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Assessment and public outreach of low water level impacts on fish community and aquatic habitat in Lake St. Lawrence

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INTRODUCTION

Historically low 2018 water levels in Lake St. Lawrence have prompted concerns that fish populations and habitat may be locally impacted. Long-term residents of the Long Sault area have indicated that low water levels have exposed an unprecedented area of river bottom that has been affecting both boat navigation and recreational fisheries. Residents have also voiced concerns over the short and long term impacts to fish populations and the health of the ecosystem.

This project seeks to address these concerns by conducting a comprehensive scientific review of the life histories and critical habitat of all known fish species inhabiting Lake St. Lawrence (Iroquois Dam to Moses-Saunders Dam). All species at risk (SAR) that inhabit Lake St. Lawrence would be identified as part of this review. Partnerships and inter-agency linkages would be developed and enhanced as part of the data-sharing process.

As part of this review, critical habitat requirements of life history stages (spawning, nursery, feeding, overwintering) were summarized for each fish species in Lake St. Lawrence. The life history schedule was then cross-referenced with monthly water level data from the Long Sault Dam to examine both recent trends (2016-2018) and the historical average (1960-2017). The combination of these two datasets (habitat requirements at various life stages and water level trends) provides a meaningful tool for both research and management purposes to assess how the seasonal timing of low water levels might affect critical periods of fish life cycles, as well as current knowledge gaps in our understanding of these impacts.

Overall this project represents an important opportunity to address public concerns about the local ecological effects of Plan 2014 on Lake St. Lawrence, while building an important dataset that can help guide water level management policies.

METHODS

Study Area

This project focuses on Lake St. Lawrence (LSL), a 49 km long section of the Upper St. Lawrence River (USLR) located between the Iroquois Control Dam and the Moses-Saunders (M-S) Power Dam (Figure 1). Prior to the construction of the St. Lawrence Seaway in the 1950s, this section of the USLR was relatively narrow and fast-flowing, with a substantial gradient of 19.8 m that formed the Long Sault Rapids. When construction of the M-S Power Dam was completed in 1959, it created an impoundment that effectively flooded the former Long Sault Rapids and increased the upstream river surface area by up to 300%, and the nearshore aquatic habitat by 20% (LePan et al, 2002). This reservoir is now known as Lake St. Lawrence. Former agricultural lands and villages were flooded and lost as part of this process, and as a consequence much of the newly created habitat is relatively shallow water overlying poor soils that have not had time to develop into productive habitats. Furthermore, these new shallow habitats were made unstable by the frequent water level fluctuations associated with the operations of the nearby M-S Power Dam. As such, submerged and emergent aquatic plants are relatively sparse above these drawdown zones, which turn into mudflats during lower water levels.

Hoople Bay is an inlet along the St. Lawrence River, closed off to the main channel by a causeway with access via a culvert. The entrance to the bay is further encircled by a chain of islands that were created by the Seaway construction, known as the Long Sault Parkway. Prior to the flooding, Hoople Bay existed as a much longer, meandering stream known as Hoople Creek, flowing through villages such as Wales and Dickinson Landing where water would eventually meet the main St. Lawrence River. During inundation of the Seaway, water filled over the banks of Hoople Creek and flooded adjacent agricultural fields, becoming what is now known as Hoople Bay. Significant and frequent water drawdowns are experienced in Hoople Bay due to its shallow depth and close upstream proximity to the M-S Power Dam. Large exposed mudflats are common in the bay, while percent cover aquatic plants is relatively low. However, during the high water levels in early spring (March), a significant spawning run of walleye make use of the bay to access Hoople Creek, where habitat rehabilitation efforts in the 1980s have provided an alternate spawning ground to the habitat that was lost from the Long Sault Rapids.

Following the Seaway construction, aquatic plant beds across LSL have established below drawdown zones in more stable areas of the river, and fish communities have shifted to adapt to a wider, slower and shallower section of river habitat. It is within this context that we examine the current state of fish communities inhabiting Lake St. Lawrence

Fish Community Data

Data on fish species occurrences were derived from several sources, including: 1) the gill net assessment program in Lake St. Lawrence jointly administered by the NYSDEC and the Ontario Ministry of Natural Resources and Forestry (OMNRF); 2) the New York State Fisheries Database (v. 61), which summarizes fish survey data from multiple organizations including the New York State Department of Environmental Conservation (NYSDEC), the U.S. Geological Survey (USGS), the U.S. Fish and Wildlife Service (USFWS), and the St. Regis Mohawk Tribe (SRMT); and 3) nearshore seine surveys conducted in the Canadian waters of LSL by the River Institute. Subject matter experts at the NYSDEC, OMNRF, and SRMT were consulted to ensure comprehensive inclusion of all available datasets.

In 1986, a collaborative fisheries assessment program for LSL was initiated through the OMNRF and the NYSDEC. A total of 32 standard sites (16 in Ontario, 16 in New York) were fished using gill nets that were placed in either shallow (12-25ft depth) or deep (30-50ft depth) waters, for an average of 18.2 hours overnight. This Lake St. Lawrence program collects fish data over a week in the summer or fall, and has been maintained by the NYSDEC since 1996.

Nearshore habitats in U.S. waters of LSL have been surveyed regularly by the NYSDEC through seining surveys that were initiated in 2007. Seining initially took place at 6 sites, however more have been added over time as resources permit. Additionally, a substantial survey effort was undertaken jointly by the USGS Tunison Laboratory of Aquatic Science (USGS TLAS) and the St. Regis Mohawk Tribe Environment Division (SRMT) from 2009-2010. This study spanned from the head of the St. Lawrence River at Cape Vincent downstream to the northern most extent of the St. Regis Mohawk territory in Quebec, Canada and included an approximate 5 km distance upstream in tributaries. The study area was broken down into 10 contiguous zones with boundaries at substantial changes in broad habitat requirements (McKenna et al., 2012) for which the data of relevance to this project occurred in Zone 8. Survey gears included beach seines of various lengths and mesh sizes, gillnets, and electrofishing. The collection of this fish capture data occurred between May through October in 2009 and April through September in 2010.

Since 2015 the River Institute (Cornwall, Ontario) has partnered with the Mohawk Council of Akwesasne (MCA) to conduct a research project call the Fish Identification Nearshore Survey (FINS). The objective of this project is to assess nearshore aquatic communities towards assessing the nearshore community of fish on the Canadian shore of the St. Lawrence River from Montreal, Quebec to Kingston, Ontario. Efforts have focussed on determining the distributions and habitat associations of species at risk, such as the pugnose shiner (*Notropis anogenus*), and mapping out the distributions of aquatic invasive species (AIS) such as the tubenose goby (*Proterorhinus semilunaris*). Survey efforts of this project consisted of beach seining the nearshore environment of the St. Lawrence River during the months of May – September from 2015-2019. A map of the seine locations completed under the FINS project can be seen Figure 1. The FINS project has generated approximately 30,000 fish records for Canadian nearshore waters of Lake St. Lawrence.

