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Following the edge of the flood: use of shallow-water habitat by larval silver carp *Hypophthalmichthys molitrix* in the upper Mississippi river system

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ABSTRACT

We examined the use of “edge of flood” habitats by larval silver carp during the extensive flooding that occurred in Pool 26 of the Upper Mississippi River near Alton, IL, USA and St. Louis, MO, USA during the summer of 2015. We captured over 12,700 individual fishes including eight taxa, over 12,000 of which ($>$ 95%) were larval silver carp between 5 and 21 mm standard length. Peak catch rates occurred near the confluence of the Illinois and Mississippi rivers. These findings suggest that larval silver carp have an affinity for edge of the flood habitat and further study is needed to better understand how this affects the dynamics of this invasive species in the Mississippi River. The high catch rates observed at the confluence of the Illinois and Mississippi rivers suggests that the Illinois River is an important source of larval silver carp to the Upper Mississippi River.

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Introduction

Silver carp *Hypophthalmichthys molitrix*, a cyprinid native to rivers in eastern Asia, were accidentally introduced into the Mississippi River in the 1970s (Kolar et al. 2005; Irons et al. 2009). Since that time, they have spread to the Upper Mississippi River (the portion of the Mississippi River upstream of its confluence with the Ohio River) and nearly all major tributaries of the Mississippi River (Baerwaldt et al. 2014). In addition to this geographic range expansion, long-term monitoring data has documented exponential population growth of this filter-feeding fish, especially in the Illinois River (Table 1) (Irons et al. 2011; Sass et al. 2010; Solomon et al. 2016).

Silver carp spawn when the water temperature reaches or exceeds 18 °C and there is a rise in the water level (Kolar et al. 2005). Spawning during water level rises is likely beneficial for silver carp because their eggs are semi-buoyant and require flows ranging from 0.3 to 3 m/sec to remain in suspension (Kolar et al. 2005; DeGrandchamp et al. 2007). Additionally, a water level rise would increase the possibilities of larvae reaching productive floodplain habitats, including backwater lakes. On the La Grange Reach of the Illinois River, population dynamics of bighead carp *Hypothalmichthys nobilis* (Li et al. 2009) and silver carp appear to be driven by sporadic spawning and recruitment linked to flooding (Gibson-Reinemer et al. 2017).

Relatively few studies on spawning and recruitment of silver carp have been conducted in the Upper Mississippi River System (the portion of the Mississippi River upstream of the Ohio River and its major tributaries). Stable isotopes from the otoliths of silver carp captured in the Illinois River revealed that some of these fish were spawned in the Missouri and Mississippi rivers in addition fish spawned within the Illinois River itself (Norman and Whitledge 2015). DeGrandchamp et al. (2007) found a greater frequency of occurrence of silver carp in larval fish samples collected in the lower portion of the Illinois River and a backwater lake during a year with flooding compared to a year without flooding. Lohmeyer and Garvey (2009) found greater densities of larval bighead carp and silver carp in the unimpounded Middle Mississippi River relative to impounded reaches of the Upper Mississippi River. Both of these studies sampled larval fishes with standard larval nets towed in the open water areas. However, schools of young of the year bighead and silver carp are often observed in very shallow habitats along the edge of flood waters by researchers (personal observation by authors), suggesting that an important habitat for larval and post-larval silver carp has not been investigated.

Table 1. The number of silver carp captured each year in Pool 26 and the Open River Reach of the Mississippi River by the Long Term Resource Monitoring (LTRM) element of U.S. Army Corps of Engineers' Upper Mississippi River Restoration program. For each reach, the total was summed across all sampling gear used and all habitat types sampled. The LTRM is a highly standardized monitoring program, with identical methods, gear, and procedures used each year at each of six trend areas (Ratcliff et al. 2014).

Year	Pool 26	Open River
2000	8	32
2001	9	7
2002	5	13
2003	14	5
2004	33	121
2005	8	16
2006	17	12
2007	556	248
2008	3911	318
2009	630	115
2010	1018	257
2011	194	58
2012	94	76
2013	1226	76
2014	4413	4035

We conducted an opportunistic study of the use of shallow habitats at the edge of flood waters by larval and post-larval silver carp. Our objectives were to assess the frequency of occurrence and abundance of larval silver carp in these habitats. Because monitoring and research indicates very high population levels of silver carp in the Illinois River (Irons et al. 2011; Sass et al. 2010; Solomon et al. 2016), we wanted to assess the abundance of larval silver carp in locations upstream of the confluence of the Illinois and Mississippi rivers, at the confluence, and downstream of the confluence. We also tested for differences in the abundance of larval silver carp between the Missouri shoreline of the Mississippi River, and the Illinois shoreline of the Mississippi River. To provide context for these data, we examined long-term monitoring data for silver carp from two reaches of the Upper Mississippi River System and compared years with strong reproduction and subsequent recruitment with patterns of flooding.

