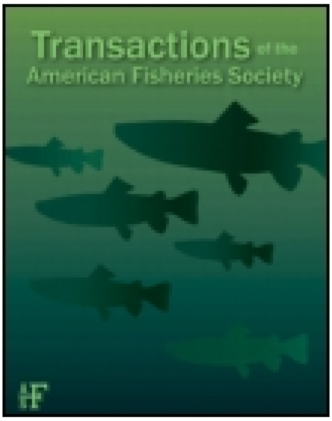

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[Article]

Movements of Adult Radio-Tagged Bighead Carp in the Illinois River

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Abstract.—Populations of invasive bighead carp *Hypophthalmichthys nobilis* in the Mississippi River basin are rapidly increasing in size and range. However, the rate of expansion is not well understood. We used radiotelemetry to document movements of bighead carp within the LaGrange Reach of the Illinois River, Illinois, where populations have been documented since 1993. We surgically implanted radio transmitters into 42 adults in June 2003 and May–July 2004. Successful relocation of individuals decreased over time and ended in August of both years. We analyzed 132 observations from 23 adults and found a mean (±SE) movement rate of 1.70 ± 0.74 km/d. The highest movement rate was 14.33 km/d. The maximum distance traveled by an individual was 163 km upstream in 35 d, and the top 10% of movements as observed by boat were between 26.5 and 56.5 km within 3–10 d. Forty-three percent of fish died or dropped transmitters for unknown reasons, but handling, environmental conditions, or both may have contributed to the loss. Our study is the first to document the movement rates and patterns of bighead carp within the United States and shows that adults are capable of moving considerable distances in a short time. Immediate actions to prevent or control their spread are warranted.

Invasive, planktivorous bighead carp *Hypophthalmichthys nobilis* have been expanding their range throughout the United States since escaping into tributaries of the Mississippi River basin in the mid-1970s (Jennings 1988). The first report of captured escapees was from the Ohio River in 1981 (Freeze and Henderson 1982). Since that time, catch frequencies have greatly increased, and reproducing populations have been identified in the Illinois, Mississippi, Missouri, and Ohio rivers (Tucker et al. 1996). Research on introduced bighead carp has determined that the species can acclimate, spread, and establish reproducing populations in less than 20 years (Abdusamadov 1987). Schrank and Guy (2002) examined age, growth, and gonadal characteristics of bighead carp in the Missouri River and determined that individuals have life history characteristics similar to established populations in Asia and Europe, which suggests that environmental conditions in the United States are favorable for this species and continued dispersal is likely. Currently, the maximum range of expansion for bighead carp is unknown and is a main concern for fisheries managers, policy makers, and the general public. If population dispersal continues, this species could become established in other regions.

Bighead carp have been documented in the Illinois River, Illinois, and its tributaries since 1993 (Burr et al. 1996). Furthermore, an exponential increase of captured individuals in the LaGrange Reach of the Illinois River was documented from 1991 to 2000 (Chick and Pegg 2001). The northern portion of the LaGrange Reach is about 220 river kilometers (rkm) downstream of the Chicago Sanitary and Ship Canal (CSSC; measuring from the confluence of the Illinois and Mississippi rivers), which connects to the Chicago River and Lake Michigan (Figure 1). Adult bighead carp were captured in 2003 only 35.4 km downstream of an electric fish barrier in the CSSC (Dettmers and Pegg 2003). The increasing numbers of bighead carp suggest that only a short time remains before the species spreads into Lake Michigan. Therefore, understanding the movements of bighead carp may provide insight into possible control mechanisms. Unfortunately, little is known about bighead carp

