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Early Detection and Monitoring of Non-Native Fishes in Lake Ontario, 2017

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1 Executive Summary

The Laurentian Great Lakes have encountered numerous aquatic non-native and invasive species introductions since Europeans settled in North America (Mills et al. 1994). The impact of aquatic invasive species (AIS) on the Great Lakes has been widely documented by the scientific community (Leung et al. 2002; Mills et al. 1993; Rosaen et al. 2012). Despite increasing regulations aimed at reducing the likelihood of the introduction and spread of AIS into the Great Lakes, there remains a need to monitor for and detect new species before they become established. This is especially true given the costs and difficulty of attempting to control or eradicate a non-native species once it is established (Trebitz et al. 2009). If a non-native species is detected prior to becoming well established, rapid response decisions can be made in an effort to eradicate or control the species from further spread. Furthermore, continuous monitoring also allows resource managers to document the baseline community, look at historical data, and assess the impact of future invasions (Trebitz et al. 2009).

This report summarizes the 2017 efforts for early detection of non-native fishes in Lake Ontario as implemented by the U.S. Fish and Wildlife Service (USFWS) Lower Great Lakes Fish and Wildlife Conservation Office (LGLFWCO). Multiple sampling locations in Lake Ontario were selected due to their high likelihood of new non-native species introductions as suggested by a risk based vector analysis as part of a regional surveillance plan for the U.S. waters of the Laurentian Great Lakes (Chadderton et al. 2016). Lake Ontario sampling was conducted in New York waters; locations included the lower Niagara River, Rochester/Irondequoit Bay, and Oswego Harbor. Within survey locations, sites were stratified by suitable gear type according to sampling depth and habitat. Sample sites were both randomly selected and also chosen by biologists while in the field (USFWS 2016). Gear used to target juvenile and adult fish at the locations sampled included day/night electrofishing, gill nets, bottom trawling, and paired fyke nets.

During adult/juvenile fish monitoring efforts conducted in 2017, surveillance crews captured a total of 1,485 fish representing 34 species in the lower Niagara River, a total of 11,382 fish representing 47 species in Rochester/Irondequoit Bay and a total of 2,595 fish representing 31 species in Oswego Harbor. Previously established invasive species were captured often during sampling (e.g., Alewife *Alosa pseudoharengus*, Common Carp *Cyprinus carpio*, Goldfish *Carassius auratus*, Rainbow Smelt *Osmerus mordax*, Round Goby *Neogobius melanostomus*, Rudd *Scardinius erythropthalmus*, and White Perch *Morone americana*).

In 2017, no new non-native species were detected in the Lake Ontario sampling locations. However, the threat of invasion remains high, such as the recent reports of Tubenose Goby *Proterorhinus semilunaris* in the St. Lawrence River. This reinforces the critical nature of an annual early detection monitoring program as an essential part of non-native and invasive species management for Lake Ontario.

2 Introduction

Establishment of aquatic non-native species in the Great Lakes has caused major ecological and economic impacts (Mills et al. 1993; Vanderploeg et al. 2002; Rosaen et al. 2012; Rothlisberger et al. 2012). The cost of aquatic non-native species to the Great Lakes Region, whose fishery is valued at $7 billion (ASA, 2008), is well over $100 million annually (Rosaen et al. 2012). An estimated $138 million is spent each year mitigating the damages generated by ship-borne non-native species, a single introduction vector representing only a portion of invasive species present in the Great Lakes (Rothlisberger et al. 2012). Non-native species have entered the Great Lakes through a variety of vectors including ballast water from shipping vessels, canals, aquarium releases, bait release, and intentional stocking by management agencies (Mills et al. 1994). The Great Lakes currently contain at least 182 identified nonindigenous aquatic species (Ricciardi 2006), 126 of which are present in the Lake Ontario watershed (Great Lakes Aquatic Nonindigenous Species Information System, GLANSIS, NOAA 2016).

The impacts of historical non-native introductions in Lake Ontario have been widely documented. Zebra mussels *Dreissena polymorpha* and quagga mussels *D. bugensis* have altered trophic dynamics by competing for resources with native bivalves, promoting conditions favorable to harmful algal blooms, and concentrating energy resources into benthos causing oligotrophication (Vanderploeg et al. 2002). Additionally, these mussels negatively impact industries such as power plants and water treatment plants (Lovell et al. 2006). Total economic costs of zebra mussels are estimated around $5 billion (Lovell et al. 2006). The introduction of Rainbow Smelt *Osmerus mordax* has caused declines of recruitment in native planktivores such as Lake Whitefish *Coregonus clupeaformis* and Lake Herring *Coregonus artedi* (Evans and Loftus 1987), and the subsequent spread of Alewife *Alsoa pseudoharengus* has been linked to reproductive failures in Lake Trout *Salvelinus namaycush* and Atlantic Salmon *Salmo salar* (Fisher et al. 1996). Furthermore, Tubenose Goby *Proterorhinus semilunaris* have been recently detected in the St. Lawrence River, a high traffic shipping corridor, which directly connects to Lake Ontario (Invasive Species Center 2012).

Great Lakes waterways continue to face the threat of new invasions. Some non-native species have been documented as present but are not yet abundant, while others are not present but pose a high risk of invasion. Currently, the most notable potential invaders of the Great Lakes basin are four infamous species of Asian Carp: Bighead Carp *Hypophthalmichthys nobilis*, Silver Carp *Hypophthalmichthys molitrix*, Grass Carp *Ctenopharyngodon idella*, and Black Carp *Mylopharyngodon piceus.* Bighead and Silver Carp are large, planktivorous fish that have been reported to dominate fish assemblages (represent as much as 97% of total fish biomass in portions of the Mississippi River basin; MICRA 2002) and alter the structure and species composition of native plankton communities (Laws and Weisburd 1990; Vörös et al. 1997; Stone et al. 2000). Grass Carp have been captured at isolated locations within nearby Lake Erie but are not known to be abundant (Baerwaldt et al. 2013; USGS 2017). Nonetheless, natural reproduction of Grass Carp has recently been documented within the Lake Erie watershed (Chapman et al. 2013; Embke et al. 2016). This species feeds on submerged aquatic macrophytes and may threaten coastal wetlands which are important spawning and rearing habitats for many species (Chapman et al. 2013). There have been isolated catches of adult Bighead Carp in neighboring Lake Erie including two captures near Sandusky in Ottawa County, Ohio in 1995 and 2000, and a capture west of Point Pelee in Ontario, Canada in 2000 (Morrison 2004). However, there has been no evidence of establishment. Populations of Silver Carp and Bighead Carp have rapidly expanded in the Mississippi River and the Illinois River and are moving closer towards Lake Michigan and the Great Lakes (Chick and Pegg 2001). In the attempt to protect the ecological and economic value of the Great Lakes region, federal and state agencies plan to spend over $25 million in Asian Carp prevention and research annually (ACRCC 2016). Asian Carp represent just a few of the potential invaders threatening the Great Lakes resulting in costly prevention measures. Furthermore, many additional species have been identified as posing a high risk of introduction through ballast water, the aquarium trade, and other vectors outside of immediately connected waterways (Kolar and Lodge 2002; GLANSIS Watchlist, NOAA 2016).

Recent observations of Northern Snakehead *Channa Argus* in areas near the mouth of the Hudson River (USGS 2017), which connects to the Erie Canal and consequently, Lake Ontario, has become a recent invader of interest. Northern Snakehead are veracious piscivores that can inhabit unfavorable conditions for long periods of time, and they display a high rate of fecundity making them potentially harmful invaders with the ability to become established within the waterways they become introduced (Courtenay and Williams 2004). Minimizing additional introductions of non-native species to the Great Lakes has become increasingly important given the significant impacts existing invaders have had on this ecosystem and the potential impact future invaders may have.

