HABITAT SELECTION AND MOVEMENT OF BIGHEAD CARP AND SILVER CARP IN THE LOWER ILLINOIS RIVER

by

Kelly Lynn DeGrandchamp

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A Thesis
Submitted in Partial Fulfillment of the Requirements for the
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Department of Zoology
in the Graduate School
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THESIS APPROVAL

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Approved by:

Dr. James E. Garvey, Chair

Dr. Brooks M. Burr

Dr. Michael W. Eichholz

Graduate School
Southern Illinois University Carbondale
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To predict the impact and potential spread of introduced exotic species, we must be able to quantify their dispersal capabilities and habitat requirements. Asian carp have become an increasing nuisance in recent years in the Illinois River, a tributary of the Mississippi River, potentially competing with native species. I implanted fifty silver carp and fifty bighead carp with ultrasonic transmitters during 2004 to quantify their macrohabitat use and their rate and extent of movement in the lower Illinois River (Rkm 130 to Rkm 0) during 2004 and 2005. Movement between Rkm 115 to Rkm 3 was continuously monitored with stationary receivers (N=9), and supplemented with intensive mobile tracking during the spawning season. Movement was associated with the rise and fall of river stage during the spawning season of both years. Mean km/day for bighead carp and silver carp was quantified for both species (bighead carp 6.8 km/day, silver carp 10.6 km/day), demonstrating that these species disperse widely. Available habitat was quantified to determine selection, and discriminant function analysis was used to describe microhabitat changes within macrohabitats between years. Both species preferred channel borders during low water periods, and island side channels during low and high water years. Both species were rarely

found in water > 4 m, and avoided main channel habitat during low water. Bighead and silver carp also selected for specific abiotic factors within macrohabitat types during low and high water years, with silver carp showing more sensitivity to abiotic factors than bighead carp. Identifying habitat areas that both species prefer will facilitate management plans to target them for harvest, and determining characteristics of these preferred habitats will aid in predicting future establishment.

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CHAPTER ONE

USING HABITAT SELECTION TO PREDICT ESTABLISHMENT OF INVASIVE ASIAN CARPS IN A LARGE RIVER

ABSTRACT

To predict the impact and potential spread of introduced exotic species, we must be able to quantify their habitat requirements. Asian carp have become an increasing nuisance in recent years in the Illinois River, a tributary of the Mississippi River, potentially competing with native species. I implanted fifty silver carp and fifty bighead carp with ultrasonic transmitters during 2004 to quantify their macrohabitat use in the lower Illinois River (Rkm 130 to Rkm 0) in 2004 and 2005. Tracking was weekly during the spawning season and intermittent during fall through winter. Available habitat was quantified to determine selection, and discriminant function analysis was used to describe microhabitat changes within macrohabitats between years. Both species preferred channel borders during low water periods, and island side channels during low and high water years. Both species were rarely found in water > 4 m, and avoided main channel habitat during low water. Bighead and silver carp also selected for specific abiotic factors within macrohabitat types during low and high water years, with silver carp showing more sensitivity to abiotic factors than bighead carp. Identifying habitat areas that both species occupy will facilitate management plans to target them for harvest, and determining characteristics of these preferred habitats will aid in predicting future establishment.

INTRODUCTION

Many nonindigenous species are successful invaders because they possess life history traits of r-selected species, generally exhibiting rapid growth rates, short generation times, exceptional dispersal capabilities, high reproductive output early in life, high abundance in their original range, and broad environmental tolerance (Ehrlich 1984; Lodge 1993). These opportunistic characteristics allow them to reach massive population numbers soon after establishing (Lodge 1993; Williamson 1996; McMahon 2002). A conservative estimate of the environmental damage and economic losses that nonindigenous fish species incur in the U.S. exceeds $1 billion annually (Pimentel et al. 2000). Riverine systems are especially vulnerable to invasions and aid in facilitating further invasions due to their broad range and high connectivity with other water bodies. Two species of Asian carp, bighead carp (*Hypophthalmichthys nobilis*) and silver carp (*H. molitrix)*, have become well established in the Mississippi and Illinois River systems exhibiting exponential population growth in recent years (Koel et al. 2000).

