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May 29, 2018

VIA EMAIL: sargentl@michigan.gov

Ms. Lori Sargent
Michigan Department of Natural Resources
Wildlife Division
PO Box 30444
Lansing, MI 48909

Re: Request for Concurrence – No Adverse Impact to Lake Sturgeon (*Acipenser fulvenscens*)
Mill Debris Fish and Wildlife Restoration Project (MDEQ Permit WRP011525 v.1) and GL&V Dredge/Habitat Restoration Project (MDEQ Permit WRP011506 v.1)
Muskegon, Michigan

Dear Ms. Sargent:

GEI Consultants of Michigan, P.C. (GEI) is working with the West Michigan Shoreline Regional Development Commission (WMSRDC) and project stakeholders on the two above-referenced mill debris removal projects. The scope of both projects involves removing an extensive amount of mill debris "slabwood" that was historically deposited in Muskegon Lake during the lumbering era. Although some slabwood can provide habitat, there are areas in the lake where slabwood deposits are over 10 feet thick and are impairing the benthic community. Michigan Department of Environmental Quality (MDEQ) permits have been issued for both projects, and we anticipate that the U.S. Army Corps of Engineers authorizations will be issued shortly.

Conditions within both MDEQ permits state "*the following threatened or endangered species are known to occur on or near this project site and may be impacted by your activities: Acipenser fulvescens, Lake Sturgeon. Issuance of this permit does not obviate the need to obtain approval under Part 365, Endangered Species, of the NREPA, from the MDNR Natural Heritage Program prior to commencement of construction activity*". Mark Tonello, Michigan Department of Natural Resources (MDNR) Central Lake Management Unit Fisheries Management Biologist, has granted a waiver of the dredge moratorium period for both projects since benthic habitat restoration is the end goal. We are requesting a similar letter or email response, concurring with an opinion of no adverse impact to lake sturgeon, from your division in order to meet regulatory requirements.

WMSRDC has been working closely with Grand Valley State University (GVSU) Annis Water Resources Institute (AWRI) fisheries and aquatic biologists throughout development of these habitat restoration projects. AWRI staff have conducted numerous fishery sampling efforts throughout Muskegon Lake. One such multi-year study was conducted on the seasonal spatial distribution of juvenile lake sturgeon in Muskegon Lake from 2008 – 2011 (Attachment 1). This study tracked the movement of juvenile sturgeon during this time period and distribution maps were generated. During summer months (defined as June – September), there were no recorded

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lake sturgeon in the vicinity of the proposed dredge footprints with the exception of one isolated occurrence in deeper water to the north of the Mill Debris project (Attachment 2). Juvenile sturgeon are typically moving toward shallower depths near the mouth of the Muskegon River during summer months, which is when all dredge activities are proposed. In addition, Dr. Carl Ruetz, GVSU AWRI Fisheries Professor, prepared a memorandum of opinion on optimal times to conduct mill debris removal/slabwood dredging in Muskegon Lake (Attachment 3). The memo summarizes that "*dredging should be targeted during times of the year when juvenile lake sturgeon are less likely to be disturbed. In my opinion, dredging during summer when the lake is thermally stratified should minimize the disturbance to lake sturgeon*." For this reason, dredging is targeted for completion in both project work areas during the studies' defined summer months of June through September.

Should you have any questions or require any further information, please do not hesitate to contact me.

Sincerely,

GEI CONSULTANTS OF MICHIGAN, P.C.

Kelly N. Rice

Kelly N. Rice, PWS
Senior Project Manager
Endangered Species Permit #2116

Attachments
Attachment 1: Seasonal spatial distribution of juvenile lake sturgeon in Muskegon Lake, Michigan, USA; Ecology of Freshwater Fish, 2013
Attachment 2: Enlarged map of mill debris removal project footprints overlaid on Figure 2a from Attachment 1
Attachment 3: Effects and timing of mill debris on lake sturgeon in Muskegon Lake, GVSU AWRI memorandum

c: Kathy Evans, West Michigan Shoreline Regional Development Commission

Ecology of Freshwater Fish 2013: 22: 467–478

ECOLOGY OF
FRESHWATER FISH

Seasonal spatial distribution of juvenile lake sturgeon in Muskegon Lake, Michigan, USA

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Abstract – We examined seasonal spatial distribution and diel movements of juvenile lake sturgeon *Acipenser fulvescens* in Muskegon Lake, Michigan (a protected, drowned river mouth lake that links the Muskegon River to Lake Michigan). We surgically implanted ultrasonic tags in 20 juveniles (age 1–7) captured in gill nets to track their locations during August–December 2008/2009 and September 2010–October 2011. Most juveniles were observed ≤ 1.5 km from the mouth of the Muskegon River in Muskegon Lake at a mean depth of 7.5 m (SE = 1.3 m) during summer. In fall, juveniles moved away from the river mouth to the deepest part of Muskegon Lake and were observed at a mean depth of 15.8 m (SE = 1.3 m) during winter. The shift in spatial distribution coincided with fall turnover (i.e., loss of thermal stratification) and with changes in dissolved oxygen (DO) concentrations in the hypolimnion. During summer, DO concentrations in the hypolimnion were typically <4 mg·l^{-1} in the deepest part of Muskegon Lake and DO concentrations at locations of tagged lake sturgeon were >7 mg·l^{-1} in 94% of instances. Tracking in 2009 revealed no significant change in depth distribution or movement over the diel cycle. We only observed two tagged juveniles immigrating to Lake Michigan, suggesting that juveniles use Muskegon Lake for multiple years. Our results suggest that: (i) Muskegon Lake serves as an important nursery habitat for juvenile lake sturgeon that hatched in the Muskegon River before they enter Lake Michigan and (ii) seasonal changes in DO concentration in the hypolimnion likely affect the spatial distribution of juveniles in Muskegon Lake.

Key words: Acipenseridae; habitat use; hypoxia; movement; nursery habitat; telemetry

Introduction

Sturgeons (Acipenseridae) are imperilled throughout their range in the Northern Hemisphere (Rochard et al. 1990; Birstein et al. 1997; Billard & Lecointre 2001). The lake sturgeon *Acipenser fulvescens*—a large, benthic fish—is the only endemic species of Acipenseridae in the Laurentian Great Lakes and has experienced dramatic population declines (Becker 1983; Auer 1996; Peterson et al. 2007). Although a basic understanding of the life history of lake sturgeon exists (e.g., Peterson et al. 2007), restoration of the species continues to be hindered by information gaps regarding spatial ecology and habitat use by various life stages.

Adult lake sturgeon often migrate upstream in large tributaries to spawn in the spring (e.g., Auer 1999; Lallaman et al. 2008). After larvae emerge from the substrate, they drift downstream to the lower portion of their natal river (Kempinger 1988; Auer & Baker 2002; Smith & King 2005a). In rivers that are connected to lakes, age-0 lake sturgeon (i.e., individuals past the larval stage) are thought to move further downstream to lentic habitats in the fall as water temperature declines (Holtgren & Auer 2004; Benson et al. 2005). Juvenile lake sturgeon generally use silt or sand substrates (Peake 1999; Benson et al. 2005; Smith & King 2005b; Trested et al. 2011), but also use areas with coarse substrate, especially in rivers (Kempinger 1996; Barth et al. 2009; Mann et al. 2011). Another important attribute of nursery habitat is the abundance of invertebrate prey (Chiasson et al. 1997; Benson et al. 2005; Smith & King 2005b). Nevertheless, much remains unknown regarding the ecological requirements of juvenile lake sturgeon

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(Auer 1996; Peterson et al. 2007), with perhaps the largest gap related to the seasonal spatial and depth distributions of juveniles.