The Great Lakes Restoration Initiative (GLRI 2014) is aimed at restoring and protecting the integrity of the Great Lakes and was first implemented in 2010. GLRI is a plan of action that recognizes regulation and education alone are not enough to protect and restore the Great Lakes. GLRI includes a number of focus areas that address Great Lakes issues including an Invasive Species component. Within the GLRI Invasive Species component, there is a charge to "conduct early detection and monitoring activities". Preventing the transfer of a new species to an ecosystem is ultimately the most effective tool to keep non-native species from becoming invasive. When complete prevention is not possible, the next most effective option is monitoring for the arrival of new species and controlling their spread before they become widespread (USEPA 2008; Trebitz et al. 2009, Hoffman et al. 2016). In 2012 the Great Lakes Water Quality Agreement (1987) was renewed and included a number of annexes to address issues in the Great Lakes. One such is Annex 6, an Aquatic Invasive Species Annex whose purpose is to *"..establish a binational strategy to prevent the introduction of Aquatic Invasive Species (AIS), to control or reduce the spread of existing AIS, and to* *eradicate, where feasible, existing AIS within the Great Lakes Basin Ecosystem"*. Included in the Programs and Measures component of the Annex is the task to develop and implement an early detection and rapid response initiative that: (a) develops species watch lists; (b) identifies priority locations for surveillance; (c) develops monitoring protocols for surveillance. Within science efforts charged by the Annex is the need for *"development and evaluation of technology and methods, including genetic techniques, that improve the ability to detect potential AIS at low levels of abundance"*.

The U.S. Fish and Wildlife Service (USFWS) developed a strategic framework for the early detection of non-native fishes and select benthic macroinvertebrates in the Great Lakes (USFWS 2014b). Fish and Wildlife Conservation Offices (FWCOs) throughout the Great Lakes lead and coordinate this program. This report describes the efforts devoted to the early detection of non-native juvenile and adult fishes at three high risk locations in the Lake Ontario basin in 2017, and is a continuation of coordinated efforts initiated in 2014.

3 Study Areas

Lake Ontario study areas were chosen through the use of a vector risk analysis for species at risk to become introduced into the Great Lakes. Study areas, sampling gears, and sampling targets were identified in the *Lake Ontario Implementation Plan for the Early Detection of Non-Native Fishes and Select Benthic Macroinvertebrates* (USFWS 2016) and risk locations identified by Chadderton et al. (2016). Three study areas were sampled in 2017. The lower Niagara River, Rochester/Irondequoit Bay, and Oswego Harbor were identified as high risk locations for introduction of non-native species (Figure 1).

3.1 Lower Niagara River

The lower Niagara River is the portion of river downstream of Niagara Falls. The lower river receives a large amount of tourism and recreational fishing year-round. The lower Niagara River is proximal to the Welland Canal (Canada), and is downstream to the western mouth of the Erie Canal. This portion of the river has deep waters with high flow rates, with an average discharge of 204,800 cubic feet per second (USGS 2003). The international border with Canada runs along near the midpoint of the river. Sampling was conducted in U.S. waters. The habitat of the Niagara River consists of varying sizes of cobble, bedrock, and large expanses of submerged vegetation. The aquatic habitat at the mouth of the Niagara River (Niagara Bar) consists of sandy substrate with infrequent submerged vegetation. The open lake habitat consists of a mixture of sand, small cobble, and Dreissena spp. colonies. The water in the Niagara River is clear and swift-moving in most locations. The total surface area of the survey location was approximately 3,500 ha.

3.2 Rochester/Irondequoit Bay

The Rochester/Irondequoit Bay sampling area includes the Genesee River, Irondequoit Bay, and Lake Ontario proper. The Genesee River and Lake Ontario proper within a mile radius of Irondequoit Bay are hereafter referred to as Rochester. This area receives high levels of recreation and tourism. The port of Rochester is located at the mouth of the Genesee River. Irondequoit Bay is located 6 kilometers east of the port of Rochester. The bay is 0.8 km wide, and 6 km long, containing many areas of suitable fish habitat. The area surveyed for Rochester includes the Genesee River, the open lake, and the entirety of Irondequoit Bay south to the mouth of Irondequoit Creek. The habitat in the Rochester system is highly variable. The Genesee River is dredged for navigation in the lower reach and the shoreline consists mostly of docks for recreational boating and sheet pilings. The upstream reach shoreline transitions to a mixture of emergent vegetation and deciduous trees. Substrate in Irondequoit Bay consists mostly of a soft, muddy bottom with patches of submerged vegetation. The total surface area of the survey location was approximately 7,766 ha.

3.3 Oswego Harbor

This area includes the harbor, bounded by breakwalls, at the mouth of the Oswego River and continues up the Oswego River to as far south as the first barrier at the Varrick Dam. The city of Oswego, NY, surrounds the harbor and is bisected by the Oswego River. The Oswego Canal runs the length of the Oswego River and connects Lake Ontario to the Erie Canal System. The area receives a high level of recreational fishing and boating. The surface area for the harbor and lower Oswego River encompasses approximately 142 hectares. Most of Oswego Harbor is dredged to maintain a deep water commercial harbor, averaging approximately 7 m deep. The harbor shoreline consists of mostly sheet piling, riprap, and docks for recreational boating. The lower river shoreline consists of cement walls as it runs through the city.

4 Methods

4.1 Adult/Juvenile Fish Sampling

Adult and juvenile fish were targeted using diverse sampling gears deployed at a range of water depths in an attempt to collect as many species present in the fish community as possible. Results from the different gear types are used to determine which gears collect the greatest number of unique species and is used to inform future sampling efforts. Sampling gears used to target adult and juvenile fish included paired fyke nets, boat electrofishing, micro-mesh gill nets, and benthic trawling.

Paired fyke nets consisted of two 0.91 m x 1.22 m fyke nets constructed of 4.69 mm (3/16" delta) stretch mesh netting that were attached together with a 15 m x 0.91 m lead resulting in a paired net. Each individual net consisted of two rectangular frames 0.91 m x 1.22 m, followed by four circular rings 0.91 m in diameter. Paired fyke nets were set parallel to the shoreline or in “weed pockets” in water depths of 1.0-4.4 m. Nets were set during the daytime, and remained in the water overnight and retrieved the following day during daylight hours. Nets were deployed for no longer than 30 hours, with a typical set time ranging from 12-30 hours. Effort was measured in overnight sets.

Boat electrofishing was conducted during both day and night hours, in water depths of 1-3 m. A pulsed DC current 60 Hz electrical unit was used with sufficient power to induce taxis in fish. The electrofishing power was dependent upon water conductivity and the level of boat-hull oxidation. Smith Root control boxes were used to generate electrical impulses used during electrofishing. Electrofishing was conducted along one 600 s transect near each predetermined way point. Effort was converted to hours fished.

Micro-mesh gill nets were 9.14 m x 1.83 m consisting of three 3.05 m long panels of 9.53 mm, 12.7 mm, and 15.88 mm square mesh. The nets were held between a floating and weighted lead that were attached on either end to a rope lead which was attached to an anchor and ball buoy on each side. Gill nets were placed on the bottom of the water column, with the remainder of the net extending upwards. Gill nets were deployed for 3 hours and effort is per each gill net set.

Benthic trawling was conducted using a Marinovich design trawl with a 4.9 m head rope, 3.8 cm stretch mesh body, and a 3.125 mm stretch mesh cod end. Trawls were recovered using a hydraulic winch or by hand. Trawl tows were performed along contours for ten minutes at a speed of approximately 4 km/h, and at depths greater than 2 m. Effort was reported as fish per minute. Benthic trawling was conducted only at locations where the substrate was even and composed of combinations of soft material such as sand, silt, or vegetation. Trawling was not conducted in areas with rocky or uneven substrate or at locations with extremely swift water currents, and therefore could not be conducted in the lower Niagara River or Irondequoit Bay due to factors listed above.

ArcGIS 10.2 was used to select sampling sites across water depth strata (<2 m, 1-2 m, and > 2 m) present in each study area according to a stratified randomized design. Study areas were predefined using polygon shapefiles in ArcGIS. A bathymetry data layer was used to define depth strata within the polygon. Random points, corresponding to GIS coordinates, were selected within each depth strata using the Create Random Points function in ArcGIS 10.2. Due to lack of available bathymetric data for many of the areas to be sampled (shallow, near shore, outside of dredged areas), shape files were modified for estimated depth ranges corresponding to gear types. Some sites were also selected by biologists while in the field based on previously defined diversity "hotspots". The Hot Spot Analysis (Getis-Ord Gi*) tool within ArcGIS 10.4 was used to statistically identify species richness clusters in all sampling locations to determine areas of proportionally high species richness in which to sample within (Ord and Getis 1995).

Gears used during this study and the amount of effort deployed was based on recommendations from Trebitz et al. (2009) and USFWS (2014a). When a randomly selected point was unable to be sampled (e.g. wrong depth, inaccessibility), an alternate site was selected by the judgement of biologists in the field (<50% of sampling site selections).