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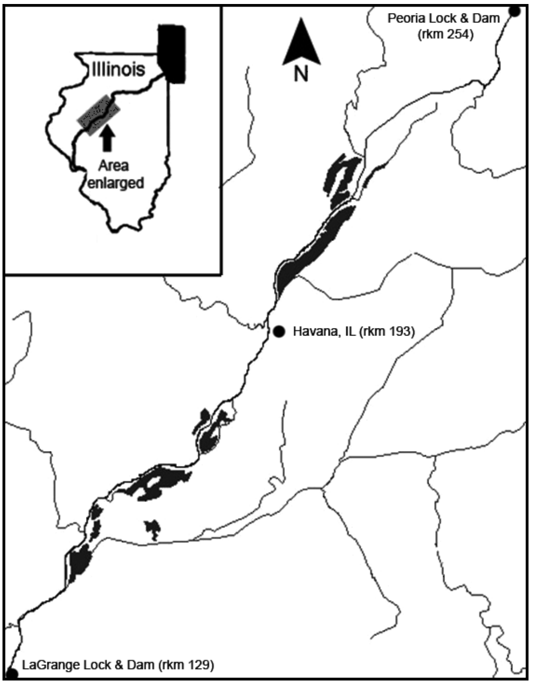

FIGURE 1.—Map of the LaGrange Reach, Illinois River, Illinois, where radiotelemetry of adult bighead carp was conducted. Adult bighead carp were captured and released at Havana. The entire reach was searched on a weekly basis during June–August 2003 and May–August 2004.

movements and dispersion. They presumably migrate large distances upstream to spawn (Abdusamadov 1987; Jennings 1988), but the extent of these migrations is not well understood, especially in North America.

The purpose of this study was to observe the movements of bighead carp within the Illinois River. Adult bighead carp were radio-tagged to gain information on their movements, including the maximum distance traveled, potential movement patterns (e.g., spawning migrations), diurnal activity, and possible correlations with river height and water temperature.

Methods

Study site and radiotelemetry.—We tracked adult bighead carp during June–August 2003 and May–August 2004 primarily in the LaGrange Reach of the Illinois River. The LaGrange Reach is 125 km in length and defined by the LaGrange Lock and Dam (rkm 129 above the confluence with the Mississippi River) and Peoria Lock and Dam (rkm 254). Adult bighead carp were captured, radio-tagged, and released near Havana, Illinois (rkm 193; Figure 1).

We used radiotelemetry to identify movements of bighead carp because it works well in shallow, turbulent water and the equipment does not require direct water contact (Stasko and Pincock 1977; Winter et al. 1978; Winter 1996). Therefore, individuals can be located in many ways (i.e., boat, stationary posts, or airplane) and searches are more efficient. Water conductivity in the LaGrange Reach is greater than 400 μS/cm (USGS 1988–2004 data available at www.umesc.usgs.gov/ltrmp.html); therefore, we used transmitters programmed to operate on the lower end (48–49 MHz) of the very high frequency band (30–300 MHz; Sisak and Lotimer 1998), as lower radio frequencies do not attenuate as quickly in high-conductivity water (Winter et al. 1978; Winter 1996; Sisak and Lotimer 1998) and can be received at greater depths (Eiler 1990; Winter 1996).

We used radio transmitters with external whip antennas (Advanced Telemetry Systems, Inc., Isanti, Minnesota; Models F1840 and F1580). Model F1840 weighed 20 g and had a nominal battery life ranging from 335 to 671 d. Model F1580 weighed 3.6 g and had a nominal battery life of 120–240 d. Transmitters emitted 50 pulses/min. Each transmitter had a unique frequency for identification. The Model F1580 transmitters were originally intended for implantation into juvenile bighead carp, but failure to capture juveniles of suitable size resulted in their use in adults. Transmitters were less than 0.008% of total body weight, which was well below the maximum recommendation of 2.0% (Winter 1996; Jepsen et al. 2002).

Surgical implantation.—We used monofilament trammel nets (35.6-cm outer mesh; 7.6-cm inner mesh) to capture 10 individuals in 2003 and 32 in 2004. Nets were set in backwater (BW) lakes, side channels (SCs), and tributaries near Havana and were pulled after 5–30 min, depending upon capture success. In 2003, we surgically implanted transmitters into fish between June 20 and 30. Surgery was conducted in the field within 1 h of capture to minimize handling stress (Otis and Weber 1982; Jepsen et al. 2002). Individuals were anesthetized in 1.995 g of sodium bicarbonate/L of river water and 0.75 mL of glacial acetic acid/L of river water (concentrations modified from Prince et al. 1995).

