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# Abundance of Ohio Shrimp (Macrobrachium ohione) and Glass Shrimp (Palaemonetes kadiakensis) in the Unimpounded Upper Mississippi River

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ABSTRACT.—Large rivers of the United States have been altered by construction and maintenance of navigation channels, which has resulted in habitat loss and degradation. Using 7 y of Long Term Resource Monitoring Program data collected from the unimpounded upper Mississippi River, we investigated Ohio and Glass Shrimp abundance collected from four physical habitats of the unimpounded upper Mississippi River: main channel border, main channel border with wing dike, open side channel and closed side channel. Our objective was to assess associations between Ohio and Glass Shrimp abundance, environmental measurements and the four habitats to better understand the ecology of these species in a channelized river system. Ohio Shrimp were most abundant in the open side channels, while Glass Shrimp were most abundant in the main channel border wing dike habitat. Thirty-two percent of the variance in Glass Shrimp abundance was explained by year 1995, year 1998, water temperature, depth of gear deployment, Secchi disk transparency and river elevation. Approximately 8% of variation in Ohio Shrimp abundance was explained by Secchi disk transparency. Catch-per-unit-effort (CPUE) was greatest in 1998 for Glass Shrimp but lowest in 1997. Conversely, CPUE was greatest in 1996 for Ohio Shrimp and lowest in 2000. Both species exhibited inter-annual variability in CPUE. Long-term impacts of river modifications on aquatic invertebrates have not been well documented in many large river systems and warrants further study. The findings from this study provide ecological information on Glass and Ohio Shrimp in a channelized river system.

## INTRODUCTION

Many large rivers in the United States have been managed and altered for navigation since the early 1800s (Carlander, 1954; Koebel, 1995; Beckett *et al.*, 1998). These modifications have caused a decline in spatial and temporal habitat heterogeneity (Dister *et al.*, 1990; Shields, 1995). Although findings suggest that the effects of these modifications have been significant for many systems, the impact on many aquatic organisms is still largely unknown (Carlander, 1954; Koebel, 1995). For example, the ecology of freshwater shrimp inhabiting large river systems of the United States is poorly understood and has received little investigation (Bowles *et al.*, 2000). Most studies have reported new records or range expansions of species (*see* Cheper, 1992; Taylor, 1992; Conaway and Hrabik, 1997; Pigg and Cheper, 1998; Poly and Wetzel, 2002; Woodley *et al.*, 2002), but little information on the status, ecology or long term trends of many species is available (Page, 1985; Bowles *et al.*, 2000).

The two native species of freshwater shrimp inhabiting the unimpounded upper Mississippi River (UMR) are the Ohio Shrimp (*Macrobrachium ohione*) and the Glass Shrimp (*Palaemonetes kadiakensis*). The Ohio Shrimp, *M. ohione*, ranges from Alabama to Texas and is

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on the northern periphery of its range in Illinois and Ohio (Page, 1985; Taylor, 1992). It also occurs along the eastern coast from Florida to Virginia (*see* Page, 1985, Fig. 83, p. 357; Taylor, 1992). This species of shrimp is endemic to the United States and is the only *Macrobrachium* sp. found in the Mississippi River drainage (Taylor, 1992). The Ohio shrimp was once abundant in the unimpounded UMR from St. Louis, Missouri, to Cairo, Illinois, until the 1930s (Page, 1985; Taylor, 1992). Possible reasons for the decline include overharvesting, river channelization and habitat loss (Page, 1985; Bowles *et al.*, 2000). Ohio Shrimp can reach a total length of 100 mm, but average 60 mm (Hunter, 1977; Taylor, 1992). This species was harvested in the unimpounded UMR by commercial fisherman mainly for bait, and collections were rare by the 1940s (Conaway and Hrabik, 1997). Collections of this species in the upper Mississippi River over the last 40 y have been rare and sporadic, as suggested by Page (1985), Taylor (1992) and Conaway and Hrabik (1997).