Although, there is a growing body of information on the movement patterns and spatial distribution of older (i.e., individuals $\geq$ age 1) juvenile lake sturgeon (Holtgren & Auer 2004; Smith & King 2005b; Barth et al. 2011; Haxton 2011; Trested et al. 2011), clear patterns across multiple populations have been slow to emerge. In rivers, juvenile lake sturgeon exhibited high site fidelity (Barth et al. 2011) and seasonal home range size of juveniles was less than adults (Trested et al. 2011). The distances moved by juveniles in a river (Trested et al. 2011) were less than those reported in lakes (Holtgren & Auer 2004; Smith & King 2005b). However, movement patterns of juveniles in lakes can be complex, varying with fish size and water depth (Smith & King 2005b). Additionally, basic questions remain regarding seasonal patterns in the spatial distribution of older juvenile lake sturgeon in relation to the abiotic environment. For instance, dissolved oxygen concentration can strongly affect habitat selection of juvenile Atlantic sturgeon *Acipenser oxyrinchus* and shortnose sturgeon *A. brevirostrum* (Secor & Gunderson 1998; Niklitschek & Secor 2009, 2010). Hypolimnetic hypoxia is a common phenomenon (e.g., Rabalais et al. 2010; Roberts et al. 2012) that can strongly shape fish behaviour (Kramer 1987), and juvenile sturgeons may be particularly sensitive to hypoxia relative to other fishes because of an inefficient osmoregulatory system (Niklitschek & Secor 2009, 2010).

This study examined whether Muskegon Lake, a drowned river mouth (DRM) lake, serves as nursery habitat for juvenile lake sturgeon as they move from the Muskegon River (after hatching in the river) to Lake Michigan. Unlike other tributaries that connect directly to a Great Lake, DRM systems consist of a tributary that flows into a lake that is connected directly to a Great Lake (Albert et al. 2005; Jude et al. 2005). Few studies have examined juvenile lake sturgeon spatial distribution and movements in river mouths or DRM systems (but see Holtgren & Auer 2004). Our primary objective was to examine the seasonal spatial distribution of juvenile lake sturgeon in a DRM system, including whether spatial distribution was associated with changes in the abiotic environment. Specifically, we focused on dissolved oxygen concentration and temperature. Second, we assessed diel movement patterns of juveniles.

Materials and methods

Study site

Muskegon Lake is a DRM lake in Muskegon County, Michigan, USA (Fig. 1). The Muskegon River enters Muskegon Lake from the east, and Muskegon Lake empties into Lake Michigan to the west. Although influenced by the Muskegon River (e.g., flushed approximately 16 times per year by the river), Muskegon Lake retains primarily a lentic characterization (Freedman et al. 1979). Muskegon Lake has a surface area of 17 km^2 and a maximum depth of 23 m (Steinman et al. 2008). Most of the surface area of the lake is shallow (0–3 m: 33.8%; 3–6 m: 11.0%; 6–9 m: 19.0%; 9–12 m: 18.3%), whereas depths >12 m accounted for <18% of lake area (12–15 m: 13.3%; 15–18 m: 3.3%; 18–23 m: 1.3%; Fig. 2). Hypoxic conditions in deeper areas of Muskegon Lake (Gillett & Steinman 2011) could affect the spatial distribution of lake sturgeon (e.g., Niklitschek & Secor 2010). Two areas of particular interest in Muskegon Lake became apparent when tracking the movements of juvenile lake sturgeon during the first two years of this study, which we termed 'deep hole' and 'river mouth' (Fig. 1). The deep hole was the deepest area of the lake, which is spatially restricted, and the river mouth is the area of the lake near the mouth of the north branch of the Muskegon River, with a depth of about 5.5 m (Fig. 2).

Capture, tagging and tracking of juvenile lake sturgeon

Juvenile lake sturgeon were sampled between late summer and early winter from 2008 to 2011 (Table 1). We considered juveniles to be individuals <100 cm total length (TL). Fish were captured using 3–6 small-mesh gill nets (length = 100 m, height = 2 m, stretch mesh = 7.5 cm) fished on the bottom of Muskegon Lake. Beginning in late summer when surface water temperatures dropped below 20 ºC, gill nets were fished in the east end of Muskegon Lake because juvenile lake sturgeon previously were captured in this area (KMS, personal observation). After juvenile lake sturgeon were acoustically tagged (described below), we used their general location as a proxy for future gill-netting sites, although gill nets were never set immediately at the location of a juvenile. When surface water temperatures were 12 –20 °C, nets were fished for about 2–3 h per set in the early morning, for a total of 2–3 sets per day. Once surface water temperatures were below 12 °C, nets were set at dusk and retrieved the following dawn (soak time $\approx$ 15 h). We set gill nets 2–4 times per week depending on weather conditions. Sampling effort was greatest in 2008 and lowest in 2011 (Table 1).

Each juvenile lake sturgeon captured was immediately placed in a holding tank while other fish were removed from the gill net. Lake sturgeon were measured for TL (to the nearest 0.1 cm) and weighed (to the nearest 0.1 g). A 12.5 $\times$ 2.07 mm passive

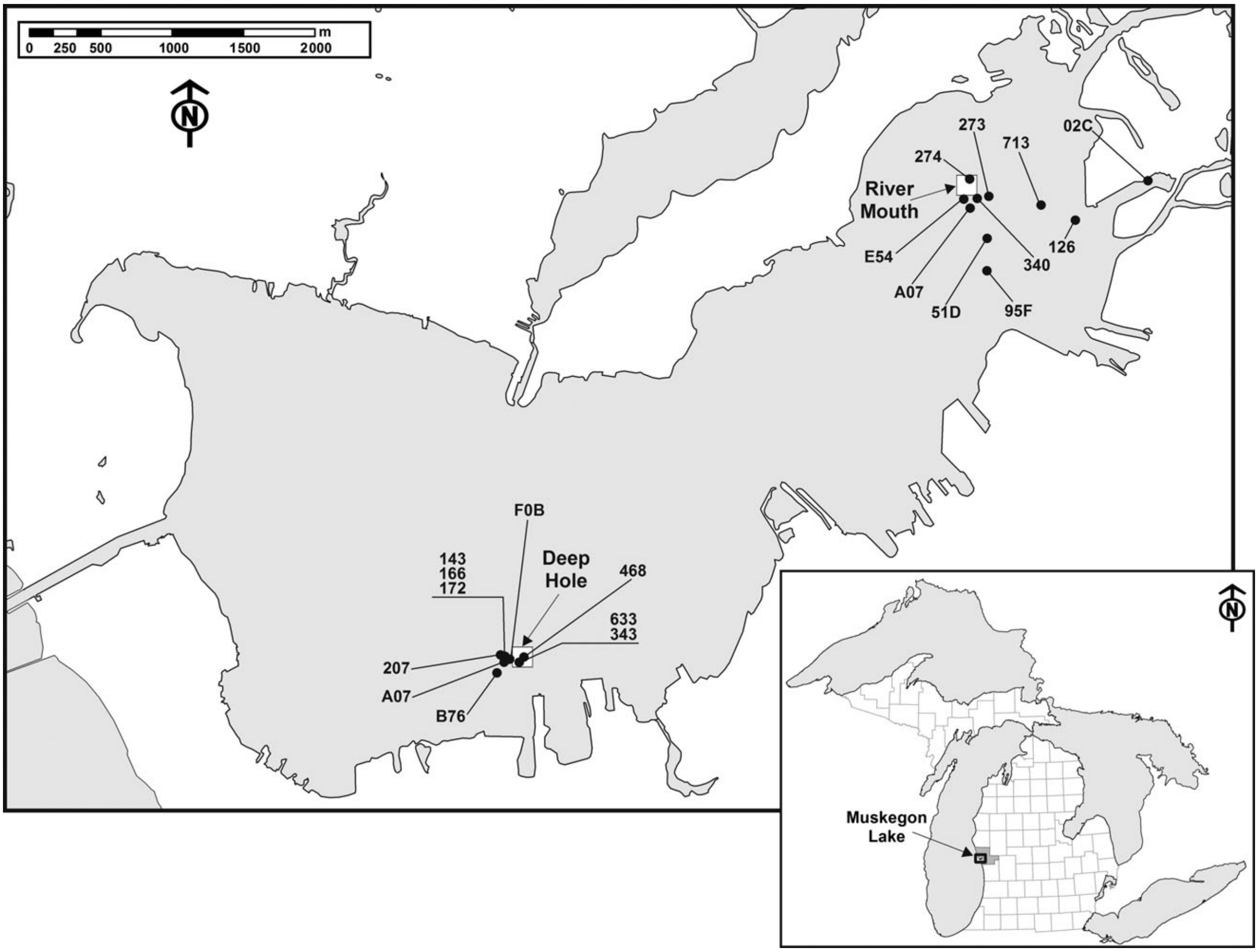

Fig. 1. Capture locations of the 20 lake sturgeon implanted with ultrasonic tags in Muskegon Lake. Identification codes are reported for each fish (see Table 2). In some instances, multiple fish were captured at the same location. The 'river mouth' and 'deep hole' correspond to the locations where we conducted vertical profiles. Muskegon Lake flows into Lake Michigan to the west.

integrated transponder (PIT) tag (125 kHz; TX1411SSL; Biomark, Inc.) was injected behind the fourth dorsal scute and a section of pectoral fin ray was collected for age determination (during 2009–2011).

