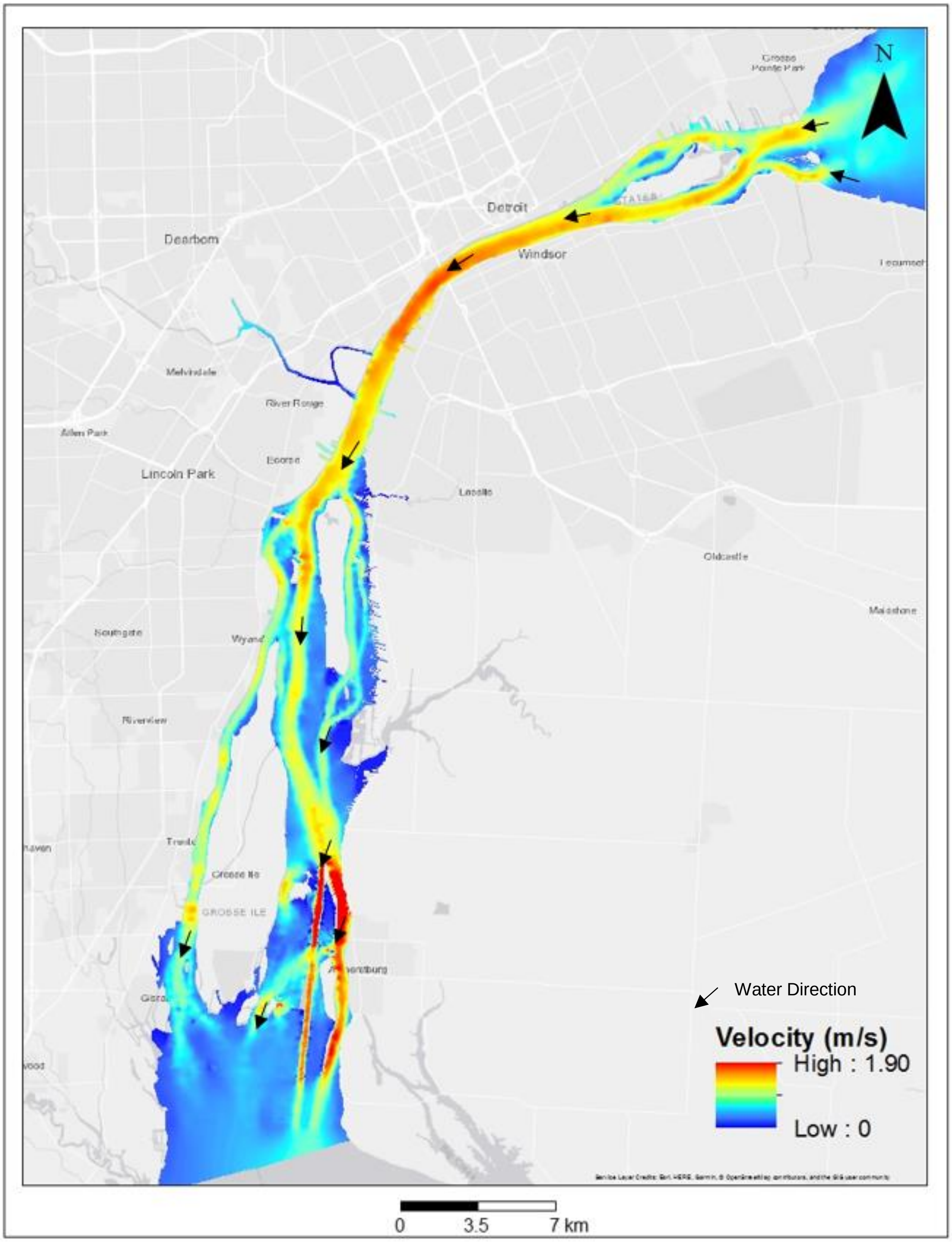


Figure 7. Detroit River velocity where higher speeds are visualized in red and direction of water flow is displayed by arrows. Velocity was calculated using a Resource Management Associates two-dimensional model (EC 2008). See Table 3 and Figure 2 (velocity) for data sources and application, respectively.

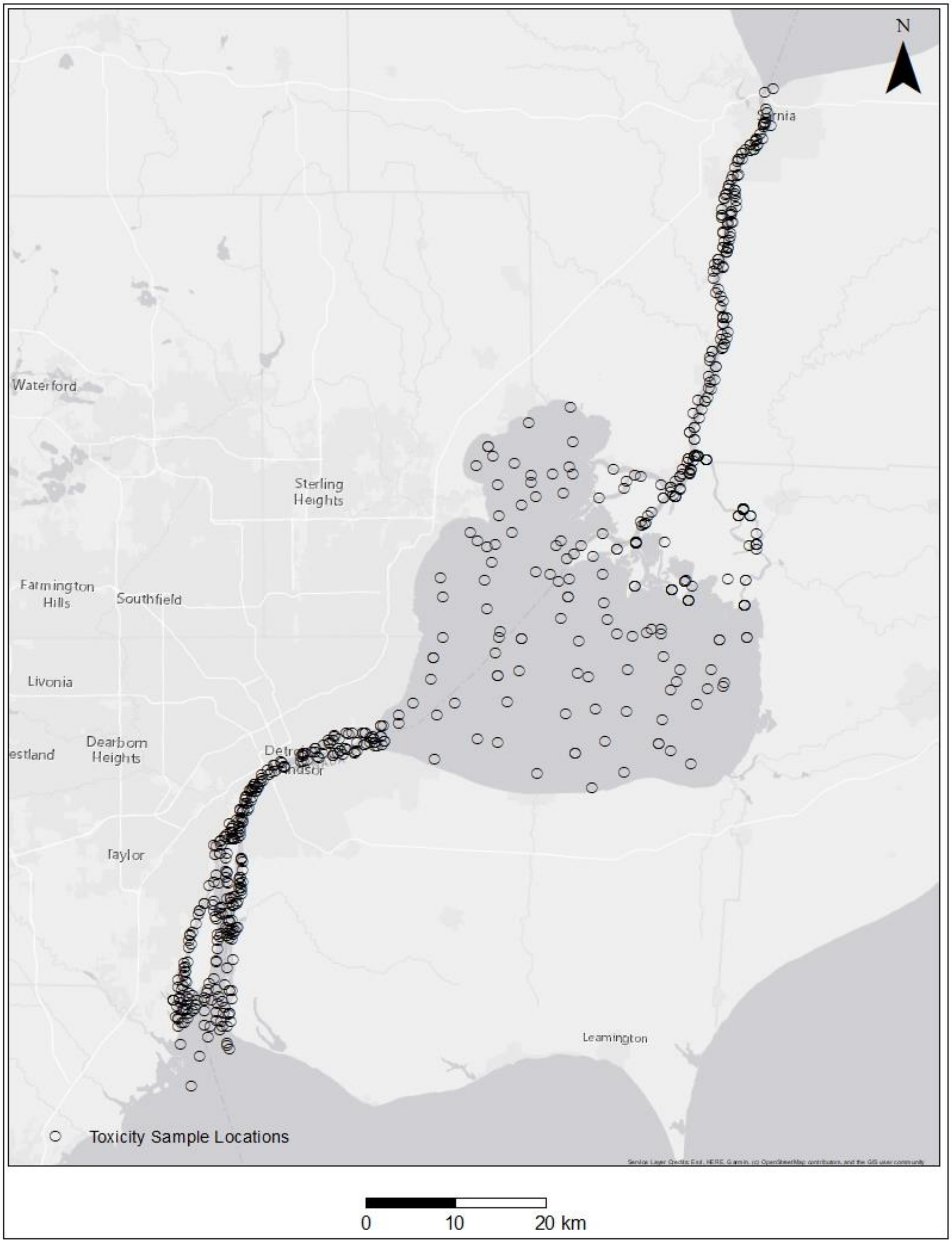


Figure 8. Toxicity data sample collection points. Data were provided by K. Drouillard (UW, GLIER, Windsor, Ontario, personal communication, 2017) and interpolated into a system-wide map by the Doka Lab. Data were collected between 1999–2015 and each sample represents either random sampling or directed sampling in the St. Clair–Detroit River System.

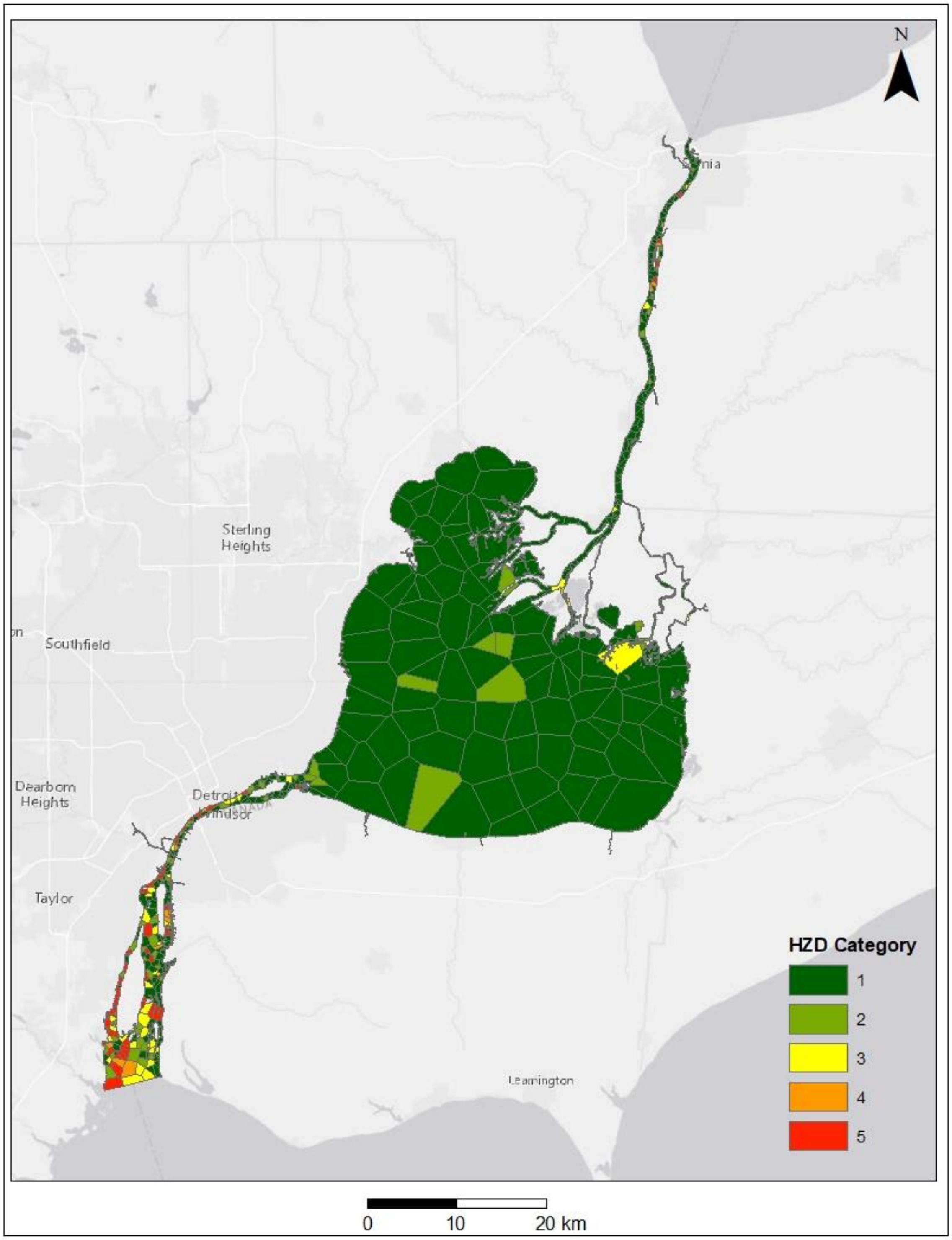


Figure 9. Map of Thiessen polygons (ESRI 2018f) used to extrapolate the cumulative anticipated toxicity levels from the hazard score (HZD) category points for the St. Clair–Detroit River System. Data were provided by K. Drouillard (UW, GLIER, Windsor, Ontario, personal communication, 2017) and interpolated into a system-wide map by the Doka Lab. With our adaptation to add “>”, HZD categories for cumulative anticipated toxicity were defined by K. Drouillard as: HZD Category 1 = 0–25%; HZD Category 2 = >25–50%; HZD category 3 = >50–75%; HZD Category 4 = >75–100% ; HZD Category 5 = >100% (Table 7).

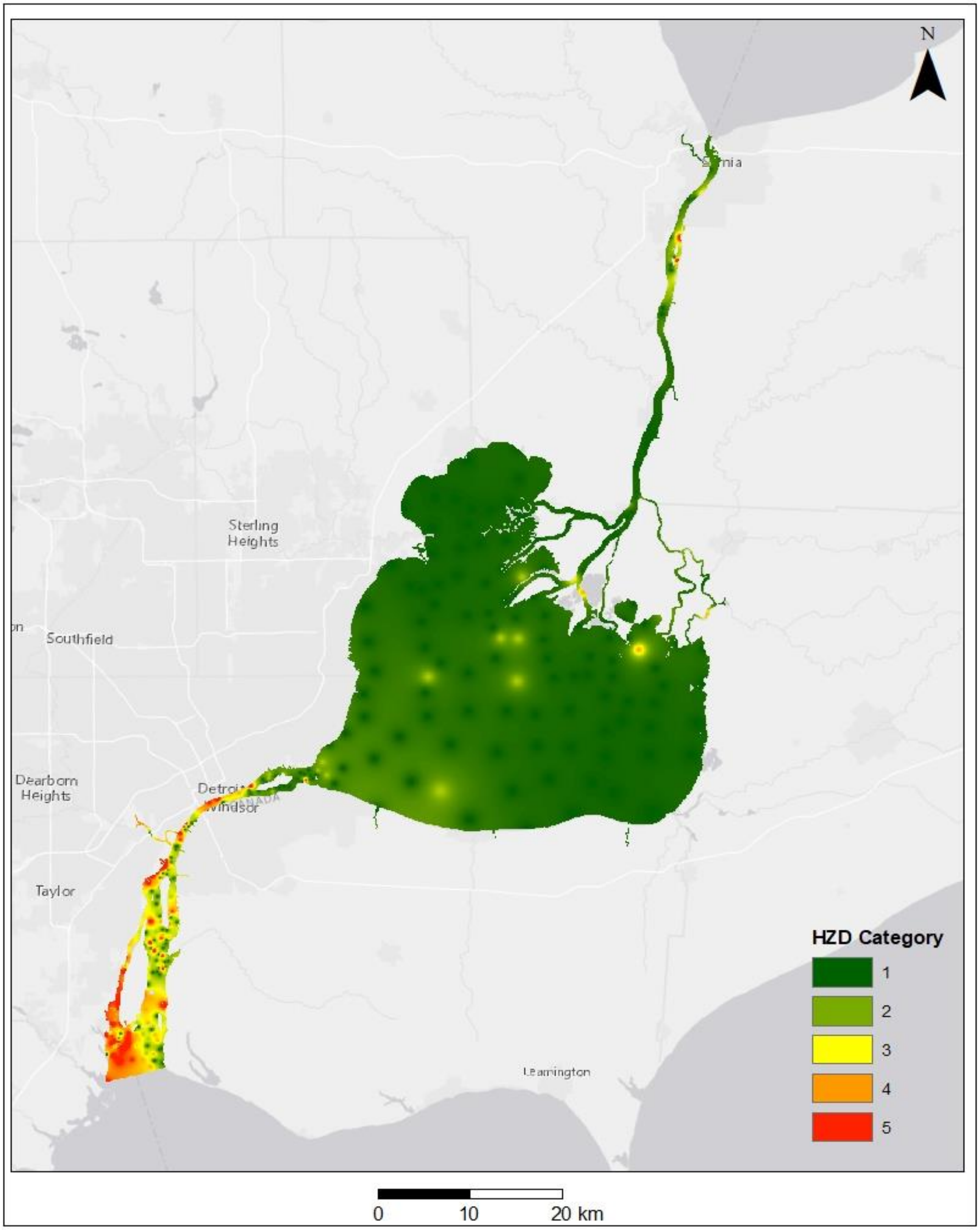


Figure 10. Map displaying the inverse distance weighting interpolation of toxicity data represented as hazard score (HZD) categories throughout the St. Clair–Detroit River System. Data were provided by K. Drouillard (UW, GLIER, Windsor, Ontario, personal communication, 2017) and interpolated into a system-wide map by the Doka Lab. With our adaptation to add “>”, HZD categories for cumulative anticipated toxicity were defined by K. Drouillard as: HZD Category 1 = 0–25%; HZD Category 2 = >25–50%; HZD category 3 = >50–75%; HZD Category 4 = >75–100% ; HZD Category 5 = >100% (Table 7).

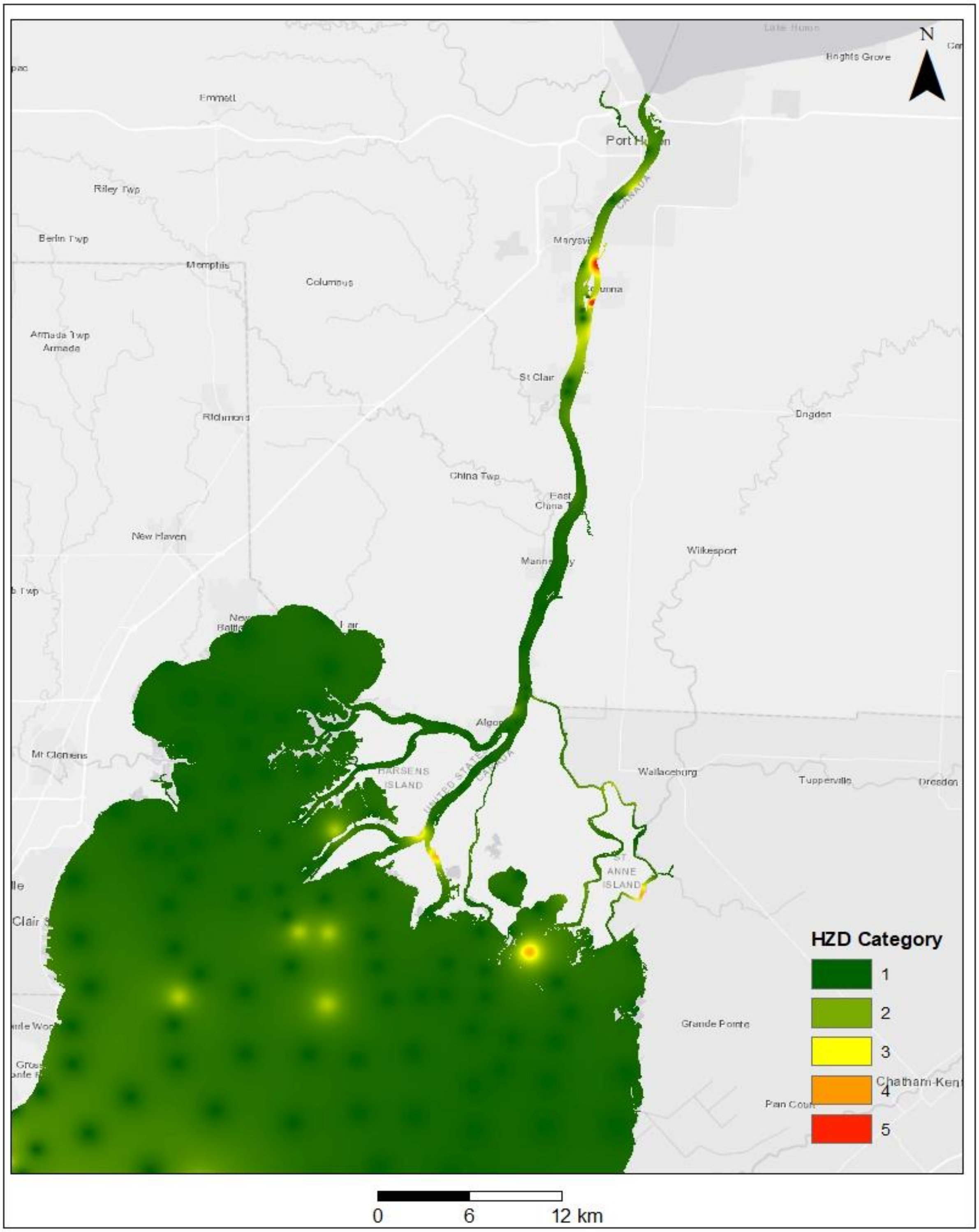


Figure 11. Map displaying the inverse distance weight interpolation of toxicity data represented as hazard score (HZD) categories throughout the St. Clair River. Data were provided by K. Drouillard (UW, GLIER, Windsor, Ontario, personal communication, 2017) and interpolated into a system-wide map by the Doka Lab. With our adaptation to add ">", HZD categories for cumulative anticipated toxicity were defined by K. Drouillard as: HZD Category 1 = 0–25%; HZD Category 2 = >25–50%; HZD category 3 = >50–75%; HZD Category 4 = >75–100% ; HZD Category 5 = >100% (Table 7).

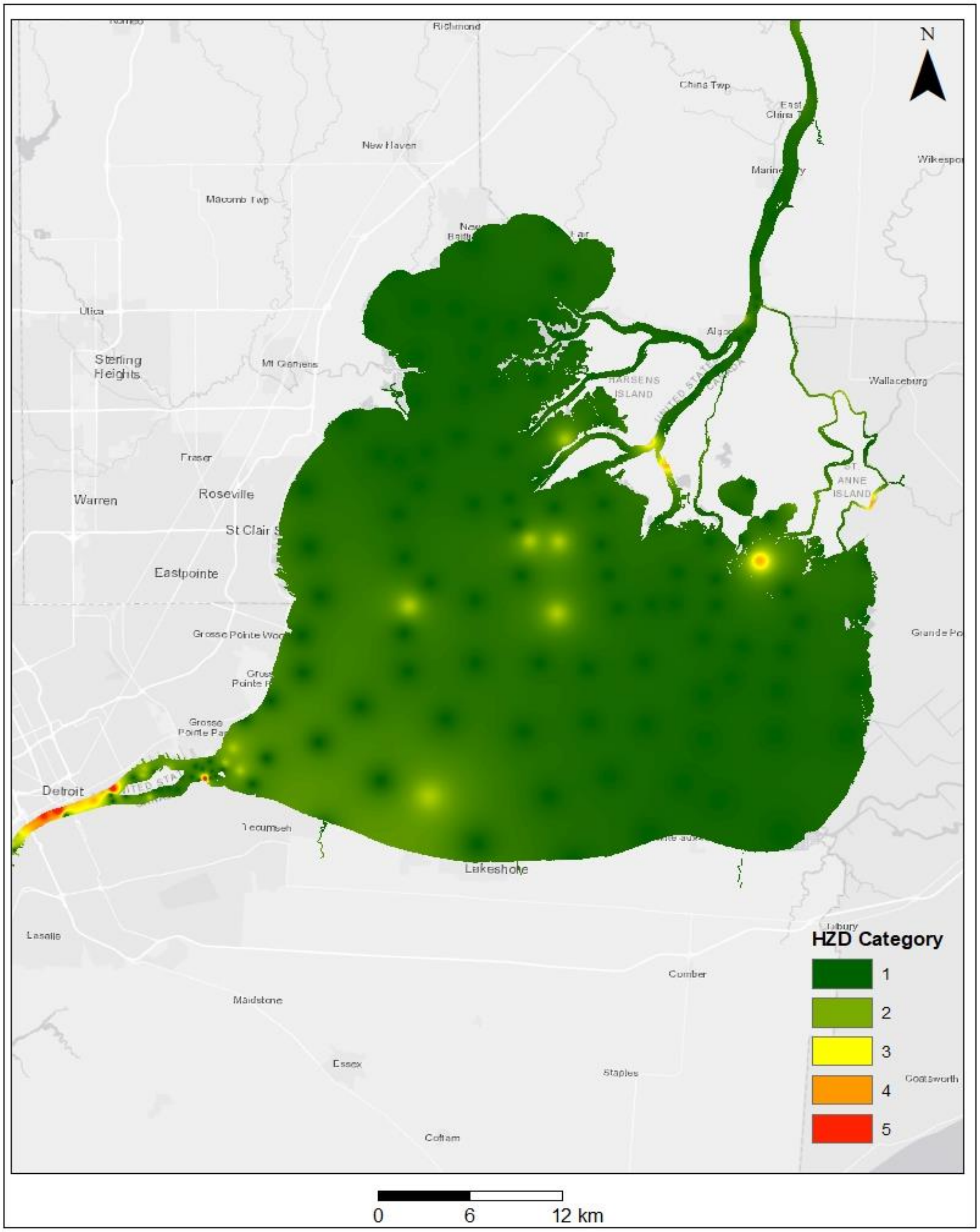


Figure 12. Map displaying the inverse distance weighting interpolation of toxicity data represented as hazard score (HZD) categories throughout Lake St. Clair. Data were provided by K. Drouillard (UW, GLIER, Windsor, Ontario, personal communication, 2017) and interpolated into a system-wide map by the Doka Lab. With our adaptation to add “>”, HZD categories for cumulative anticipated toxicity were defined by K. Drouillard as: HZD Category 1 = 0–25%; HZD Category 2 = >25–50%; HZD category 3 = >50–75%; HZD Category 4 = >75–100% ; HZD Category 5 = >100% (Table 7).