Methods

Sampling silver carp in shallow habitat

In 2015, moderate to major flooding occurred on the Mississippi and Illinois rivers from the middle of June till the beginning of August (Figure 1; note that the Grafton Gauge is immediately downstream of the confluence of the Illinois and Mississippi rivers). We conducted opportunistic sampling on June 22, 24, and 26, 2015, sampling small fishes from the shoreline at the edge of the flood in locations accessible by truck. Examples of the types of sites sampled include areas where flood water covered a road, areas with flooded lawns, flooded forested areas, etc., and a site would encompass only one of these habitats (i.e., a flooded road, a flooded lawn, etc.). Water depth at the sites where we collected the fish ranged from 2 cm to 500 cm. Sites were selected for sampling based on accessibility via roads, the visual detection of small fish from the shoreline and the ability to sample small fish from the shoreline at the site.

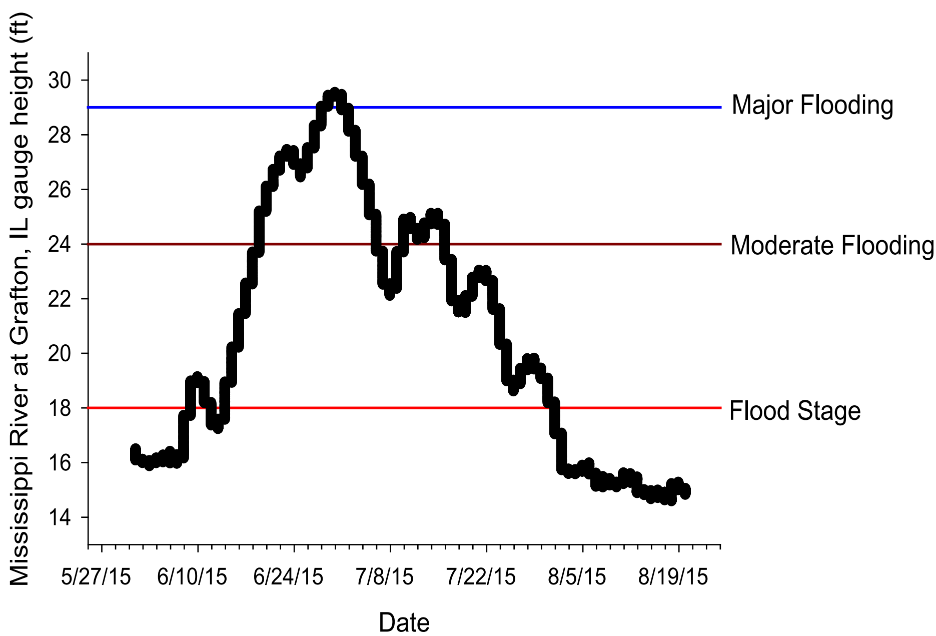

Figure 1. River stage (gauge height – feet) for the Mississippi River at Grafton, IL from June 1 to August 15, 2015.

Figure 2. An example of the net used to sample larval silver carp and other fishes in shallow water habitats.

