U.S. Fish and Wildlife Service

LAKE HURON

IMPLEMENTATION PLAN FOR THE EARLY DETECTION OF NON-NATIVE FISHES

MARCH 2016

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Introduction

Aquatic invasive species pose a serious threat to Lake Huron with at least 70 non-native aquatic species already present (NOAA 2014). Ecological degradation in Lake Huron has been extensive from invasive species such as Sea Lamprey *Petromyzon marinus*, Zebra and Quagga Mussels *Dreissena polymorpha* and *Dreissena rostriformis bugensis*, and Round Gobies *Neogobius melanostomus*. The Sea Lamprey contributed to depletion or localized extirpations of Lake Trout populations in Lake Huron (Lake Huron Binational Partnership 2004). Zebra and Quagga Mussels have caused dramatic changes to the Lake Huron ecosystem, shifting energy from pelagic to benthic sources and leading to reductions in fish production and growth rates, among other impacts (Lake Huron Binational Partnership 2004).

Resource agencies and managers around the Great Lakes have identified the need to monitor existing aquatic invasive species as well as detect the arrival of new species (Great Lakes Water Quality Agreement 2012; Great Lakes Restoration Initiative 2014; USEPA 2008). The Lake Huron Binational Partnership Action Plan (Lake Huron Binational Partnership 2004) outlined objectives to 1) prevent the introduction of any non-indigenous aquatic species that are not currently established in Lake Huron, 2) prevent or delay the spread of non-indigenous nuisance species, where feasible, and 3) eliminate or reduce populations of non-indigenous nuisance species, where feasible. Invasive species prevention plans recognize that preventative measures are the best actions for deterring the establishment of new invasive species. However, subsequent actions should include monitoring for new species arrivals so that the spread of a new species may be controlled when their abundance is low and spatial distribution restricted (Myers et al. 2000; USEPA 2008).

This Lake Huron specific implementation plan elaborates on the strategic framework outlined in the proposed *Strategic Framework for the Early Detection of Non-native Fishes and Select Benthic Macroinvertebrates in the Great Lakes* (USFWS 2014) by defining how the U.S. Fish and Wildlife Service (USFWS) will carry out non-native species early detection in Lake Huron and its connecting channels (Figure 1).

The USFWS, Alpena Fish and Wildlife Conservation Office (FWCO) identified the risk associated with specific vectors at locations across the station's area of responsibility on Lake Huron and western Lake Erie. Locations were prioritized based on vector risk such that locations with the highest risk of introduction were considered for sampling to maximize the likelihood of detecting a new non-native species, should it arrive.

Based on the risk characterization across all areas of responsibility for the Alpena FWCO and required time/staff to implement early detection efforts, one high risk location in the Lake Huron basin will be sampled in 2016 (Figure 1).

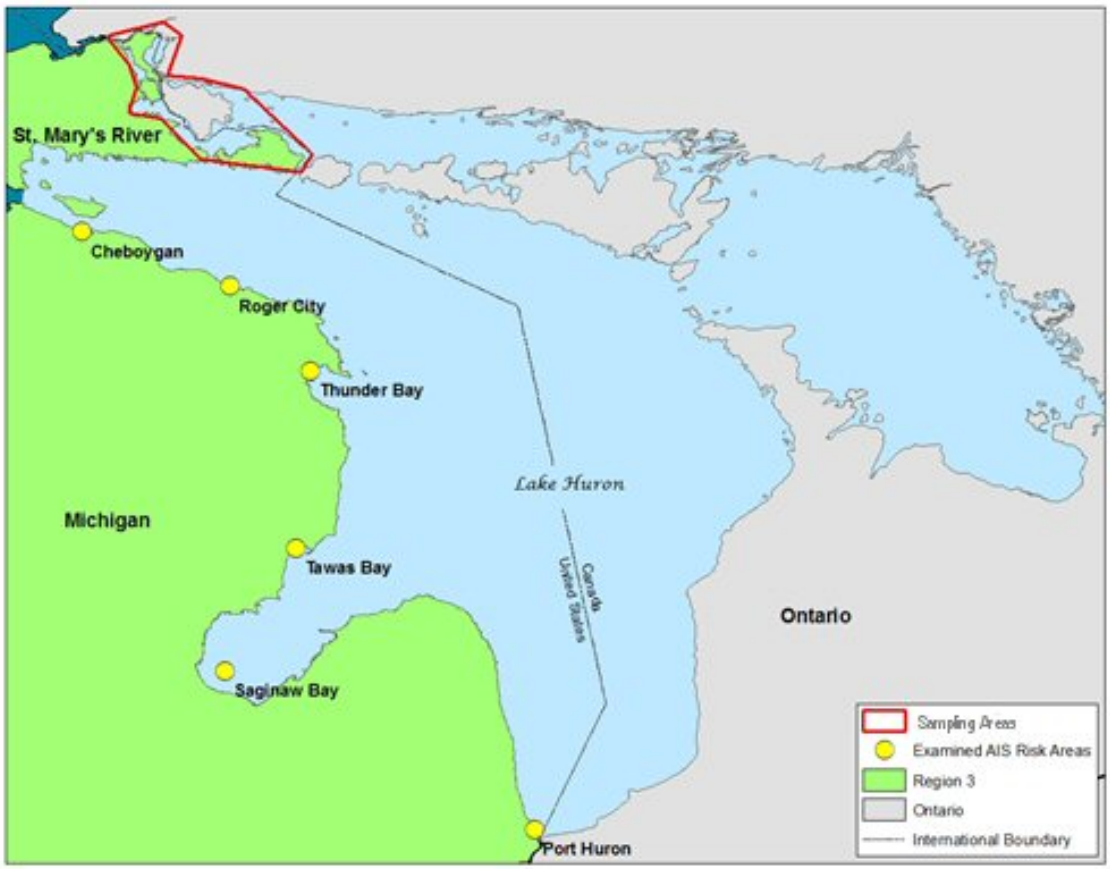

Figure 1. The Lake Huron Implementation Plan addresses Lake Huron and its connecting channels.

Risk Characterization

The Alpena FWCO calculated risk of introduction by site for new non-native species using a master watch list of priority non-native fishes, amphipods, and bivalves that may invade and cause harm, and an analysis of pathways or vectors for introductions. The combination of these two elements helped identify locations with the highest risk for introduction of non-native species for this implementation plan.

Species of Greatest Concern/Risk

Several risk assessments have been conducted to predict likelihood of introduction of non-native organisms to the Great Lakes. Species highlighted as being of particular concern for this Lake Huron implementation plan (Table 1) are based on assessments conducted by the Great Lakes Mississippi River Interbasin Study (GLMRIS 2011), USEPA (2008), Grigorovich et al. (2003), Kolar and Lodge (2002), and the current Great Lakes Aquatic Nonindigenous Species Information System watchlist (NOAA 2016).

Table 1. Non-native species of particular focus for USFWS early detection monitoring activities in the Lake Erie and Lake Huron watersheds for 2016. Refer to key below table for code definitions. The "*" denotes presence in the Great Lakes system; the "+" denotes presence in the Mississippi River system; and the "!" denotes it has been found in the Lake Erie or Lake Huron systems.