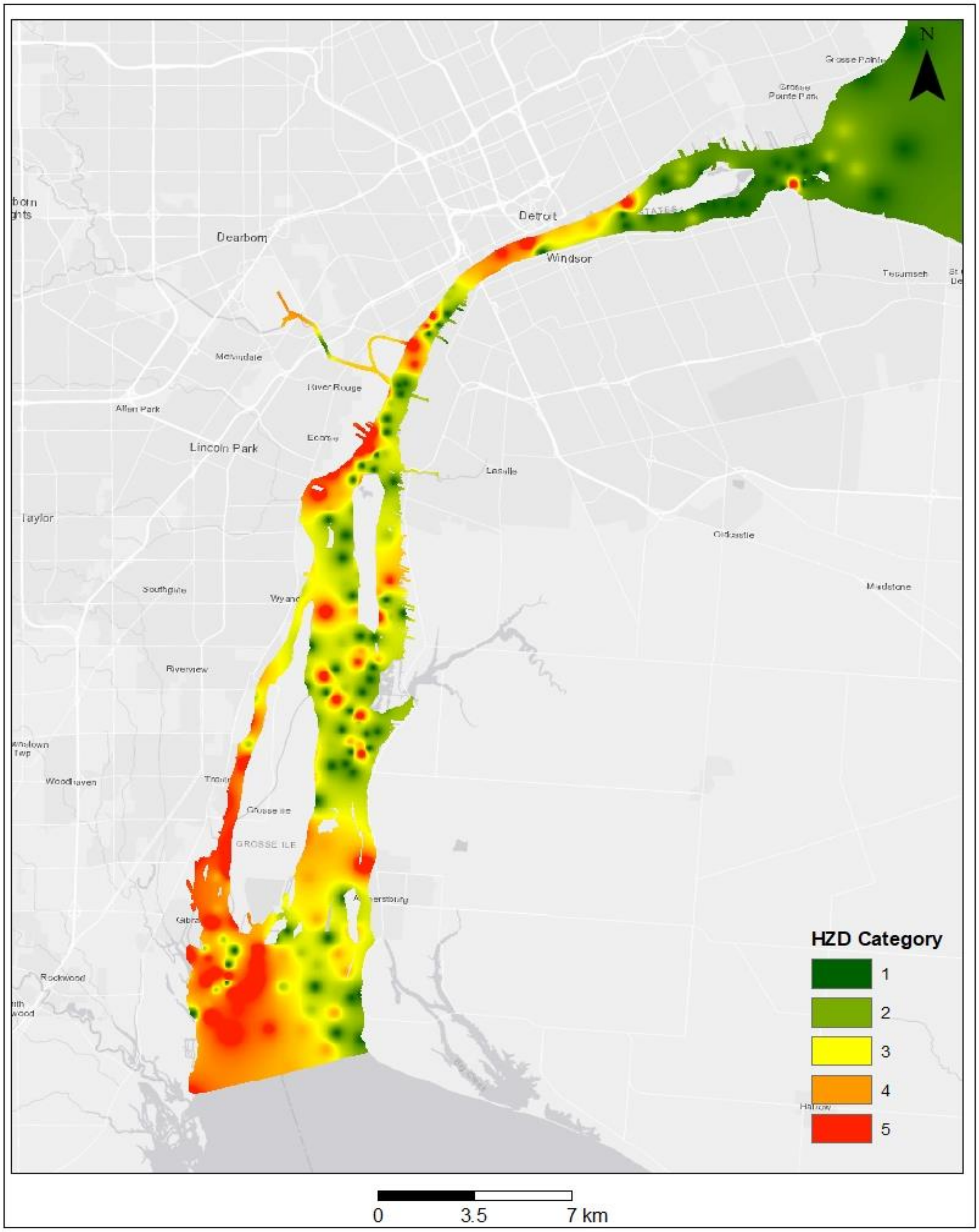


Figure 13. Map displaying the inverse distance weighting interpolation of toxicity data represented as hazard score (HZD) categories throughout the Detroit River. Data were provided by K. Drouillard (UW, GLIER, Windsor, Ontario, personal communication, 2017) and interpolated into a system-wide map by the Doka Lab. With our adaptation to add ">", HZD categories for cumulative anticipated toxicity were defined by K. Drouillard as: HZD Category 1 = 0–25%; HZD Category 2 = >25–50%; HZD category 3 = >50–75%; HZD Category 4 = >75–100% ; HZD Category 5 = >100% (Table 7).

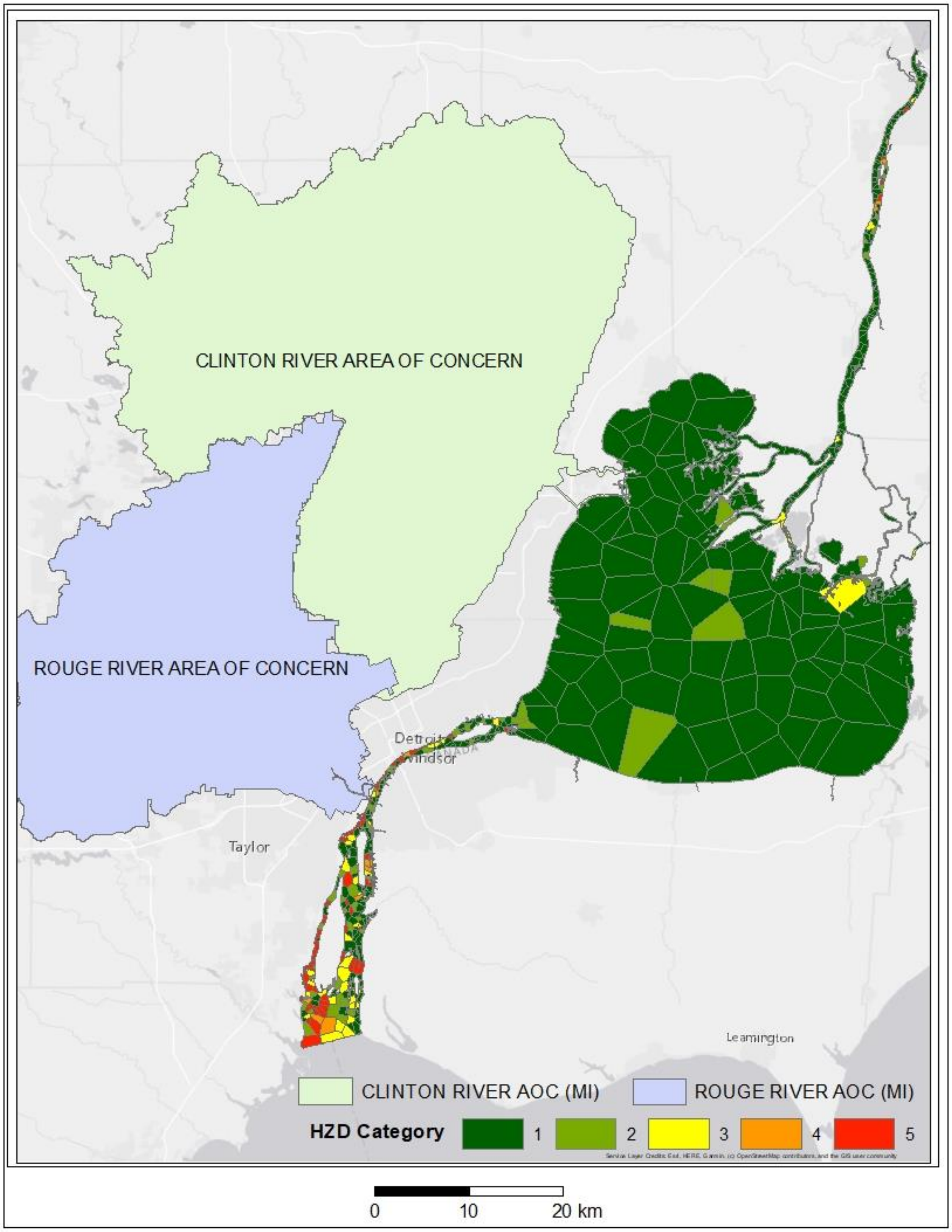


Figure 14. Map of U.S. Areas of Concern (AOCs) watersheds for the Clinton and Rouge River AOC (EPA 2019a, 2019b) and Thiessen polygons (ESRI 2018f) of cumulative anticipated toxicity in the St. Clair–Detroit River System. Data were provided by K. Drouillard (UW, GLIER, Windsor, Ontario, personal communication, 2017) and interpolated into a system-wide map by the Doka Lab. With our adaptation to add ">", HZD categories for cumulative anticipated toxicity were defined by K. Drouillard as: HZD Category 1 = 0–25%; HZD Category 2 = >25–50%; HZD category 3 = >50–75%; HZD Category 4 = >75–100% ; HZD Category 5 = >100% (Table 7).

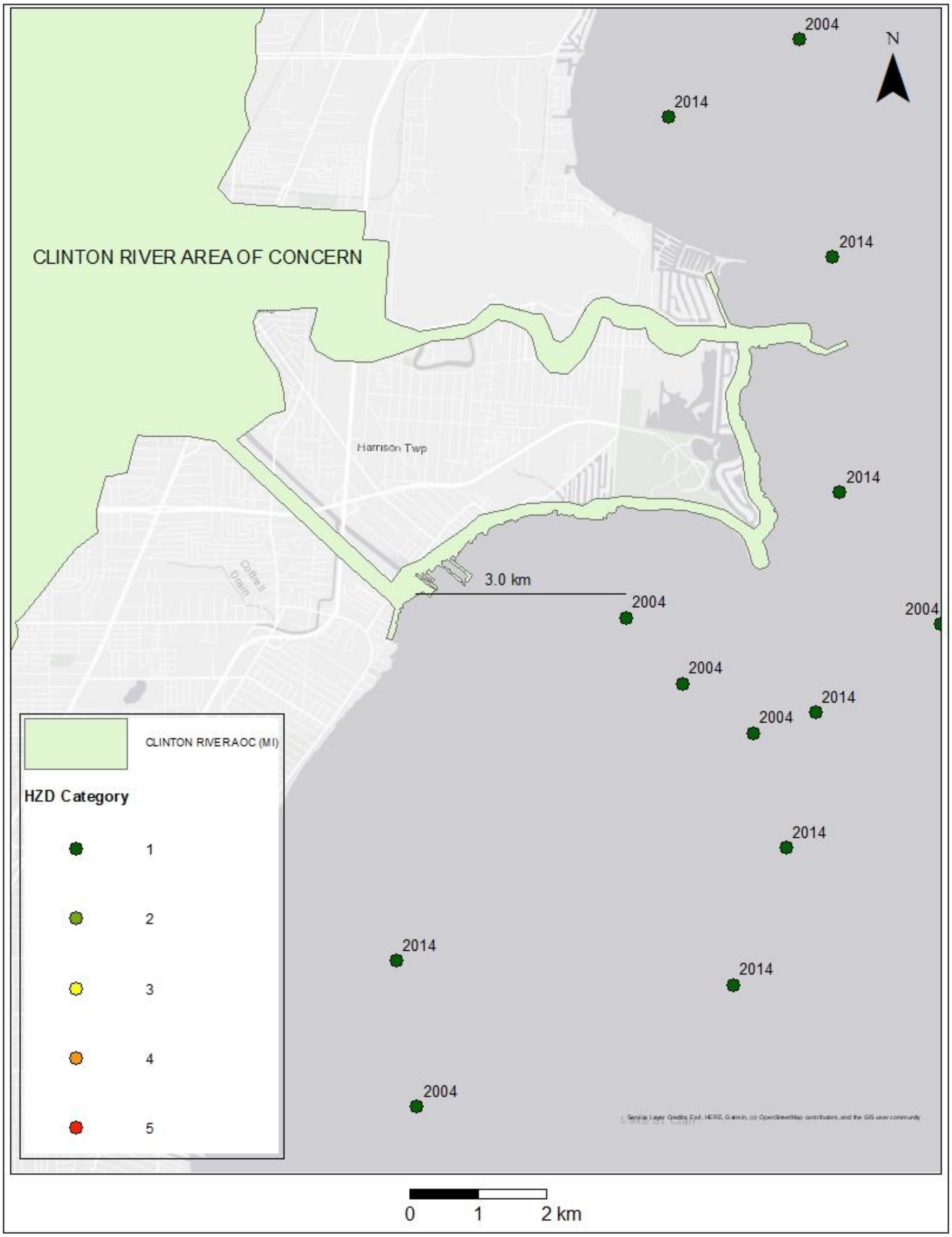


Figure 15. Map indicating toxicity data sample collection points for all time stanzas at the area where the U.S. Clinton River Area of Concern watershed drains to Lake St. Clair. Data were provided by K. Drouillard (UW, GLIER, Windsor, Ontario, personal communication, 2017) and interpolated into a system-wide map by the Doka Lab. With our adaptation to add ">", HZD categories for cumulative anticipated toxicity were defined by K. Drouillard as: HZD Category 1 = 0–25%; HZD Category 2 = >25–50%; HZD category 3 = >50–75%; HZD Category 4 = >75–100% ; HZD Category 5 = >100% (Table 7).

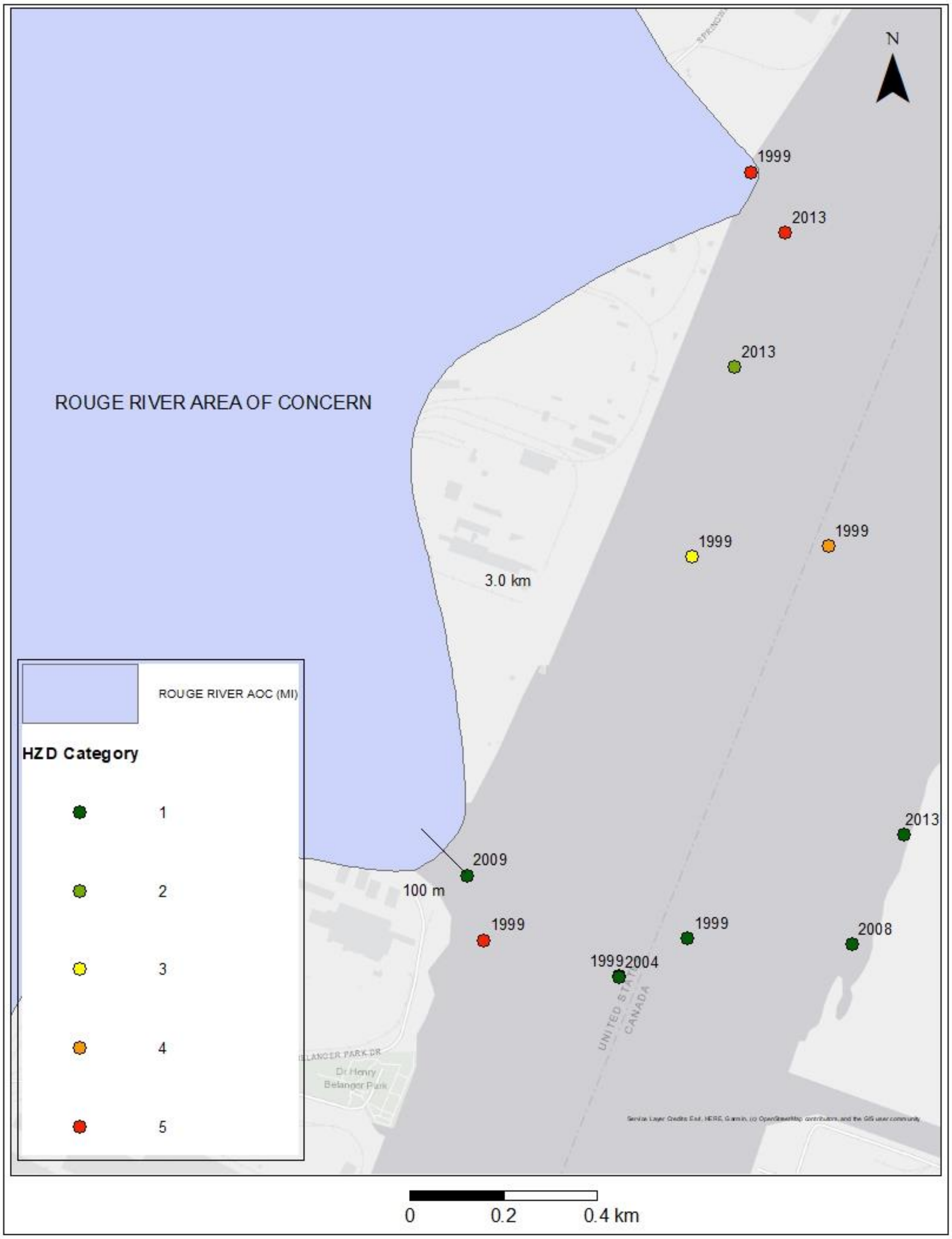


Figure 16. Map indicating sample collection points for all time stanzas at the area where the U.S. Rouge River Area of Concern watershed drains into the Detroit River. Closest sample that was collected is approximately 100 m from the mouth of the river. MI = Michigan. Data were provided by K. Drouillard (UW, GLIER, Windsor, Ontario, personal communication, 2017) and interpolated into a system-wide map by the Doka Lab. With our adaptation to add “>”, HZD categories for cumulative anticipated toxicity were defined by K. Drouillard as: HZD Category 1 = 0–25%; HZD Category 2 = >25–50%; HZD category 3 = >50–75%; HZD Category 4 = >75–100% ; HZD Category 5 = >100% (Table 7).

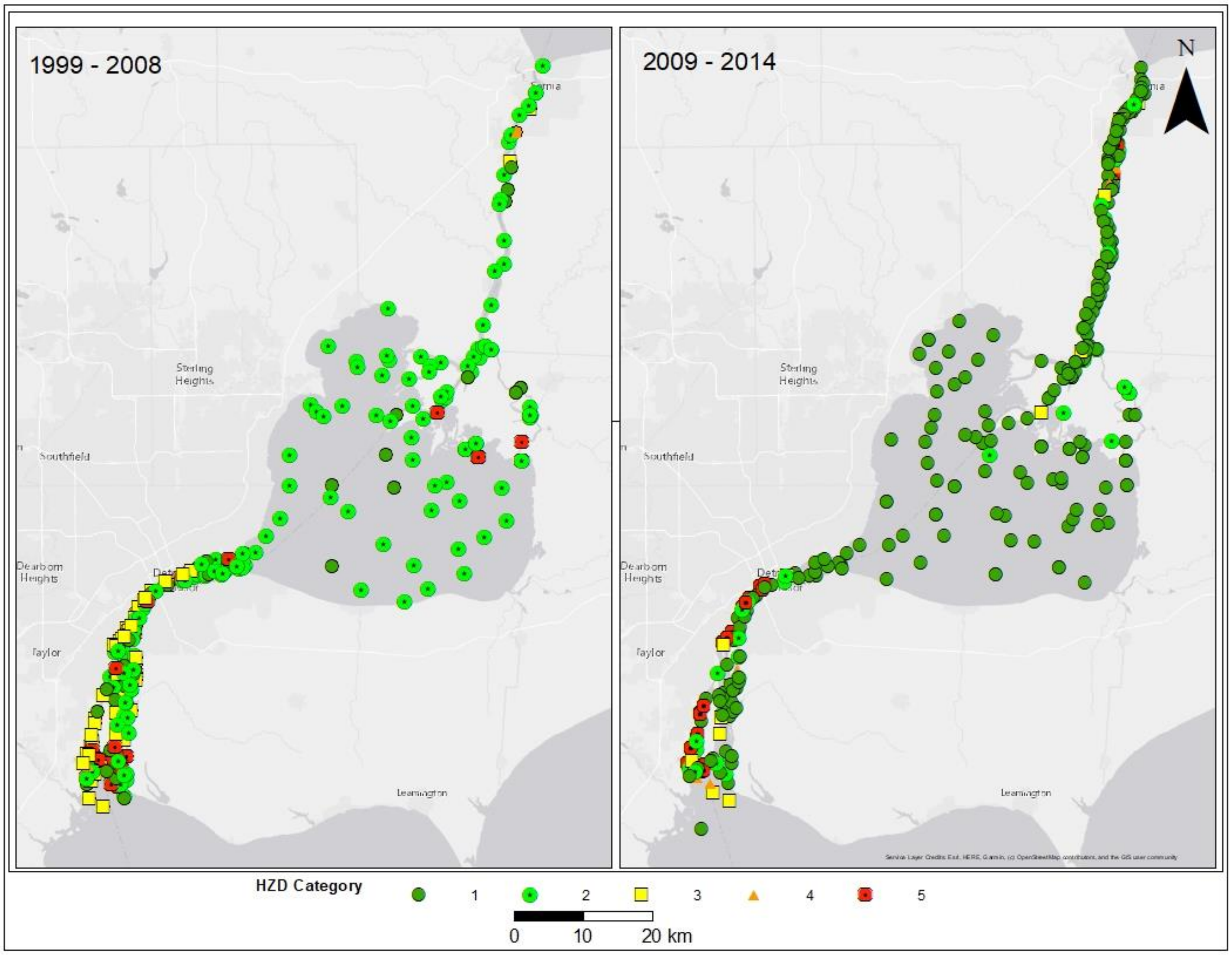


Figure 17. Map detailing locations of toxicity sample collection points for two time stanzas in the St. Clair–Detroit River System: 1999–2008 (left) and 2009–2014 (right). Data were provided by K. Drouillard (UW, GLIER, Windsor, Ontario, personal communication, 2017) and interpolated into a system-wide map by the Doka Lab. With our adaptation to add ">", HZD categories for cumulative anticipated toxicity were defined by K. Drouillard as: HZD Category 1 = 0–25%; HZD Category 2 = >25–50%; HZD category 3 = >50–75%; HZD Category 4 = >75–100% ; HZD Category 5 = >100% (Table 7).

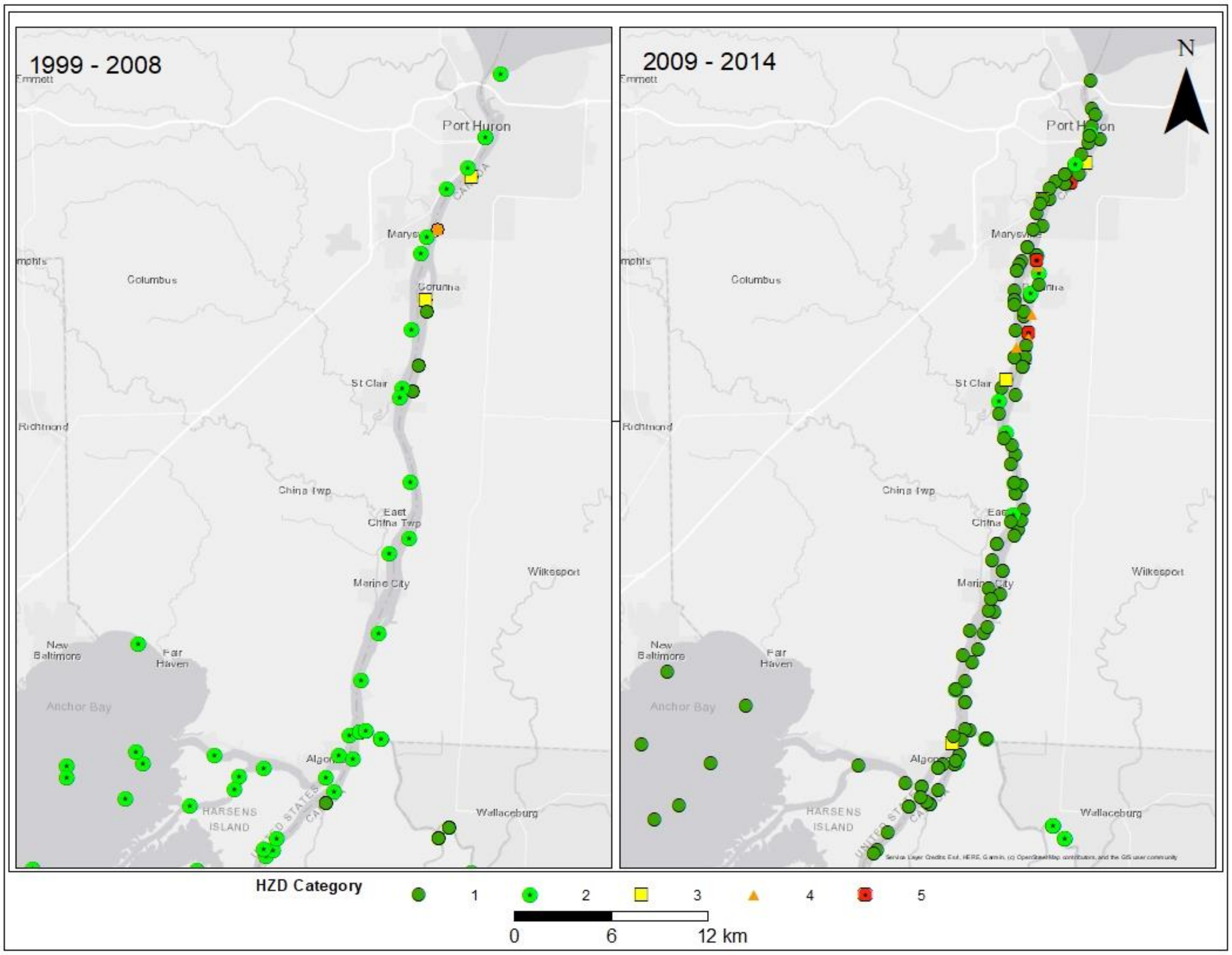


Figure 18. Map detailing locations of toxicity sample collection points for two time stanzas in the St. Clair River: 1999–2008 (left) and 2009–2014 (right). Data were provided by K. Drouillard (UW, GLIER, Windsor, Ontario, personal communication, 2017) and interpolated into a system-wide map by the Doka Lab. With our adaptation to add “>”, HZD categories for cumulative anticipated toxicity were defined by K. Drouillard as: HZD Category 1 = 0–25%; HZD Category 2 = >25–50%; HZD category 3 = >50–75%; HZD Category 4 = >75–100% ; HZD Category 5 = >100% (Table 7).

