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MUDPUPPY (NECTURUS MACULOSUS MACULOSUS) SPATIAL DISTRIBUTION, BREEDING WATER DEPTH, AND USE OF ARTIFICIAL SPAWNING HABITAT IN THE DETROIT RIVER

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***Abstract*.—Mudpuppy (*Necturus maculosus maculosus*) populations have been declining in the Great Lakes region of North America. However, during fisheries assessments in the Detroit River, we documented Mudpuppy reproduction when we collected all life stages from egg through adult as by-catch in fisheries assessments. Ten years of fisheries sampling resulted in two occurrences of Mudpuppy egg collection and 411 Mudpuppies ranging in size from 37–392 mm Total Length, collected from water 3.5–15.1 m deep. Different types of fisheries gear collected specific life stages; spawning females used cement structures for egg deposition, larval Mudpuppies found refuge in eggmats, and we caught adults with baited setlines and minnow traps. Based on logistic regression models for setlines and minnow traps, there was a higher probability of catching adult Mudpuppies at lower temperatures and in shallower water with reduced clarity. In addition to documenting the presence of all life stages of this sensitive species in a deep and fast-flowing connecting channel, we were also able to show that standard fisheries research equipment can be used for Mudpuppy research in areas not typically sampled in herpetological studies. Our observations show that typical fisheries assessments and gear can play an important role in data collection for Mudpuppy population and spawning assessments.**

Key Words.—amphibian eggs; by-catch; fisheries gear; life stages

INTRODUCTION

The Mudpuppy (*Necturus maculosus maculosus*; Crother 2012) is the largest salamander in Michigan, USA, and its only extant fully aquatic amphibian species. It is a long-lived, slow growing species that does not typically reach sexual maturity until 7–10 y and can live over 30 y (Matson 2005). They have a varied diet consisting of several species of fish, amphibians, insects, crustaceans, worms, and snails (Lagler and Goellner 1941; Petranka 1998; Holman 2012), and will readily consume carrion, which is located using a well-developed sense of smell (Harding 1997). Mudpuppies have also been observed to actively feed on the invasive Round Goby (*Neogobius melanostomus*) and are suspected of opportunistically using clumps of Zebra Mussels (*Dreissena polymorpha*) for foraging sites and as cover for young animals (Richard Kik IV, pers. comm.). Mudpuppies are associated with cold water and can be found in a wide variety of habitats in lentic and lotic water bodies including rivers, reservoirs, inland lakes, and Great Lakes bays and shallows (Harding 1997). Mudpuppies were historically abundant throughout the Great Lakes region (Holman 2012), but in recent years populations have significantly declined in many parts of the Great Lakes, including mass die-offs in portions of the Detroit River, Lake St. Clair, and Lake Erie of North America (King et al. 1997; Faisal 2006). Some management practices, such as the application of lampricide chemicals, are known to cause large-scale mortality events among local Mudpuppy populations (Matson 1998; Christie 2000; Reaser 2000; Boogaard et al. 2003). Other factors that contribute to the decline of this species include climate change, habitat degradation and loss, and the alteration of aquatic communities by invasive species and toxic algal blooms from excessive nutrient loading (Matson 2005; Holman 2012). Additionally, Mudpuppy populations experience negative pressure due to persecution, unsustainable harvest, and trade (Harding 1997; Holman 2012). Anglers will often kill Mudpuppies caught on baited hooks because of the erroneous belief they are poisonous or excessively consume game fish and fish eggs (Ruthven et al. 1912; Bishop 1941; Petranka 1998).

