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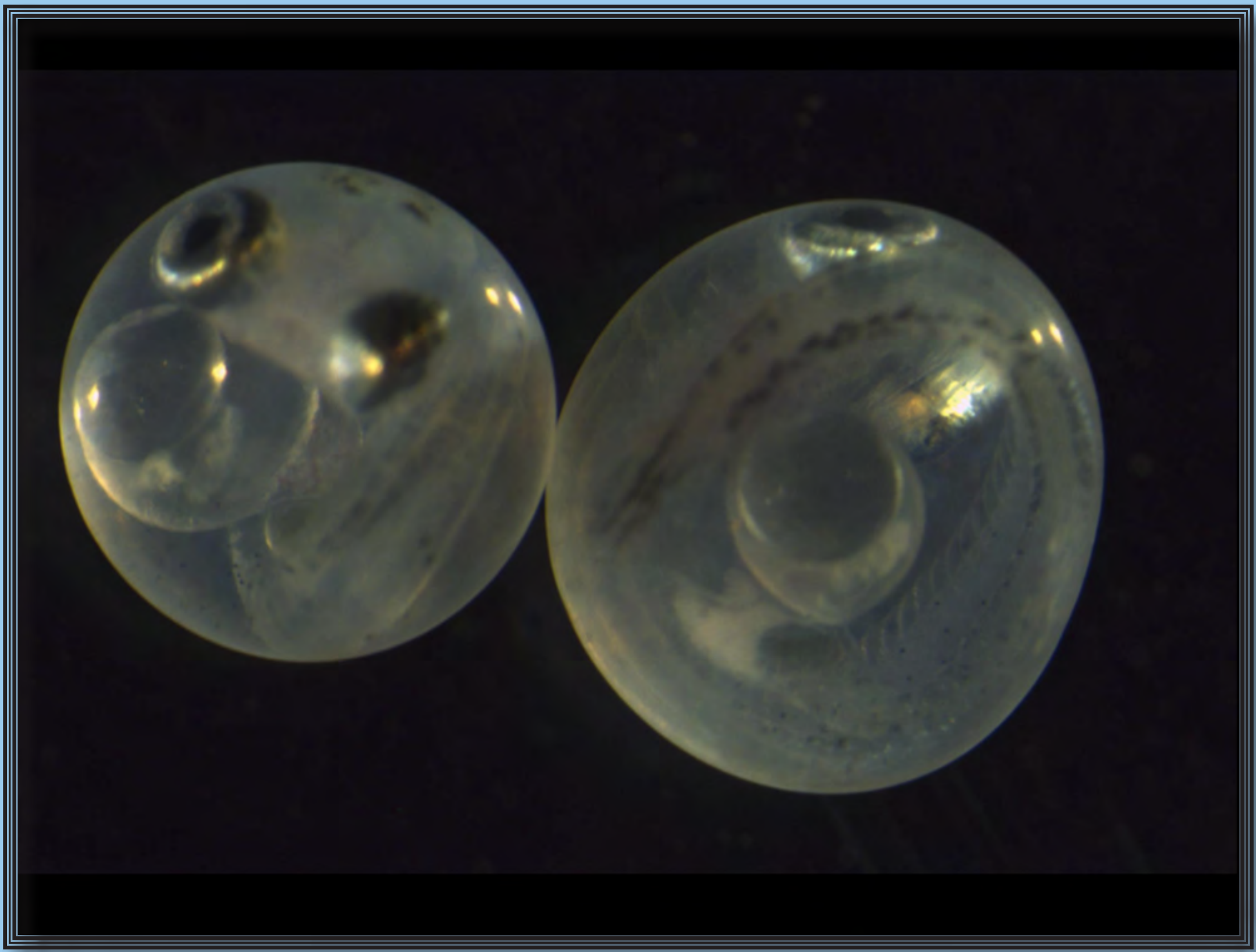
Egg Deposition by Lithophilic-Spawning Fishes in the Detroit and Saint Clair Rivers, 2005–14



Scientific Investigations Report 2017–5003

U.S. Department of the Interior
U.S. Geological Survey

Cover. Viable lake whitefish eggs collected from the Detroit River. Photograph by U.S. Geological Survey Great Lakes Science Center staff.

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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.394	inch (in)
meter (m)	3.28	foot (ft)
kilometer (km)	0.621	mile (mi)
	Area	
hectare (ha)	2.47	acre
square meter (m^2)	10.8	square foot (ft^2)
hectare (ha)	0.00386	square mile (mi^2)
	Volume	
cubic meter (m^3)	35.3	cubic feet (ft^3)
	Flow rate	
meter per second (m/s)	3.28	foot per second (ft/s)
cubic meter per second (m^3/s)	35.3	cubic foot per second (ft^3/s)
	Mass	
kilogram (kg)	2.20	pound (lb)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as

$$°F = (1.8 \times °C) + 32$$

Abbreviations

CPUE catch-per-unit effort

GLSC Great Lakes Science Center

SCDRS Saint Clair-Detroit River System

USGS U.S. Geological Survey

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Abstract

A long-term, multiseason, fish egg sampling program conducted annually on the Detroit (2005–14) and Saint Clair (2010–14) Rivers was summarized to identify where productive fish spawning habitat currently exists. Egg mats were placed on the river bottom during the spring and fall at historic spawning areas and candidate fish spawning habitat restoration sites throughout both rivers. Widespread evidence was found of lithophilic spawning by numerous native fish species, including walleye (*Sander vitreus*), lake whitefish (*Coregonus clupeaformis*), lake sturgeon (*Acipenser fulvescens*), suckers (Catostomidae spp.), and trout-perch (*Percopsis omiscomaycus*). Walleye, lake whitefish, and suckers spp. spawned in nearly every region of each river in all years on both reef and nonreef substrates. Lake sturgeon eggs were collected almost exclusively over constructed reefs. Catch-per-unit effort of walleye, lake whitefish, and sucker eggs was much greater in the Detroit River than in the Saint Clair River, while Saint Clair River sites supported the greatest collections of lake sturgeon eggs. Collections during this study of lake sturgeon eggs on man-made spawning reefs suggest that artificial reefs may be an effective tool for restoring fish populations in the Detroit and Saint Clair Rivers; however, the quick response of lake sturgeon to spawn on newly constructed reefs and the fact that walleye, lake whitefish, and sucker eggs were often collected over substrate with little interstitial space to protect eggs from siltation and predators suggests that lack of suitable spawning habitat may continue to limit reproduction of lithophilic-spawning fish species in the Saint Clair-Detroit River System.

Introduction

The Saint Clair-Detroit River System (SCDRS) is the 148-kilometer (km) long waterway connecting Lakes Huron, Saint Clair, and Erie and forms a portion of the international border between Canada and the United States (fig. 1). At the turn of the 20th century, 28 native fish species spawned in the SCDRS including walleye (*Sander vitreus*), lake whitefish (*Coregonus clupeaformis*), cisco (*Coregonus artedi*), and lake sturgeon (*Acipenser fulvescens*) (Goodyear and others, 1982) that all contributed to a thriving commercial fishery (Baldwin and others, 2009); however, habitat changes from over a century of shipping channel excavation and dredging, shoreline development, and pollution cumulatively resulted in huge losses of fish spawning and nursery habitats (Edsall and others, 1988; Manny and others, 1988; Bennion and Manny, 2011). These perturbations, in combination with heavy commercial fishing pressure, led to large-scale losses of fish populations in these rivers, including the local extirpations of cisco and lake trout (*Salvelinus namaycush*) (Smith, 1972), the near extirpation of lake whitefish (Smith, 1915, 1917; Roseman and others, 2007), and declines in walleye (Manny and others, 2010) and lake sturgeon (McClain and Manny, 2000; Manny and Kennedy, 2002). Although the extents to which overfishing, habitat alterations, and pollution contributed to the declines of each species likely vary, perpetual habitat modifications that succeeded their declines currently inhibit their recovery to former levels of abundance (Hondorp and others, 2014). Specifically, the lack of suitable spawning habitat limits the restoration of lake sturgeon (Manny and others, 2005) and likely other lithophilic-spawning fishes in the SCDRS.

Since 2004, the Saint Clair–Detroit River System Initiative has coordinated research and management efforts towards science-based restoration of environmental services within the SCDRS and the Great Lakes Basin (http://www.scdrs.org). This initiative is a binational partnership of Federal, State, provincial, academic, First Nations, and private sector entities whose primary objective is restoring functional fish spawning habitat. The SCDRS Initiative required contemporary information on the locations of functional fish spawning habitat throughout the SCDRS to direct restoration efforts to areas where (1) new habitat may be most effective, and (2) the deleterious effects of altering habitats presently supporting fish spawning may be avoided.

Little direct evidence of fish egg deposition in the SCDRS exists. Of the 28 native species that historically spawned in the SCDRS, most spawned in tributaries to the

