U.S. Fish and Wildlife Service

LAKE ERIE

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

MAY 2014

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Working Document Statement

This is a work in progress and was produced to guide U.S. Fish and Wildlife Service early detection monitoring efforts for non-native aquatic species on the Lake Erie system in 2014. The information included was based on the most contemporary data that could be compiled at the time with existing resources. Subsequent versions will include the best information available and able to be compiled at the time.

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 temporary 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 gobies *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 food webs 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., Eurasian ruffe *Gymnocephalus cernuus*) 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 trade, 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 (Great Lakes Water Quality Agreement 2012; Great Lakes Restoration Initiative 2010; USEPA 2008, Ryan et al. 2003). 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 (Lake Erie Lakewide Action and Management Plan, Annual Report 2013). 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 *In review*) by defining how the U.S. Fish and Wildlife Service (USFWS) will carry out invasive species detection in Lake Erie and its connecting channels of the St. Clair River, Lake St. Clair, Detroit River, and Upper Niagara River (Fig. 1). From a USFWS regional perspective, Lake Erie falls between two regional jurisdictions and fisheries activities on the lake are shared between the Region 3 Alpena Fish and Wildlife Conservation Office (Alpena FWCO) and the Region 5 Lower Great Lakes Fish and Wildlife Conservation Office (Lower Great Lakes FWCO). Region 3 coverage includes the states of Michigan and Ohio and Region 5 coverage includes the states of Pennsylvania and New York. The two offices are coordinating and working 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.

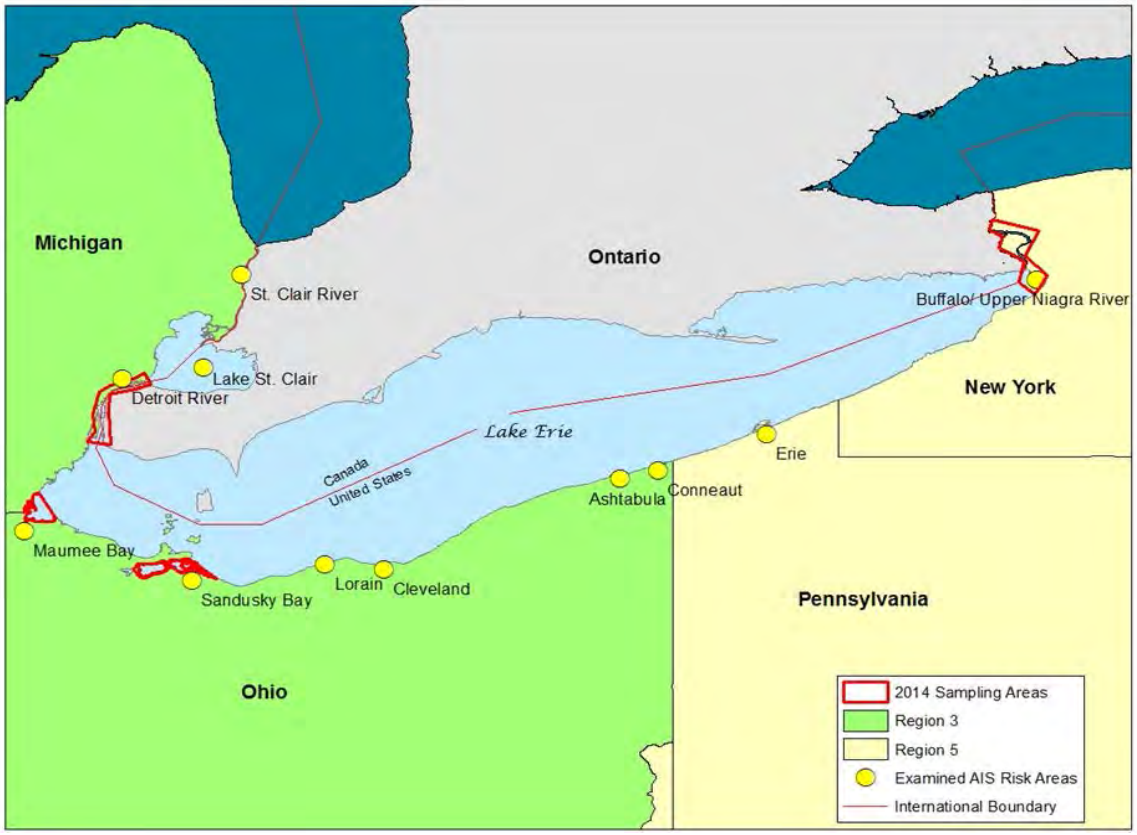

Figure 1. The Lake Erie Implementation Plan covers Lake Erie and its connecting channels of the St. Clair River, Lake St. Clair, Detroit River, and the Upper Niagara River. USFWS Regions 3 and 5 share fishery management on Lake Erie and are working in coordination to detect new non-native species.

The USFWS has conducted risk assessments for eleven Lake Erie locations (Fig. 1). The risk characterization was based on a vector risk analysis of pathways for invasive species introduction and an analysis of species of greatest risk to invade the Lake Erie basin. Based on the risk characterization, four locations will be sampled in 2014.