Like other amphibians, the Mudpuppy is an indicator species and can reveal considerable information about ecosystem health (Gendron et al. 1997; Welsh and Ollivier 1998; Marcogliese et al. 2000; Barrett and Guyer 2008). Due to their high sensitivity to pollutants and degraded water quality, these large salamanders can

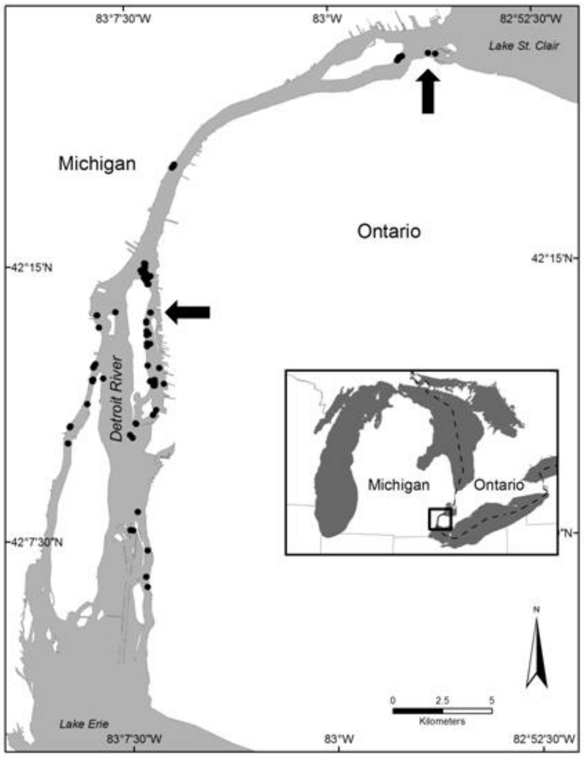

FIGURE 1. Locations in the Detroit River where Mudpuppies (*Necturus maculosus maculosus*) were caught as by-catch in fisheries assessment surveys, 2003–2013. Arrows show locations where Mudpuppy eggs were collected.

act as an early warning system for environmental problems that can affect the health of fish and other aquatic organisms (Bonin et al. 1995; Bishop and Gendron 1998). The Mudpuppy is listed by the Michigan Department of Natural Resources as a Species of Greatest Conservation Need (Eagle et al. 2005). Mudpuppies are also obligate hosts to Salamander Mussels (*Simpsonaias ambigua*), a state-listed threatened species in Michigan and a federal candidate for protection (Watson et al. 2001).

Due to the fully aquatic nature of this species, information on its natural history and behavior is limited (McDaniel et al. 2009). Mudpuppies find refugia under large rocks, logs, and other objects during the day and feed at night (Harding 1997; Petranka 1998; Holman 2012). Studies have suggested that Mudpuppies prefer water depths ranging between 0.2–1.0 m; however, they are commonly found in depths up to 30 m (Hacker 1957; Sajdak 1982). Their selection of water depth is temporal, typically occupying shallower water from late fall through early spring when water temperatures are lowest. During this period of activity in shallow water, a majority of the mating, nesting, and larval development occurs (Harding 1997; Holman 2012).

Human impacts to the Detroit River in the heavily-populated metropolitan areas of Detroit, Michigan, USA and Windsor, Ontario, Canada, and its use for commercial shipping, have resulted in aquatic and terrestrial habitat destruction and degradation through water pollution and the loss of wooded areas and wetlands. In 1815, approximately 2,768 ha of coastal wetlands existed along the Detroit River and among the islands, and those wetlands on the main shoreline extended a mile from the edge of the river (Manny 2003). To date, much of the shoreline has been hardened with steel sheet-piling, concrete breakwalls, and fill material, resulting in a 97% areal reduction in coastal wetlands (Manny 2003), significantly reducing the beneficial ecosystem processes provided by riparian wetlands to the river itself. The Detroit River is listed as an Area of Concern (AOC; Environmental Protection Agency. 1987. Great Lakes Areas of Concern. Available from http://www2.epa.gov/detroit-river-aoc/about-detroit-river-aoc [Accessed 9 November 2015]).

Over the past decade, fisheries research has been conducted within the Detroit River by the U.S. Geological Survey (USGS) and U.S. Fish and Wildlife Service (USFWS). Some study sites were general fish population index stations while others were targeted areas for fish spawning habitat rehabilitation (Bouckaert et al. 2014; Bennion and Manny 2011; Roseman et al. 2011b). During this research, Mudpuppies were recorded as by-catch and all life stages of the species were observed. The incidental data collected during these studies can reveal important information regarding the distribution and habitat selection of Mudpuppies in the Detroit River, including breeding water depth as well as the use of artificial structure for spawning habitat and egg placement. Our objectives were to report on the occurrence of all Mudpuppy life-history stages in the Detroit River, discuss the effectiveness of typical fisheries gear for collecting Mudpuppies, and share a predictive tool for selecting time of year and habitat characteristics where adult Mudpuppy collection would be most successful.