The Glass Shrimp, *P. kadiakensis*, is the only species in this genus that occurs in the unimpounded UMR (Page, 1985). This shrimp ranges from northeastern Mexico, north to the Great Lakes and east to Florida (*see* Page, 1985; Fig. 87, p. 360). In large rivers, this shrimp associates with low velocity backwaters (Hobbs and Jass, 1988). The Glass Shrimp reaches a total length of 36 mm (Nielsen and Reynolds, 1977). This species is common in the central and southeastern United States. However, because of its limited commercial value, it has not been well studied (Cheper, 1988).

Because little information on the ecology and habitat requirements of riverine shrimp is available, our objective was to assess associations between Ohio and Glass Shrimp abundance (*i.e.*, number of individuals), environmental measurements and physical habitats of the unimpounded UMR.

## MATERIALS AND METHODS

Our study was conducted in the unimpounded UMR, which is located between the confluences of the Missouri and Ohio Rivers (Fig. 1) between river kilometers (RK) 48 and 129. In this reach, river channel meandering has been restricted by channelization and the construction of levees and wing dikes (Simons *et al.*, 1975). In addition, the unimpounded UMR lacks submerged and floating-leaf vegetation (Yin and Nelson, 1995). Shrimp were incidentally captured using fish sampling protocol developed by the Long Term Resource Monitoring Program (LTRMP) from 1994–2000 during three annual sampling periods (Jun. 15–Jul. 31; Aug. 1–Sep. 15; Sep. 16–Oct. 30; Gutreuter *et al.*, 1995). Fishing gears deployed included daytime electrofishing, hoop netting (small and large), trawling, seining, mini-fyke netting fyke netting and gill netting (*see* Gutreuter *et al.*, 1995 for gear descriptions). Sampling was conducted in four physical habitats including main channel border wing dike, main channel border, open side channel and closed side channel (Wilcox, 1983; Gutreuter *et al.*, 1995). Main channel border habitat was defined as the zone between the margins of the main navigation channel and the nearest shoreline without wing dikes, while main channel border wing dike habitat was defined as main channel border with a wing dike as the main physical structure (Gutreuter *et al.*, 1995). Open side channels had both ends connecting to the main river channel, while closed side channels had only one end connecting with the main river channel during normal river elevation (Barko and Herzog, 2003). Sample sites were determined for each physical habitat prior to the sampling season using a geographic information system (GIS) to overlay a 50 m × 50 m grid on the study reach. Site locations were randomly chosen for each sampling gear within each physical habitat for each sampling period. Catch-per-unit-effort (CPUE) was calculated for each shrimp species each year to assess inter-annual variability.

FIG. 1.—Geographic representation of the unimpounded upper Mississippi River. Our study was conducted between RK 48–129

At each site, measurements of water temperature, Secchi transparency, depth of gear deployment, water velocity and specific conductance were made prior to gear deployment. Water temperature was measured to the nearest 0.1 C and specific conductance was measured in μS/cm using a Labcomp digital specific conductance meter. A Marsh-McBirney meter (model 201 D) was used to measure water velocity to the nearest 0.01 m/s. Depth of gear deployment was measured to the nearest 0.1 m using boat-mounted sonar. River stage (m; measured at Cape Girardeau, Missouri) was obtained from the U.S. Geological Survey for each day of sampling.

We used stepwise multiple regression with indicator variables in an effort to produce an unbiased model describing the relationship between the predictor and response variables (Barko *et al.*, *in press*). Four indicator variables were used to characterize the physical habitats (Neter and Wasserman, 1974; Kullberg and Scheibe, 1989). Thus, $X_1 = 1$ if the physical habitat was main channel border wing dike, and 0 otherwise, $X_2 = 1$ if the physical habitat was closed side channel, and 0 otherwise, $X_3 = 1$ if the physical habitat was open side channel, and 0 otherwise and $X_4 = 1$ if the physical habitat was main channel border, and 0 otherwise. In addition, seven indicator variables were used to characterize the seven sampling years. This approach obviated the need for multiple pairwise comparisons (Barko *et al.*, *in press*). We used the default significance parameters of 0.15 for entry and removal from the models (SAS Institute Inc., 1989).