Risk Characterization

Vector Risk Analysis

Eight vectors have been identified and detailed by which non-native species may be introduced to the Laurentian Great Lakes (henceforth referred to simply as 'Great Lakes'): 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) (Fig. 2). The USFWS

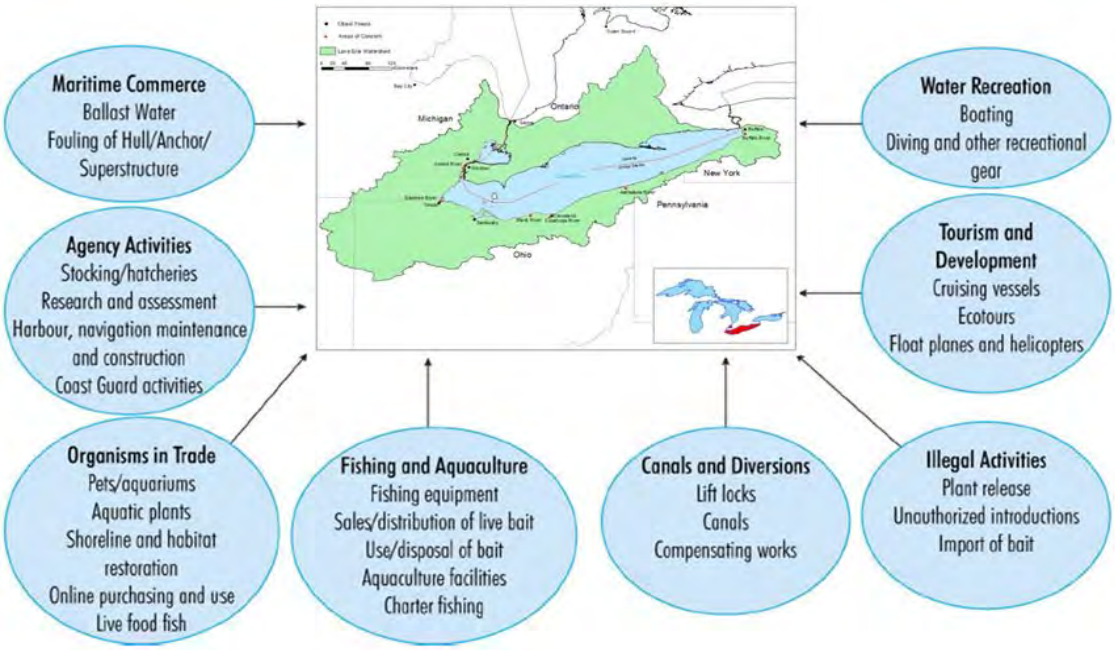

Figure 2. Vector and pathway concept map for Lake Erie (modified from Lake Superior Work Group 2010).

has prioritized these vectors for likelihood of non-native species introductions in Lake Erie based on historical introduction pathways for the Great Lakes (Fig. 3) and an assessment of vectors for invasive species currently found in the Lake Erie basin (Table 1). Relative importance of vectors can change over time, and, as such, this prioritization will be revisited annually. For 2014, vector risk for Lake Erie has been prioritized from highest to lowest risk as follows: 1) maritime commerce, 2) canals and water diversions, 3) fishing and aquaculture, 4) organisms in trade, 5) agency activities, 6) illegal activities,

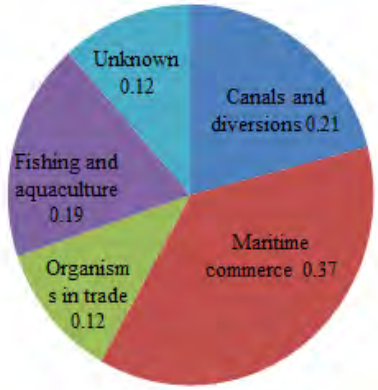

Figure 3. Sources of non-native fish, amphipod, and bivalve introductions to the Lake Erie system (USGS 2013). Numbers are proportions by which non-native species have been introduced. Numbers sum to 1.01 due to rounding. Note: Stocking activities by agencies were removed from consideration, as these values are to be used to weight vector risks for new non-native organisms, and agency stocking is not currently considered to be a source of likely introduction to Lake Erie; also see accompanying note for Table 1.

Table 1. Historical non-native fish, amphipod, and bivalve introductions to Lake Erie (USGS 2013). Vector codes are: M = maritime commerce, A = agency activities, C = canals and water diversions, F = fishing and aquaculture, O = organisms in trade, U = unknown. Note: the USGS Nonindigenous Aquatic Species database (2013) includes a disclaimer that information is not guaranteed to be correct. Some of the data regarding Lake Erie species could not be verified from the USGS 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
Alewife	*Alosa pseudoharengus*	C, A	canal, stocked, stocked for forage
American shad	*Alosa sapidissima*	A	stocked for food
White catfish	*Ameiurus catus*	F, A	Escaped captivity - aquaculture, stocked for sport
American eel	*Anguilla rostrata*	C	canal
Goldfish	*Carassius auratus*	O	aquarium release
River carpsucker	*Carpiodes carpio*	F	hitchhiker w/stocked fish
Unidentified pacu	*Colossoma* or *Piaractus*	O	aquarium release
Grass carp	*Ctenopharyngodon idella*	A	stocked for biocontrol
Common carp	*Cyprinus carpio*	F, A	escaped captivity - pond, bait release, stocked for food, stocked for forage
Gizzard shad	*Dorosoma cepedianum*	C	canal
Muskellunge	*Esox masquinongy ohioensis*	A	stocked for sport
Chain pickerel	*Esox niger*	A	stocked for sport
Banded killifish	*Fundulus diaphanus*	A	hitchhiker w/stocked fish
Blackstripe topminnow	*Fundulus notatus*	U	unknown
Western mosquitofish	*Gambusia affinis*	A	stocked for biocontrol
Eastern mosquitofish	*Gambusia holbrooki*	A	stocked for biocontrol
Threespine stickleback	*Gasterosteus aculeatus*	C, F, U	canal, bait release, unknown
Bighead carp	*Hypophthalmichthys nobilis*	F, A	escaped captivity aquaculture, stocked for biocontrol
Bigmouth buffalo	*Ictiobus cyprinellus*	A	stocked
Black buffalo	*Ictiobus niger*	C	canal
Redbreast sunfish	*Lepomis auritus*	A	stocked for sport
Green sunfish	*Lepomis cyanellus*	A	stocked for sport
Warmouth	*Lepomis gulosus*	A	stocked for sport
Orangespotted sunfish	*Lepomis humilis*	F, A	hitchhiker w/stocked fish, stocked for sport
Redear sunfish	*Lepomis microlophus*	A	stocked for sport
White perch	*Morone americana*	C	canal
White bass x white perch hybrid	*Morone chrysops x M. americana*	C	canal
Round goby	*Neogobius melanostomus*	M	shipping ballast water, dispersed
Ghost shiner	*Notropis buchanani*	F	bait release
Pink salmon	*Oncorhynchus gorbuscha*	F/A	hitchhiker w/stocked fish, stocked for sport
Coho salmon	*Oncorhynchus kisutch*	A	stocked for sport
Rainbow trout	*Oncorhynchus mykiss*	A	stocked for sport
Sockeye salmon	*Oncorhynchus nerka*	A	stocked for sport
Chinook salmon	*Oncorhynchus tshawytscha*	A	stocked for sport