Type	Common name	Scientific name	Vector(s)	Donor region	Reproduction & larval temp. (C)	Habitat	Potential effective gear
A	Amphipod	*Dikerogammarus haemobaphes*	M	PC	10 - 25.6[1]		A, B, C, D
A	Amphipod	*Echinogammarus warpechowski*	M	PC			A, B, C, D
A	Amphipod	*Pontogammarus aralensis*	M	PC			A, B, C, D
A	Amphipod	*Pontogammarus robustoides*	M	PC	7.5 - 24.2[4]	S, V, G, H	A, B, C, D
A	Caspian Mud Shrimp	*Corophium curvispinum*	M	PC	12 - 26.5[8]	S, V, H, Z	A, B, C, D
A	Killer Shrimp	*Dikerogammarus villosus*	M	PC	13 - 30[7]	G, H	A, B, C, D
B	Basket (European) Shell	*Corbula gibba*	M	E	Unknown[13]	S, Z	C, D, P
B	Golden Mussel	*Limnoperna fortunei*	M	A	16 - 28[12]	H, LO, LE	C, D, P
B	Mussel	*Hypanis (Monodacna) colorata*	M	PC			C, D, P
F	Bighead Carp +!	*Hypophthalmichthys nobilis*	C, F, I, O	A	18 - 30[5]		E, G, L, P
F	Bitterling	*Rhodeus sericeus*	O[28]	E, A[28]	18-21[28]	LE,S	F, E, G, L, P
F	Black Carp +	*Mylopharyngodon piceus*	C, F	A	26- 30[6]		E, G, L, P
F	Black Sea Silverside	*Atherina boyeri*	F, O	PC	10- 30[25,26]		E, F, L, P, S
F	Bleak	*Alburnus alburnus*	F, O	PC	>15[14]	S, G	L, P
F	Blotched Snakehead	*Channa maculata*	F, A, O[30]	A[29]		LE, LO, S, V[29]	E, F, G, L, P, S
F	Blue Catfish +	*Ictalurus furcatus*	F, I	NA	21 - 24[23]		L, P
F	Blueback Herring *	*Alosa aestivalis*	C, F, M	NA	14 - 273		E, G, L, P
F	Bullhead	*Cottus gobio*	F, O	E	7.5 - 13.5[15]	G	L, P
F	Bullseye Snakehead	*Channa marulius*	I, F, O[31]	A[31]		G, LE, LO, S, V[31]	E, F, G, L, P, S
F	Caucasian Goby	*Knipowitschia caucasica*	M	PC		V, G, Z	L, P
F	Eastern Mosquitofish*	*Gambusia holbrooki*	A, F[44]	NA[44]	>16[46]	LE, V[44]	E, F, L, M, P, S
F	Eurasian Dace	*Leuciscus leuciscus*	F, O	PC	5 - 10[20]	G, LO	L, P
F	Eurasian Minnow	*Phoxinus phoxinus*	F, O	PC	>11.4[24]	G, LO	E, L, P, S
F	European Perch	*Perca fluviatilis*	F, O	PC	7 - 20[27]		E, G, L, P, S

Type	Common name	Scientific name	Vector(s)	Donor region	Reproduction & larval temp. (C)	Habitat	Potential effective gear
F	European Whitefish (Vendace)	*Coregonus albula*	F	E	2-7[18]	S, G	G, L, P
F	Giant Snakehead	*Channa micropeltes*	O[32]	A[32]		LE, LO, V[33]	E, F, G, L, P, S
F	Grass Carp *!	*Ctenopharyngodon idella*	F, I, O	A	15 - 30[2]	V	E, G, L, P, S
F	Ide	*Leuciscus idus*	A, F[34]	E[34]	8-23[35]	LE, LO, G, V[34]	E, F, G, L, P,
F	Monkey Goby	*Neogobius fluviatilis*	M	A, E	>13[22]	V, G, Z	E, T, L, P, S
F	Northern Snakehead +	*Channa argus*	O[37]	A, PC[37]	25-31[37]	LO, S, V[37]	E, F, G, L, P, S
F	Oriental Weatherfish *	*Misgurnus anguillicaudatus*	O[36]	A[36]		LE, S[36]	F, L, M, P, S, T
F	Roach	*Rutilus rutilus*	F	PC	8 - 14[14]	V, LE	E, F, L, P
F	Rudd *!	*Scardinius erythrophthalmus*	F[38]	A, E, PC[38]	>18[38]	LE, LO, V[38]	E, G, L, P
F	Ruffe *!	*Gymnocephalus cernua*	C, F, M	PC	10 - 20[11]		L, P
F	Sand Goby	*Pomatoschistus minutus*	F, O	PC	8 - 15[17]	S, Z	E, L, P, S
F	Silver Carp +	*Hypophthalmichthys molitrix*	C, F, I, O	A	18 - 26[5]	LE	E, G, L, P
F	Stone Moroko	*Pseudorasbora parva*	F[39]	A[39]	20[40]	LE, V[39]	E, F, L, M, P, S
F	Sunbleak	*Leucaspius delineatus*	C	PC	16 - 20.4[16]	V, LE	L, P
F	Tench	*Tinca tinca*	C, F	PC	20 - 31.6[9]	S, V, LE	E, L, P
F	Toothed Carp	*Aphanius fasciatus*	C	PC	21 - 33[10]	LE	L, P
F	Tyulka/Caspian Kilka	*Clupeonella cultriventris/caspia*	M	PC	10 - 25[19]		E, G, L, P
F	Walking Catfish	*Clarias batrachus*	F, O, I[41]	A[41]		LE, LO, S, V[41]	F, G, L, P
F	Wels Catfish	*Silurus glanis*	F, O[42]	E, A[42]	18-22[42]	LE, LO, V, B[42]	G, L, P
F	Western Mosquitofish *!	*Gambusia affinis*	A, F[45]	NA[45]	>16[46]	LE, V[45]	E, F, L, M, P, S
F	Western Tubenose Goby *!	*Proterorhinus semilunaris*	M[43]	PC[43]		H, V[43]	E, T, L, P, S
F	Zander	*Sander lucioperca*	C, F	PC	8 - 15[21]	G, LE	G, L, P

Key for codes listed in Table 1:

Organism Type	Vectors of introduction	Donor Region	Habitat	Effective Gears	
A= amphipod	A= agency activities	A= Asia	H=boulder/hard	A= amphipod trap	G= gillnet
B= bivalve	C= canals/diversions	E= Europe	LE= lentic	B= benthic sled	L= quatrefoil light trap
F= fish	F= fishing/aquaculture	NA= North America	LO= lotic	C= colonization sampler	M= minnow trap
	I= illegal activities	PC= Ponto-Caspian	S= silt/mud/sand	D= dredge (e.g. Ponar/Ekman)	P= plankton net
	M= maritime commerce		V= vegetation	E= electrofishing	S= seine
	O= organisms in trade		Z= dreissenid beds	F= fyke/trap netting	T= bottom trawl
	T= tourism and development				

Table 1 Citation Summary:

