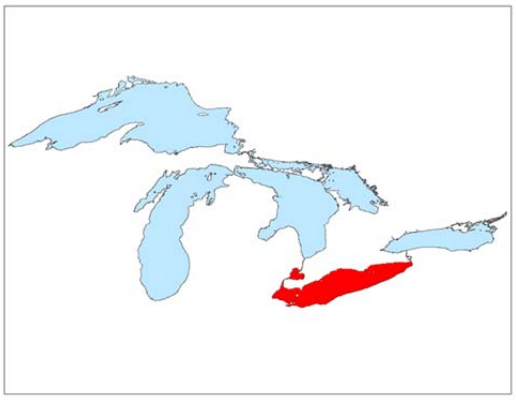
U.S. Fish and Wildlife Service

LAKE ERIE

IMPLEMENTATION PLAN FOR THE EARLY DETECTION OF NON-NATIVE FISHES AND SELECT BENTHIC MACROINVERTEBRATES



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Introduction

Aquatic invasive species pose a serious threat to Lake Erie and its connecting channels with at least 86 established non-native aquatic species already present (NOAA 2014), the high frequency and amount of ballast water discharge into Lake Erie ports each year (USEPA 2008), and the threat of new non-native species such as Silver Carp *Hypophthalmichthys molitrix* and Bighead Carp *Hypophthalmichthys nobilis* entering the lake through connections with the Mississippi River basin (GLMRIS 2011). Ecological degradation in Lake Erie has been extensive from invasive species (Munawar et al. 2005) such as Zebra and Quagga Mussels *Dreissena polymorpha* and *Dreissena rostriformis bugensis*, Round Goby *Neogobius melanostomus*, and Sea Lamprey *Petromyzon marinus*. Zebra and Quagga Mussels have caused dramatic changes to the Lake Erie ecosystem, shifting energy from pelagic to benthic zones and leading to reductions in fish production and growth rates, among other impacts (Ryan et al. 2003). The threat of colonization from other invasive species present in the Great Lakes (e. g., Ruffe *Gymnocephalus cernua*) and the Mississippi River basin (e. g., Silver and Bighead Carp), but outside of the Lake Erie basin, are of concern – in addition to the potential impacts of non-native species that are poised to enter the Great Lakes from other areas of the country or the world. A number of ongoing activities in the Lake Erie system, including ballast water transfer and commercial trade of organisms, provide vectors for potential non-native species introductions.

Resource agencies and managers around Lake Erie and the Great Lakes have identified the need to monitor existing aquatic invasive species as well as detect the arrival of new species (Ryan et al. 2003; USEPA 2008; Great Lakes Water Quality Agreement 2012; Great Lakes Restoration Initiative 2014). The Lake Erie Lakewide Management Plan (2004) recognized the threat of invasive species to biodiversity and outlined objectives to prevent and reduce their impact through development of a framework for aquatic invasive species control and management. Challenges identified in the 2013 Lake Erie Lakewide Action and Management Plan Annual Report included preventing the invasion of Silver and Bighead Carp. 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 early detection 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 Erie 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 2014a) by defining how the U.S. Fish and Wildlife Service (USFWS) will carry out non-native species early detection in Lake Erie and its connecting channels of the St. Clair River, Lake St. Clair, Detroit River, and Upper Niagara River (Figure 1). From a USFWS management perspective, Lake Erie falls between two regional jurisdictions and fisheries management on the lake is shared between USFWS Region 3's Alpena Fish and Wildlife Conservation Office (Alpena FWCO located in Alpena, Michigan) and USFWS Region 5's Lower

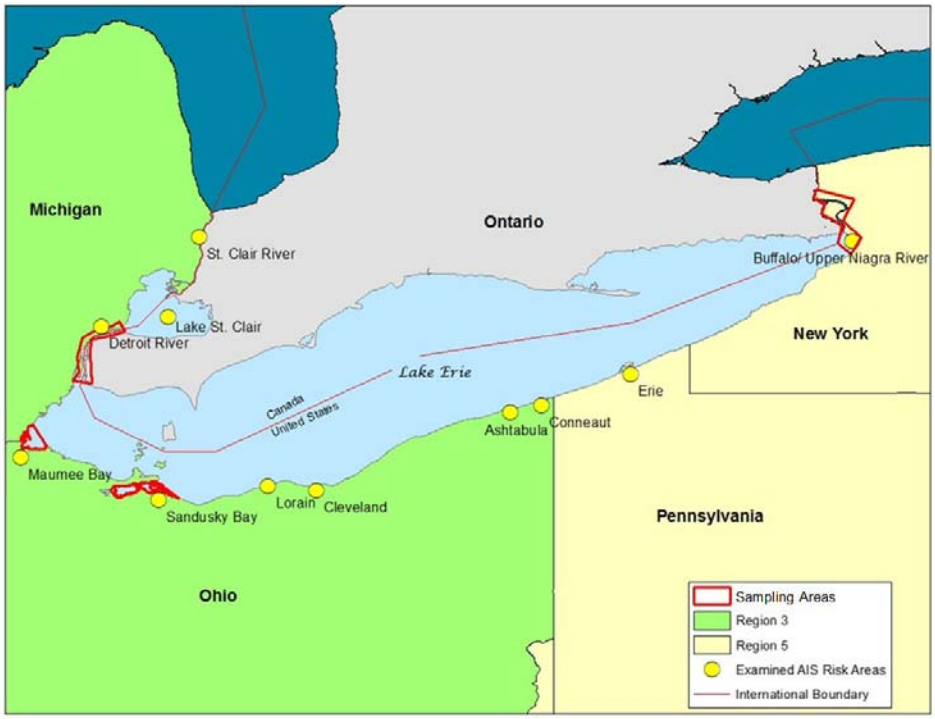

Figure 1. The Lake Erie Implementation Plan addresses Lake Erie and its connecting channels. U. S. Fish and Wildlife Service Regions 3 and 5 share fishery management on Lake Erie and are working in coordination to detect new non-native species.

Great Lakes Fish and Wildlife Conservation Office (Lower Great Lakes FWCO located in Basom, New York). USFWS Region 3 covers an eight state area including Michigan and Ohio which border Lake Erie, and Region 5 covers a thirteen state area including Pennsylvania and New York which also border Lake Erie. The two USFWS offices worked together to identify Lake Erie-specific vectors and to prioritize sampling areas to maximize the likelihood of detecting a new non-native species, should it arrive.