MATERIALS AND METHODS

Study site.—The Detroit River is the large channel that connects Lake St. Clair to Lake Erie and is bound on the west by Michigan, USA, and on the east by Ontario, Canada (Fig. 1). It is 44 km long, 0.80–4.02 km wide, and has a mean discharge of 5,300 m^3/s. The river flows through a heavily-populated metropolitan area and is used for commercial shipping, industrial and municipal water intake and discharge, recreation, and fishing. We established sample locations throughout the entire length of the river in water > 5 m deep and surface flows up to 1.0 m/s.

FIGURE 2. Fisheries gear that resulted in Mudpuppy (*Necturus maculosus maculosus*) by-catch, clockwise from top left: a) fyke net; b) setline; c) minnow traps; d) eggmats, complete setup ready for deployment; e) interior of an eggmat; f) telemetry receiver cement anchor; g) Mudpuppy eggs on underside of cement anchor; h) larval mudpuppy collected from same cement anchor that previously had eggs. (Fig. 2a–c photographed by US Fish and Wildlife Service and Fig. 2d–h photographed by US Geological Survey).

Sampling gear.—We used various standard techniques to sample for fish that resulted in Mudpuppy as by-catch. These gear types included fyke nets, baited setlines, baited minnow traps, eggmats, and cement anchors (Fig. 2). All sampling gear except fyke nets were designed to sample at the river bottom.

We set fyke nets (mesh size 48 mm, n = 130, 24-h sets; Fig. 2a) in December 2011 as part of Sea Lamprey (*Petromyzon marinus*) assessments. We attached nets to navigation buoys (water depth > 10 m) and we set them for 24 h after which they were inspected and redeployed. Mudpuppy collection occurred in the top 1 m of the water column.

We set setlines (n = 618, 24-h sets; Fig. 2b) in April and May, 2003–2013, as part of Lake Sturgeon (*Acipenser fulvescens*) assessments. We used both small (1/0) and large (9/0) hooks that we baited with dead Round Goby (Thomas and Haas 1999). We also attached minnow traps (n = 1,139, 24-h sets, 23 cm cage diameter by 44.5 cm long with 30 mm diameter openings; Fig. 2c) to setlines to monitor the benthic fish community. We baited these with either cheese cubes or dry dog food and inspected setlines and minnow traps every 24 h.

Throughout the Detroit River, we deployed eggmats (n = 24; Fig. 2 d,e) to sample for eggs deposited by lithophilic broadcast spawning fishes (Roseman et al. 2011a). They were set on the bottom of the river and lifted and inspected on a weekly basis from ice-out in March through a water temperature of 16.0° C in June. They were set again for a fall sampling period, from 10.0° C in October until ice formed in December, following the same weekly inspection methods.

We placed stationary fish telemetry receivers (n = 24; Fig. 2f) throughout the Detroit River in 2013. We secured the receivers to a 90-kg cement anchor and serviced it bi-annually. To do so, we lifted the entire anchor aboard the boat, the equipment was swapped out, and the gear was replaced on the river bottom in the same location. The cement anchor was approximately 24 cm tall and 43 cm in diameter; the substrate side was completely flat and approximately 1.4 m^2.

We collected various data on captured Mudpuppies; method of collection, general health condition (e.g., deformities, wounds, etc.), and total length (TL), which we measured from tip of the snout to the end of the tail. We released Mudpuppies back into the river after data collection. We recorded GPS coordinates and when

TABLE 1. Mudpuppy (*Necturus maculosus maculosus*) by-catch collections from the Detroit River, 2003–2013. Abbreviations are Occur Freq = occurrence frequency; n = number of individuals collected; TL = total length; Depth = collection depth. Water depth and sample depth are the same for all gear except fyke nets, which sampled the top meter of >10 m water column. For cement anchors, eggs were attached but were not enumerated. Occurrence frequency and collection depth are calculated for all setlines due to mixture of hooks on an individual setline.