These comprehensive datasets included characteristics such as location of fish capture, which assisted in the interpretations to be made about potential fish located within Hoople Bay, or solely in LSL. Survey sites were mapped using ArcMap (v. 10.4.1). A map of all capture locations can be found in Figure 1.

The Ontario Ministry of Natural Resources and Forestry hosts an online platform known as Fish ON-line which documents known water bodies, and MNRF confirmed species by location (see https://www.gisapplication.lrc.gov.on.ca/FishONLine/Index.html?site=FishONLine&viewer=FishONLine&locale=en-US). This database was accessed for the areas known as Lake St. Lawrence, and Hoople Creek.

Capture sites used various net strategies to trap fish, which included seine and gill nets. The specific netting strategy at each site must be accounted for during interpretations, as unwanted species bias may occur from the use of a specific type of net, at a specific depth, or with a specific mesh size. Datasets may have also been extracted from projects which aimed at trapping a specific species, therefore using relevant methods or equipment for that individual.

Data that was recorded in all datasets included species and abundance, while other site characteristics that were commonly present among data, but not entirely, included: bottom substrate, vegetation abundance, shoreline type/ depth, water temperature, and turbidity.

Critical life stage habitat requirements

Critical habitat requirements for LSL fish species were compiled through a comprehensive literature review that included peer-reviewed publications, published reference guides, and government reports. Primary sources of information included a series of reports by Lane et al. (1996a, 1996b, 1997c), which summarize and describe key habitat requirements for spawning, young-of-the-year, and adult fish of the Great Lakes on behalf of the Department of Fisheries and Oceans Canada. Habitat requirements were divided into categories of water depth, submergent or emergent plant cover, and substrate types (e.g. bedrock, gravel, sand). These reports were summarized and combined into a single table in order to relate how water level fluctuations in LSL may impact the habitat requirements of various life stages of fish species.

Other important references included Scott and Crossman (1973) and the ROM Field Guide to Freshwater Fishes of Ontario (Erling et al., 2010). Information for various species was often lacking in these resources if the respective species has only been identified on the U.S side (e.g. blueback herring), has not been identified in Ontario in many years, or if its life history is not well understood. In such cases, peer reviewed literature was then used to supplement these specific characteristics such as thermal tolerances or spawning strategies. An emphasis was placed on the applicability of the literature towards the conditions inhabited by freshwater fishes in LSL.

The relevant characteristics were collected and cross-referenced across the various resources through the compilation of an excel spreadsheet organized by species. Interpretations of species occurrences were assisted through the comparison of this species by life history chart with the recorded habitat data (from databases) of where individual species were actually documented. In addition to the aforementioned databases and literary resources, consultations with local fisherman and independent experts were conducted to assist interpretations of fish species located within the area of interest (Hoople bay) or that may be effected by the low water levels.

Water Level Data

Water Level data was retrieved from the Great Lakes – St. Lawrence Regulation Office, of the Environment & Climate Change Division of the Government of Canada. Relevant data was collected from the Long Sault Dam located on Barnhart Island, Massena, New York and was organized as daily water levels (m) and outflow (m/s^3) from 2017-2018. Data was averaged out to monthly means, and then compared with potential fish activity using an excel spreadsheet. The differences in monthly water levels and outflows from 2017 to 2018 were also calculated using these averages. This spreadsheet organized water levels and outflows along with potential species spawning and FRY activity on a monthly basis.

Water Levels and outflows at the Long Sault generating station from 2017 were compared with the data from 2018. Monthly water levels at the Long Sault station in 2017, on average, were found to be 0.47m above what they were in 2018. Short and long-term water level fluctuations were related to preferred spawning depths of fish that may be impacted seasonally by monthly trends (Figure 3).

RESULTS & DISCUSSION

A total of 73 fish species were documented in LSL from the cumulative records derived from the NYSDEC/OMNRF gill net surveys, the NYS Fisheries Database (v.61) and River Institute seine surveys (Table 1). A total of 32 species have been documented in gill net surveys since 1986, most of which have been consistently found throughout the time series (26 species). A total of 57 species were cumulatively documented by seine surveys in U.S. and Canadian nearshore waters of LSL. Of these, 41 species were documented on both north and south shores of LSL. A total of 24 fish species have been documented within the Hoople Bay section of LSL (Figure 2).

There was a total of 7 species currently listed (Feb 2019) as at-risk in Ontario: American eel, bridle shiner, cutlip minnow, grass pickerel, lake sturgeon, pugnose shiner, and silver lamprey. The NYSDEC list of threatened, endangered and special concern wildlife species was also consulted, within which lake sturgeon and mooneye are considered threatened, while the Pugnose Shiner is listed as endangered. Each of these species will be discussed further in their respective paragraphs found below with respect to location of capture, and most recent identification. No species at risk were found within Hoople Bay.

Of the 73 species documented in LSL, 10 species had only one individual documented (American shad, brassy minnow, chinook salmon, finescale dace, lake chub, johnny darter, rainbow smelt, rainbow trout, stonecat, trout-perch), possibly due to their rarity, lack of catchability due to the gear types used, or misidentification. An additional two species were flagged as questionable identifications in the NYS Fisheries Database (chain pickerel and grass pickerel). Lake trout have also not been recorded in any catches since they were last documented in gill net surveys of LSL in 1993. These rare, questionable, and older documented species were removed from further analysis to focus on the remaining fish assemblage (61 species) for which there are multiple and reliable identifications provided. Non-native fish species (including alewife, blueback herring, brown trout, and gizzard shad) were excluded from the summary of habitat requirements for this assemblage, with the exception of round gobies and common carp that are found in high abundance throughout the river. Overall, the summary of habitat requirements for documented, native LSL fish focused on 56 species (Table 2).

Analysis of the life history characteristics of the 56 relatively common, native fish species of LSL revealed that all are spring and summer spawners. Exact spawning dates for each species may vary by weeks from year to year, and are primarily driven by water temperatures. Since water tends to warm more quickly in shallow margins of the river, these areas may become more attractive than deeper, more stable environments if other conditions are met (e.g. aquatic vegetation cover).

Usage of these shallow environments for spawning could potentially create hazards for fish and their early life stages (eggs, larvae) during scenarios where water levels rapidly decrease. While possible, this may be unlikely given that LSL water levels have historically been highest during spring and early summer when these activities would take place (Figure 3). However, in 2018 water levels deviated substantially from the long-term spring mean (Figure 3), which may have impacted spawning and early life stages of fish during this time.