The USFWS conducted a risk characterization that was based on an analysis of species of greatest risk to invade the Great Lakes basin, and a vector risk analysis of pathways for invasive species introduction across lakes Huron and Erie. Alpena FWCO provides fishery management for lakes Huron and Erie, and the highest risk locations among these two lakes needed to be identified in order to prioritize sampling. Only the Lake Erie portion of the risk analysis is represented in this implementation plan. Based on the risk characterization, four locations will be sampled in 2016 (Figure 1).

Risk Characterization

The Alpena and Lower Great Lakes FWCOs 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 Erie 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 (GLANSIS) 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 system.

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

Type	Common name	Scientific name	Vector(s)	Donor region	Reproduction & larval temp. (C)	Habitat	Potential effective gear
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
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 cernuus*	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

Type	Common name	Scientific name	Vector(s)	Donor region	Reproduction & larval temp. (C)	Habitat	Potential effective gear
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

A= amphipod
B= bivalve
F= fish

Vectors of introduction

A= agency activities
C= canals/diversions
F= fishing/aquaculture
I= illegal activities
M= maritime commerce
O= organisms in trade
T= tourism and development

Donor Region

A= Asia
E= Europe
NA= North America
PC= Ponto-Caspian

Habitat

H=boulder/hard
LE= lentic
LO= lotic
S= silt/mud/sand
V= vegetation
Z= dreissenid beds

Effective Gears

A= amphipod trap
B= benthic sled
C= colonization sampler
D= dredge (e.g. Ponar/Ekman)
E= electrofishing
F= fyke/trap netting
G= gillnet
L= quatrefoil light trap
M= minnow trap
P= plankton net
S= seine
T= bottom trawl

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. They 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).

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 vector risk for this plan.

For past early detection planning, the Alpena and Lower Great Lakes 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.

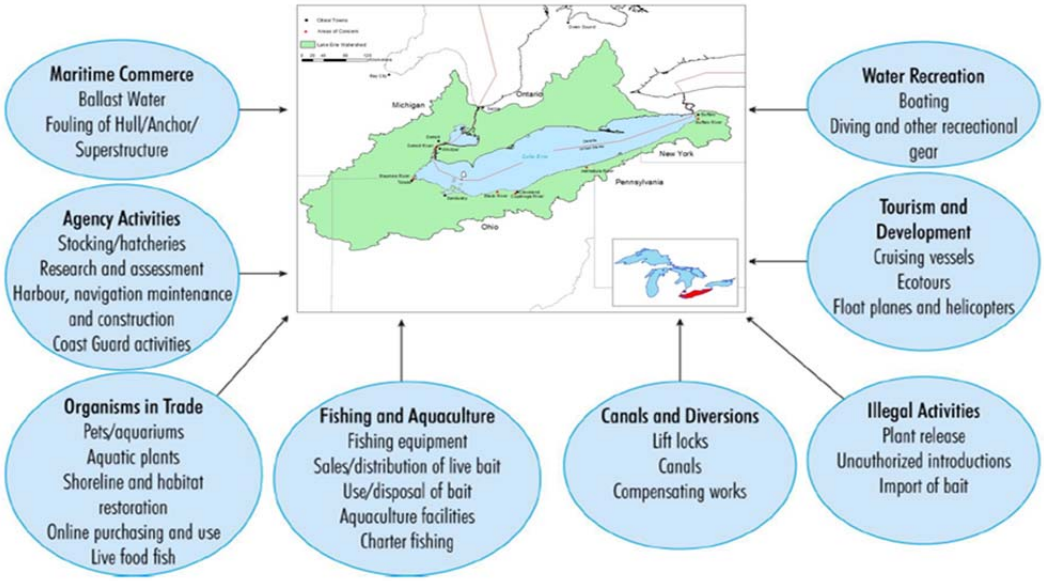

Figure 2. Vector and pathway concept map for Lake Erie (modified from Lake Superior Work Group 2010).

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 indicated target measures that would be useful but were not analyzed for risk in this implementation plan. Vector category abbreviations are as follows: 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			

Target Measure	Maritime	Agency	Canals	Trade	F&A	Recreation	Tourism	Illegal
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 Erie (USGS 2013). Vector category abbreviations are as follows: M = maritime commerce, A = agency activities, C = canals and water diversions, F = fishing and aquaculture, O = organisms in trade, and U = unknown. The USGS NAS database includes a disclaimer that information is not guaranteed to be correct, and some of the data regarding Lake Erie 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	*Corophium mucronatum*	M	shipping
Amphipod	*Gammarus tigrinus*	M	shipping
Freshwater Shrimp	*Gammarus fasciatus*	M	shipping-ballast water
Scud	*Echinogammarus ischnus*	M, U	shipping, shipping-ballast water, unknown
Asian Clam	*Corbicula fluminea*	U	unknown
European Fingernail Clam	*Sphaerium corneum*	M	shipping
Greater European Peaclam	*Pisidium amnicum*	M	shipping solid ballast
Henslow Peaclam	*Pisidium henslowanum*	M	shipping solid ballast
Humpbacked Peaclam	*Pisidium supinum*	U	unknown
Pygmy Peaclam	*Pisidium moitessierianum*	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, stocked for forage
American Eel	*Anguilla rostrata*	C	canal
American Shad	*Alosa sapidissima*	A	stocked for food
Atlantic Salmon	*Salmo salar*	A	stocked for sport
Banded Killifish	*Fundulus diaphanus*	A	hitchhiker w/stocked fish
Bighead Carp	*Hypophthalmichthys nobilis*	F, A	escaped captivity aquaculture, stocked for biocontrol
Bigmouth Buffalo	*Ictiobus cyprinellus*	A	stocked
Black Buffalo	*Ictiobus niger*	C	canal
Blackstripe Topminnow	*Fundulus notatus*	U	unknown
Brook Trout	*Salvelinus fontinalis*	A	stocked for sport
Brown Trout	*Salmo trutta*	A	stocked escaped, stocked for sport
Chain Pickerel	*Esox niger*	A	stocked for sport
Chinook Salmon	*Oncorhynchus tshawytscha*	A	stocked for sport
Coho Salmon	*Oncorhynchus kisutch*	A	stocked for sport