4.2 Rarefaction and Species Accumulation

Species accumulation models describe the cumulative number of species recorded in a particular environment as a function of the cumulative search effort. While these models describe the rate at which species have been observed, they do not describe the total number of species that may have been missed. To estimate total species richness we used incidence-based functions that assume the number of not captured species is related to the number of rare species. Singletons (species detected once) and doubletons (species detected twice) identify rare species and contribute to rarefaction analysis as they can affect the number of predicted species (if there are many singletons and/or doubletons the amount of species predicted will increase). The Chao estimator assumes the number of missed species is related to the proportional difference between singletons (f_1) and doubletons (f_2) within the reference sample (sampling event, n):

$$S_C = S_{Obs} + \frac{f_1^2}{2f_2}\left(\frac{n-1}{n}\right)$$

Sample-based rarefaction and extrapolation were conducted and species accumulation curves were calculated using the Chao asymptotic richness estimator in the package "iNEXT" with R statistical software (Chao et al. 2014; Hsieh et al. 2016; R Core Team 2016) and species abundance data (randomized pooling of data) from 2012-2017 for 300 sample extrapolations at 100 replications. The methods used followed Chao et al. (2009). Estimated species richness is the asymptote of the extrapolated rarefaction curve.

Catch per unit effort was determined for all fish species captured in 2017. Any unique or new species collected in 2017, but not seen in previous years, were noted. All statistical analyses found within this report were performed using the computing environment R (R Core Team 2016).

5 Results

5.1 Lower Niagara River

A total of 1,485 fish representing 34 species were collected between August 29, 2017 and September 26, 2017 (Table 1, Figure 2). No undocumented non-native species were identified; however, 6 existing non-native species were detected and are denoted within the catch summary.

A total of 396 fish representing 28 species were collected using 12 electrofishing transects sampled between August 29, 2017 and September 26, 2017 at surface water temperatures between 21.7 and 22.7° C. The two species that comprised the largest percentages of the total catch were; Yellow Perch (32.3%) and Smallmouth Bass (15.4%). Notable species from the remainder of the catch was composed of Golden Redhorse (12.6%), White Sucker (11.6%), and Brown Bullhead (3.8%).

A total of 1,089 fish representing 23 species were collected as a result of 8 paired fyke net sets sampled overnight between September 25, 2017 and September 26 2017 at surface water temperatures between 21.7 and 22.5° C. The two species that comprised the largest percentages of the total catch were; Bluegill (56.5%)

and Yellow Perch (12%). Notable species from the remainder of the catch was composed of Rock Bass (10.7%), White Perch (7.2%), and Bluntnose Minnow (3.2%).

5.2 Rochester/Irondequoit Bay

A total of 11,382 fish representing 47 species were collected between May 18, 2017 and October 31, 2017 (Table 2, Figure 3). No undocumented non-native species were identified; however, 11 existing non-native species were detected and are denoted within the catch summary.

A total of 1,368 fish representing 40 species were collected using 36 electrofishing transects sampled between June 20, 2017 and October 31, 2017 at surface water temperatures between 8.9 and 26.1° C. The two species that comprised the largest percentages of the total catch were; Yellow Perch (22.9%) and Gizzard Shad (15.3%). Notable species from the remainder of the catch was composed of Largemouth Bass (12.9%), Bluegill (12.7%), and Golden Shiner (4.3%).

A total of 9,755 fish representing 23 species were collected as a result of 12 paired fyke net sets sampled overnight between October 02, 2017 and October 04, 2017 at surface water temperatures between 17.1 and 21° C. The two species that comprised the largest percentages of the total catch were; Bluegill (93.5%) and Yellow Perch (1.7%). Notable species from the remainder of the catch was composed of Spotfin Shiner (1.4%), Round Goby (1.3%), and Rock Bass (0.5%).

A total of 84 fish representing 6 species were collected using 4 micro-mesh gill net sets sampled between June 13, 2017 and June 13, 2017 at surface water temperatures between 22.9 and 23.4° C. The two species that comprised the largest percentages of the total catch were; Yellow Perch (60.7%) and Alewife (26.2%). Notable species from the remainder of the catch was composed of White Perch (8.3%), Spotfin Shiner (2.4%), and Walleye (1.2%).

A total of 175 fish representing 18 species were collected using 8 bottom trawl tows sampled between May 18, 2017 and October 12, 2017 at surface water temperatures between 16.1 and 23.2° C. The two species that comprised the largest percentages of the total catch were; Trout-Perch (36%) and Freshwater Drum (9.1%). Notable species from the remainder of the catch was composed of Alewife (8.6%), Brown Bullhead (7.4%), and Channel Catfish (6.9%).

5.3 Oswego Harbor

A total of 2,595 fish representing 31 species were collected between August 14, 2017 and August 17, 2017 (Table 3, Figure 4). No undocumented non-native species were identified; however, 7 existing non-native species were detected and are denoted within the catch summary.

A total of 1,066 fish representing 21 species were collected using 16 electrofishing transects sampled between August 15, 2017 and August 16, 2017 at surface water temperatures between 23.4 and 25.3° C. The two species that comprised the largest percentages of the total catch were; Gizzard Shad (56.9%) and Pumpkinseed (12.5%). Notable species from the remainder of the catch was composed of Largemouth Bass (6.3%), Bluegill (4.5%), and Rock Bass (4.5%).

A total of 1,287 fish representing 22 species were collected as a result of 12 paired fyke net sets sampled overnight between August 14, 2017 and August 16, 2017 at surface water temperatures between 24 and 26.5° C. The two species that comprised the largest percentages of the total catch were; Bluegill (53.4%) and Yellow Perch (11.1%). Notable species from the remainder of the catch was composed of Pumpkinseed (10.1%), Bluntnose Minnow (7.1%), and Rock Bass (6%).

A total of 242 fish representing 11 species were collected using 12 micro-mesh gill net sets sampled between August 15, 2017 and August 17, 2017 at surface water temperatures between 22.9 and 25.3° C. The two species that comprised the largest percentages of the total catch were; Yellow Perch (53.7%) and White Perch (12%). Notable species from the remainder of the catch was composed of Alewife (8.3%), Spottail Shiner (7.4%), and Round Goby (5.8%).

5.4 Rarefaction and Species Accumulation

Rarefaction Curves for juvenile and adult fish sampling were generated for all Lake Ontario sampling locations based on data collected from 2013 to 2017.

Lower Niagara River - An estimated 70.65 species are present as a result of 2013-2017 data analysis; while 46 species were captured using all sampling gears (Figure 5). A total of 71 sites have been sampled since the beginning of surveillance at this location.

Rochester/Irondequoit Bay - An estimated 71.61 species are present as a result of 2014-2017 data analysis; while 61 species were captured using all sampling gears (Figure 6). A total of 191 sites have been sampled since the beginning of surveillance at this location.

Oswego Harbor - An estimated 34.7 species are present as a result of 2016-2017 data analysis; while 27 species were captured using all sampling gears (Figure 7). A total of 20 sites have been sampled since the beginning of surveillance at this location.

6 Discussion

The 2017 field season was a continuation of annual sampling for the early detection of non-native species at Lake Ontario locations using a vector based risk analysis since 2013 (USFWS 2016). A total of 15,462 juvenile and adult fish (consisting of both native and non-native species) were collected by an assortment of gears during this survey.

Targeting juvenile and adult fish can be challenging due to fish behavior, refined habitat requirements, and gear avoidance. Non-native species at low abundances can be difficult to detect as juveniles or adults using traditional sampling gear. To account for this, multiple gear types were used to target juveniles and adults. Electrofishing generally had the highest species richness among gear types, however, paired fyke nets tended to captured more individuals than any other gear type annually. The larger sample size for electrofishing (compared to paired fyke nets) may have played a role in these findings. Despite high overall performance of electrofishing, it is recognized that a single sampling gear approach only provides a partial representation of the juvenile and adult fish assemblage (Murphy and Willis 1996), and multi-gear approaches are required to adequately characterize fish communities (Jackson and Harvey 1997; Eggleton et al. 2010; Hoffman et al. 2011; Ruetz et al. 2007).