Species invasions threaten the biological integrity of river ecosystems. Presently, at least 536 unique fish taxa have been introduced outside their native range into U.S. waters, and all 50 states have nonindigenous fish in their open waters (Fuller et al. 1999). Known impacts of these introductions include habitat alterations, competition with native species, hybridization, and overcrowding (Taylor et al. 1984). Rahel (2000) argued that introductions of species play a greater role than extirpations in homogenizing fish faunas. Further, no unintentional aquatic introductions have been considered beneficial (Steirer 1992). The unintentional introduction of bighead carp and silver carp into the Mississippi River drainage in the early 1980's (Freeze & Henderson 1982; Costa-Pierce 1992) is no

exception, raising concerns about their impact on native species. Currently, bighead carp are present in 19 states, and silver carp occur in 12 states (Fuller et al. 1999). Both species have become ubiquitous in the Illinois River, a tributary of the Mississippi River, presenting potential problems of resource competition with native species (Schrank et al. 2003).

Using ultrasonic telemetry, we quantified habitat preference of both species in the lower reach of the Illinois River and one of its major backwaters, the 1,100 ha Swan Lake. The Illinois River is a large, impounded river that is a tributary of the Mississippi River. Swan Lake has been restored by the U.S. Army Corps of Engineers Mississippi River Environmental Management Program, through its Habitat Restoration and Enhancement Projects, to reduce sedimentation rates and to enhance fish production. The lake was separated into three management compartments by levees to form Lower Swan Lake, Middle Swan Lake, and Upper Swan Lake (Fuller Lake). Lower Swan Lake comprises nearly half the area, and is the only compartment continuously connected with the Illinois River to facilitate fish passage. Middle Swan Lake becomes connected with the river and Lower Swan Lake during flooding.

I hypothesized that habitat selection could be related to foraging or reproductive needs of these species. Although both species diets can vary with life stage and environmental conditions, it is widely accepted that bighead carp primarily feed on zooplankton, while silver carp primarily forage on phytoplankton (Jennings 1988; Costa-Pierce 1992). Williamson and Garvey (2005) found phytoplankton to be most abundant in diets of Middle Mississippi River silver carp. Therefore, changes in abundance or availability of food resources may influence habitat selection. Abiotic factors facilitating

or inhibiting primary production in this system would in turn influence selection of habitat.

Spawning needs may also play an important role in habitat use. Reproductive needs of bighead and silver carp are similar and have been documented as requiring water temperatures of at least 17º C, with an optimum range of 21 – 26ºC (Verigin et al. 1978; Krykhtin and Gorbach 1981; Abdusamadov 1987; Jennings 1988), and a rise in water velocity with a minimum of 0.7 m/s (Krykhtin and Gorbach 1981; Abdusamadov 1987). Gorbach and Krykhtin (1980) documented the minimum length of spawning river for silver carp to be 100 km. The length of river and swift current required serves to prevent their bathypelagic eggs from sinking and being covered with silt (Soin and Sukhanova 1972; Rothbard 1981). Bighead carp have been observed spawning at the confluences of rivers or behind sandbars, stonebeds, and islands (Huet 1970), and a Missouri River study found that increased water discharge and a temperature of 22°C initiated spawning (Schrank et al. 2001). Specific spawning habitat requirements would also influence spatial selection.

This study is one of the first to quantify habitat use of these exotic species, and to gain insight into individual behavior. An understanding of what habitat these fish are using and what influences selection of that habitat is essential for predicting conditions for their establishment, and diagnosing their potential impact on other species.