Gear	Occur Freq (%)	Mudpuppy (n)	TL (mm) mean (min - max)	Depth (m) mean (min–max)	Collection Dates	Attractant
Eggmats	16.7	4	43 (37–51)	7.0 (5.0–10.0)	May 2012, Nov 2013	Refugia
Fyke nets	10	36	152 (80–360)	1.0	Dec 2011	None
Minnow traps	8.8	159	240 (76–330)	8.5 (3.5–12.4)	April-May, 2003, 2005–2013	Cheese or dog food
Cement anchor	8.3	1	42	9.2 (8.5–9.8)	Oct 2011	Refugia
Setline, unknown hook		115	305 (154–392)		April-May, 2003–2011	Type Unkown
Setline, large hook	18	15	343 (290–385)	8.5 (3.7–12.0)	April-May, 2011–2013	Round Goby
Setline, small hook		81	292 (180–365)		April-May, 2011–2013	Round Goby

possible, we took photographs to contribute to the Michigan Herp Atlas project (http://www.miherpatlas.org).

Analysis.**—**We used Mudpuppy by-catch data to create a predictive tool for selecting times and locations for future targeted adult collection; sample sizes were too small for all other life stages. We modeled the probability that at least one Mudpuppy would be captured as by-catch using the combination of setline and minnow traps using logistic regression based on environmental variables. The variables we used included the mean water depth at set locations (m), secchi depth (m), and surface water temperature (°C). We only used sets that used both small and large hooks and three minnow traps in analysis. Prior to executing logistic regression, we randomly removed 20% of the data (37 sets); we used this subset to validate the models. We used a Kolmogorov-Smirnov univariate test to determine if the data were normally distributed. Data were not normal so we log-transformed them, which met assumptions of normality. We found that secchi depth correlated with both mean depth ($r = 0.26$, $t = 3.270$, $P = 0.001$) and surface water temperature ($r = 0.38$, $t = 4.971$, $P < 0.001$) based on a Spearman correlation and thus was not included in models containing those variables. Akaike's information criterion with correction for small sample sizes (AIC_C; Burnham and Anderson 2002) was used to select the best model. We tested four models with logistic regression using 149 sets to predict the probability of capturing at least one Mudpuppy using a setline with large and small hooks and three minnow traps. Using the subset of data removed for validation, we used Cohen's kappa statistic to determine how effective the models were at predicting the capture of at least one Mudpuppy (similar to analysis used by Chu et al. 2005). We calculated Cohen's kappa statistic as

$$K = [(a+d) - (((a+c)(a+b) + (b+d)(c+d))/n)] \div [n - (((a+c)(a+b) + (b+d)(c+d))/n)]$$

where K is the kappa coefficient, a is the number of true positives (capturing a Mudpuppy), b is the number of false positives, c is the number of false negatives, d is the number of true negatives (not capturing a Mudpuppy), and n is number of observations (37). Kappa values less than 0.4 indicate poor models; values between 0.4 and 0.75 indicate good models; and values greater than 0.75 indicate excellent models (Fielding and Bell 1997). We analyzed data using SAS (v9.1, SAS Institute Inc., Cary, NC). For all tests, $\alpha = 0.05$.

RESULTS

After 10 y of sampling throughout the entire length of the Detroit River, we caught 411 Mudpuppies ranging in size from 37–392 mm collected as fisheries by-catch from water 3.5–15.1 m deep (Table 1; Fig. 1). Visual inspection showed no signs of illness, wounds, or deformities. We frequently captured young-of-the-year Mudpuppies in eggmats throughout the river, but the limited amount of data collected cannot be interpreted beyond presence-absence and signs of recruitment. Minnow traps were successful in capturing a wide range of sizes of Mudpuppies at varying depths. The 30 mm opening set the upper size limit for this gear. Setlines with baited hooks also collected many Mudpuppies, but these were generally larger adults. There was a significant difference in total length of Mudpuppies caught on small and large hooks ($t = 6.01$, df = 28, $P < 0.001$). The average size of Mudpuppies caught using