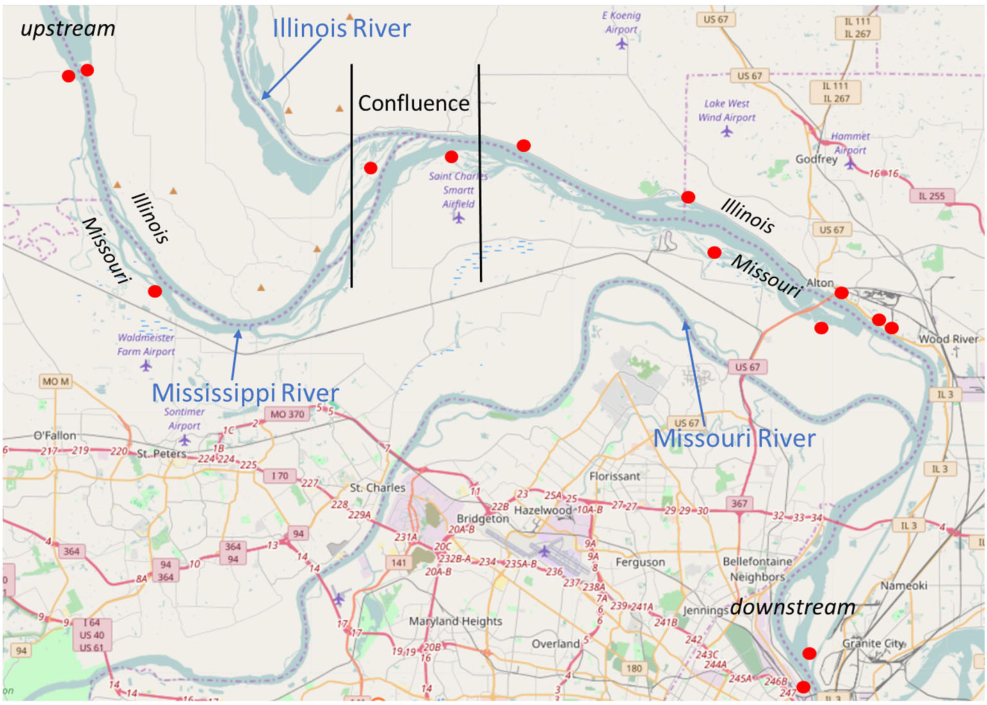

Figure 3. Map show the 14 sampling locations where fishes were captured in shallow water habitats at the edge of the flood in the Mississippi River in June 2015. Red dots represent individual sampling locations.

We sampled a total of 14 sites to allow the comparison of fish abundance between the Missouri and Illinois shorelines, and whether sites were upstream of, downstream of, or at the confluence of the Illinois and Mississippi rivers (Figure 2). On the Illinois shoreline, we sampled at 1 site upstream of the confluence, 6 sites downstream of the confluence and 1 site at the confluence. On the Missouri shoreline, we sample 2 sites upstream of the confluence, 3 sites downstream of the confluence, and 1 site on the Missouri shoreline across from the confluence of the Mississippi and Illinois rivers. These shallow areas are not conducive to most standard fish sampling methods, so we collected fishes using 10.2 × 10.2 cm aquarium nets taped to 3.8-cm diameter x 2 m long PVC pipes (Figure 3). At each sampling location, three people would dip fishes for five minutes and by each dipper were preserved in 5% buffered formalin in separate jars for laboratory identification and processing. This was an active sampling technique, requiring the samplers to visually detect larval fish in the water and attempt to dip these fish out of the water with the aquarium nets duct-taped to the PVC poles. The dippers were spaced at least 50 m apart so that the sampling activity of one dipper would not affect the other dippers. We calculated mean catch-per-unit-effort (CPUE = sum of all larvae captured by the 3 dippers divided by 3) as an index of abundance along with the standard error of CPUE.

Fish were identified to the lowest taxonomic level possible and measurements of standard length were made to the nearest 1.0 mm. Identification of larval fishes was mad using Holland-Bartels et al. (1990) and Chapman (2006). All silver carp captured in our sampling were in the larval to post-larval stages and are referred to simply as larval silver carp throughout the manuscript. As a check on our identifications, we sent 47 larval bigheaded carp to the USFWS Midwest Fisheries Center for DNA sequencing. Because of the small size of the larvae and preservation issues only 22 larval bigheaded carp could be sequenced, all of which were identified as silver carp.

Analyses

We used a two-way analysis of variance (ANOVA) to test for differences CPUE of larval silver carp between the Illinois and Missouri shoreline locations, and in relation to the confluence of the Illinois and Mississippi rivers (Figure 3). Our model included the main effects of 1) State Shoreline and 2) Relation to the Confluence, and the interaction of these main effects. Residuals from the ANOVA were examined, and we found no evidence that the assumptions of homoscedasticity or normality were violated. Because the two main effects had a significant interaction, we also conducted one-way ANOVA's for each state to test for differences in Relation to the Confluence. Tukey's HSD to test multiple comparisons among locations upstream, at the confluence, and downstream of the confluence of the Mississippi and Illinois rivers.

Results

Larval silver carp dominated fish community found in the shallow habitats sampled along the edge of the flood. We captured a total of 12,701 fishes, including eight species (Table 2). A total of 12,295 larval silver carp were captured comprising 97.8% of all fishes

Table 2 Summary of fishes captured in shallow water habitats at the edge of the flood near Alton, IL, USA and St. Louis, MO, USA.