A total of 55 of the 56 species use very shallow depths (0-1 m) for spawning (Table 2), while 35 species spawn at 1-2 m depth and 15 spawn at 2-5 m depth. However, many of these species also have a high degree of dependency on submergent aquatic vegetation during spawning (19 species), and may therefore avoid the sparsely vegetated nearshore zones of LSL (where they occur). More species prefer to spawn on gravel (33 spp) and sand (36 spp) compared to silt (20 spp) and clay (4 spp), which again would suggest that many species would avoid spawning over the muddy flats of LSL margins.

A high proportion of species (54 of 56) have young-of-the-year life stages that make use of very shallow waters (0-2 m depth). Since these early life stages often lack substantial means of mobility, they can be very vulnerable to rapid changes in water levels, and could become stranded during drawdowns. Use of shallow habitats by these early life stages occurs most often in spring and early summer (Table 2) when water levels are highest (Figure 3), but they can also linger into late summer and fall when drawdowns become more substantial. For example, the River Institute has documented young-of-the-year sunfish species in 5 cm of water in Hoople Bay, where they could be vulnerable to rapid water level fluctuations. Slower pacing of drawdowns may be advisable from late summer to fall to avoid impacting these early life stages of fish.

Frequent and extreme water fluctuations have been known to have negative and sometimes unanticipated consequences to the ecological integrity of littoral aquatic communities (Hynes, 1961; Gaboury and Patalas, 1984; Zohary and Ostrovsky, 2011; Sutela et al., 2013; Carmignani and Roy, 2017). Our assessment of the relative impacts of water level fluctuations on fish communities of LSL was based on available information from fisheries surveys, known species habitat requirements, and overall characterization of the historical changes that have occurred in the St. Lawrence River due to the flooding of the Seaway. Decades of surveys have shown that LSL has a relatively rich diversity of fish species that have adapted to the significant habitat modifications that have occurred since 1959, although substantial changes have occurred for species that were previously adapted to the conditions of the Long Sault Rapids (e.g. lake sturgeon, sucker species, walleye). Ongoing water level fluctuations in LSL, and in particular significant drawdowns like the summer of 2018, will undoubtedly continue to impact the quantity and quality of nearshore habitats in the area. The impacts of a warming climate on the health of these fish communities also remains unclear and should be considered. However, given the timing of average high water levels in the spring that coincide with spawning and early life stages for all species, the relatively unsuitable conditions of drawdown areas in terms of vegetation and substrates, as well as the available abundance of quality habitat below drawdown areas, the available evidence suggests that existing fish communities of LSL have not been substantially impacted by recent low water levels, at least compared to conditions that have been present for the past 40 years. Regular monitoring is recommended to evaluate and provide feedback on the ecological status of LSL littoral zones and aquatic communities as the river transitions into a new water level management regime under Plan 2014.

ACKNOWLEDGEMENTS

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FIGURES

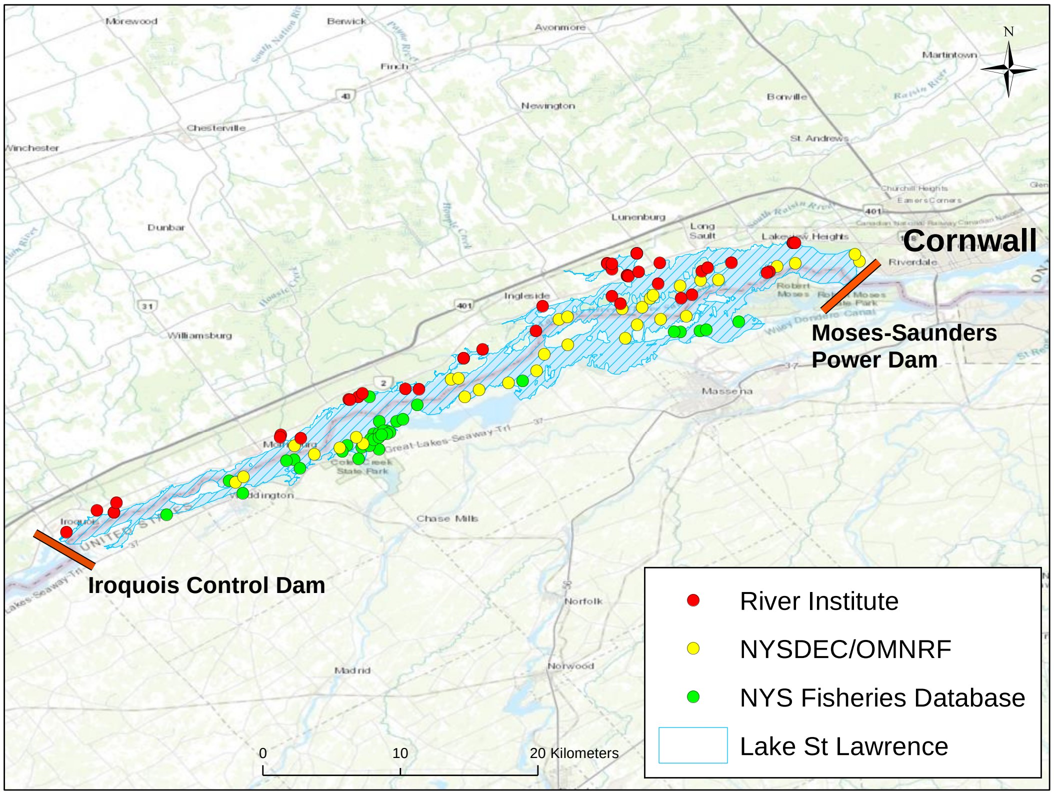

Figure 1. Locations of historical fish surveys in Lake St. Lawrence, including: 1) gill net index surveys conducted jointly by the New York State Department of Environmental Conservation (NYSDEC) and Ontario Ministry of Natural Resources and Forestry (OMNRF); 2) seining, trapnetting, and electrofishing surveys conducted by various organizations and sourced from the NYS Fisheries Database (v. 61); and 3) seining surveys conducted by River Institute. The boundaries of Lake St. Lawrence between the Iroquois Control Dam and the Moses-Saunders Power Dam near Cornwall are shown.