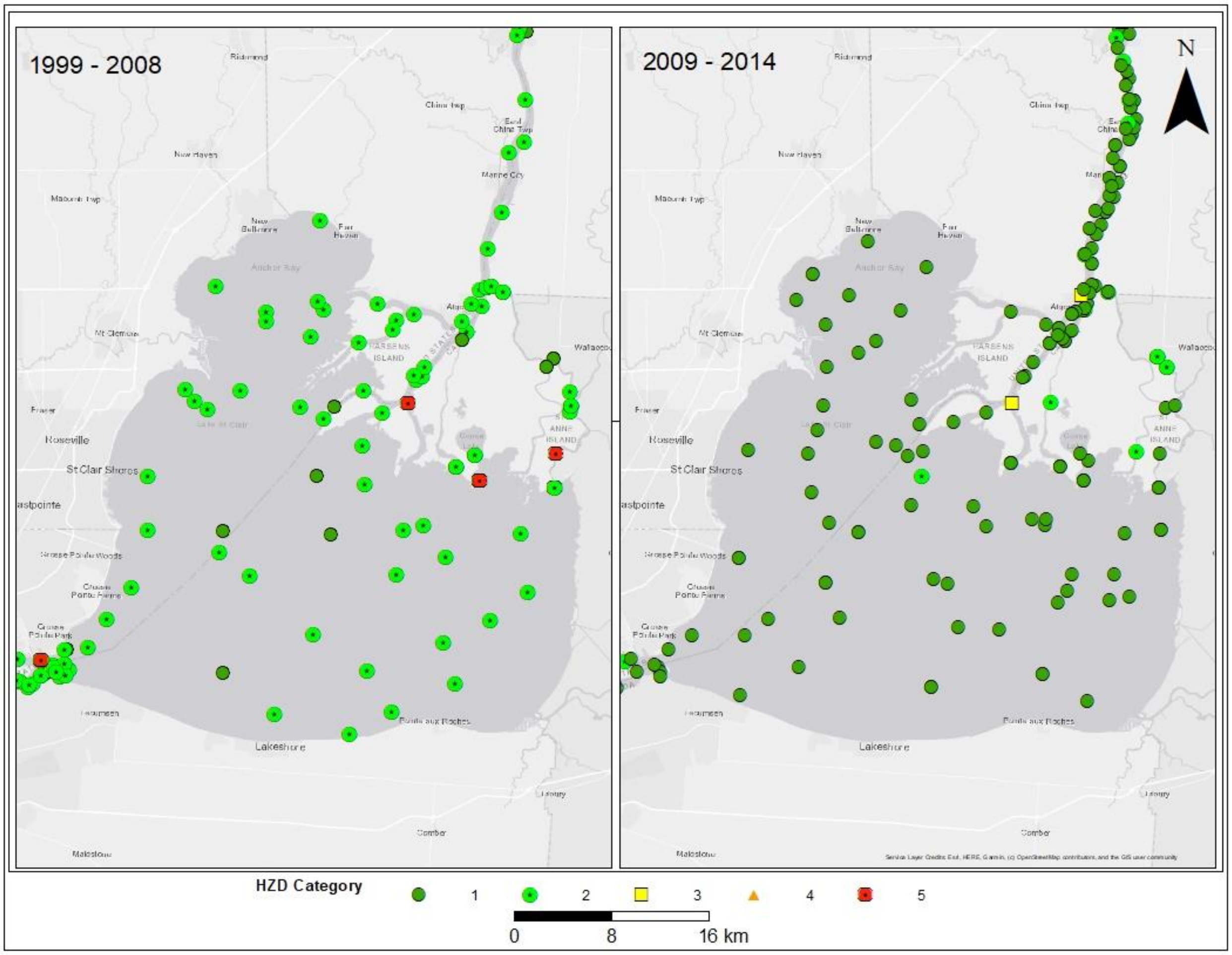


Figure 19. Map detailing locations of toxicity sample collection points for two time stanzas in Lake St. Clair: 1999–2008 (left) and 2009–2014 (right). Data were provided by K. Drouillard (UW, GLIER, Windsor, Ontario, personal communication, 2017) and interpolated into a system-wide map by the Doka Lab. With our adaptation to add ">", HZD categories for cumulative anticipated toxicity were defined by K. Drouillard as: HZD Category 1 = 0–25%; HZD Category 2 = >25–50%; HZD category 3 = >50–75%; HZD Category 4 = >75–100% ; HZD Category 5 = >100% (Table 7).

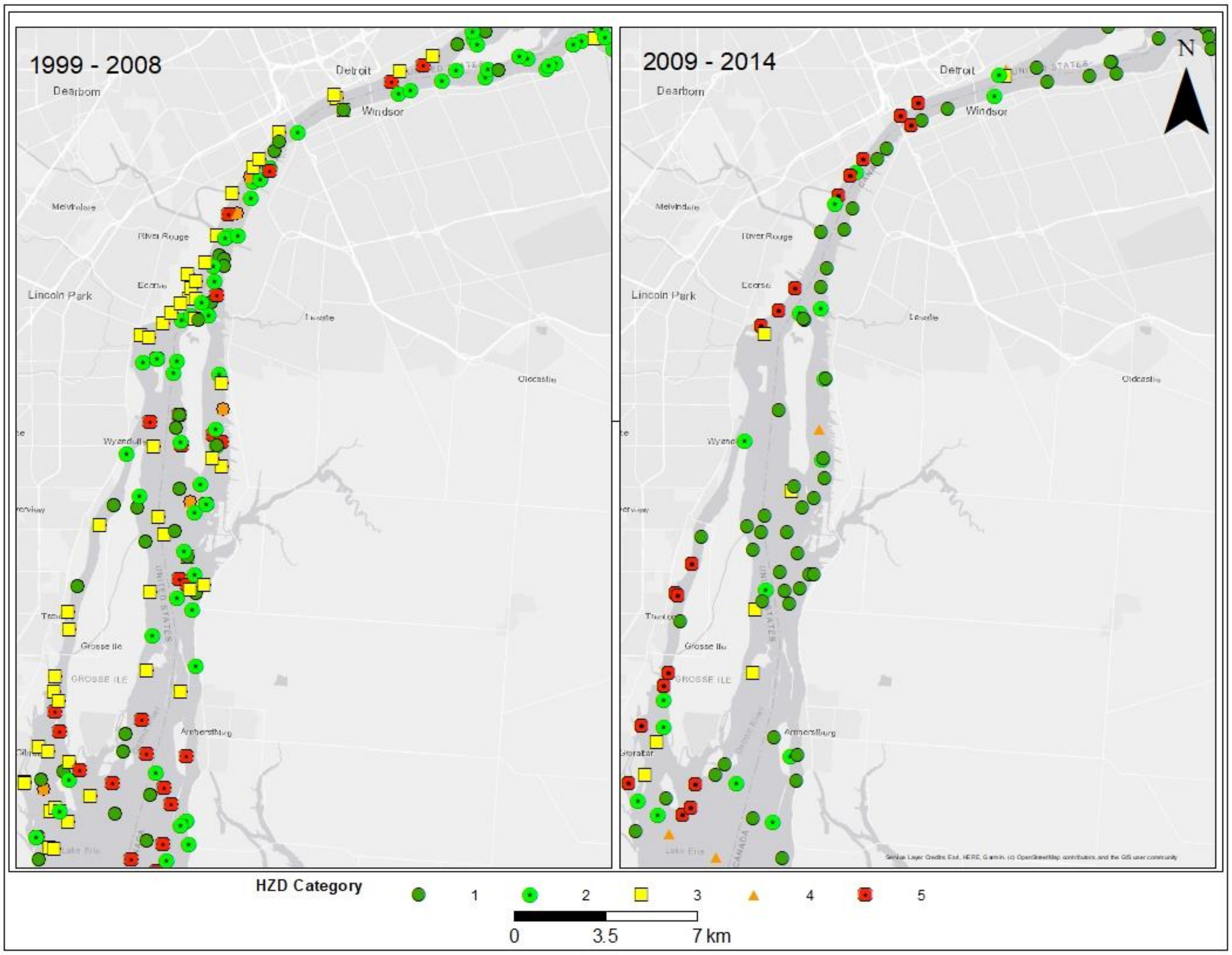


Figure 20. Map detailing locations of toxicity sample collection points in the Detroit River for two time stanzas: 1999–2008 (left) and 2009–2014 (right). Data were provided by K. Drouillard (UW, GLIER, Windsor, Ontario, personal communication, 2017) and interpolated into a system-wide map by the Doka Lab. With our adaptation to add “>”, HZD categories for cumulative anticipated toxicity were defined by K. Drouillard as: HZD Category 1 = 0–25%; HZD Category 2 = >25–50%; HZD category 3 = >50–75%; HZD Category 4 = >75–100% ; HZD Category 5 = >100% (Table 7).

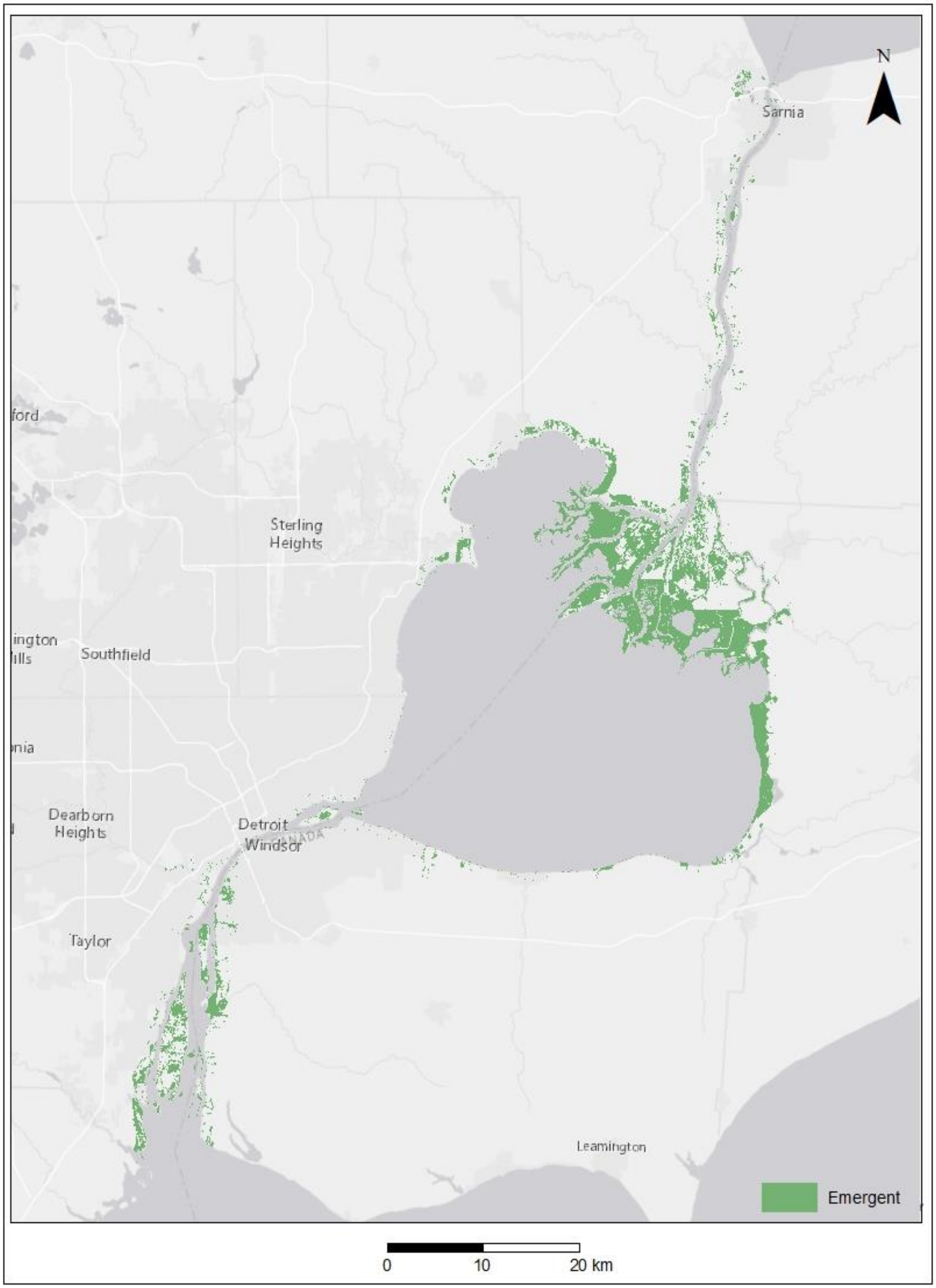


Figure 21. Map of emergent vegetation (EV) in the St. Clair–Detroit River System within a 1-km distance from the shoreline. All EV data collected between 2004–2017, selected based on classification definitions and were merged to represent one type of EV. See Table 3 and Figure 2 (emergent vegetation) for data sources and application, respectively.

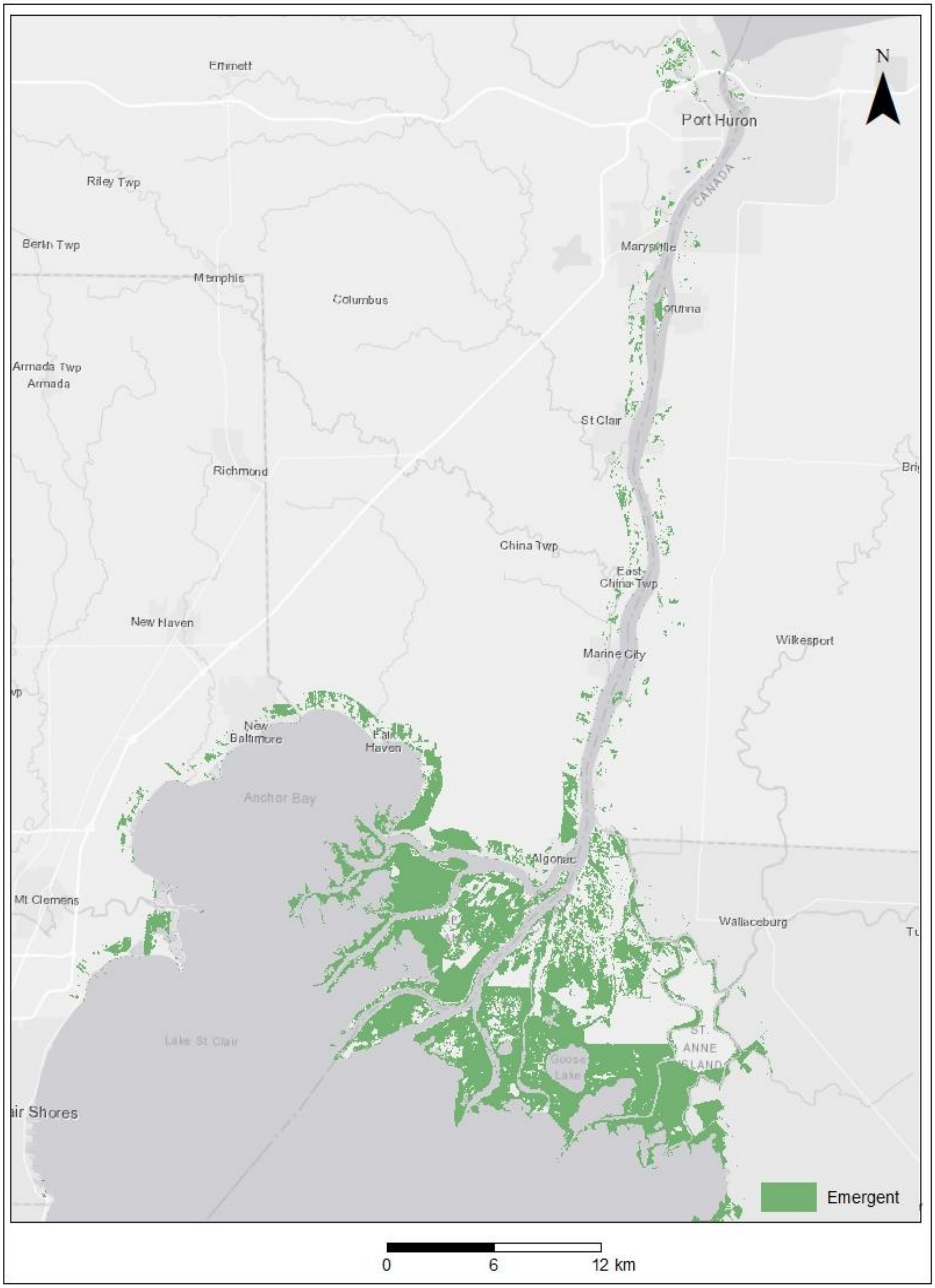


Figure 22. Map of all emergent vegetation (EV) in the St. Clair River at a 1-km distance from the shoreline. All EV data collected between 2004–2017, selected based on classification definitions and were merged to represent one type of EV. See Table 3 and Figure 2 (emergent vegetation) for data sources and application, respectively.

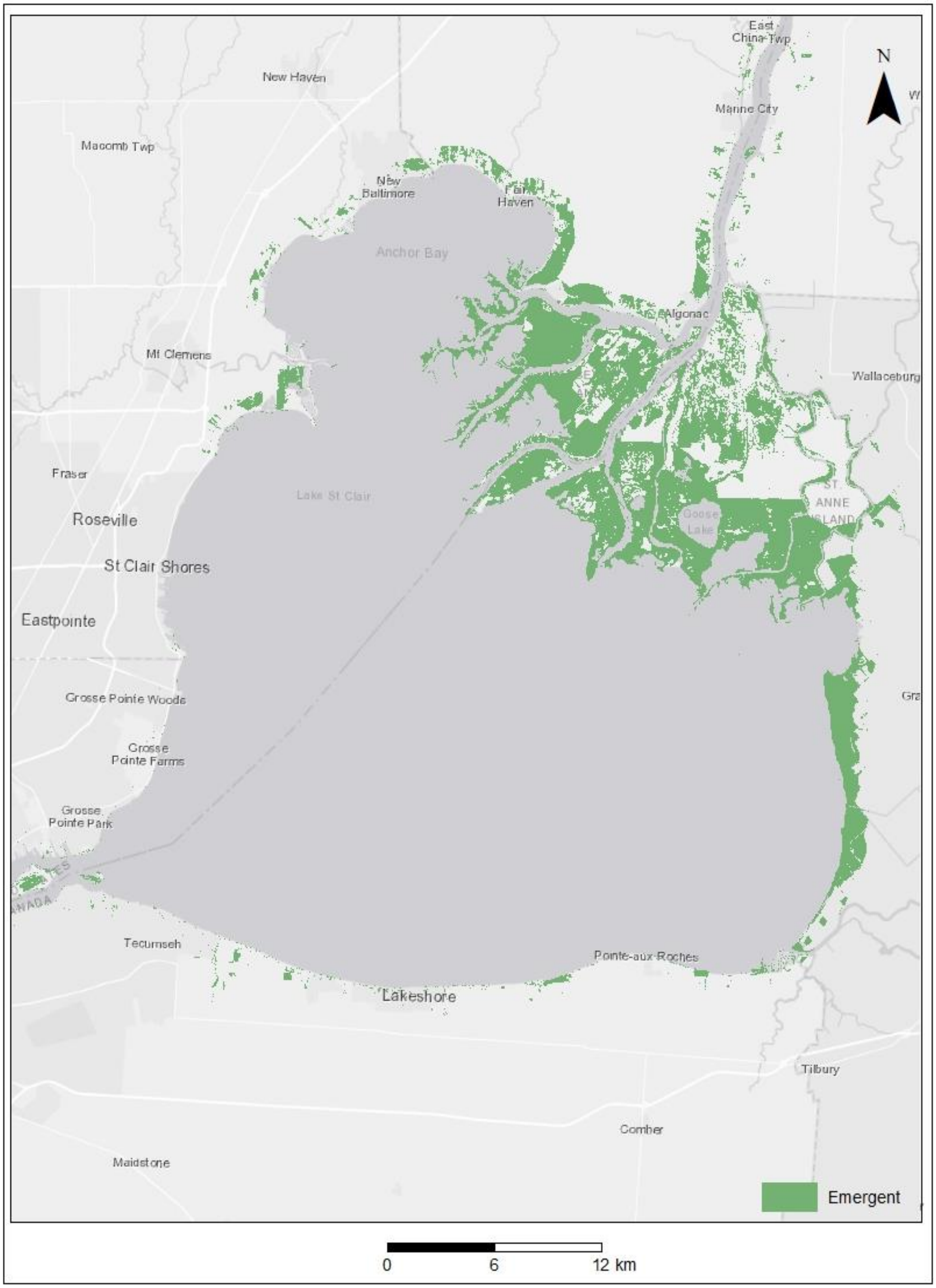


Figure 23. Map of all emergent vegetation (EV) in Lake St. Clair within a 1-km distance from the Lake St. Clair shoreline. All EV data collected between 2004–2017, selected based on classification definitions and were merged to represent one type of EV. See Table 3 and Figure 2 (emergent vegetation) for data sources and application, respectively.

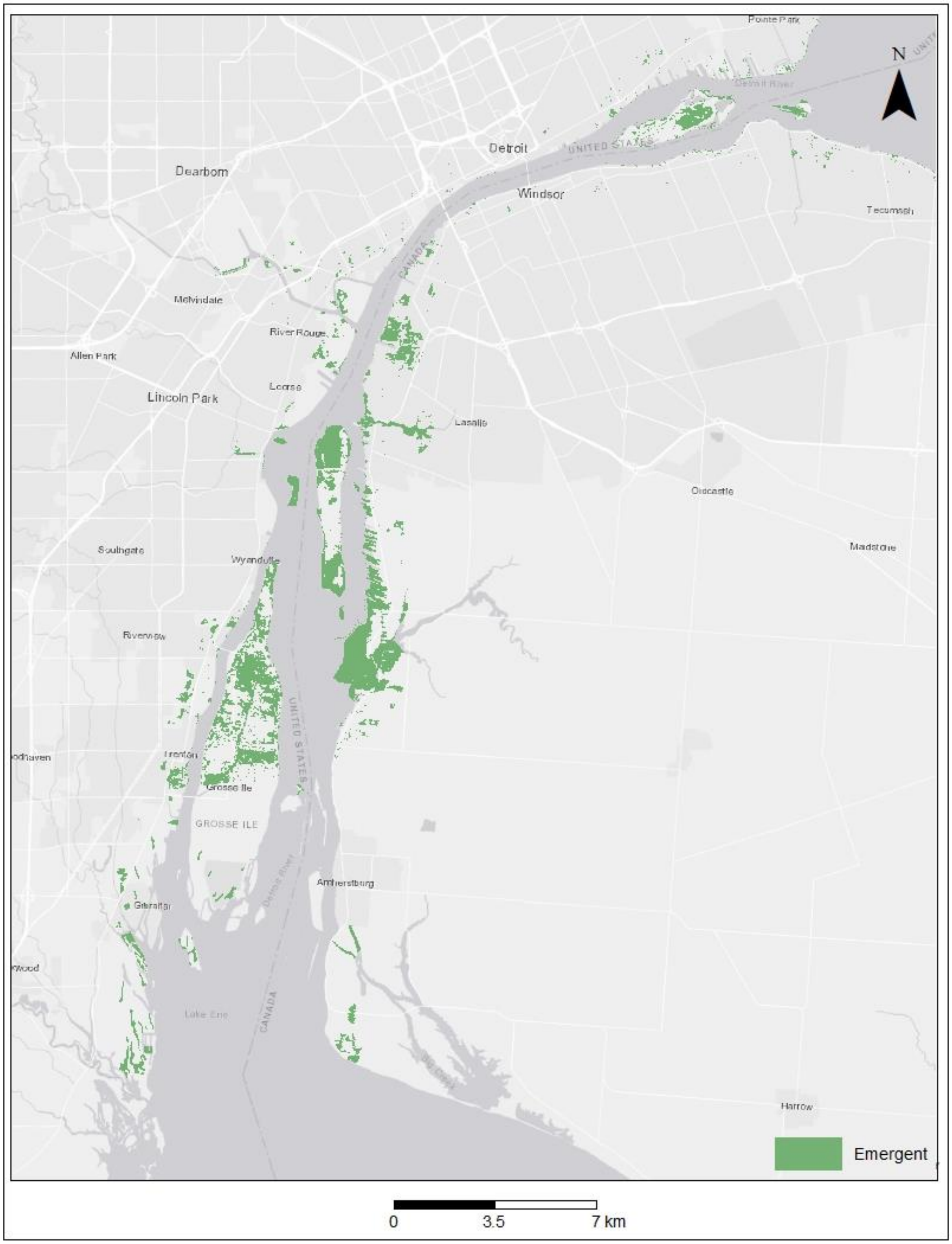


Figure 24. Map of emergent vegetation (EV) in the Detroit River at a 1-km distance from the shoreline. All EV data collected between 2004–2017, selected based on classification definitions and were merged to represent one type of EV. See Table 3 and Figure 2 (emergent vegetation) for data sources and application, respectively.