Ultrasonic tags were surgically implanted in 20 juvenile lake sturgeon. In 2008 and 2009, we used VEMCO tags (model V9-2L, frequency = 63, 75, 78 kHz; VEMCO, a division of AMIRIX Systems Inc., Bedford, NS, Canada) that had an estimated active battery life of 68 days and weighed 4.5 g (in air). In 2010 and 2011, we used Sonotronics tags (model IBT-96-9-I, frequency = 71, 73–81 kHz; Sonotronics Inc., Tucson, AZ, USA) that had an estimated active battery life of 270 days and weighed 8.4 g (in air). Transmitter weight did not exceed 2% of the total body weight of tagged individuals (Nielsen 1992), except for one juvenile weighing 188 g in 2008. The tags were programmed either with a 3-day active/4-day inactive cycle to preserve battery life (transmitters functioned for approximately 5 months in 2008 and 2009; 2 years in 2010 and 2011) or to be on continuously (transmitters function for approximately 2 months; 5 fish captured during October–November 2009).

Surgical procedures for implanting ultrasonic tags followed those of Smith & King (2005b). To implant a tag, a 2-cm incision was made ventrally in the body cavity posterior to the pectoral fins and the transmitter was placed in the body cavity. Oxytetracycline (0.1 ml$\cdot$kg^{-1} body weight) was then injected into the body cavity to prevent infection. The incision was closed using a simple continuous suture pattern and drops of Nexabond glue were placed on suture knots. The fish was then held until normal respiration and movements were observed before being released at the approximate location of capture.

Tracking was conducted on days transmitters were active and as weather permitted. Except for diel tracking, locations of juvenile lake sturgeon were determined during daylight hours between 0830 and 1930 h. A tracking receiver (VEMCO VR100) and

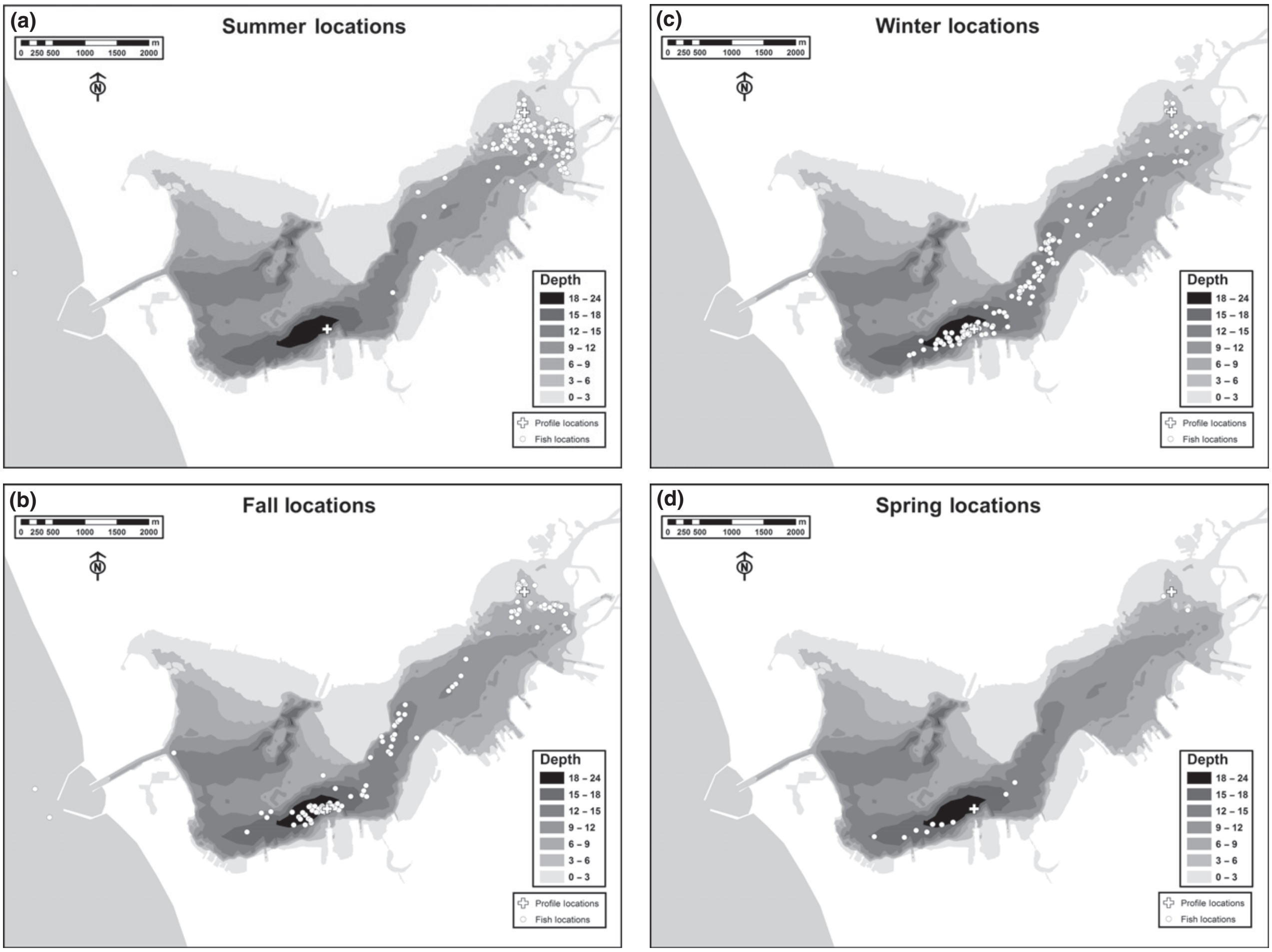

Fig. 2. Locations of lake sturgeon (circles) and vertical profiles (cross) in Muskegon Lake during daytime tracking from 2008 to 2011 during (a) summer, (b) fall, (c) winter, and (d) spring. Note that the locations of vertical profiles correspond to the 'deep hole' (south west) and 'river mouth' (north east). The Muskegon River enters Muskegon Lake from the north east and Muskegon Lake flows into Lake Michigan to the west.

Table 1. Sampling effort (total soak time of gill nets) and catch of juvenile lake sturgeon in Muskegon Lake.