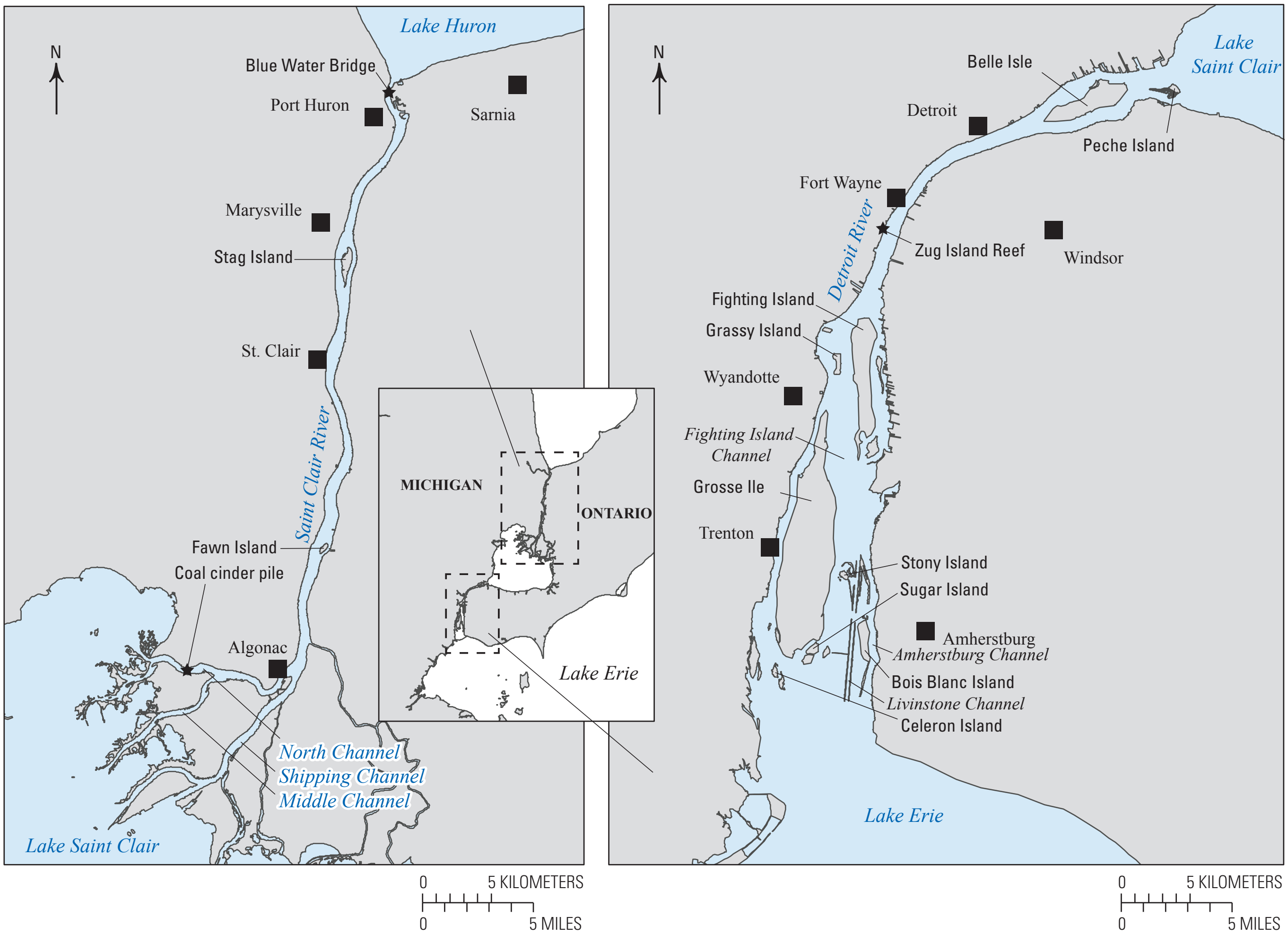


Figure 1. Location of the Saint Clair–Detroit River System identifying major landmarks and metropolitan areas.

system or in the more lentic, nearshore areas (Goodyear and others, 1982); in contrast, walleye, lake whitefish, and lake sturgeon were reported by Goodyear and others (1982) to spawn in the deeper flows of the main channels of both rivers. Muth and others (1986) were the first to document walleye eggs in both rivers in a large-scale effort to characterize the abundance and distribution of fish eggs and larvae in the SCDRS; however, lake whitefish and lake sturgeon were not among the 18 other species whose eggs were identified. Since Muth and others (1986), there have been no published accounts of walleye or lake whitefish eggs in the Saint Clair River, although eggs of both species have been consistently observed in the Detroit River (Manny and others, 2007, 2010; Roseman and others 2007; Roseman, Boase, and others 2011; Roseman, Manny, and others 2011).

Lake whitefish once supported the largest commercial fishery in the SCDRS. Landings averaged 64.5 thousand kilograms (kg) in the SCDRS from 1871 to 1917, with a peak harvest of 451.8 thousand kg in 1874 (Baldwin and others, 2009). Following the construction of the Fighting Island Channel (1914–15) that extended from shoal areas at the base of Fighting Island to the east side of Grassy Island (fig. 1), the commercial fishery for lake whitefish quickly collapsed and spawning runs of lake whitefish into the Detroit River disappeared (Bennion and Manny, 2011). Lake whitefish eggs have never been reported from the Saint Clair River, although several studies have recorded low densities of their larvae in that river (Goodyear and others, 1982; Hatcher and Nester, 1983; Leslie and Timmins, 1991). It was not until the collection of lake whitefish adults and eggs in the Detroit River by Roseman and others (2007, 2012) that this species' presence in the SCDRS was confirmed for the first time since the mid-20th century when lake whitefish populations in the river collapsed (Baldwin and others, 2009).

Lake sturgeon populations in the Great Lakes are listed as threatened by the Michigan and Ontario governments (Manny and Mohr, 2013), meaning they are likely to become endangered if factors threatening them are not addressed. In the SCDRS, lake sturgeon are known to actively spawn on natural substrate at the head of the Saint Clair River in the vicinity of the Blue Water Bridge (fig. 1; Manny and Kennedy, 2002); however, prior to the construction of modern artificial reefs in the Saint Clair River, the only other lake sturgeon spawning activity that had been documented was on a residual bed of coal cinders in the North Channel Saint Clair River (Manny and Kennedy, 2002; Nichols and others, 2003; Thomas and Haas, 2004; Bouckaert and others, 2014). This man-made spawning site was likely formed in the late 1800s by the offloading of spent coal by coal-burning vessels (Thomas and Haas, 2004). The spawning of lake sturgeon in the Detroit River was considered unknown until 2001 when Caswell and others (2004) collected eggs from another residual coal cinder bed offshore of Zug Island. Prior to 2001, no lake sturgeon eggs had been collected on any natural substrates sampled in the Detroit River.

Lake sturgeon spawning on the residual coal cinder beds in both rivers provided evidence that artificial substrates can support lithophilic fish spawning in the SCDRS. This finding, and additional reports of successful spawning by lake sturgeon on artificial spawning substrates in other large rivers (Bruch and Binkowski, 2002; Johnson and others, 2006; Dumont and others, 2011), prompted reef construction projects at Belle Isle (2004) and Fighting Island (2008) in the Detroit River (Manny, 2006; Manny and others, 2015) and in the Middle Channel Saint Clair River (2012) and at Pointe aux Chenes (2014) near Algonac, Michigan, in the Saint Clair River (Read and Manny, 2014; Manny and others, 2015) to address restoration needs. Combined, these projects created new, rocky substrate over 8,400 square meters (m^2) of river bottom in areas with suitable physical condition; for example, current velocities ≥0.5 meter per second (m/s), depth greater than the photic zone of about 4.5 meters (m), and sufficient distance from shipping channels (Bennion and Manny, 2014) . Spawning responses of lake sturgeon and other fish species to these artificial spawning beds has been monitored with an intensive egg sampling program started by the U.S. Geological Survey Great Lakes Science Center (USGS–GLSC) since the onset of the restoration program.

The primary objective of this report is to summarize the areal extent of lithophilic-spawning fish egg collections in the Detroit (2005–14) and Saint Clair (2010–14) Rivers. The dates and water temperatures at the onset and cessation of spawning for the primary taxa are also described. These results depict contemporary use of naturally occurring and man-made spawning habitats by lithophilic-spawning fishes in the SCDRS. The confines of egg mat sampling methods and considerations for future research also are discussed.

Methods

Study Location

The study area encompasses the full lengths of the Detroit and Saint Clair Rivers (fig. 1). Among the major rivers of the Great Lakes, these two connecting channels are exceptional in that they remain free of barriers; however, the SCDRS is an ecosystem that is heavily impacted by human activities (Hondorp and others, 2014). Throughout the ecosystem, two Areas of Concern have been designated by the International Joint Commission, and 14 Beneficial Use Impairments have been identified by the U.S. Environmental Protection Agency, including the losses of fish and wildlife habitat and degradation of fish and wildlife populations (Manny, 2003; Great Lakes Water Quality Agreement, 2013).

The Saint Clair River is the upper 65 km of the SCDRS. It connects Lake Huron to Lake Saint Clair and has a mean discharge of 5,150 cubic meters per second (m^3/s) (Liu and others, 2012). The river has few islands in the upper and middle sections but forms a large delta that serves as an important nursery area for fishes (Edsall and others, 1988). The habitat alterations which are due to the formation and maintenance of shipping channels began in 1855 and continued regularly through the mid-20th century. Most notable was the excavation of a shipping channel (213 m wide × 8.2 m deep) in 1959 that extended 9.7 km through the southeastern bend of the river. This project alone involved the removal of approximately 18.2 million cubic meters (m^3) of sand and clay (Larson, 1995).

The Detroit River is the lower 44 km of the SCDRS. It connects Lakes Saint Clair and Erie and has a mean discharge of 5,300 m^3/s (Derecki, 1984). The river is heavily altered; approximately 87 percent of the Michigan shore is lined with concrete or steel bulkheads, and less than 3 percent of the coastal wetlands historically adjacent to the river still exist (Manny, 2003); additionally, a network of deep (greater than 10 m) shipping channels runs the length of the river (Manny and others, 1988). Habitat alteration from excavation and maintenance of these channels in the Detroit River has been more extensive than in the Saint Clair River. At least 46.2 million m^3 of material have been dredged or excavated from the river, the spoils of which now cover an additional 4,050 hectares (ha) of river bottom (Bennion and Manny, 2011). The Livingstone Channel, which was dredged through a shallow bedrock sill, is the largest of these channel projects and concentrated a majority of the discharge from the Detroit River into a singular outflow into Lake Erie (Bennion and Manny, 2011). Twelve large islands exist in the Detroit River—many of these in the lower reaches comprise parts of the more than 2,300 ha in the Detroit River International Wildlife Refuge (Hartig and others, 2010). Despite the degree to which the Detroit River has been modified, the islands and refuge remain some of the most biologically diverse regions in North America (Bull and Craves, 2003).

Fish Egg Sampling

Furnace filter egg mats (38 × 50 × 2.5 centimeters [cm] wrapped around a 38 × 24 × 0.5-cm metal frame) placed on the river bottom were used to assess fish egg deposition. Egg sampling was conducted typically from mid-March through June, from ice-out until eggs were no longer collected, and again from mid-October through mid-December, when ice cover prevented further egg sampling. Methods for egg mat design, deployment, and retrieval are summarized by Roseman, Boase, and others (2011). Generally, egg mat gangs for a given site consisted of 3 to 12 egg mats that were deployed early in the season and checked weekly thereafter for the presence of fish eggs. Earlier survey years employed the buoyed egg mat sampling strategy described by Nichols and others (2003). In subsequent years, a buoy-less design was used in which sampling sites were identified and revisited using the Global Positioning System (Roseman, Boase, and others, 2011). After retrieval, all eggs were carefully removed with forceps and counted, and egg mat gangs were redeployed in the same location. All eggs removed from the egg mats were identified based on size, color, transparency, oil globule position (Auer, 1982), and timing of spawning. In general, eggs were identified by the naked eye and categorized as walleye, suckers (Catostomid species [spp.]), trout-perch (*Percopsis omiscomaycus*), or lake sturgeon in the spring, and as lake whitefish in the fall. For confirmation, subsets of eggs were taken to the GLSC to be hatched following Sutherland and others (2014); the larval fish were then identified following Auer (1982). Eggs of round goby (*Neogobius melanostomus*) and *Morone* spp. (that is, white bass [*Morone chrysops*] and white perch [*Morone americana*]) were noted when present but were not counted because of their small size, high densities, and the lengthy amount of time to process and remove their eggs from the egg mats.