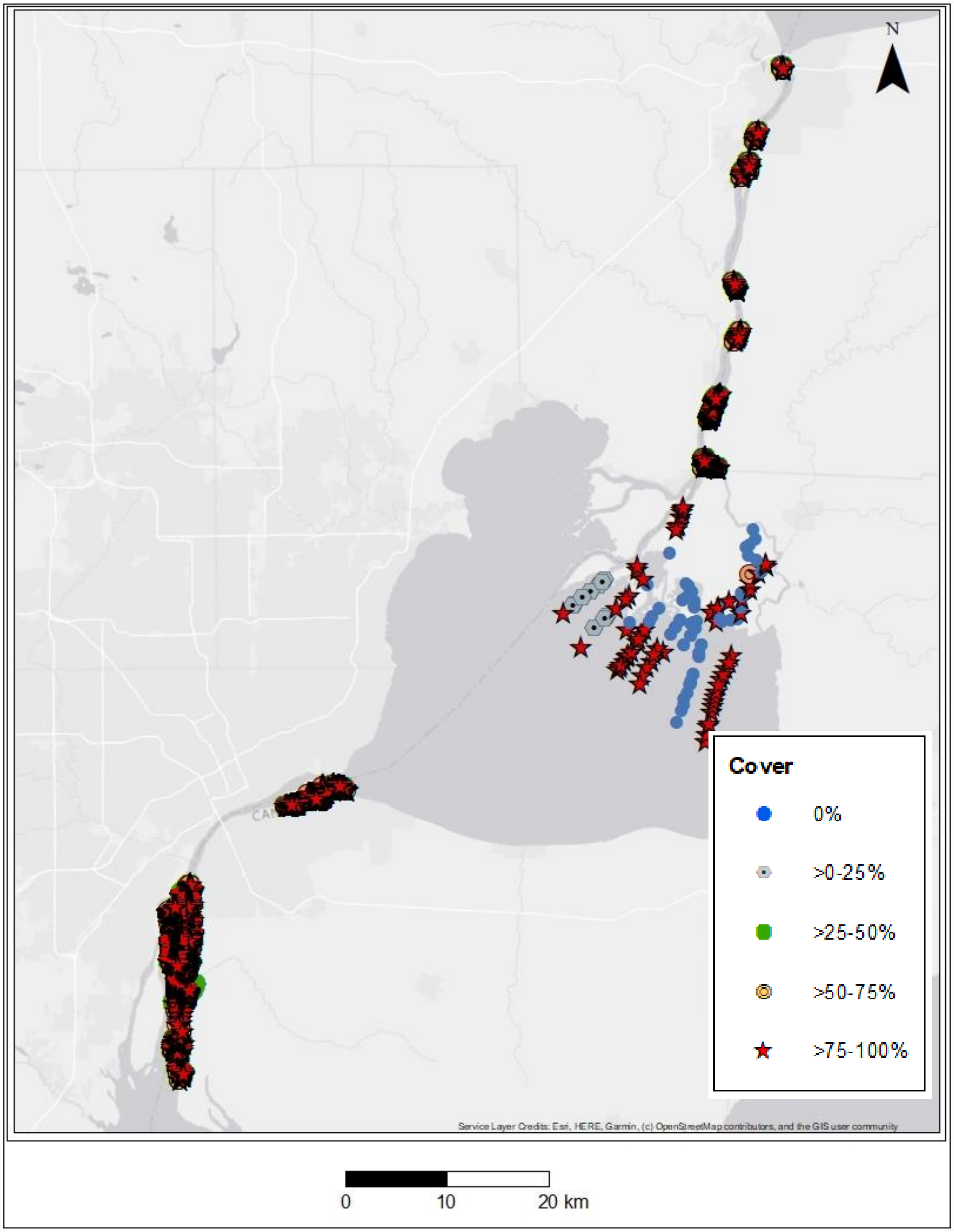


Figure 25. St. Clair–Detroit River System submerged aquatic vegetation hydroacoustic sample collection locations displayed in percent cover for samples collected in 2007, 2008, 2010, 2015, and 2017. Note: sampling occurred on the Canadian side only, in the connecting channel rivers and the Saint Clair River delta. See Table 3 and Figure 2 (submerged aquatic vegetation) for data source and application, respectively.

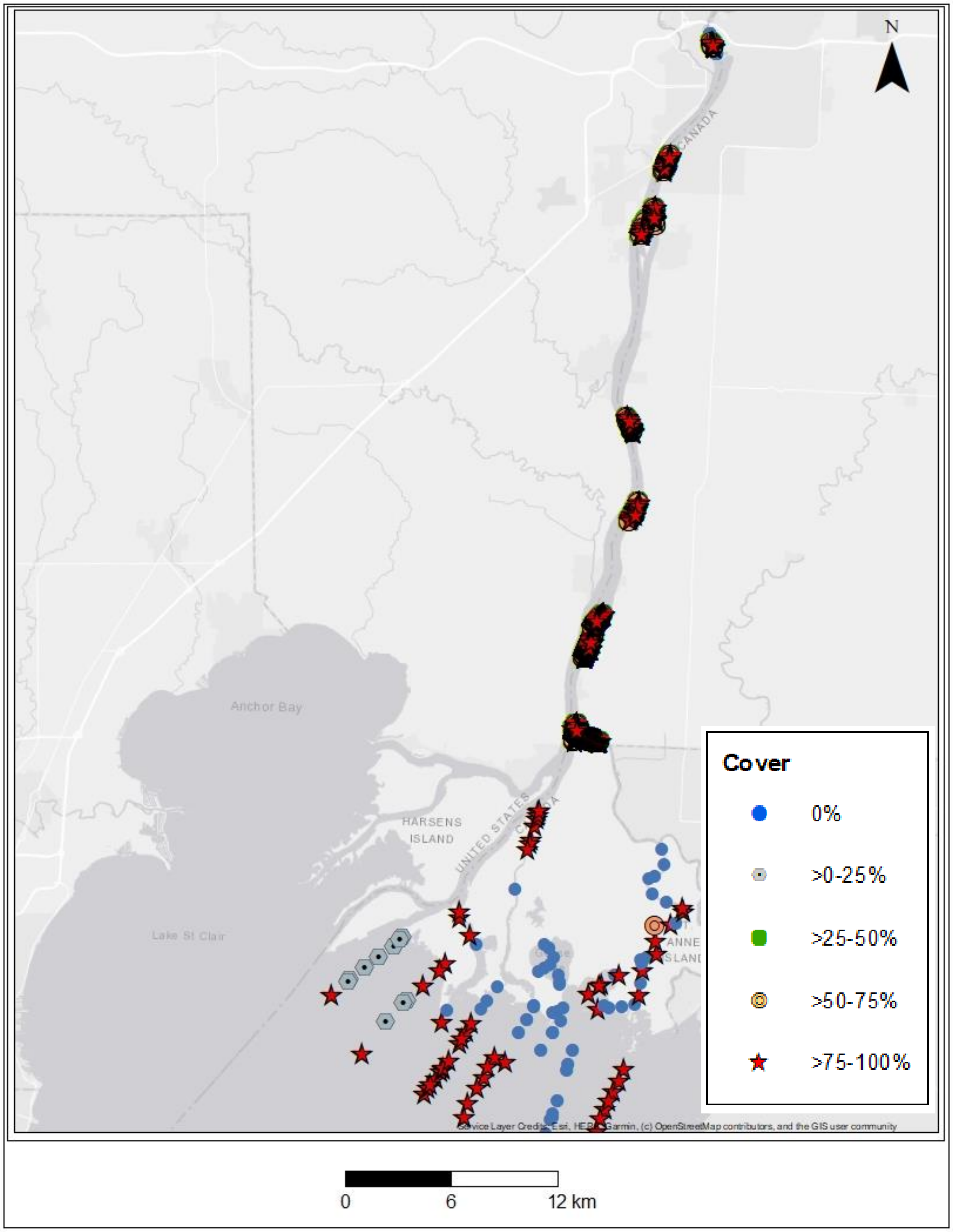


Figure 26. St. Clair River submerged aquatic vegetation hydroacoustic sample collection locations displayed in percent cover for samples collected in 2007, 2008, 2010, and 2017. Note: sampling occurred on the Canadian side only, in the rivers and the delta. See Table 3 and Figure 2 (submerged aquatic vegetation) for data source and application, respectively.

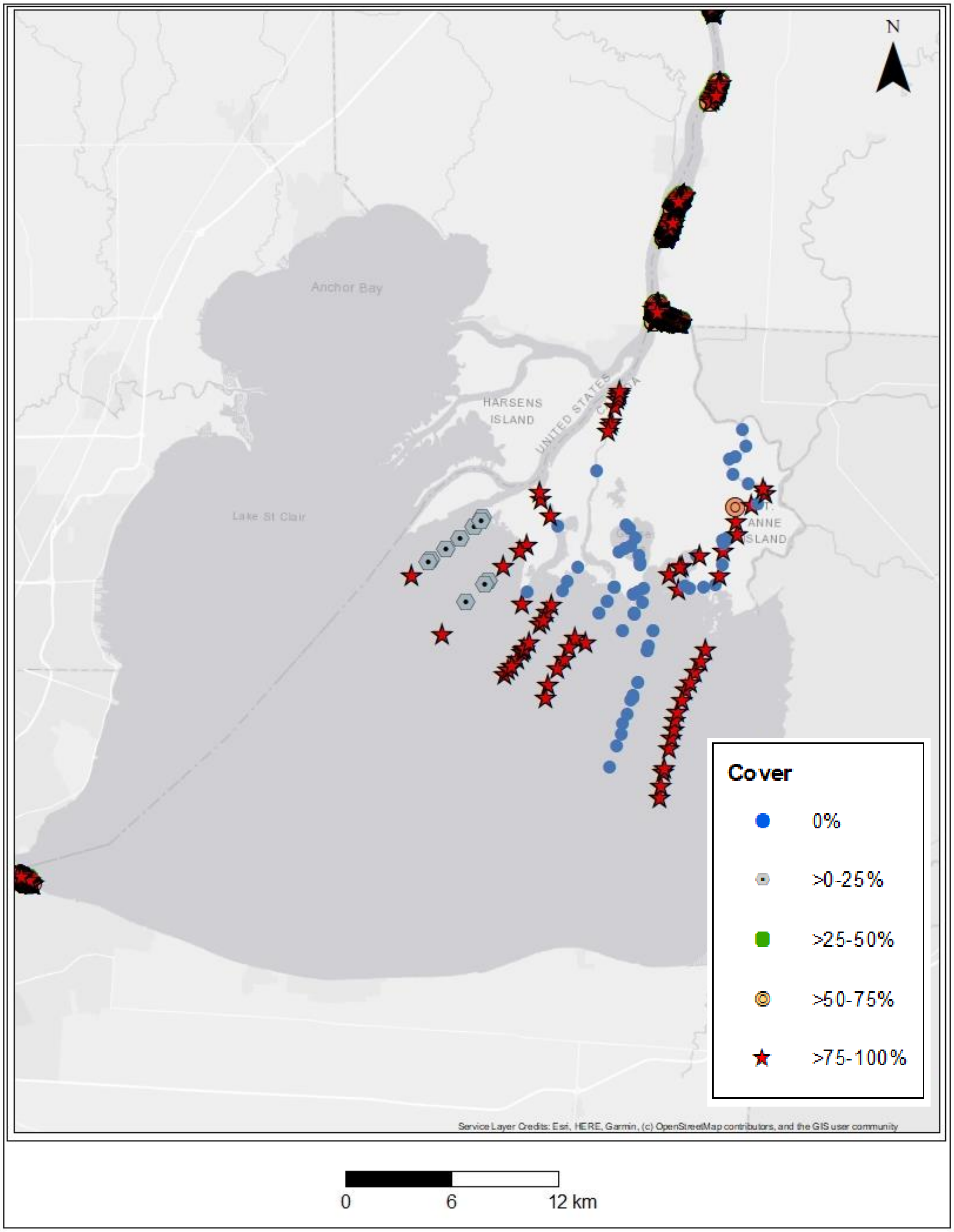


Figure 27. Lake St. Clair submerged aquatic vegetation hydroacoustic sample collection locations displayed in percent cover for samples collected in 2007,2008, 2010, and 2015 - 2017. Note sampling occurred on the Canadian side only. Sampling also occurred at Walpole Island, however was not distributed to the most of Lake St. Clair due to its size. See Table 3 and Figure 2 (submerged aquatic vegetation) for data source and application, respectively.

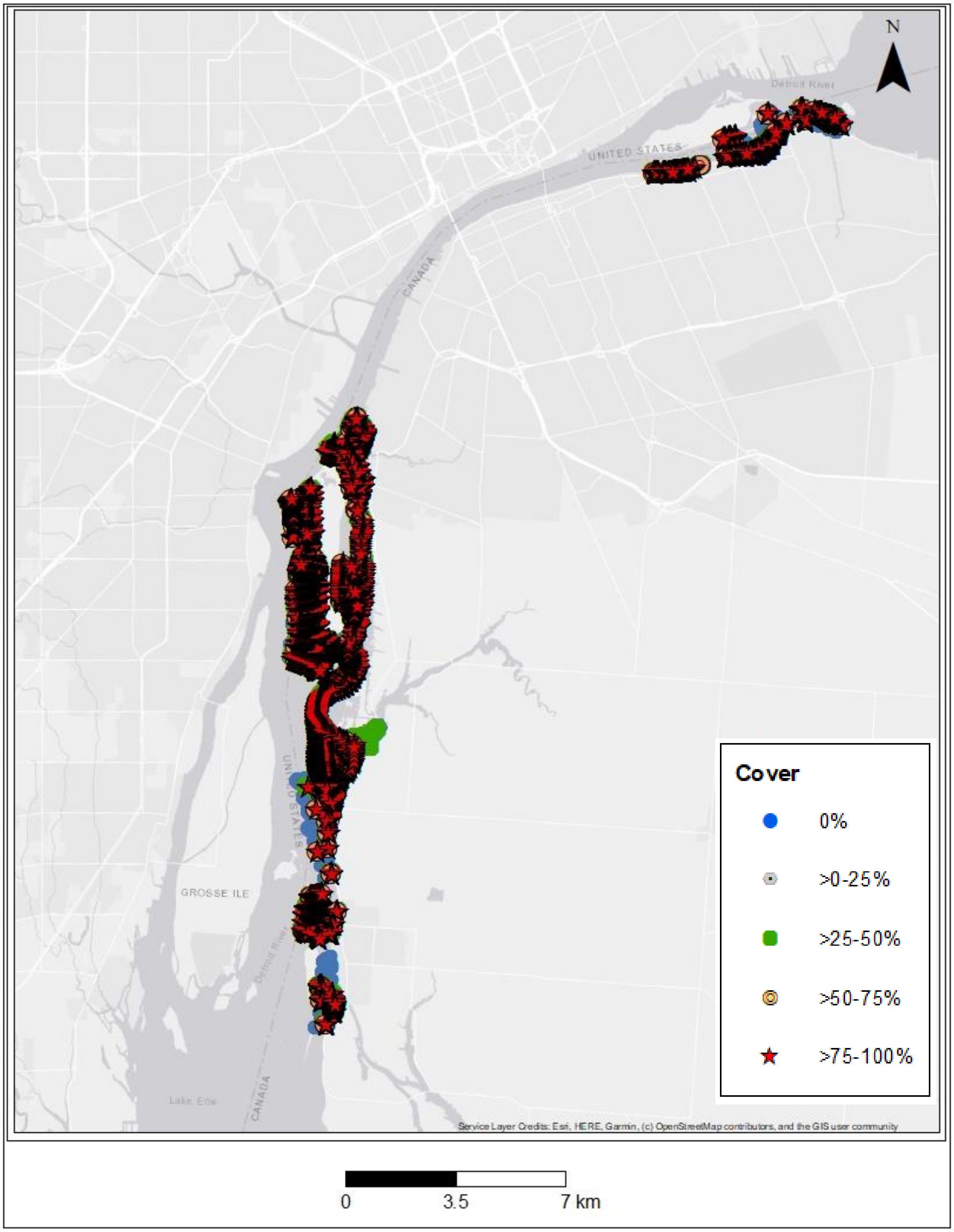


Figure 28. Detroit River submerged aquatic vegetation hydroacoustic survey locations displayed in percent cover for samples collected in 2007, 2008, 2010 and 2017. Note sampling occurred on the Canadian side only, in the rivers and the delta. See Table 3 and Figure 2 (submerged aquatic vegetation) for data source and application, respectively

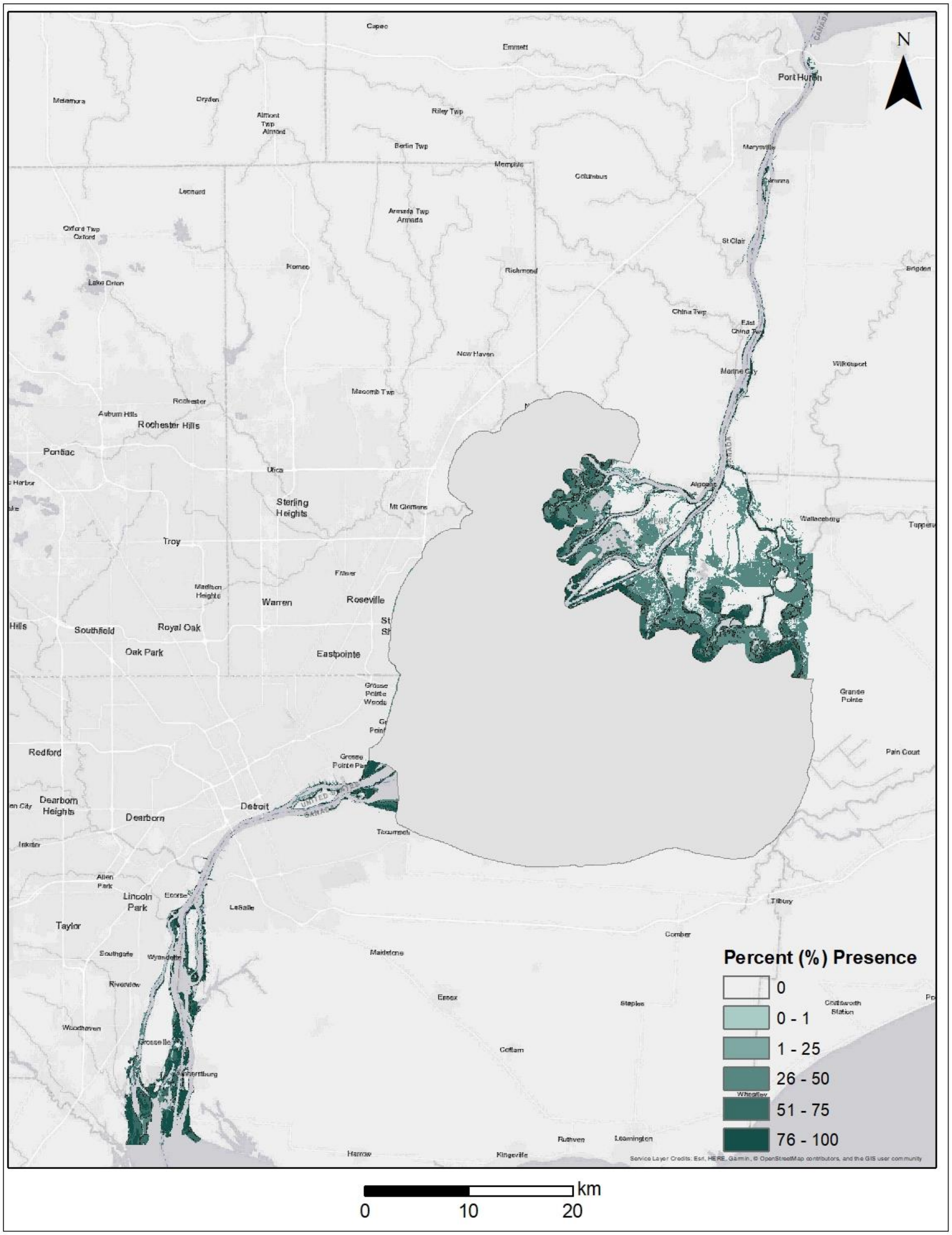


Figure 29. Model output data from interpolations of sample data collected using hydroacoustic pings in the St. Clair–Detroit River System (Midwood 2020). Detections are measured on presence/absence and converted to a percent cover using the statistical program R software (R Foundation for Statistical Computing, Vienna, Austria). The model uses distance to shipping channel and water depth as variables to predict submerged aquatic vegetation growth in the rivers.

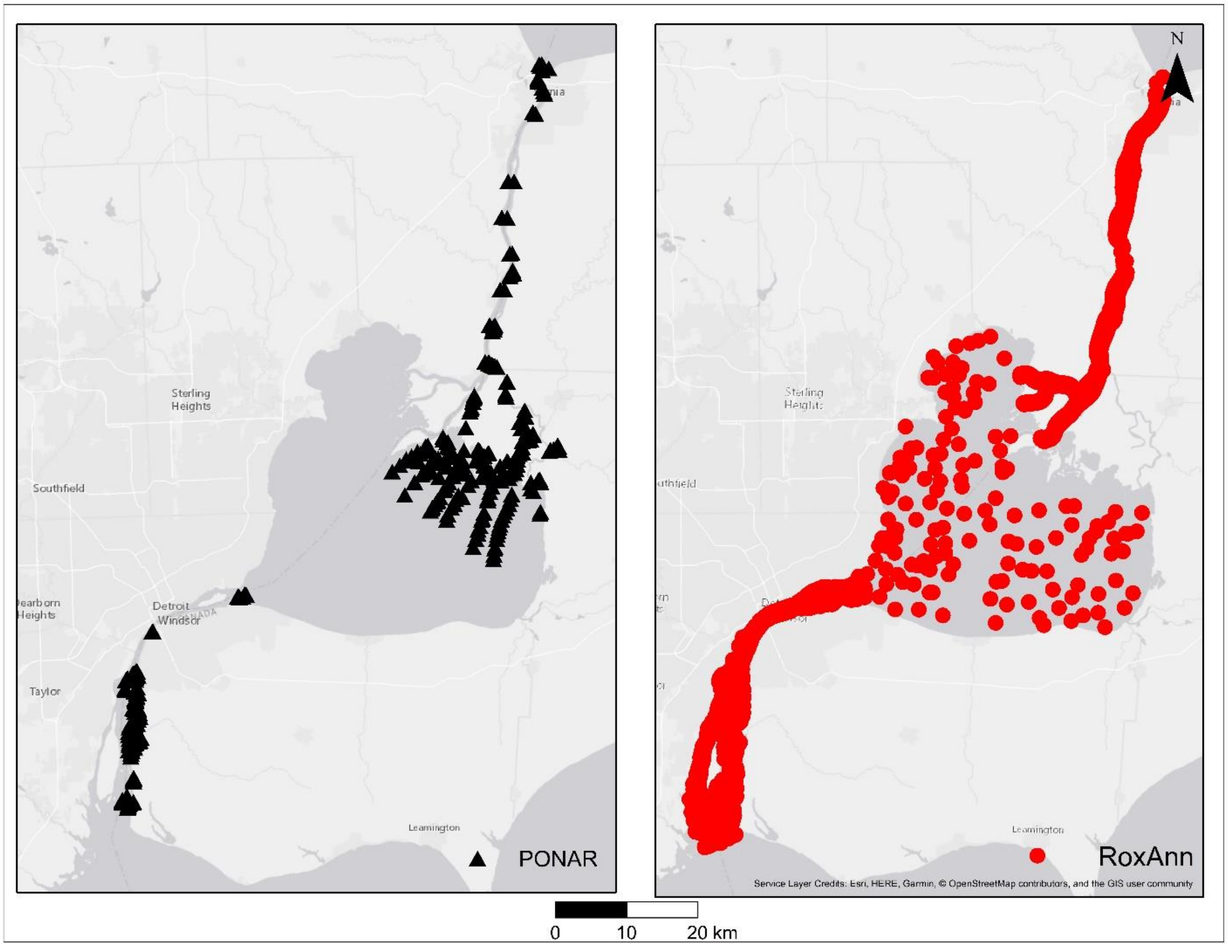


Figure 30. Sample locations for substrate sampling via RoxAnn hydroacoustics and Ponar sediment collections between 1999–2015 in the St. Clair–Detroit River System (Doka et al., unpublished data, Appendix A; K. Tallon, Sea Lamprey Control Centre, Sault Ste. Marie, Ontario, personal communication, 2013; N. Rukavina and H. Biberhofer, National Water Research Institute, Environment Canada, Burlington, Ontario, personal communication, 2003). See Table 3 and Figure 2 (substrate) for data sources and application, respectively.