METHODS

Study Site

The lower Illinois River extends between the La Grange Lock and Dam (River kilometer, Rkm 130) at Beardstown, Illinois to the confluence of the Mississippi River (Rkm 0) at Grafton, Illinois. Lower Swan Lake is located at the lower end of the reach, near the confluence at Grafton, Illinois (Rkm 8). This reach of river is free flowing, but has been channelized for navigation. Despite a century of alterations due to dredging, water diversion from Lake Michigan, channelization, and levee construction, the river still retains its annual flood pulse (Karr et al. 1985; Sparks 1995). Species richness is higher in the lower Illinois River than the upper half of the river (Pegg & McClelland 2004), because the lower river is geologically older with a low gradient, characterized as an alluvial floodplain (Starrett 1971).

Surgical Procedure

Ultrasonic transmitters (69 kHz; 10 g in water and 65 mm in length; V16, Vemco Ltd., Nova Scotia, Canada) for remote individual identification were surgically implanted into fish of both species during spring 2004 through spring 2005. During spring 2004, twenty-five bighead carp and twenty-five silver carp were tagged with transmitters. During fall 2004, an additional fifteen fish from each species were tagged. During spring 2005, another ten individuals within each species were tagged (50 total each species).

Ultrasonic transmitters were less than 2% of body weight (Winter 1996). Tagged fish were ≥ 500 mm total length (TL). The first 50 transmitters implanted into fish in the spring of 2004 had a minimum life expectancy of 570 days. The remaining 50

transmitters (fall 2004 and spring 2005) had a minimum life expectancy of 366 days. Each transmitter was tested for recognition prior to its use with a portable hydrophone and receiver (Vemco Model VH11 hydrophone, and Vemco Model VR60 receiver, respectively).

Tagged fish were collected either from the lower Illinois River, in the vicinity of Swan Lake, or from Lower Swan Lake. Trammel netting (experimental nets of 51 mm, 76 mm, 102 mm and 89 mm bar mesh panels; 3.7 m, 4 m, 4.3 m and 4 m outer wall respectively; 91.4 m in length) was the primary method of capture, but hoop nets (38 mm bar mesh, 1 m diameter fiberglass hoops), trap nets, commercial fishers, electrofishing, and fish jumping into the boat were also sources of fish. Mean length and weight of tagged bighead carp were 774 mm ± 6 (SE) and 5657 g ± (SE). Total lengths ranged from 665 – 865 mm, and weights ranged from 3200 – 9500 g. Mean length and weight of tagged silver carp were 740 mm ± 13 (SE) and 5024 g ± 264 (SE). Total lengths ranged from 538 – 954 mm, and weights ranged from 1800 – 8250 g.

The fish were moved to a holding tank with buffered (sodium bicarbonate) river water and carbon dioxide (CO_2) gas was diffused into the tank for anesthetization (Summerfelt and Smith 1990). When fish reached stage 3 (the partial loss of equilibrium; Summerfelt and Smith 1990), they were measured (total length, TL, mm), weighed (kg), and placed in a V-board. River water was circulated over their gills. Scales were removed from the ventral left area of the fish, posterior to the pelvic fin and anterior to the anal opening. For the silver carp, the surgical incision was made further dorsally to account for the displacement of the body cavity due to the well-developed ventral keel.

After the removal of scales, the area was disinfected with betadine. All surgical utensils were sanitized in 70% ethanol.

A scalpel (no. 22) and curved hemostats were used to insert the tag and avoid damage to organs. The transmitter was pushed down and away from the incision site to alleviate any added stress on the wound. Incisions were closed with Ethilon® monofilament suture material attached to a FS-2 curved cutting needle using 5 to 7 simple interrupted sutures, as documented by Summerfelt and Smith (1990). The incision and sutures were also sealed with cyanoacrylate resin to prevent infection and to hold the wound and suture knots together securely. Immediately following the surgical procedure, fish were placed in a recovery tank supplemented with oxygen. After the fish regained control of buoyancy and orientation, they were released at the capture site. Fish were only released if they were able to swim independently. Fish that were found less than twice were excluded from habitat preference analysis. Habitat preference analysis was conducted on fish during the spring and summer of both years, which was considered the spawning season for Asian carp.