Common Name	Scientific Name	Vector	USGS NAS pathway
Common Carp	*Cyprinus carpio*	F, A	escaped captivity - pond, bait release, stocked for food, stocked for forage
Eastern Mosquitofish	*Gambusia holbrooki*	A	stocked for biocontrol
European Flounder	*Platichthys flesus*	M	shipping ballast water
Fathead Minnow	*Pimephales promelas*	A	stocked
Freshwater Tubenose Goby	*Proterorhinus semilunaris*	M	shipping ballast water
Gizzard Shad	*Dorosoma cepedianum*	C	canal
Ghost Shiner	*Notropis buchanani*	F	bait release
Goldfish	*Carassius auratus*	O	aquarium release
Grass Carp	*Ctenopharyngodon idella*	A	stocked for biocontrol
Green Sunfish	*Lepomis cyanellus*	A	stocked for sport
Muskellunge	*Esox masquinongy ohioensis*	A	stocked for sport
Orangespotted Sunfish	*Lepomis humilis*	F, A	hitchhiker w/stocked fish, stocked, stocked for sport
Pink Salmon	*Oncorhynchus gorbuscha*	F/A	hitchhiker w/stocked fish, stocked for sport
Rainbow Smelt	*Osmerus mordax*	A, U	stocked escaped, stocked for forage, unknown
Rainbow Trout	*Oncorhynchus mykiss*	A	stocked for sport
Red Piranha	*Pygocentrus nattereri*	O	aquarium release
Red-bellied Pacu	*Piaractus brachypomus*	O	aquarium release
Redbreast Sunfish	*Lepomis auritus*	A	stocked for sport
Redear Sunfish	*Lepomis microlophus*	A	stocked for sport
River Carpsucker	*Carpiodes carpio*	F	hitchhiker w/stocked fish
Round Goby	*Neogobius melanostomus*	M	shipping ballast water, dispersed
Rudd	*Scardinius erythrophthalmus*	C, F, A	canal, bait release, stocked
Sea Lamprey	*Petromyzon mainus*	C	canal
Sockeye Salmon	*Oncorhynchus nerka*	A	stocked for sport
Suckermouth Minnow	*Phenacobius mirabilis*	F	bait release
Tench	*Tinca tinca*	A	stocked for sport
Threespine Stickleback	*Gasterosteus aculeatus*	C, F, U	canal, bait release, unknown
Unidentified pacu	*Colossoma* or *Piaractus*	O	aquarium release
Warmouth	*Lepomis gulosus*	A	stocked for sport
Western Mosquitofish	*Gambusia affinis*	A	stocked for biocontrol
White Bass x White Perch hybrid	*Morone chrysops x M. americana*	C	canal
White Catfish	*Ameiurus catus*	F, A	Escaped captivity - aquaculture, stocked for sport
White Perch	*Morone americana*	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.

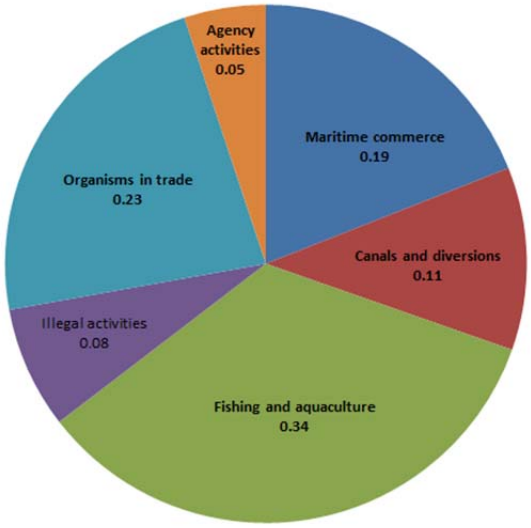

Figure 3. Vector pathways for high risk non-native fish, amphipod, and bivalves (Table 1) that are of concern to become introduced into the Great Lakes. Numbers are proportions by which at risk non-native species may become introduced.

Fishing and Aquaculture

Fishing and aquaculture was identified as the most common vector (Figure 3) for introduction of high risk non-native organisms found in Table 1; anticipated to provide a vector for 34% of the species listed. Ten non-native species were historically introduced to Lake Erie 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-native species on their fishing equipment, boats, nets, or other fishing gear; and the survival of discarded live bait. 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 Erie.

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. For example, juvenile Silver and Bighead Carp could be confused with other fishes commonly used as bait. Commercial harvesting of baitfish does not routinely occur in Lake Erie, although it does occur in the Great Lakes basin. Those fish are distributed across the region for use by anglers, potentially moving live non-native species to new locations. Each governmental jurisdiction in the Lake Erie basin addresses the sale and distribution of live bait through its own regulations. Illegal activities regarding the movement or illegal stocking of live bat is a concern for this vector category.

Target measures that were used to assess the risk of fishing and aquaculture at Lake Erie locations included: number of boat harbor slips (Table 4), number of boat access sites (Table 5), number of

boat ramp parking spaces (Table 6), and number of bait shops per county bordering Lake Erie (Table 7).

Table 4. Boat harbor slips counted along the Lake Erie shoreline using Google Earth (Google Inc. 2016). Proportion is a fraction of the sum of boat harbor slips where Lakes Erie and Lake Huron locations were assessed cumulatively. 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. Only Lake Erie locations are represented in the table below.

Water Area	Number	Proportion	Risk
Sandusky Bay	10,281	0.292	High
Lake St. Clair	3,300	0.094	Low
Buffalo, NY/UNR	3,290	0.094	Low
St. Clair River	2,845	0.081	Low
Maumee Bay	2,794	0.079	Low
Detroit River	2,418	0.069	Low
Erie, PA	2,387	0.068	Low
Lorain, OH	1,087	0.031	Low
Cleveland, OH	1,039	0.030	Low
Ashtabula, OH	803	0.023	Low
Lake County, OH	639	0.018	Low
Eastern Lake Erie	491	0.014	Low

Table 5. Boat access sites counted along the Lake Erie shoreline using Google Earth (Google Inc. 2016). Proportion is a fraction of the sum of boat access sites where Lakes Erie and Lake Huron locations were assessed cumulatively. 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. Only Lake Erie locations are represented in the table below.

Water Area	Number	Proportion	Risk
Sandusky Bay	60	0.192	High
St. Clair River	27	0.086	Medium
Maumee Bay	23	0.073	Medium
Detroit River	21	0.067	Medium
Buffalo, NY/UNR	19	0.061	Low
Lake St. Clair	16	0.051	Low
Erie, PA	16	0.051	Low
Lake County, OH	15	0.048	Low
Cleveland, OH	12	0.038	Low
Lorain, OH	10	0.032	Low
Ashtabula, OH	6	0.019	Low
Eastern Lake Erie	6	0.019	Low

Other targeted measures for fishing and aquaculture were difficult to assess in a standard 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 access sites (Table 5), and boat ramp parking spaces (Table 6) were analyzed by examining the Lake Erie shoreline using a satellite imagery (Google Inc. 2016) and counting the number of boat harbor slips, boat access sites, 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 Erie 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. 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. Only Lake Erie locations are represented in the table below.