Ultimately, designing a long-term monitoring program is challenging due to the need to balance detection efficiency with available resources (Trebitz et al. 2009). These challenges become exacerbated when considering early detection monitoring for newly introduced non-native species because of the exorbitant amounts of effort and high survey efficiency (95% species detection) required. It is therefore beneficial to use results from previous sampling as a guide to adapt future survey design and improve overall sampling efficiency and effectiveness. For example, in Duluth-Superior Harbor, Lake Superior, Hoffman et al. (2011) used a re-sampling approach and found that using a targeted sampling design (i.e. resampled areas with high species richness) resulted in greater species richness and detected non-native species with a significantly higher probability than a spatially balanced random design (also see Trebitz et al. 2009). Although the effort required to detect rare (i.e. non-natives at first introduction) species remained large, non-metric multi-dimensional scaling analysis could also be used to determine whether gear types are capturing complementary or redundant species assemblage data (cf. Ruetz et al. 2007; Frances et al. 2014). For example, if two gear types capture redundant assemblages then the least efficient gear (according to the ability to catch unique species) could be eliminated, focusing additional effort towards the most efficient gear types, and thereby increase survey effort and theoretically sampling efficiency.

In closing, the early detection and monitoring program for non-native species will continue in Lake Ontario during 2018. Survey design will continue to be critically re-evaluated following the completion of next years field season. All available options for increasing sampling efficiency to provide the most comprehensive early detection and monitoring program for non-native species will be considered.

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8 Figures and Tables

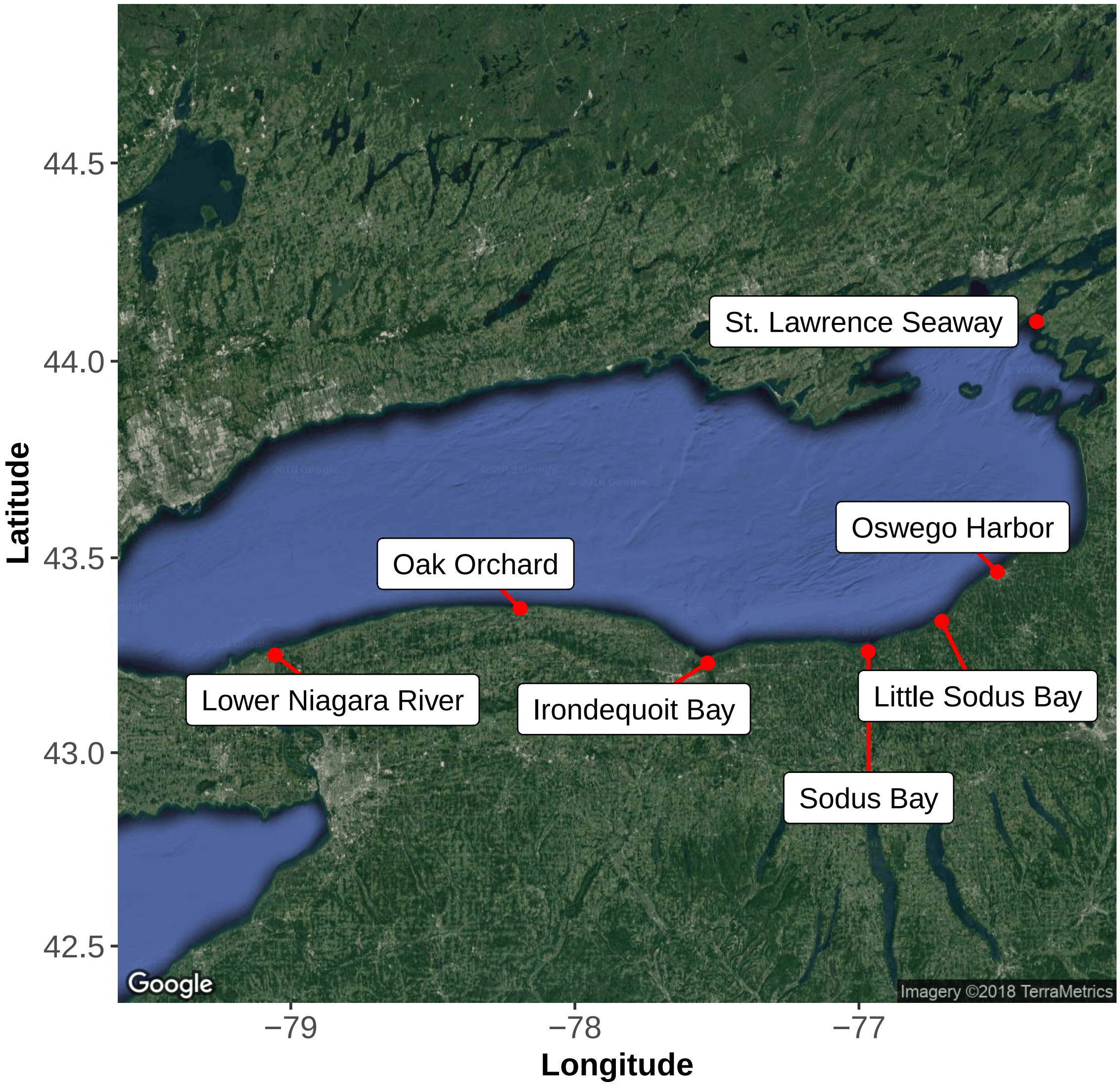

Figure 1: The Lake Ontario Basin showing high risk areas and locations sampled.

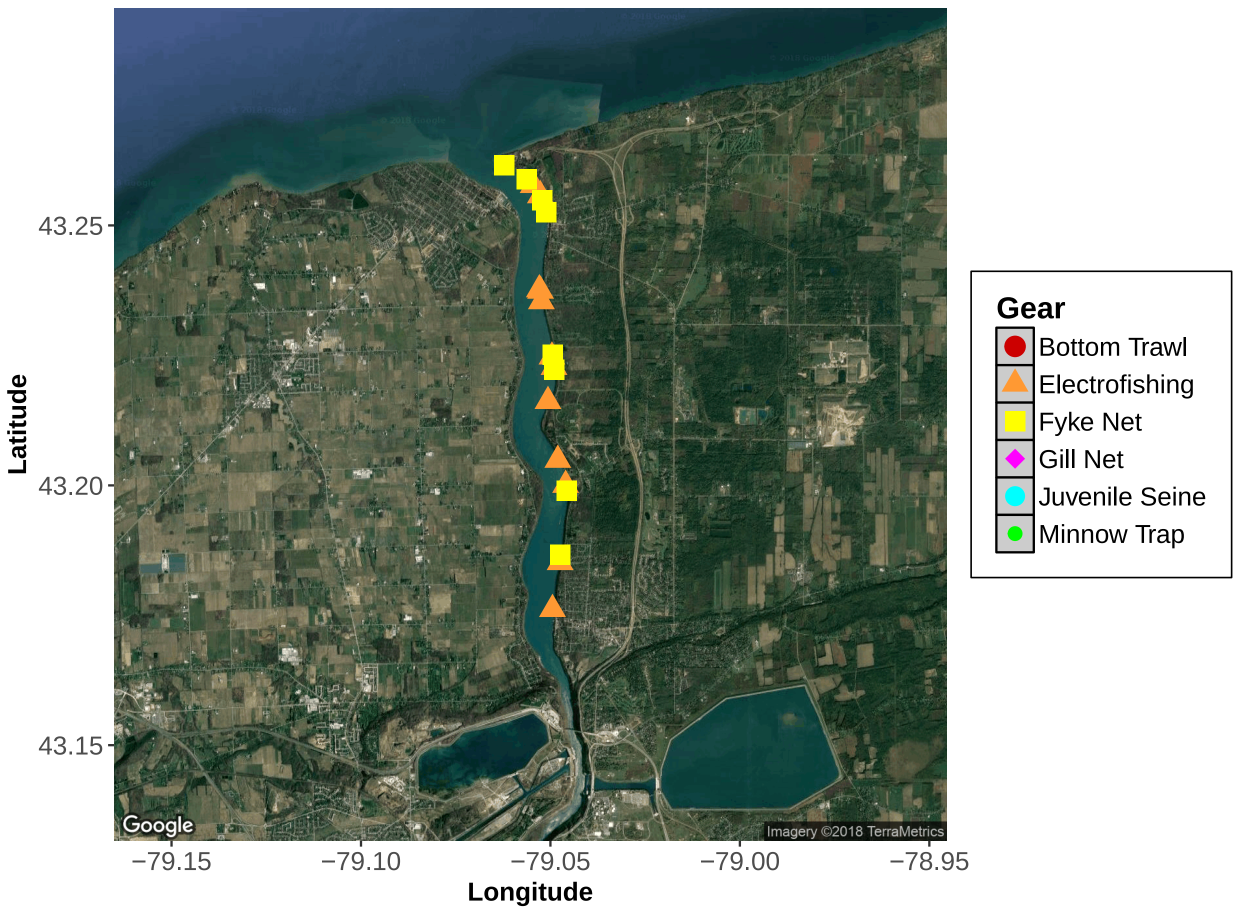

Figure 2: Lower Niagara River showing locations sampled for juvenile and adult fish.