Fish egg sampling from the Detroit River began in the spring of 2005 following construction of the Belle Isle spawning reefs (Manny, 2006) and was conducted annually through 2014. In 2007, the egg sampling program was expanded to 19 sites as an exploratory assessment of lithophilic spawning, targeting historically important walleye and lake sturgeon spawning grounds from Belle Isle downstream to Sugar and Celeron Islands (fig. 1). In spring 2008, the river-wide sampling regime was expanded, and an additional 10 sites were sampled offshore of the northeast (NE) shore of Fighting Island (NE Fighting Island) where an artificial fish spawning reef was subsequently constructed that summer (Roseman, Manny, and others, 2011). Sampling efforts in spring 2009 were restricted to postassessment of the Fighting Island reef project. Sampling was expanded in 2010 to again include Belle Isle sites. With the exception of 2012, when only sites at NE Fighting Island were sampled, years 2011–14 constituted a long-term monitoring approach whereby sites at Belle Isle, a nearshore debris mound adjacent to Joe Louis Arena, NE Fighting Island, offshore of the northwest (NW) shore of Fighting Island (NW Fighting Island/Grassy Island), northern Livingstone Channel, Hole-in-the-Wall (a break in the dike of the Livingstone Channel), and Sugar Island were consistently revisited.

Fall sampling targeting lake whitefish eggs from the Detroit River began in 2006 following the discovery of adult lake whitefish and eggs (Roseman and others, 2007) and incidental catches in early spring 2006 at Belle Isle of hatch-ready lake whitefish eggs. Exploratory sampling of historic lake whitefish spawning sites (Goodyear and others, 1982) and sites randomly distributed throughout the river (Roseman and others, 2012) was conducted in fall 2006–7. An average of 30 sites per year were sampled from Peche Island downstream to Sugar and Celeron Islands, providing a preliminary inventory of primary lake whitefish spawning areas in the Detroit River. Fall sampling efforts were reduced to NE Fighting Island and Belle Isle (2010) or restricted to only NE Fighting Island (2009, 2011), mostly because of constraints on financial and personnel resources associated with the addition of the Saint Clair River fish egg sampling program that began in 2010. With the areal extent of lake whitefish spawning generally inventoried, fall sampling during 2012–14 targeted sites favored by lake whitefish with a more long-term monitoring focus.

Spring and fall sampling from the Saint Clair River began in 2010 and is still being conducted. In the springs of 2010 and 2011, an average of 26 sites were sampled that targeted known and historically important walleye and lake sturgeon spawning areas (Goodyear and others, 1982). Sampling sites were located from the outlet of Lake Huron to the downstream ends of the North, Middle, and Main Shipping Channel Saint Clair River. Similar to Detroit River efforts, spring sampling in the Saint Clair River from 2012 to 2014 was reduced to monitoring sites identified in the previous 2 years as fish spawning areas as well as preassessment and postassessment of the Middle Channel Saint Clair River reefs, which were constructed in June 2012. Fall sampling efforts from the Saint Clair River have remained relatively consistent, averaging 22 sites per year from 2010 to 2014.

Data Analyses

Cumulative catch-per-unit effort (CPUE) of eggs collected per species per spawning season was calculated and reported by river regions, which are composed of pooled sampling sites (fig. 2). Cumulative CPUE was derived by summing all the eggs sampled per gang at each site for a given year and dividing by the number of mats fished. Because of the influences of water velocity and substrate complexity on egg transport and retention (Jason L. Fischer, U.S. Geological Survey, unpublished data, 2016), it is unlikely that catchability is equal between egg mats and the river bottom; therefore, egg data in this report are reported as CPUE instead of egg density per unit area, and readers are cautioned against extrapolating egg densities on mats to egg densities on the river bottom.

Mean cumulative CPUEs and their associated standard errors were calculated on the natural log ($\log_e$) scale under the assumption that egg densities followed a lognormal distribution among sampling sites within a given region. Direct comparisons of egg CPUEs among years should be made with some caution as not all sites were sampled each year, and sites were added or removed. Every effort was made to present these data in such a way that statistical biases were not introduced because of heterogeneity in the spatial and temporal scope of the dataset; finally, because means of $\log_e$-transformed data

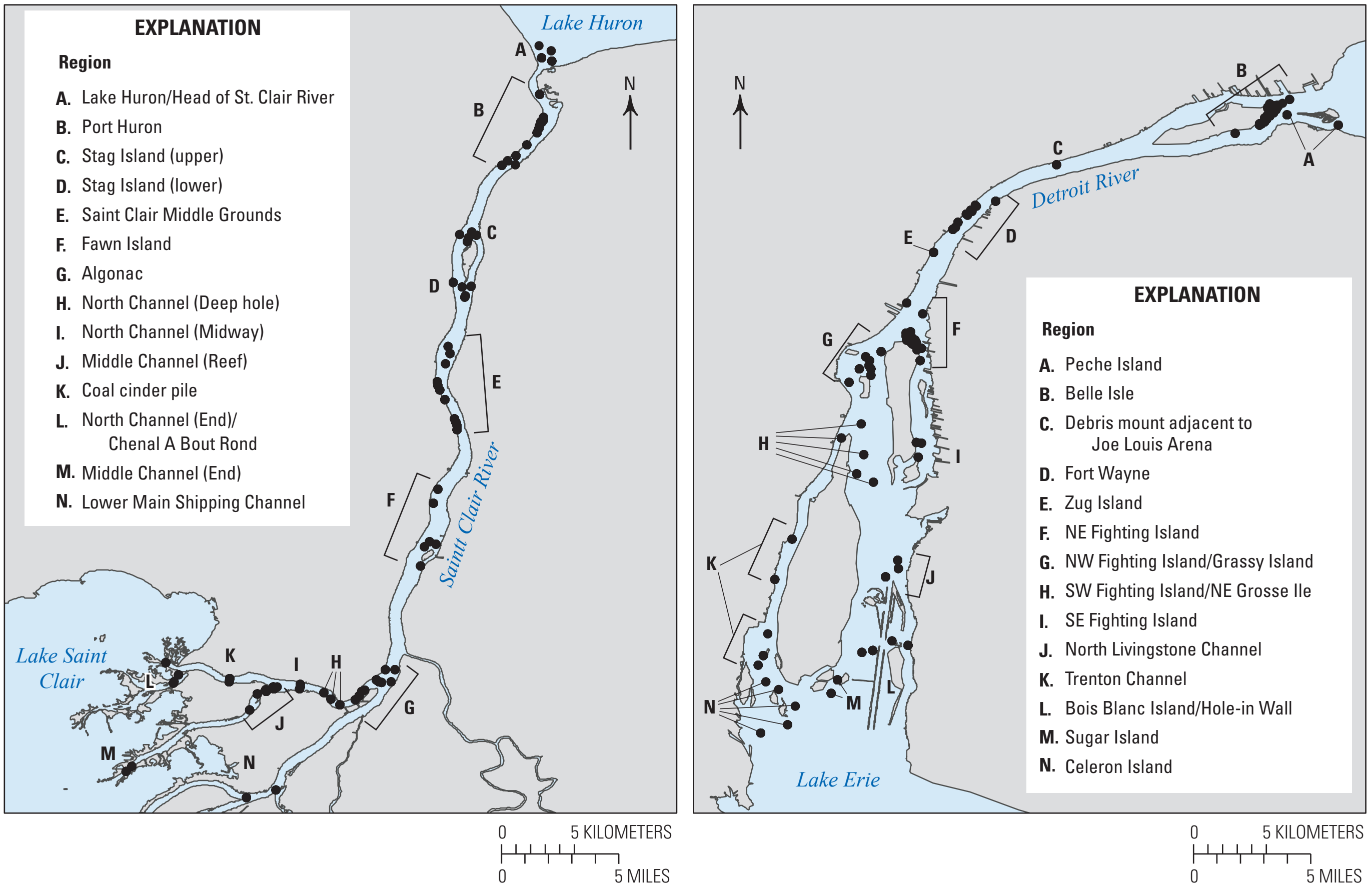


Figure 2. Egg sampling locations on the Saint Clair and Detroit Rivers.

represent median values on the original scale of the data, CPUEs were reported as mean values on the $\log_e$ scale and as median values when back transformed from the $\log_e$ scale to the scale of the data.

Dates and water temperatures of onset and cessation of spawning are presented for the primary taxa observed in each river. Surface-water temperatures were measured using the onboard electronic sensor. In many cases, eggs were collected during the first or last week of sampling. If greater than 5 percent of the total eggs collected in a given year for a given taxon were collected during the first or last week of sampling, it was concluded that the onset or cessation of spawning, respectively, was missed. Otherwise, spawning onset dates were estimated as the first egg mat set date for which greater than 2.5 percent of the total eggs collected for each taxon were observed. Similarly, spawning cessation dates were estimated as the first egg mat pull date for which greater than 97.5 percent of the total eggs collected for each taxon were observed. Thus, the reported onset and cessation dates and water temperatures conservatively describe at least 95 percent of the egg deposition for a given taxon in a given year. Note that in spring 2012, sampling in the Detroit River only occurred from April 24 to May 15; therefore, conclusions were not made regarding the onset and cessation of spawning of any species except lake sturgeon.

Rearing of collected sucker eggs in the laboratory and identifying the hatched larvae has revealed that small sucker eggs are *Carpiodes* spp. (quillback [*Carpiodes cyprinus*] or river carpsucker [*Carpiodes carpio*]) and large sucker eggs are either white sucker (*Catostomus commersonii*) or northern hog sucker (*Hypentilium nigricans*) (Jaquelyn M. Craig, U.S. Geological Survey, unpublished data, 2016). Because collected sucker eggs likely represent at least four species that cannot be readily discriminated during early life history stages, the resolution of the analyses of sucker eggs is limited to either small or large, or all sucker eggs in aggregate.

Egg mats are a tool for documenting spawning activity in large, deep rivers where other sampling methods are not feasible. While an important tool for assessing egg deposition, egg mats have some limitations. Eggs may become dislodged from mats, may be transported from upstream spawning activity, and may hatch or be predated upon between deposition and egg mat retrieval; thus, egg CPUEs are provided only as an *index* of abundance, and standard errors of egg CPUEs are depicted to describe the variability in the data. Focusing on the objective of summarizing the sampling program and contemporary egg deposition of lithophilic-spawning fishes in the system, refrainment from statistical comparisons of egg CPUEs was exercised (unless noted), and a detailed consideration of the aforementioned uncertainties was provided in the

"Discussion" section of the report. Descriptive phrases such as "was greater than" or "did not differ" are based solely on interpretation of the observed egg CPUEs and their associated standard errors.