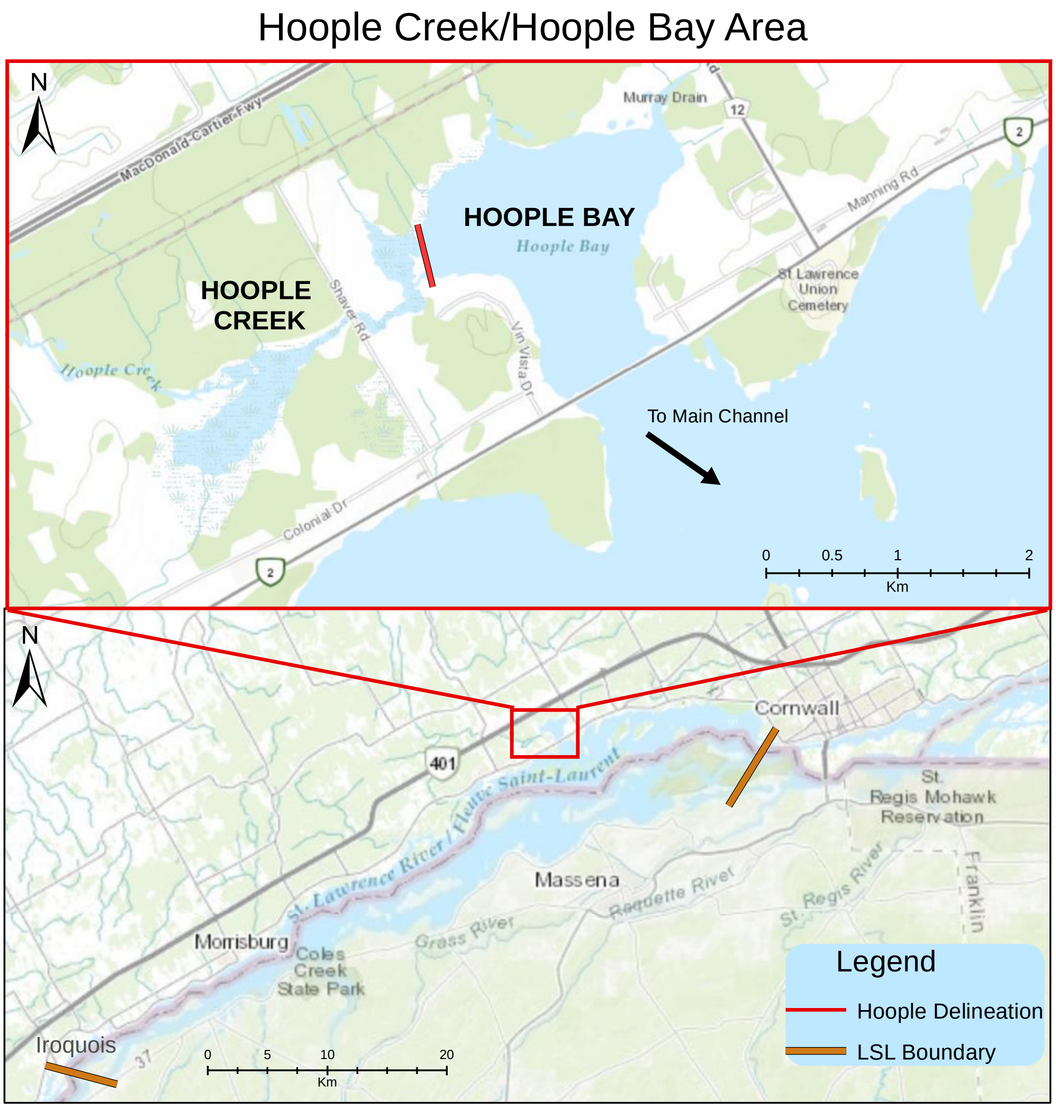

Figure 2. Upper St. Lawrence River, showing the boundaries of Lake St. Lawrence between the Iroquois Control Dam and the Moses-Saunders Power Dam near Cornwall (lower) and the location of Hoople Bay (upper).

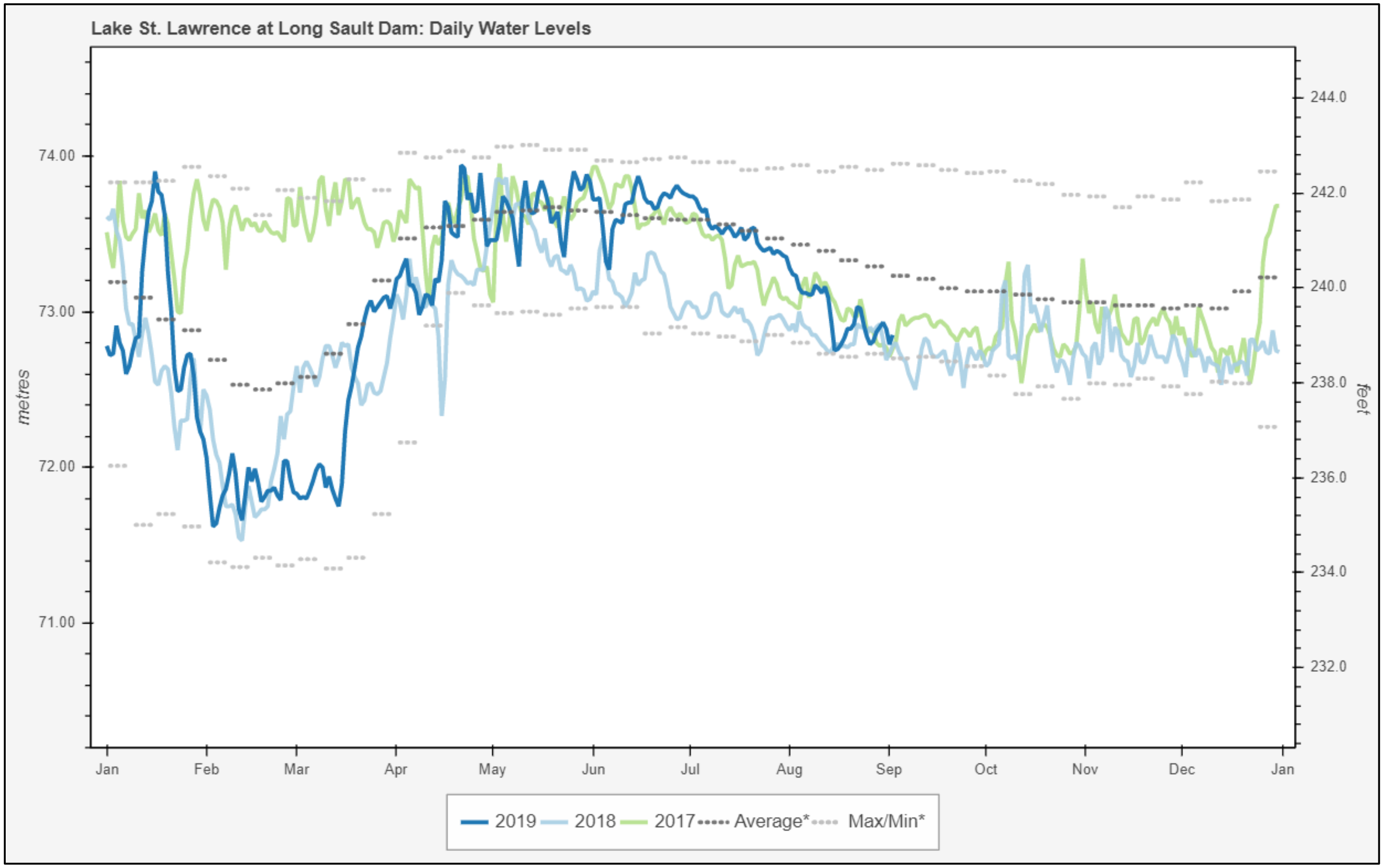

Figure 3. Recent and long-term water level fluctuations in Lake St. Lawrence in relation to preferred spawning depths of fish species. Source: International Lake Ontario-St. Lawrence River Board.