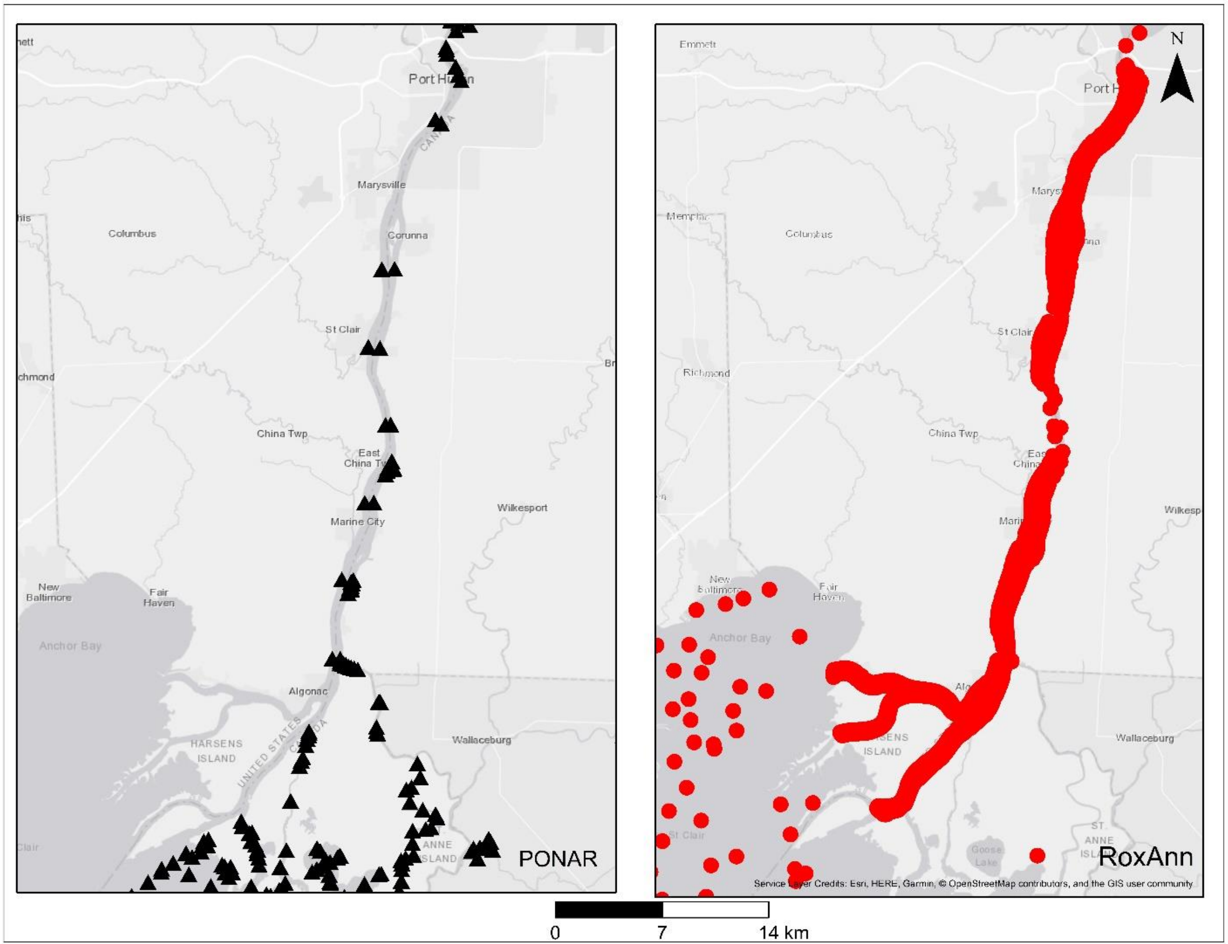


Figure 31. Sample locations for substrate sampling via RoxAnn hydroacoustics and Ponar between 1999–2015 in the St. Clair River (Doka et al., unpublished data, Appendix A; K. Tallon, Sea Lamprey Control Centre, Sault Ste. Marie, Ontario, personal communication, 2013; N. Rukavina and H. Biberhofer, National Water Research Institute, Environment Canada, Burlington, Ontario, personal communication, 2003). See Table 3 and Figure 2 (substrate) for data sources and application, respectively.

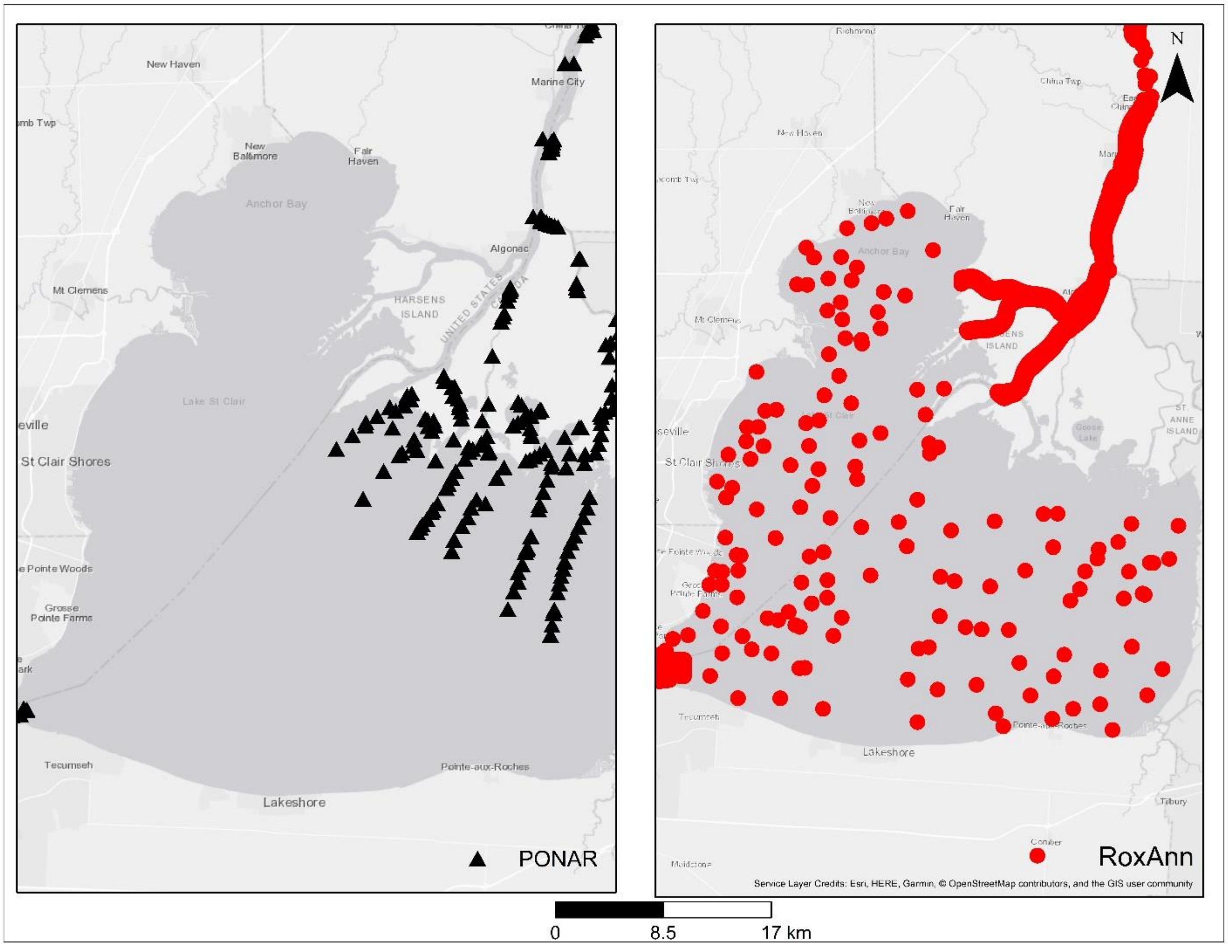


Figure 32. Sample locations for substrate sampling via RoxAnn hydroacoustics and Ponar between 1999–2015 in Lake St. Clair (Doka et al., unpublished data, Appendix A; K. Tallon, Sea Lamprey Control Centre, Sault Ste. Marie, Ontario, personal communication, 2013; N. Rukavina and H. Biberhofer, National Water Research Institute, Environment Canada, Burlington, Ontario, personal communication, 2003). See Table 3 and Figure 2 (substrate) for data sources and application, respectively.

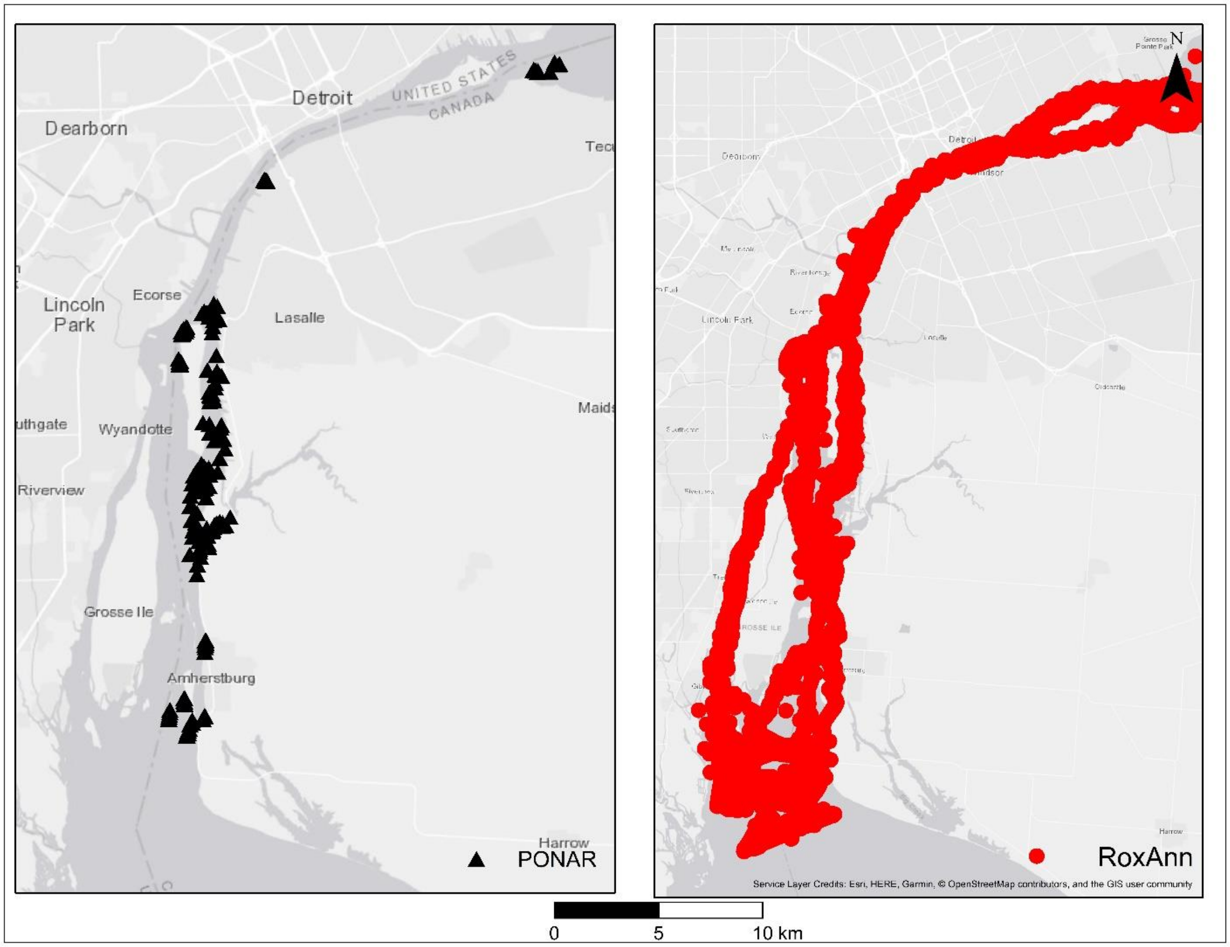


Figure 33. Sample locations for substrate sampling via RoxAnn hydroacoustics and Ponar between 1999–2015 in the Detroit River (Doka et al., unpublished data, Appendix A; K. Tallon, Sea Lamprey Control Centre, Sault Ste. Marie, Ontario, personal communication, 2013; N. Rukavina and H. Biberhofer, National Water Research Institute, Environment Canada, Burlington, Ontario, personal communication, 2003). See Table 3 and Figure 2 (substrate) for data sources and application, respectively.

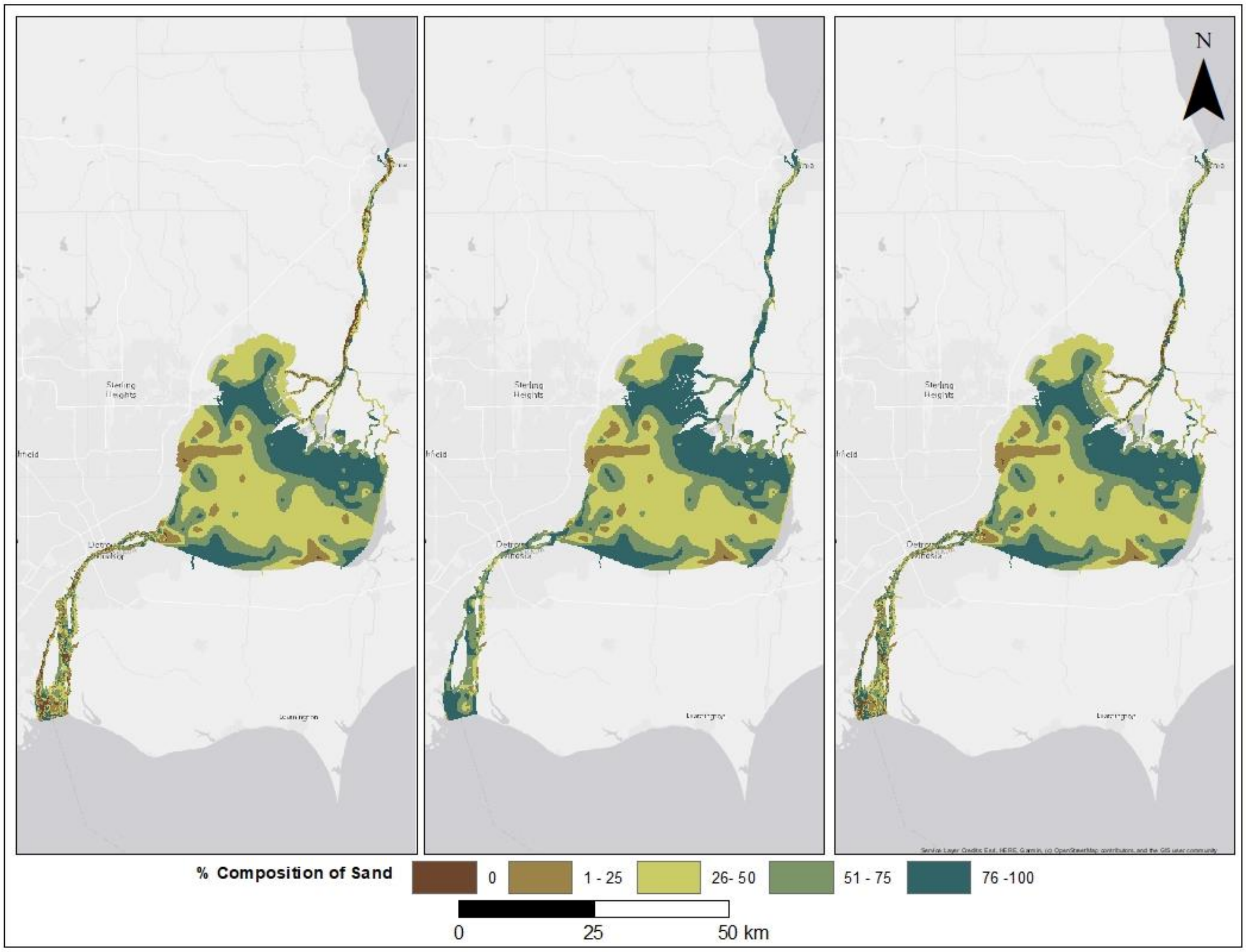


Figure 34. The percent composition of sand using three spatial interpolation approaches in the St. Clair–Detroit River System. The left map is an interpolation using all substrate samples (acoustic and Ponar); the centre map is an interpolation of the Ponar grab samples only; and the right map presents a blend of the first two maps. The latter approach used the Ponar grab sample interpolation but points were clipped to a 250-m buffer around each sample point and then overlaid on the interpolation of all substrate samples combined. Sand distribution is for display purposes only. See Table 3 and Figure 2 (substrate) for data sources and application, respectively. Sources: Doka Lab data, Appendix A; K. Tallon, Sea Lamprey Control Centre, Sault Ste. Marie, Ontario, personal communication, 2013; N. Rukavina and H. Biberhofer, National Water Research Institute, Environment Canada, Burlington, Ontario, personal communication, 2003.

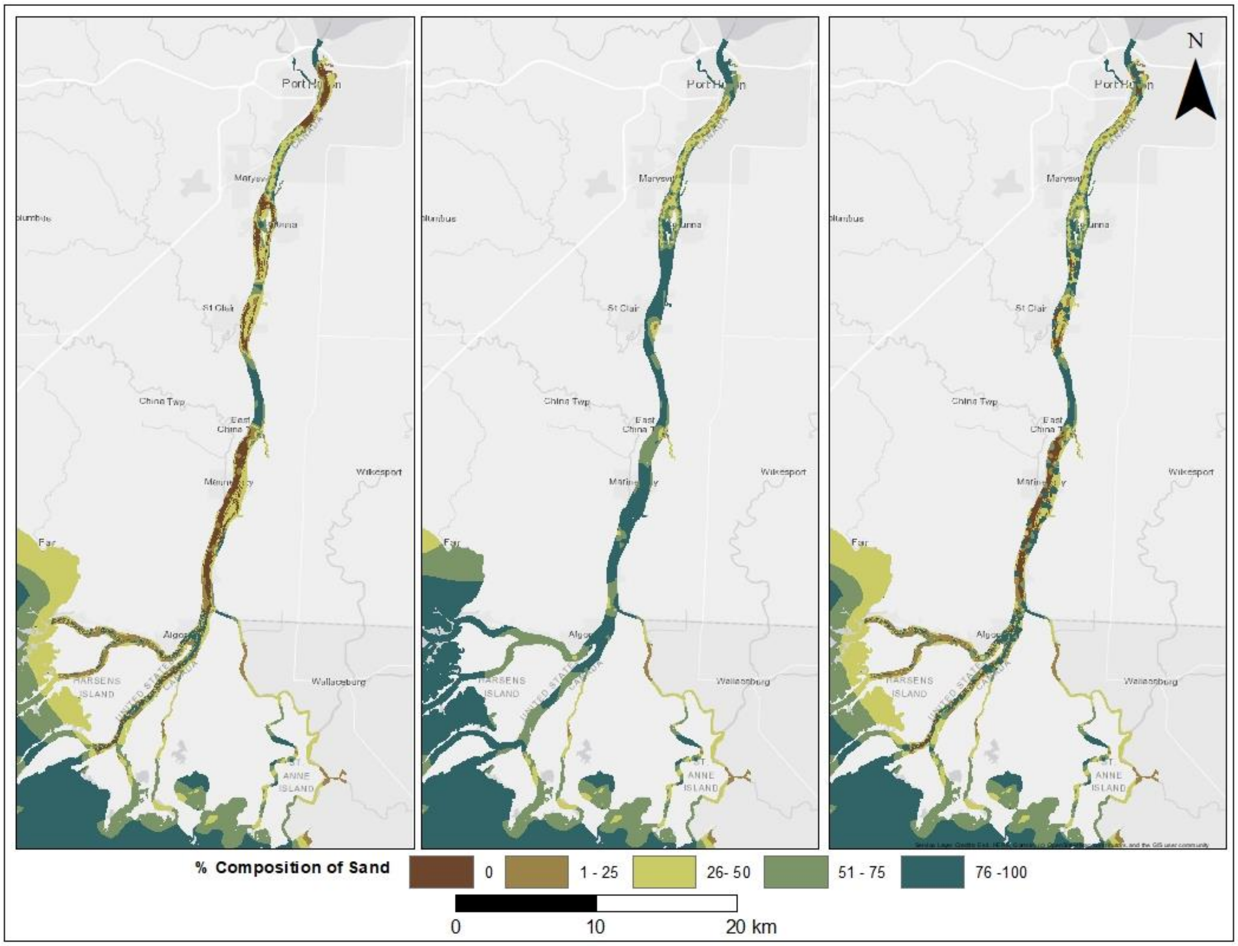


Figure 35. The percent composition of sand using three spatial interpolation approaches in the St. Clair River. The left map is an interpolation using all substrate samples (acoustic and Ponar); the centre map is an interpolation of the Ponar grab samples only; and the right map presents a blend of the first two maps. The latter approach used the Ponar grab sample interpolation but points were clipped to a 250-m buffer around each sample point which was then overlaid on the interpolation of all substrate samples combined. Sand distribution is for display purposes only. See Table 3 and Figure 2 (substrate) for data sources and application, respectively. Sources: Appendix A; K. Tallon, Sea Lamprey Control Centre, Sault Ste. Marie, Ontario, personal communication, 2013; N. Rukavina and H. Biberhofer, National Water Research Institute, Environment Canada, Burlington, Ontario, personal communication, 2003.

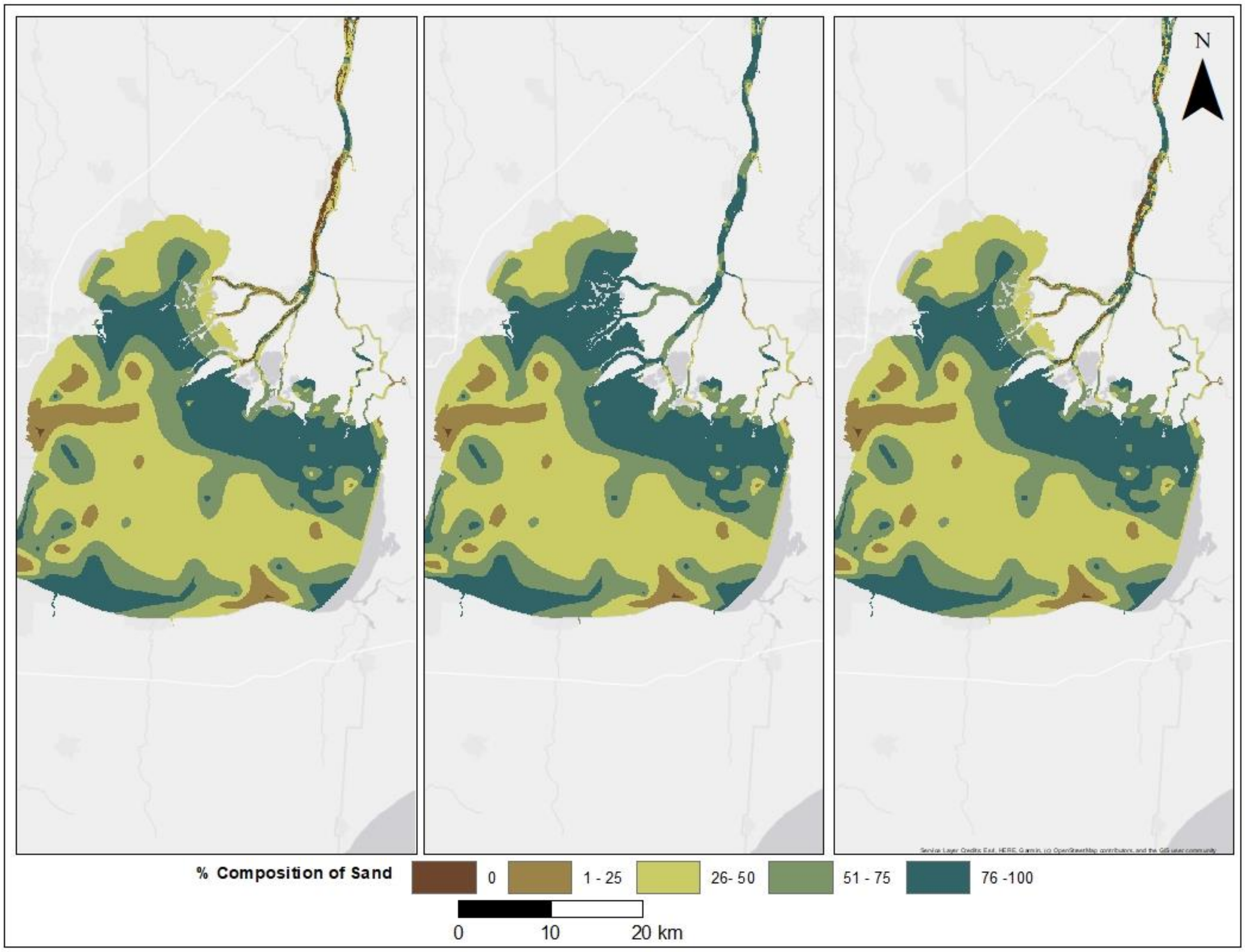


Figure 36. The percent composition of sand using three spatial interpolation approaches in Lake St. Clair. The left map is an interpolation using all substrate samples (acoustic and Ponar); the centre map is an interpolation of the Ponar grab samples only; and the right map presents a blend of the first two maps. The latter approach used the Ponar grab sample interpolation but it was clipped to a 250-m buffer around each sample point which was then overlaid on the interpolation of all substrate samples combined. Sand distribution is for display purposes only. See Table 3 and Figure 2 (substrate) for data sources and application, respectively. Sources: Appendix A; K. Tallon, Sea Lamprey Control Centre, Sault Ste. Marie, Ontario, personal communication, 2013; N. Rukavina and H. Biberhofer, National Water Research Institute, Environment Canada, Burlington, Ontario, personal communication, 2003.