Tracking

Fish were tracked using a boat with a Vemco hydrophone and receiver. Each fish location was georeferenced. At each fish location, depth (m), water temperature (ºC at 1 m depth; YSI Model 85 Dissolved Oxygen Meter; Yellow Springs Instruments, Yellow Springs, Ohio, USA), dissolved oxygen (D.O.; mg/L at 1 m depth; YSI 85), water velocity (m/s at 1 m depth; Flo-Mate Model 2000 Velocity Meter; Marsh-McBirney, Inc., Fredrick, Maryland, USA), turbidity (NTU; Orbeco-Hellige Model 966 Portable

Turbidimeter; Orbeco Analytical Systems, Inc., Farmingdale, New York, USA), and sediment structure were quantified. The site was described qualitatively. Sediment was sampled from the bottom of the river channel using a stainless steel Petite Ponar Grab (2.4 L volume; Wildlife Supply Company, Buffalo, New York, USA). Sediment was classified by dominant material (clay, silt, sand, gravel, organic material).

Tracking intensity differed seasonally and among locations. In spring 2004, newly tagged fish were located two weeks after implantation between Rkm 130 to Rkm 0 and the lower and middle compartments of Swan Lake. The 130 km reach was tracked monthly during April through August (spawning season) of both years. Tracking was decreased to one entire track of the reach in the fall (October), and once more in the winter (February). Swan Lake was tracked once to twice monthly during April through August, and tracked monthly during fall and winter. Rkm 15.3 to Rkm 0 was also tracked monthly during fall 2004 through winter 2005, to monitor over-wintering activity of both species.

Statistical Analysis

I classified the lower 41 km of the Illinois River, including Swan Lake, into four macrohabitat categories: main channel; channel border; island side channel; and backwater. The proportion of available habitat was derived using digital raster graphic (DRG) topographic maps obtained from the Illinois Natural Resources Geospatial Clearinghouse (http://www.isgs.uiuc.edu/nsdihome/), ArcMap 9.0 and USACE navigation maps. Areas of the river with a depth less than 5.0 m at normal pool (NP) were classified as channel border, areas equal to and greater than 5.0 m NP were

classified as main channel, areas inside islands classified as island side channel, and Swan Lake (Lower and Middle) comprised the backwater habitat. Spring was defined as March to May, summer as June to August, fall as September to November, and winter as December to February.

Habitat preference was the likelihood that a resource will be chosen given the proportion of habitat available (Johnson 1980; Manly et al. 2002). To preserve the variation added by habitat preferences among individuals, we calculated habitat use statistics using the individual fish as the sampling unit (Otis and White 1999). Each species, season (spring and summer) and year was quantified separately. To determine habitat selection, a likelihood chi-square test was conducted to test the null hypotheses: $H_0(1)$ fish locations of each species were uniformly distributed so that fish were using the available habitat in a similar way, and $H_0(2)$ the proportion of habitat used was equal to the proportion of habitat available. To test the first null hypothesis, whether fish are using habitats in a similar fashion, we used the equation presented by Manly et al. (2002) if: u_{ij} = the amount of habitat type i used by fish j; u_{i+} = the amount of type i habitat used by all fish; u_{+j} = the total amount of habitat units used by fish j; and u_{++} = the total number of habitat units used by all fish, then the log-likelihood test statistic is

$$X_{L1}^2 = 2\sum_{j=1}^{n}\sum_{i=1}^{I} u_{ij} \ln (u_{ij} / (E\, u_{ij}))$$

where $E(u_{ij}) = u_{i+}u_{+j}u_{++}$. If the resulting value, with $(I - 1)(n - 1)$ degrees of freedom (where I = number of habitat categories and n = number of fish), is large compared to the chi-square distribution, then there is evidence that fish are using the habitats differently (Manly et al. 2002). A significant p-value ($\alpha = 0.05$) allows one to conclude that fish are using the habitat differently.