Year	Sampling dates	Effort (h)	Catch (no.)
2008	15 August–14 November	869	2
2009	6 August–10 November	647	11
2010	3 August–16 November	492	29
2011	14 September–4 November	152	31

directional hydrophone (VEMCO VH110) were used to manually locate fish. Each tracking session began at the location where the fish was last detected. At this location, we listened for a signal while slowly rotating the hydrophone 360°. If a signal was not detected in the immediate area, then we systematically searched Muskegon Lake starting at the east end, continuing until the signal was detected. We travelled about 275 m between observations, which was less than the maximum distance we could detect transmitters under optimal conditions. Once detected, the signal was followed until it was equally strong in all directions, indicating direct position above the fish. At the location of a juvenile, we measured water depth. We assumed that lake sturgeon were located on the lake bottom, which is characteristic of their behaviour (e.g., Becker 1983; Kempinger 1996; Collins et al. 2002). We also measured water temperature and dissolved oxygen concentration (using a YSI 6600V2 sonde; Yellow Springs, Ohio, USA) at the surface and 0.75-depth (e.g., if depth was 10 m, then we took measurements at 7.5 m). We measured water temperature and dissolved oxygen concentrations at 0.75-depth rather than at the bottom to avoid disturbing the behaviour of juveniles and because 0.75-depth was below the thermocline when the lake was thermally stratified. We tracked the locations of ultrasonic-tagged juvenile lake sturgeon in Muskegon Lake beginning the day after release. During 2009, substrate composition was assessed at fish locations using an Aqua-Vu underwater camera. Additionally, we conducted five 24-h tracking events (1–2 individuals per event) to describe diel movement patterns from 27 August to 11 November 2009 on four juveniles (Table 2). Three of the four fish were tracked during two diel cycles ($N = 7$ observations). Fish were located approximately every hour and water depth was measured. Finally, starting in August 2010, temperature and dissolved oxygen measurements were taken at the surface and the bottom of two locations frequented by juvenile lake sturgeon (deep hole and river mouth; Fig. 1) to assess factors potentially influencing movement patterns.

Data analysis

To assess seasonal differences in the water depth at which juvenile lake sturgeon were located, we used a randomised block analysis of variance. The response variable was mean depth for a fish, which was calculated from all depth observations (including only the first daylight observation for a fish tracked over a diel cycle) made for an individual during each season (i.e., individual was the experimental unit). We blocked by individual fish and only used fish that had locations during at least two seasons in the analysis. When we detected a significant effect of season, we used Tukey-Kramer test (GLM procedure; SAS Institute 2008) to detect significant differences among seasons. We defined season as fall (October), winter (November–April, though we were unable to track fish between ice formation in mid-December and ice out in early-March), spring (May), and summer (June –September) based on thermal stratification in the lake (see Results).

Temporal differences in diel movement rates and water depth at which fish were located were analysed using a mixed-model method (MIXED procedure; SAS Institute 2008) to explicitly incorporate covariance structure of repeated observations on fish in statistical models (Littell et al. 2000). We used fish nested within tracking event as our experimental unit. Movement rate was measured as the linear distance between consecutive locations (determined using geographic information system based on global positioning system locations) standardised by time ($km \cdot h^{-1}$). We used four time periods to depict the diel cycle: dusk ($\pm$ 2 h from sunset), night (2 h after sunset to 2 h before sunrise), dawn ($\pm$ 2 h from sunrise), and day (2 h after sunrise to 2 h before sunset). Six covariate structures (simple, compound symmetric, first-order autoregressive, first-order autoregressive with random effect for individual, Toeplitz, and unstructured) were assessed and selected based on Akaike's

Table 2. Tracking information on lake sturgeon implanted with ultrasonic tags in Muskegon Lake, Michigan, USA. The identification code (ID) for each fish, date of capture (i.e., when tag was surgically implanted in fish), date of last confirmed location in Muskegon Lake, capture location (RM = river mouth, DH = deep hole; see Fig. 1), number of times we located (no. of locations) and attempted to locate a fish (tracking attempts; only includes the first location on a day a fish was tracked over a diel cycle), maximum linear displacement distance (dist) between all locations, and the total length (TL), weight, and age of fish at capture.

ID	Date: Captured	Date: Last location	Capture location	No. of locations	Tracking attempts	Dist (km)	TL (cm)	Weight (g)	Age (year)
273	4 September 2008	–	RM	–	–	–	39.0	188.1	1*
340	11 September 2008	22 November 2008	RM	18	19	5.3	78.0	2270.0	4*
A07[†,‡]	6 August 2009	20 November 2009	RM	19	20	5.6	51.1	552.5	2*
	8 November 2010	28 October 2011	DH	80	80	6.4	66.1	1305.0	3
02C[‡]	11 August 2009	2 December 2009	RM	39	40	6.2	44.5	359.5	1*
51D[‡]	12 August 2009	20 November 2009	RM	21	23	5.0	52.4	593.8	2*
95F[‡]	25 August 2009	2 December 2009	RM	27	27	5.8	69.4	1325.0	4
468	21 October 2009	2 December 2009	DH	19	19	5.2	51.0	563.4	2
F0B	21 October 2009	2 December 2009	DH	20	20	2.8	55.4	625.8	2
633	10 November 2009	2 December 2009	DH	10	10	2.6	75.6	2200.0	3
343	10 November 2009	2 December 2009	DH	10	10	4.0	86.7	3400.0	7
B76	10 November 2009	2 December 2009	DH	9	9	2.8	49.6	530.3	2
274[§]	2 September 2010	15 July 2011	RM	44	45	5.0	68.4	1243.0	3
E54	2 September 2010	7 October 2011	RM	57	58	5.8	52.5	626.9	2*
713[§]	17 September 2010	4 October 2010	RM	4	6	8.2	64.1	1045.0	2
126	22 September 2011	28 October 2011	RM	8	8	5.0	66.9	1091.0	4
166	7 October 2011	28 October 2011	DH	6	6	4.2	55.2	666.2	4
143	7 October 2011	28 October 2011	DH	6	6	4.2	61.7	951.3	4
207	7 October 2011	28 October 2011	DH	3	3	4.2	84.6	2600.0	5
172	7 October 2011	28 October 2011	DH	6	6	4.6	55.7	599.2	3

*Age was estimated based on length using a von Bertalanffy growth model (ACW, unpublished data).
[†]This fish was recaptured; the old ultrasonic tag was removed and a new tag was surgically implanted.
[‡]Individuals that were used for diel-tracking surveys.
[§]Fish that immigrated to Lake Michigan and was not observed again in Muskegon Lake.

information criterion. When assessing differences in movement rate over a diel cycle, compound symmetric (i.e., homogenous covariance not dependent on lag between observations [Littell et al. 2000;]) provided the best fit for covariance structure, whereas Toeplitz (i.e., covariance depends only on lag [Littell et al. 2000]) provided the best fit when depth use was the response variable.

Results

Overall, 73 juvenile lake sturgeon were captured in gill nets between 2008 and 2011 (Table 1). Six of those juveniles were recaptures of fish tagged in previous years of the study. The juveniles we captured in gill nets represented multiple cohorts, ranging in age from 0 to 8 years (Fig. 3). Twenty juvenile lake sturgeon were surgically implanted with ultrasonic tags; these fish ranged from 39.0 to 86.7 cm TL, weighed between 188 and 3400 g, and were age 1–7 years (Table 2). Of the 20 fish captured in gill nets that were implanted with ultrasonic tags, 10 were caught near the river mouth, and 10 were caught near the deep hole (Table 2; Fig. 1). One juvenile lake sturgeon captured in 2010 was a recaptured fish (Table 2); the old ultrasonic tag was surgically removed and a new tag was implanted. Additionally, one individual tagged in 2008 did not move after release for the life of the tag and was excluded from all analyses (Table 2) because we concluded that this fish shed its tag or died. Therefore, the maximum number of unique fish we could use in any particular analysis was 18 individuals.

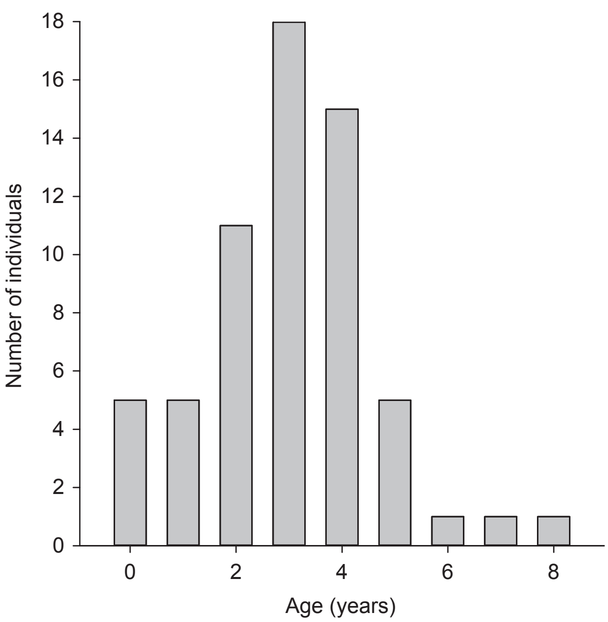

Fig. 3. Frequency of juvenile lake sturgeon by year class based on gill netting in Muskegon Lake. Note that sample size (N = 62) is less than the total number of juveniles captured (see Table 1) because we were not able to make an age determination for every fish.