Stepwise multiple regression (SAS Institute Inc., 1989) was used to assess associations between species abundance, environmental measurements and physical habitats. A separate stepwise multiple regression analysis was done for each shrimp species. Data were square-root transformed before regression analysis to meet assumptions of normality (Krebs, 1999). The resulting Glass Shrimp regression model had the form:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \varepsilon,$$

where $X_1$ represents year 1995, $X_2$ represents year 1998, $X_3$ represents Secchi transparency, $X_4$ represents water temperature, $X_5$ represents depth of gear deployment and $X_6$ represents river elevation. The resulting Ohio Shrimp regression model had the form:

$$Y = \beta_0 + \beta_1 X_1 + \varepsilon,$$

where $X_1$ represents Secchi disk transparency.

## RESULTS

Only four fishing gears captured shrimp including daytime electrofishing (DE), trawling (T), fyke netting (F) and mini-fyke netting (MF). One-thousand and eighty Glass Shrimp (GS) and 235 Ohio Shrimp (OS) were captured during the 7 y period (DE: 46 GS and 36 OS; T: 1 OS; F: 1 OS; MF: 227 OS and 1034 GS). Using these four gears, more than 900 samples were taken during this study. Because mini-fyke nets captured the most shrimp (94% of all captures), CPUE was calculated using only data collected from this gear ($n = 483$ samples). For Glass Shrimp, CPUE was greatest in 1998 and lowest in 1997 (Fig. 2). Conversely, CPUE for Ohio Shrimp was greatest in 1996 and lowest in 2000. Ohio Shrimp were most abundant in open side channels ($n = 42$; 54/100 net nights), followed by main channel borders ($n = 59$; 50/100 net nights), main channel border wing dikes ($n = 39$; 44/100 net nights) and closed side channels ($n = 77$; 39/100 net nights). Conversely, Glass Shrimp were most abundant in the main channel border wing dikes ($n = 448$; 503/100 net nights), followed by main channel borders ($n = 209$; 176/100 net nights), closed side channels ($n = 272$; 138/100 net nights) and open side channels ($n = 84$; 108/100 net nights).

Because of low catch rates from most sampling gears, only individuals captured using mini-fyke netting were used in the stepwise multiple regression analyses and we only present data from samples that captured one or more shrimp ($n = 169$). Approximately 8% of the variation in Ohio Shrimp abundance was explained by one independent variable, Secchi transparency, that entered the stepwise regression model ($F = 5.24$; d.f. $= 1, 59$; $R^2 = 0.0816$; $P = 0.0257$; Table 1). This relationship was negatively correlated with Ohio Shrimp abundance. This model did not reveal any significant effects of temperature, depth of gear deployment, specific conductance, physical habitats, year, water velocity or river elevation on Ohio Shrimp abundance.

Approximately 32% of the variation in Glass Shrimp abundance was explained by six independent variables that entered the stepwise regression model ($F = 8.28$; d.f. $= 6, 108$; $R^2 = 0.3152$; $P < 0.0001$; Table 2). Glass Shrimp abundance was positively correlated with years 1995 and 1998 and water temperature, but negatively correlated with Secchi visibility, depth of gear deployment and river elevation. However, the year 1995 was non-significant (Table 2). Abundance was lower when mini-fyke nets were set in shallow water, water transparency (Secchi) was low and sampling was conducted when river elevation was high. This model did not reveal any significant effects of specific conductance, water velocity or physical habitats on Glass Shrimp abundance. Environmental variables measured at the sampling sites are summarized in Table 3 and are separated by species.