Once an individual reached stage-4 anesthesia (total loss of swimming motion and weak operculum movement; Yoshikawa et al. 1988), the area of incision was descaled and a transmitter was inserted into the body cavity through a 1.5–2.0-cm incision that was cut parallel to the midventral line (Schramm and Black 1984; Jepsen et al. 2002). Next, a hypodermic needle was inserted into the body cavity slightly below and to the right of the incision, and the transmitter antenna was fed through the needle to rest on the outside of the body (Ross 1982). We closed the incision with seven to eight stainless steel skin staples (Ethicon, Inc., Somerville, New Jersey; 35W). Once surgery was completed, the incision area was washed with Betadine solution and rinsed. Individuals were released back into the river after they were upright and swimming independently, typically less than 5 min after surgery.

In 2004, we implanted transmitters in 20 adults on May 12–14, 9 on June 15–16, and 3 on July 2. Individuals that received transmitters in June and July carried the smaller, Model F1580 transmitters. Surgical implantation was similar to 2003 procedures, except that blue monofilament polypropylene sutures (Ethicon; Prolene 8842) were used instead of skin staples. We determined that skin staples, while reducing surgery time, did not readily enter the thick ventral musculature of bighead carp and securely close the incision. Laboratory tests on a congeneric species, silver carp *H. molitrix*, showed that individuals receiving skin staples ($n = 11$) had 34% greater mortality 14 d postsurgery than did individuals receiving monofilament sutures (L.M.P., unpublished data).

Individual location and tracking pattern.—Daily tracking (approximately 6–8 h) was conducted by boat with a mounted, four-element Yagi antenna. Individual frequencies were programmed into the receiver and scanned every 2–4 s. Boat speed was adjusted depending on the number of frequencies programmed. The initial search pattern included river areas 10 km upstream and downstream of the release site. If any individual was not found in the local area after 2 d of searching, efforts extended to the entire LaGrange Reach. The entire reach was searched at least once per week, which typically required 2 d. Searches of backwaters, tributaries, and river locations outside of the LaGrange Reach were conducted once the entire reach was searched. When an individual was located, the following information was recorded: date, time, Universal Transverse Mercator (UTM) coordinates, approximate river kilometer, water temperature, and general observations (i.e., difficulty in obtaining signal, fish movement up or downstream). We also noted the river location as a BW lake, main channel (MC), or SC. If an individual was located within the same 20-m area at least three times, the fish was designated as unmoving and we assumed that the fish had died or the transmitter had been expelled.

We also conducted aerial tracking to search for individuals that had not been found by boat for more than 2 weeks. Searches were conducted on August 13 and September 15, 2003, and on July 1 and August 6, 2004. Two loop antennae were mounted in a side-looking configuration (Gilmer et al. 1981) to the wing struts of a Cessna 182 airplane. Aircraft altitude was about 200–300 m above ground level, and speed was typically 160 km/h or the slowest possible (Gilmer et al. 1981; Seddon and Maloney 2004). Aerial tracking always started and ended around Havana (rkm 193). On August 13, 2003, and July 1 and August 6, 2004, we searched upstream to Starved Rock Lock and Dam (rkm 372). On September 15, 2003, our search was focused downstream to the confluence of the Illinois and Mississippi rivers (rkm 0). When a fish was located, we recorded the date, time, and approximate river kilometer as determined from maps.

Diurnal observations.—We attempted to monitor diurnal movements by locating individuals during several 24-h periods. Individual sites were selected based on the presence of several fish to optimize data collection efforts and encompassed a 6–8-km stretch of river. Individuals that were initially located within the chosen 6–8-km section of river were tracked for the remaining 24 h. Searches began every 6 h at 0600, 1200, 1800, 2400, and 0600 hours. For each time period, the chosen stretch of river was covered by boat twice before continuing the search to upstream and downstream areas. A time period search ended when each individual had been successfully located. To obtain a more precise location, we used a loop antenna after initial location by Yagi antenna (Winter 1996). Time, UTM coordinates, water temperature, and river kilometer were recorded.