Water Area	Number	Proportion	Risk
Lake St. Clair	1,159	0.132	Medium
Detroit River	1,061	0.121	Medium
Maumee Bay	906	0.103	Medium
St. Clair River	568	0.065	Low
Sandusky Bay	540	0.061	Low
Buffalo, NY/UNR	315	0.036	Low
Erie, PA	270	0.031	Low
Lorain, OH	220	0.025	Low
Eastern Lake Erie	185	0.021	Low
Ashtabula, OH	120	0.014	Low
Cleveland, OH	120	0.014	Low
Lake County, OH	65	0.007	Low

Table 7. Number of bait shops per county for counties bordering Lake Erie. Proportion is a fraction of the sum of bait shops where Lake Erie and Lake Huron locations were assessed cumulatively. 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. Only Lake Erie locations are represented in the table below.

Water Area	Number	Proportion	Risk
Sandusky Bay	20	0.089	Medium
Detroit River	18	0.080	Medium
Buffalo, NY/UNR	18	0.080	Medium
Maumee Bay	15	0.067	Low
St. Clair River	10	0.044	Low
Lake St. Clair	10	0.044	Low
Erie, PA	8	0.036	Low
Lorain, OH	7	0.031	Low
Ashtabula, OH	6	0.027	Low
Cleveland, OH	6	0.027	Low
Eastern Lake Erie	5	0.022	Low
Lake County, OH	4	0.018	Low

Organisms in Trade

Most aquatic animals in pet stores, such as snails and fish, are not native to the Great Lakes. 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 a non-native species introduction. Examples highlighting incidence of pet shop releases include a fancy Goldfish which was caught during a recent USFWS sampling effort in the River Raisin, and aquarium fish found in a pet store bag floating on the Erie Canal (Scott Sanders, USFWS, personal communication).

Historically, four species have been identified as being introduced to Lake Erie via organisms in trade (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).

Target measures that were used to assess the risk of organisms in trade at Lake Erie locations included the number of aquarium and pond shops per county bordering Lake Erie (Table 8) and population size of U.S. cities and metropolitan areas bordering Lake Erie (Table 9) as a surrogate for the frequency of pet shops. Population was used as a surrogate for pet shops because an assessment of pet shops could not be conducted within the time needed to complete this plan. Fish markets per area was another targeted measure for organisms in trade that was difficult to assess in a standard manner for all locations analyzed and therefore was not used to assess risk for this implementation plan.

Table 8. Number of aquarium and pond shops per county for counties bordering Lake Erie. Proportion is a fraction of the sum of aquarium and pond shops where Lake Erie and Lake Huron locations were assessed cumulatively. 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. Only Lake Erie locations are represented in the table below.

Water Area	Number	Proportion	Risk
Lake St. Clair	23	0.165	High
Detroit River	22	0.158	High
Maumee Bay	22	0.158	High
Cleveland, OH	21	0.151	High
Buffalo, NY/UNR	19	0.137	High
Lake County, OH	5	0.036	Low
Erie, PA	3	0.022	Low
St. Clair River	2	0.014	Low
Lorain, OH	2	0.014	Low
Eastern Lake Erie	2	0.014	Low
Sandusky Bay	1	0.007	Low

The number of aquarium and pond shops per county bordering Lake Erie (Table 8) was analyzed

based on a search of the internet. The U.S. population numbers bordering Lake Erie were compiled using U.S. Census Bureau information (U.S. Census Bureau 2010). The proportion provided is the number counted divided by the total number present. 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 9. Population for U.S. counties bordering Lake Erie 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. 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. Only Lake Erie locations are represented in the table below.

Water Area	Population	Proportion	Risk
Lake St. Clair	2,789,764.80	0.238	High
Detroit River	1,781,760.30	0.152	Medium
Cleveland, OH	1,269,855.80	0.108	Medium
Rocky River, OH	1,269,855.80	0.108	Medium
Buffalo, NY/UNR	1,134,572.80	0.097	Medium
Maumee Bay	438,794.75	0.037	Low
Cooley Canal, OH	438,794.75	0.037	Low
Vermilion, OH	378,439.75	0.032	Low
Lorain, OH	301,902.25	0.026	Low
Erie, PA	280,651.00	0.024	Low
Lake County, OH	229,830.25	0.020	Low
Sandusky Bay	178,407.00	0.015	Low
St. Clair River	161,418.50	0.014	Low
Western Lake Erie	151,213.00	0.013	Low
Eastern Lake Erie	133,914.50	0.011	Low
Ashtabula, OH	100,667.50	0.009	Low
Conneaut, OH	100,667.50	0.009	Low
Huron, OH	76,537.50	0.007	Low
Port Clinton/Marblehead, OH	41,347.25	0.004	Low
Toussaint, OH	41,347.25	0.004	Low

Maritime Commerce

Based on historical precedent, maritime commerce was the vector of greatest risk by which non-native species were introduced to Lake Erie (Table 3). 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 no ballast on board (NOBOB) status can transport non-native species to the system, particularly invertebrates. Lake Erie ports, including Toledo and Ashtabula, were among U.S. ports in the Great Lakes that received the most ballast water from ships that entered the St. Lawrence Seaway without ballast on board,

picked up ballast water in the Great Lakes, and then deposited that water at a different Great Lakes port (USEPA 2008).

Ballast water from commercial ships that operate only in the Great Lakes can also be a vector for accelerating the spread of non-native species within the system (Rup et al. 2010). In addition, barge traffic entering the Great Lakes from the Mississippi River basin, via the St. Lawrence Seaway, and Erie Canal system can carry non-native species. Those barges could be sources for new introductions.

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

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 number of metric tons discharged in the water area divided by the total metric tons discharged. 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 10. Ballast water discharged (by volume in metric tons) at Lake Erie 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. 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. Only Lake Erie locations are represented in the table below.

Water Area	Overseas	Coastwise	Unknown	Total Ballast	Overseas Proportion	Total Ballast Proportion	Risk
Maumee Bay	43,174	8,909,927	56,609	9,009,710	0.590	0.590	High
Cleveland, OH	22,691	2,169,795	48,421	2,240,907	0.310	0.310	High
Erie, PA	3,593	485,274	581	489,448	0.049	0.049	Medium
Detroit River	2,180	1,276,208	36,665	1,315,053	0.030	0.030	Medium
Ashtabula, OH	1,584	5,178,175	25,314	5,205,073	0.022	0.022	Medium
Sandusky Bay	0	12,458,791	21,514	12,480,305	0	0	Low
Conneaut, OH	0	662,613	16,307	678,920	0	0	Low
Lake County, OH	0	698,941	12,452	711,393	0	0	Low
Lorain, OH	0	255,974	0	255,974	0	0	Low
Buffalo, NY/UNR	0	184,510	16,104	200,614	0	0	Low
St. Clair River	0	49,976	11,379	61,355	0	0	Low

Canals and Water Diversions

Canals and water diversions can open pathways for non-native species to enter the Great Lakes.