We found that Muskegon Lake was stratified during summer. The lake was thermally stratified at the deep hole but not at the river mouth (Fig. 4), which is likely an important factor in explaining the seasonal spatial distribution of juvenile lake sturgeon (see below). As expected, a loss of thermal stratification occurred each fall (termed turnover). In 2008 and 2009, turnover occurred about 7 October. Vertical temperature profiles indicated that Muskegon Lake was stratified in July and September (see Steinman et al. 2008; Gillett & Steinman 2011), whereas after 7 October water temperatures measured in concert with fish tracking indicated the loss of thermal stratification (Table 3). In 2010 and 2011, we made weekly vertical profiles at the deep hole to define turnover and assess seasonal stratification patterns in Muskegon Lake, finding that turnover occurred on about 25 October 2010 and 18 October 2011 (Fig. 4). The lake was not thermally stratified throughout winter, and thermal stratification formed again in the spring. We only had temperature profiles in 2011 to assess when the lake became thermally stratified, which was about 16 May (Fig. 4). Finally, in areas where Muskegon Lake was thermally stratified during summer, we found that dissolved oxygen concentrations in the hypolimnion were $<4\ \mathrm{mg{\cdot}l^{-1}}$ (i.e., concentrations found to degrade nursery habitats of juvenile Atlantic sturgeon [Secor & Gunderson 1998;]) in 50% of measurements, whereas all measurements of dissolved oxygen concentrations were $>4\ \mathrm{mg{\cdot}l^{-1}}$ at the river mouth (Fig. 4).

Seasonal distribution

A total of 406 locations was recorded for 18 individuals that were implanted with ultrasonic tags. The number of times a fish was located ranged from 3 to 99 with an average of 23 locations per fish (Table 2). Over the duration of the study, we located juvenile lake sturgeon on over 97% of all tracking attempts (i.e., number of times we attempted to locate a fish) in Muskegon Lake (Table 2). Of the 18 juveniles that we actively tracked, we only located two juveniles in Lake Michigan. These fish (ages 2 and 3) immigrated to Lake Michigan in the summer and fall (Table 2) and were not located again in Muskegon Lake. Although we were unable to track fish between ice formation in mid-December and ice out in early-March, the longer battery life of the ultrasonic tags we implanted in fish during fall 2010 allowed us to track those same individuals in spring 2011 (N = 3 fish; Table 2) and all fish that were in Muskegon Lake before ice formation were present

Table 3. Mean (± 1SE) water temperature and dissolved oxygen concentration at the surface and bottom of Muskegon Lake. Before fall turnover (i.e., loss of thermal stratification), measurements were taken at two sites in 2008 and 2009 as part of a long-term monitoring project in Muskegon Lake (see Steinman et al. 2008; Gillett & Steinman 2011). After fall turnover, measurements were collected while tracking juvenile lake sturgeon. All measurements were made in the same general area near the deep hole.

			Temperature (ºC)		Dissolved oxygen (mg·l^{-1})	
Fall turnover	Sampling date	N	Surface	Bottom	Surface	Bottom
2008						
Before	15 July	2	22.8 ± 0.2	19.4 ± 0.9	8.86 ± 0.12	1.89 ± 1.89
Before	16 September	2	19.6 ± 0.0	13.3 ± 0.1	9.00 ± 0.03	1.26 ± 0.64
After	10 October–22 November	10	12.8 ± 1.3	12.6 ± 1.1	–	9.68 ± 0.28
2009						
Before	14 July	2	23.3 ± 0.2	11.8 ± 0.7	10.00 ± 0.29	4.44 ± 0.38
Before	10 September	2	21.8 ± 0.3	11.4 ± 0.2	10.33 ± 0.52	7.38 ± 0.52
After	8 October–20 November	23	10.2 ± 0.3	10.0 ± 0.4	9.94 ± 0.09	9.73 ± 0.09

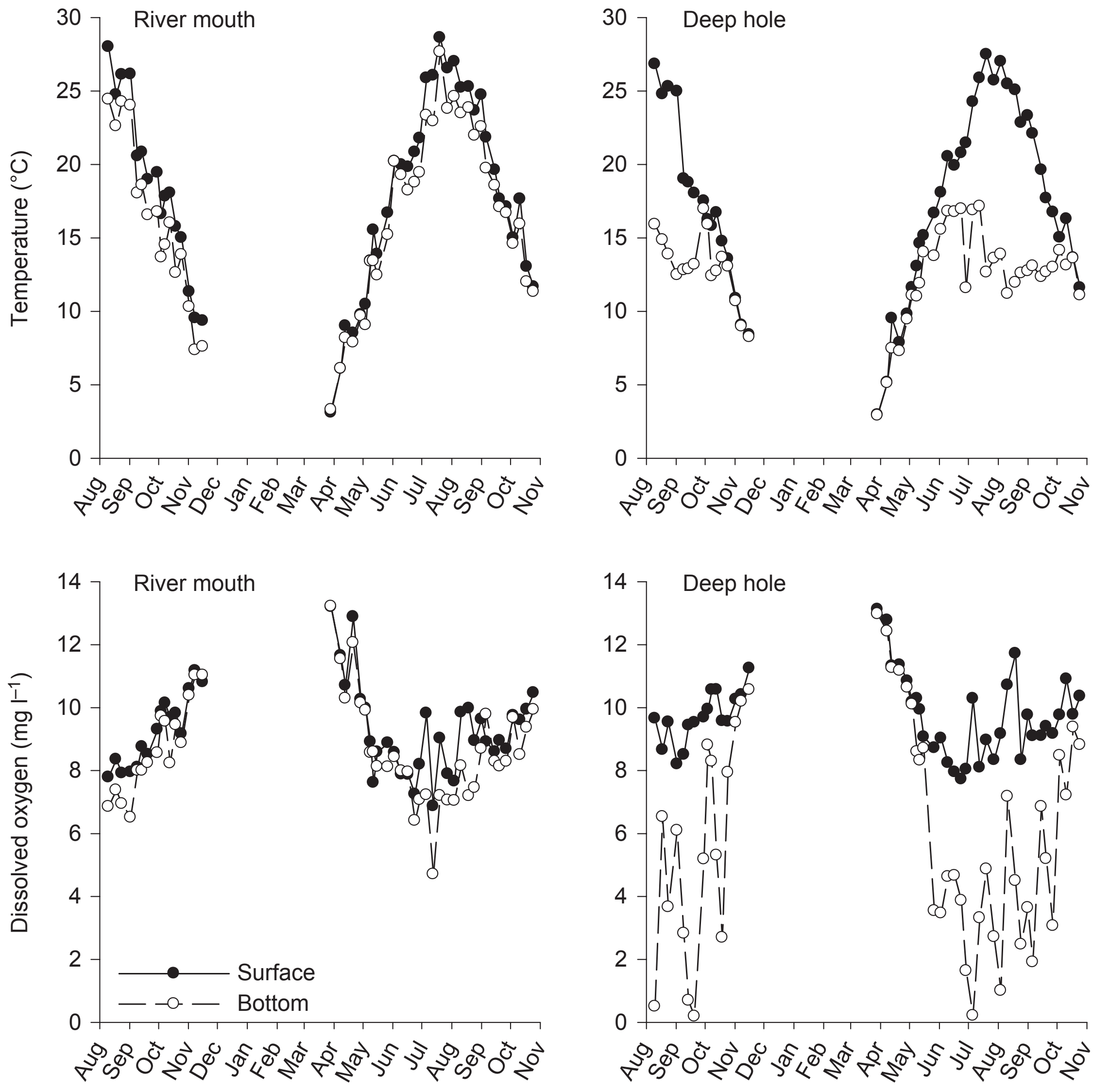

Fig. 4. Weekly surface and bottom water temperature and dissolved oxygen concentration at the river mouth (depth = 5.5 m) and the deep hole (depth = 23.0 m) in Muskegon Lake during 2010 and 2011.