TABLES

Table 1. Fish species that have been documented within the Lake St. Lawrence section of the St. Lawrence River. Occurrences were derived from multiple sources, including the New York State Fisheries Database (NYS FD), the New York State Department of Environmental Conservation (NYSDEC), the Ontario Ministry of Natural Resources and Forestry (OMNRF), and the River Institute (RI). Where appropriate the gear type used is indicated (seine, gill net). All gear types also include trap nets and electrofishing.

Common Name	Scientific Name	Status	NYS FD seine (1996-2018)	RI seine (2015-2019)	NYSDEC/OMNRF gill net (1986-2018)	NYS FD all gear (1986-2018)
LAMPREYS	PETROMYZONTIDAE					
Silver lamprey	*Ichthyomyzon unicuspis*	Native			6	10
STURGEONS	ACIPENSERIDAE					
Lake sturgeon	*Acipenser fulvescens*	Native			12	1789
GARS	LEPISOSTEIDAE					
Longnose gar	*Lepisosteus osseus*	Native	59	18		69
BOWFINS	AMIIDAE					
Bowfin	*Amia calva*	Native	3	90	10	111
HERRINGS	CLUPEIDAE					
Alewife	*Alosa pseudoharengus*	Non-native	341	11	97	341
American shad	*Alosa sapidissima*	Non-native		1		
Gizzard shad	*Dorosoma cepedianum*	Non-native	2073		97	6
Blueback herring	*Alosa aestivalis*	Non-native	6			6
SALMON & TROUT subfamily	SALMONINAE					
Chinook salmon	*Oncorhynchus tshawytscha*	Non-native			2	1
Rainbow trout	*Oncorhynchus mykiss*	Non-native			1	
Brown trout	*Salmo trutta*	Non-native			4	3
Lake Trout	*Salvelinus namaycush*	Native				
SMELTS	OSMERIDAE					

Common Name	Scientific Name	Status	NYS FD seine (1996-2018)	RI seine (2015-2019)	NYSDEC/OMNRF gill net (1986-2018)	NYS FD all gear (1986-2018)
Rainbow smelt	*Osmerus mordax*	Non-native			2	
PIKES	ESOCIDAE					
Northern pike	*Esox lucius*	Native	104	42	385	337
Muskellunge	*Esox masquinongy*	Native	179	4	2	192
Grass Pickerel	*Esox americanus vermiculatus*	Native	2			2
Chain pickerel	*Esox niger*	Non-native	2			2
MUDMINNOWS	UMBRIDAE					
Central mudminnow	*Umbra limi*	Native	4	22		4
SUCKERS	CATOSTOMIDAE					
White sucker	*Catostomus commersonii*	Native	2437	1992	644	3309
Silver redhorse	*Moxostoma anisurum*	Native	2		360	157
Shorthead redhorse	*Moxostoma macrolepidotum*	Native			73	3
Greater redhorse	*Moxostoma valenciennesi*	Native			10	67
Moxostoma sp.	*Moxostoma sp.*	Native	114	1		134
CARPS and MINNOWS	CYPRINIDAE					
Finescale dace	*Chrosomus neogaeus*	Native		1		
Lake chub	*Couesius plumbeus*	Native			1	
Common carp	*Cyprinus carpio*	Non-native	24	12	456	142
Cutlip minnow	*Exoglossum maxillingua*	Native	1	4		2
Brassy minnow	*Hybognathus hankinsoni*	Native		1		
Eastern silvery minnow	*Hybognathus regius*	Native	271			271
Golden shiner	*Notemigonus crysoleucas*	Native		2299	8	2094
Pugnose shiner	*Notropis anogenus*	Native	15	419		15
Emerald shiner	*Notropis atherinoides*	Native	32	7		45
Bridle shiner	*Notropis bifrenatus*	Native	71	48		71
Common shiner	*Luxilus cornutus*	Native	75	5		75

Common Name	Scientific Name	Status	NYS FD seine (1996-2018)	RI seine (2015-2019)	NYSDEC/OMNRF gill net (1986-2018)	NYS FD all gear (1986-2018)
Blackchin shiner	*Notropis heterodon*	Native	1321	1376		1322
Blacknose shiner	*Notropis heterolepis*	Native		2		1
Spottail shiner	*Notropis hudsonius*	Native	139	43		139
Rosyface shiner	*Notropis rubellus*	Native	2	1		42
Spotfin shiner	*Cyprinella spiloptera*	Native	415	522		415
Sand shiner	*Notropis stramineus*	Native	8	169	4	8
Mimic shiner	*Notropis volucellus*	Native	5	1577		12
Bluntnose minnow	*Pimephales notatus*	Native	1266	5114		1301
Fathead minnow	*Pimephales promelas*	Native	39	48		48
Longnose dace	*Rhinichthys cataractae*	Native				6
Creek chub	*Semotilus atromaculatus*	Native	36	4		37
Fallfish	*Semotilus corporalis*	Native	58	1027	141	149
North American CATFISHES	ICTALURIDAE					
Yellow bullhead	*Ameiurus natalis*	Native		2	1	
Brown bullhead	*Ameiurus nebulosus*	Native	425	1902	729	1467
Channel catfish	*Ictalurus punctatus*	Native			70	6
Stonecat	*Noturus flavus*	Native			1	
Tadpole madtom	*Noturus gyrinus*	Native		8		
FRESHWATER EELS	*ANGUILLIDAE*					
American eel	*Anguilla rostrata*	Native	4		1	15
TOPMINNOWS/KILLIFISHES	FUNDULIDAE					
Banded killifish	*Fundulus diaphanus*	Native	1986	2453		2003
STICKLEBACKS	GASTEROSTEIDAE					
Brook stickleback	*Culaea inconstans*	Native	87	8		87
TROUT-PERCHES	PERCOPSIDAE					
Trout-perch	*Percopsis omiscomaycus*	Native	1			1