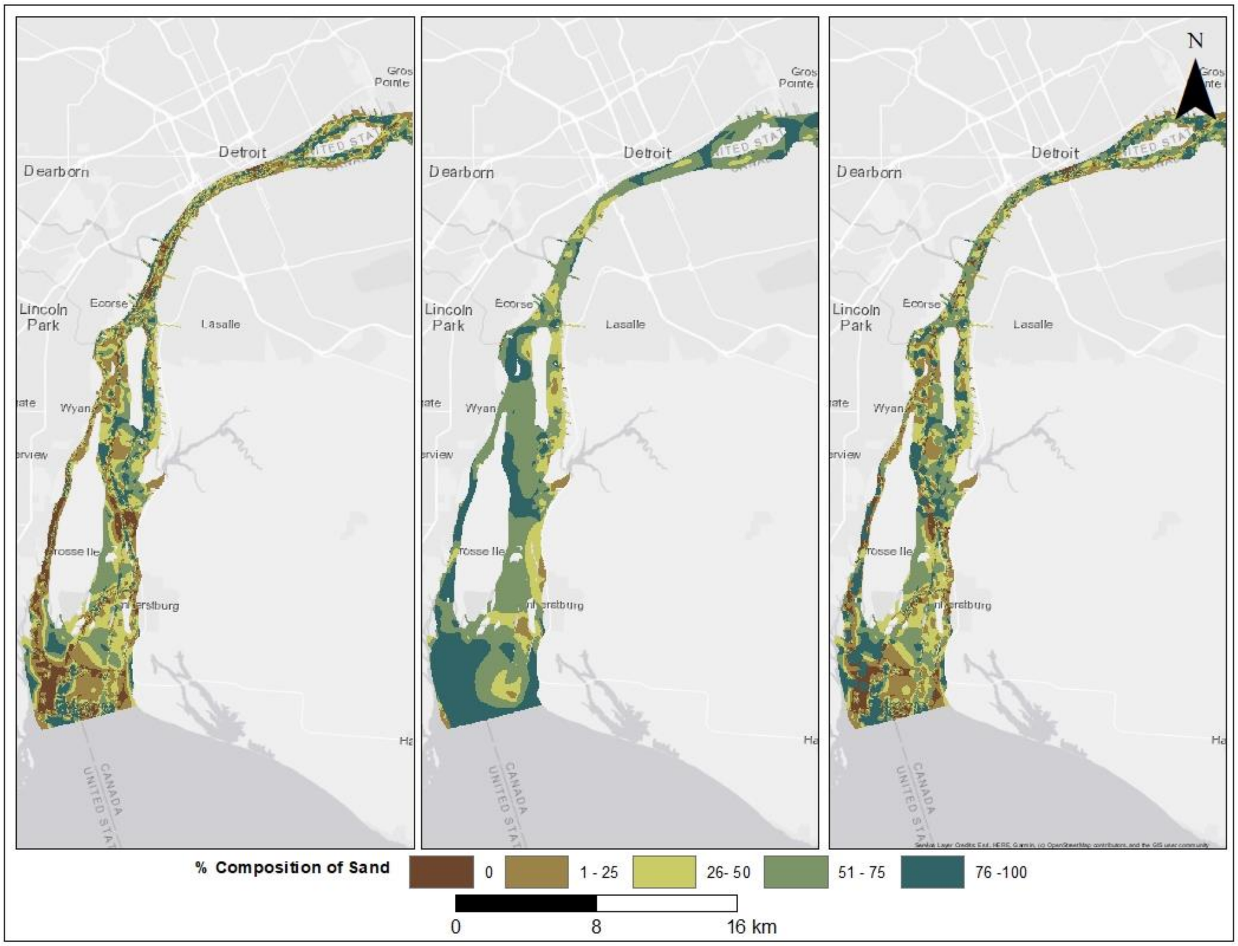


Figure 37. The percent composition of sand using three spatial interpolation approaches in the Detroit River. The left map is an interpolation using all substrate samples (acoustic and Ponar); the centre map is an interpolation of the Ponar grab samples only; and the right map presents a blend of the first two maps. The latter approach used the Ponar grab sample interpolation but points were clipped to a 250-m buffer around each sample point which was then overlaid on the interpolation of all substrate samples combined. Sand distribution is for display purposes only. See Table 3 and Figure 2 (substrate) for data sources and application, respectively. Sources: Doka Lab, Appendix A; K. Tallon, Sea Lamprey Control Centre, Sault Ste. Marie, Ontario, personal communication, 2013; N. Rukavina and H. Biberhofer, National Water Research Institute, Environment Canada, Burlington, Ontario, personal communication, 2003.

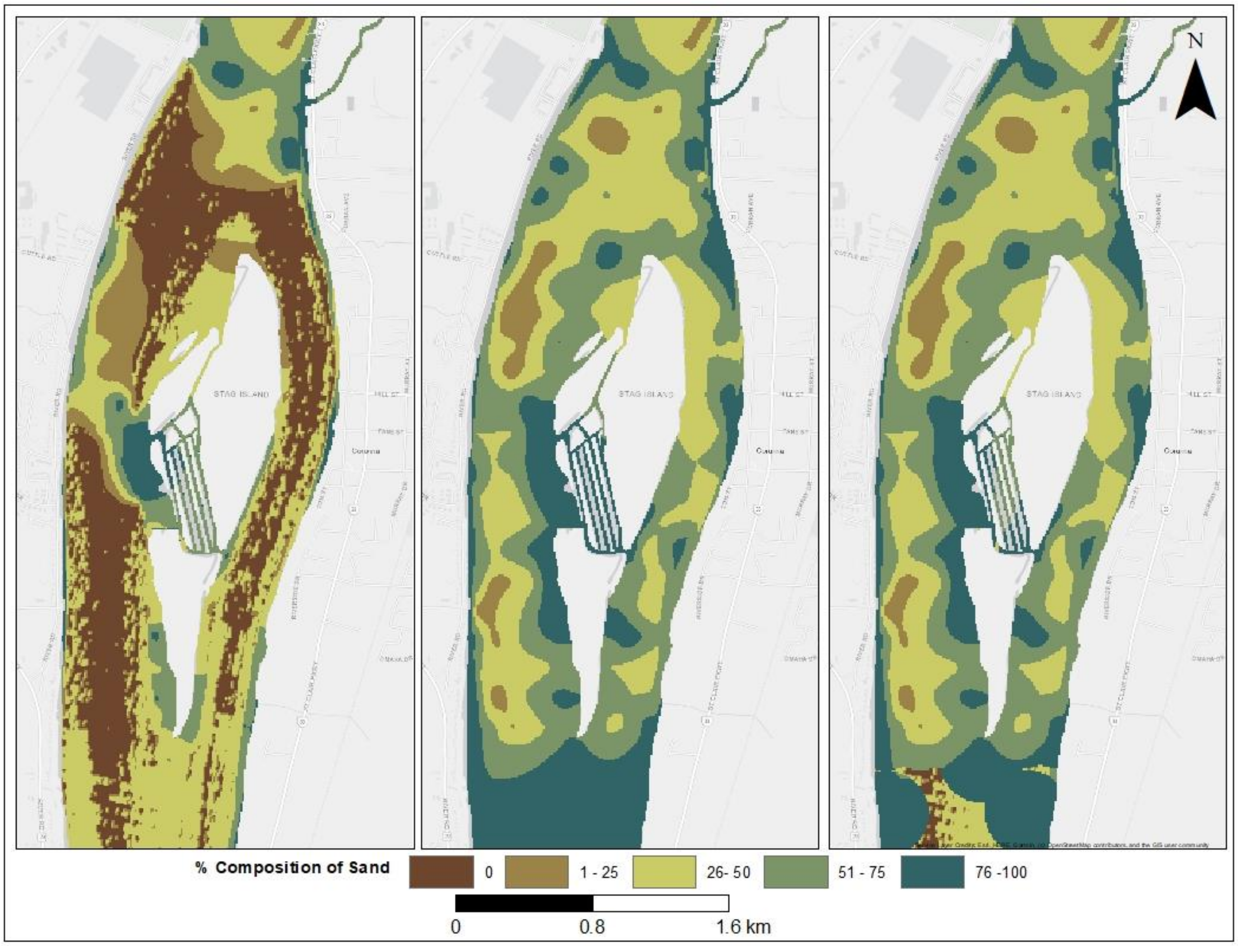


Figure 38. The percent composition of sand using three spatial interpolation approaches in the Stag Island section of the Detroit River. The left map is an interpolation using all substrate samples (acoustic and Ponar); the centre map is an interpolation of the Ponar grab samples only; and the right map presents a blend of the first two maps. The latter approach used the Ponar grab sample interpolation but points were clipped to a 250-m buffer around each sample point which was then overlaid on the interpolation of all substrate samples combined. Sand distribution is for the display purposes only. See Table 3 and Figure 2 (substrate) for data sources and application, respectively. Sources: Doka Lab, Appendix A; K. Tallon, Sea Lamprey Control Centre, Sault Ste. Marie, Ontario, personal communication, 2013 N. Rukavina and H. Biberhofer, National Water Research Institute, Environment Canada, Burlington, Ontario, personal communication, 2003.

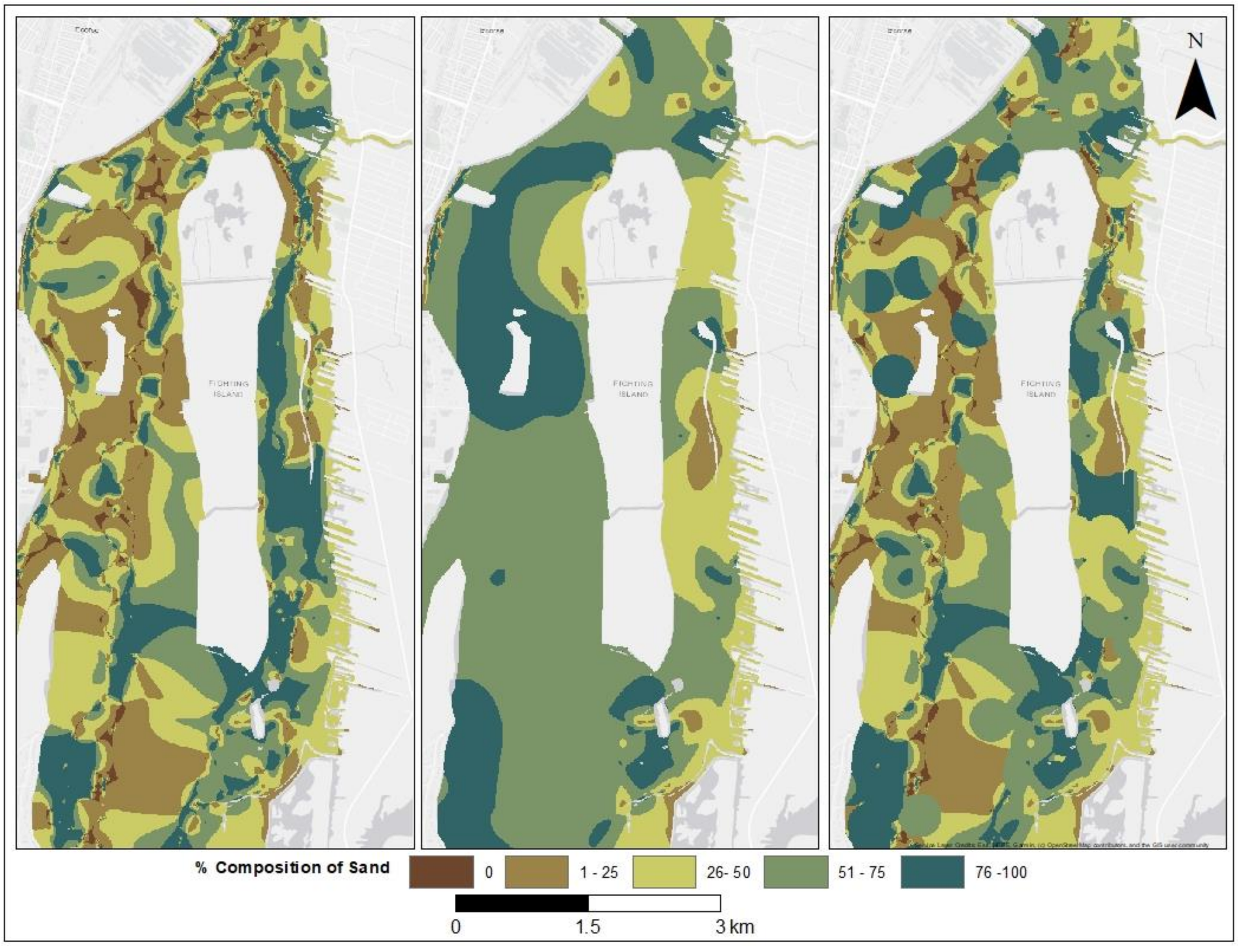


Figure 39. The percent composition of sand using three spatial interpolation approaches in the Fighting Island section of the Detroit River. The left map is an interpolation using all substrate samples (acoustic and Ponar); the centre map is an interpolation of the Ponar grab samples only; and the right map presents a blend of the first two maps. The latter approach used the Ponar grab sample interpolation but points were clipped to a 250-m buffer around each sample point which was then overlaid on the interpolation of all substrate samples combined. Sand distribution is for display purposes only. See Table 3 and Figure 2 (substrate) for data sources and application, respectively. Sources: Appendix A; K. Tallon, Sea Lamprey Control Centre, Sault Ste. Marie, Ontario, personal communication, 2013; N. Rukavina and H. Biberhofer, National Water Research Institute, Environment Canada, Burlington, Ontario, personal communication, 2003.

APPENDIX A

St. Clair River and Detroit River Hydroacoustic Submerged Aquatic Vegetation Surveys 2007, 2008 and 2010

Draft report, October 31st, 2016

Background: In both the St. Clair River and Detroit River Areas of Concern, there have been extensive changes in the amount and quality of aquatic habitat with declines of 72% of wetland area along the U.S. shoreline and comparable losses on the Canadian side. Consequently, an important Beneficial Use Impairment that must be resolved for delisting these Areas of Concern is the impairment to fish and wildlife habitat. At both sites, conservation efforts in support of delisting have been directed towards maintaining the current extent of habitat and, where possible, increasing the area of wetland and aquatic habitats that support different functions. In aquatic ecosystems, submerged aquatic vegetation (SAV) provides important food and habitat to a wide range of species, specifically for fishes, a majority of which use SAV for spawning, nursery, or foraging habitat at some point during their life cycle. Consequently, the objectives of the present report are to characterize the spatial coverage of SAV in the St. Clair and Detroit rivers, with particular focus on major tributaries and nearshore features.

Methods & Results: Similar techniques were used across all three years to collect hydroacoustic and field verification data. Surveys were conducted from mid-July until late August in 2007, 2008, and 2010. Nine sites were sampled in both the Detroit (6 in 2007/2008 and 3 in 2010) and St. Clair rivers (8 in 2007/2008 and 2 in 2010); one site, Marshy Creek (St. Clair River), was sampled in both 2008 and 2010 (Figure A1; Table A1).

Field Verification

To support and corroborate the findings of the hydroacoustic surveys and also provide an assessment of the substrate composition in the surveyed areas, field verification points were established. At each of these field verification points, the depth was measured and a substrate sample was collected using a petit Ponar. Substrate composition in the 2007/2008 samples was assessed by the Fish Habitat Lab at Fisheries and Oceans Canada and in 2010 samples were assessed by the Environment Canada and Climate Change's Sediment Lab. Plant species composition and SAV percent cover were estimated at most sites using rake hauls; however, some sites were too deep for sample collection. In 2010, field verification points were surveyed at Clay Creek (St. Clair River) and LaSalle (Detroit River), but due to time constraints and equipment failure these sites could not be surveyed using hydroacoustics as well.

Therefore substrate data for these two sites are provided, but they are not included in the interpretation of hydroacoustic data.

Data from a total of 62 verification points were collected during the 2007/2008 surveys with roughly equal sampling effort at sites in the St. Clair and Detroit rivers. SAV information was available for only 25 of these points and these overlapped slightly with the 47 points where substrate samples were collected. A greater number of verification points were collected in 2010 (n = 120) with a larger number in the Detroit River (68 points for SAV and 64 for substrate) relative to the St. Clair River (27 points for SAV and 42 for substrate).

At the site level, sand was typically the dominant substrate (Table A2). Within individual sites, sand also tended to be pervasive, but other substrate types were apparent, particularly at Clay Creek (St. Clair River) in 2010 where clay and gravel were also dominant at some sampling locations (Figure A2a). Other sites where sand was not dominant included offshore deeper waters at Turkey Creek (Detroit River, silt and gravel was dominant), as well as upstream at LaSalle and Canard River (silt and clay were dominant; Figure A2a,b).

During the 2007/2008 surveys, 14 species of SAV were found in the Detroit River, with *Vallisneria americana*, *Najas* spp., *Elodea canadensis* , and *Potamogeton richardsonii* being the most common. Fewer species of SAV (12) were found in the St. Clair River, with slightly different dominant species (*Chara* spp., *Vallisneria americana*, and *Potamogeton richardsonii*). There was considerable variability among sites in terms of species richness, which ranged from 4-9 in the Detroit River (min – West Windsor; max – West Fighting Island/Amherstburg Channel) and 2-9 in the St. Clair River (min – Sarnia Harbour; max – Marshy Creek).

There was a similar species composition in both systems in the 2010 surveys with *Vallisneria americana*, *Najas* spp., *Elodea canadensis, and Potamogeton* spp. being dominant in the Detroit River and *Chara* spp., *Potamogeton* spp., and *Vallisneria americana* dominating in the St. Clair River. Again, there was higher species richness in the Detroit River (range 7-13; min – Lasalle; max – Canard River) compared to the St. Clair River (range 9-10; min – Clay Creek; max – Chenal Ecarte /Marshy Creek). Other common plant species found during vegetation surveys included: *Myriophyllum spicatum*; *Heteranthera dubia*; *Nitella* spp., and *Ceratophyllum demersum*.

At a subset of verification points, Secchi depth data were collected as water clarity is an important determinant of SAV distributions. In many instances, Secchi depth could not be measured because of excess vegetation or fast flowing waters. At some sites with shallow, clear waters, Secchi depth could also not be determined since the disc was visible lying on the bottom. In these last instances, Secchi depth was assumed to be greater than the water depth. In 2007/2008, Secchi depth could not be determined for the majority of sites in the St. Clair River for the reason described above. For the two sites that could be assessed, Secchi depths were greater than 1.0 and 2.0 m (Suncor site and Talford Creek, respectively; Table A1). More estimates were available in the Detroit River, where Secchi depths ranged from 0.8 m (East Windsor) to 1.8 m (Peche Island). In 2010, Secchi depth was typically less than 1.0 m in the Detroit River (range, 0.9–1.0 m). There was a wider range in the St. Clair River with a mean Secchi depth low of 0.8 m in Clay Creek and a high of 5.5 m (Chenal Ecarte; Table A1). Secchi depth at Marshy Creek could not be estimated since the disc was on bottom for the majority of the surveys; however, these samples were attempted at water depths between 1.1to 3.9 m, suggesting Secchi depth was greater than 4.0 m at this site.

Hydroacoustics

At each site, boat transects were run both perpendicular and parallel to shore and were a mixture of relatively straight lines or a zig-zag pattern. This approach was used to identify the spatial coverage of SAV in a region and the deep-water edge of the SAV bed to be mapped. Data were all geo-referenced, which allowed for mapping and an assessment of the spatial coverage and density of SAV using a GIS. For all surveys, echosounding sampling used a BioSonics DT-X with a 430 kHz 6.8° transducer. These echosounding data were analyzed using EcoSAV 2.0 software (BioSonics 2001) to determine water depth, SAV percent cover, and SAV height. Input parameters for the hydroacoustic analysis were determined separately for the St. Clair and Detroit Rivers by comparing results of the echosounding with verification observations.

Specifically in the Detroit River, parameters had to be adjusted for a few transects because SAV height approached the water surface and led to the rejection of ping cycles by exceeding the number of noisy or out-of-water pings. In some instances, the output data were subsequently manually adjusted to account for the erroneous assignment of high SAV cover along steep slopes. These manual adjustments involved a visual analysis of maps with depth profiles, echograms, Excel graphs, ground-truth samples and other nearby data points. These adjustments were consistently applied throughout the SAV analysis, with a preference for ground-truth results where available.

For each site, the mean (± standard deviation; SD), inter-quartile range, and complete range (min-max) were calculated for the depth, SAV percent cover, and SAV height of the hydroacoustic data. These data were also plotted in a GIS to show the spatial coverage of the SAV and its associated depths.

Generally, there was a larger range in depth at sites surveyed in the St. Clair River relative to the Detroit River and the upper quartile and maximum observed depths also tended to be deeper (Table A3; Figures A3a,b). Not surprisingly, there was also a general trend in the spatial distribution of water depths with deeper waters typically being found towards the center of the rivers (Figures A3a,b). At the majority of sites, the mean water depth where SAV was present tended to be shallower than where it was absent, although there were some exceptions (discussed below).

In general, SAV was less prevalent at St. Clair River sites (e.g., fewer hydroacoustic points surveyed contained SAV) relative to the Detroit River, although there were two notable exceptions in the St. Clair River at Chenal Ecarte and Marshy Creek where SAV occurred at greater than 60% of the hydroacoustic points (Table A4; Figures A4a,b). Sites in the Detroit River tended to be shallower than those in the St. Clair River and SAV occurred at greater than 60% of the hydroacoustic points at all but one site (West Fighting Island; Table A4). This site is situated along the western shore of Fighting Island and is therefore directly adjacent to the shipping channel, and likely exposed to wave action from passing ships. It was also one of three sites (including Chenal Ecarte in the St. Clair River and LaSalle in the Detroit River) where the mean water depth was greater at sites where SAV was present relative to sites where there was no SAV (Table A4). Where SAV was present, it typically had coverage greater than 50%; Clay Creek was the sole exception with mean SAV coverage of 44.9 ± 30.7 and a lower interquartile range (Table A4). Clay Creek also had low proportional coverage of SAV (0.12) suggesting that not only is the SAV percent cover generally low at this site, it also had a smaller areal distribution. Marshy Creek had the highest mean SAV percent cover at greater than 80%, but relatively low proportional coverage of SAV (0.20 of the area surveyed); Table A4). Mean SAV height was typically less than 0.5 m (Table A4), which is consistent with the dominant species typically being non-canopy forming SAV (e.g, *Vallisneria americana*, *Najas* spp., *Elodea canadensis,* and *Chara* spp.).

Finally, the relationship between water depth and SAV percent cover was explored visually. There were clear differences between the St. Clair and Detroit rivers with SAV percent cover typically peaking between shallower depths in the Detroit River (1–4 m; Figure A5) compared to the St. Clair River (2-7 m; Figure 6). During the 2010 surveys, three sites (Turkey Creek, LaSalle and Chenal Ecarte) had SAV at depths at or greater than 10-m (Figure A7), but the mean depth of occurrence for SAV at all these sites was still between 3-5 m suggesting it may occur only occasionally at these deeper depths when water clarity permits.

Discussion: Based on the SAV hydroacoustic surveys and their associated field verification data (i.e. ground-truthing), there are clear differences in both the environmental conditions and the coverage of SAV in the Detroit and St. Clair rivers. Water clarity, evaluated using a Secchi disc, was typically higher in the St. Clair River and consequently the distribution of depths at which SAV occurred was also deeper than in the Detroit River. The mean depth also tended to be deeper in the St. Clair River, which is consistent with the bathymetric profile of this system with a comparatively steep and narrow nearshore zone; this is likely why SAV cover was lower in the St. Clair River. Exceptions to this steep profile occur in proximity to Stag and Fawn islands; however, the proportional area of these shallow grade nearshore areas is considerably less than in the Detroit River. Indeed, outside of the shipping and navigation channels, the nearshore of the Detroit River has a shallower grade and a more complex and protected shoreline, with the exception of the Walpole Island area.

Even with higher water clarity and a wider depth distribution of occurrence, SAV was generally less common and had a lower area in the St. Clair River relative to the Detroit River. In the St. Clair River there also tended to be a shallow water zone where SAV was absent (<2 m). A potential explanation for these differences relates to the relative level of exposure to both natural and human-influenced physical processes in the two systems. As previously noted, the St. Clair River is a more channelized system with fewer protected backwater areas. Consequently, sites in this system are more exposed to the natural currents in the system and resulting ice scour as well as the wake from shipping and recreational vessels. In contrast, many of the sites in the Detroit River are away from the main shipping channel and therefore likely experience less physical disturbance as they are more protected. West Fighting Island in the Detroit River was one of the few sites in close proximity to the main channel and it had the lowest proportional coverage of SAV in this system. Regardless of the mechanism behind the observed patterns in SAV coverage, the sites surveyed in the St. Clair River generally had more marginal, fringe SAV coverage relative to the Detroit River.

Finally, despite the noted differences in environmental condition and SAV coverage, substrate composition in both rivers were very similar (i.e. dominated by sand) as were the dominant SAV species (e.g., *Vallisneria americana* and *Potamogeton richardsonii*). From a species perspective this is not surprising given that these two systems are directly connected and likely have similar growing seasons despite moderate differences in other physical characteristics (e.g. flows and bathymetry).

APPENDIX A REFERENCE

BioSonics. 2001. BioSonics Software [online]. Available from. https://www.biosonicsinc.com/wp-content/uploads/2017/03/BioSonics-Visual-Habitat-Software-Data-Sheet1.pdf (accessed November 2019).

APPENDIX A TABLES AND FIGURES

Table A1. Site codes and year sampled as well as mean Secchi depth for the Detroit River (DR) and St. Clair River (SCR) systems. For many sites, Secchi depth could not be assessed due to weather conditions. Also, at some shallow sites with clear water, the Secchi disc reached the bottom. In these instances the mean Secchi depth was assigned a value of greater than the bottom depth. Locations where Secchi was not collected in that time stanza are identified with a "—".