[1]Bacela et al. (2009); [2]Cudmore and Mandrak (2004), [3]Fuller et al. (2014), [4]Grabowski (2011), [5]Kolar et al. (2007), [6]USACOE (2014a), [7]USACOE (2014b), [8]Musko (1992), [9]Nordstrom (2014), [10]Lotan and Ben-Tuvia (1996), [11]Froese and Pauly (2014), [12]USACOE (2014c), [13]Brenko (2006), [14]U.K. Environment Agency (2014), [15]Fox (1978), [16]Gozlan et al. (2003), [17]Marine Life Information Network for Britain and Ireland (2014), [18]Vourinen et al. (1981), [19]Freyhof and Kottelat (2008b), [20]Kennedy (1969), [21]Cultured Aquatic Species Information Programme (2012), [22]Kottelat and Freyhof (2007), [23]Graham (1999), [24]Bengtsson (1974), [25]Freyhof and Kottelat (2008a), [26]Kehayias et al. (2004), [27]Sandstrom et al. (1997), [28]USFWS (2015), [29]Nico et al. (2014), [30]USFWS (2003), [31]Fuller et al. (2015), [32]Nico et al. (2013), [33]Froese and Pauly (2015), [34]USFWS (2011a), [35]USGS and NOAA (2015a), [36]GISD (2010a), [37]GISD (2009), [38]USFWS (2011b), [39]USFWS (2014b), [40]Gozlan et al. (2010), [41]GISD (2010b), [42]USGS and NOAA (2015b), [43]USFWS (2011c), [44]Nico and Fuller (2016), [45]Nico et al. (2016), [46]Pyke (2005).

Vector Risk Assessment

Eight vectors were identified and detailed by which non-native species may be introduced to the Great Lakes and include: maritime commerce, agency activities, canals and water diversions, organisms in trade, fishing and aquaculture, water recreation, tourism and development, and illegal activities (Lake Superior Work Group 2010) (Figure 2).

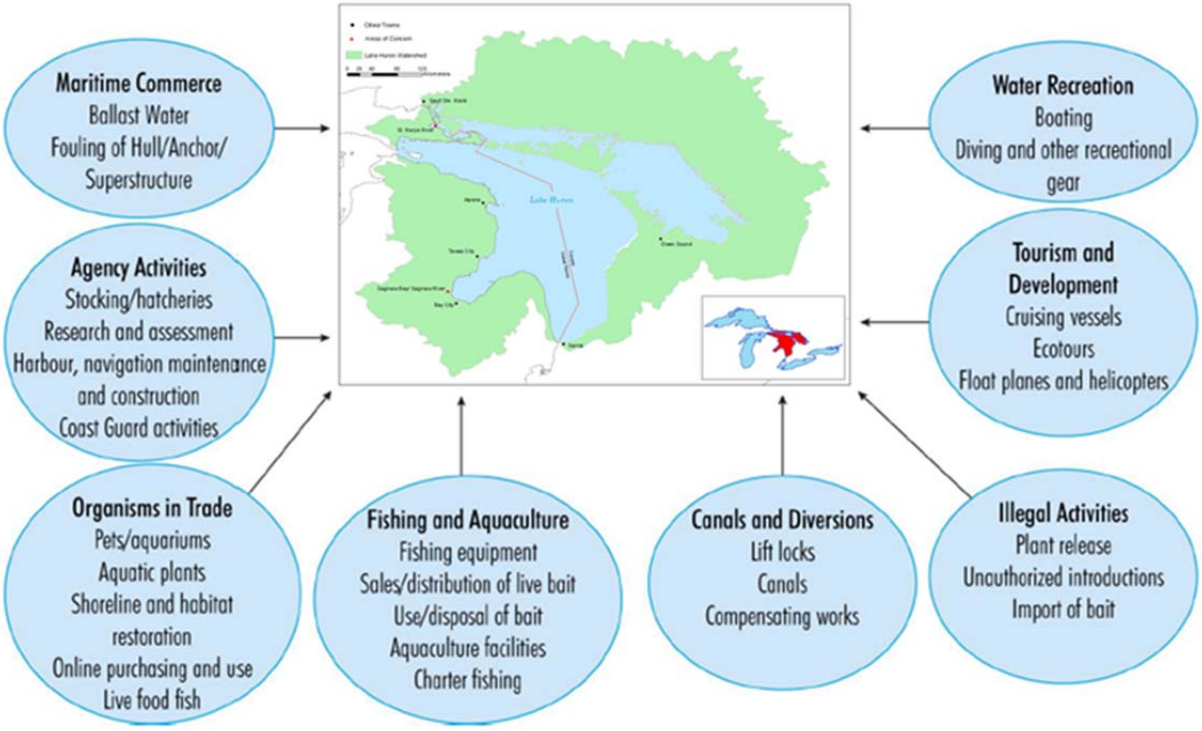

Figure 2. Vector and pathway concept map for Lake Huron (modified from Lake Superior Work Group 2010).

There are many target metrics that could prove useful for assessing risk by location for these vector categories (Table 2). We have assessed metrics for a number of these elements in an effort to gauge risk for this plan.

For past early detection planning, the Alpena FWCOs prioritized these vectors (Figure 2) based on pathways for historical non-native species introductions (Table 3). In 2016, prioritization was changed to now focus on pathways for species at risk for introduction into the Great Lakes (Table 1). The change is relevant because the importance of pathways changes with the economy, population and other factors. For example, the pathway for organisms in trade and the movement of non-native species to new locations through commerce has become a greater concern through time now that Internet trade has made a wide variety of species readily available to almost anywhere.

Table 2. Target measures to assess risk of vectors at potential monitoring sites for non-native aquatic species in the Great Lakes. Uppercase "X" shaded cells indicate target measures analyzed for risk in this implementation plan. Lowercase "x" unshaded cells indicate target measures that would be useful but were not analyzed for risk in this implementation plan. Vector category codes are: Maritime = maritime commerce; Agency = agency activities; Canals = canals and water diversions; Trade = organisms in trade; F&A = fishing and aquaculture; Recreation = water recreation; Tourism = tourism and development; and Illegal = illegal activities.

Target Measure	Maritime	Agency	Canals	Trade	F&A	Recreation	Tourism	Illegal
Angling effort					x			
Aquaculture					x			
Aquariums & pond shops/area				X				
Bait shops/area					X			
Ballast discharge	X							
Boat access sites					X	X		
Boat ramp spaces					X	X		
Charter boat trips					x			
Commerce barges	x							
Commercial fishing					x			
Cruise ship visits							X	
Ecotourism businesses/area							x	
Fish markets/area				x				
Float aircraft visits							x	
Harbor slips					X	X		
Live bait usage					x			
Pet shops/area				X				
Population				X				X
Science sampling visits		x						
Shipping maintenance appropriations		X						
Shipping traffic	x							
Water connections/area			X					
Work barge visits		x						

Table 3. Historical non-native fish, amphipod, and bivalve introductions to Lake Huron (USGS 2016). Vector codes are: M = maritime commerce, A = agency activities, C = canals and water diversions, F = fishing and aquaculture, O = organisms in trade, U = unknown. The USGS NAS database includes a disclaimer that information is not guaranteed to be correct, and some of the data regarding Lake Huron species could not be verified from the listed citations, but this data source was considered the most applicable for the purposes of this implementation plan.