Historically, canals and water diversions accounted for approximately 21% of non-native aquatic species introductions to Lake Erie (Table 3). Many species were able to enter the upper Great Lakes, and specifically Lake Erie, when the Welland Canal provided a pathway around Niagara Falls (Mills et al. 1993). This vector includes canals, lift locks, water diversions, compensating works, and other hydrologic connections as pathways of potential non-native species introductions. 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 three primary canals and water diversions that may allow non-native species to enter Lake Erie (Table 11). Connections between the Mississippi River basin and the Great Lakes basin are of particular concern as a vector for the introduction of Silver, Bighead, and Black Carp.

The target measure that was used to assess the risk of canals and water diversions at Lake Erie locations was the number of canals, diversions, or connections associated with each location (Table 10). The proportion provided is the number of connections divided by the total number of connections in Lake Erie and Lake Huron combined. 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 11. Number of canals and other hydrologic connections that may create pathways for introduction of non-native species to Lake Erie from other basins. Proportion is a fraction of the total number of connections for Lake Erie and Lake Huron locations combined. 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. Only Lake Erie locations are represented in the table below.

Closest Site	Number of Connections	Proportion	Risk
Buffalo, NY/UNR	3	0.500	High
Cleveland, OH	2	0.333	High
Sandusky, OH	1	0.167	Medium

Illegal Activities

This vector accounts for activities such as illegal stocking of fish, illegal introduction of plants, or illegal release of other organisms. There are regulations involving the sale and transport of species that vary by state and province. Unauthorized fish stocking is typically conducted for the purpose of creating new recreational or commercial fisheries and is illegal due to harmful and negative effects on existing recreational, commercial, and bait fisheries (USFWS 2006).

The number of species historically introduced to Lake Erie through unauthorized releases is uncertain. However, Grass Carp found in the Sandusky River in 2012 were determined to have likely been hatched there (Chapman et al. 2013), which may have been the result of unauthorized stocking. Eight percent of high risk non-native species are anticipated to be introduced to the Great Lakes via this pathway vector (Figure 4).

The target measure that was used to assess the risk of illegal activities at Lake Erie locations was population size of counties bordering Lake Erie (Table 9). Lacking a measurable way to estimate risk of this vector, population was used as a surrogate, as a constant percentage of the population was anticipated to be prone to conduct illegal activities. The proportion provided (Table 9) is the population of the water area divided by the total lakeshore population of Lake Erie and Lake Huron combined. 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

A variety of agencies move within Lake Erie and the Great Lakes to maintain navigation, commerce routes, and shipping/boating structures. As a result, non-native species could potentially be introduced to new areas from the movement of maintenance barges and various other vessels. One example of this type of activity took place in 2001 when two barges with hulls infested with invasive zebra mussels were transported from the lower Great Lakes to Lake Superior locations (Marquette, Duluth-Superior harbor, Isle Royale) to serve as maintenance work platforms (Lake Superior Work Group 2010).

Additionally, management agencies have stocked a number of species into Lake Erie for various purposes (Table 3). These stockings primarily occurred in the late 1800s and early 1900s, and stocking activities by agencies is not currently a likely source of new non-native species introductions to Lake Erie.

Fishery research and management agencies are cognizant that biological assessments also pose a threat to transport invasive species to new locations. Survey equipment is designed to capture biological specimens and is routinely moved to new assessment areas. Fishery agencies take active measures to prevent transfer of species and pathogens; strict disinfection policies are employed to prevent spread of species to new areas.

Five percent of new high risk non-native species introductions are anticipated to arrive via agency activity (Figure 3). The target measure that was used to assess the risk of agency activities at Lake Erie locations was the U.S. Army Corps of Engineers appropriations cost associated with shipping maintenance from 2014-2016 (Table 12). Other targeted measures for agency activities that were difficult to assess in a standard manner for all locations analyzed and therefore were not used to assess risk for this implementation plan included scientific sampling and work barges.

Water Recreation

Water recreation employs the use of a variety of equipment including but not limited to: boats, jet skis, water skis, wake boards, pull ropes, flotation devices, snorkeling, and SCUBA gear. This equipment may retain water or invasive species and may be moved from location to location, providing a vector for invasive species spread. To date, diving and recreational gear has not been

identified as a mechanism for previous non-native species introductions into Lake Erie. Water recreation was not specifically identified as a pathway vector for new high risk species with potential to become introduced into the Great Lakes (Table 1). However target measures that were identified to assess this risk at Lake Erie locations would include 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).

Table 12. Actual and expected U.S. Army Corps of Engineers shipping maintenance appropriations for 2014-2016 at Lake Erie locations (USACOE 2015). Proportion is a fraction of the sum of appropriations where Lake Erie and Lake Huron locations were assessed cumulatively. 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. Only Lake Erie locations are represented in the table below.

Water Area	Actual and Expected Appropriation (2014-2016)	Proportion	Risk
Cleveland, OH	69,149	0.229	Medium
Detroit River	19,518	0.065	Low
Buffalo, NY/UNR	18,244	0.060	Low
Maumee Bay	17,791	0.059	Low
Fairport, OH	13,605	0.045	Low
Lorain, OH	10,613	0.035	Low
Huron, OH	5,161	0.017	Low
Sandusky Bay	5,109	0.017	Low
Erie, PA	4,204	0.014	Low
Conneaut, OH	3,685	0.012	Low
St. Clair River	3,625	0.012	Low
Ashtabula, OH	3,460	0.011	Low
Western Lake Erie	2,510	0.008	Low
Lake St. Clair	532	0.002	Low
Eastern Lake Erie	499	0.002	Low
Port Clinton/Marblehead, OH	50	0	Low
Vermilion, OH	13	0	Low
Cooley Canal, OH	0	0	Low
Rocky River, OH	0	0	Low
Toussaint, OH	0	0	Low

Tourism and Development

Tourism and development also provide a pathway for the introduction of non-native species. Touring vessels, Eco tours, and float planes may travel into the Great Lakes from outside of the basin, and/or from location to location within the basin potentially spreading species. No non-native species are reported to have been introduced to Lake Erie in the past through tourism and development. This vector was not specifically identified as a pathway for new high risk species with potential to become introduced into the Great Lakes (Table 1). However, target measures that were identified to assess this risk at Lake Erie locations included the number of cruise ship visits (Table 13), the number of float aircraft visits (float planes etc.), and the number of ecotourism businesses.