Results

Detroit River

Among all the years sampled, walleye were the most prolific lithophilic-spawning fish species, both in terms of areal extent of egg deposition and in CPUE of eggs collected. Walleye eggs were caught in all regions of the river each spring, with the exception of the Trenton Channel in 2007. Walleye egg CPUEs were greatest in the vicinity of NW Fighting Island/Grassy Island and at Bois Blanc Island/Hole-in-the-Wall, where median cumulative egg CPUEs peaked in 2013 at 1,593 and 5,902 eggs/mat, respectively (table 1). Bois Blanc Island/Hole-in-the-Wall supported the greatest walleye egg CPUEs in 4 of the 5 years in which it was sampled. Further upstream, high egg CPUEs were consistently observed at Belle Isle (peaking at 310 eggs/mat in 2011) and the nearshore debris mound adjacent to Joe Louis Arena (peaking at 849 eggs/mat in 2013). Other notable high densities of walleye eggs were observed at Fort Wayne in 2007 (124 eggs/mat) and 2013 (778 eggs/mat), as well as at Zug Island in 2011 (111 eggs/mat), and at Sugar Island in 2013 (103 eggs/mat).

Collections of small and large sucker eggs were also widespread throughout the Detroit River each year. Large sucker eggs were observed slightly more frequently, being collected in 31 of 50 year-region combinations, whereas small sucker eggs were observed in 29 of 50 year-region combinations. Sucker eggs were observed in at least one year from every region that was sampled except the nearshore debris mound adjacent to Joe Louis Arena, SW Fighting Island/NE Grosse Ile, and Celeron Island. Overall, peak combined sucker egg CPUEs in a given spring were much lower than those of walleye, ranging from less than 1 percent of walleye egg CPUEs in 2011 to 23 percent in 2006 when only Belle Isle was sampled. However, local sucker egg CPUEs occasionally exceeded those of walleye, and this was observed at SE Fighting Island (2007), Zug Island (2008) and NE Fighting Island (2008 and 2014). Among years where a majority of the regions were sampled, the NE Fighting Island region ranked first or second in 4 out of 5 years (table 2). The greatest sucker egg CPUEs were observed at NE Fighting Island in 2013 (57.7 eggs/mat) and 2014 (60.9 eggs/mat). Other relatively large cumulative CPUEs of sucker eggs were observed at

Table 1. Median cumulative catch–per–unit effort (CPUE) of walleye eggs collected during spring egg mat sampling in the Detroit River, 2005–14. Italics denote sampling season ended early because of gear loss and values may be underestimated.

[–, site was not sampled]

Region (in downstream order)	Walleye CPUE (eggs/mat)—Detroit River									
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Peche Island	–	–	–	45	–	–	–	–	–	–
Belle Isle	29	9.4	99	263	–	–	310	–	290	32
Debris mound adjacent to Joe Louis Arena	–	–	–	–	–	–	293	–	849	–
Fort Wayne	–	–	124	14	–	–	–	–	778	–
Zug Island	–	–	111	5.0	–	–	–	–	–	–
NE Fighting Island	–	–	33	4.8	98	14	43	11	115	31
NW Fighting Island/ Grassy Island	–	–	132	45	–	–	735	–	1,593	1,073
SW Fighting Island/ NE Grosse Ile	–	–	7.3	*3.1*	–	–	–	–	–	–
SE Fighting Island	–	–	0.33	1.0	–	–	–	–	–	–
N Livingstone Channel	–	–	8.3	1.7	–	–	3.3	–	365	47
Trenton Channel	–	–	0	4.0	–	–	–	–	–	–
Bois Blanc Island/ Hole–in–Wall	–	–	350	137	–	–	2,584	–	5,902	2,735
Sugar Island	–	–	49	14	–	–	18	–	103	2.0
Celeron Island	–	–	*7.7*	–	–	–	–	–	–	–

Zug Island in 2008 (15.0 eggs/mat) and NW Fighting Island/Grassy Island in 2011 (16.1 eggs/mat). Although large sucker eggs were observed most often, the greatest sucker egg CPUEs tended to be comprised mostly of small sucker eggs.

Lake sturgeon eggs were only observed following the 2008 construction of an artificial spawning reef at Fighting Island (Roseman, Manny, and others, 2011; Bouckaert and others, 2014; Manny and others, 2015) and were collected from this site in 2009, 2010, 2012, and 2014. Chronologically, median lake sturgeon egg CPUEs for these years among all sites sampled at NE Fighting Island were 1.0, 0.33, 5.9, and 9.0 eggs/mat, respectively. However, almost all of these eggs were collected on the artificial reef. Median cumulative egg CPUEs among the four reef sites closest to the shore (corresponding to reef treatments A–D from Roseman, Manny, and others [2011]) were considerably greater: 22.6, 1.2, and 40.2 for 2009, 2010, and 2012, respectively. The CPUE of lake sturgeon eggs among these four sites decreased in 2014 (3.3 eggs/mat); however, this followed the 2013 construction of downstream extensions to the reef, which had a higher median CPUE (117 eggs/mat). Lake sturgeon eggs were not collected from any other sites in the Detroit River during this study.

Trout-perch eggs were collected in the spring across a broad spatial and temporal extent. They were observed at NE Fighting Island (7 of 8 years sampled), Belle Isle (4 of 8 years), Bois Blanc Island/Hole-in-the-Wall (4 of 5 years), Sugar Island (2 of 5 years), and NW Fighting Island/Grassy Island (1 of 5 years). Median cumulative egg CPUEs were always low, only exceeding 5 eggs/mat at Sugar Island where CPUEs of 11.0 eggs/mat (in 2007) and 13.7 eggs/mat (2011) were observed (table 3).

Lake whitefish eggs were collected from all river regions except Zug Island and Celeron Island from 2006 to 2014 (table 4). Spawning by lake whitefish was prevalent throughout the Detroit River and typically began within the first two weeks of November (mean onset temperature was 8.1 degrees Celsius [˚C]) and continued into mid-December (mean cessation temperature was 2.7 ˚C; table 5). River-wide, lake whitefish egg CPUEs were generally intermediate to those of walleye and suckers. Median cumulative egg CPUEs for a given year-region combination rarely exceeded 10 eggs/mat (table 4), but an exceptionally high density was observed at NE Fighting Island in 2014 (110 eggs/mat) and at NW Fighting Island/Grassy Island in 2013 and 2014 (63.4 and 47.9 eggs/mat, respectively).

Table 2. Median cumulative catch–per–unit effort (CPUE) of sucker eggs collected during spring egg mat sampling in the Detroit River, 2005–14. Italics denote sampling season ended early because of gear loss and values may be underestimated.

[–, site was not sampled]

Region (in downstream order)	Sucker CPUE (eggs/mat)—Detroit River									
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Peche Island	–	–	–	1.0	–	–	–	–	–	–
Belle Isle	6.1	2.2	0.29	3.1	–	0.37	1.0	–	0.24	0.89
Debris mound adjacent to Joe Louis Arena	–	–	–	–	–	–	0	–	0	–
Fort Wayne	–	–	0	0.33	–	–	–	–	2.0	–
Zug Island	–	–	2.7	15.0	–	–	–	–	–	–
NE Fighting Island	–	–	2.4	10.8	6.8	8.4	7.0	*1.1*	58	61
NW Fighting Island/ Grassy Island	–	–	0.49	0.53	–	–	16.1	–	10	0.48
SW Fighting Island/ NE Grosse Ile	–	–	0	0	–	–	–	–	–	–
SE Fighting Island	–	–	3.0	0	–	–	–	–	–	–
N Livingstone Channel	–	–	0.33	0	–	–	0	–	0.33	0
Trenton Channel	–	–	0	2.2	–	–	–	–	–	–
Bois Blanc Island/ Hole–in–Wall	–	–	1.5	0.73	–	–	6.3	–	3.7	6.0
Sugar Island	–	–	9.3	*0*	–	–	0.67	–	0	0
Celeron Island	–	–	*0*	–	–	–	–	–	–	–

Table 3. Median cumulative catch–per–unit effort (CPUE) of trout–perch eggs collected during spring egg mat sampling in the Detroit River, 2005–14. Italics denote sampling season ended early because of gear loss and values may be underestimated.

[–, site was not sampled]

Region (in downstream order)	Trout-perch CPUE (eggs/mat)—Detroit River									
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Peche Island	–	–	–	0	–	–	–	–	–	–
Belle Isle	0	0.04	0.19	0	–	0	0.05	–	0	0.33
Debris mound adjacent to Joe Louis Arena	–	–	–	–	–	–	0	–	0	0
Fort Wayne	–	–	0	0	–	–	–	–	0	–
Zug Island	–	–	0	0	–	–	–	–	–	–
NE Fighting Island	–	–	0	0.26	0.74	0.29	1.7	*1.0*	4.6	0.40
NW Fighting Island/ Grassy Island	–	–	0	0	–	–	0.53	–	0	0
SW Fighting Island/ NE Grosse Ile	–	–	0	0	–	–	–	–	–	–
SE Fighting Island	–	–	0	0	–	–	–	–	–	–
N Livingstone Channel	–	–	0	0	–	–	0	–	0	0
Trenton Channel	–	–	0	0	–	–	–	–	–	–
Bois Blanc Island/ Hole–in–Wall	–	–	0.29	0	–	–	2.7	–	1.3	1.3
Sugar Island	–	–	11	0	–	–	14	–	0	0
Celeron Island	–	–	*0*	–	–	–	–	–	–	–

Table 4. Median cumulative catch–per–unit effort (CPUE) of lake whitefish eggs collected during fall egg mat sampling in the Detroit River, 2006–14. Italics denote sampling season ended early because of gear loss and values may be underestimated.