Common Name	**Scientific Name**	**Vector**	**USGS NAS pathway**
Amphipod	*Gammarus tigrinus*	M	shipping ballast water
Freshwater Shrimp	*Gammarus fasciatus*	M	shipping-ballast water
Scud	*Echinogammarus ischnus*	M	shipping ballast water
Asian Clam	*Corbicula fluminea*		unknown
European Fingernail Clam	*Sphaerium corneum*	M	shipping
Greater European Peaclam	*Pisidium amnicum*	M	shipping solid ballast
Quagga Mussel	*Dreissena rostriformis bugensis*	M	shipping, shipping-ballast water
Zebra Mussel	*Dreissena polymorpha*	M	shipping, shipping-ballast water
Alewife	*Alosa pseudoharengus*	C, A	canal, stocked
American Eel	*Anguilla rostrata*	C	canal
American Shad	*Alosa sapidissima*	C	canal
Atlantic Salmon	*Salmo salar*	A	stocked for sport
Black Buffalo	*Ictiobus niger*	C	canal
Brown Trout	*Salmo trutta*	A	stocked for sport
Chinook Salmon	*Oncorhynchus tshawytscha*	A	stocked for sport
Coho Salmon	*Oncorhynchus kisutch*	A	stocked for sport
Common Carp	*Cyprinus carpio*	A	stocked
Cutthroat Trout	*Oncorhynchus clarkii*	A	stocked for sport
European Flounder	*Platichthys flesus*	M	shipping ballast water
Ghost Shiner	*Notropis buchanani*	F+A	bait release
Goldfish	*Carassius auratus*	O, A	aquarium release, stocked
Grass Carp	*Ctenopharyngodon idella*	A	stocked for biocontrol
Green Sunfish	*Lepomis cyanellus*	A	stocked for sport
Longear Sunfish	*Lepomis megalotis*	A	stocked for sport
Pink Salmon	*Oncorhynchus gorbuscha*	A	stocked for sport
Rainbow Smelt	*Osmerus mordax*	A	stocked
Rainbow Trout	*Oncorhynchus mykiss*	A	stocked for sport
Red-bellied Pacu	*Piaractus brachypomus*	O	aquarium release
Red Piranha	*Pygocentrus nattereri*	O	aquarium release
Round Goby	*Neogobius melanostomus*	M	shipping ballast water, dispersed
Ruffe	*Gymnocephalus cernua*	M	shipping ballast water, dispersed
Sea Lamprey	*Petromyzon marinus*	C	canal
Splake	*Salvelinus fontinalis x namaycush*	A	stocked for sport
Sockeye Salmon	*Oncorhynchus nerka*	A	stocked for sport
Striped Bass	*Morone saxatilis*	C	canal
Threespine Stickleback	*Gasterosteus aculeatus*	C, F+A	unknown (canal, bait release)
White Bass x White Perch hybrid	*Morone chrysops x M. americana*	C	canal
White Perch	*Morone americana*	C, M	canal, shipping ballast water
Yellow Bass	*Morone mississippiensis*	C	canal

Therefore, using vector pathways for non-natives with high risk to become introduced to the Great Lakes (Table 1), the eight vector categories were prioritized from highest to lowest risk as follows

(Figure 3): 1) fishing and aquaculture with an anticipated 34% of species introductions, 2) organisms in trade with an anticipated 23% of species introductions, 3) maritime commerce with an anticipated 19% of species introductions, 4) canals and diversions with an anticipated 11% of species introductions, 5) illegal activities with an anticipated 8% of species introductions, and 6) agency activities with an anticipated 5% of species introductions. Water recreation and tourism, and development were not readily identified as vector pathways for high risk species.

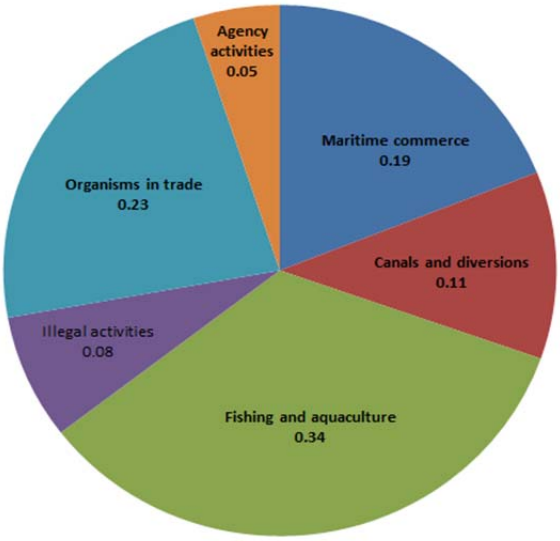

Figure 3. Vector pathways for high risk non-native fish, amphipod, and bivalves (Table 1) that are of concern to become introduced into the Great Lakes. Numbers are proportions by which at risk non-native species may become introduced.

Fishing and Aquaculture

Fishing and aquaculture was identified as the most common vector for introduction of high risk non-native organisms found in Table 1 (Figure 3), anticipated to provide a vector for 34% of the species listed. Two non-native species were historically introduced to Lake Huron as a result of fishing or aquaculture operations (Table 3).

Some issues related to fishing and aquaculture risk for the introduction and spread of non-native species include the potential for recreational and charter anglers and commercial fishermen to move non-natives on their fishing equipment, boats, nets or other fishing gear; and the survival of live bait. Recreational and charter anglers and commercial fishermen have the potential to move non-native species on their fishing gear. Some species can survive for long periods inside boat livewells. Even so, fishing equipment alone has not been identified as a source of former species introductions into Lake Huron.

Many Great Lakes anglers use live bait, and the sale and use of live bait is cause for concern as a vector for the introduction of non-native species. Juvenile Silver and Bighead Carp, for example,

could be confused with other fishes commonly used as bait. Commercial harvesting of baitfish routinely occurs in Lake Huron and at other Great Lakes locations. These fish are distributed across the region, potentially moving live non-native species to new locations for use by angers. Each governmental jurisdiction in the Lake Huron basin addresses the sale and distribution of live bait through its own regulations. Illegal activities regarding the movement or illegal stocking of live bait is a concern for this vector category.

Table 4. Boat harbor slips counted along the Lake Huron shoreline using Google Earth (Google Inc. 2016). Proportion is a fraction of the sum of boat harbor slips, where Lake Erie and Lake Huron locations were assessed cumulatively. Only Lake Huron locations are represented. Risk was assigned based on thirds of the proportion with the top ⅓ represented as high risk, middle ⅓ as medium risk, and bottom ⅓ as low risk, respectively.

Water Area	Number	Proportion	Risk
Saginaw Bay	1,836	0.0521	Low
Cheboygan County, MI	592	0.0168	Low
Northern Lake Huron	344	0.0097	Low
Southern Lake Huron	292	0.0083	Low
Presque Isle County, MI	256	0.0072	Low
St. Marys River	248	0.0070	Low
Thunder Bay	141	0.0040	Low
Alcona County, MI	98	0.0027	Low

Table 5. Boat access sites counted along the Lake Huron shoreline using Google Earth (Google Inc. 2016). Proportion is a fraction of the sum of boat access sites, where Lake Erie and Lake Huron locations were assessed cumulatively. Only Lake Huron locations are represented. Risk was assigned based on thirds of the proportion with the top ⅓ represented as high risk, middle ⅓ as medium risk, and bottom ⅓ as low risk, respectively.