Only risk associated with cruise ship visits (Table 13) was assessed for this plan.

Table 13. Number of cruise ship visits to Lake Erie 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. 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. Only Lake Erie locations are represented in the table below.

Water Area	Total Visits	Proportion	Risk
Cleveland, OH	17	0.213	High
Detroit River	15	0.188	High
Buffalo, NY/UNR	9	0.113	Medium
Erie, PA	7	0.088	Medium

Risk Summary

The warm shallow waters of Lake Erie 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 Erie locations that have been considered for early detection of new non-native species (Tables 14, 15, and 16). High priority locations were determined by the ranks of vector risk (Table 15) and the proportions of high risk species that could use the vectors (Figure 3). Low priority sampling areas may be vulnerable to fewer vectors and fewer associated species classified as high risk of invasion.

Individual target measures (Table 2) were identified in the Vector Risk Assessment above and respective rankings from Tables 4-13 were applied to Lake Erie locations in Table 14.

Individual target measures in Table 14 contributed to the overall risk for individual vector pathways (Table 2). The goal of our effort was to establish the risk associated with vector pathways. The overall risk represented by the different vector pathways (Table 15) was determined based on the rankings of the target measures (Tables 4- 13) included in that vector as discussed previously.

In order to calculate overall risk associated with Lake Erie locations, the risk associated with the respective vector pathway was multiplied by the corresponding vector weighting factor (Figure 3). The scores are summarized in Table 16.

An additional ’Precedent’ category was included in the calculation to account for previous sightings found in the USGS Nonindigenous Species Database (USGS 2016), GLANSIS (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

Table 14. Risk assignments for individual target measures at Lake Erie locations. Risk was assessed for Lake Erie and Lake Huron locations cumulatively and is represented as H=high, M=medium, and L=low. Only Lake Erie locations are represented in the table below. Target measure 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
Maumee Bay	L	M	M	L	H	L	H		L	
Buffalo, NY/UNR	L	L	L	M	H	M	L	H	L	M
Sandusky Bay	H	H	L	M	L	L	L	M	L	
Erie, PA	L	L	L	L	L	L	M		L	M
Cleveland, OH	L	L	L	L	H	M	H	H	M	H
Western Lake Erie	L	L	L	L	L	L	L		L	
Port Clinton/ Marblehead, OH	L	L	L	L	L	L	L		L	
Detroit River	L	M	M	M	H	M	M		L	H
Lake St. Clair	L	L	M	L	H	H	L		L	
Ashtabula, OH	L	L	L	L	L	L	M		L	
Rocky River, OH	L	L	L	L	L	M	L		L	
St. Clair River	L	M	L	L	L	L	L		L	
Lake County, OH	L	L	L	L	L	L	L		L	
Lorain, OH	L	L	L	L	L	L	L		L	
Huron, OH	L	L	L	L	L	L	L		L	
Conneaut, OH	L	L	L	L	L	L	L		L	
Eastern Lake Erie	L	L	L	L	L	L	L		L	
Vermilion, OH	L	L	L	L	L	L	L		L	
Cooley Canal, OH	L	L	L	L	L	L	L		L	
Toussaint, OH	L	L	L	L	L	L	L		L	

Table 15. Risk assignment summary for individual vector categories at Lake Erie locations. Risk was assessed for Lake Erie and Lake Huron locations cumulatively and is represented as H=high, M= medium, and L=low. Only Lake Erie locations are represented in the table below. Vector category abbreviations are as follows: 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.

Water Area	F&A	Trade	Maritime	Canals	Illegal	Agency	Recreation	Tourism
Maumee Bay	L	L	H		L	L	L	
Buffalo, NY/UNR	L	M	L	H	M	L	L	M
Sandusky Bay	M	L	L	M	L	L	M	
Erie, PA	L	L	M		L	L	L	M
Cleveland, OH	L	M	H	H	M	M	L	H
Western Lake Erie	L	L	L		L	L	L	
Port Clinton/ Marblehead, OH	L	L	L		L	L	L	

Water Area	F&A	Trade	Maritime	Canals	Illegal	Agency	Recreation	Tourism
Detroit River	L	M	M		M	L	L	H
Lake St. Clair	L	M	L		H	L	L	
Ashtabula, OH	L	L	M		L	L	L	
Rocky River, OH	L	L	L		M	L	L	
St. Clair River	L	L	L		L	L	L	
Lake County, OH	L	L	L		L	L	L	
Lorain, OH	L	L	L		L	L	L	
Huron, OH	L	L	L		L	L	L	
Conneaut, OH	L	L	L		L	L	L	
Eastern Lake Erie	L	L	L		L	L	L	
Vermilion, OH	L	L	L		L	L	L	
Cooley Canal, OH	L	L	L		L	L	L	
Toussaint, OH	L	L	L		L	L	L	

Table 16. Vector scores by Lake Erie location. Vector scores were assessed for Lake Erie and Lake Huron locations cumulatively and are based on target measure scores for individual vectors multiplied by vector weights (values in bold, from Figure 3). Only Lake Erie locations are represented in the table below. Overall priority is represented as H=high, M=medium, and L=low. Vector category abbreviations are as follows: 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. 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**			
Maumee Bay *	0.51	0.38	0.57	0	0.08	0.05	0	0	2	3.59	H
Cleveland, OH	0.34	0.46	0.57	0.33	0.16	0.10	0	0	1	2.96	H
Sandusky Bay *	0.77	0.31	0.19	0.22	0.08	0.05	0	0	1	2.61	H
Erie, PA	0.34	0.23	0.38	0	0.08	0.05	0	0	1	2.08	M
Ashtabula, OH	0.34	0.23	0.38	0	0.08	0.05	0	0	1	2.08	M
Lorain, OH	0.34	0.23	0.19	0	0.08	0.05	0	0	1	1.89	M
Western Lake Erie	0.34	0.23	0.19	0	0.08	0.05	0	0	1	1.89	M
Port Clinton/Marblehead, OH	0.34	0.23	0.19	0	0.08	0.05	0	0		1.89	M
Detroit River *	0.60	0.54	0.38	0	0.16	0.05	0	0		1.72	M
Buffalo, NY/UNR	0.43	0.54	0.19	0.33	0.16	0.05	0	0		1.69	M
Lake St. Clair	0.43	0.54	0.19	0	0.24	0.05	0	0		1.44	M
Rocky River, OH	0.34	0.31	0.19	0	0.16	0.05	0	0		1.05	L
St. Clair River	0.43	0.23	0.19	0	0.08	0.05	0	0		0.98	L
Lake County, OH	0.34	0.23	0.19	0	0.08	0.05	0	0		0.89	L
Huron, OH	0.34	0.23	0.19	0	0.08	0.05	0	0		0.89	L
Conneaut, OH	0.34	0.23	0.19	0	0.08	0.05	0	0		0.89	L
Eastern Lake Erie	0.34	0.23	0.19	0	0.08	0.05	0	0		0.89	L
Vermilion, OH	0.34	0.23	0.19	0	0.08	0.05	0	0		0.89	L
Cooley Canal, OH	0.34	0.23	0.19	0	0.08	0.05	0	0		0.89	L
Toussaint, OH	0.34	0.23	0.19	0	0.08	0.05	0	0		0.89	L