Common Name	Scientific Name	Status	NYS FD seine (1996-2018)	RI seine (2015-2019)	NYSDEC/OMNRF gill net (1986-2018)	NYS FD all gear (1986-2018)
TEMPERATE BASSES	MORONIDAE					
White perch	*Morone americana*	Non-native		5	905	122
White bass	*Morone chrysops*	Native			12	1
SUNFISHES	CENTRARCHIDAE					
Rock bass	*Ambloplites rupestris*	Native	2102	218	3117	3139
Pumpkinseed	*Lepomis gibbosus*	Native	1721	1528	340	2041
Bluegill	*Lepomis macrochirus*	Native	581	649	11	1961
Smallmouth bass	*Micropterus dolomieu*	Native	91	85	1985	1302
Largemouth bass	*Micropterus salmoides*	Native	5963	960	146	6920
Black crappie	*Pomoxis nigromaculatus*	Native	1292	509	33	1501
PERCH	PERCIDAE					
Yellow perch	*Perca flavescens*	Native	11500	3211	6309	13788
Walleye (Yellow Pickerel)	*Sander vitreus*	Native	3	1	1315	387
Iowa darter	*Etheostoma exile*	Native	1	19		2
Fantail darter	*Etheostoma flabellare*	Native				7
Johnny darter	*Etheostoma nigrum*	Native	1			1
Logperch	*Percina caprodes*	Native	979	181		1002
Tessellated darter	*Etheostoma olmstedi*	Native	245	35		300
NEW WORLD SILVERSIDES	ATHERINOPSIDAE					
Brook silverside	*Labidesthes sicculus*	Native	4326	2019		4340
GOBIES	GOBIIDAE					
Round goby	*Neogobius melanostomus*	Non-native	12212	1773		12319
DRUMS	SCIAENIDAE					
Freshwater drum	*Aplodinotus grunniens*	Native			18	14
SCULPINS	COTTIDAE					
Mottled sculpin	*Cottus bairdii*	Native				24

Table 2. Depth strata, type of cover, and substrate used by Lake St. Lawrence fishes. Habitat associations with life history stages are defined as spawning (S), nursery (N), and adult (A). In terms of seasonal usages of these habitats, spring is defined as the period during which water temperatures are increasing (spring-early summer), fall is defined as the period during which water temperatures are declining (late summer-fall), winter is defined as the period during which water temperatures are at a minimum and stable, and year is defined as no seasonal differences. Strength of association with cover and substrate categories are based on estimates from the literature. Table contents adapted from Lane et al. (1996a, 1996b, 1996c).

			Water Depth (m)				**Cover**			**Substrate**							
Common name	**Spawning season**	**Spawning Temp ° C**	**0-1**	**1-2**	**2-5**	**5+**	**Submergent vegetation**	**Emergent vegetation**	**Other**	**Bedrock**	**Boulder**	**Cobble**	**Rubble**	**Gravel**	**Sand**	**Silt**	**Clay**	**Hard-pan clay**
silver lamprey	spring	18	summer (A)	year (A)	year (A)	year (N, A)	low (N, A)	low (N, A)		-	-	-	-	medium (N)	high (N)	high (N)		
lake sturgeon	spring	13-21	spring (S)	spring (S)	spring (S), year (N, A)	year (N, A)	-	-	rocks, logs	-	high (S)	high (S)	high (S), medium (N)	high (S), low (A), medium (N)	high (S, N), low (A)	high (N,A)	-	high (S)
longnose gar	spring	19-29	spring (S, N)	fall (N)	year (A)	year (A)	high (S, N, A)	high (S), low (A)	*Cladophora*	-	-	-	-	medium (S), high (A)	high (S,N,A)	high (S,N,A)	medium (A)	-
bowfin	spring	16-19	spring (S, N), year (A)	spring (S), fall (N), year (A)	year (A)	-	high (S, N, A)	high (S)	-	-	-	-	-	high (A)	high (S,N,A)	high (S,N,A)	-	-
northern pike	spring	2-18	spring (S, N), year (A)	spring (S, N), year (A)	fall (N), year (A)	-	high (N, A)	high (S, A)	flooded terrestrial vegetation	-	-	-	low (S)	low (S,A)	high (S,A)	high (S,N,A)	-	-
muskellunge	spring	8-18	spring (S), year (N, A)	spring (S), year (N, A)	year (A)	year (A)	high (S, N, A)	high (S, A)	stumps, logs	-	-	-	-	low (A)-	high (A), medium (S, N)	high (S,N,A)	high (S)	-
central mudminnow	spring	13 (approx)	spring (S), year (N, A)	year (N)	-	-	high (S, A)	high (S, N, A)	-	-	-	-	-	low (A)	high (A)	high (S,N,A)	-	-

			Water Depth (m)				Cover			Substrate								
Common name	**Spawning season**	**Spawning Temp ° C**	**0-1**	**1-2**	**2-5**	**5+**	**Submergent vegetation**	**Emergent vegetation**	**Other**	**Bedrock**	**Boulder**	**Cobble**	**Rubble**	**Gravel**	**Sand**	**Silt**	**Clay**	**Hard-pan clay**
white sucker	spring	6-23	spring (S), year (N, A)	spring (S), year (N, A)	year (N, A)	year (A)	low (S), high (N)	low (S), medium (A)	-	low (A)	low (A)	low (N, A)	medium (S, A), low (N)	high (S, A)	medium (S), high (N,A)	low (A), medium (N)	-	-
silver redhorse	spring	13[c]	spring (S), year (N, A)	year (N, A)	-	-	-	high (N)	-	-	-	high (S)	high (S), medium (A)	high (S, A)	high (N,A)	high (N,A)	medium (A)	-
shorthead redhorse	spring	11-21	spring (S), year (N, A)	year (N, A)	-	-	low (A)	-	-	-	-	medium (A)	high (S,A)	high (S,A), medium (N)	medium (A), high (S,N)	medium (A)	-	-
greater redhorse	spring	17-19	spring (S), year (N, A)	spring (S), year (N)	spring (S)	-	-	-	-	medium (N)	high (S,A)	-	medium (A)	high (S,N,A)	high (S,N,A)	-	-	-
common carp	spring	17-28	spring (S), year (N), summer (A)	spring (S), year (N), winter (A)	-	-	high (S, N, A)	high (S, N, A)	-	-	-	-	medium (S), low (A), high (N)	medium (S,A), high (N)	medium (S), high (N,A)	high (S,N,A)	high (N)	-
cutlips minnow	spring	n/a	spring (S), year (N, A)	year (N)	-	-	-	-	large rocks, stones, logs	-	-	medium (S)	high (S)	high (S,N,A)	Meium (N,A)	-	-	-
golden shiner	spring	20-27	spring (S), year (N, A)	spring (S), year (N, A)	year (A)	-	high (S, N, A)	high (S, N, A)	organic debris, filamentous algae	-	-	-	-	medium (A)	high (S,N,A)	high (S,N,A)	-	-
pugnose shiner	spring	21-29	spring (S), year (N, A)	spring (S), year (N)	-	-	high (S, N, A)	high (S, N, A)	-	-	-	-	-	medium (S)	high (S,N,A)	high (S,N,A)	medium (A, N)	-
emerald shiner	spring	20-23	spring (S, N), summer (A)	spring (S, N), year (A)	spring (S), fall (N), year (A)	spring (S)	low (S), medium (N)	low (S), medium (N)	-	-	medium (S)	medium (S)	high (S,N)	high (S)	medium (A), high (S,N)	medium (A), high (N)	high (N)	-