To determine whether individual fish were selecting or avoiding specific habitat types (second null hypothesis), Manly et al. (2002) proposed the use of the same log-likelihood test statistic, but now $E(u_{ij}) = \pi_i u_{+j}$, with π_i = the proportion of the population of available units in habitat type i. In this case, selection or avoidance is established if the chi-square is large with $n(I - 1)$ degrees of freedom. A significant p-value determines if the fish are selective in their habitat choice. The difference between the two chi-square values describes, on average, if fish are using the specific habitat types in proportion to their availability (Manly et al. 2002). A significant p-value indicates selection for a specific habitat type.

Once selection was demonstrated, a selection ratio was used to determine the selected habitat type. Since I was interested in the population as a whole, with species per season per year as a population, Manly et al. (2002) estimated the ratio to be $\hat{W}_i = (u_{i+}) / (\pi_j u_{++})$. This selection ratio, designated as $\hat{W}i$, is a measure of the proportion of habitat used over the proportion of habitat available. These selection ratios demonstrate a selection for a certain habitat type with values above 1, while avoidance of a certain habitat type is demonstrated by values below 1, with values equal to 1 exhibiting neutral selection. The population as a whole determines the selection ratio, but variation from each fish is incorporated (Manly et al. 2002). Bonferroni confidence intervals around this ratio ensure the probability of all intervals containing their true parameter values (Thomas and Taylor 1990), so only values with 95% confidence intervals completely within the bounds of a selection range indicate true selection or avoidance. Confidence intervals resulting in negative prediction values were replaced with 0.0 (Manly et al.

2002). Pearson correlation was conducted to test the relationship between bighead and silver carp habitat selection ratios.

To determine how the microhabitat characteristics chosen by fish within each of the four macrohabitats changed through time, discriminant function analysis (DFA) was conducted on four habitat variables (depth, velocity, temperature, and dissolved oxygen) for both species, and then for each species individually. DFA was conducted to account for the different water level conditions present among years, with the high water of 2004 (flood year) and the low water of 2005 (drought). Observations that included a value for all 4 habitat variables were included in the analysis (N=386 observations). Habitat analyses were conducted for both species combined, with groups defined by year (2004 or 2005), season (spring or summer), and habitat type (backwater, main channel, channel border, or island side channel). To determine if there was a species effect, a second DFA was conducted for bighead and silver carp separately. Four discriminant functions were generated for each DFA; the first two were retained in each analysis because they accounted for most of the variance. A structure matrix, where the correlation between each variable and each discriminant function determined the differences between macrohabitat types, ranked habitat variables. All statistical analyses were conducted with SPSS 13.0 (Chicago, IL, USA) and SAS 9.1 (SAS Institute 1996).

RESULTS

Data for 35 silver carp and 45 bighead carp were retained for habitat use analyses. The remaining were never located or lost. The habitat of the lower 41 km was classified into four macrohabitat categories with the percentage of total habitat available: main

channel (28.72%); channel border (41.13%); island side channel (7.08%); and backwater (23.1%).

Bighead carp used habitats differently in all seasons, with the exception of summer 2005, and showed an overall pattern of habitat use in all seasons (Table 1). The Bonferroni confidence intervals around the selection ratios for bighead carp in spring 2004 did not indicate true selection or avoidance for any habitat type (Figure 1). Bighead carp in summer 2004 avoided backwater and main channel habitat (Figure 1). Bighead carp avoided main channel habitat in spring 2005 (Figure 1). Bighead carp selected for channel border habitat, and selected against backwater and main channel habitat in summer 2005 (Figure 1). Bighead carp avoided backwater and main channel in the summer of both years.

Silver carp used habitats differently in all seasons except for spring 2005, and showed a pattern of selection or avoidance in all seasons (Table 1). The Bonferroni confidence intervals around the selection ratios for spring 2004 silver carp did not indicate true selection or avoidance for any habitat type (Figure 2). No selection or avoidance was evident visually for silver carp in summer 2004 (Figure 2). Silver carp avoided main channel habitat and selected for channel border habitat in spring 2005 (Figure 2). Silver carp avoided both backwater and main channel habitat in summer 2005 (Figure 2).