[–, site was not sampled]

Region (in downstream order)	Lake whitefish CPUE (eggs/mat)—Detroit River							
	2006	2007	2008	2010	2011	2012	2013	2014
Peche Island	1.2	1.2	–	–	–	–	–	–
Belle Isle	1.7	8.7	–	6.2	–	11.1	0.6	0.87
Debris mound adjacent to Joe Louis Arena	–	–	–	–	–	1.0	–	3.7
Fort Wayne	–	0.7	–	–	–	19	*0*	–
Zug Island	–	0	–	–	–	–	–	–
NE Fighting Island	7.8	6.0	3.7	3.2	17	8.4	3.8	110
NW Fighting Island/Grassy Island	0.29	6.5	–	–	–	–	63	48
SW Fighting Island/ NE Grosse Ile	1.4	2.6	–	–	–	–	–	–
SE Fighting Island	0.33	0.33	–	–	–	–	–	–
N Livingstone Channel	3.4	2.3	–	–	–	–	0	1.0

Table 4. Median cumulative catch–per–unit effort (CPUE) of lake whitefish eggs collected during fall egg mat sampling in the Detroit River, 2006–14. Italics denote sampling season ended early because of gear loss and values may be underestimated.—Continued

[–, site was not sampled]

Region (in downstream order)	Lake whitefish CPUE (eggs/mat)—Detroit River							
	2006	2007	2008	2010	2011	2012	2013	2014
Trenton Channel	0	0.63	–	–	–	–	–	–
Bois Blanc Island/Hole–in–Wall	5.3	8.2	–	–	–	3.7	8.0	28
Sugar Island	4.3	6.2	–	–	–	3.7	–	25
Celeron Island	0	–	–	–	–	–	–	–

Table 5. Water temperatures corresponding to the onset and cessation of egg collections in the Detroit River, 2005–14. Reported values are daily mean water temperatures in degrees Celsius.

[–, eggs of this species were not collected during sampling; DNS, did not sample; NA, onset or cessation was missed and therefore temperature was not available; %, percent; CI, confidence interval]

Year	Walleye		Sucker (large)		Trout-perch	
	Onset	Cessation	Onset	Cessation	Onset	Cessation
2005	NA	11.5	5.8	15.7	–	–
2006	NA	13.0	9.0	19.0	11.8	13.0
2007	6.5	13.4	3.8	16.1	9.0	13.0
2008	5.6	10.7	10.2	14.5	10.2	13.8
2009	4.6	12.6	5.6	12.5	7.6	NA
2010	NA	11.7	NA	20.3	NA	20.0
2011	5.1	11.5	9.8	14.4	8.2	18.9
2012	NA	NA	NA	NA	NA	NA
2013	5.4	12.4	7.8	10.6	7.8	16.5
2014	4.8	12.3	8.2	14.2	8.3	17.8
Mean	5.3	12.1	7.5	15.3	9.1	16.1
95% CI	4.8–5.9	11.6–12.7	6.0–9.1	13.3–17.2	8.0–10.2	14.0–18.3

Year	Sucker (small)		Lake sturgeon		Lake whitefish	
	Onset	Cessation	Onset	Cessation	Onset	Cessation
2005	5.8	12.8	–	–	DNS	DNS
2006	6.2	12.0	–	–	NA	2.9
2007	13.4	17.1	–	–	8.9	1.7
2008	10.9	12.2	–	–	DNS	DNS
2009	10.6	NA	10.6	12.5	9.5	3.8
2010	13.3	19.9	13.3	12.9	8.3	0.3
2011	11.5	14.5	–	–	NA	NA
2012	NA	NA	9.3	13.1	NA	4.8
2013	7.8	14.9	–	–	6.0	NA
2014	7.5	17.8	8.2	11.5	7.6	NA
Mean	9.7	15.1	10.3	12.5	8.1	2.7
95% CI	7.8–11.6	13.2–17.1	8.2–12.5	11.8–13.2	6.9–9.3	1.2–4.2

In the spring, walleye eggs were the earliest to be collected with a mean onset date of April 8, corresponding with a mean water temperature at onset of 5.3 ˚C (table 5). Collections of walleye eggs were generally followed by large sucker eggs (mean onset April 21; 7.5 ˚C), trout-perch eggs (April 28; 9.1 °C), small sucker eggs (April 28; 9.7 ˚C), and lake sturgeon eggs (May 1; 10.3 ˚C). Walleye also were the earliest species to complete spawning, with an average cessation date of May 7 and water temperature of 12.1 ˚C (table 5), followed by lake sturgeon (May 16; 12.5 ˚C), sucker species with large eggs (May 27; 15.3 ˚C), sucker species with small eggs (May 29; 15.1 ˚C), and trout-perch (June 2; 16.1 ˚C). Lake sturgeon eggs were collected over a shorter duration than eggs of the other taxa, with 95 percent of the eggs being collected over an annual mean of 15.5 days (fig. 3). The relation of egg collections to temperature was strongest for walleye, with 95 percent confidence intervals for the mean temperatures of both onset and cessation among all years spanning only 1.1 ˚C (table 5).

Fish egg CPUEs generally were similar among reef and nonreef sites in the Belle Isle region (fig. 4*A*), where a fish-spawning reef was constructed in 2004. With the exception of lake whitefish in fall 2012, where the median cumulative egg CPUE among three artificial reef sites was 26.9 eggs/mat compared to zero for a single adjacent natural substrate site, egg deposition did not differ substantially between artificial reef sites and adjacent sites with natural substrate at Belle Isle.

Since 2008, the greatest proportion of fish egg sampling effort in the Detroit River has been in the NE Fighting Island region. The spatial relation was examined between egg deposition and position relative to the location of the artificial spawning reef by estimating egg CPUEs among sites similarly distanced upstream and downstream from the reef (fig. 5). Lake sturgeon exhibited the greatest use of the reef relative to sites upstream or downstream and showed the strongest, positive postconstruction response. Lake sturgeon eggs were not collected at any Fighting Island sites prior to the construction of the reefs in 2008 but were collected on reef sites in 2009 (1.9 eggs/mat), 2010 (0.76 eggs/mat), 2012 (17.5 eggs/mat), and 2014 (3.3 eggs/mat); additionally, smaller CPUEs of lake sturgeon eggs were collected among sites averaging 135 m downstream from the Fighting Island reefs in 2009 (0.49 eggs/mat), 2012 (1.5 eggs/mat), and 2014 (1.0 eggs/mat). Trout-perch showed evidence of increased egg deposition on the Fighting Island reef following its construction in 2008 (fig. 5). Among all years following the reef construction (2009–14), trout-perch egg CPUEs were greatest on the Fighting Island reef sites (1.2 eggs/mat/year), slightly exceeding those among sites averaging 135 m downstream (0.88 eggs/mat/year).

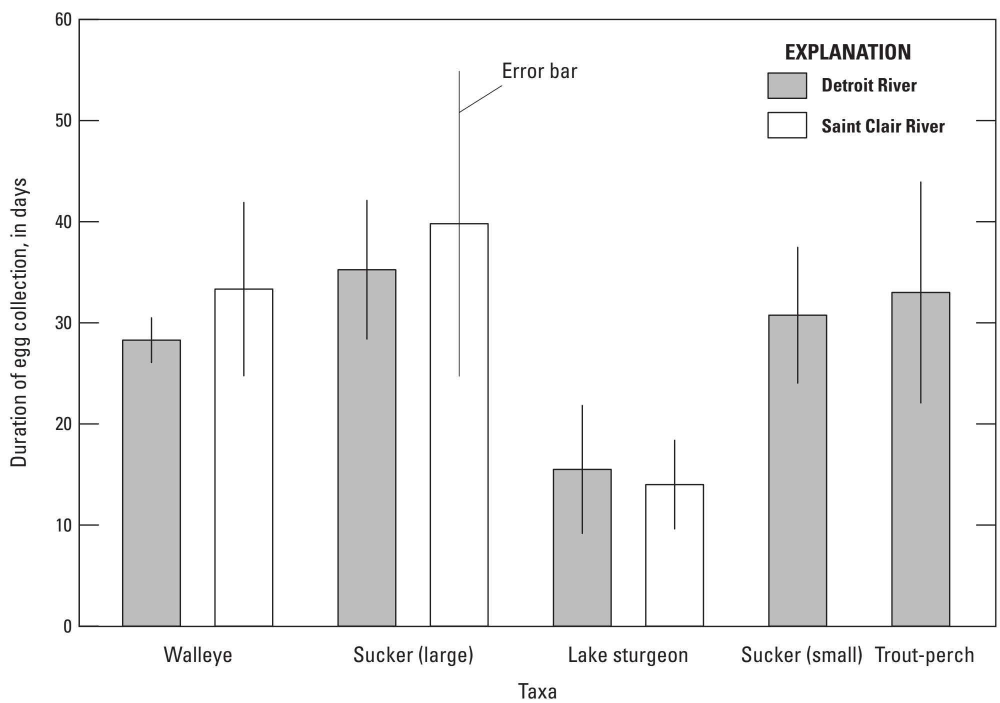
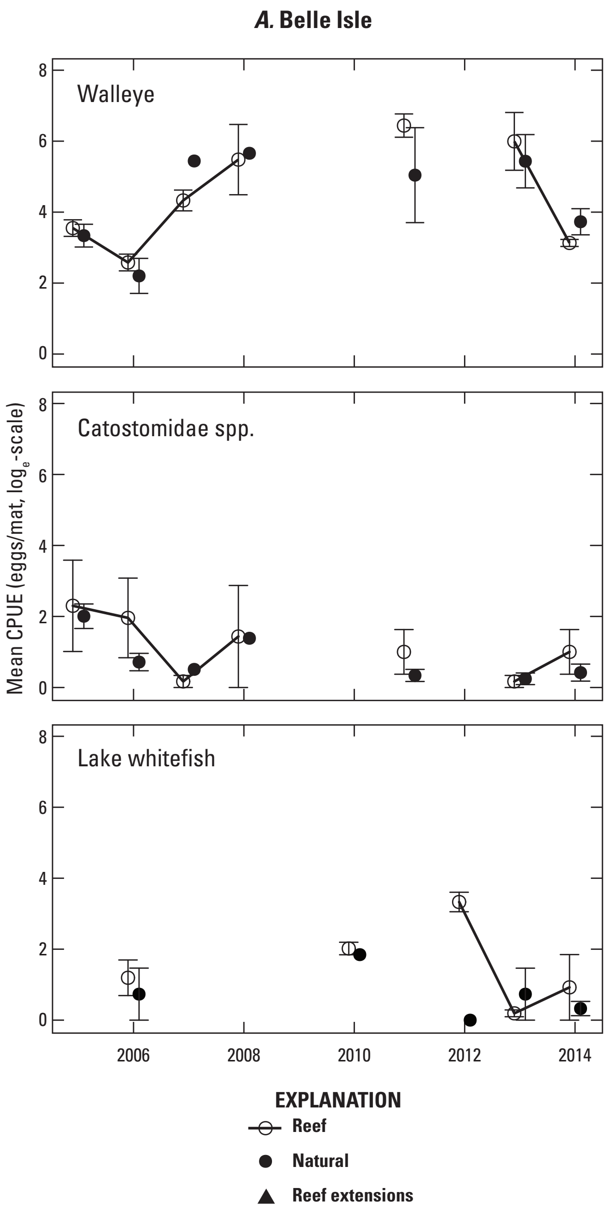


Figure 3. Average duration of egg collections of lithophilic-spawning fishes in the Detroit and Saint Clair Rivers for years in which the onset and cessation of spawning were detected. Error bars denote ±1 standard error.