## DISCUSSION

Ohio and Glass Shrimp appear to inhabit different physical habitats of the unimpounded UMR. The greatest abundance of Ohio Shrimp was collected from open side channels and main channel borders, once common habitats of the unimpounded UMR. Side channel habitat is being lost in this system because of sedimentation and reduced connectivity to the main channel during low river stages (Simons *et al.*, 1975; Theiling, 1999). Page (1985)

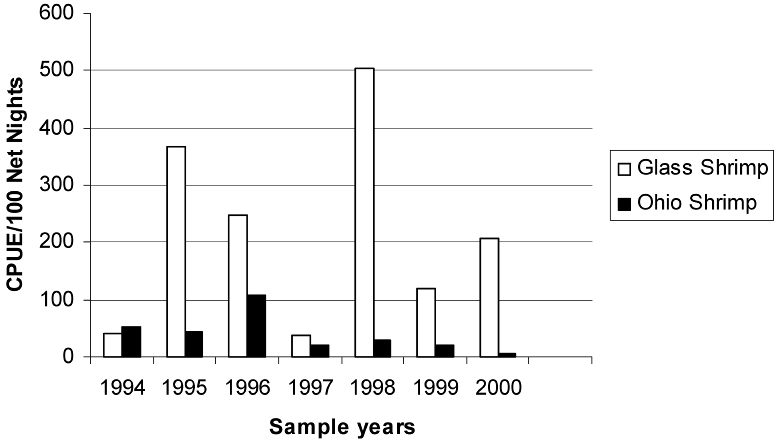

FIG. 2.—Catch-per-unit-effort (CPUE) of Glass and Ohio Shrimp collected in the unimpounded upper Mississippi River from 1994–2000 using mini-fyke nets. The number of mini-fyke nets set in the four physical habitats (main channel border, main channel border wing dike, closed side channel and open side channel) each year were 71, 75, 80, 79, 72, 64 and 42, respectively

suggested that Ohio Shrimp may have declined as a result of channelization and habitat loss in large rivers, such as the UMR. Beckett *et al.* (1998) concluded that river modifications in the Ohio River, which created reduced water velocity, assisted in the demise of one amphipod species (*Crangonyx pseudogracillis*) and allowed for the establishment of a newly introduced (*e.g.,* range expansion) amphipod species (*Gammarus* nr. *fasciatus*). It is probable that wing dikes, which create scours of reduced water velocity, fragment main channel border physical habitat and isolate side channels during moderate to low river elevation, have aided in both the reduction of Ohio Shrimp and the establishment of Glass Shrimp in the unimpounded UMR (Logsdon, 1993; Hobbs, 2001; Barko and Herzog, 2003; Barko *et al.*, *in press*).

Authors have suggested that Ohio Shrimp prefer low velocity water (Conaway and Hrabik, 1997). However, we found no correlations between water velocity and Ohio Shrimp abundance. In addition, open side channels, a preferred habitat of Ohio Shrimp, have flow during normal river elevations (Barko and Herzog, 2003). We also captured a high abundance of Ohio Shrimp in main channel border habitat. Main channel border is characterized by the presence of velocity and is often inhabited by riverine species. McCormick (1934) reported capturing Ohio Shrimp along the shoreline of the unimpounded UMR using shrimp sets made from willow or cottonwood branches. We speculate this physical habitat is used when terrestrial habitat is flooded and plant and animal material is available for foraging (Truesdale and Mermilliod, 1979). Although main channel borders are still present in the unimpounded UMR, they have been fragmented by the creation of wing dikes and have been converted to revetment in some areas. Conaway and Hrabik (1997) reported capturing 86% (6 out of 7 individuals) of Ohio Shrimp at main channel border wing dikes. However, we found lower abundance of Ohio Shrimp in main channel border wing dikes when compared to open side channel and main channel border habitats. We suggest that Ohio Shrimp have been negatively impacted by the addition of rock structures, both revetment and wing dikes, because these structures create areas of reduced velocity and particulate matter suspension (*i.e.,* increase visibility). Our results