Common Name	Scientific Name	Vector	USGS NAS pathway
Rainbow smelt	*Osmerus mordax*	A, U	stocked escaped, stocked for forage, unknown
Sea lamprey	*Petromyzon mainus*	C	canal
Suckermouth minnow	*Phenacobius mirabilis*	F	bait release
Red-bellied pacu	*Piaractus brachypomus*	O	aquarium release
Fathead minnow	*Pimephales promelas*	A	stocked
European flounder	*Platichthys flesus*	M	shipping ballast water
Freshwater tubenose goby	*Proterorhinus semilunaris*	M	shipping ballast water
Red piranha	*Pygocentrus nattereri*	O	aquarium release
Atlantic salmon	*Salmo salar*	A	stocked for sport
Brown trout	*Salmo trutta*	A	stocked escaped, stocked for sport
Brook trout	*Salvelinus fontinalis*	A	stocked for sport
Rudd	*Scardinius erythrophthalmus*	C, F, A	canal, bait release, stocked
Tench	*Tinca tinca*	A	stocked for sport
Asian clam	*Corbicula fluminea*	U	unknown
Zebra mussel	*Dreissena polymorpha*	M	shipping, shipping-ballast water
Quagga mussel	*Dreissena rostriformis bugensis*	M	shipping, shipping-ballast water
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
European fingernail clam	*Sphaerium corneum*	M	shipping
Amphipod	*Corophium mucronatum*	M	shipping
Scud	*Echinogammarus ischnus*	M, U	shipping, shipping-ballast water, unknown
Freshwater shrimp	*Gammarus fasciatus*	M	shipping-ballast water
Amphipod	*Gammarus tigrinus*	M	shipping

7) water recreation, and 8) tourism and development. Several target measures have been identified as ways to estimate risk of each the eight vector categories (Table 2). These target measures were not all able to be quantified at the time this implementation plan was written, but they are recommended to be used in the future for assessing vector category risk.

Table 2. Target measures to assess risk of vectors at potential monitoring sites for non-native aquatic species in the Great Lakes. 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			
Bait shops/capita					X			

Target Measure	Maritime	Agency	Canals	Trade	F&A	Recreation	Tourism	Illegal
Ballast discharge	X							
Boat ramp spaces					X	X		
Charter boats					X			
Commerce barges	X							
Commercial fishing					X			
Cruising vessels							X	
Ecotourism							X	
Fish markets/capita				X				
Float aircraft							X	
Harbor slips					X	X		
Live bait usage					X			
NOBOB discharge	X							
Pet shops/capita				X				
Population				X				X
Science sampling		X						
Shipping maintenance		X						
Water connections			X					
Work barges		X						

Maritime Commerce

Based on historical precedent, this was determined to be the vector of greatest risk by which non-native species would likely be introduced to Lake Erie (Fig. 3). The factors falling under this category include ballast water discharged from ships entering the Great Lakes coming from foreign ports with either ballast water in their tanks or claiming no ballast on board (NOBOB), ballast water transport by commercial ships operating within the Great Lakes system, and barges being moved around both from outside and within the Great Lakes.

Ballast water from commercial ships has been 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). During 2006-2007, four Lake Erie ports (Toledo, Erie, Lorain, and Ashtabula) were among 13 U.S. Great Lakes ports that received ballast water discharges from ships that originated outside the Great Lakes (USEPA 2008). These Lake Erie ports ranked 2, 10, 11, and 13, respectively (Table 3), of ports that received the greatest frequency of discharge (tanks discharged).

Ships entering the Great Lakes claiming NOBOB status can transport non-native species to the system, particularly invertebrates. During 2006, six Lake Erie ports (Toledo, Ashtabula, Sandusky, Conneaut, Buffalo, and Lorain) were among 14 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 (NOBOB), picked up ballast water in the Great Lakes, and then deposited that water at a different Great Lakes port (USEPA 2008). These Lake Erie ports ranked 1, 3, 5, 9, 10, and 12, respectively (Table 4), in order of frequency of NOBOB vessel ballast tank discharge.

Table 3. Ballast water discharges at U.S. Great Lakes ports during 2006-2007. Includes only vessels whose original source of ballast water (prior to ballast water exchange) came from outside the Great Lakes (USEPA 2008).