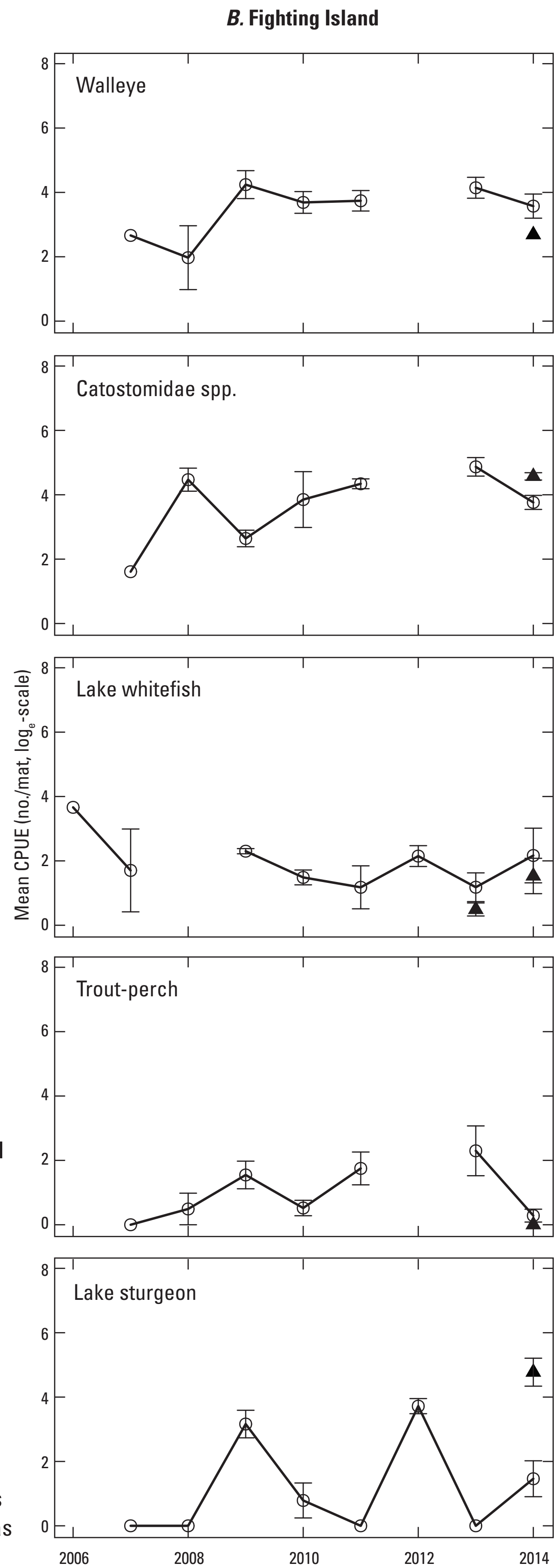


Figure 4. Cumulative mean catch-per-unit effort (CPUE) of eggs on mats sampled on or near the artificial reef complex off the northeastern shores of *A*, Belle Isle 2005–14; and *B*, Fighting Island 2006–14. Symbols represent the yearly means of the log$_e$ (total eggs collected + 1) per mat among sampling sites. In *A*, open circles correspond to sites on the reefs and shaded circles correspond to sites on natural substrate at the head of Belle Isle. In *B*, open circles correspond to sites sampled on the reefs (2009–14) or where the reefs were later built (2006–8). Shaded triangles describe the cumulative mean log$_e$-CPUE of eggs sampled on reef extensions installed immediately downstream from the original reefs, summer 2013. In both *A* and *B*, error bars denote ±1 standard error. Note that not every region was sampled in each year.

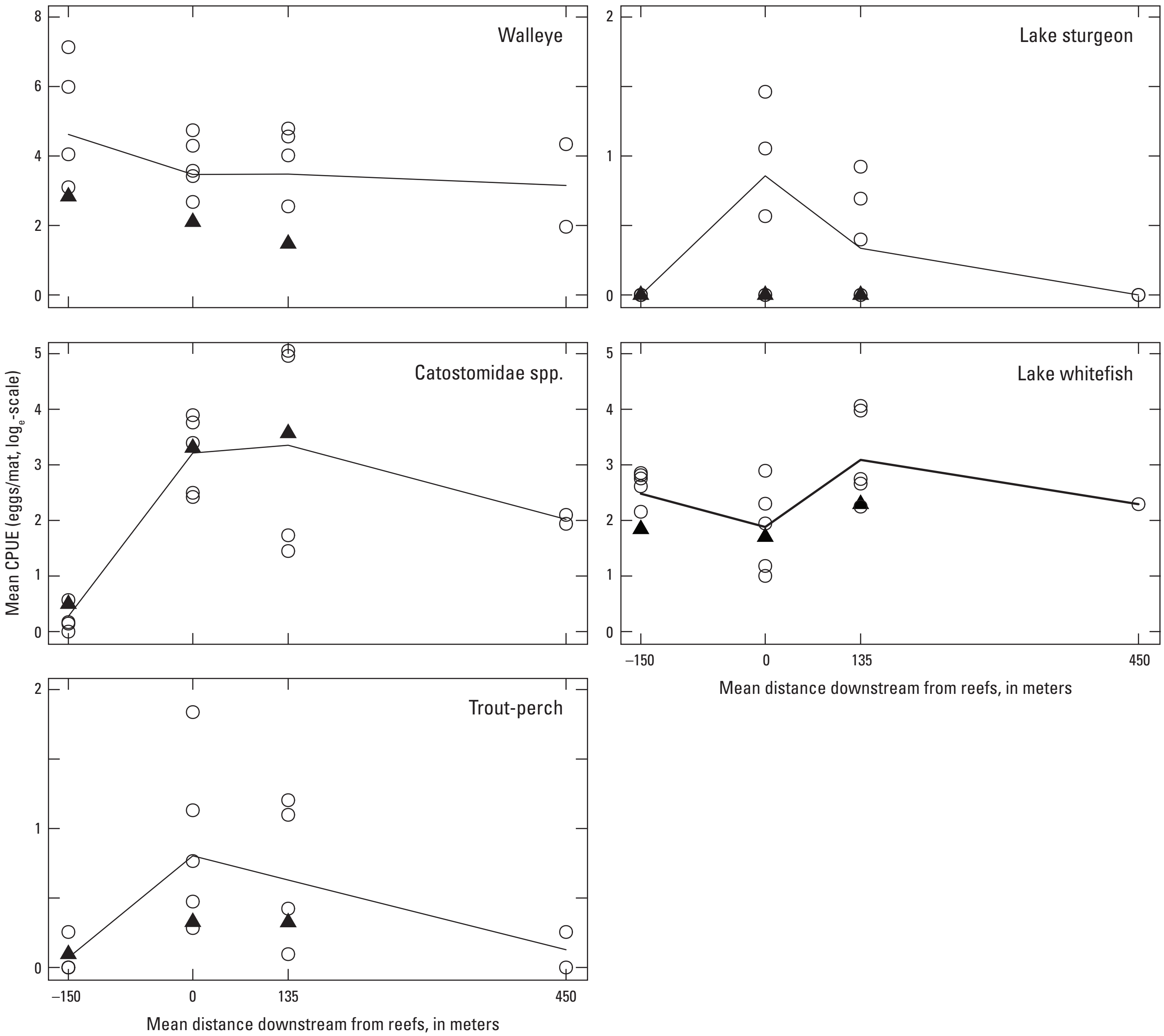


Figure 5. Cumulative mean catch-per-unit effort (CPUE) of eggs on mats sampled in the vicinity of the artificial reef complex at the head of Fighting Island. Symbols represent the yearly means of the log$_e$ (total eggs collected + 1) per mat among sampling sites both upstream and downstream from the reefs, as well as on the reefs themselves. Shaded triangles and open circles correspond to preconstruction and postconstruction of artificial spawning reefs, respectively (that is, before and after summer 2008), and the line describes the mean of the time series. Note that not every distance was sampled each year.

Walleye, Catostomidae spp., and lake whitefish showed similar spatial patterns in egg CPUEs preconstruction and postconstruction of the Fighting Island reef (fig. 5). Although median egg CPUEs on the reef were greatest for walleye, more eggs were collected from the upstream sites than on the reefs. The average values of annual median walleye egg CPUE (that is, back-transformed from log$_e$-CPUE in fig. 5) among sampling sites averaging 150 m upstream from the Fighting Island reef were greater (100 eggs/mat/year) than at sites on the reef (31.1 eggs/mat/year) or sites averaging 135 m downstream from the reefs (31.4 eggs/mat/year), although interannual variability was high. Sucker egg CPUEs were greatest at the reef sites (23.8 eggs/mat/year) and at sites averaging 135 m downstream (27.6 eggs/mat/year), but this pattern was essentially the same before construction of the reef (fig. 5). Compared to sites sampled upstream (11.0 eggs/mat/year) and downstream (21.0 eggs/mat/year) from the Fighting Island reef, lake whitefish egg CPUEs appeared depressed at sites on the reefs (5.6 eggs/mat/year) among all years, although this may not be significant because of interannual variability. The Fighting Island reef was enlarged on the downstream side in summer 2013, and this new area was heavily utilized by lake sturgeon in 2014 (117 eggs/mat; fig. 4b).

Saint Clair River

The CPUEs of fish eggs in the Saint Clair River were much lower than those in the Detroit River; nonetheless, eggs of at least one species were collected among all regions of the Saint Clair River that were sampled throughout the time series. The greatest walleye egg CPUEs throughout the time series were observed in the Algonac region, where median cumulative CPUE peaked in 2013 (36.3 eggs/mat) and was also high in 2011 (10.1 eggs/mat). The third greatest catch of walleye eggs occurred at Fawn Island in 2013, where 8.2 eggs/mat were observed. No other local annual walleye catches exceeding 5.0 eggs/mat were observed in the Saint Clair River.

Throughout the time series, collections of walleye and lake sturgeon eggs were similar in magnitude (1,085 and 975 total eggs, respectively) but varied greatly in their areal extents. From 2010 to 2014, lake sturgeon eggs were only collected at 4 of the 14 regions, while walleye eggs were collected in every region in at least one year except the coal cinder pile in North Channel Saint Clair River or North Channel Saint Clair River (end)/Chenal A Bout Rond. The majority (88.5 percent) of lake sturgeon eggs sampled from the Saint Clair River were collected at the coal cinder pile (fig. 6). The CPUE peaked at the coal cinder pile in 2011 at 161 eggs/mat, which is more than four times greater than the highest densities of lake sturgeon eggs collected at the Fighting Island reef in 2012. High CPUEs of lake sturgeon eggs were also collected in 2010, 2013, and 2014 with 45.7, 57.0, and 19.7 eggs/mat, respectively, at the coal cinder pile (fig. 6).