TABLE 1.—Results of the stepwise multiple regression analysis comparing Ohio Shrimp to physical measurements in the unimpounded upper Mississippi River

| Variable | Parameter estimate | Standard error | Type II sum of squares | F | P |
|---|---|---|---|---|---|
| Intercept | 2.9019 | 0.5430 | 24.0633 | 28.56 | <0.0001 |
| Secchi | −0.2786 | 0.1217 | 4.4153 | 5.24 | 0.0257 |

indicate that Ohio Shrimp have greater abundance in areas with reduced visibility (*i.e.,* suspended particulate matter). This is likely a predator avoidance response because Ohio Shrimp occupy low visibility physical habitats (*e.g.,* open side channel) that are also occupied by predatory fishes, such as Flathead Catfish (*Pylodictis olivaris*) and White Bass (*Morone chrysops*; Page, 1985; Barko and Herzog, 2003). Avoidance of such areas by Ohio Shrimp would also explain the lower abundance associated with closed side channels, which also have reduced velocity and higher visibility.

Conversely, Glass Shrimp had the highest abundance at main channel border wing dikes (high visibility and low water velocity) and the lowest abundance in side channels. Pigg and Cheper (1998) and Page (1985) reported capturing high abundances of Glass Shrimp in areas with shallow water and low velocity. We hypothesize that Glass Shrimp inhabit wing dike scours to use the crevice habitat for hiding and/or feeding. In addition, Glass Shrimp feed on dead plant and/or animal material (Page, 1985), which is likely found in the scours when they are functioning as sediment sinks during normal to low river elevations. We found a negative correlation between Glass Shrimp abundance and depth of gear deployment, indicating that this shrimp was more abundant in shallower water in the unimpounded UMR. Glass Shrimp also were most abundant when river elevation was lower. Lower elevations occur during the summer months (*e.g.,* sampling period 2) when water temperatures are warmer, which promotes fecundity (Hobbs, 2001). We also found that Glass Shrimp abundance was lowest in the side channels when compared to the other physical habitats. Closed side channels have low water velocity and high visibility, which are characteristic conditions for this species (Page, 1985; Barko and Herzog, 2003). Hence, the low abundance of Glass Shrimp in closed side channels was puzzling. Barko and Herzog (2003) reported high abundances of Centrarchidae in closed side channels, such as Orangespotted Sunfish (*Lepomis humilis*), Bluegill (*L. macrochirus*) and Green Sunfish (*L. cyanellus*). Based on the findings of Creaser (1932), we conclude that Glass Shrimp use this habitat but abundance remains low because of fish predation. Creaser (1932) reported high abundances of Glass Shrimp in pools with low fish abundance. The use of wing dikes by

Table 2.—Results of the stepwise multiple regression analysis comparing Glass Shrimp to physical measurements in the unimpounded upper Mississippi River

| Variable | Parameter estimate | Standard error | Type II sum of squares | F | P |
|---|---|---|---|---|---|
| Intercept | −2.9167 | 1.9799 | 3.8262 | 2.17 | 0.1436 |
| Year 1998 | 1.3349 | 0.3235 | 30.8025 | 17.02 | <0.0001 |
| Depth of gear deployment | −1.0948 | 0.4919 | 8.9633 | 4.95 | 0.0281 |
| Secchi | −0.5040 | 0.1379 | 24.1737 | 13.36 | 0.0004 |
| Temperature | 1.3688 | 0.4041 | 30.7531 | 11.47 | 0.0010 |
| River elevation | −1.0359 | 0.2840 | 24.0694 | 13.30 | 0.0004 |
| Year 1995 | 0.6687 | 0.3691 | 5.9388 | 3.28 | 0.0728 |