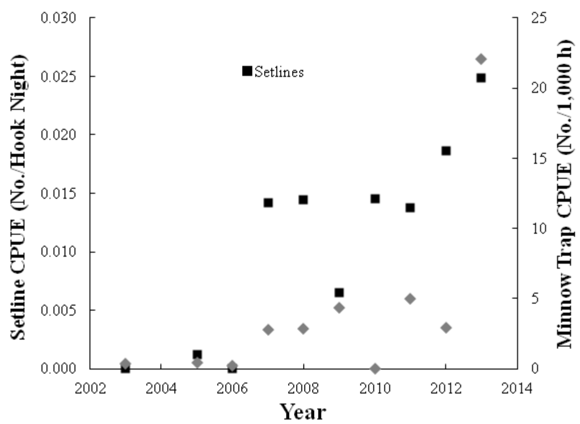

FIGURE 3. Mudpuppy (*Necturus maculosus maculosus*) catch per unit effort (CPUE) for setlines (number caught per hook night) and minnow traps (number caught per 1000 hours) from 2003 to 2013 in the Detroit River. Setlines and minnow traps were not set in 2004.

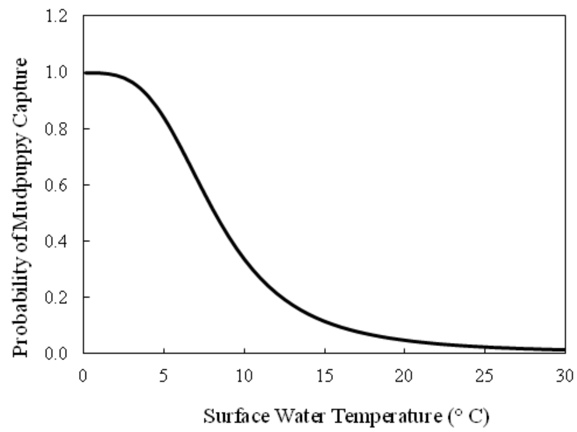

FIGURE 4. Probability of capturing at least one Mudpuppy (*Necturus maculosus maculosus*) using a setline with small (1/0) and large (9/0) hooks and 3 minnow traps attached to it in the Detroit River based on the best model created by logistic regression (based on AIC_C criteria).

large hooks was 343 mm and the average size using small hooks was 292 mm (Table 1). This difference was probably due to the gape size needed to swallow a larger hook. Adult Mudpuppy by-catch rate increased since setline and minnow trap sampling began in the Detroit River in 2003 (Fig. 3).

Of particular interest is the collection of eggs at two locations (Fig. 1), both involving the cement anchors used with the acoustic receivers. During gear maintenance on 27 June 2013, Mudpuppy eggs were attached to the flat underside of the cement anchor, covering approximately 30% of the surface area (Fig. 2g). The collection site was located at the downstream end of the Peche Island Channel at the head of the Detroit River. Water temperature was 21.0° C and collection depth was 9.8 m. USGS SCUBA divers had been diving in this area on 26 June 2013 and reported that the substrate was hardpan clay overlain in areas with sand, gravel, and small rocks, and imbedded rubble in places. Hardpan clay was also adhered to the cement anchor. The anchor was redeployed with most of the eggs still attached and was serviced again on 29 October 2013 (water temperature = 9.3° C), bringing up with it a 42-mm larval Mudpuppy (Fig. 2h). We found a second collection of eggs 17 June 2014 at a depth of 8.5 m and water temperature of 18.7° C, this time in the middle section of the river in the Fighting Island Channel on the eastern side of Fighting Island. As with the Peche Island Channel, the Fighting Island Channel substrate is hardpan clay with patches of sand, gravel, and rubble. Again, the anchor was redeployed with many of the eggs still attached.