Water Area	Number	Proportion	Risk
Saginaw Bay	40	0.1277	High
St. Marys River	11	0.0351	Low
Cheboygan County, MI	8	0.0255	Low
Northern Lake Huron	8	0.0255	Low
Presque Isle County, MI	5	0.0159	Low
Thunder Bay	4	0.0127	Low
Alcona County, MI	3	0.0095	Low
Southern Lake Huron	3	0.0095	Low

Target measures that were used to assess the risk of fishing and aquaculture at Lake Huron locations included: number of boat harbor slips (Table 4), number of boat accesses (Table 5), number of boat ramp parking spaces (Table 6), and number of bait shops per county bordering Lake Huron (Table 7). Other targeted measures for fishing and aquaculture were difficult to assess in an equal manner for all locations analyzed and therefore were not used to assess risk for this implementation plan.

They included angling effort, aquaculture, charter boat fishing, commercial fishing, and live bait usage.

The number of boat harbor slips (Table 4), boat accesses (Table 5), and boat ramp parking spaces (Table 6) were analyzed by examining the Lake Huron shoreline using a satellite image on Google Earth (Google Inc. 2016) and counting the number of boat harbor slips, boat accesses, and boat ramp parking spaces present. The number of bait shops (Table 7) was counted per county based on a search of the Internet. The proportion provided is the number counted at any given location divided by the sum total for all locations. High risk was assigned to the top ⅓, medium risk was assigned to the middle ⅓, and low risk was assigned to the bottom ⅓.

Table 6. Boat ramp parking spaces counted along the Lake Huron shoreline using Google Earth (Google Inc. 2016). Proportion is a fraction of the sum of boat ramp parking spaces, where Lake Erie and Lake Huron locations were assessed cumulatively. Only Lake Huron locations are represented. Risk was assigned based on thirds of the proportion with the top ⅓ represented as high risk, middle ⅓ as medium risk, and bottom ⅓ as low risk, respectively.

Water Area	Number	Proportion	Risk
Saginaw Bay	1,864	0.2118	High
Cheboygan County, MI	264	0.0300	Low
Thunder Bay	245	0.0278	Low
Southern Lake Huron	232	0.0263	Low
Presque Isle County, MI	188	0.0213	Low
Alcona County, MI	175	0.0198	Low
St. Marys River	159	0.0180	Low
Northern Lake Huron	143	0.0162	Low

Table 7. Number of bait shops per county for counties bordering Lake Huron. Proportion is a fraction of the sum of bait shops, where Lake Erie and Lake Huron locations were assessed cumulatively. Only Lake Huron locations are represented. Risk was assigned based on thirds of the proportion with the top ⅓ represented as high risk, middle ⅓ as medium risk, and bottom ⅓ as low risk, respectively.

Water Area	Number	Proportion	Risk
Saginaw Bay	46	0.2044	High
St. Marys River	15	0.0666	Low
Northern Lake Huron	10	0.0444	Low
Cheboygan County, MI	10	0.0444	Low
Presque Isle County, MI	8	0.0355	Low
Alcona County, MI	4	0.0177	Low
Thunder Bay	4	0.0177	Low
Southern Lake Huron	1	0.0044	Low

Organisms in Trade

Most aquatic animals in pet stores, such as snails and fish, are not native to the Great Lakes and

unwanted aquatic pets are often released into a nearby waterway because pet owners believe it is a humane effort as opposed to disposal, however this is not an ecologically sound way to dispose of pets because their survival could result in an infestation. Examples highlighting incidence of pet shop releases include a fancy Goldfish *Carassius auratus* which was caught during a recent USFWS sampling effort in the River Raisin, and aquarium fish were found in a pet store bag floating on the Erie Canal (Scott Sanders, USFWS, personal communication).

Historically, three species have been identified as being introduced to Lake Huron via this vector category (Table 3), and this remains an important means for new non-native species introductions. Twenty-three percent of species with high risk to invade the Great Lakes are anticipated to arrive in the Great Lakes via this pathway (Figure 3).

Table 8. Number of aquarium and pond shops per county for counties bordering Lake Huron. Proportion is a fraction of the sum of aquarium and pond shops, where Lake Erie and Lake Huron locations were assessed cumulatively. Only Lake Huron locations are represented. Risk was assigned based on thirds of the proportion with the top ⅓ represented as high risk, middle ⅓ as medium risk, and bottom ⅓ as low risk, respectively.

Water Area	Number	Proportion	Risk
Saginaw Bay	14	0.1007	Medium
Thunder Bay	1	0.0071	Low
St. Marys River	1	0.0071	Low
Southern Lake Huron	1	0.0071	Low

Table 9. Population for U.S. counties bordering Lake Huron based on U.S. Census information (U.S. Census Bureau 2010). Proportion is a fraction of the total sum of population, where Lake Erie and Lake Huron locations were assessed cumulatively. Only Lake Huron locations are represented. Risk was assigned based on thirds of the proportion with the top ⅓ represented as high risk, middle ⅓ as medium risk, and bottom ⅓ as low risk, respectively.

Water Area	Population	Proportion	Risk
Saginaw Bay	210,450.75	0.0179	Low
Southern Lake Huron	75,113.25	0.0063	Low
St. Marys River	38,676.50	0.0032	Low
Central Lake Huron	36,272.75	0.0030	Low
Thunder Bay	29,322.75	0.0024	Low
Cheboygan County, MI	25,915.75	0.0022	Low
Presque Isle County, MI	13,185.75	0.0011	Low
Northern Lake Huron	11,090.00	0.0009	Low

Target measures that were used to assess the risk of organisms in trade at Lake Huron locations included the number of aquarium and pond shops per county bordering Lake Huron (Table 8) and population size of counties bordering Lake Huron (Table 9). Population was used as a surrogate for pet shops because an assessment of pet shops was not conducted within the time needed to complete

this plan. Another targeted measure for organisms in trade that was difficult to assess in an equal manner for all locations analyzed and therefore was not used to assess risk for this implementation plan was fish markets per area.

The number of aquarium and pond shops per county bordering Lake Huron (Table 8) was analyzed based on a search of the Internet. The U.S. population numbers for counties bordering Lake Huron were compiled using U.S. Census Bureau information (U.S. Census Bureau 2010). The proportion provided is the number counted or population at any given location divided by the sum total for all locations. High risk was assigned to the top ⅓, medium risk was assigned to the middle ⅓, and low risk was assigned to the bottom ⅓.

Maritime Commerce

Historically, a number of non-native species were introduced to Lake Huron (Table 3) and the Great Lakes via maritime commerce. In an analysis of priority species poised to become introduced to the Great Lakes, maritime commerce continued to be a potential vector pathway for 19% of the species listed (Figure 3, Table 1).

Historically, ballast water from commercial ships was identified as the most important vector for introduction of non-native organisms to the Great Lakes, accounting for 65% of species invasions from 1960-2006 (USEPA 2008). Ships entering the Great Lakes claiming NOBOB status can transport non-native species to the system, particularly invertebrates.

Ballast water from commercial ships that operate only in the Great Lakes can also be a vector that accelerates the spread of non-native species within the system (Rup et al. 2010). In addition, barge traffic enters the Great Lakes from the Mississippi River basin and potentially via the St. Lawrence Seaway or Erie Canal system and the movement of non-native species on infested barges can be a potential source of new species introduction.