Site	System	Site [a] code	Sample year	Mean Secchi depth (m)
Amherstburg Channel	DR	DR_AC	2007/2008	—
Peche Island	DR	DR_PI	2007/2008	1.84 ± N/A
South Fighting Island	DR	DR_SFI	2007/2008	—
West Fighting Island	DR	DR_WFI	2007/2008	—
Windsor East	DR	DR_WE	2007/2008	0.75 ± 0.14
Windsor West	DR	DR_WW	2007/2008	0.77 ± 0.04
Clay Creek	SCR	SC_CP	2008	—
Fawn Island	SCR	SC_FI	2008	—
Marshy Creek	SCR	SC_SFI	2008	—
N Stag Island	SCR	SC_NSI	2008	—
ON Power Generation	SCR	SC_OPG	2008	—
Sarnia Harbour	SCR	SC_SH	2008	—
Suncor Site	SCR	SC_SS	2008	> 1.0
Talford Creek	SCR	SC_TC	2008	> 2.0
Canard River	DR	DR_CR	2010	0.94 ± 0.36
LaSalle	DR	DR_NFI	2010	0.87 ± 0.40
Turkey Creek	DR	DR_TC	2010	1.03 ± 0.28
Clay Creek	SCR	SC_CP	2010	0.82 ± 0.76
Chenal Ecarte	SCR	SC_CE	2010	5.53 ± 0.33
Marshy Creek	SCR	SC_SFI	2010	> 2–3 m

Table A2. Dominant substrate composition determined from samples collected at the field verification points. Substrate with '—' identified indicate no granular composition was detected.

Site code [a]	Year	Dominant substrate	Gravel	Sand	Silt	Clay
DR_TC	2010	Sand	3.4 ± 14.2	82.9 ± 20.3	42.0 ± 25.5	7.8 ± 5.8
DR_NFI	2010	Sand	11.9 ± 17.9	61.8 ± 31.1	70.6 ± 19.2	12.9 ± 9.8
DR_CR	2010	Sand	2.7 ± 8.2	64.9 ± 23.6	43.0 ± 15.5	17.2 ± 15.8
SC_CE	2010	Sand	6.7 ± 18.6	91.7 ± 18.2	—	—
SC_SFI	2010	Sand	17.0 ± 20.3	80.7 ± 19.4	—	—
			Cobble	**Sand**	**Silt/clay**	**Organic**
SC_SH	2008	Sand	0.2 ± 0.2	96.1 ± 2.4	2.1 ± 1.8	1.6 ± 0.5
SC_SS	2008	Sand/Cobble	39.3 ± 30.9	55.9 ± 30.4	2.8 ± 1.6	1.9 ± 0.8
SC_TC	2008	Sand	9.2 ± 0.8	80.7 ± 1.5	8.2 ± 1.8	2.0 ± 0.5
SC_NSI	2008	Sand/Cobble	48.2 ± 30.7	48.4 ± 29.6	2.0 ± 1.6	1.4 ± 0.1
SC_OPG	2008	Sand	13.1 ± 21.2	82.9 ± 19.9	2.8 ± 1.1	1.3 ± 0.5
SC_CP	2008	Sand	9.8 ± 4.5	82.3 ± 6.6	5.9 ± 2.6	2.0 ± 0.1
SC_FI	2008	Sand	2.1 ± 3.5	83.6 ± 17.0	12.4 ± 16.7	1.9 ± 1.3
SC_SFI	2008	Sand	14.8 ± 14.7	78.8 ± 13.6	5.0 ± 2.8	1.4 ± 0.3
DR_PI	2007/2008	Sand	2.2 ± 3.9	70.5 ± 9.7	22.5 ± 11.4	4.8 ± 2.2
DR_WE	2007/2008	Sand	17.0 ± 25.4	69.1 ± 24.1	10.3 ± 8.7	3.7 ± 2.0
DR_WW	2007/2008	Sand	16.4 ± 16.8	77.2 ± 14.7	4.8 ± 1.7	1.6 ± 0.5
DR_WFI	2007/2008	Sand	4.4 ± 2.9	73.6 ± 4.9	18.7 ± 3.3	3.3 ± 0.7
DR_SFI	2007/2008	Sand	6.9 ± 13.6	65.9 ± 6.8	22.1 ± 14.6	5.1 ± 1.4
DR_AC	2007/2008	Sand	4.3 ± 7.5	76.5 ± 10.8	14.3 ± 7.3	4.9 ± 3.6

[a] See Table A1 for site code definitions

Table A3. Results from the hydroacoustic (HA) surveys showing the number of pings where submerged aquatic vegetation (SAV) was present (P) or absent (A). The mean, inter-quartile range and minimum-to-maximum depth where SAV were present or absent are also presented.

Site [a] code	Sample year	SAV P/A	HA pings	Depth(m)		
				Mean	1st – 3rd Quartile	Min to Max
DR_AC	2007/2008	P	911	1.87 ± 0.40	1.68–1.94	1.11–7.19
		A	599	5.90 ± 1.84	4.74–7.17	0.95–12.49
DR_PI	2007/2008	P	1148	1.56 ± 0.52	1.26–1.71	0.90–5.15
		A	783	3.90 ± 2.07	2.31–5.61	0.85–8.37
DR_SFI	2007/2008	P	2394	1.70 ± 0.55	1.37–1.77	0.85–7.13
		A	1225	4.35 ± 2.22	2.64–6.22	0.83–8.39
DR_WFI	2007/2008	P	175	4.69 ± 1.25	3.64–5.82	2.18–7.28
		A	759	3.24 ± 2.35	1.35–4.88	0.85–8.82
DR_WE	2007/2008	P	1025	1.71 ± 0.29	1.49–1.96	1.06–2.74
		A	505	3.94 ± 1.77	2.68–5.43	1.10–7.37
DR_WW	2007/2008	P	1092	2.16 ± 0.56	1.75–2.44	1.18–4.69
		A	685	4.66 ± 1.74	3.57–5.86	1.13–8.37
SC_CP	2008	P	346	3.53 ± 1.07	2.94–4.08	1.37–7.81
		A	2437	4.10 ± 2.89	1.46–6.86	0.87–10.13
SC_FI	2008	P	588	4.26 ± 1.42	2.98–5.43	1.33–7.19
		A	999	5.85 ± 2.90	2.42–7.85	1.01–11.45
SC_SFI	2008	P	306	4.20 ± 1.37	3.06–5.23	1.54–6.78
		A	1239	6.86 ± 3.20	4.71–9.50	1.08–10.55
SC_NSI	2008	P	286	3.55 ± 0.98	2.80–4.03	1.65–6.32
		A	1995	4.63 ± 2.21	3.15–5.94	1.35–10.29
SC_OPG	2008	P	493	3.60 ± 1.16	2.74–4.39	1.33–6.53
		A	1043	5.54 ± 2.83	2.92–7.04	1.02–11.81
SC_SH	2008	P	175	4.69 ± 1.25	3.64–5.52	2.18–7.28
		A	920	7.90 ± 2.34	6.9–9.29	1.77–12.55
SC_SS	2008	P	263	4.46 ± 0.82	3.93–5.13	2.06–6.14
		A	1106	7.22 ± 1.96	6.67–8.44	1.38–10.95
SC_TC	2008	P	328	3.23 ± 1.12	2.35–4.17	1.14–7.62
		A	1270	5.65 ± 2.61	3.23–7.74	0.90–10.40
DR_CR	2010	P	5926	1.51 ± 0.68	1.16–1.66	0.58–7.03
		A	2796	2.97 ± 2.44	1.03–4.49	0.53–10.31
DR_NFI	2010	P	2513	4.02 ± 2.15	2.20–5.46	0.52–10.95
		A	1179	3.53 ± 3.16	0.86–6–87	0.50–10.37
DR_TC	2010	P	3499	3.06 ± 3.04	1.24–2.36	0.54–9.81
		A	713	6.78 ± 2.70	4.53–8.99	0.51–9.81
SC_CE	2010	P	3601	4.88 ± 2.32	2.88–7.07	0.52–10.95
		A	1238	3.66 ± 3.15	0.86–6.90	0.50–10.37
SC_SFI	2010	P	2272	3.72 ± 1.56	2.45–5.08	0.70–7.27
		A	1327	4.28 ± 3.87	1.06–8.11	0.52–13.73

[a] See Table A1 for site code definitions

Table A4. Results from the hydroacoustic surveys for submerged aquatic vegetation (SAV). The proportion of hydroacoustic points where SAV was present (Prop. SAV) is shown as are the mean, inter-quartile range, and minimum to maximum values for SAV percent cover and SAV height.

			SAV % cover			SAV height (m)		
Site [a] code	Year	Prop. SAV	Mean	1st–3rd Quartile	Min–Max	Mean	1st–3rd Quartile	Min–Max
DR_AC	2007/2008	0.60	60.3 ± 26.1	40–80	10–100	0.48 ± 0.15	0.37–0.58	0.20–1.04
DR_PI	2007/2008	0.59	66.7 ± 28.4	50–90	10–100	0.38 ± 0.12	0.30–0.44	0.20–0.94
DR_SFI	2007/2008	0.66	65.8 ± 27.4	44–90	9–100	0.43 ± 0.17	0.31–0.50	0.20–1.66
DR_WFI	2007/2008	0.19	61.1 ± 29.1	40–90	9–100	0.69 ± 0.32	0.43–0.86	0.00–1.92
DR_WE	2007/2008	0.67	77.0 ± 26.0	60–100	9–100	0.38 ± 0.13	0.30–0.43	0.20–0.95
DR_WW	2007/2008	0.61	76.4 ± 26.2	60–100	10–100	0.32 ± 0.10	0.26–0.36	0.20–1.17
SC_CP	2008	0.12	44.9 ± 30.7	20–70	10–100	0.48 ± 0.17	0.98–0.52	0.34–1.54
SC_FI	2008	0.37	76.8 ± 28.4	60–100	10–100	0.71 ± 0.30	0.47–0.85	0.34–1.93
SC_SFI	2008	0.20	74.1 ± 30.7	60–100	10–100	0.65 ± 0.24	0.46–0.78	0.34–1.49
SC_NSI	2008	0.13	50.2 ± 31.3	20–80	9–100	0.55 ± 0.18	0.41–0.65	0.34–1.25
SC_OPG	2008	0.32	66.2 ± 29.0	40–90	10–100	0.69 ± 0.30	0.45–0.84	0.34–1.83
SC_SH	2008	0.16	61.1 ± 29.1	40–90	9–100	0.69 ± 0.32	0.43–0.86	0.00–1.92
SC_SS	2008	0.19	61.9 ± 29.7	40–90	10–100	0.51 ± 0.13	0.41–0.60	0.34–0.89
SC_TC	2008	0.21	57.2 ± 31.2	30–90	1–100	0.52 ± 0.18	1.39–0.62	0.34–1.36
DR_CR	2010	0.68	78.4 ± 28.8	66–100	5–100	0.38 ± 0.19	0.24–0.49	0.09–1.86
DR_NFI	2010	0.68	79.3 ± 29.2	60–100	9–100	0.44 ± 0.35	0.16–0.65	0.09–2.10
DR_TC	2010	0.83	73.8 ± 26.8	60–100	9–100	0.34 ± 0.17	0.21–0.44	0.05–1.37
SC_CE	2010	0.74	77.9 ± 29.5	60–100	9–100	0.37 ± 0.32	0.13–0.51	0.09–2.10
SC_SFI	2010	0.63	83.4 ± 27.7	70–100	9–100	0.57 ± 0.45	0.20–0.89	0.09–2.31

[a] See Table A1 for site code definitions

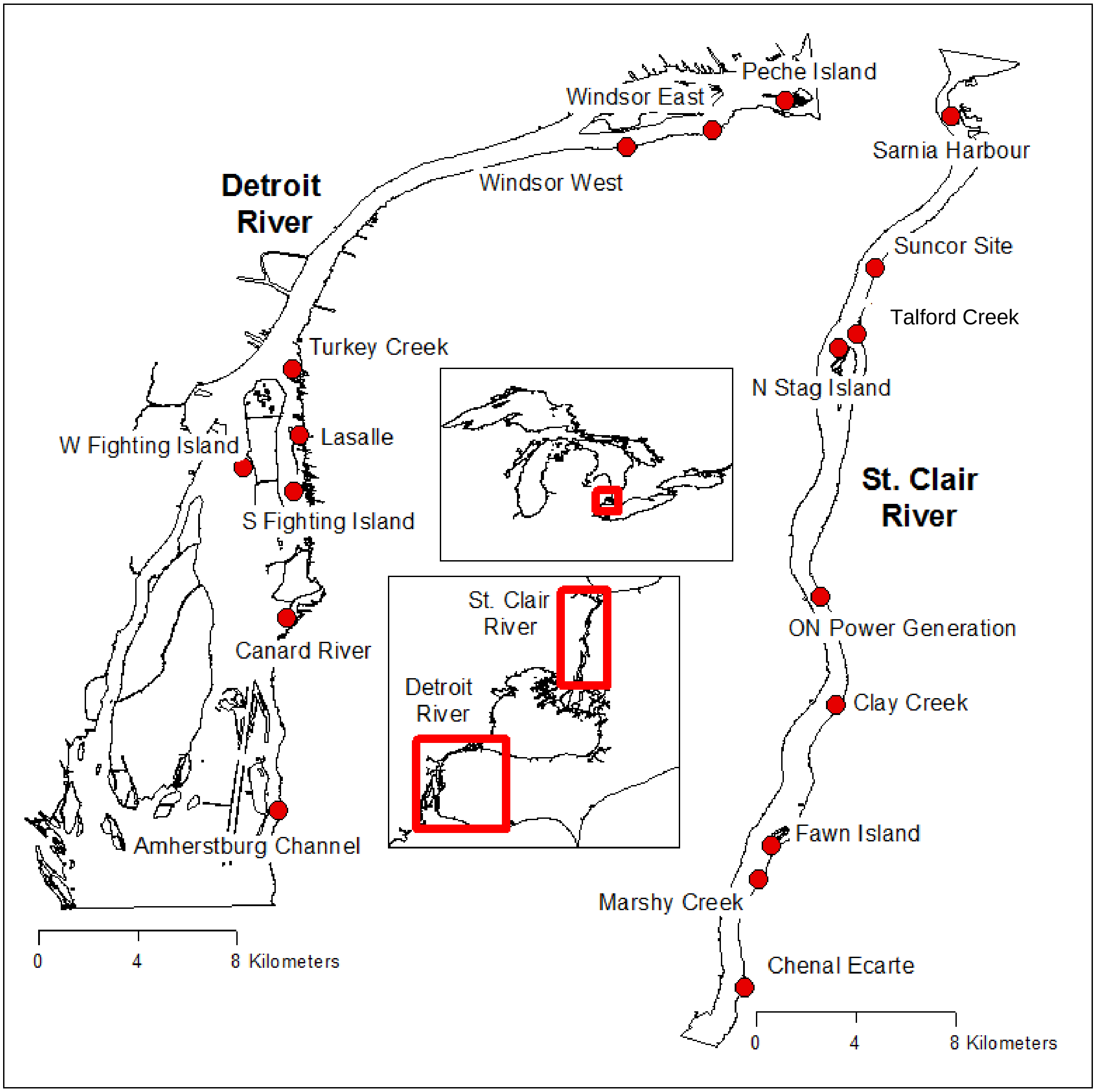
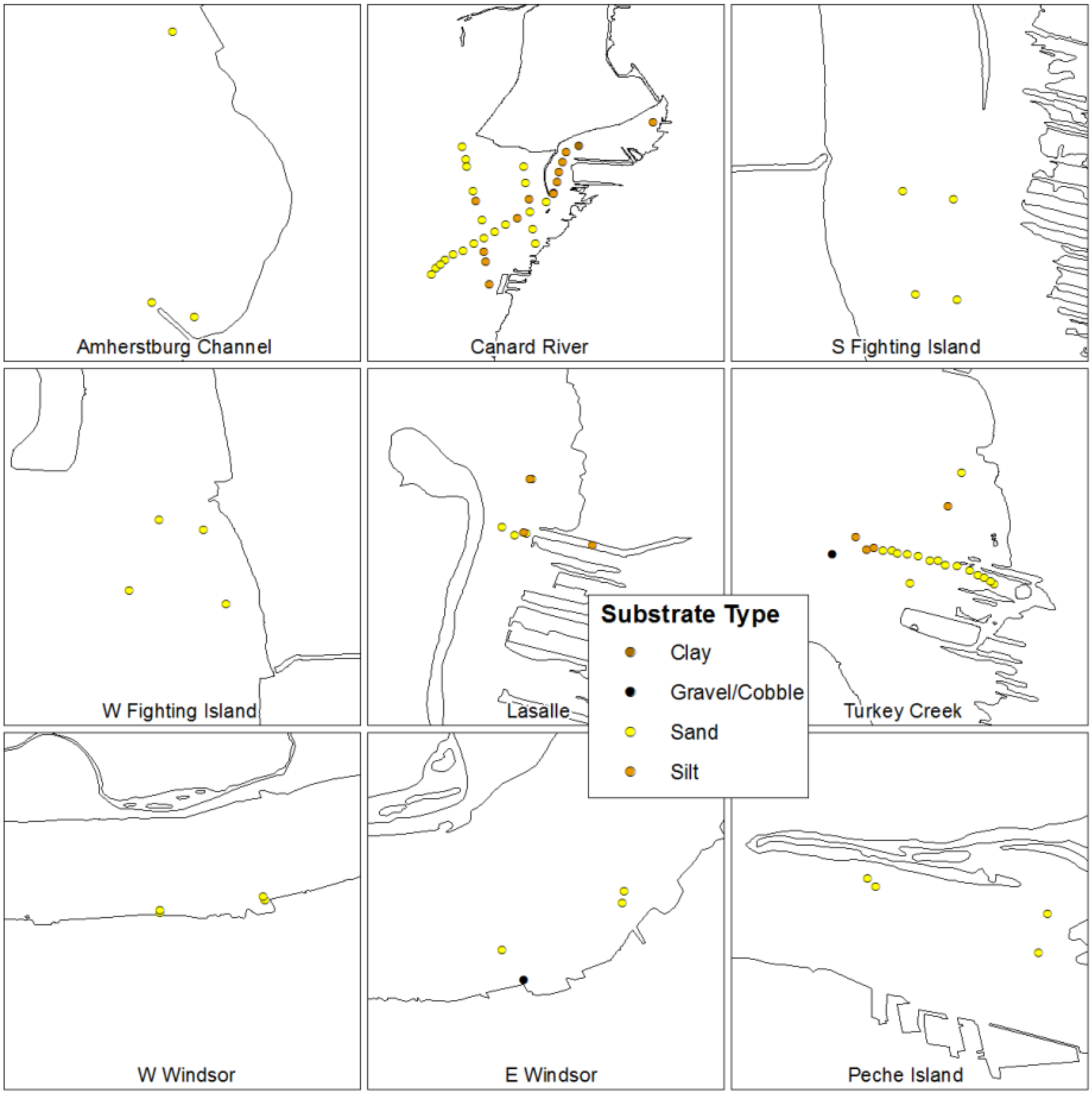


Figure A1. Location of survey sites in the Detroit and St. Clair Rivers. For detailed information on survey year see Table 1.

A2a. Detroit River



A2b. St. Clair River

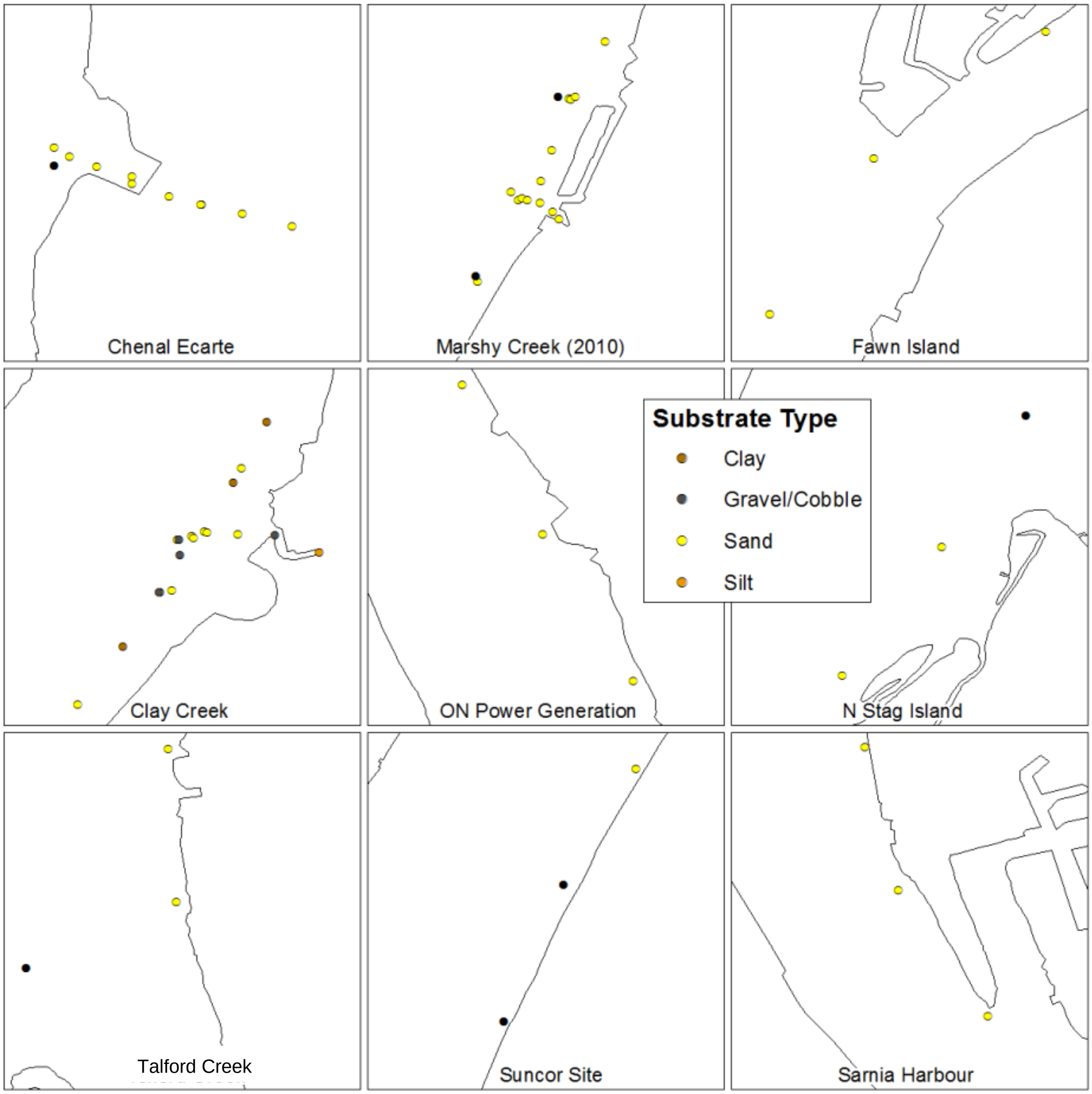
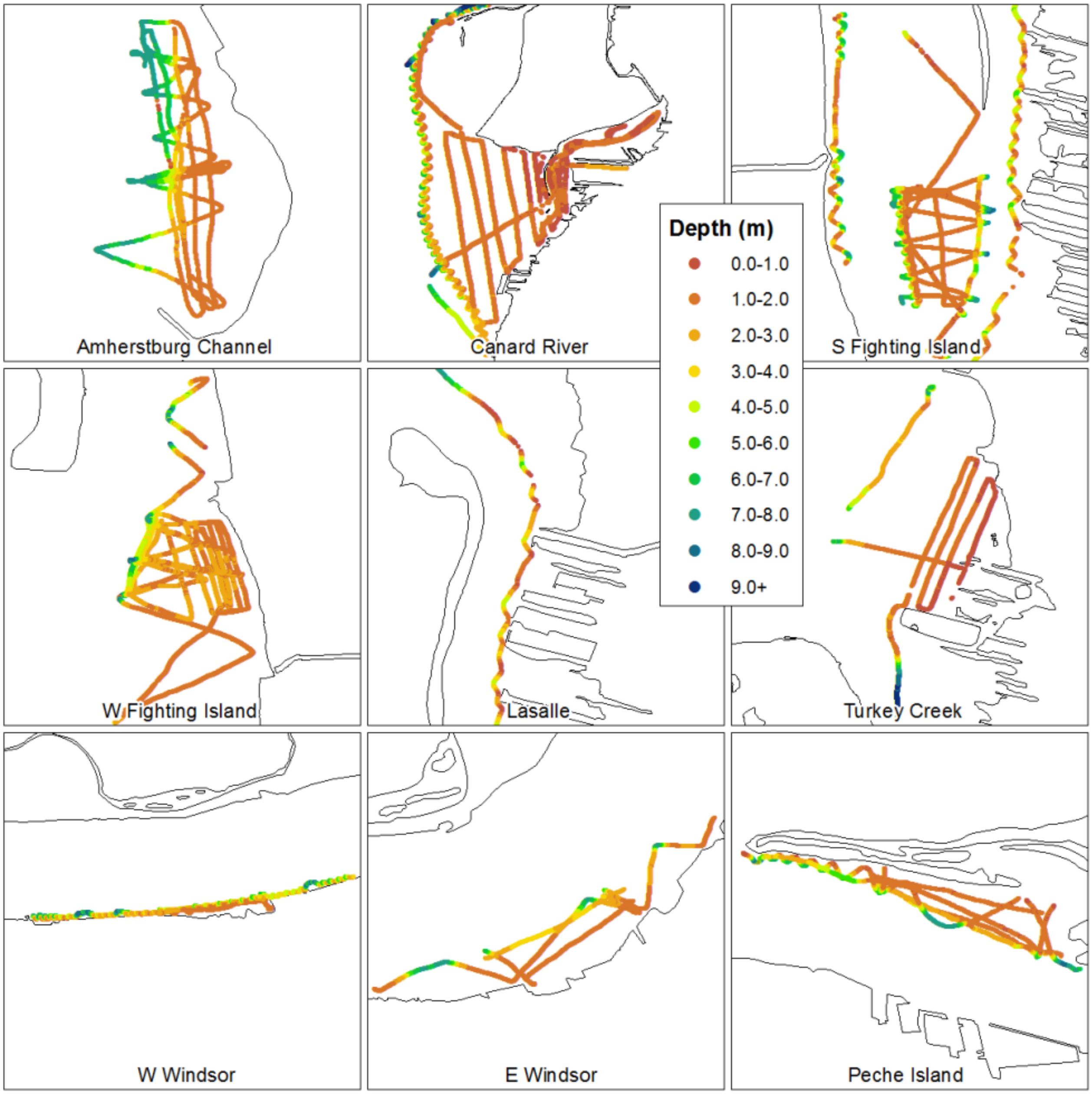


Figure A2. Location of the verification points at each site in the Detroit River (**A2a**) and and the St. Clair River (**A2b)**, and the dominant substrate type for each point. Considerably more substrate samples were collected in the 2010 surveys relative to the 2007/2008 surveys. Regardless, sand was by far the most common substrate type at all sites during all surveys.