			Water Depth (m)				Cover			Substrate								
Common name	**Spawning season**	**Spawning Temp ° C**	**0-1**	**1-2**	**2-5**	**5+**	**Submergent vegetation**	**Emergent vegetation**	**Other**	**Bedrock**	**Boulder**	**Cobble**	**Rubble**	**Gravel**	**Sand**	**Silt**	**Clay**	**Hard-pan clay**
bridle shiner	spring	14-26	spring (S), year (N, A)	year (N)	-	-	high (S, A), low (N)	high (S)	-	-	-	-	-	medium (N)	high (S,N,A)	high (S,N,A)	-	-
common shiner	spring	14-28	spring (S), year (N, A)	year (N)	-	-	low (S), medium (N, A)	low (S), medium (N, A)	-	-	-	-	medium (S), high (A)	high (S,N,A)	medium (S,A), high (N)	medium (N,A)	-	-
blackchin shiner	spring	n/a	spring (S), year (N, A)	year (N)	-	-	high (S, N, A)	high (S)	-	-	-	-	-	high (S,A)	high (S,A)	high (S,N,A)	-	-
blacknose shiner	spring	n/a	spring (S), year (N, A)	year (N)	-	-	high (S, N, A)	high (S, N, A)	roots of aquatic vegetation	-	-	-	-	medium (S), high (A)	high (S,N,A)	high (N)	medium (N)	-
eastern silvery minnow	spring	13-21	spring (S), year (N, A)	year (N)	-	-	high (S), low (A)	high (S), medium (N), low (A)	-		-	-	-	medium (N, A)	medium (N), high (A)	high (S), medium (N, A)	-	-
longnose dace	spring	11-24	spring (S), year (N, A)	spring (S), year (N)	-	-	low (N)	low (N)	-	-	medium (A)	medium (S, A)	high (S, A), medium (N)	high (S, A), medium (N)	medium (S), high (N, A)	high (N)	-	-
spottail shiner	spring	18-22	spring (S), year (N, A)	spring (S), year (N, A)	spring (S), year (N, A)	year (N, A)	medium (S), high (N, A)	medium (S), high (N)	-	-	-	medium (S)	medium (S,A)	high (S,N,A)	high (S,N,A)	medium (N,A)	-	-
rosyface shiner	spring	20-29	spring (S), year (N, A)	year (N)	-	-	-	low (N)	-	-	-	high (S)	high (S), low (N)	high (S,A), low (N)	high (S,A), medium (N)	medium (N)	medium (N)	-
spotfin shiner	spring	18-29	spring (S), year (N, A)	spring (S), year (N)	-	-	low (S, N, A)	low (S)	undersides of fixed objects	-	-	-	-	high (S)	high (S, A)	high (S, A)	-	-

			Water Depth (m)				Cover			Substrate								
Common name	**Spawning season**	**Spawning Temp ° C**	**0-1**	**1-2**	**2-5**	**5+**	**Submergent vegetation**	**Emergent vegetation**	**Other**	**Bedrock**	**Boulder**	**Cobble**	**Rubble**	**Gravel**	**Sand**	**Silt**	**Clay**	**Hard-pan clay**
sand shiner	spring	21	spring (S), year (N, A)	spring (S), year (N, A)	year (A)	year (A)	low (S, A), medium (N)	low (S, A), medium (N)	roots of aquatic vegetation	-	-	-	-	high (S,N,A)	high (S,N,A)	medium (A)	-	-
mimic shiner	spring	n/a	spring (S), year (N), summer (A)	spring (S), year (N), winter (A)	spring (S), year (N)	-	high (S, N), low (A)	high (S, N), low (A)	-	-	-	-	-	medium (S), high (A)	high (S,N,A)	low (S), medium (A), high (N)	medium (N)	-
bluntnose minnow	spring	20-28	spring (S), year (N, A)	spring (S), year (N, A)	spring (S)	-	medium (S, N), high (A)	medium (S, N, A)	undersides of fixed objects	-	medium (S)	medium (S)	high (S), medium (A)	high (S,A)	medium (S), high (N,A)	high (N,A)	-	-
fathead minnow	spring	16-29	spring (S), year (N, A)	spring (S), year (N)	-	-	medium (S, N), high (A)	medium (S, N), high (A)	undersides of fixed objects	-	-	medium (A)	medium (A)	medium (S), high (A)	high (S,N,A)	high (S,N,A)	-	-
creek chub	spring	13-27	spring (S), year (N, A)	year (N)	-	-	medium (N, A)	medium (A)	-	-	-	-	high (S), low (A)	high (S,A), medium (N)	high (S,N,A)	high (N,A)	-	-
fallfish	spring	16	spring (S), year (N, A)	year (N)	-	-	low (N)	low (N)	-	-	-	-	high (S), medium (A)	high (S,A), medium (N)	high (N,A)	high (N)	-	-
yellow bullhead	spring	n/a	spring (S), year (N, A)	spring (S), year (N)	-	-	high (S, N, A)	high (S, N, A)	logs, tree roots, boards, debris	-	-	-	-	medium (S,N,A)	high (S,N,A)	high (S,N,A)	-	-
brown bullhead	spring	14-29	spring (S), year (N, A)	spring (S), year (N, A)	-	-	medium (S), high (N, A)	medium (S), high (N, A)	logs, tree roots, boards, debris	-	-	-	high (N)	medium (A), high (N)	high (S,N,A)	high (S,A), medium (N)	high (S)	-