Data analysis and statistics.—All UTM coordinates were plotted on topographic maps obtained from the Illinois Natural Resources Geospatial Clearinghouse (available at www.isgs.uiuc.edu/nsdihome/) by use of ArcView GIS software. We also used ArcView GIS to calculate the distances (km) between two UTM coordinates over time (d) to obtain a movement rate (km/d) as well as direction of movement (i.e., upstream and downstream). Movement data for fish that either died or expelled a transmitter within 20 d postsurgery were excluded from all analyses because it was assumed that those fish behaved abnormally due to stress from surgery. Observations made by boat and airplane were analyzed separately because daily movement rates determined from aerial searches were typically derived from more days between locations and these individuals were rarely located by boat. Additionally, some fish locations by boat also had a large period of time between observations. Using these data may be less reliable, as the individual probably moved considerably more than our conservative straight-line estimates would indicate. Therefore, the 5% of all movement rates ($N = 8$) that involved the largest intervals between observations

TABLE 1.—Mean movement rate (km/d) and distance (km) for upstream, downstream, and combined movements of bighead carp in the LaGrange Reach of the Illinois River, 2003–2004. Maximum movement rate and distance (km) are also listed. For boat locations, the number of upstream and downstream movements *N* does not sum to overall movements because some fish moved too little between observations to allow accurate assessment of movement direction.

		Mean (±SE)		Maximum	
Movement direction	*N*	Movement rate	Distance	Movement rate	Distance
Location by boat					
Combined	129	0.983 ± 0.211	4.13 ± 0.90		
Upstream	68	0.786 ± 0.197	4.04 ± 1.10	10.28	44.3
Downstream	56	1.290 ± 0.417	4.55 ± 1.55	14.33	56.5
Location by airplane					
Combined	5	2.410 ± 1.260	78.50 ± 22.80		
Upstream	3	3.140 ± 2.160	91.70 ± 21.30	7.46	134.0
Downstream	2	0.786 ± 0.554	58.70 ± 57.20	1.33	116.0

(15–57 d) were excluded from analyses of mean movement rate.

Statistical analyses were conducted with SYSTAT, and significance was determined with a significance level of 0.05. Analysis of variance was used to compare mean movement rates for 2003 and 2004. Paired *t*-tests were used to compare mean movement rates (km/d) of individuals for direction of movement (upstream versus downstream), river flow (increasing versus decreasing), and daily movement patterns (day versus night). We also looked for differences in upstream versus downstream movement rates when river flow was either increasing or decreasing to determine the potential for spawning migrations. For each test, multiple movement rates for each fish were averaged to attain one movement rate per individual. Individuals that were missing data (e.g., no upstream movements, no movements during increasing water levels) were excluded from hypothesis testing. Data were $\log_{10}$ transformed to meet assumptions of normality. River flow data were obtained from the U.S. Geological Survey (waterdata.usgs.gov). Pearson's product-moment correlations were used to examine the relation between mean weekly (i.e., data collected from 4 to 8 d) movement rates (km/d), river flow (m^3/s), and water temperature (°C).

Results

Mean (±SE) length and weight of adult bighead carp were 738 ± 12.4 mm and 4,500 ± 160.8 g, respectively. Average (±SE) surgery time (min:s) in 2003 (skin staples) was 3:03 ± 0:13, and recovery time (time until upright swimming was exhibited) was 1:25 ± 0:12. Surgery and recovery times (min:s) in 2004 (sutures) were 6:50 ± 0:10 and 1:57 ± 0:10, respectively. While postsurgery laboratory results showed higher mortalities for silver carp with skin staples, results from the field showed little difference in the percentage of bighead carp that were deemed to be unmoving (40% of individuals with staples; 44% with sutures). For both years, 18 individuals (43%) were deemed to be unmoving for an average of 21 d postsurgery (range = 2–85 d). Of the 18 individuals, 11 were excluded from all analyses, as they died within 20 d postsurgery.