A3a. Detroit River Sites



A3b. St. Clair River Sites

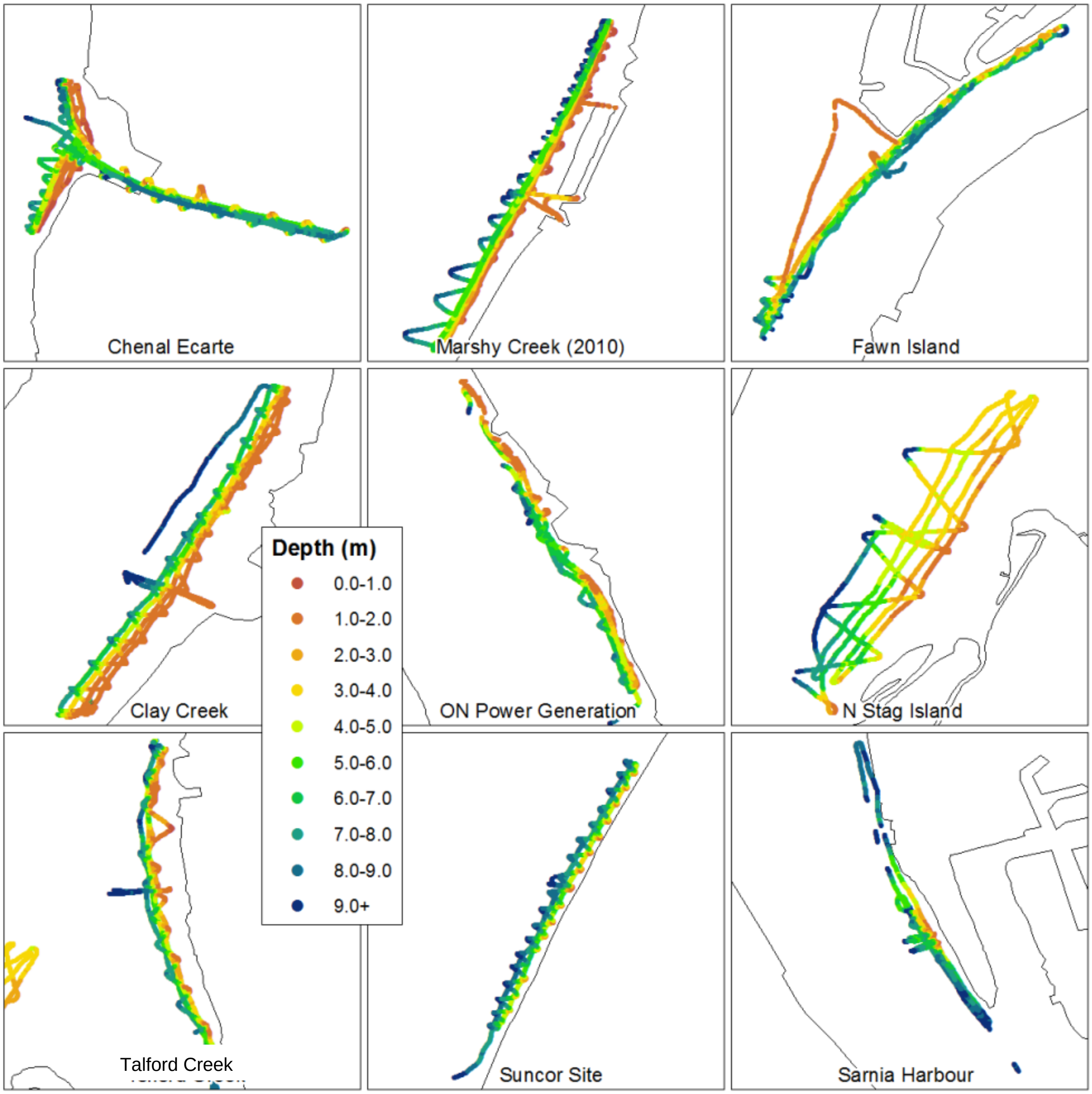
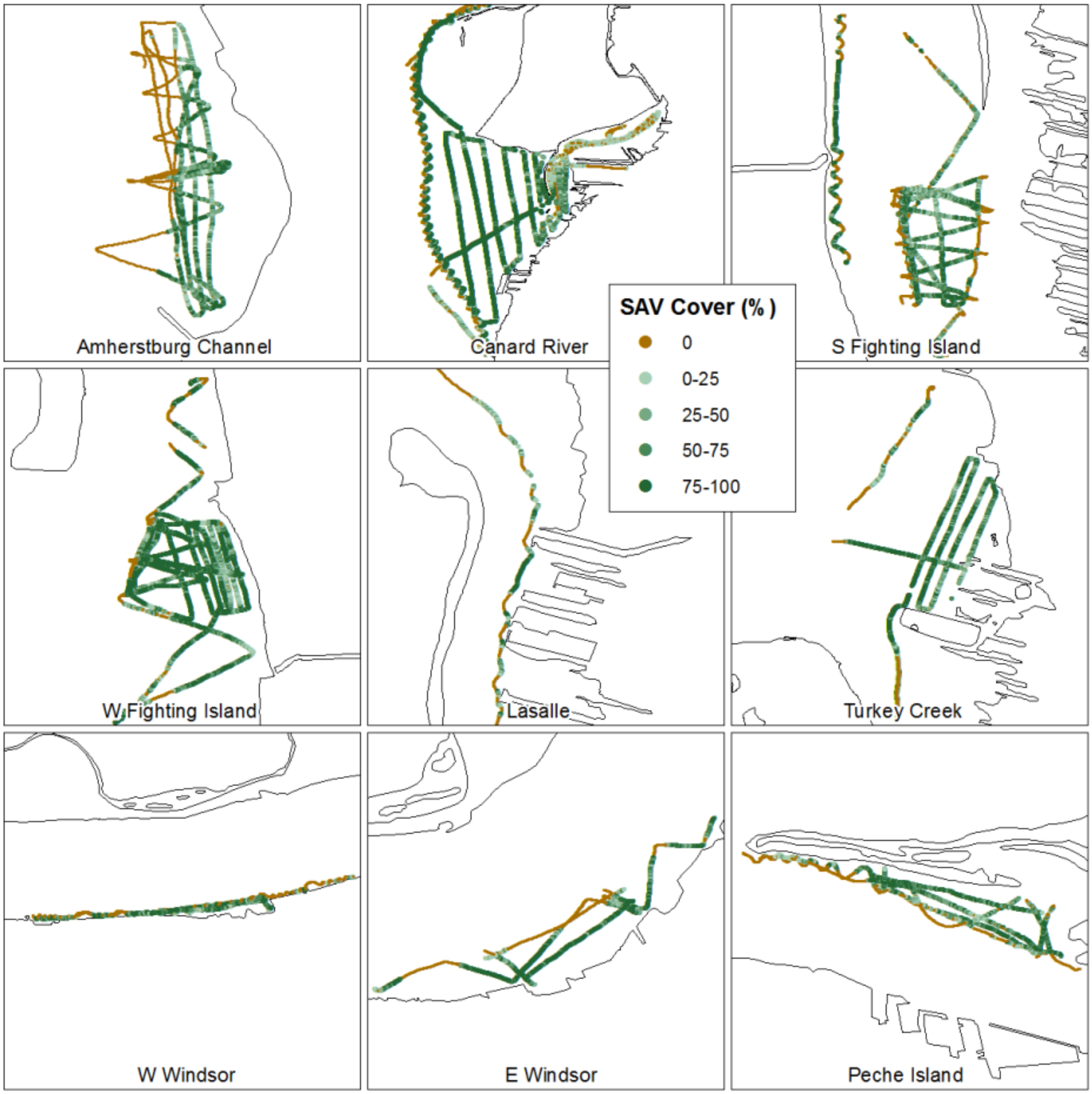


Figure A3. Depth determined from the hydroacoustic surveys. **A3a:** Detroit River sites—Turkey Creek and Canard River were sampled in 2010; the other sites were surveyed in 2007/2008. **A3b:** St. Clair River sites—Chenal Ecarte was sampled in 2010 and Marshy Creek was sampled in both 2007/2008 and 2010, but only the 2010 surveys in Marshy Creek are shown in this figure. All other sites were surveyed in 2007/2008.

A4a. Detroit River Sites



A4b. Detroit River Sites

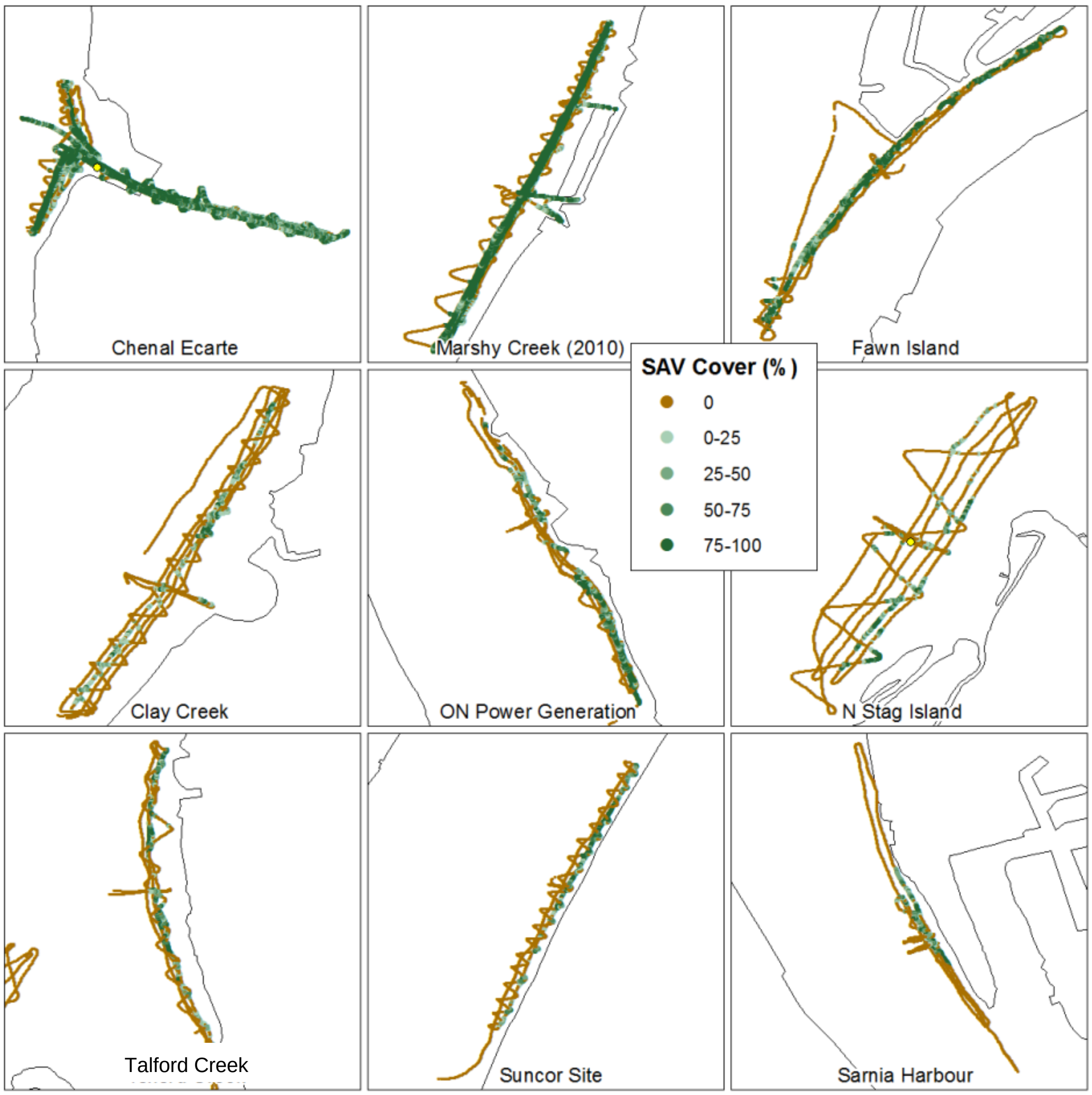


Figure A4. Spatial distribution of submerged aquatic vegetation (SAV) percent cover at: **A4a)** Detroit River sampling sites. Turkey Creek and Canard River were sampled in 2010, and the other sites were surveyed in 2007/2008. Verification points were collected at LaSalle (center panel) in 2010, but hydroacoustic surveys were not completed within this system; and **A4b)** Clair River sampling sites. Chenal Ecarte was sampled in 2010 and Marshy Creek was sampled in both 2007/2008 and 2010, but only the 2010 surveys for Marshy Creek are shown in this figure. All other sites were surveyed in 2007/2008.

Detroit River Sites

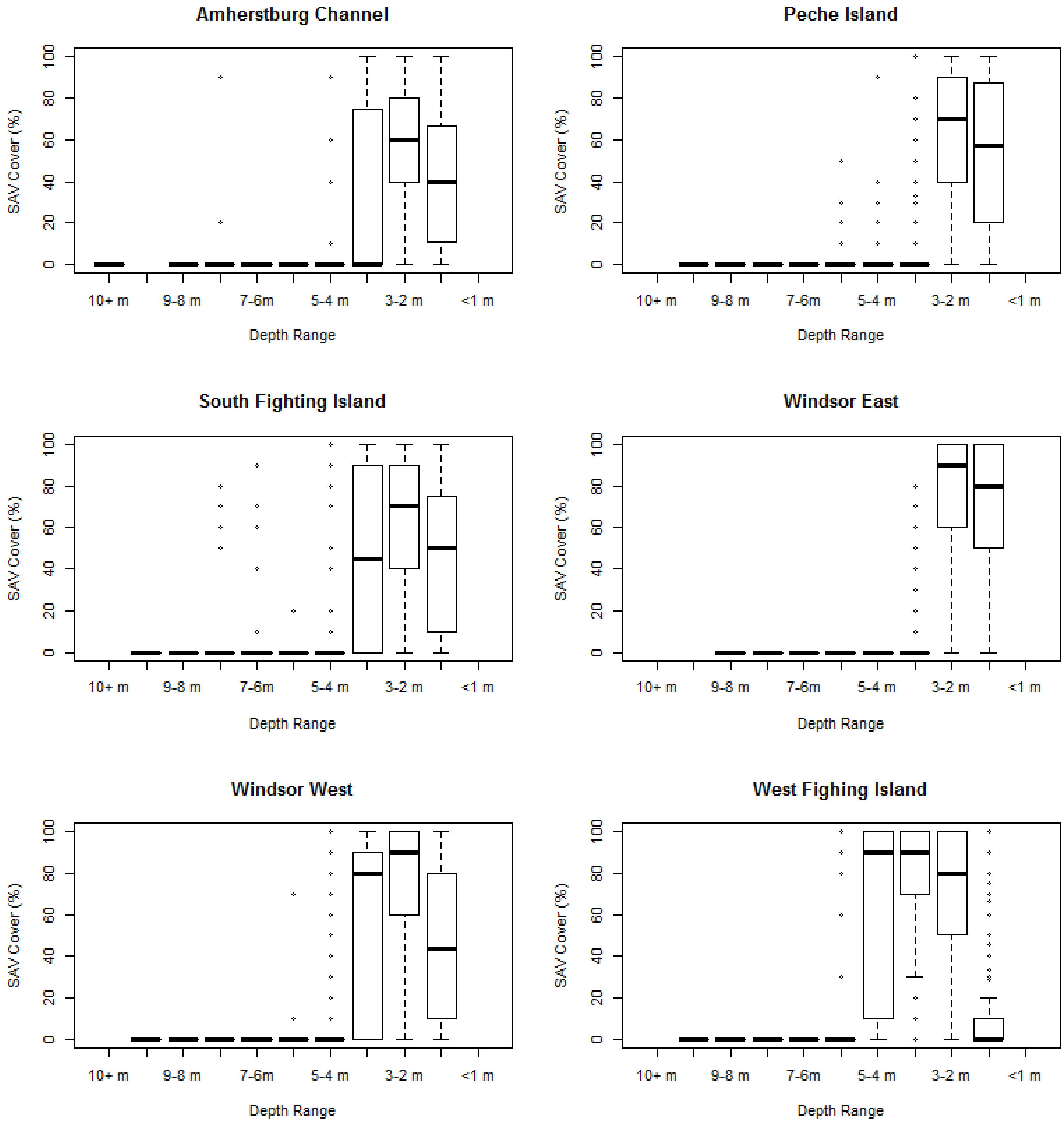


Figure A5. Submerged aquatic vegetation (SAV) percent cover as a function of depth range for each of the sites in the Detroit River that were surveyed in 2007/2008.

Detroit River Sites

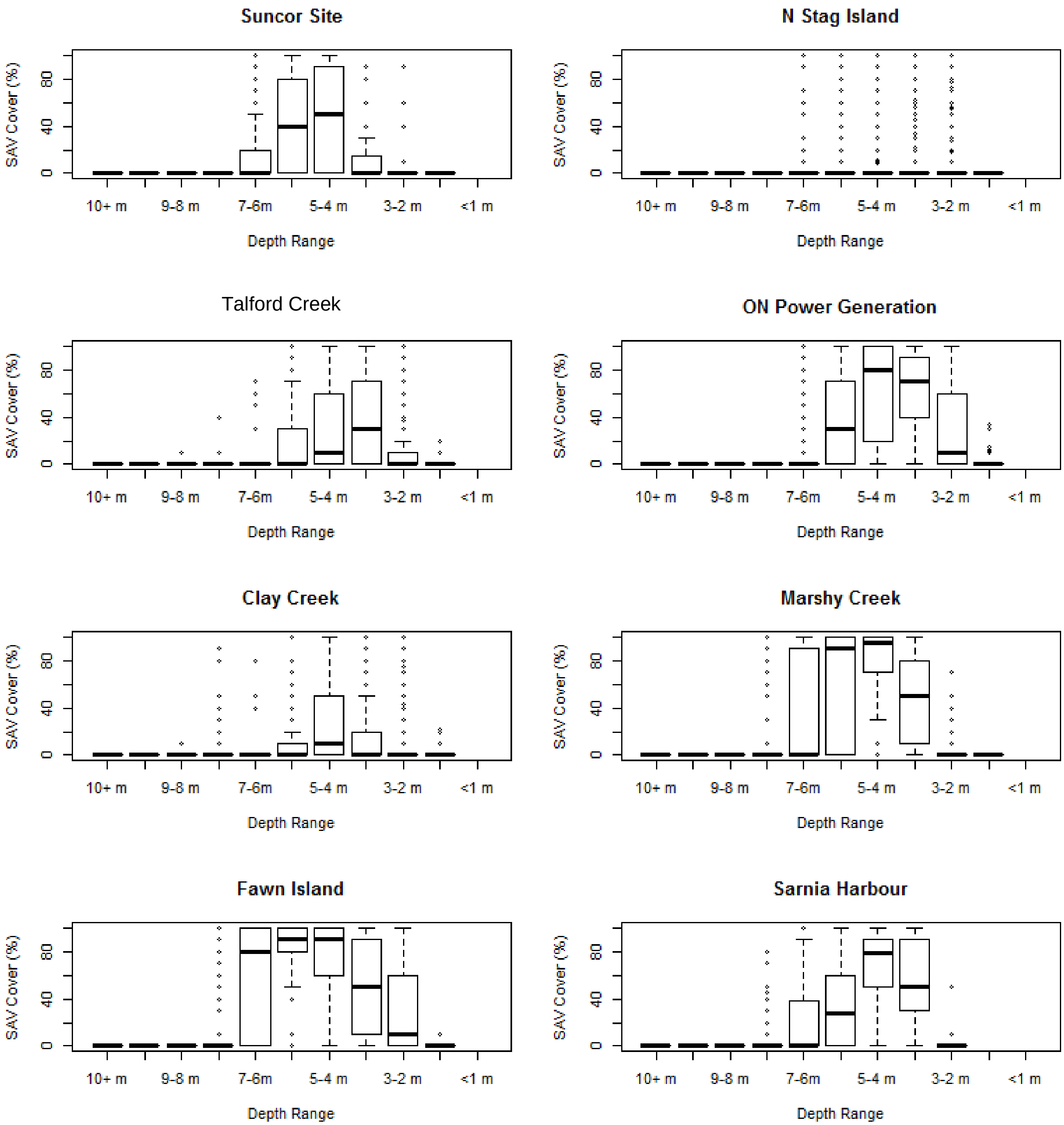


Figure A6. Submerged aquatic vegetation (SAV) percent cover as a function of depth range for each of the sites in the St. Clair River that were surveyed in 2008.

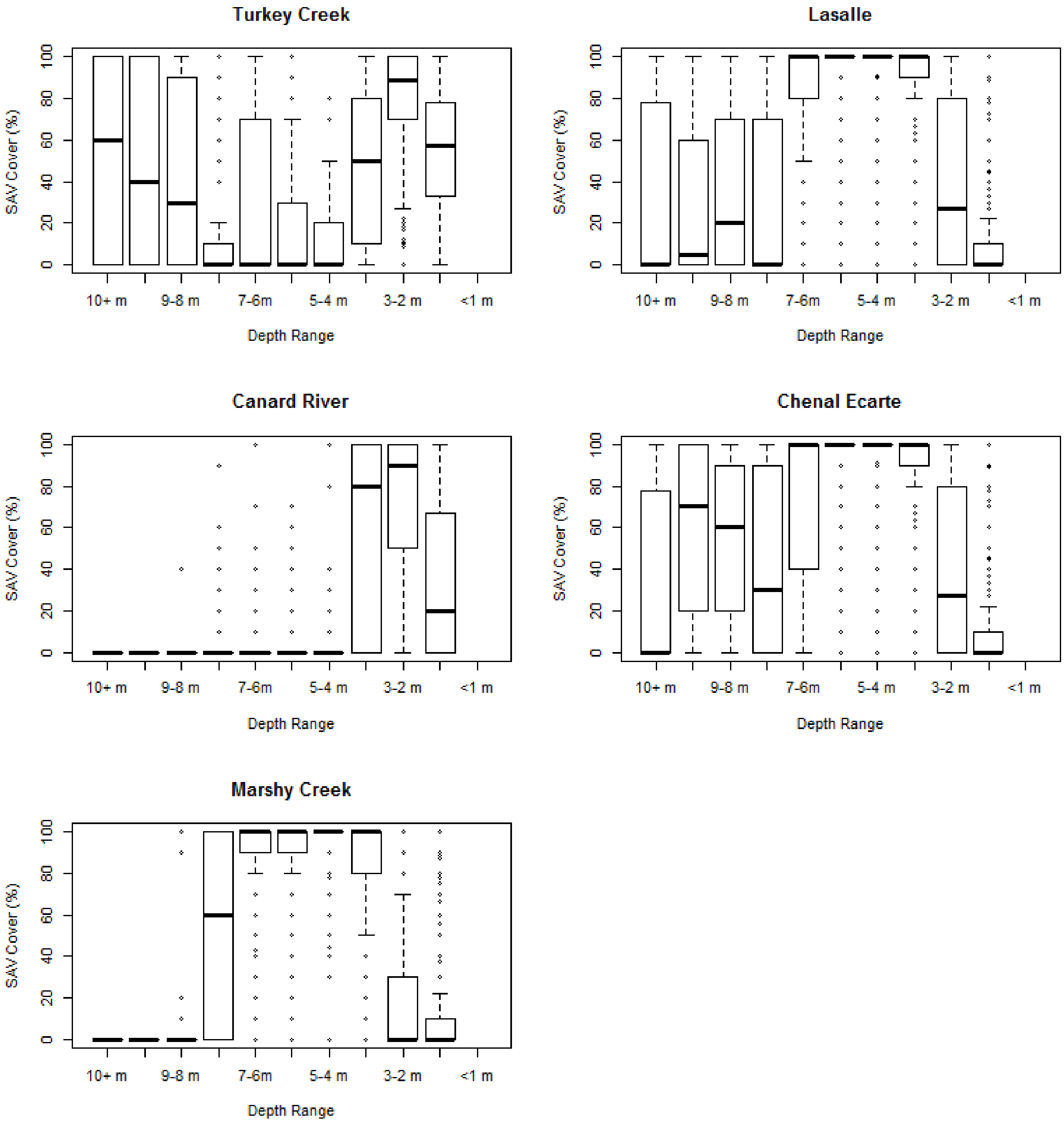


Figure A7. Submerged aquatic vegetation (SAV) percent cover as a function of depth range for each of the sites in the Detroit and St. Clair Rivers that were surveyed in 2010.