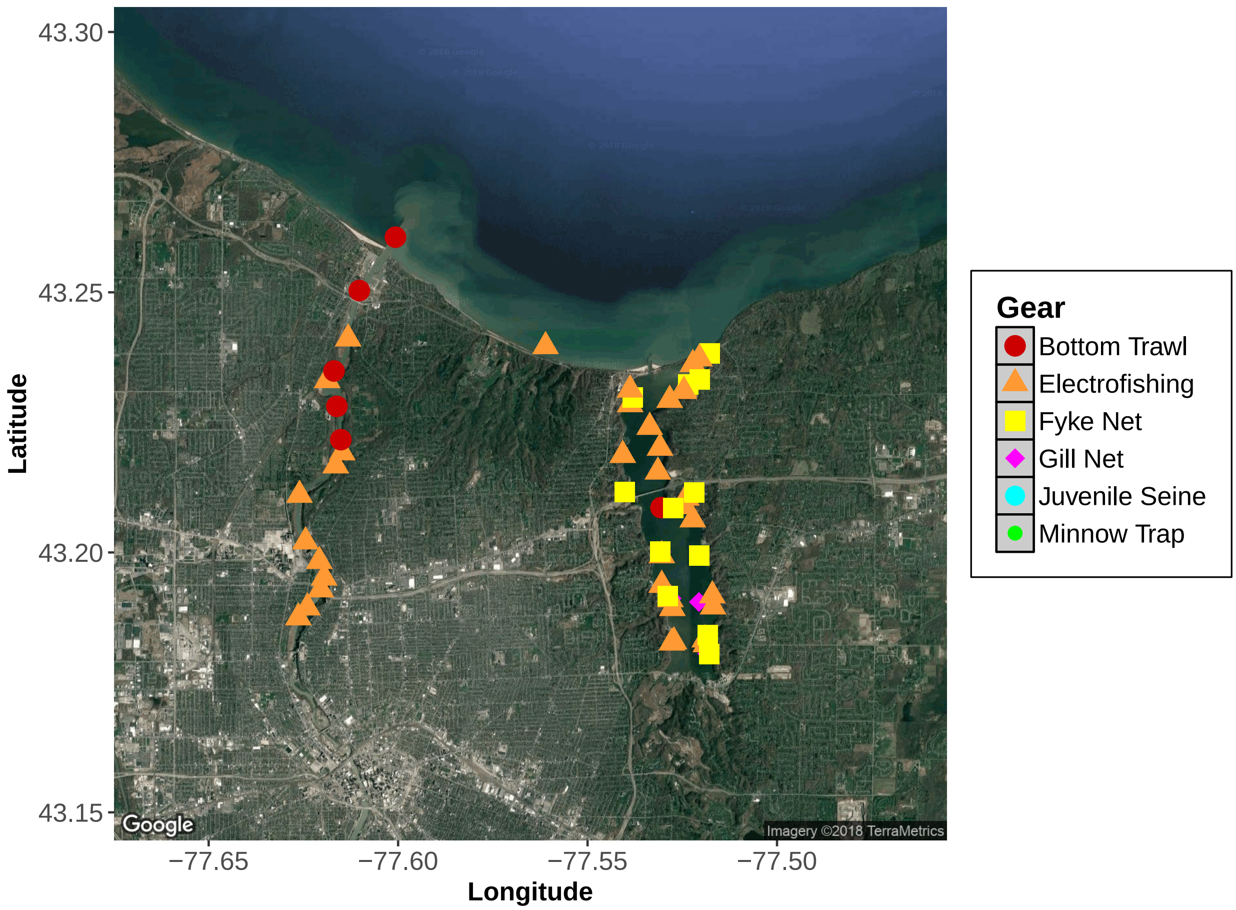

Figure 3: Rochester/Irondequoit Bay showing locations sampled for juvenile and adult fish.

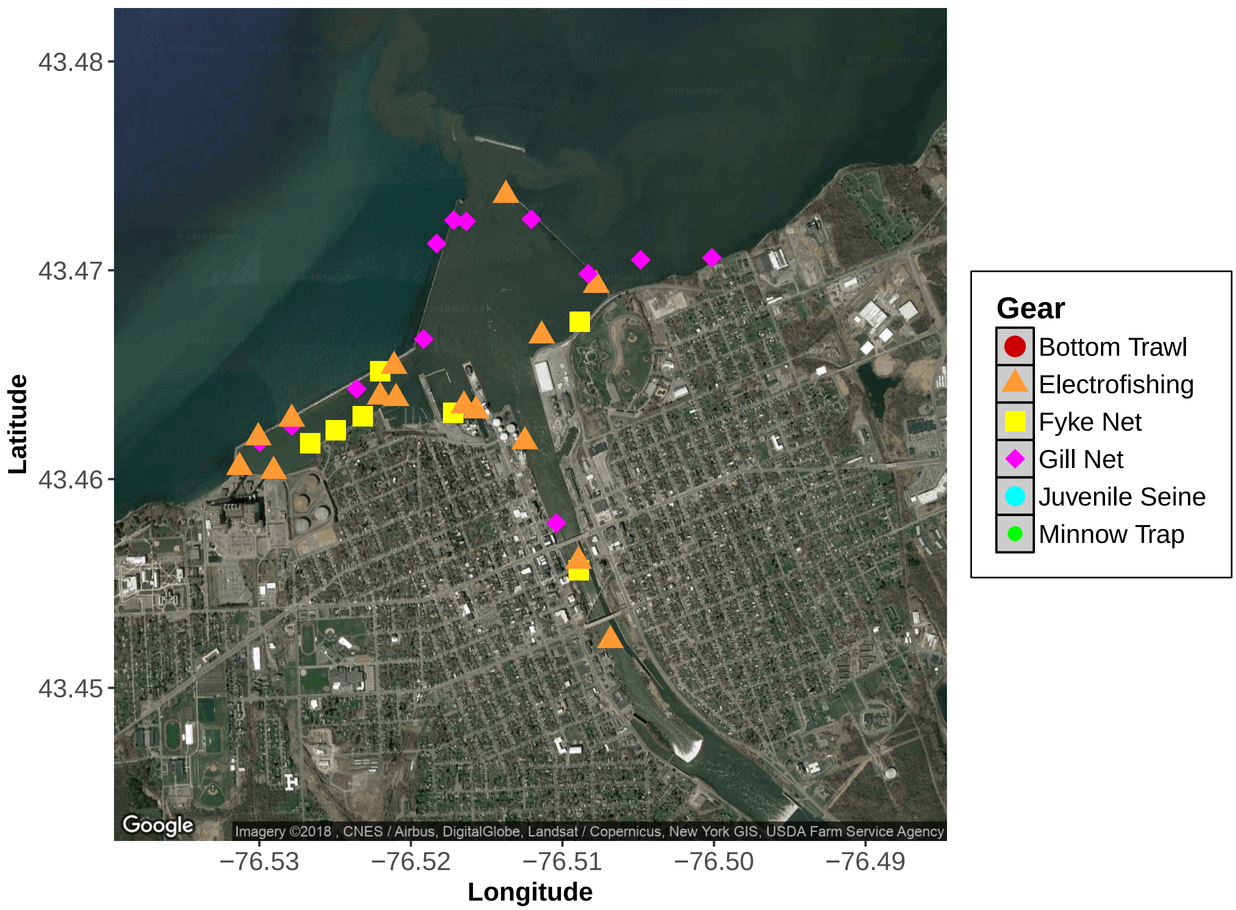

Figure 4: Oswego Harbor showing locations sampled for juvenile and adult fish.