Bighead and silver carp habitat selection patterns were similar. Both species avoided main channel and backwater habitat during low water, favoring channel borders. Use of island side channels varied widely among individuals in the spring and summer of both years, with habitat selection ratios being positively correlated ($r = 0.60$, $p=0.01$).

The DFA correctly classified grouped cases 89.5% of the time for backwater habitat; 76.2% for main channel habitat; 75.1% for channel border habitat; 82.0% for island side channel habitat, suggesting separation between macrohabitat types. The first discriminant function (F1) ranked depth and velocity as explaining 45.9% of the variance; the second discriminant function (F2) ranked temperature and dissolved oxygen as explaining 38.3% of the variance (84.2% cumulative variance). Summer habitat types were associated with higher temperatures with lower D.O. concentrations, while spring habitat types were associated with cooler temperatures with higher D.O. concentrations (Figure 3). Backwater habitat was shallow with low velocities in both years (Figure 3). Channel border and island side channel habitat types of each season were clustered, indicating characteristics of these macrohabitat types were similar (Figure 3). Channel border habitat was slightly shallower and had slower velocities than island side channels during spring and summer of both years (Figure 3). Main channel habitat was consistently deeper with relatively faster water velocities in both years (Figure 3). The proximity of centroids for each group (macrohabitat type, season, and year) indicates that similar conditions were selected despite markedly different water level conditions between 2004 and 2005 (Figure 3).

The DFA correctly classified individual species habitat selection 58.6% of the time for bighead carp, and 57.9% of the time for silver carp. For bighead carp, the first discriminant function (F1) ranked depth and velocity as explaining 46.2% of the variance; the second discriminant function (F2) ranked temperature and dissolved oxygen as explaining 36.3% of the variance (82.4% cumulative variance). For silver carp, the first discriminant function (F1) ranked depth and velocity as explaining 51.3% of the

variance; the second discriminant function (F2) ranked temperature and dissolved oxygen as explaining 35.2% of the variance (86.5% cumulative variance). The abiotic factors selected by bighead and silver carp were similar within seasons and among species (Table 2). Although patterns in macrohabitat and microhabitat use were similar for both species, silver carp showed tighter clustering in microhabitat use (Figure 5) than bighead carp (Figure 4).

DISCUSSION

Distributions of bighead and silver carp in the lower Illinois River were not uniform, with adults actively selecting and avoiding macrohabitats seasonally. Different water conditions between years produced different microhabitat conditions within macrohabitats, yet both species shifted their position to meet the same specific microhabitat criteria between years. Within macrohabitats, locations of bighead and silver carp were influenced by abiotic factors, specifically depth, temperature, velocity, and D.O., and these preferences changed temporally, but were largely congruent between species. Silver carp appeared to be more selective for abiotic conditions.

Foraging

The consistent avoidance of the main channel by both species during periods of low water may have been related to seasonal abundances of plankton. Chlorophyll *a* is positively associated with bighead and silver carp in the middle and upper Illinois River (K. Stainbrook, INHS, personal communication). Silver carp in the Middle Mississippi River have been shown to use low velocity structures, such as wing dikes, and were

likely to consume high phytoplankton production behind these structures (Williamson and Garvey 2005). The Illinois River is highly productive for plankton; the main channel has especially high densities during high water periods (Dettmers et al. 2001). Zooplankton densities increased after the inundation of backwater lakes and side channel habitats (Goodrich 1999), suggesting that zooplankton are washed out of these areas and into the main channel of the Illinois River. The main channel of the lower Illinois River contained higher zooplankton densities in the spring and summer of 2004 when high water was present than in the drought of 2005 (Csoboth et al. 2006). Bighead and silver carp used the main channel more during the high water year when plankton were likely abundant and productive. Without the flood pulse in 2005 to supply the main channel with plankton, bighead and silver carp preferred channel border habitat.