U.S. Great Lake Port	Tanks Discharged	Volume Discharged (metric tons)	Vessels Discharging
Duluth	407	184,844	58
Toledo	85	65,335	13
Superior	50	78,085	10
Green Bay	18	5,984	4
Gary	17	11,154	4
Milwaukee	11	10,768	2
Oswego	8	1,239	5
Chicago	7	17,916	3
Ludington	5	1,913	1
Erie	4	490	1
Lorain	3	2,320	3
Menominee	2	380	2
Ashtabula	1	1,500	1

Table 4. Frequency and volume of ballast tank discharges into U.S. Great Lakes ports from NOBOB vessels during 2006 (USEPA 2008).

U.S. Great Lakes Port	Tanks Discharged	Volume Discharged (metric tons)
Toledo	353	511,181
Superior	340	524,446
Ashtabula	297	579,785
Duluth	289	379,999
Sandusky	116	243,137
Milwaukee	89	68,522
Gary	60	52,987
Chicago	48	76,607
Conneaut	43	76,335
Buffalo	37	73,197
Calumet	30	33,974
Lorain	13	25,729
Two Harbors	8	13,444
Brevort	7	20,914

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.

Relative risk of non-native species introductions via maritime commerce was calculated based on a combination of ballast water discharge from ships entering the Great Lakes with ballast on board as well as NOBOB vessels. To account for greater risk associated with ships entering the Great Lakes with ballast on board, values for Lake Erie ports from Tables 3 and 4 were normalized based on the proportion of species of primary concern (Table 8 in the Species of Greatest Concern/Risk section of this plan) that would likely be transported in ships entering the Great Lakes carrying ballast water (all types of organisms, 32 species) vs. NOBOB vessels (only amphipods and bivalves, 9 species). This resulted in multiplying NOBOB ballast values by 0.28 since 28% of the species of concern were likely to be introduced by NOBOB vessels. Risk scores were then calculated for each port by adding the normalized values for both types of vessels when applicable, determining proportion of values for each site, and then ranking sites as high, medium, or low risk based on proportion of threat (high = at least 0.5, medium = at least 0.15 to 0.49, low = less than 0.15) (Table 5). Assignment of threat category was based on natural numerical split.

Table 5. Risk assessment of maritime commerce activities in Lake Erie ports based on normalized ballast water discharge values reported for 2006 and 2007 (USEPA 2008). Proportions listed in parentheses are weighted values used in risk determination.

U.S. Lake Erie Port	Tanks Discharged	Volume Discharged (metric tons)	Risk
Toledo	184 (0.55)	433,385 (0.25)	High
Ashtabula	84 (0.25)	998,730 (0.58)	Medium
Sandusky	32 (0.10)	175,058 (0.10)	Low
Conneaut	12 (0.04)	54,961 (0.03)	Low
Buffalo	10 (0.03)	52,701 (0.03)	Low
Lorain	7 (0.02)	20,844 (0.01)	Low
Erie	4 (0.01)	490 (0.00)	Low

Canals and Water Diversions

Canals and water diversions can open pathways for non-native species to enter the Great Lakes. Historically, many species were able to enter the upper Great Lakes, specifically Lake Erie, when the Welland Canal opened water access for organisms to swim 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 into Lake Erie. There are seven primary canals and water diversions that may allow non-native species to enter Lake Erie (Table 6). 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 *Mylopharyngodon piceus*. Historically, canals and water diversions have accounted for approximately 21% of non-native aquatic species introductions to Lake Erie (Fig. 3).

Fishing and Aquaculture

Ten non-native species have been reported in Lake Erie as a result of fishing or aquaculture operations (Table 1). Anglers and commercial harvesters have the potential to transport non-native species with or on their fishing equipment or boats and some invasive species can survive for long periods inside boat livewells. Even so, fishing equipment has not been identified as a source of non-native fish, amphipod, or bivalve introduction in Lake Erie. The sale and use of 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 does not routinely occur in Lake Erie, although it does occur in the Great Lakes basin, and these fish may be distributed to other Great Lakes locations. Each governmental jurisdiction in the Lake Erie Basin addresses the sale and distribution of live bait through its own regulations. The illegal import of bait is also a concern for this vector category.

Table 6. Canals and other hydrologic connections that may create pathways for introduction of invasive species to Lake Erie from other basins. An "*" indicates a connection identified by the USACOE GLMRIS (2011).

Closest Site	Connector	Connection Between (basins)	Risk
Maumee	Eagle Marsh*	Mississippi and GL	High
Cleveland	Long Lake*	Mississippi and GL	Medium
Cleveland	Little Killbuck Creek*	Mississippi and GL	Medium
Sandusky	Grand Lake-St Mary's*	Mississippi and GL	High
Buffalo/UNR	East Mud Lake*	Mississippi and GL	Medium
Buffalo/UNR	Erie Canal	Hudson and GL	Medium
Buffalo/UNR	Welland Canal	Passage up Niagara Falls	Low

Many target measures could prove useful for assessing risk by site of this vector category (Table 2), and ideally, angling effort, presence of aquaculture operations, number of bait shops/capita, number of boat ramp spaces, number of charter fishing operations, presence of commercial fishing operations, number of harbor slips, and the frequency of live bait usage are all factors that would be considered in the future. For 2014 vector risk assessment, population (Table 7) was used as a surrogate measure, as data for the target factors were not able to be compiled and analyzed before field plans needed to be made.

Organisms in Trade

Most aquatic animals in pet stores are not native to the Great Lakes and many believe it is humane to release their unwanted pet into a nearby waterway. Historically, four species have been identified as being introduced to Lake Erie via this vector category (Table 1), and this remains an important means for new non-native species introductions. For example, fancy goldfish *Carassius auratus* have been caught during recent USFWS sampling efforts in the River Raisin, and aquarium fish were found in a pet store bag floating on the Erie Canal (Scott Sanders, USFWS, personal communication). For risk assessment of

this vector for Lake Erie, population size and pet shops or fish markets per capita were target metrics. The top population centers for the Lake Erie system are metropolitan areas (Table 7). Data on pet shops and fish markets per capita were not found.