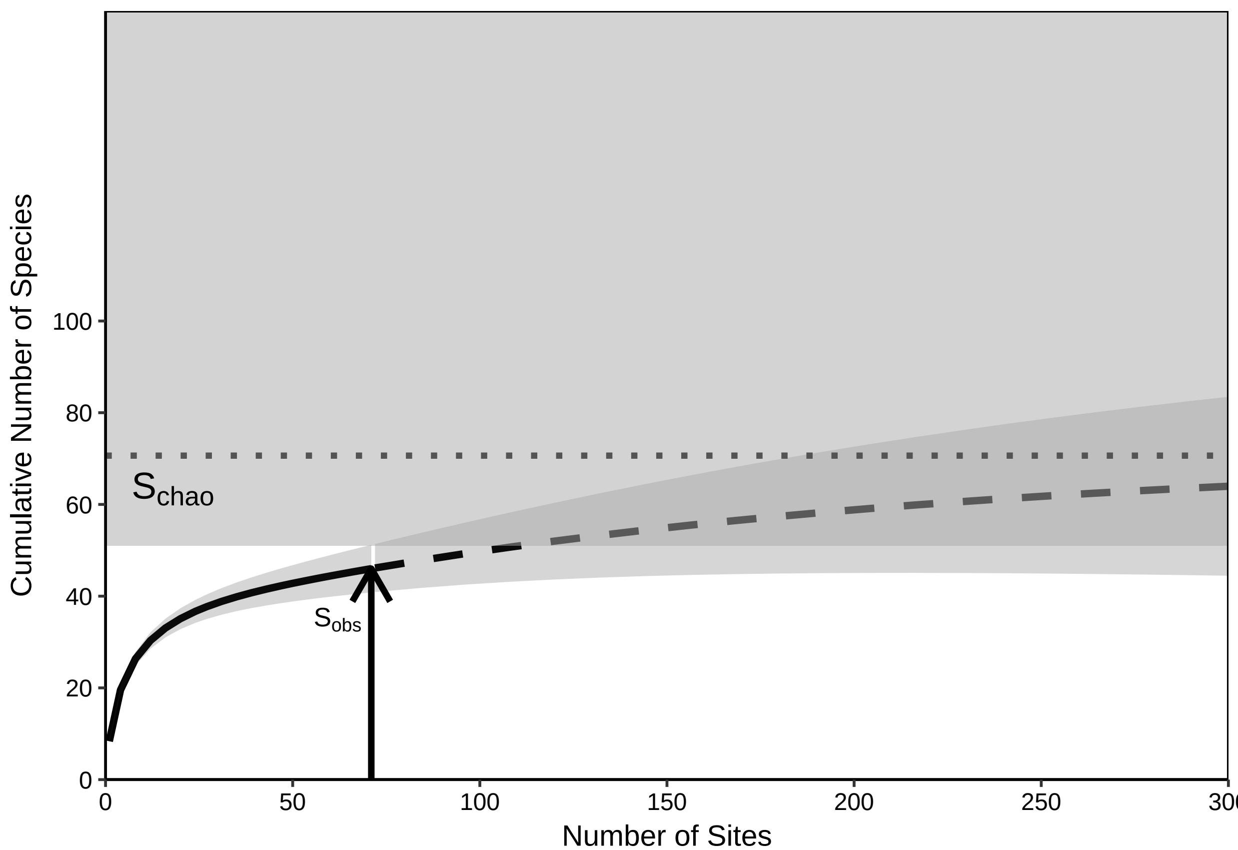

Figure 5: Species accumulation curves for all sampling gears fished for juvenile and adult fish combined in the lower Niagara River, NY, 2013-2017. Schao = total number of species estimated based on the Chao asymptotic richness estimator (horizontal dotted line). Sobs = total number of species caught. Shaded regions represent the 95% confidence intervals.

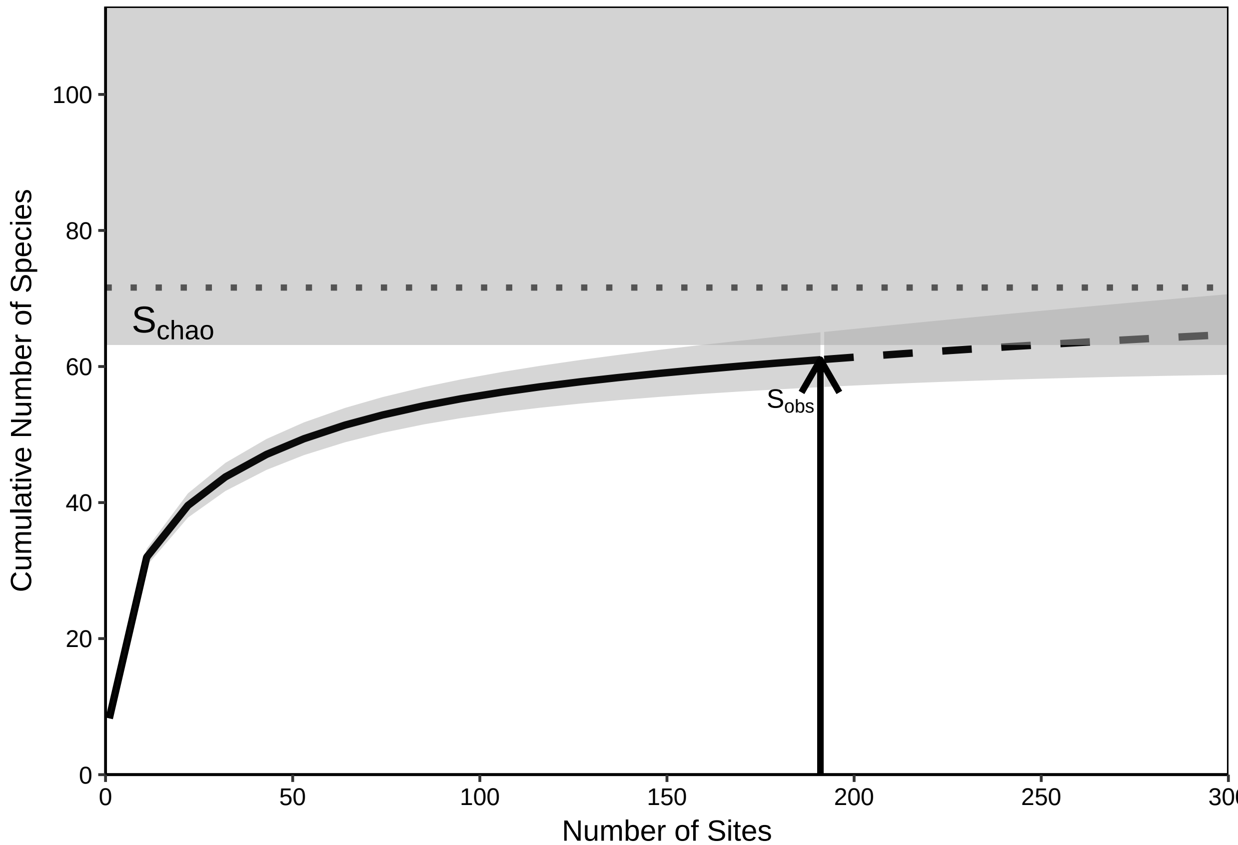

Figure 6: Species accumulation curves for all sampling gears fished for juvenile and adult fish combined in Rochester/Irondequoit, NY, 2014-2017. Schao = total number of species estimated based on the Chao asymptotic richness estimator (horizontal dotted line). Sobs = total number of species caught. Shaded regions represent the 95% confidence intervals.