In 2003, all 10 individuals were located at least once after implantation and the number of continued locations decreased through time. By the end of the study period, only one individual was consistently located. In 2004, seven individuals were never found after implantation, and the number of successful locations decreased over time; only four individuals were successfully located by airplane on August 6, 2004.

Mean rate of movement (km/d) did not differ between years (ANOVA: $F_{1,21}$ = 0.30, P = 0.59); mean (±SE) movement rates were 0.92 ± 0.52 km/d in 2003 and 1.25 ± 0.31 km/d in 2004. Therefore, movement data for both years (n = 134) were combined in further analyses. Mean movement rate for all observations was 1.70 ± 0.74 km/d. The mean movement rate for observations made by boat (N = 129) was 0.983 ± 0.211 km/d (range = 0.009–14.33 km/d; Table 1). Mean distance traveled between two locations was 4.13 ± 0.90 km and ranged from 0.01 to 56.50 km (Table 1). Mean movement rate and distance traveled by fish located via airplane (N = 5) were 2.41 ± 1.26 km/d and 78.50 ± 22.80 km, respectively, which were higher than movements obtained by boat. However, of the observations recorded by boat, 9 of the 23 fish (35%) moved distances ranging from 14.90 to 56.50 km over 3–10 d and had movement rates ranging from 3.09 to 14.33 km/d. The total maximum distance traveled upstream by an individual for the entire study period was 163 km over a period of 35 d (July 2–August 6, 2004). For both years, the mean downstream