Sixty-two lake sturgeon eggs were collected in a trial 24-hour, three-mat-gang set during construction of the Middle Channel Saint Clair River reef (May 30, 2012), but there are no other fish egg data for 2012 because of reef construction. In the year following construction of the Middle Channel Saint Clair River reef, lake sturgeon eggs were collected in low CPUEs (1.4 eggs/mat); in 2014, no lake sturgeon eggs were collected from this region. The only other collections of lake sturgeon eggs in the Saint Clair River occurred in 2014, during which a median cumulative CPUE of 2.9 eggs/mat was observed among four sites sampled in the Saint Clair Middle Grounds region, and a single lake sturgeon egg was collected among three sites at Port Huron (0.10 eggs/mat).

Low CPUEs of large sucker eggs were observed from every region of the Saint Clair River except Fawn Island, Middle Channel Saint Clair River (end), and the Lower Main Shipping Channel Saint Clair River. Median cumulative egg CPUEs seldom exceeded 1.0 eggs/mat, with the primary exception of 10.3 eggs/mat at Port Huron in 2010. The second greatest CPUE of large sucker eggs was at the Saint Clair Middle Grounds in 2013, where 2.3 eggs/mat were collected. Other notable catches of large sucker eggs occurred at the North Channel Saint Clair River (end)/Chenal A Bout Rond region (2.0 eggs/mat in 2011) and at Algonac (1.9 and 1.8 eggs/mat in 2011 and 2013, respectively).

Unlike the Detroit River, trout-perch and small sucker eggs were rarely collected in the Saint Clair River. Only five small sucker eggs were identified among all regions sampled in 2013 and 2014. Trout-perch eggs were only collected in 2011; however, CPUEs in the North Channel Saint Clair River (end)/Chenal A Bout Rond region were extremely high at 107 eggs/mat. Trout-perch eggs were also collected among three sites at Algonac, with a median cumulative CPUE of 0.79 eggs/mat.

Lake whitefish eggs were collected on two occasions at sites in the Saint Clair Middle Grounds region. In 2012, three lake whitefish eggs were collected (median CPUE of 0.26 eggs/mat), and in 2014, one egg was collected (0.15 eggs/mat). These collections are the first accounts of lake whitefish eggs from the Saint Clair River.

Five regions were sampled in all years from 2010 to 2014 in the Saint Clair River (fig. 6). Among all taxa, 2011 and 2013 tended to support the greatest egg CPUEs at each region. Walleye and large sucker egg CPUEs showed very similar temporal patterns within each of the regions of Port Huron, Saint Clair Middle Grounds, and Algonac.

The temporal order in which fish taxa spawned in the Saint Clair River was similar to that of the Detroit River, although spawning began later for all species. Walleye were the first to begin spawning, with a mean onset of April 17 among years in which the onset was captured (mean onset water temperature = 3.1 ˚C; table 6). Mean onsets of large sucker eggs (May 3; 7.2 ˚C) and lake sturgeon eggs (May 25; 11.4 ˚C) followed. On average, collections of walleye eggs ceased May 20 (11.0 ˚C), followed by lake sturgeon (June 8; 14.5 ˚C), and large sucker eggs (June 11; 14.9 ˚C). The durations of spawning for each taxon were similar between the Detroit and Saint Clair Rivers, and, as was observed in the Detroit River, lake sturgeon spawned over a shorter duration in the Saint Clair River than the other taxa (fig. 3). Water temperatures at the onset of walleye spawning were significantly colder in the Saint Clair River than the Detroit River among years where the onset was captured by sampling in both rivers (two-sided paired t-test; $p = 0.04$); however, water temperatures at cessation of spawning by walleye were not significantly different between rivers, and temperatures characteristic of the onset and cessation of egg collections were not significantly different between rivers for any other taxa.

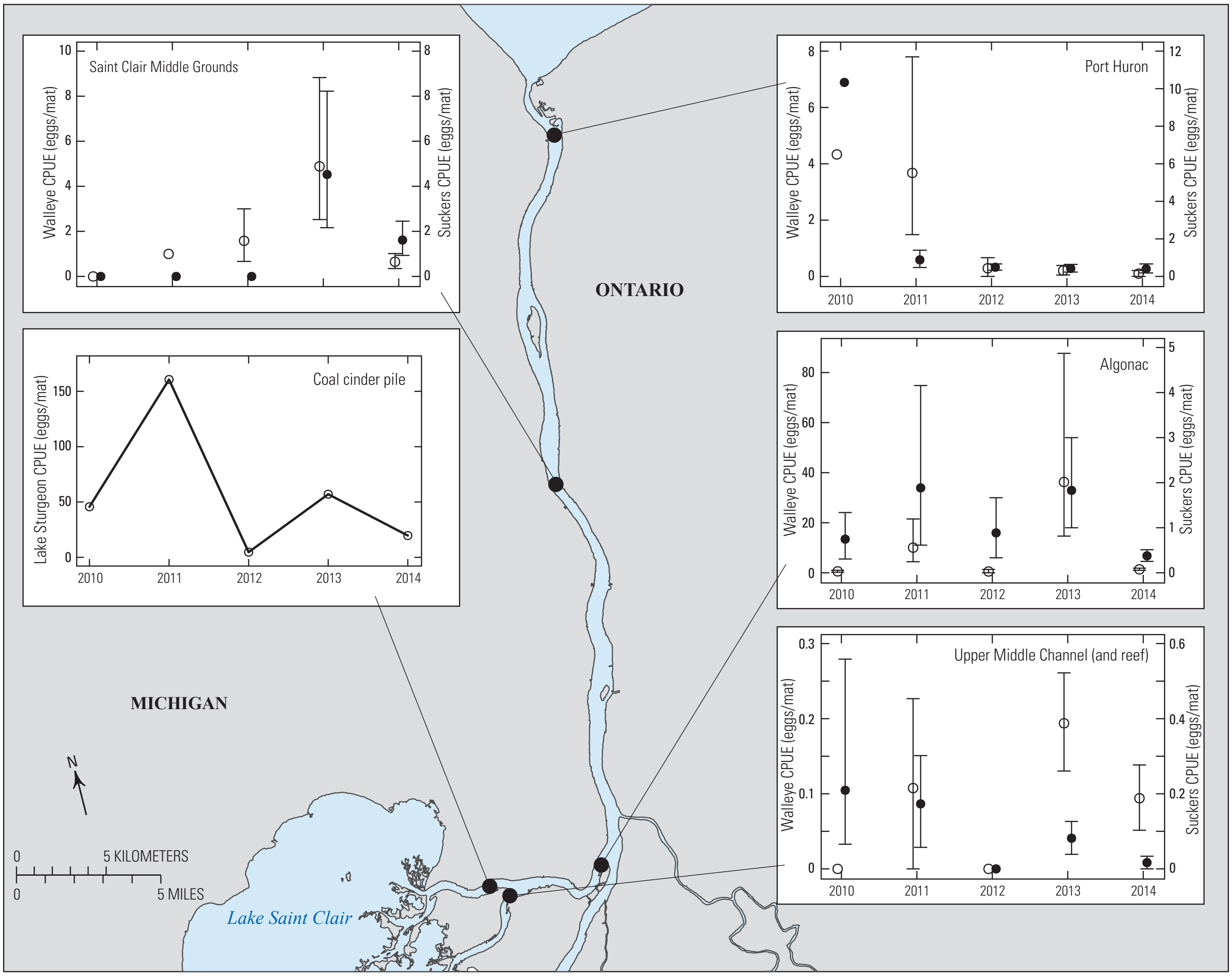


Figure 6. Densities of eggs collected 2010–14 at five regions sampled each year in the Saint Clair River. Catch-per-unit effort (CPUE) values are the back-transformed mean $\log_e$ (total eggs caught/mat + 1) among all sampled sites within a river region during the whole sampling season. For all regions except coal cinder pile, open circles correspond to walleye egg densities (left y-axis), and filled circles correspond to sucker egg densities (right y-axis). Error bars represent ±1 standard error.

Table 6. Water temperatures corresponding to the onset and cessation of egg collections in the Saint Clair River, 2010–14. Reported values are daily mean water temperatures in degrees Celsius, measured by boat among all sites.

[NA, onset or cessation was missed and therefore temperature was not available; %, percent; CI, confidence interval]

Year	Walleye		Sucker (large)		Lake sturgeon	
	Onset	Cessation	Onset	Cessation	Onset	Cessation
2010	NA	12.1	7.4	19.5	10.9	17.4
2011	2.7	8.8	5.1	15.8	10.7	13.4
2012	NA	13.1	7.4	14.8	13.1	14.8
2013	3.2	9.2	9.0	12.6	11.0	12.6
2014	3.3	11.6	7.3	11.8	11.2	14.3
Mean	3.1	11.0	7.2	14.9	11.4	14.5
95% CI	2.7–3.4	9.3–12.6	6.0–8.5	12.3–17.6	10.5–12.3	12.9–16.1

Discussion

This report provides a contemporary account of where spawning occurs by ecologically and economically important lithophilic-spawning fish species in the Detroit and Saint Clair Rivers—a key first step in tracking the success of fish habitat restoration progress in the SCDRS. Historically, the Detroit and Saint Clair Rivers were important for fish spawning and subsequent recruitment (Goodyear and others, 1982), but the habitats and flow regimes therein have been highly altered (Manny and others, 1988; Bennion and Manny, 2011; Hondorp and others, 2014), and this has contributed to multiple declines of fisheries and limited their recovery (Smith, 1972; McClain and Manny, 2000; Roseman and others, 2007; Manny and others, 2010). Through the large-scale survey of fish spawning in these two rivers, a better understanding was gained of how these connecting channels currently contribute to the structure and restoration of fish communities in the SCDRS and in adjacent Lakes Huron and Erie.

It was found that walleye and an unresolved diversity of sucker species (Catostomidae spp.) spawn throughout the Detroit and Saint Clair Rivers in the spring. Aside from the recent documentation of white sucker spawning at Belle Isle (Manny and others, 2010), knowledge of historic sucker (and most other species) spawning activity in the SCDRS was previously limited to collections of fish larvae (Goodyear and others, 1982; Hatcher and Nester, 1983; Muth and others, 1986). For walleye, limited previous accounts suggested spawning in the Detroit River was confined to the lower reaches around Stony and Bois Blanc Islands, the Livingstone and Amherstburg Channels, and the lower Trenton Channel extending to the western shore of Sugar Island (Goodyear and others, 1982). It was also thought that walleye may not even spawn in the Saint Clair River proper, and that adult walleye in the Saint Clair River were migrating to and from tributaries to the SCDRS and the western basin of Lake Erie (Goodyear and others, 1982). This report is the first account of collections of walleye eggs from the Saint Clair River since Muth and others (1986), who collected only a single walleye egg during sampling in 1983–84.