Table 7. Top population centers around the Lake Erie system based on most recent census values (Statistics Canada 2011, U.S. Census Bureau 2012). Values represent city populations rather than greater metropolitan area populations. Proportional risk categories were assigned high (at least 0.20), medium (between 0.10 and 0.19), and low values (less than 0.10). Assignment of risk category was based on natural numerical split.

City	State/Province	Population	Risk
Detroit/Windsor	Michigan/Ontario	1,020,721 (0.44)	High
Cleveland	Ohio	390,928 (0.17)	Medium
Toledo	Ohio	284,012 (0.12)	Medium
Buffalo	New York	259,384 (0.11)	Medium
Erie	Pennsylvania	101,047 (0.04)	Low
Sarnia	Ontario	72,366 (0.03)	Low
Lorain	Ohio	63,707 (0.03)	Low
Port Huron	Michigan	29,684 (0.01)	Low
LaSalle	Ontario	28,643 (0.01)	Low
Leamington	Ontario	28,403 (0.01)	Low
Sandusky	Ohio	25,493 (0.01)	Low
Monroe	Michigan	20,535 (0.01)	Low
Painesville	Ohio	19,634 (0.01)	Low
Ashtabula	Ohio	18,811 (0.01)	Low

Agency Activities

A variety of agencies are responsible for maintaining navigation and shipping/boating structures and commerce routes. They employ barges and various vessels to conduct maintenance activities. Such maintenance activities could result in the potential introduction of non-native species to new areas. For example, in 2001, two barges with hulls carrying zebra mussels from the lower Great Lakes were transported to Lake Superior sites (Marquette, Duluth-Superior harbor, then Isle Royale) to serve as maintenance work platforms (Lake Superior Work Group 2010). 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 routinely moved to new assessment areas. Fishery agencies actively take preventative measures to prevent transfer of species and pathogens. Strict survey and disinfection policies must continue to prevent spread of species to new areas.

Historically, many species were stocked in Lake Erie for various purposes by management agencies (Table 1), but these stockings primarily occurred in the late 1800s and early 1900s. Stocking activities by agencies is not currently a likely source of new non-indigenous species introduction to Lake Erie.

Illegal Activities

This vector accounts for activities such as illegal stocking of fish or intentional release of other organisms. Regulations involving the sale and transport of species 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 their harmful nature and negative effect on existing recreational, commercial, and bait fisheries (USFWS 2006). The number of species introduced to Lake Erie through unauthorized releases is uncertain. However, grass carp *Ctenopharyngodon idella* 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. Lacking a measurable way to estimate the risk of this vector, population (Table 7) was used as a surrogate measure.

Water Recreation

Water recreation activities involve many types of equipment in addition to boats (e.g., jet skis, water skis, wake boards, pull ropes, flotation devices, snorkeling/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 other recreational gear has not been identified as a mechanism for non-native species introductions in Lake Erie. Population (Table 7) was used to estimate risk for this vector category.

Tourism and Development

Cruising vessels, ecotours, helicopters, and float planes provide potential pathways for the introduction of non-native species into Lake Erie via tourism and development. Even so, no non-native species have been reportedly introduced to Lake Erie through tourism and development. Population (Table 7) was used to estimate risk for this vector category.

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 in this Lake Erie implementation plan (Table 8) 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 2014).

Table 8. Non-native species of particular focus for USFWS early detection monitoring activities in the Lake Erie watershed for 2014. 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	Killer shrimp	*Dikerogammarus villosus*	M	PC	13 - 30[7]	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		*Dikerogammarus haemobaphes*	M	PC	10 - 25.6[1]		A, B, C, D
A		*Echinogammarus warpachowskyi*	M	PC			A, B, C, D
A		*Pontogammarus aralensis*	M	PC			A, B, C, D
A		*Pontogammarus robustoides*	M	PC	7.5 - 24.2[4]	S, V, 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		*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	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	Blue catfish +	*Ictalurus furcatus*	F, I	NA	21 - 24[23]		L, P

Type	Common name	Scientific name	Vector(s)	Donor region	Reproduction & larval temp. (C)	Habitat	Potential effective gear
F	Blueback herring *	*Alosa aestivalis*	C, F, M	NA	14 - 27[3]		E, G, L, P
F	Bullhead	*Cottus gobio*	F, O	E	7.5 - 13.5[15]	G	L, P
F	Caucasian goby	*Knipowitschia caucasica*	M	PC		V, G, Z	L, P
F	Common 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 ruffe *	*Gymnocephalus cernuus*	C, F, M	PC	10 - 20[11]		L, P
F	European whitefish (vendace)	*Coregonus albula*	F	E	2-7[18]	S, G	G, L, P
F	Grass carp !	*Ctenopharyngodon idella*	F, I, O	A	15 - 30[2]	V	E, G, L, P, S
F	Monkey goby	*Neogobius fluviatilis*	M	A, E	>13[22]	V, G, Z	E, T, L, P, S
F	Roach	*Rutilus rutilus*	F	PC	8 - 14[14]	V, LE	E, F, 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	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	Zander +	*Sander lucioperca*	C, F	PC	8 - 15[21]	G, LE	G, L, P

Key for codes listed in Table 4:

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

Table 8 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 (2008), [20]Kennedy (1969), [21]Cultured Aquatic Species Information Programme (2014), [22]Kottelat and Freyhof (2007), [23]Graham (1999), [24]Bengtsson (1974), [25]Freyhof and Kottelat (2008), [26]Kehayias et al. (2004), [27]Sandstrom et al. (1997)