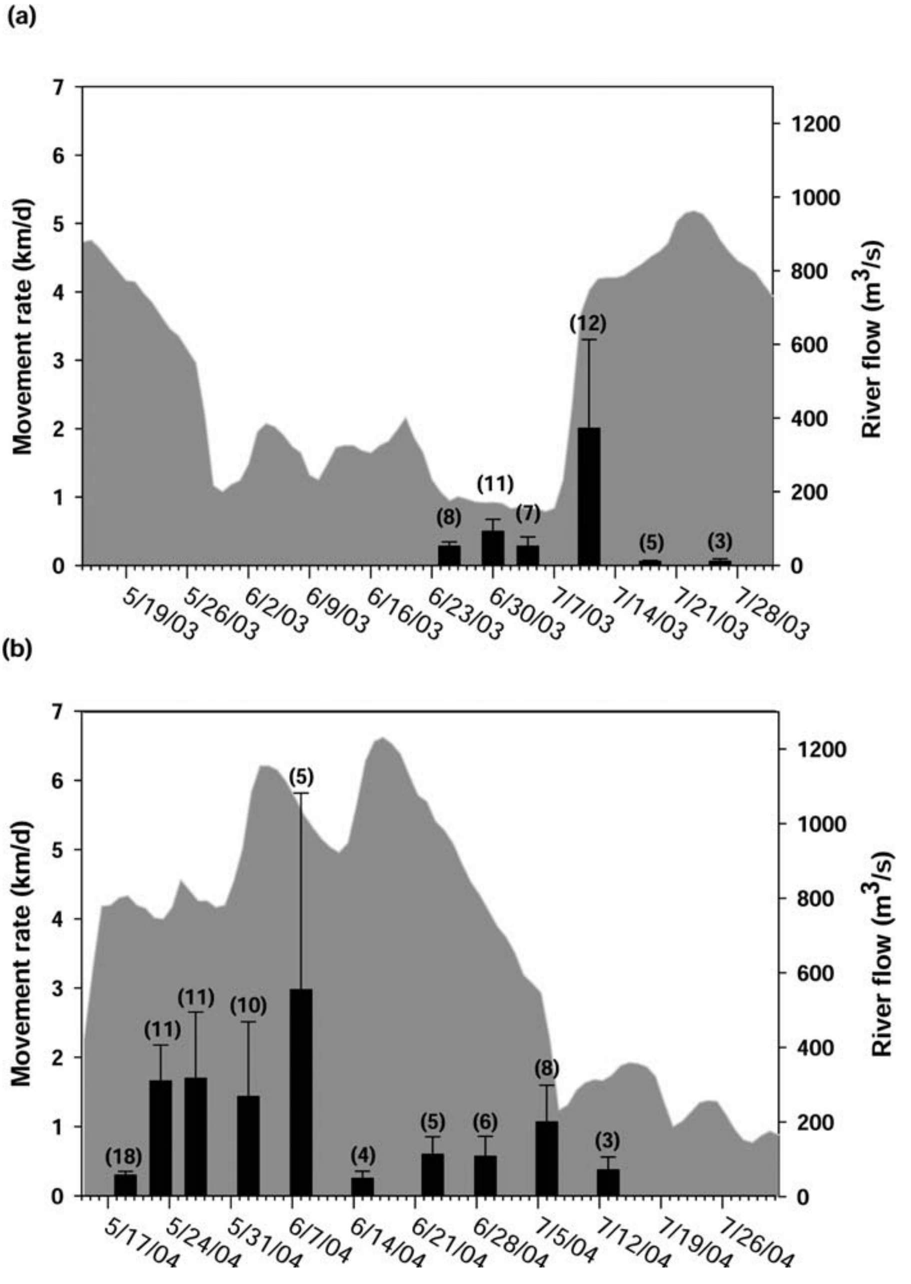

FIGURE 2.—Weekly mean (±SE) movement rates (bars) of bighead carp in the LaGrange Reach, Illinois River, Illinois, during **(a)** June–July 2003 and **(b)** May–August 2004. River flow data are also presented (shading). The numbers in parentheses are the total number of movements for each mean.

movement rate was 0.771 ± 0.140 km/d, which was significantly higher than the mean upstream movement rate of 0.270 ± 0.149 km/d (t = 2.16, df = 16, P = 0.046).

Movement rates peaked during the weeks of July 11, 2003, and June 8, 2004, when river flow was approximately 630 and 1,030 m^3/s, respectively (Figure 2). The 2003 peak in mean weekly movement rates coincided with a rapid increase in river flow and a high water temperature of 28.2°C. In 2004, river flow peaked between May and June and the highest mean weekly movement rates were observed during that

TABLE 2.—Mean daytime (0600–1800 hours) and nighttime (1800–0600 hours) movement rates (km/h) for five adult bighead carp observed in June 2004 in the LaGrange Reach of the Illinois River.

Individual	Movement rate (±SE)	
	Day	Night
1	1.030 ± 0.577	0.868
2	0.198 ± 0.059	0.071 ± 0.016
3	0.255 ± 0.047	0.061 ± 0.047
4	0.276 ± 0.168	0.043 ± 0.021
5	0.017 ± 0.012	0.014 ± 0.006

time. However, mean temperature during the high river flow was lower than in 2003 at 24.4°C. Weekly movement rates for both 2003 and 2004 ($n = 16$) were not significantly correlated with river flow (Pearson's product-moment correlation: $r = 0.282$, $P = 0.870$) or water temperature ($r = -0.296$, $P = 0.796$), and we did not find a correlation between weekly temperature and river flow ($r = -0.548$, $P = 0.084$). Mean movement rate was 0.605 ± 0.110 km/d during decreasing river flow and 0.378 ± 0.195 km/d during increasing river flow, a difference that was not significant ($t = 1.03$, df = 15, $P = 0.322$). We also found no differences between upstream and downstream movement rates during increasing river flow ($t = 1.89$, df = 13, $P = 0.082$) or decreasing river flow ($t = 0.557$, df = 9, $P = 0.591$).

We successfully characterized 122 locations as occurring in BW lake, MC, and SC areas. Locations in MCs were most prominent (50%), followed by those in SCs (33%) and BW lakes (17%). The BW lake locations were only recorded in 2004 and only for three fish.

Diurnal Observations

We observed eight individuals over two 24-h periods for a total of 41 observations. Attempts to locate more individuals failed because of fish dispersing. Two individuals were repeatedly located on June 8, 2004, and six were located on June 22, 2004. Three individuals were ultimately excluded from analysis, as they did not move after initial location, remained unmoving after diurnal observations, and were presumed to have died or expelled their transmitters. Mean (±SE) rate of movement was 0.286 ± 0.103 km/h and the maximum rate of movement was 2.74 km/h for a fish in the MC, whereas all other individuals ($n = 4$) were located in a BW lake during the diurnal study. Mean water temperature was similar for both dates at 23.7 ± 0.057°C. Movement rates were significantly higher ($t = 3.66$, df = 4, $P = 0.021$) during the day (0600–1800 hours) than at night (1800–0600 hours; Table 2), and movement rates decreased from day to night by an average of 48.5% (range = 15.6–84.3%).