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. Confirming the presence, but not significant establishment, of the species in the area would allow for rapid response with a high chance of success at eradication or control. Once a species is established it is more difficult to enact rapid response or provide control.

A precedent was included for six Lake Erie locations based on former findings of high risk species. Maumee Bay received a precedent rating of "2" due to a Silver Carp eDNA positive finding in the Maumee River in 2013 (USFWS 2016a) and a Grass Carp finding in 2013 (USGS 2015a). Erie, PA received a precedent rating of "1" due to Rudd sightings as recently as 2012 (USGS 2015b). Sandusky Bay, Western Lake Erie, Port Clinton/Marblehead, OH, Ashtabula, OH, Lorain, OH, and Cleveland, OH (Cuyahoga River) all received a precedent rating of "1" due to the presence of Grass Carp from 2010-2015 (USGS 2015a).

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 Erie locations have been analyzed for early detection monitoring (Table 16), however USFWS staffing levels and time restrictions limit the number of locations that can be surveyed in a given year. The Alpena FWCO's area of responsibility covers Lake Huron and western Lake Erie, and the Lower Great Lakes FWCO's area of responsibility covers eastern Lake Erie and Lake Ontario. Each office has prioritized sampling across their area of coverage 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: Alpena FWCO - Maumee Bay, Sandusky Bay, and Detroit River; Lower Great Lakes FWCO - Buffalo/upper Niagara River. These efforts continue a 3 year (2013-2015) dataset to quantify rare species detection at these locations. Sampling efforts will target ichthyoplankton, juvenile and adult fish, and benthic macroinvertebrates including bivalves and amphipods.

Maumee Bay, Michigan and Ohio

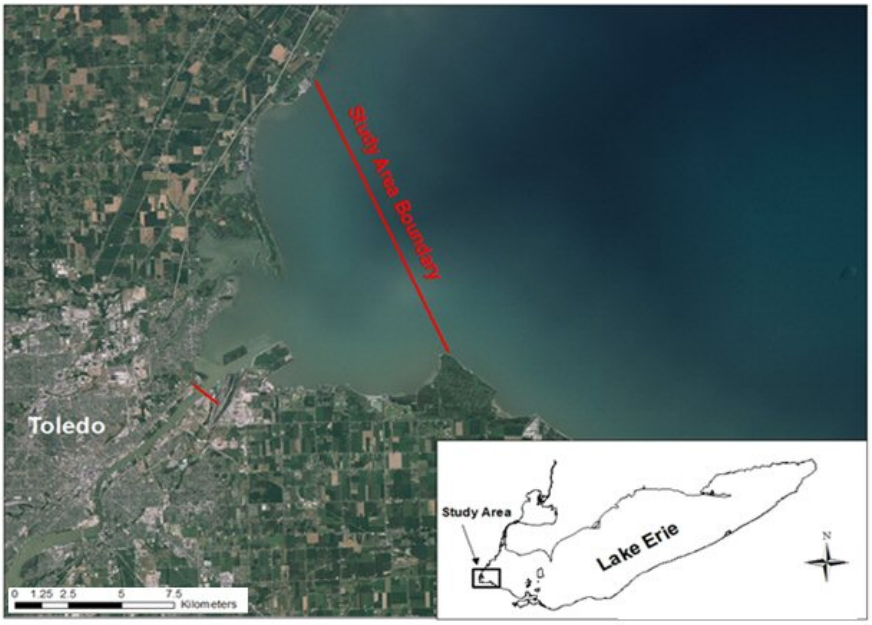

Figure 4. Maumee Bay showing 2013-2016 USFWS study area boundary.

Sampling effort and gears

Ichthyoplankton sampling, juvenile and adult fish sampling, and benthos sampling have been conducted in Maumee Bay annually from 2013 to 2015 and will continue in 2016 (Figure 4).

- Ichthyoplankton sampling: All ichthyoplankton sampling will occur at night. In 2016, 30 sites will be sampled during May-July. Effort will be distributed based on depth strata, with 20 sites sampled using 5-minute, surface bongo net tows and 10 sites sampled using quatrefoil light traps. Light traps will be used at sites less than 1m in depth; surface bongo tows will be used at sites of greater depth.

- 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.

- Benthos sampling: In 2016, 30 sites will be sampled during May-October. Amphipods will be targeted using experimental amphipod traps deployed at night. Bivalves will be collected using colonization samplers set for at least 1.5 months.

Sandusky Bay, Ohio

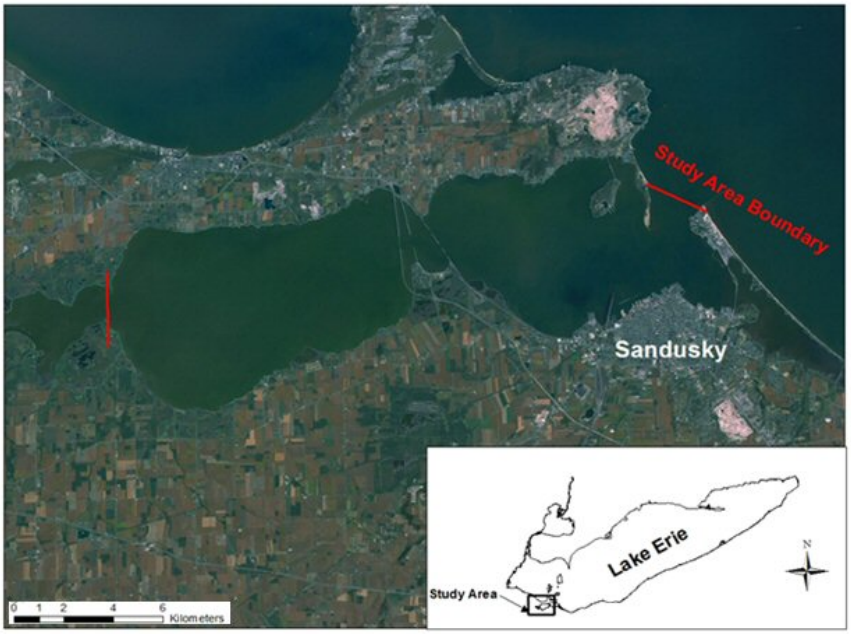

Figure 5. Sandusky Bay showing 2013-2016 USFWS study area boundary.