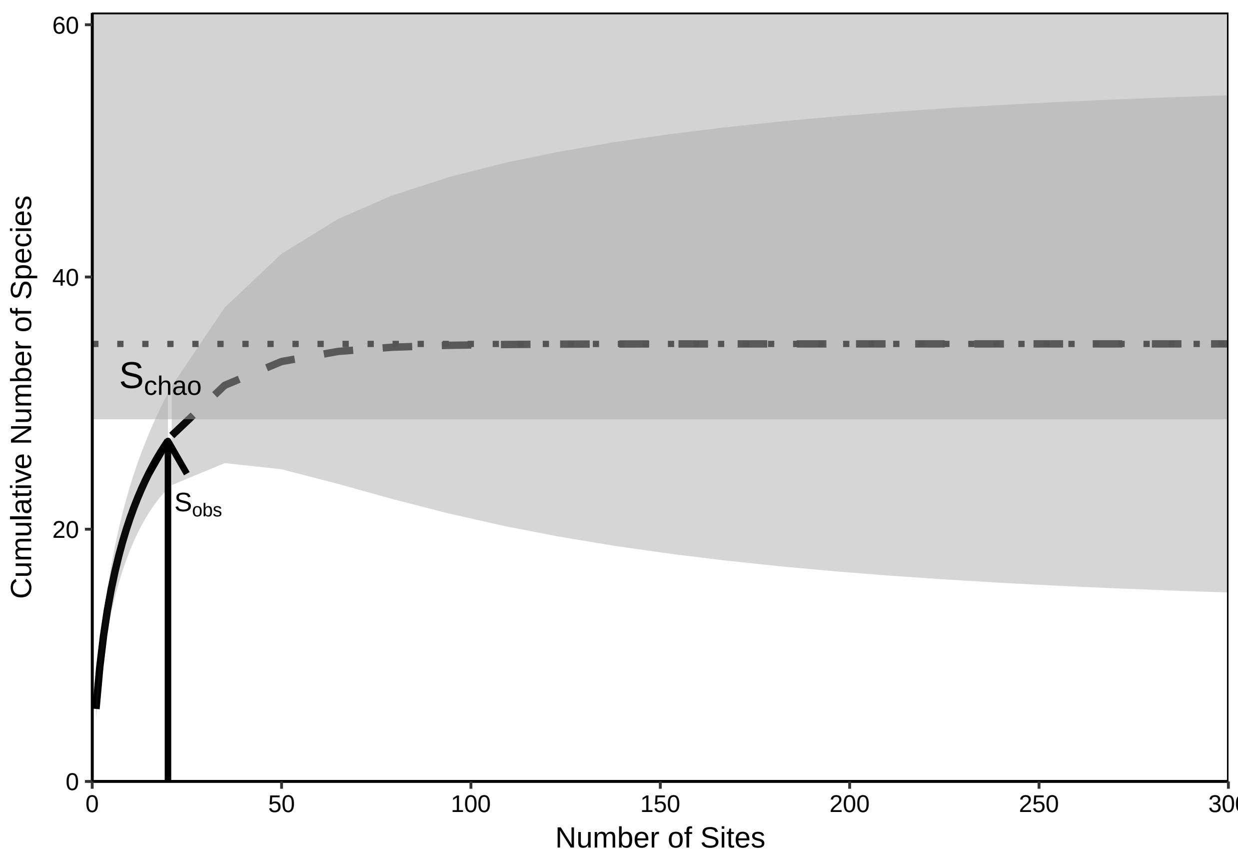

Figure 7: Species accumulation curves for all sampling gears fished for juvenile and adult fish combined in Oswego Harbor, NY, 2016-2017. Schao = total number of species estimated based on the Chao asymptotic richness estimator (horizontal dotted line). Sobs = total number of species caught. Shaded regions represent the 95% confidence intervals.

Table 1: Catch summary for species captured during juvenile and adult fish sampling* in the lower Niagara River, 2017.

			Electrofishing		Paired Fyke Net		
Scientific Name	Common Name	Status	Collected	CPUE (fish/hr)	Collected	CPUE (fish/set)	Total
Alosa pseudoharengus	Alewife	Non-native	7	3.5	1	0.12	8
Anguilla rostrata	American Eel	Native	1	0.5	3	0.38	4
Fundulus diaphanus	Banded Killifish	Native	0	0.0	1	0.12	1
Lepomis macrochirus	Bluegill	Native	1	0.5	615	76.88	616
Pimephales notatus	Bluntnose Minnow	Native	0	0.0	35	4.38	35
Amia calva	Bowfin	Native	1	0.5	0	0.00	1
Labidesthes sicculus	Brook Silverside	Native	2	1.0	0	0.00	2
Ameiurus nebulosus	Brown Bullhead	Native	15	7.5	7	0.88	22
Cyprinus carpio	Common Carp	Non-native	5	2.5	0	0.00	5
Notropis atherinoides	Emerald Shiner	Native	0	0.0	1	0.12	1
Dorosoma cepedianum	Gizzard Shad	Native	3	1.5	0	0.00	3
Moxostoma erythrurum	Golden Redhorse	Native	50	25.0	2	0.25	52
Notemigonus crysoleucas	Golden Shiner	Native	1	0.5	0	0.00	1
Carassius auratus	Goldfish	Non-native	1	0.5	1	0.12	2
Moxostoma valenciennesi	Greater Redhorse	Native	15	7.5	2	0.25	17
Lepomis cyanellus	Green Sunfish	Non-native	1	0.5	5	0.62	6
Nocomis biguttatus	Hornyhead Chub	Native	3	1.5	0	0.00	3
Micropterus salmoides	Largemouth Bass	Native	6	3.0	1	0.12	7
Percina caprodes	Logperch	Native	1	0.5	0	0.00	1
Notropis volucellus	Mimic Shiner	Native	0	0.0	1	0.12	1
Esox masquinongy	Muskellunge	Native	1	0.5	0	0.00	1
Esox lucius	Northern Pike	Native	0	0.0	1	0.12	1
Lepomis gibbosus	Pumpkinseed	Native	1	0.5	29	3.62	30
Ambloplites rupestris	Rock Bass	Native	10	5.0	116	14.50	126
Neogobius melanostoma	Round Goby	Non-native	12	6.0	23	2.88	35
Moxostoma macrolepidotum	Shorthead Redhorse	Native	8	4.0	0	0.00	8
Moxostoma arisurun	Silver Redhorse	Native	1	0.5	0	0.00	1

Table 1: Catch summary for species captured during juvenile and adult fish sampling* in the lower Niagara River, 2017. *(continued)*

			Electrofishing		Paired Fyke Net		
Scientific Name	Common Name	Status	Collected	CPUE (fish/hr)	Collected	CPUE (fish/set)	Total
Micropterus dolomieui	Smallmouth Bass	Native	61	30.5	10	1.25	71
Cyprinella spiloptera	Spotfin Shiner	Native	0	0.0	2	0.25	2
Notropis hudsonius	Spottail Shiner	Native	4	2.0	14	1.75	18
Sander vitreum	Walleye	Native	3	1.5	0	0.00	3
Morone americana	White Perch	Non-native	8	4.0	78	9.75	86
Catostomus commersonii	White Sucker	Native	46	23.0	10	1.25	56
Perca flavescens	Yellow Perch	Native	128	64.0	131	16.38	259

* Sampling effort for electrofishing was 2 hours, and paired fyke nets was 8 overnight sets.

Table 2: Catch summary for species captured during juvenile and adult fish sampling* in Rochester/Irondequoit Bay, NY.

			Electrofishing		Paired Fyke Net		Gill Net		Bottom Trawl		
Scientific Name	Common Name	Status	Collected	CPUE (fish/hr)	Collected	CPUE (fish/set)	Collected	CPUE (fish/set)	Collected	CPUE (fish/minute)	Total
Alosa pseudoharengus	Alewife	Non-native	3	0.57	0	0.00	22	5.50	15	0.19	40
Anguilla rostrata	American Eel	Native	1	0.19	0	0.00	0	0.00	0	0.00	1
Fundulus diaphanus	Banded Killifish	Native	1	0.19	1	0.08	0	0.00	0	0.00	2
Pomoxis nigromaculatus	Black Crappie	Native	0	0.00	1	0.08	0	0.00	0	0.00	1
Lepomis macrochirus	Bluegill	Native	174	32.83	9117	759.75	0	0.00	0	0.00	9291
Pimephales notatus	Bluntnose Minnow	Native	40	7.55	8	0.67	0	0.00	0	0.00	48
Amia calva	Bowfin	Native	16	3.02	10	0.83	0	0.00	0	0.00	26
Labidesthes sicculus	Brook Silverside	Native	25	4.72	0	0.00	0	0.00	0	0.00	25
Ameiurus nebulosus	Brown Bullhead	Native	30	5.66	12	1.00	0	0.00	13	0.16	55
Salmo trutta	Brown Trout	Non-native	2	0.38	0	0.00	0	0.00	0	0.00	2
Ictalurus punctatus	Channel Catfish	Native	2	0.38	0	0.00	0	0.00	12	0.15	14
Oncorhynchus tshawytscha	Chinook Salmon	Non-native	4	0.75	0	0.00	0	0.00	0	0.00	4
Cyprinus carpio	Common Carp	Non-native	8	1.51	3	0.25	0	0.00	2	0.02	13
Notropis atherinoides	Emerald Shiner	Native	7	1.32	0	0.00	0	0.00	0	0.00	7
Aplodinotus grunniens	Freshwater Drum	Native	1	0.19	0	0.00	0	0.00	16	0.20	17
Dorosoma cepedianum	Gizzard Shad	Native	209	39.43	3	0.25	0	0.00	3	0.04	215
Moxostoma erythrurum	Golden Redhorse	Native	45	8.49	0	0.00	0	0.00	0	0.00	45
Notemigonus crysoleucas	Golden Shiner	Native	59	11.13	4	0.33	0	0.00	0	0.00	63
Carassius auratus	Goldfish	Non-native	1	0.19	0	0.00	0	0.00	0	0.00	1
Moxostoma valenciennesi	Greater Redhorse	Native	4	0.75	0	0.00	0	0.00	0	0.00	4
Lepomis cyanellus	Green Sunfish	Non-native	5	0.94	1	0.08	0	0.00	0	0.00	6
Acipenser fulvescens	Lake Sturgeon	Native	0	0.00	0	0.00	0	0.00	2	0.02	2
Micropterus salmoides	Largemouth Bass	Native	177	33.40	30	2.50	0	0.00	0	0.00	207
Percina caprodes	Logperch	Native	1	0.19	0	0.00	0	0.00	0	0.00	1
Notropis volucellus	Mimic Shiner	Native	4	0.75	1	0.08	0	0.00	0	0.00	5
Esox lucius	Northern Pike	Native	8	1.51	0	0.00	0	0.00	0	0.00	8
Lepomis gibbosus	Pumpkinseed	Native	34	6.42	44	3.67	0	0.00	0	0.00	78
Osmerus mordax	Rainbow Smelt	Non-native	0	0.00	0	0.00	0	0.00	3	0.04	3
Oncorhynchus mykiss	Rainbow Trout	Non-native	2	0.38	0	0.00	0	0.00	0	0.00	2
Ambloplites rupestris	Rock Bass	Native	17	3.21	52	4.33	0	0.00	6	0.08	75
Neogobius melanostoma	Round Goby	Non-native	11	2.08	126	10.50	0	0.00	9	0.11	146