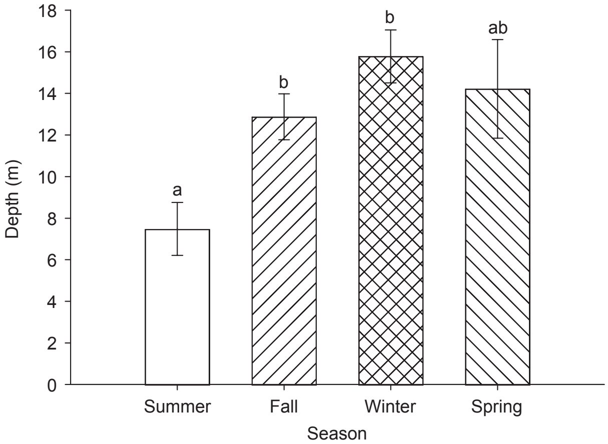

Fig. 5. Least-squares mean (± 1SE) water depth at locations of juvenile lake sturgeon in Muskegon Lake during summer (N = 9), fall (N = 11), winter (N = 9), and spring (N = 3) that were tracked for at least two seasons during 2008–2011. Bars with different lowercase letters were significantly different (P < 0.05) based on the Tukey-Kramer test.

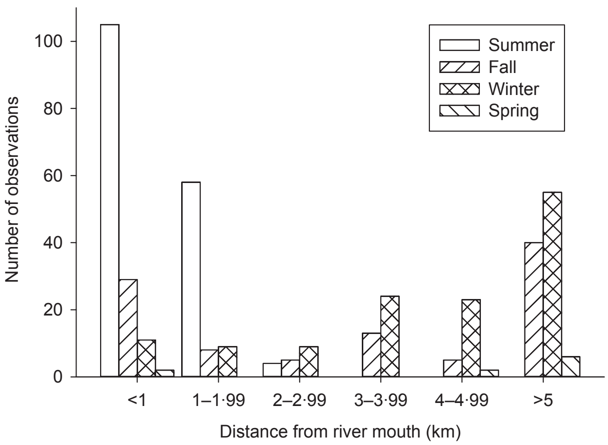

Fig. 6. Frequency of juvenile lake sturgeon locations in relation to season and distance from the mouth of the Muskegon River in Muskegon Lake.

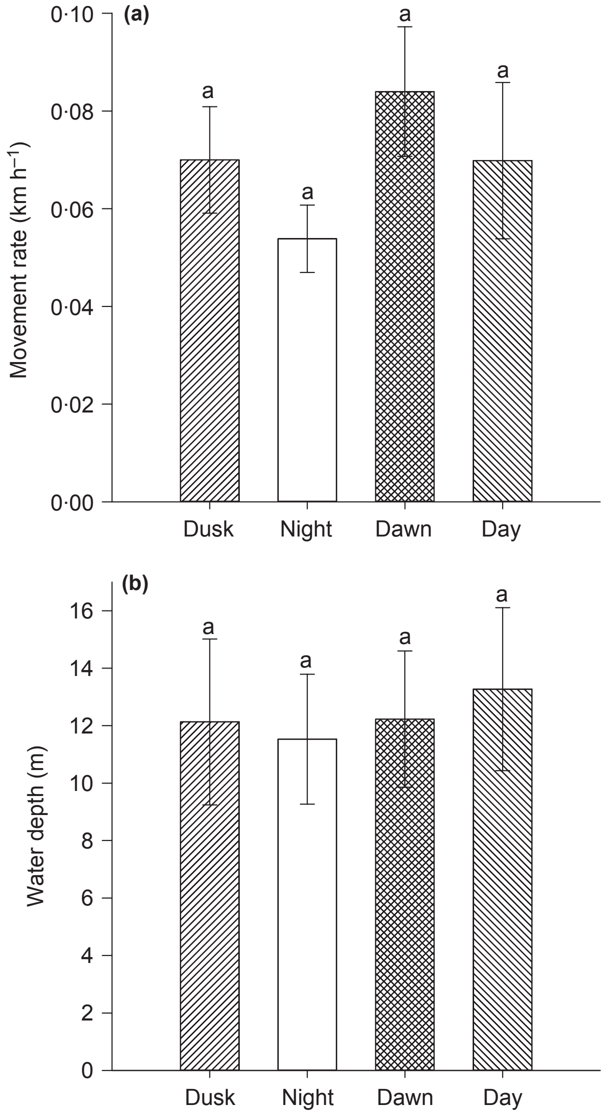

Fig. 7. (a) Mean (± 1SE) movement rates and (b) mean (± 1SE) depth at which four juvenile lake sturgeon were located over 24 h in Muskegon Lake. Bars with the same lowercase letter were not significantly different (P < 0.05).

the following spring. For all the fish tracked, the maximum linear displacement among all observations in Muskegon Lake for an individual ranged from 2.6 km to 8.2 km with a mean of 4.9 km (Table 2).

Using only individuals tracked in multiple seasons (N = 11 fish, which served as the blocking variable in the analysis), we found the depth where juveniles were located differed significantly among seasons ($F_{3,18}$ = 7.40, P = 0.002). Juveniles were at significantly shallower depths during summer than winter (Tukey-Kramer, P = 0.001) and during summer than fall (Tukey-Kramer, P = 0.023; Fig. 5). In winter, juvenile lake sturgeon usually were located in the deepest area of Muskegon Lake (deep hole), which is about 5.5 km from the mouth of the Muskegon River (Fig. 2c), whereas juveniles were located near the river mouth during summer (Fig. 2a). The change in depth at which juvenile lake sturgeon were located was indicative of seasonal changes in spatial distribution that appeared to be associated with the loss and formation of thermal stratification during fall and spring, respectively, resulting in changes in dissolved oxygen concentrations in the hypolimnion (Table 3; Fig. 4).

During summer (June–September), juvenile lake sturgeon were caught and located primarily near the mouth of the Muskegon River (Figs 2a and 6) at a mean depth of 7.5 m (Fig. 5). Of the 167 summer tracking locations, 93% were located within 1.5 km of the river mouth (Fig. 6). Loss of thermal stratification occurred each year in October in Muskegon

Lake (Table 3; Fig. 4). During this time, we observed juvenile lake sturgeon moving from the east end of the lake near the river mouth to the west, following the historic river channel in Muskegon Lake, toward the deepest area in Muskegon Lake (Fig. 2b). During winter months, we found that fish tended to reside in the deeper (mean depth = 15.8 m; Fig. 5) west end of the lake (Figs 2c and 6). Of 131 winter tracking locations, 78% were located ≥ 3 km from the river mouth (Fig. 6). The deployment of ultrasonic tags with a longer battery life in 2010 allowed us to continue tracking fish tagged in summer 2010 during spring 2011. Consequently, we observed juveniles near the deep hole in the spring (Fig. 2d) and these fish moved toward the river mouth as the lake began to thermally stratify in May.

Juvenile lake sturgeon typically were observed at locations in Muskegon Lake with relatively high dissolved oxygen concentration and bare substrate. The mean dissolved oxygen concentration, measured at 0.75-depth, associated with locations of lake sturgeon was 9.11 $mg{\cdot}l^{-1}$ (SE = 0.46). While juveniles were occasionally located in areas with dissolved oxygen concentrations <4.0 $mg{\cdot}l^{-1}$, this was rare, with most observations (94%) in areas with dissolved oxygen concentrations >7.0 $mg{\cdot}l^{-1}$. Silt or sand/silt substrates were observed at all locations of juvenile lake sturgeon in 2009, whereas submerged aquatic vegetation was never observed at locations where juveniles were located.

Diel patterns

We did not find evidence that diel period affected the movement and depth distribution of juvenile lake sturgeon in Muskegon Lake during 2009. We did not detect a significant difference in movement rate among the four diel periods ($F_{3,18} = 1.46$, $P = 0.260$; Fig. 7a). Similarly, mean depth where juvenile lake sturgeon were located did not differ significantly among diel periods ($F_{3,8.4} = 0.94$, $P = 0.462$; Fig. 7b).