Sampling effort and gears

Ichthyoplankton sampling and juvenile and adult fish sampling have been conducted in Sandusky Bay annually from 2013 to 2015 and will continue in 2016 (Figure 5).

- Ichthyoplankton sampling: All ichthyoplankton sampling will occur at night. In 2016, 30 sites will be sampled during the course of May-July. Effort will be distributed based on depth strata, with 20 sites sampled using 5-minute, surface bongo net tows and 10 sites sampled using quatrefoil light traps. Light traps will be used at sites less than 1m in depth; surface bongo tows will be used at sites of greater depth.

- 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.

Buffalo/upper Niagara River, New York

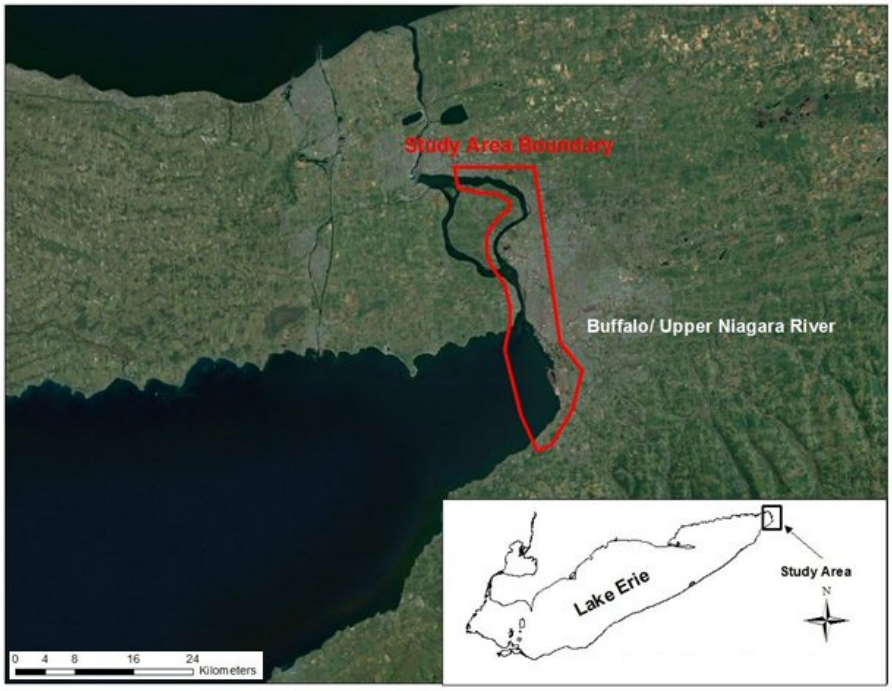

Figure 6. Buffalo/Upper Niagara River showing 2012-2016 USFWS study area boundary.

Sampling effort and gears

Ichthyoplankton sampling, juvenile and adult fish sampling, and benthos sampling will be conducted in the Buffalo/upper Niagara River in 2016 (Figure 6).

- Ichthyoplankton sampling: All ichthyoplankton sampling will occur at night. In 2016, 30 sites will be sampled during May-July. Effort will be distributed based on depth strata, with 20 sites sampled using 5-minute, surface bongo net tows and 10 sites sampled using quatrefoil light traps. Light traps will be used at sites less than 1m in depth; surface bongo tows will be used at sites of greater depth.

- Juvenile and adult fish sampling: In 2016, 70 sites will be sampled during June-October. Effort will be distributed among four gear types: paired fyke net overnight sets at 12 sites, daytime and nighttime electrofishing 600 s transects at 40 sites, daytime bottom trawling five-minute tows at 10 sites, and micro-mesh gill nets four-hour sets at 8 sites.

- Benthos sampling: In 2016, 20 sites will be sampled during May-October. Effort will be distributed among two gear types: benthic sled 2-minute tows (10 sites), and Hester-Dendy colonization sampler 36 day sets +/- 5 days (10 sites).

Detroit River, Michigan and Ontario

Figure 7. Detroit River showing 2013-2016 USFWS study area boundary.

Sampling effort and gears

Juvenile and adult fish sampling have been conducted in the Detroit River annually from 2013 to 2015 and will continue in 2016 (Figure 7).

- 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 minnow trap arrays at 15 sites.

Monitoring Program Progress and Evaluation

The Lower Great Lakes FWCO has been conducting non-native species early detection for juvenile and adult fish species and benthos since 2012 in western Lake Erie and the Buffalo/upper Niagara River using bottom trawls, daytime electrofishing, and a benthic sled. The Alpena FWCO joined sampling efforts during 2013, conducting non-native species detection for juvenile and adult fish species using bottom trawls, nighttime electrofishing, and paired fyke nets in Maumee Bay, Sandusky Bay, and the Detroit River. Sampling strategies were harmonized across all four Lake Erie sampling locations in 2013, modeling sampling strategy and gear types 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). Ichthyoplankton surveys were first conducted on Lake Erie at

Maumee and Sandusky Bays in 2013 and were added at the Buffalo/upper Niagara River location in 2014. A pilot study to examine benthos, including amphipods and bivalves, was initiated in Maumee Bay during 2013 and the Buffalo/upper Niagara River during 2014.

An evaluation of Lake Erie juvenile and adult fish sampling efforts was completed after the 2015 field season to estimate the rate at which new species were detected, the number of additional samples needed to detect 95% and 100% of the complete species richness, and identify sampling gears that captured the largest number of unique or rare fish species (USFWS 2016b).

Partnering Agencies

The scope of invasive species monitoring in a multi-jurisdictional system like Lake Erie is beyond the resource capabilities of any single agency. The USFWS will work collaboratively with partnering agencies including state, federal, provincial, academic, and non-governmental groups to fully implement strategic sampling for non-native species in Lake Erie. 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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