2014 Priority Sampling

The warm shallow waters of Lake Erie tend to provide ideal habitats for invasive species to become established and multiply. The USFWS early detection monitoring program will focus sampling efforts for non-native fish and macroinvertebrates on areas vulnerable to multiple vectors and with environmental conditions favorable for high-risk organisms. Below is the scored list of locations that have been considered for early detection of new non-native species (Table 9). Vectors were weighted based on historical sources of non-native fish, amphipods, and bivalve introductions to the Lake Erie system (Fig.3), with the four vectors fitting into the 'unknown' category being assigned weights according to potential historical introductions. The risk value associated with each vector per site was based on vector risk descriptions from Tables 5, 6, and 7 (high risk = 3, medium risk = 2, and low risk = 1). An additional "Precedent" category was included in the calculation to account for previous introductions or known imminent risk of introduction of high priority species. Sandusky and Maumee bays received precedence ratings for 2014 sampling due to imminent risk of bighead and silver carp invasion from temporal connecting waterways upstream from these locations. Table 10 shows ultimate ranking for Lake Erie sites considered at risk for non-native species introductions. 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 9. Lake Erie priority sample site scores and vector weighting factors. Vector codes are: Maritime = maritime commerce, Canals = canals and diversions, F&A = fishing and aquaculture, Trade = organisms in trade, Agency = agency activities, Illegal = illegal 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.

	Maritime	**Canals**	**F&A**	**Trade**	**Agency**	**Illegal**	**Recreation**	**Tourism**	**Precedent**	
Weight factor	**0.37**	**0.21**	**0.19**	**0.12**	**0.04**	**0.04**	**0.02**	**0.02**		
Site										**Score**
Maumee Bay	3	3	2	2	3	2	2	2	1	3.64
Sandusky Bay	1	3	1	1	1	1	1	1	1	2.43
Cleveland	1	2	2	2	1	2	2	2		1.61
Buffalo/Upper Niagara River	1	2	2	2	1	2	2	2		1.61
Detroit River	1	0	3	3	1	3	3	3		1.58
Ashtabula	2	0	1	1	2	1	1	1		1.21
St. Clair River	1	0	1	1	1	1	1	1		0.8
Lake St. Clair	1	0	1	1	1	1	1	1		0.8
Lorain	1	0	1	1	1	1	1	1		0.8
Erie	1	0	1	1	1	1	1	1		0.8
Conneaut	1	0	1	1	1	1	1	1		0.8

Table 10. Lake Erie sites of particular concern for introduction of non-native fishes, amphipods, and bivalves showing vector(s) of potential introduction and USFWS sample priority ranking. Vector 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; Illegal = illegal activities. These prioritizations were numerically scored, and relative risk was calculated for each site. The order of priority is reflected in this table, and priority levels were assigned based on the proportional scores calculated in Table 9 (High = greater than 10%, Medium = 6-10%, Low = 0-5%). The "*" denotes sites to be sampled in 2014.

Site	Maritime	Canals	F&A	Trade	Agency	Illegal	Recreation	Tourism	Precedent	Priority
Maumee Bay*	H	H	M	M	H	M	M	M	H	High
Sandusky Bay*	L	H	L	L	L	L	L	L	H	High
Cleveland	L	M	M	M	L	M	M	M		Medium
Buffalo/UNR*	L	M	M	M	L	M	M	M		Medium
Detroit River*	L		H	H	L	H	H	H		Medium
Ashtabula	M		L	L	M	L	L	L		Medium
St. Clair River	L		L	L	L	L	L	L		Low
Lake St. Clair	L		L	L	L	L	L	L		Low
Lorain	L		L	L	L	L	L	L		Low
Erie	L		L	L	L	L	L	L		Low
Conneaut	L		L	L	L	L	L	L		Low

Although a number of Lake Erie locations have been analyzed for early detection monitoring, 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 2014, the following Lake Erie locations will be sampled: Maumee Bay, Sandusky Bay, Detroit River, and Buffalo/Upper Niagara River (Table 10).

The majority of sampling efforts across each office's area of responsibility fall in the Lake Erie basin in 2014 due to concerns with the invasion of Asian carp 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 will target ichthyoplankton, juvenile and adult fish, and benthic macroinvertebrates including bivalves and amphipods.

The sampling strategy for early detection of invasive species at priority locations was designed to detect rare species. We presumed 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. Limits due to time and staffing indicate that adequate samples will be collected after approximately three years. 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.