Common name	Genus species	Number Captured
Silver carp	*Hypothalmichthys molitrix*	12,295
Western mosquitofish	*Gambusia affinis*	325
Unidentified cyprinid	*Cyprinidae*	37
Spotfin shiner	*Cyprinella spiloptera*	14
Shortnose gar	*Lepisosteus platostomus*	13
Emerald shiner	*Notropis atherinoides*	9
Gizzard shad	*Dorosoma cepedianum*	3
Smallmouth buffalo	*Ictiobus bubalus*	3
Southern redbelly dace	*Chrosomus erythrogaster*	1
Unidentified fish		1
Total		12,701

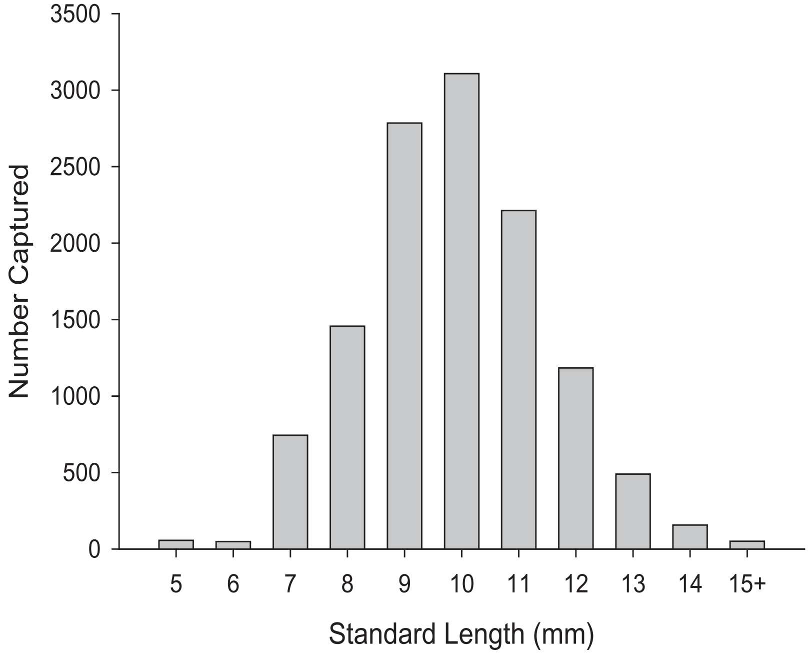

Figure 4. The length distribution (standard length – mm) of larval and post-larval silver carp captured in shallow water habitats at the edge of the flood in the Mississippi River near Alton, Illinois, USA, and St. Louis, Missouri, USA, in June 2015.

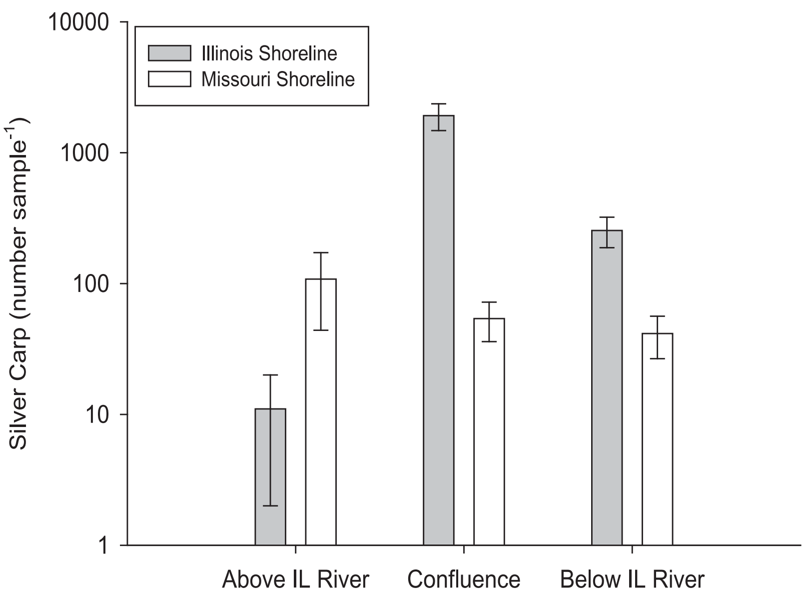

Figure 5. The mean number of fish captured per sample (5 minutes of dipping) from shallow water habitats at the edge of the flood in Mississippi River near Alton, Illinois, USA, and St. Louis, Missouri, USA, in June 2015.[AQ8]

captured. Of the 14 locations we sampled, larval silver carp were present in all but one. Larval silver carp standard length ranged from 5 to 21 mm total length, with a mean of 9.88 (± 0.1 standard error) mm (Figure 4).