Target measures that were used to assess the risk of maritime commerce at Lake Huron locations included the volume of ballast water discharged by overseas vessels, coastwise vessels, and unknown vessels (Table 10). Other targeted measures for maritime commerce that were difficult to assess in an equal manner for all locations analyzed and therefore were not used to assess risk for this implementation plan were commerce barge ballast and shipping traffic.

The volume (metric tons) of overseas, coastwise, and unknown ballast water discharged during 2010-2015 (Table 10) was obtained from the National Ballast Information Clearinghouse (2016). The proportion provided is the volume at any given location divided by the sum total for all locations. High risk was assigned to the top ⅓, medium risk was assigned to the middle ⅓, and low risk was assigned to the bottom ⅓.

No Lake Huron ports received known overseas ballast water from outside the Great Lakes (Table

10), however Lake Huron ports did receive large volumes of coastwise ballast water (Table 10). Coastwise ballast water transfer could move non-native species introduced outside of the basin to a port within Lake Huron.

Table 10. Ballast water discharged (by volume in metric tons) at Lake Huron locations (National Ballast Information Clearinghouse 2016). Proportion is a fraction of the sum of respective ballast water discharge, where Lake Erie and Lake Huron locations were assessed cumulatively. Only Lake Huron locations are represented. Risk was assigned based on thirds of the proportion with the top ⅓ represented as high risk, middle ⅓ as medium risk, and bottom ⅓ as low risk, respectively.

Water Area	Overseas	Coastwise	Unknown	Total Ballast	Overseas Proportion	Total Ballast Proportion	Risk
Presque Isle County, MI	0	32,410,679	53,143	32,463,822	0	0	Low
Thunder Bay	0	4,892,153	30,582	4,922,735	0	0	Low
St. Marys River	0	2,409,784	5,661	2,415,445	0	0	Low
Northern Lake Huron	0	2,087,144		2,087,144	0	0	Low
Saginaw Bay	0	46,047	536	46,583	0	0	Low
Cheboygan County, MI	0	12,567		12,567	0	0	Low

Canals and Water Diversions

Canals and water diversions are pathways by which non-native species can enter the Great Lakes. Historically, canals and water diversions accounted for approximately 24% of non-native aquatic species introductions to Lake Huron (Table 3). Many species were able to enter the upper Great Lakes when the Welland Canal was constructed, opening water access which allowed organisms to swim around Niagara Falls (Mills et al. 1993). This vector category includes canals, lift locks, water diversions, compensating works, and other hydrologic connections which may provide a pathway for non-native species to become introduced. Eleven percent of high risk species with potential to become introduced into the Great Lakes are anticipated to arrive via this vector pathway (Figure 3).

There are no canals or water diversions in U.S. waters of Lake Huron. We recognize that the Canadian Trent-Severn Waterway in Georgian Bay is a canal that connects Lake Huron and Lake Ontario, however we did not analyze risk for Canadian locations for this plan.

The target measure that was used to assess the risk of this vector at other locations within the Great Lakes where canals were present (e.g., Lake Erie) was the number of canals, diversions, or connections associated with each location. Proportions were generated and high risk was assigned to the top ⅓, medium risk was assigned to the middle ⅓, and low risk was assigned to the bottom ⅓.

Illegal Activities

Illegal activities exist in the form of illegal non-native fish introduction or stocking, introduction of non-native plants, or release of other organisms. States and provinces regulate the sale and transport of species, and regulations vary by state and province. Unauthorized fish stocking may be conducted to create new recreational or commercial fisheries, however, the illegal stocking of non-

native species may have an overall negative impact on existing recreational, commercial, and bait fisheries.

Historically, the number of non-native species illegally introduced to Lake Huron is uncertain. Illegal activity has been identified as a vector pathway for eight percent of priority non-native species at risk for introduction to the Great Lakes (Figure 4).

The target measure that was used to predict the risk associated with illegal activity as a means for non-native species introductions into Lake Huron was the population of counties that border the Lake Huron shoreline (Table 9). Lacking a measurable way to estimate illegal activity as a vector for the release of non-native species, population was used as a surrogate such that a constant percentage of the population may be anticipated to be prone to conduct illegal activities. The proportion provided is the population at any given location divided by the sum total for all locations. High risk was assigned to the top ⅓, medium risk was assigned to the middle ⅓, and low risk was assigned to the bottom ⅓.

Agency Activities

Federal, state, municipal, and non-governmental agencies conduct activities that require the movement of equipment and vessels within Lake Huron and across the Great Lakes as a means to maintain navigation, commerce routes, and shipping/boating structures. Non-native species may potentially become introduced to new areas as a result of the movement of this equipment. One example where non-native species were moved by agency equipment took place in 2001. Two barges with zebra mussel infested hulls were transported from the lower Great Lakes to Lake Superior locations (Marquette, Duluth-Superior harbor, then Isle Royale) to serve as maintenance work platforms (Lake Superior Work Group 2010).

Agencies have also accidentally introduced unwanted species into Lake Huron during fish stocking activities (Table 3). These incidences primarily occurred in the late 1800s and early 1900s, and agency stocking of non-native species is not a likely source for the introduction of new non-native species into Lake Huron.

Federal and state research and management agencies are cognizant that the biological assessment activities that they conduct could pose a source for transport of invasive species from an infested area to a non-infested area. The survey equipment used by agencies is designed to capture biological specimens, and that equipment is routinely moved to new sampling locations. Fishery agencies actively take preventative measures and have strict disinfection policies in place for boats, sampling equipment, and other gear as a precaution against the transfer of unwanted species and pathogens.

Agency led activities have been responsible for the introduction of five percent of priority non-native species at risk for introduction into the Great Lakes (Figure 3). We anticipate that these

species may become introduced in a similar way with similar risk. The target measure that was used to assess the risk associated with agency led activities at Lake Huron locations was the U.S. Army Corps of Engineers (USACOE) shipping maintenance appropriations cost from 2014-2016 (Table 11). Other targeted measures for agency led activities that were difficult to assess in an equal manner for all locations and therefore not used to estimate risk for this implementation plan included science or fishery assessment related sampling and work barge traffic.

Table 11. Actual and expected U.S. Army Corps of Engineers shipping maintenance appropriations for 2014-2016 at Lake Huron locations (USACOE 2015). Proportion is a fraction of the sum of appropriations, where Lake Erie and Lake Huron locations were assessed cumulatively. Only Lake Huron locations are represented. Risk was assigned based on thirds of the proportion with the top ⅓ represented as high risk, middle ⅓ as medium risk, and bottom ⅓ as low risk, respectively.