For the datasets (setline and minnow trap) we used to create the models we tested with logistic regression, mean water depth ranged from 6.05 to 12.15 m (mean = 9.09 m), secchi depth ranged from 0.25 to 2.75 m (mean = 1.21 m), and surface water temperature ranged from 2.2 to 26.1 °C (mean = 10.2 °C). The best model created based on AIC_C criteria included only the surface water temperature variable. The equation for the probability of capturing at least one Mudpuppy was:

$$P(\text{capturing at least one Mudpuppy}) = e^{7.05-7.74(\log(\text{temp}))}/1+e^{7.05-7.74(\log(\text{temp}))},$$

where temp equals surface temperature (°C; Fig. 4). This best model also had the highest kappa statistic (0.56) and predicted the highest percentage (81%) of sets correctly (tied with the second best model for both; Table 2). The second best model had a Δi value less than 2, therefore also having substantial evidence in its favor. The equation for the probability of capturing at least one Mudpuppy with this model was:

$$P(\text{capturing at least one Mudpuppy}) = e^{10.09-7.84(\log(\text{temp})-3.07(\log(\text{dep}))}/1+ e^{10.09-7.84(\log(\text{temp})-3.07(\log(\text{dep}))},$$

where temp equals surface temperature (°C) and dep equals mean water depth (m). Kappa statistics indicated that the best three of the four models were Good. Based on the models, there was a higher probability of catching a Mudpuppy in cool, shallow water with a low secchi depth.

DISCUSSION

Most of our sampling was conducted in the cooler spring months when spring spawning fish species were targeted. The resulting model predictions are based on the water depth, secchi depth, and surface temperature ranges in our fisheries surveys. The depths used in creating the models ranged from 6.05 to 12.15 m; shallower water for the Detroit River is likely deeper

TABLE 2. All four Kullback-Liebler models produced from logistic regression to predict the probability of capturing at least one Mudpuppy (*Necturus maculosus maculosus*) using a setline with small (1/0) and large (9/0) hooks and 3 minnow traps attached to it in the Detroit River with their corresponding AIC_C, Δi (delta AIC), and w_i (Akaike weight), kappa statistic, and validation prediction results. Kappa statistics > 0.40 indicate a good fit.

Variables in Model	AIC*c*	Δi	w_i	Kappa Statistic	Validation Results (% correct)
Water temperature	155.695	0.00	0.66	0.56	81
Depth & water temperature	156.983	1.29	0.34	0.56	81
Secchi depth	187.904	32.21	0.00	0.46	76
Depth	206.907	51.21	0.00	-0.19	59

than the depths most Mudpuppy researchers study. However, depth was not an important factor in predicting Mudpuppy capture and by itself created a model deemed Poor. Regardless, Mudpuppy by-catch collections and the resulting prediction model are in-line with what is known about this species: they prefer cool shallower water, seek refuge and nest under objects, and will prey on the invasive Round Goby (Richard Kik IV, pers. comm.).

The fisheries gear and associated bait provided food or refuge and therefore were successful in capturing Mudpuppies. Mudpuppies are not uncommon by-catch as part of fisheries surveys in the Detroit River and during this study we collected several life stages from egg to adult in various types of gear. We collected eggs from an artificial cement structure on two occasions, young-of-the-year Mudpuppies in eggmats, and juvenile and adults in nets, minnow traps, and on hooks. These results suggest that Mudpuppies are successfully spawning in the Detroit River and different types of fisheries research gear can be effectively used to target specific life stages. In addition to the notable collection of eggs in the system, the water depth at which they were caught is deeper than typically reported in the Great Lakes region. Harding (1997) lists spawning depths up to 3 m, but we found eggs as deep as 9.8 m. This is likely due to limitations on sampling in typical herpetological studies, not an anomaly within the Mudpuppies of the Detroit River. We caught young-of-the-year Mudpuppies in eggmats during spring and fall fish egg assessments, and the rate at which we caught adults with setlines and minnow traps has increased over time. We have used setlines and minnow traps in the Detroit River since 2003, but sampling methods and locations have not been consistent over time. Until 2007, setlines and minnow traps were only set at the head of the river near Belle Isle, and only large hooks were used on setlines. Beginning in 2007, we set setlines and minnow traps in more diverse locations, and the bait we used on setlines was only consistent since 2011 (dead Round Goby). There has been a general increase in Mudpuppy by-catch since these sampling techniques were standardized in 2011. Sampling effort with each gear type changed over years and throughout the river, but generally speaking, 8–18% of the total sets per gear type collected Mudpuppies (occurrence frequency, Table 1).