Discussion

Juvenile lake sturgeon were observed in Muskegon Lake throughout the year. Seasonal shifts in the spatial distribution of juveniles in Muskegon Lake were associated with corresponding dynamics of dissolved oxygen concentration in the hypolimnion and thermal stratification. We observed a shift in distribution of juveniles from the area where the north branch of the Muskegon River enters Muskegon Lake (river mouth) to the deepest area of Muskegon Lake (deep hole). Juveniles captured in Muskegon Lake represented multiple age classes, suggesting that Muskegon Lake is an important nursery habitat. Of the juvenile lake sturgeon we implanted with ultrasonic tags, we only detected two individuals (ages 2 and 3) immigrating to Lake Michigan (Table 2). We recaptured one ultrasonic-tagged juvenile in a gill net 15 months after initially tagging the fish, providing additional evidence that juveniles use Muskegon Lake as nursery habitat for extended periods. We hypothesise that juvenile lake sturgeon, after hatching in the Muskegon River, use Muskegon Lake as a nursery habitat for multiple years before immigrating to Lake Michigan because of abundant food resources in Muskegon Lake.

Juvenile lake sturgeon may avoid the deepest areas of Muskegon Lake when the lake is thermally stratified because the hypolimnion is periodically hypoxic (Gillett & Steinman 2011; Fig. 4). Hypoxic conditions (i.e., dissolved oxygen concentrations < 4.0 $mg{\cdot}l^{-1}$) can cause mortality in white sturgeon *A. transmontanus* and impair growth rates of Atlantic sturgeon (Cech et al. 1984; Secor & Gunderson 1998). While abundant prey are present throughout most of Muskegon Lake (Carter et al. 2006; Nelson & Steinman 2013), low dissolved oxygen concentrations in deeper areas may limit the distribution of juveniles to areas with more suitable conditions (e.g., near the mouth of the Muskegon River) when the lake is thermally stratified during summer. Vertical profiles in Muskegon Lake show that depths >8 m can be hypoxic during the summer months (Table 3; Fig. 4). Although dissolved oxygen concentrations were generally high (i.e., >7 $mg{\cdot}l^{-1}$) in the area of Muskegon Lake immediately adjacent (≤ 1.5 km) to the mouth of the Muskegon River during summer, water temperatures were often above 17 °C (e.g., June–September in Fig. 4 at river mouth), which can cause thermal stress (McKinley & Power 1991; McKinley et al. 1998). Our results suggest that juvenile lake sturgeon traded cooler water temperatures found in the deepest areas of Muskegon Lake for high dissolved oxygen concentrations and warmer water temperatures near the mouth of the Muskegon River. This finding is consistent with research on other sturgeon species that showed particular sensitivity to hypoxia (Niklitschek & Secor 2009, 2010).

Juvenile lake sturgeon moved to the deepest areas of Muskegon Lake in early fall in concert with decreases in water temperature and when dissolved oxygen concentrations in those areas were comparable with levels near the mouth of the Muskegon River before turnover (i.e., >7.0 $mg{\cdot}l^{-1}$). Decreases in water temperatures have been shown to affect juvenile lake sturgeon distribution (Benson et al. 2005) and may serve as a cue for juveniles to move to deeper areas of Muskegon Lake during fall. For instance, observations of age-0 lake sturgeon revealed a propensity for downstream redistribution from rivers to lentic environments as water temperatures decreased during fall (Holtgren & Auer 2004; Benson et al. 2005). Additionally, decreasing water temperatures may prompt downstream redistribution of other juvenile sturgeon species in search of warmer waters or overwintering areas (Rochard et al. 2001; Collins et al. 2002; Sweka et al. 2007). We hypothesise that the seasonal distribution of juvenile lake sturgeon in Muskegon Lake is driven by dissolved oxygen concentration in the hypolimnion, with decreasing water temperature in the fall serving as the cue to move to deeper water and low dissolved oxygen concentration in the spring serving as the cue to move to shallower areas where the lake is not thermally stratified. Nevertheless, the question remains why do juvenile lake sturgeon inhabit the deep-hole area in Muskegon Lake during winter rather than stay near the river mouth. We hypothesise the deep-hole area of Muskegon Lake may buffer juvenile lake sturgeon from environmental changes, providing a more stable environment in terms of abiotic conditions during winter months. Selecting deep waters in response to seasonal changes has been documented in radio-tagged juvenile lake sturgeon (Benson et al. 2005; but see Holtgren & Auer 2004) as well as shortnose sturgeon (Collins et al. 2002).

We suspect that food resources did not have an important role in determining the seasonal distribution of juvenile lake sturgeon in Muskegon Lake. Benthic invertebrate densities in Muskegon Lake were highest at a cluster of sampling sites located within 1.0 km of the mouth of the Muskegon River (mean = 9295 ind·m^{-2}; Carter et al. 2006), which is the area where we found juvenile lake sturgeon during summer. However, only 5 of the 27 total sites sampled in Muskegon Lake by Carter et al. (2006) had significantly lower invertebrate densities (when compared with sites near the mouth of the Muskegon River), suggesting factors other than prey densities affect the distribution of juvenile lake sturgeon in Muskegon Lake. More recently (2008–2010), mean benthic invertebrate densities sampled at six sites in Muskegon Lake ranged between 7349 and 23,290 ind·m^{-2} (Nelson & Steinman 2013), which are much higher than those reported in other studies for areas inhabited by juvenile lake sturgeon (Chiasson et al. 1997; Nilo et al. 2006). The high density of benthic invertebrates reported in Muskegon Lake provides a potential explanation why lake sturgeon use Muskegon Lake as a nursery habitat.

Juvenile lake sturgeon were found at depths >3 m in Muskegon Lake for 96% of tagged fish observation, especially during the winter. Other studies have reported that juvenile lake sturgeon often use deeper habitats when they are available (Holtgren & Auer 2004; Smith & King 2005b; Barth et al. 2009; Haxton 2011), although there are exceptions (e.g., some age-1 lake sturgeon in a study by Smith & King 2005b used depths <3 m). We found that ultrasonic-tagged juveniles tended to be located in habitats with bare substrate, avoiding littoral habitats (i.e., area from shore to a depth of 3 m) with submerged aquatic vegetation, and often used the historic river channel (i.e., deepest areas) of Muskegon Lake (Fig. 2). Our results support the growing consensus that juvenile lake sturgeon avoid areas with aquatic vegetation (Kempinger 1996; Holtgren & Auer 2004; Smith & King 2005b).

Juvenile lake sturgeon in Muskegon Lake did not display significant changes in movement rates or depth over a diel cycle, although we only assessed diel patterns on a small number of individuals during one year of our study. Nevertheless, our findings suggest that tracking of ultrasonic-tagged fish during daylight hours adequately characterised their spatial distribution over a diel cycle. In contrast, juvenile lake sturgeon (Holtgren & Auer 2004) and juvenile white sturgeon (Haynes & Gray 1981; Parsley et al. 2008) moved to shallower water during nighttime hours, presumably to increase foraging opportunities. A possible explanation for the lack of change in movement rates and depth by juvenile lake sturgeon over a diel cycle in this study was the high abundances of invertebrate prey throughout Muskegon Lake (Carter et al. 2006; Nelson & Steinman 2013), which may make such behaviours unnecessary to increase feeding efficiency.