The distribution of larval silver carp differed between the Illinois and Missouri shores of the Mississippi River, and in relation to the confluence of the Mississippi and Illinois rivers. Our ANOVA model was significant ($F_{5,\ 38} = 11.90$; $R^2 = 0.61$; $P < 0.001$), as were the main effects of state ($F_{1,\ 38} = 16.77$; $P < 0.001$), location relative to the confluence ($F_{2,\ 38} = 11.95$; $P < 0.001$), and the interaction of these main effects ($F_{2,\ 38} = 11.10$; $P < 0.001$). When the two state shorelines were analyzed separately, CPUE of larval silver carp on the Illinois shoreline differed significantly in relation to the confluence of the Illinois and Mississippi rivers ($F_{2,23} = 16.46$, $R^2 = 0.59$, $P < 0.001$), whereas CPUE of larval silver carp did not vary significantly on the Missouri shoreline in relation to the confluence ($F_{2,\ 15} = 0.09$, $R^2 = 0.01$, $P = 0.91$). The greatest abundance of larval and post-larval silver carp in our samples occurred on the Illinois shoreline at the confluence of the Mississippi and Illinois rivers (Figure 5). On the Illinois shoreline, CPUE of larval silver carp was significantly greater (Tukey's HSD $P < 0.05$) at the confluence relative to either the upstream or downstream sampling sites, whereas there was no significant (Tukey's HSD $P > 0.05$) CPUE between the upstream and downstream sites.

Discussion

Although we identified a total of eight species of fish in our samples form shallow habitats during this flood, larval silver carp accounted for over 97% of all individuals captured. Larval silver carp were captured in all but one of our fourteen sampling locations. Relative to the number of larval silver carp captured in previous larval fish sampling efforts, the 12,295 larval silver carp captured in this study from shallow water habitat is remarkable. For example, the Lohmeyer and Garvey (2009) study captured a total of 1,111 larval Bigheaded carp (bighead and silver carp, the authors identified larvae only to genus – Hypophthalmichthys) in samples collected in the main stem of the Upper Mississippi River in 2005 and 2006 (Dr. Jim Garvey, Southern Illinois University Carbondale, personal communication). The substantially greater number of larval silver carp captured in this study likely reflects a combination of population growth since this earlier study as well as an apparent affinity for shallow habitats at the edge of floods by larval and post-larval silver carp.

The distribution of larval silver carp in relation to the confluence of the Illinois and Mississippi rivers suggests that the Illinois River is an important source of silver carp recruitment in the Mississippi River. The greatest number of larval silver carp captured occurred on the Illinois shoreline site located at the confluence of the Mississippi and Illinois rivers, followed by locations on the Illinois shoreline downstream of the confluence. In contrast, the distribution of larval silver carp among locations on the Missouri shoreline was consistent among locations upstream of the confluence, at the confluence, and downstream of the confluence. Given that we were sampling during moderate flood stages, it is very unlikely that larvae spawned in the Illinois River would be able to cross the Mississippi River or move upstream in the Mississippi River due to high flows. Therefore, larval silver carp captured on the Missouri and Illinois shorelines upstream of the confluence almost certainly originated from spawning in the Upper Mississippi River. This contrasts with the findings of Lohmeyer and Garvey (2009) who found substantially more larval Bigheaded carp in the Middle Mississippi River relative to the Upper Mississippi River and suggested that flow conditions in the pooled portion of the Upper Mississippi River may be unconducive to Bigheaded carp reproduction. Their sampling was conducted in the main channel of the Mississippi River in 2005 and 2006, years with lower overall population levels of silver carp and little to no flooding, which likely contributes to the differences from our findings.

The results of this study suggest that shallow habitats at the edge of the flood have been an underappreciated habitat for larval silver carp in the Upper Mississippi River System. Traditional sampling techniques for larval fishes, such as sampling with neuston nets or modified plankton nets in open water areas of rivers and lakes, will completely miss larval silver carp in shallow habitats at the edge of flood waters. The use of these habitats during flooding may also have implications for the use stable isotopes for identifying the natal origin of fishes. Comparing the otolith Sr:Ca and $\delta^{18}O$ to the same profiles in water from different locations allows scientists to match up the areas where fish were spawned (Zeigler and Whitledge 2010). It is possible that stable isotope profiles of river water from the main channel when the river is not in flood stage may vary from the stable isotope profiles of water from shallow habitats during floods. Given the affinity of larval silver carp for these edge of the flood habitats, any differences in the stable isotope profiles between main channel water and water at the edge of the flood may obscure determinations of the natal origin of silver carp. We also know very little about prey resources for larval silver carp in these edge of flood habitats. Finally, our study only sampled fishes in shallow habitats at the edge of the flood. Future studies should attempt to sample fishes from both these habitats and the main channel of rivers during flooding events to get a full picture of the distribution of larval silver carp.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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