Water Area	Actual and Expected Appropriations (2014-2016)	Proportion	Risk
St. Marys River	111,254	0.3686	High
Saginaw Bay	12,173	0.0403	Low
Cheboygan County, MI	610	0.0020	Low
Thunder Bay	0	0	Low
Central Lake Huron	0	0	Low
Northern Lake Huron	0	0	Low
Presque Isle County, MI	0	0	Low
Southern Lake Huron	0	0	Low

Water Recreation

A variety of recreational equipment including boats, jet skis, water skis, wake boards, pull ropes, flotation devices, snorkeling gear, SCUBA gear, and other recreational equipment may retain water and potentially retain invasive organisms. The movement of this equipment from one lake or area to another during recreational activities could spread non-native species. To date, diving and the use of recreational gear has not been identified as a mechanism for past non-native species introductions into Lake Huron (Table 3). Activities associated with recreational gear were not specifically identified as pathways for priority non-native species with potential to become introduced into the Great Lakes (Table 1). Even so, we identified a number of target measures that would be useful to assess the risk of recreational activities at Lake Huron locations including the number of harbor slips (Table 4), the number of boat access sites (Table 5), and the number of boat ramp parking spaces (Table 6).

Tourism and Development

Touring vessels and vehicles associated with tourism and development are moved to areas from outside of the Great Lakes and also between locations within the Great Lakes. Touring vessels, ecotours, and float planes are examples of vehicles and vessels associated with tourism. Movement

associated with these vessels could be a source of non-native species introductions into Lake Huron. No non-native species are known to have become introduced into Lake Huron via this vector (Table 3), however we identified a number of target measures that would be useful to assess the risk of tourism and development at Lake Huron locations including the number of cruise ship visits (Table 12), the number of float aircraft visits (float planes etc), and the number of ecotourism businesses. Only the number of cruise ship visits to Lake Huron ports (Table 12) was examined for this implementation plan. Tourism was not specifically identified as a pathway for new high risk species with potential for to become introduced into the Great Lakes (Table 1).

Table 12. Number of cruise ship visits to Lake Huron locations (National Ballast Information Clearinghouse 2016). Proportion is a fraction of the sum of visits, where Lake Erie and Lake Huron locations were assessed cumulatively. Only Lake Huron locations are represented. Risk was assigned based on thirds of the proportion with the top ⅓ represented as high risk, middle ⅓ as medium risk, and bottom ⅓ as low risk, respectively.

Water Area	Total Visits	Proportion	Risk
Northern Lake Huron	21	0.2625	High
St. Marys River	11	0.1375	Medium

Risk Summary

Nearshore waters of Lake Huron have the potential to provide ideal habitats for non-native species to become established and multiply. This early detection monitoring program will focus sampling efforts on areas vulnerable to multiple vectors and with environmental conditions favorable for high-risk organisms (Table 1). Risk was summarized for high priority Lake Huron locations that have been considered for early detection of new non-native species (Tables 13, 14, and 15). High priority locations have one or more top ranking vectors along with species classified as high risk of invasion for that area. Low priority sampling areas may be vulnerable to fewer ranking vectors and fewer species classified as high risk of invasion.

Table 13. Risk assignments for individual target measures at Lake Huron locations. Risk is represented as H=high, M=medium, and L=low. Abbreviations are as follows: Harbor = Harbor boat slips; Boat = Boat access sites; Parking = Boat ramp parking spaces; Bait = Bait shops; Pond = Aquarium and pond shops; Pop. = U.S. population; Ballast = Ballast discharged; Canals = Canals and hydrologic connections; Ship = Shipping maintenance appropriations; and Cruise = Cruise ship visits.

Water Area	Harbor	Boat	Parking	Bait	Pond	Pop.	Ballast	Canals	Shipping	Cruise
St. Marys River	L	L	L	L	L	L	L		H	M
Cheboygan County, MI	L	L	L	L	L	L	L		L	
Thunder Bay	L	L	L	L	L	L	L		L	
Presque Isle County, MI	L	L	L	L	L	L	L		L	
Saginaw Bay	L	H	H	H	M	L	L		L	
Central Lake Huron	L	L	L	L	L	L	L		L	
Northern Lake Huron	L	L	L	L	L	L	L		L	H
Southern Lake Huron	L	L	L	L	L	L	L		L	

Individual target measures (Table 2) were identified in the Vector Risk Assessment above and respective rankings from Tables 4-12 were applied to Lake Huron locations in Table 13.

Individual target measures in Table 13 contributed to risk for individual vector pathways (Table 2). The goal of our effort was to establish the risk associated with vector pathways. The risk associated with target measures was culminated by respective vector pathway in Table 14.

Table 14. Risk assignment summary for individual vector categories at Lake Huron locations. Vector codes are: F&A = fishing and aquaculture, Trade = organisms in trade, Maritime = maritime commerce, Canals = canals and diversions, Illegal = illegal activities, Agency = agency activities, Recreation = water recreation, Tourism = tourism and development, and Precedent = non-native species of primary concern captured or scientifically indicated to be found at a location. Risk is represented as H=high, M=medium, and L=low.

Water Area	F&A	Trade	Maritime	Canals	Illegal	Agency	Recreation	Tourism
St. Marys River	L	L	L		L	H	L	M
Cheboygan County, MI	L	L	L		L	L	L	
Thunder Bay	L	L	L		L	L	L	
Presque Isle County, MI	L	L	L		L	L	L	
Saginaw Bay	M	M	L		L	L	M	
Central Lake Huron	L	L	L		L	L	L	
Northern Lake Huron	L	L	L		L	L	L	H
Southern Lake Huron	L	L	L		L	L	L	

In order to calculate overall risk associated with Lake Huron locations, the risk associated with target measures was scored, culminated by respective vector pathway, and multiplied by the vector weighting factor representing proportion of anticipated new non-species introductions (Figure 3). The scores are summarized in Table 15.

A “Precedent” category was included in the calculation to account for previous sightings found in the USGS Nonindigenous Species Database (USGS 2016), Great Lakes Aquatic Nonindigenous Species Information System (NOAA 2016), or other scientific finding of a high risk species (Table 1) in a prohibited area (i.e. prohibited by a state or province) during 2010 to 2015. A precedent value of “1” was included for evidence of each priority species found at a particular location. A precedent was not provided where the prohibited species was classified in the search databases above as “established”. The rationale for a “Precedent” category was to flag areas where high risk species have been captured recently (within 5 years) yet are not established, in an effort to determine the status of that species at the location. This effort would lend toward early detection and rapid response. Once a species is established it is more difficult to enact rapid response or provide control.

A precedent was included for four Lake Huron locations based on positive environmental DNA

(eDNA) findings for Ruffe (Table 15). Positive findings for Ruffe eDNA were identified from the the upper St. Marys River, Cheboygan River (Cheboygan County, Michigan), Trout River (Presque Isle County, Michigan), and Devils River in Thunder Bay (Tucker et al. 2016). Each of these locations received a precedent rating of "1" which was included with other vector scores.

Table 15. Vector scores by Lake Huron location based on target measure scores for individual vectors multiplied by vector weights (values in bold, from Fig. 3). Vector codes are: F&A = fishing and aquaculture, Trade = organisms in trade, Maritime = maritime commerce, Canals = canals and diversions, Illegal = illegal activities, Agency = agency activities, Rec. = water recreation, Tourism = tourism and development, and Prec. = non-native species of primary concern captured or scientifically indicated to be found at a location. Risk is represented as H=high, M=medium, and L=low. The "*" denotes sites to be sampled in 2016.