In conclusion, we suspect that Muskegon Lake serves as an important nursery habitat for juvenile lake sturgeon after hatching in the Muskegon River. We also suspect that juveniles remain in Muskegon Lake for multiple years before entering Lake Michigan, possibly because of abundant food resources, based on the presence of multiple cohorts of juvenile lake sturgeon in Muskegon Lake, recaptures of juveniles in gill nets during subsequent years, and observation that most ultrasonically-tagged juveniles (i.e., 16 of 18 fish) remained in Muskegon Lake during our study. With the understanding that juvenile lake sturgeon habitat availability and suitability are key components of the restoration process (e.g., Schueller & Hayes 2010), continued research detailing nursery habitats is critical. We found the spatial distribution of juvenile lake sturgeon in Muskegon Lake likely was associated with seasonal shifts in dissolved oxygen concentration and thermal stratification. Our research suggests that DRM lakes serve as more than simple conduits for juvenile lake sturgeon to pass through as they emigrate from their place of hatching to a Great Lake and raises the importance of river mouths and embayments as nursery habitats for lake sturgeon. Future studies should investigate the residency of juveniles in nursery habitats and explore seasonal patterns of spatial distribution to determine the generality of the patterns we observed in Muskegon Lake to other populations of lake sturgeon.

Acknowledgements

This work would not have been possible without the help of Jordan Allison, Megan Altenritter, Travis Ellens, Ray Gulvas, Brandon Harris, Jessica Higgins, William Keiper, Garry Sanders, and Kurt Thompson. We thank John Gulvas (Consumers Energy), Leo Torvinen (Consumers Energy), Brendan Earl (URS Corporation), and Tammy Newcomb (Michigan Department of Natural Resources) for assistance with project management and coordination. We thank Dave Janetski and anonymous reviewers for helpful comments on earlier drafts of this manuscript. Funding for this project was provided by Consumers Energy and the Michigan Department of Natural Resources. ACW also received a scholarship from Sonotronics to partially offset the cost of ultrasonic tags.

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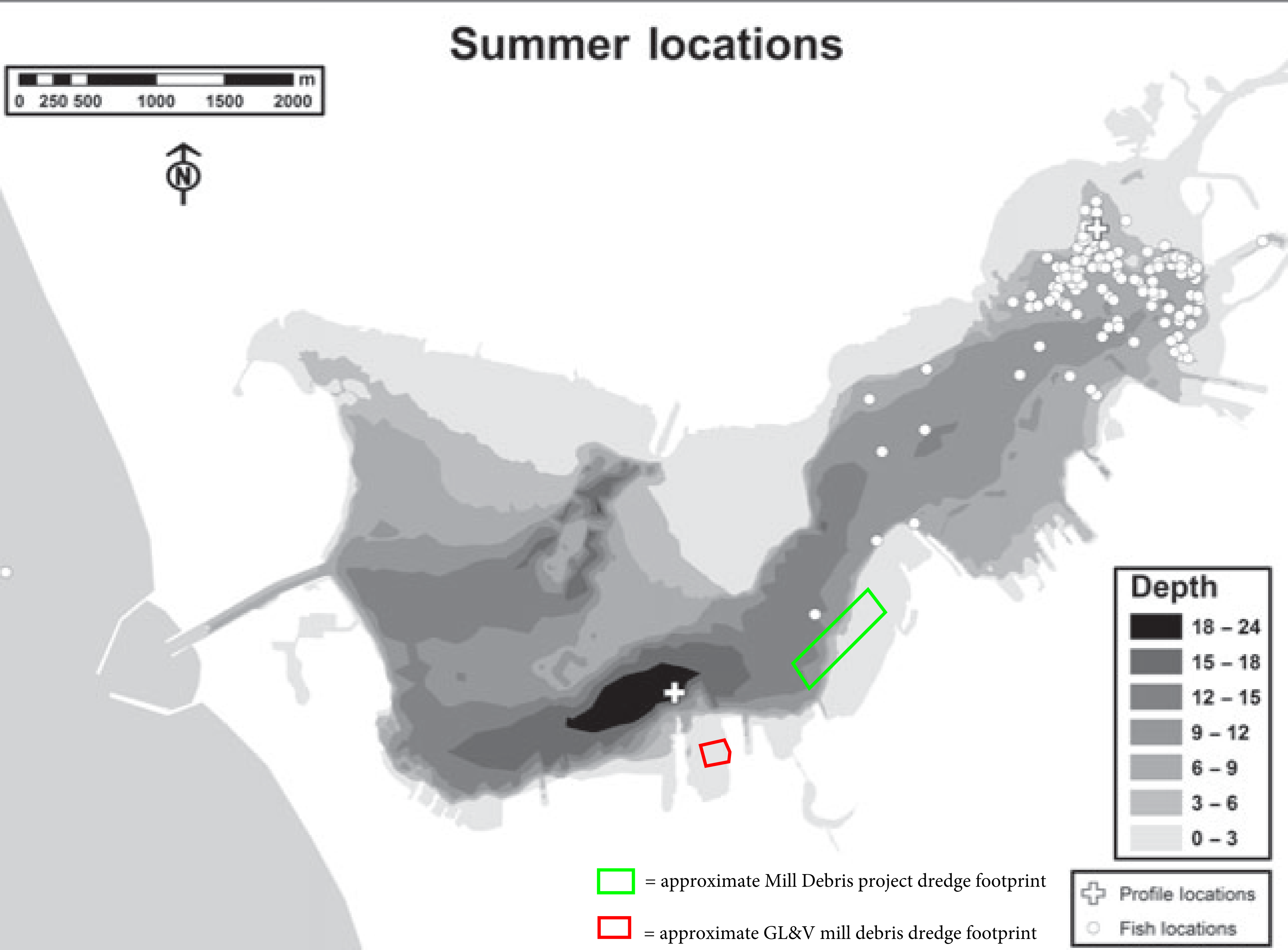

Taken from Altenritter et al. 2013. Seasonal spatial distribution of juvenile lake sturgeon in Muskegon Lake, Michigan; Ecology of Freshwater Fish. Figure 2a.

Grand Valley State University
www.gvsu.edu

To: Dr. Rick Rediske
From: Dr. Carl Ruetz
Date: 12 December 2017
RE: Effects and timing of mill debris on lake sturgeon in Muskegon Lake

The Muskegon River supports a genetically-distinct spawning run of lake sturgeon (DeHaan et al. 2006; Homola et al. 2012). The lake sturgeon population associated with the Muskegon River is a remnant of its historical size (e.g., Harris et al. 2017), which is not unique because the lake sturgeon is considered threatened throughout much of its range (Peterson et al. 2007). Thus, lake sturgeon conservation is a priority for the Muskegon River population.

Lake sturgeon (both adults and juveniles) associated with the Muskegon River population are known to use Muskegon Lake. The lake serves as an important nursery habitat for juvenile lake sturgeon throughout the year (Altenritter et al. 2013) and a staging area for adults prior to their spawning run in the river (Harris et al. 2017). Additionally, preliminary results from an ongoing telemetry study in Muskegon Lake suggest adults use the lake throughout the year, although use may be highest when staging for their spawning run (Ruetz, unpublished data). Given that lake sturgeon is primarily a benthic (bottom-dwelling) species (Peterson et al. 2007), targeted restoration of benthic habitats in Muskegon Lake should benefit lake sturgeon. For example, restoration that resulted in greater abundance and "healthier" assemblages of benthic macroinvertebrates should benefit lake sturgeon via improved foraging areas.

Research in Muskegon Lake suggests that juvenile lake sturgeon use depths ≥7.5 m (7.5 m ≈ 24.6 ft.) and avoid areas with dense beds of aquatic macrophytes (Altenritter et al. 2013), so portions of the areas target for dredging to remove mill debris should be in habitats that are frequented by lake sturgeon. Altenritter et al. (2013) found that seasonal patterns in spatial and depth distribution of juvenile lake sturgeon in Muskegon Lake. Juveniles tended to use shallower (mean = 7.5 m) areas near where the north branch of the Muskegon River enters Muskegon Lake during summer (i.e., when the lake is thermally stratified), moving to the deepest part of Muskegon Lake (mean = 15.8 m ≈ 51.8 ft.) once the lake turns over (i.e., loss of thermal stratification during autumn), and remaining in the deeper area until the lake becomes thermally stratified in early summer (Altenritter et al. 2013). Thus, dredging should be targeted during times of the year when juvenile lake sturgeon are less likely to be disturbed. In my opinion, dredging during summer when the lake is thermally stratified should minimize the disturbance to lake sturgeon (see Figure 2a in Altenritter et al. 2013).

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