Discussion

While the mean movement rate for adult bighead carp was 1.7 km/d, 35% of our analyzed individuals had movement rates ranging from 3 to 14 km/d. One individual moved 163 km in 5 weeks. These results contrast the findings of Konagaya and Cai (1987), who observed only slow, localized movements, and indicate that bighead carp adults are capable of rapidly expanding their range, specifically in the spring and summer months. Downstream movement rates were 0.50 km/d higher than upstream movement rates and, as there was no difference between upstream and downstream movement rates occurring at high and low river flows, we attribute the difference to bighead carp swimming faster with the current. While we expected higher movement rates during increasing flows, we were only able to show a peak in weekly mean movement rates during increasing river flows, which may have been the result of only a few individuals moving at higher rates. The peak in weekly movement rates occurred during late spring and early summer and may have been the result of spawning migrations as discussed in past literature (Verigin et al. 1978; Jennings 1988), although our small sample size prevents us from making this conclusion. In addition, Schrank (1997) found that temperatures above 22°C and high levels of discharge (>2,700 m^3/s) were correlated with spawning events in the Missouri River, as indicated by the presence of larval bighead carp. For both years of our study, temperatures were above 22°C and river flows were peaking. We also observed multiple pairs of bighead carp spawning at the confluence of the Mackinaw and Illinois rivers on June 2, 2004. While our diurnal observations showed significantly higher movement rates of bighead carp during the day than at night, we recognize that a larger sample size is needed before solid conclusions about diurnal behavior patterns of bighead carp can be made.

As this study is one of the first radiotelemetry studies on bighead carp, there were some problems encountered. First, 43% of all implanted fish were presumed dead or to have expelled a transmitter. Despite efforts to locate a strong signal on or close to shore, no fish or transmitters were recovered. The exact cause of death or expelled transmitter is unknown, though past research has shown that implantation in warm water can cause high rates of infection and mortality (Knights and Lasee 1996; Bunnell and Isely 1999; Walsh et al. 2000). There is also a distinct possibility that, while best practices were used, bighead carp may be more sensitive than other species to the handling and surgical procedures used. Further examination of the effects of transmitter implantation on bighead carp, including the effects of temperature, is warranted to reduce transmitter and fish loss in future studies.

Second, the number of successful fish locations decreased through time. The habitat complexity (i.e., numerous backwaters, ditches, tributaries, and SCs) within the LaGrange Reach made it logistically difficult to explore all areas. It is apparent that one search team using only one or two search methods is not sufficient for following the movements of bighead carp in a large, open river system. Therefore, to fully understand the movements of bighead carp and other highly mobile species in the future, multiple observers and tracking methods are recommended. It may also be pertinent to conduct similar studies using a multiagency approach, similar to the Mississippi Interstate Cooperative Research Association. This is especially true in river systems that span multijurisdictional, interstate, and international boundaries.

Third, use of radiotelemetry for fish locations has several known disadvantages. Water conductivity and fish depth can severely impact location success, as can landscape and underwater obstructions, boat motor noise, and airplane engine noise (Stasko and Pincock 1977; Gilmer et al. 1981; Otis and Weber 1982; Winter 1996). In addition, the maximum distance traveled as observed by airplane was over two times greater than that observed by boat, which further stresses the need for using more than one search method to successfully obtain locations of actively moving species.

Despite the aforementioned problems, valuable movement data were collected that represent the first quantification of bighead carp movements in the United States. Our study clearly shows that bighead carp movements are highly variable and not necessarily slow and localized. Finally, the fact that bighead carp continue to spread emphasizes the need for better prevention methods and management plans for areas into which these fish are likely to move in the future.

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