Table 2: Catch summary for species captured during juvenile and adult fish sampling* in Rochester/Irondequoit Bay, NY. *(continued)*

			Electrofishing		Paired Fyke Net		Gill Net		Bottom Trawl		
Scientific Name	Common Name	Status	Collected	CPUE (fish/hr)	Collected	CPUE (fish/set)	Collected	CPUE (fish/set)	Collected	CPUE (fish/minute)	Total
Scardinius erythrophthalmus	Rudd	Non-native	0	0.00	4	0.33	0	0.00	0	0.00	4
Cyprinella analostana	Satinfin Shiner	Native	1	0.19	0	0.00	0	0.00	0	0.00	1
Moxostoma macrolepidotum	Shorthead Redhorse	Native	4	0.75	0	0.00	0	0.00	0	0.00	4
Moxostoma arisurun	Silver Redhorse	Native	5	0.94	0	0.00	0	0.00	5	0.06	10
Micropterus dolomieui	Smallmouth Bass	Native	29	5.47	8	0.67	0	0.00	0	0.00	37
Cyprinella spiloptera	Spotfin Shiner	Native	21	3.96	138	11.50	2	0.50	7	0.09	168
Notropis hudsonius	Spottail Shiner	Native	19	3.58	2	0.17	0	0.00	0	0.00	21
Noturus gyrinus	Tadpole Madtom	Native	0	0.00	0	0.00	0	0.00	1	0.01	1
Etheostoma olmstedi	Tessellated Darter	Native	2	0.38	0	0.00	0	0.00	0	0.00	2
Percopsis omiscomaycus	Trout-Perch	Native	0	0.00	0	0.00	0	0.00	63	0.79	63
Sander vitreum	Walleye	Native	10	1.89	0	0.00	1	0.25	2	0.02	13
Morone chrysops	White Bass	Native	2	0.38	0	0.00	1	0.25	0	0.00	3
Morone americana	White Perch	Non-native	12	2.26	16	1.33	7	1.75	2	0.02	37
Catostomus commersonii	White Sucker	Native	59	11.13	12	1.00	0	0.00	4	0.05	75
Ameiurus natalis	Yellow Bullhead	Native	0	0.00	1	0.08	0	0.00	0	0.00	1
Perca flavescens	Yellow Perch	Native	313	59.06	161	13.42	51	12.75	10	0.12	535

* Sampling effort for electrofishing was 5.3 hours, paired fyke nets was 12 overnight sets, gill netting was 4 sets.

Table 3: Catch summary for species captured during juvenile and adult fish sampling* in Oswego Harbor, NY.

			Electrofishing		Paired Fyke Net		Gill Net		
Scientific Name	Common Name	Status	Collected	CPUE (fish/hr)	Collected	CPUE (fish/set)	Collected	CPUE (fish/set)	Total
Alosa pseudoharengus	Alewife	Non-native	0	0.00	0	0.00	20	1.67	20
Anguilla rostrata	American Eel	Native	2	0.74	1	0.08	0	0.00	3
Fundulus diaphanus	Banded Killifish	Native	1	0.37	1	0.08	0	0.00	2
Lepomis macrochirus	Bluegill	Native	48	17.78	687	57.25	0	0.00	735
Pimephales notatus	Bluntnose Minnow	Native	7	2.59	92	7.67	0	0.00	99
Amia calva	Bowfin	Native	15	5.56	7	0.58	0	0.00	22
Labidesthes sicculus	Brook Silverside	Native	3	1.11	0	0.00	0	0.00	3
Ameiurus nebulosus	Brown Bullhead	Native	0	0.00	21	1.75	0	0.00	21
Ictalurus punctatus	Channel Catfish	Native	0	0.00	3	0.25	0	0.00	3
Cyprinus carpio	Common Carp	Non-native	6	2.22	2	0.17	0	0.00	8
Notropis atherinoides	Emerald Shiner	Native	0	0.00	0	0.00	8	0.67	8
Aplodinotus grunniens	Freshwater Drum	Native	5	1.85	0	0.00	0	0.00	5
Dorosoma cepedianum	Gizzard Shad	Native	607	224.81	13	1.08	9	0.75	629
Moxostoma erythrurum	Golden Redhorse	Native	10	3.70	0	0.00	0	0.00	10
Notemigonus crysoleucas	Golden Shiner	Native	2	0.74	7	0.58	8	0.67	17
Carassius auratus	Goldfish	Non-native	0	0.00	1	0.08	0	0.00	1
Moxostoma valenciennesi	Greater Redhorse	Native	2	0.74	0	0.00	0	0.00	2
Lepomis cyanellus	Green Sunfish	Non-native	0	0.00	3	0.25	0	0.00	3
Micropterus salmoides	Largemouth Bass	Native	67	24.81	13	1.08	4	0.33	84
Percina caprodes	Logperch	Native	0	0.00	1	0.08	0	0.00	1
Lepisosteus osseus	Longnose Gar	Native	0	0.00	1	0.08	0	0.00	1
Lepomis gibbosus	Pumpkinseed	Native	133	49.26	130	10.83	0	0.00	263
Ambloplites rupestris	Rock Bass	Native	48	17.78	77	6.42	0	0.00	125
Neogobius melanostoma	Round Goby	Non-native	2	0.74	60	5.00	14	1.17	76
Scardinius erythrophthalmus	Rudd	Non-native	0	0.00	1	0.08	0	0.00	1
Micropterus dolomieui	Smallmouth Bass	Native	45	16.67	13	1.08	1	0.08	59
Notropis hudsonius	Spottail Shiner	Native	6	2.22	0	0.00	18	1.50	24

Table 3: Catch summary for species captured during juvenile and adult fish sampling* in Oswego Harbor, NY. *(continued)*

			Electrofishing		Paired Fyke Net		Gill Net		
Scientific Name	Common Name	Status	Collected	CPUE (fish/hr)	Collected	CPUE (fish/set)	Collected	CPUE (fish/set)	Total
Sander vitreum	Walleye	Native	12	4.44	0	0.00	1	0.08	13
Morone americana	White Perch	Non-native	0	0.00	10	0.83	29	2.42	39
Catostomus commersonii	White Sucker	Native	1	0.37	0	0.00	0	0.00	1
Perca flavescens	Yellow Perch	Native	44	16.30	143	11.92	130	10.83	317

* Sampling effort for electrofishing was 2.7 hours, paired fyke nets was 12 overnight sets, and gill netting was 12 sets.