			Water Depth (m)				Cover			Substrate								
Common name	**Spawning season**	**Spawning Temp ° C**	**0-1**	**1-2**	**2-5**	**5+**	**Submergent vegetation**	**Emergent vegetation**	**Other**	**Bedrock**	**Boulder**	**Cobble**	**Rubble**	**Gravel**	**Sand**	**Silt**	**Clay**	**Hard-pan clay**
channel catfish	spring	18-29	spring (S), year (A)	spring (S), year (A)	spring (S)	-	low (S, N)	low (S, N)	undercut banks, log jams, rocks	-	-	high (S), medium (N)	high (S,N,A)	high (S,N,A)	high (S,A)	high (S)	high (S)	-
tadpole madtom	spring	n/a	spring (S), year (N, A)	spring (S), year (N, A)	year (A)	year (A)	medium (S), high (N, A)	medium (S), high (N, A)	under boards, logs, roots, logs, roots, cans									
banded killifish	spring	21-32	spring (S), year (N, A)	year (N)	year (N)		high (S, N, A))	high (S, N), medium (A)	-	-	-	-	high (S)	high (S,N,A)	high (S,N,A)	high (A), medium (S,N)	-	-
American eel			year (A)	year (A)	year (A)	year (A)	high (A)	high (A)	any crevices									
brook stickleback	spring	8-19	spring (S, N)	spring (N), year (A)	fall (N), year (A)	fall (N), year (A)	high (S), medium (N, A)	high (S)	sticks	-	-	-	-	medium (S), high (A)	high (S,A)	high (S,A)	-	-
white perch	spring	11-15	spring (S, N), summer (A)	spring (S, N), summer (A)	spring (S, N), winter (A)	fall (N), winter (A)	medium (S, N)	medium (S)	-	medium (S)	medium (S)	medium (S)	medium (S)	medium (S), high (N)	medium (S), high (N,A)	high (A), medium (S,N)	high (A), medium (S,N)	medium (S)
white bass	spring	13-26	spring (S, N), summer (A)	spring (S, N), summer (A)	spring (S, N), winter (A)	spring (S), fall (N)	low (S), medium (N)	low (S)	-	high (S)	high (S)	high (S)	medium (A), high (S,N)	medium (A), high (S, N)	medium (S), high (N,A)	low (S), high (A), medium (N)	low (S), medium (N)	medium (S,N)
rock bass	spring	14-24	spring (S), year (N), summer (A)	spring (S), year (N), winter (A)	year (N)	-	low (S), high (N, A)	low (S)	under rocks, logs	medium (A)	medium (A)	high (S,A)	high (S,A), medium (N)	high (S,N,A)	medium (S,A)	medium (S,A), high (N)	medium (S)	-
pumpkinseed	spring	13-29	spring (S), year (N, A)	spring (S), year (N)	-	-	high (S, N, A)	high (S, N, A)	-	-	-	-	low (A)-	high (S), medium (A)	high (S,N,A)	high (A,N)	medium (S)	-

			Water Depth (m)				Cover			Substrate								
Common name	**Spawning season**	**Spawning Temp ° C**	**0-1**	**1-2**	**2-5**	**5+**	**Submergent vegetation**	**Emergent vegetation**	**Other**	**Bedrock**	**Boulder**	**Cobble**	**Rubble**	**Gravel**	**Sand**	**Silt**	**Clay**	**Hard-pan clay**
bluegill	spring	19-27	spring (S), year (N, A)	spring (S), year (N, A)	-	spring (N)	high (S, N, A)	high (S, N, A)	-	-	-	-	-	high (S), medium (A)	high (S,N,A)	medium (S), high (N,A)		-
smallmouth bass	spring	13-24	spring (S, N), summer (A)	spring (S, N), year (A)	spring (S, N), year (A)	fall (N)	low (S, A)	low (S, A)	boulders, docks, logs	medium (S, N)	high (N,A)	high (N,A)	high (S,N,A)	high (S,A), medium (N)	low (A), medium (S,N)	low (N)	-	medium (A)
largemouth bass	spring	14-21	spring (S), year (N, A)	spring (S), year (N, A)	fall (N)	-	medium (S), high (N, A)	medium (S), high (N, A)	-	-	-	-	low (S)	low (S,A)	high (S,A), medium (N)	high (S,N,A)	high (S), low (A)	-
black crappie	spring	16-26	spring (S), year (N, A)	spring (S), year (N, A)	spring (S), year (N)	-	high (S, N, A)	high (S, N, A)	-	-	-	-	low (A)	high (S,A)	high (S,N,A)	high (S,N,A)	-	-
yellow perch	spring	7-22	spring (S, N), year (A)	spring (S, N), year (A)	spring (S, N), year (A)	spring (S), fall (N), year (A)	medium (S, N, A)	medium (S, N, A)	rocks, brush, debris	low (A)	low (A)	low (A)	medium (S), low (A)	medium (A), high (S,N)	high (S,N,A)	medium (S), high (N,A)	medium (S), low (A)	-
walleye	spring	4-12	spring (S, N), year (A)	spring (S, N), year (A)	spring (S, N), summer (A)	spring (S), fall (N)	low (S, N, A)	low (S, N, A)	-	high (S)	high (S), medium (A)	high (S), medium (A)	high (S,A)	high (S,N,A)	high (S,N,A)	medium (A)	-	low (A), high (S,N)
Iowa darter	spring	12-15	spring (S), year (N, A)	year (N, A)	year (N)	-	medium (S, N, A)	medium (S)	undercut banks, fibrous roots	-	-	-	high (S)	high (S,N,A)	high (S,N,A)	high (S,N,A)	-	-
fantail darter	spring	19-24	spring (S), year (N, A)	year (N)	-	-	medium (N), low (A)	-	undersides of rocks	-	medium (A)	high (S,A)	high (S,A)	high (S,N,A)	medium (A), high (S,N)	medium (N)	-	-

			Water Depth (m)				Cover			Substrate								
Common name	**Spawning season**	**Spawning Temp ° C**	**0-1**	**1-2**	**2-5**	**5+**	**Submergent vegetation**	**Emergent vegetation**	**Other**	**Bedrock**	**Boulder**	**Cobble**	**Rubble**	**Gravel**	**Sand**	**Silt**	**Clay**	**Hard-pan clay**
logperch	spring	15-Oct	spring (S, N), year (A)	spring (S, N), year (A)	year (A)	fall (N), year (A)	medium (N, A)	medium (N)	-	-	medium (S), low (A)	medium (S,A)	high (S), medium (N,A)	high (S,N,A)	high (S,N,A)	medium (N)	low (N)	-
tesselated darter	spring	13-19	spring (S), year (N, A)	year (N, A)	year (N, A)	-	medium (N, A)	-	undersides of objects	-		-	high (S)	high (S,N)	high (S,N,A)	high (N,A)	-	-
brook silverside	spring	20-23	spring (S), year (N, A)	year (N)	-	spring (N)	high (S), medium (A), low (N)	high (S)	-	-	-	-	medium (S)	medium (S), high (N,A)	high (S,N,A)	high (A)	medium (N)	-
freshwater drum	spring	19-22	spring (S)	spring (S), year (A)	spring (S), year (N, A)	spring (S), year (N, A)	medium (N), low (S, A)	medium (N), low (S)	-	medium (S)	medium (S)	medium (S)	medium (S)	medium (S,N,A)	medium (S), high (N,A)	high (A), medium (S,N)	medium (S,N)	medium (S)
mottled sculpin	spring	6-16	spring (S), year (N, A)	year (N, A)	-	year (N)	medium (A), low (N)	low (N)	crevices, under rocks, burrows	-	high (S,N)	high (S,N)	medium (A), high (S,N)	high (S,A), medium (N)	high (S,A), medium (N)	medium (A)	-	-
round goby	spring	n/a	spring (S, N), year (A)	spring (S, N), year (A)	spring (S), fall (N), winter (A)	spring (S), fall (N), winter (A)	low (S), medium (N, A)	-	undersides of logs, cans	-	high (N)	high (S,N,A)	high (S,N,A)	high (S,N,A)	medium (S,N,A)	-	medium (N)	-