	F&A	**Trade**	**Maritime**	**Canals**	**Illegal**	**Agency**	**Rec.**	**Tourism**	**Prec.**	**Score**	**Overall priority**
Water Area	**0.34**	**0.23**	**0.19**	**0.11**	**0.08**	**0.05**	**0**	**0**			
St. Marys River *	0.34	0.23	0.19	0	0.08	0.15	0	0	1	1.99	M
Cheboygan County, MI	0.34	0.23	0.19	0	0.08	0.05	0	0	1	1.89	M
Thunder Bay	0.34	0.23	0.19	0	0.08	0.05	0	0	1	1.89	M
Presque Isle County, MI	0.34	0.23	0.19	0	0.08	0.05	0	0	1	1.89	M
Saginaw Bay	0.85	0.46	0.19	0	0.08	0.05	0	0		1.63	M
Central Lake Huron	0.34	0.23	0.19	0	0.08	0.05	0	0		0.89	L
Northern Lake Huron	0.34	0.23	0.19	0	0.08	0.05	0	0		0.89	L
Southern Lake Huron	0.34	0.23	0.19	0	0.08	0.05	0	0		0.89	L

2016 Sampling Allocation

This sampling strategy for early detection of non-native species at priority locations was designed to detect rare species. We presume that non-native species may be few in number, and therefore potentially rare, early in their arrival at new location. Effectively sampling for rare species would increase the likelihood that those species present in low abundance would be detected.

Generally, sampling for rare species involves collecting the entire suite of species known to inhabit a location using a variety of gear types that sample a variety of habitats and water depths. In order to determine which gears are most effective at sampling for a greater diversity of species, equal samples will be collected across a variety of gear types in a spatially balanced random survey design. The number of samples collected in each location will be analyzed to ensure enough effort is employed to detect rare species or 95% of all species present (Hoffman et al. 2011). Adequate samples will be collected after approximately three years, estimated based on limits due to time and

staffing. Once an adequate amount of samples has been collected, an evaluation will determine the appropriate sampling gear mixtures to maximize the number of fish species detected, the rate at which new species were detected, and the number of additional samples needed to detect 95% and 100% of the estimated complete species richness.

A number of Lake Huron locations have been analyzed for early detection monitoring (Tables 14 and 15), however USFWS staffing levels and time restrictions limit the number of locations that can be surveyed in a given year. The Alpena FWCO has prioritized sampling across its area of responsibility for Lake Huron and western Lake Erie in an effort to identify the locations of most concern based on vectors and risk of invasion.

In 2016, the following locations will be sampled by the Alpena FWCO: lower St. Marys River (St. Marys River compensating works downstream) in Lake Huron, Maumee Bay in Lake Erie, Sandusky Bay in Lake Erie, and Detroit River in Lake Erie. These efforts will continue a 3 year (2013-2015) dataset to quantify rare species detection at these locations. The majority of sampling efforts fall in the Lake Erie basin in 2016. These locations were mainly selected based on risk due to concerns with Grass Carp reproduction, the invasion of Asian carps via temporary connections with the Mississippi River system, and due to the amount and frequency of ballast water discharge into Lake Erie ports. Sampling efforts in the lower St. Marys River will continue to target juvenile and adult fishes.

Lower St. Marys River, Michigan and Ontario

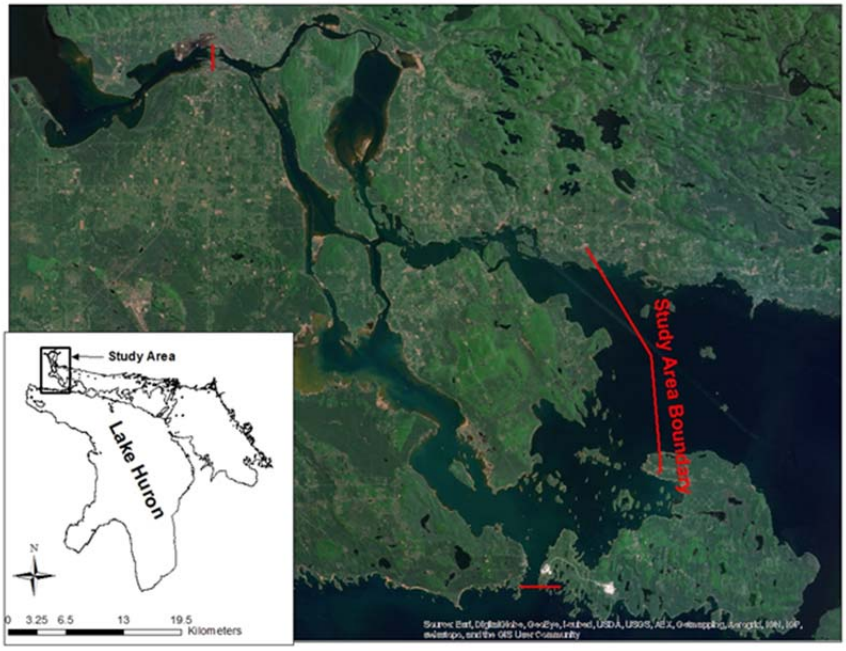

Figure 4. The St. Marys River showing 2013-2016 USFWS study area boundary.

Sampling effort and gears

- Juvenile and adult fish sampling have been conducted in the lower St. Marys River annually from 2013 to 2015 and will continue in 2016 (Figure 4).
- Juvenile and adult fish sampling: In 2016, 45 sites will be sampled during August-October. Effort will be distributed equally among three gear types: paired fyke net overnight sets at 15 sites, nighttime electrofishing 600 s transects at 15 sites, and daytime bottom trawling five minute tows at 15 sites.
- In addition to this effort on Lake Huron, prioritized sampling will also be conducted at four other high risk locations on Lake Erie by the USFWS Alpena FWCO and the USFWS Lower Great Lakes FWCO in 2016. Those locations include the Detroit River, Maumee Bay, Sandusky Bay, and Buffalo/upper Niagara River.

Monitoring Program Progress and Evaluation

The USFWS Alpena FWCO and partner agencies have been conducting early detection for non-native juvenile and adult fish species in the lower St. Marys River since 2013. The sampling strategy and gear types were modeled after ongoing efforts by the USFWS and USEPA in other portions of the Great Lakes (Trebitz et al. 2009; Hoffman et al. 2011; Schloesser and Quinlan 2014).

An evaluation of Lake Huron juvenile and adult fish sampling efforts was completed after the 2015 field season to estimate the rate at which new species were detected, estimate the number of additional samples needed to detect 95% of the complete species richness, and identify sampling gears that captured the largest number of unique or rare fish species (USFWS 2016).

Partnering Agencies

The scope of invasive species monitoring in a multi-jurisdictional system like Lake Huron is beyond the resource capabilities of any single agency. The Ontario Ministry of Natural Resources and Forestry, Upper Great Lakes Management Unit has been partnering with the USFWS Alpena FWCO to conduct sampling in the lower St. Marys River. The USFWS will work collaboratively with other partnering agencies including state, federal, provincial, academic and non-governmental groups to fully implement strategic sampling for invasive species monitoring in Lake Huron. Specifically, the USFWS will need assistance with field sampling and data contributions.

Taxonomic Experts

In the event a specimen cannot be identified by USFWS staff, a qualified taxonomic expert will be

contacted for assistance. The Aquatic Nuisance Species Task Force maintains a database of taxonomic experts that can be contacted for invasive species identification (http://www.invasivespeciesinfo.gov/toolkit/expertise.shtml).

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