2014 Sampling Locations

Maumee Bay, Michigan and Ohio

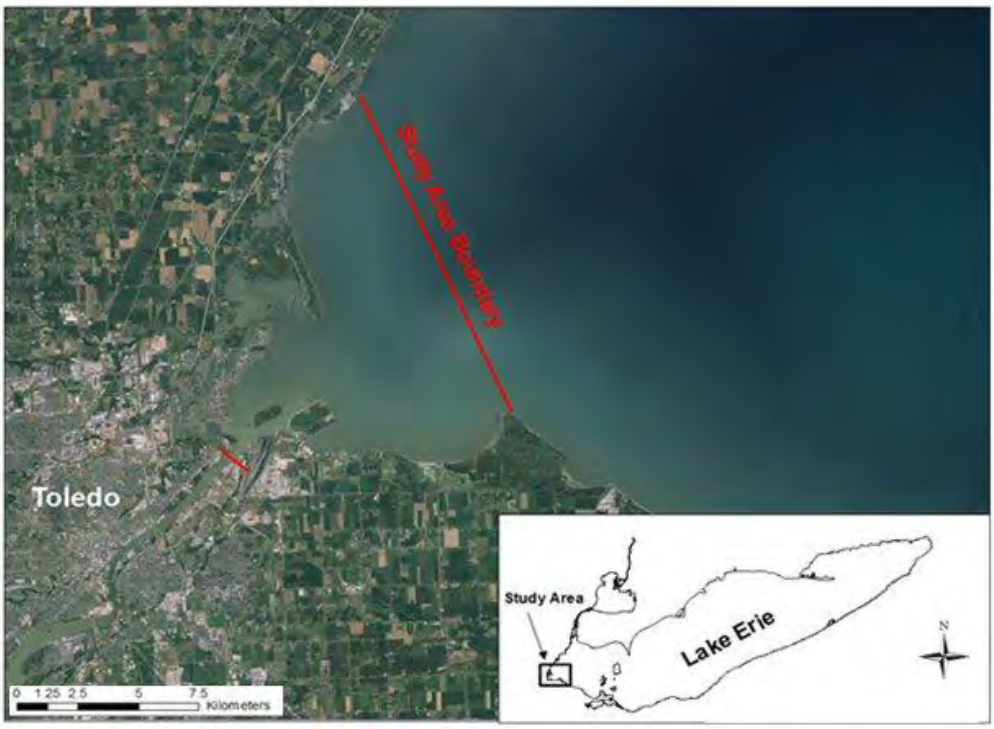

Figure 4. Maumee Bay showing 2014 USFWS study area boundary.

Sampling effort and gears

Ichthyoplankton sampling, juvenile and adult fish sampling, and benthos sampling will be conducted in Maumee Bay during 2014 (Fig. 4).

- Ichthyoplankton sampling: All ichthyoplankton sampling will occur at night. During 2014, 60 sites will be sampled during May-July. Effort will be distributed based on depth strata, with 42 sites being sampled by 5-minute, surface bongo net tows and 18 sites being covered using quatrefoil light traps.

- Juvenile and adult fish sampling: During 2014, 45 sites will be sampled during late summer (August-October). Effort will be distributed equally among three gear types: paired fyke net overnight sets (15 sites), nighttime electrofishing 600 s transects (15 sites), and daytime bottom trawling five minute tows (15 sites).

- Benthos sampling: In 2014, 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 and night plankton net tows (to collect veliger larvae). Benthic sled (need SOP also) 30 sites will be sampled during July-October nighttime sampling 2 min tows.

Sandusky Bay, Ohio

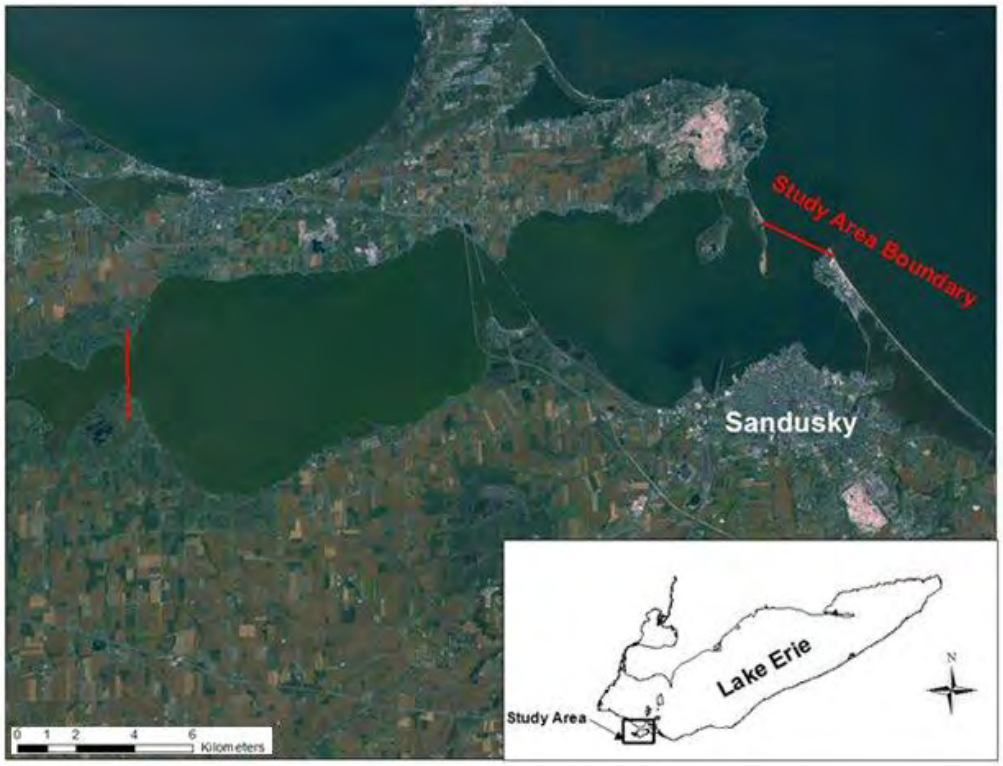

Figure 5. Sandusky Bay showing 2014 USFWS study area boundary.

Sampling effort and gears

Ichthyoplankton sampling and juvenile and adult fish sampling will be conducted in Sandusky Bay during 2014 (Fig. 5).

- Ichthyoplankton sampling: All ichthyoplankton sampling will occur at night. During 2014, 60 sites will be sampled during the course of May-July. Effort will be distributed based on depth strata, with 44 sites being sampled by 5-minute, surface bongo net tows and 16 sites being covered using quatrefoil light traps.

- Juvenile and adult fish sampling: During 2014, 45 sites will be sampled during late summer (August-October). Effort will be distributed equally among three gear types: paired fyke net overnight sets (15 sites), nighttime electrofishing 600 s transects (15 sites), and daytime bottom trawling five minute tows (15 sites).