The collections of trout-perch eggs were somewhat unexpected given that the sampling sites tended to be in deep water near the main flow of the rivers; however, Muth and others (1986) collected trout-perch eggs at depths ranging from 2.7 to 13.7 m in the Saint Clair River and from 3.7 to 8.2 m in the Detroit River in 1983 and 1984, primarily over mixtures of sand and gravel substrate. In other systems, trout-perch have been observed to spawn in shallow depths, but little else is known about their spawning behavior. Magnuson and Smith (1963) observed trout-perch exhibiting broadcast spawning along the shores of and in tributaries to Lower Red Lake, Minnesota, in less than 1 m of water. They found that spawning took place in one tributary within 13 cm of the surface and was concentrated in shallow water near the edges of the stream. Similarly, Muth (1975) hypothesized that in Twelvepole Creek, West Virginia, trout-perch spawned at night in shallow riffles, usually less than 0.45 m deep. In contrast to these studies, the findings in this report and those of Muth and others (1986) highlight the potential importance of deeper, swifter flows to trout-perch reproduction in the SCDRS.

It was found that lake whitefish spawn throughout the Detroit River in the fall, which is congruent with historic depictions of Detroit River lake whitefish spawning runs extending from the river mouth up to Belle Isle (Goodyear and others, 1982). The consistent sampling of lake whitefish eggs in the Detroit River underscores the continued recovery of this stock from its collapse in the early 1900s. Additionally, it is promising that some of the greatest lake whitefish egg CPUEs that were observed over the time series occurred in 2011–14 (table 4).

In the SCDRS, lake sturgeon showed the greatest discretion in choosing when and where to spawn. Their eggs were collected almost exclusively on artificial reefs, but not on every reef each year. The apparently greater spawning discretion shown by lake sturgeon in the SCDRS, as compared to walleye, suckers, and lake whitefish, is likely influenced by their respective life histories and spawning strategies. Lake sturgeon is a long-lived species that matures late (males age 12–15 years, females age 18–27 years), and individuals potentially spawn several times throughout their adult lives over the span of multiple decades (see Peterson and others [2007] for a summary of lake sturgeon ecology). As a result, lake sturgeon tend to be exposed to a greater diversity of spawning conditions throughout their lives than other lithophilic-spawning fish in the SCDRS. Thus, when suitable spawning habitat or environmental conditions are not detected, the energetic savings of not spawning and (or) resorbing gametes, which take several years to develop (Roussow, 1957), may exceed the benefits of spawning under conditions where early life stages of lake sturgeon are not likely to survive (that is, mitigates losses of reproductive fitness because of poor year classes). The immediate spawning responses by lake sturgeon to the construction of the Fighting Island and Middle Channel Saint Clair River reefs suggest lake sturgeon are very aware of their environment, and the hypothesis that low availability of suitable spawning habitat remains a limiting factor to their reproduction is supported.

In contrast to lake sturgeon, walleye, lake whitefish, and suckers spawned in nearly every region of each river in all years and on both reef and nonreef substrates. For these comparatively shorter-lived species, less judicious gametic resource allocation may be an alternative strategy to increase reproductive fitness in the SCDRS. Compared to lake sturgeon, eggs of walleye and suckers were collected over a wider range of spawning conditions both spatially and temporally in the spring (fig. 3) within a given year. However, although high egg CPUEs were observed for walleye, lake whitefish, and suckers, the fact that many of these eggs are spawned over substrate with little interstitial space to protect the deposited eggs means these high CPUEs do not necessarily indicate successful reproduction (that is, egg survival or recruitment). For example, some of the greatest walleye egg CPUEs were observed at the head of Belle Isle (fig. 4*A* and table 1) where the natural river bottom consists mostly of clay covered by coarse sand (Manny and others, 2010). Additional high walleye and sucker egg CPUEs on natural substrates at NE Fighting Island were over thin patches of small diameter gravel and sand on sculpted hard-pan clay (Roseman, Manny, and others, 2011). Walleye and suckers in the SCDRS have shown a generally consistent spatial pattern in their egg CPUEs, thus substrate characteristics may not be the primary driver of where they choose to spawn in the SCDRS. Walleye spawn over a wide range of substrates and microhabitats, with depth and flow velocity often being important predictors of reproductive effort (Bozek and others, 2011). In the Saint Clair River, site-specific conditions favorable for spawning may be similar between walleye and suckers because similar temporal patterns are shown within each of the regions of Port Huron, Saint Clair Middle Grounds, and Algonac, which were sampled every year from 2010 to 2014 (fig. 6). Interestingly, walleye eggs were never collected at the coal cinder pile in North Channel Saint Clair River—a presumably preferable substrate compared to sand and clay. It was noted that the creation of reefs in both rivers has shown no obvious impact on where walleye, lake whitefish, and suckers choose to spawn but has likely increased the survival of eggs deposited over them by decreasing rates of egg siltation, predation, or of being washed downstream (Crane and Farrell, 2013).

In order for egg mat collection data to more accurately represent fish spawning in the SCDRS, many uncertainties need to be addressed. First, laboratory studies to evaluate the influence of current velocity, substrate, and species-specific egg characteristics on egg capture efficiency and retention may inform correction factors that could be applied to egg mat data from this study. Alternatively, D-frame drift nets are a sampling gear that would alleviate losses of eggs during sampling and gear retrieval, and when coupled with flow meters, could also measure the volume of water sampled. However, such gear is more prone to fouling by masses of aquatic vegetation than egg mats and requires a buoy to keep the net upright. Experience in this study suggests that this is particularly problematic in the Detroit and Saint Clair Rivers because of high freighter and recreational angling boat traffic, and this was the impetus for the development of the buoy-less egg mat sampling method (Roseman, Boase, and others, 2011). Additionally, D-frame drift nets can only capture eggs in transit, whereas eggs can be directly deposited over egg mats by spawning fish. Lastly, there have been recent advances in three-dimensional measurements of water velocity in the SCDRS using acoustic Doppler current profiling (Fischer and others, 2015). If coupled with three-dimensional hydrodynamic transport modeling (Beletsky and others, 2007), such information could provide a greater depiction of egg transport and settling.

Next, careful consideration must be given to the influence of incubation time on egg mat collections and its interactions with water temperature and downstream drift. Estimates of incubation time for walleye and white sucker eggs from 1982 to 1991 in the Valley River, Manitoba, Canada (Johnston and others, 1995), averaged 12.0 and 14.8 days, respectively, although water temperatures were not reported. Furthermore, controlled laboratory experiments by Hamel and others (1997) found that white sucker eggs raised below 16.6 ˚C had incubation times of at least 11.3 days between deposition and hatching. For comparison, the collections of large sucker eggs in this study generally were between 7.5 and 15.3 ˚C in the Detroit River (table 5) and between 7.2 and 14.9 ˚C in the Saint Clair River (table 6). For lake sturgeon, Kempinger (1988) reports egg incubation durations ranging from 8 to 14 days in the Lake Winnebago system, Wisconsin; Smith and King (2005) report egg incubation durations ranging from 5 to 11 days in the Black River, Michigan; and Johnson and others (2006) report average incubation times of 6 days for eggs reared at 16 ˚C, which is a warmer temperature than most of the lake sturgeon egg collections reported herein (tables 5 and 6). Multiple studies (Brooke, 1975; Brown and Taylor, 1992) indicate that lake whitefish eggs deposited in the fall incubate over winter. Thus, with the possible exception of lake sturgeon, weekly gear retrieval is a reasonable frequency to collect deposited eggs from egg mats before they hatch.

Widespread spawning by numerous native indicator fish species suggests improvement of spawning habitat in the SCDRS that is reflective of environmental quality improvements since the 1970s (Hartig and others, 2009); however, the production of lithophilic broadcast spawning fish species in the SCDRS is likely still limited by the availability of suitable spawning substrate. The construction of artificial reefs may be an effective tool toward the restoration of such habitat within the Great Lakes (Manny and others, 2015; McLean and others, 2015), the availability of which may trigger the act of spawning (as seen with lake sturgeon) or increase the survival of fish eggs. To predict the potential for further restoration efforts to effectively address conservation objectives, future research is needed to estimate (1) the relation between observed fish egg densities and other habitat characteristics (for example, proximity to nursery habitats), and (2) the influence of natural and artificial substrates in the SCDRS on fish egg survival. Ultimately, this research offers a unique insight to fish use of the SCDRS and their responses to restoration efforts, providing new contemporary knowledge needed to guide fisheries management.

Summary

The areal extent of lithophilic-spawning fish egg collections in the Detroit (2005–14) and Saint Clair (2010–14) Rivers was summarized. Cumulative catch-per-unit effort (CPUE) of eggs collected per species per spawning season was calculated and reported by river regions, and dates and water temperatures of the onset and cessation of spawning were presented for the primary taxa observed in each river.

Walleye (*Sander vitreus*), lake whitefish (*Coregonus clupeaformis*), lake sturgeon (*Acipenser fulvescens*), suckers (Catostomidae spp.), and trout-perch (*Percopsis omiscomaycus*) were found to spawn extensively throughout the Detroit and Saint Clair Rivers. The CPUEs of walleye, lake whitefish, and sucker eggs were much greater in the Detroit River than in the Saint Clair River, while lake sturgeon egg CPUEs were highest from the Saint Clair River. Walleye, lake whitefish, and sucker eggs were collected from both reef and nonreef substrates from among the majority of sampling locations in both rivers. In contrast, lake sturgeon eggs were collected mainly on man-made, artificial fish spawning reefs in the Detroit and Saint Clair Rivers. Collections of lake sturgeon eggs on artificial, fish spawning reefs (Fighting Island Reef, Detroit River and Middle Channel Saint Clair River reefs) during postassessment years, but not during preassessment years, suggests lake sturgeon were able to locate and use these structures for their intended purpose.

The response exhibited by lake sturgeon of spawning on newly constructed reefs indicates that successful reproduction by lithophilic-spawning fishes may be limited in the Saint Clair-Detroit River System. Additionally, the fact that eggs of walleye, lake whitefish, and suckers were often collected over natural substrates with little interstitial space to protect the deposited eggs from siltation, sedimentation, or downstream scouring, suggests that lack of suitable spawning habitat may continue to limit successful reproduction of these species as well.

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