Reproduction

Reproductive activity of bighead and silver carp may rely on available spawning habitat, and therefore affect the spatial distribution of both species. Spawning habitat criteria for both species were met in 2004 with the high water level conditions, but not in 2005 due to a lack of a sharp rise in river stage. Lack of available spawning habitat could also have been driving the habitat selection of bighead and silver carp both years. However, both species are broadcast spawners that spawn in large aggregations (Verigin et al. 1999), and reproductive requirements are mostly dependent on water temperature and velocity. Therefore, the shifts in spatial selection demonstrated by both species coinciding with shifts in abiotic variables were most likely due to foraging.

Management Implications

Bighead and silver carp should be able to establish and thrive in a variety of systems because of their apparent generalist macrohabitat requirements. Their preferences for areas that overlap many native and larval fish habitat create potential problems for native species through competition for food and space (Schrank et al. 2003). In a recent survey of the Illinois River, channel border habitat was used by 67 fish species (including 9 nonnative species and 3 nonnative hybrids; Bartels et al. 2004), a habitat type used frequently by both bighead and silver carp during all seasons. Individuals of both species were also often closely associated with rare island side channels, highlighting a potentially important role in the life history of both species. The large range of variance displayed by bighead and silver carp around these areas may provide insight into the season and habitat where they can be targeted for harvest. This is especially evident during the drought year where both species displayed a true avoidance of main channel habitat, favoring side channel habitats. Management plans for biomass reduction should focus on these areas during low water years.

The annual flood pulse plays an important role in the life history of bighead and silver carp, with different water level conditions allowing us to predict preferred habitat usage. Bighead and silver carp display similar habitat selection behavior, allowing similar management plans of these species. The fact that adults of both species actively select and avoid certain macrohabitats demonstrates there are conditions for establishment, and determining characteristics of these favored habitats will allow managers to predict future establishment. Identifying specific habitat criteria for

macrohabitat selection of bighead and silver carp makes these species vulnerable to harvest by predicting areas they prefer.

Table 1. Likelihood chi-square statistics testing the distribution of Asian carp across habitat types ($H_0(1)$), and a selection or avoidance of a habitat type ($H_0(2)$). A significant p-value for the distribution test indicates fish were using habitats differently; non-significance (*n.s.*) indicates similar use of habitats. A significant p-value for the selection test indicates a pattern of habitat use.

	Distribution ($H_0(1)$)			Selection ($H_0(2)$)		
	χ^2	df	p-value	χ^2	df	p-value
Bighead carp						
Spring 2004	134.1	63	0.001	145.9	66	0.001
Summer 2004	72.2	39	0.001	106.5	42	0.001
Spring 2005	121.4	66	0.001	163.5	69	0.001
Summer 2005	48.2	36	*n.s.*	101.5	39	0.001
Silver carp						
Spring 2004	60.7	42	0.03	66.8	45	0.02
Summer 2004	49.5	33	0.03	51.5	36	0.04
Spring 2005	49.1	45	*n.s.*	65.8	48	0.04
Summer 2005	51.8	33	0.02	109.8	36	0.001

Table 2. Classification of microhabitat abiotic factors selected by bighead and silver carp in the lower Illinois River and Swan Lake during spring and summer 2004 and 2005. Depth (m), velocity (m/s), temperature (ºC), dissolved oxygen (mg/L).