Buffalo/Upper Niagara River, New York

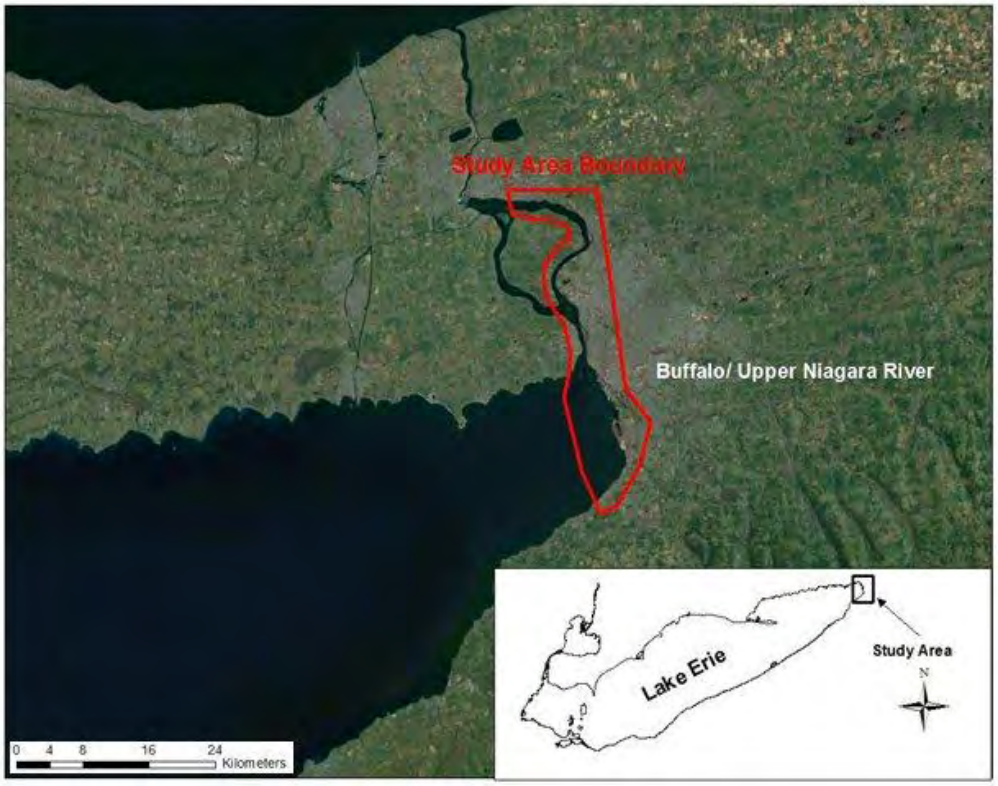

Figure 6. Buffalo/Upper Niagara River showing 2014 USFWS study area boundary.

Sampling effort and gears

Ichthyoplankton sampling, juvenile and adult fish sampling, and benthos sampling will be conducted in Buffalo/Upper Niagara River during 2014 (Fig. 6).

- Ichthyoplankton sampling: All ichthyoplankton sampling will occur at night. During 2014, 60 sites will be sampled during May-July. Effort will be distributed based on depth strata, with 42 sites being sampled by 5-minute, surface bongo net tows and 18 sites being covered using quatrefoil light traps.

- Juvenile and adult fish sampling: During 2014, 100 sites will be sampled (May-October). Effort will be distributed among three gear types: paired fyke net overnight sets (20 sites), daytime and nighttime electrofishing 600 s transects (50 sites), and daytime bottom trawling five-minute tows (30 sites).

- Benthos sampling: In 2014, 60 sites will be sampled during May-October. Amphipods will be targeted using experimental amphipod traps deployed at night, and benthic sled two-minute tows.

Detroit River, Michigan and Ohio

Figure 7. Detroit River showing 2014 USFWS study area boundary.

Sampling effort and gears

Juvenile and adult fish sampling will be conducted in the Detroit River during 2014 (Fig. 7).

- Juvenile and adult fish sampling: During 2014, 45 sites will be sampled during late summer (August-October). Effort will be distributed equally among three gear types: paired fyke net overnight sets (15 sites), nighttime electrofishing 600 s transects (15 sites), and minnow trap arrays (15 sites).

  .

Monitoring Program Progress and Evaluation

The Lower Great Lakes FWCO has been conducting invasive species early detection for juvenile and adult fish species and benthos in western Lake Erie, and the Buffalo/Upper Niagara River using bottom trawls, daytime electrofishing, and a benthic sled since 2012. The Alpena FWCO joined sampling efforts in Sandusky Bay and Maumee Bay during 2013, conducting invasive species detection for juvenile and adult fish species using bottom trawls, nighttime electrofishing, and paired fyke nets in Maumee Bay, Sandusky Bay, and the the Detroit River. Ichthyoplankton surveys were also conducted at Maumee and Sandusky Bays in 2013, and a pilot study to examine benthos was initiated in Maumee Bay during 2013. Sampling strategy and gear types for 2013 sampling 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 Maumee Bay, Sandusky Bay, and Detroit River sampling efforts will be completed after the field season in 2015 to determine the following: the appropriate sampling gear mixtures to maximize the number of fish species detected, estimate the rate at which new species were detected, and estimate the number of additional samples needed to detect 95% and 100% of the complete species richness (Hoffman et al. in preparation).

Survey efforts including targeted sampling for larval, juvenile, and adult fishes as well as amphipods and bivalves are being initiated in Buffalo/Upper Niagara River in 2014. An evaluation of those efforts will completed after the field season in 2015 to 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.

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 invasive species monitoring 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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