It is important to note that often times Mudpuppies that we captured on setlines had completely swallowed the bait and hook. Gape limitations seemed to be a factor as smaller hooks were swallowed more often. However, with both large and small hooks, if they were fully ingested, it took a considerable amount of effort to remove the hooks and it is likely a proportion of the Mudpuppies suffered post-release mortality. Baited hooks are used successfully to capture adult Mudpuppies in studies throughout other parts of the range and mortalities likely caused by this method have been reported as well (Chellman 2011). Given these uncertainties, the use of baited hooks is not a recommended sampling technique.

Likely due to improvements in water quality and habitat and regulated fishing over the past four decades, several aquatic species have started to make a comeback in the Detroit River, including Walleye (*Sander vitreus*; Manny et al. 2007), Lake Sturgeon (Roseman et al. 2011b), and Lake Whitefish (*Coregonus clupeaformis*; Roseman et al. 2007). By-catch of Mudpuppies on setlines and in minnow traps has also increased in recent years, and the collection of eggs is an important milestone in monitoring this species and the health of the river.

An immediate application of locating Mudpuppy spawning sites is to inform Sea Lamprey control operations within the Detroit River. The Detroit River is actively treated with lampricides, and known Mudpuppy spawning location information from this study may protect Mudpuppy egg incubation and larval growth. Mortality of Mudpuppies due to Sea Lamprey control is common (Gilderhus and Johnson 1980) and can lead to declines in Mudpuppy populations (Matson 1990). However, Boogaard et al. (2003) found that adult Mudpuppies were not as sensitive as Sea Lamprey ammocoetes when exposed to the minimum lethal concentration for the ammocoetes, and they state that more testing is needed for Mudpuppy larval and juvenile stages.

The Detroit River is difficult to sample for Mudpuppies because of its length, depth, flow, and recreational and commercial shipping traffic. Targeted Mudpuppy sampling typically occurs in shallow regions and includes capture by hand, minnow traps, and dipnets. Mudpuppies are known to inhabit deeper habitats (Hacker 1957; Sajdak 1982), but these areas are not always included in typical herpetofaunal surveys, and a majority of targeted Mudpuppy studies have been conducted in depths that do not exceed 2.0 m (Chellman 2011). Data on the Eastern Hellbender (*Crptobranchus alleganiensis*), a species similar to the Mudpuppy, is also biased toward shallow water depths. Recent studies targeting this species, which is sympatric with the Mudpuppy, have focused on deep water habitat and proved useful for gathering valuable information that can be applied to species conservation (Briggler et al. 2013).

Our work in the Detroit River demonstrates a unique opportunity to collect information on Mudpuppies in deep water with fast currents while conducting fisheries research or similar projects. In an area of unremarkable habitat and lack of cover, a spawning Mudpuppy used an artificial structure in the center of the channel. This unconventional use of artificial habitat structure provides a unique opportunity to gather information on Mudpuppies in a region that is lacking natural habitat (Bennion and Manny 2011). In Missouri, there has been success with artificial spawning structures targeting Hellbender species in riverine habitat (Briggler and Ackerson 2012). With the absence of natural structure in the Detroit River, there may be opportunities to create habitat features for improved nesting opportunities and population viability of Mudpuppies in the Great Lakes region. Eggmats and other large objects placed on the river bottom in ice-free times of the year can be used as passive sampling devices that attract spawning adults and young-of-the-year Mudpuppies seeking refugia, while baited minnow traps and fyke nets can be used as a non-lethal way to collect larger juveniles and adults. It is known that Mudpuppies will occupy various objects for habitat including wooden doors, canvas, and other debris (Eycleshymer 1906).

This project presents a unique opportunity to use different methods including artificial habitat to sample for the species in non-traditional locations. Mudpuppy research and monitoring in large rivers is possible using standard fisheries equipment, though some modifications may make the sampling easier. Reducing the vertical profile on the cement structure would make it lighter without reducing the surface area available for egg attachment. The gear used in these fishery assessments can be modified to meet the sample location characteristics, complications, and logistics that typically deter research and monitoring of Mudpuppies in hard-to-sample areas.

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