TABLE 3—Mean (±standard deviation) of environmental variables measured at sites where Ohio and Glass Shrimp were captured in the unimpounded UMR from 1994–2000. Minimum (min.) and maximum (max.) values for each environmental variable are given after the mean (±standard deviation)

| Environmental variable | Ohio Shrimp | (min.–max.) | Glass Shrimp | (min.–max.) |
|---|---|---|---|---|
| Secchi | 19.7 (8.8) | (6.0–48.0) | 22.4 (11.6) | (3.0–69.0) |
| Specific conductance (μS/cm) | 531.7 (43.7) | (416.0–642.0) | 530.4 (68.8) | (324.0–767.0) |
| Temperature (C) | 26.9 (2.9) | (16.3–31.2) | 26.4 (3.5) | (16.2–33.6) |
| Depth at Gear Deployment (m) | 1.2 (0.7) | (0.3–3.9) | 1.0 (0.5) | (0.3 – 2.7) |
| Water Velocity (m/s) | 0.1 (0.1) | (0.0–0.5) | 0.1 (0.1) | (0.0–0.8) |
| River Stage (m) | 6.8 (1.6) | (3.0–9.6) | 6.2 (1.7) | (3.0–9.6) |

Glass Shrimp is likely because low velocity backwater areas are no longer common and are often unavailable to aquatic organisms because of sedimentation and the creation of levees. Levees have separated the main river channel from the floodplain. Hobbs and Jass (1988) reported that Glass Shrimp inhabit low velocity habitats of lotic systems.

The high CPUE for Ohio Shrimp in 1996 suggests that the flood of 1993 produced conditions that were favorable for Ohio Shrimp reproduction. Ohio Shrimp live approximately 2 y and females produce 6272 to 24,000 eggs (Truesdale and Mermilliod, 1979; Page, 1985; Hobbs, 2001) after reaching sexual maturity. It is plausible that the high CPUE in 1996 was because of a successful reproductive effort in 1993, resulting in an increased population size in 1996. The Ohio Shrimp is on the northern periphery of its range in the unimpounded UMR and is a large river species that likely receives reproductive cues from spring flood spates and uses flooded terrestrial habitat for reproduction. Unfortunately, little is known regarding the life history of Ohio Shrimp (Hobbs, 2001). The declining CPUE of Ohio Shrimp after the peak in 1996 may be because of reduced fecundity, resulting from reduced connectivity with the floodplain because of levees, closing structures and wing dikes. Field collections in this river reach have yielded no gravid females (D. Herzog, pers. comm.) using LTRMP sampling protocol, which suggests that this population is barely persisting in the unimpounded UMR. Glass Shrimp live for approximately 1 y, produce between 8–160 eggs (Page, 1985; Hobbs, 2001) and are most likely to be affected by annual fluctuations in environmental conditions (*i.e.,* seasonal drying and extended high water; Hobbs, 2001). Instantaneous fluctuations in environmental variables could explain the inter-annual variability in CPUE observed for Glass Shrimp. Conversely, the low CPUE of Glass Shrimp in 1997 could be because of competitive exclusion by the larger Ohio Shrimp, which had the highest CPUE in 1996.

In summary, Glass Shrimp were the most abundant shrimp species in the unimpounded UMR. The construction of wing dikes seems to have created low-velocity areas conducive for Glass Shrimp. However, open side channels and main channel borders supported the greatest abundance of Ohio Shrimp. Neither of these aquatic areas is maintained by flooding or management practices, which has likely impacted populations of this species in the unimpounded UMR. Side channels are becoming disjunct from the main river channel because of sedimentation and lack of connectivity during low river elevations (Simons *et al.*, 1975; Theiling, 1999), while rock structures continue to be created within the main channel border. Although Ohio and Glass Shrimp are not of economic importance, their role in riverine systems needs to be better understood. The decline of key river macroinvertebrates, such as Ohio Shrimp, suggests that anthropogenic river modifications and reduced floodplain connectivity are likely impacting additional riverine species, such as the

Pallid Sturgeon (*Scaphirhynchus albus*) and Alligator Snapping Turtle (*Macroclemys temminckii*). The impacts of these modifications on aquatic organisms warrant further study and this knowledge is necessary before species or habitat recovery/restoration efforts can be successful.

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