Species	Season	Habitat Variable	Minimum	Maximum	Mean
Bighead	Spring	Depth	0.5	13.7	4.0
		Velocity	0.0	0.7	0.2
		Temperature	5.6	25.7	16.1
		Dissolved oxygen	3.4	19.1	9.9
	Summer	Depth	0.9	8.5	4.1
		Velocity	0.0	1.0	0.2
		Temperature	22.8	31.6	27.0
		Dissolved oxygen	2.3	13.5	6.0
Silver	Spring	Depth	0.5	8.3	3.8
		Velocity	0.0	0.6	0.2
		Temperature	5.9	26.5	17.7
		Dissolved oxygen	3.4	18.5	9.0
	Summer	Depth	0.8	9.1	3.9
		Velocity	0.0	1.2	0.2
		Temperature	21.7	32.0	27.1
		Dissolved oxygen	2.2	13.5	6.4

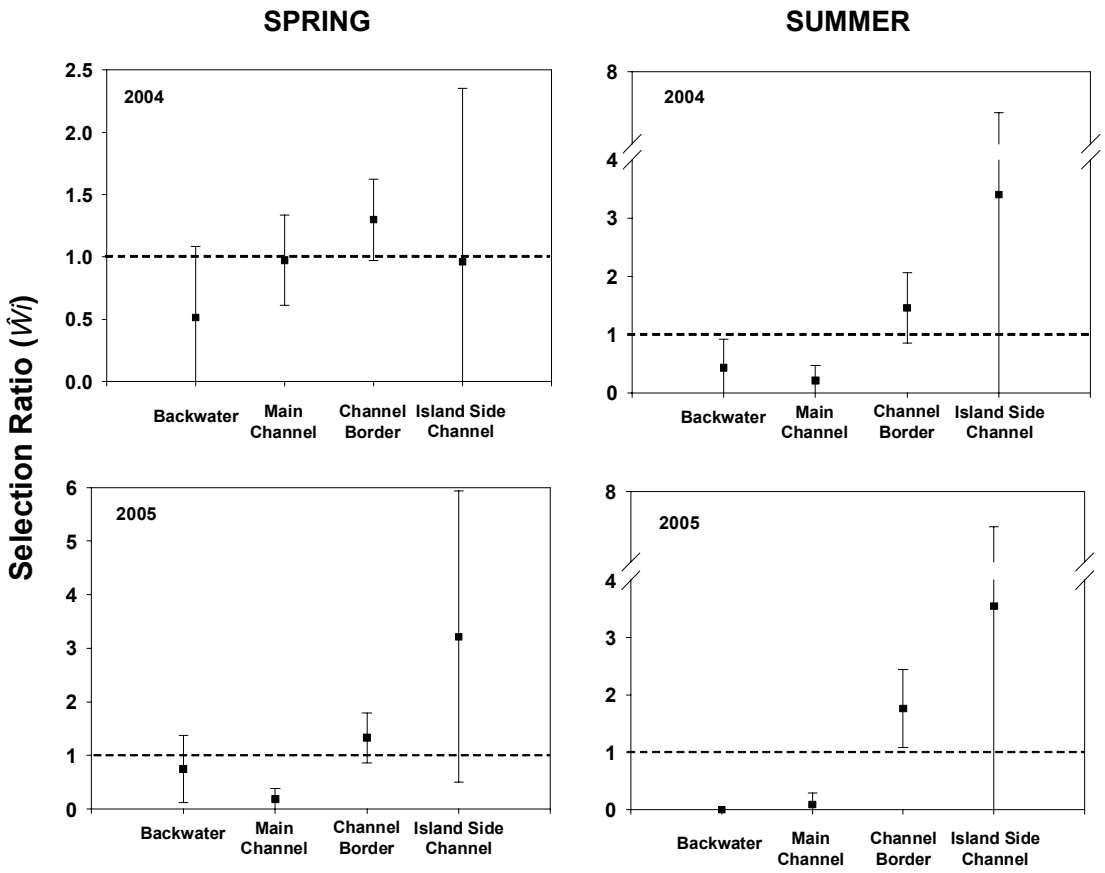

Figure 1. Mean habitat selection by bighead carp in the lower Illinois River. Dotted line equals no selection. Points above line indicate selection for certain habitat type (preference); points below line indicate selection against habitat (avoidance). Error bars are ± 95% Bonferroni confidence intervals. Spring 2004, N = 22 individuals. Summer 2004, N = 14. Spring 2005, N = 23. Summer 2005, N = 13.

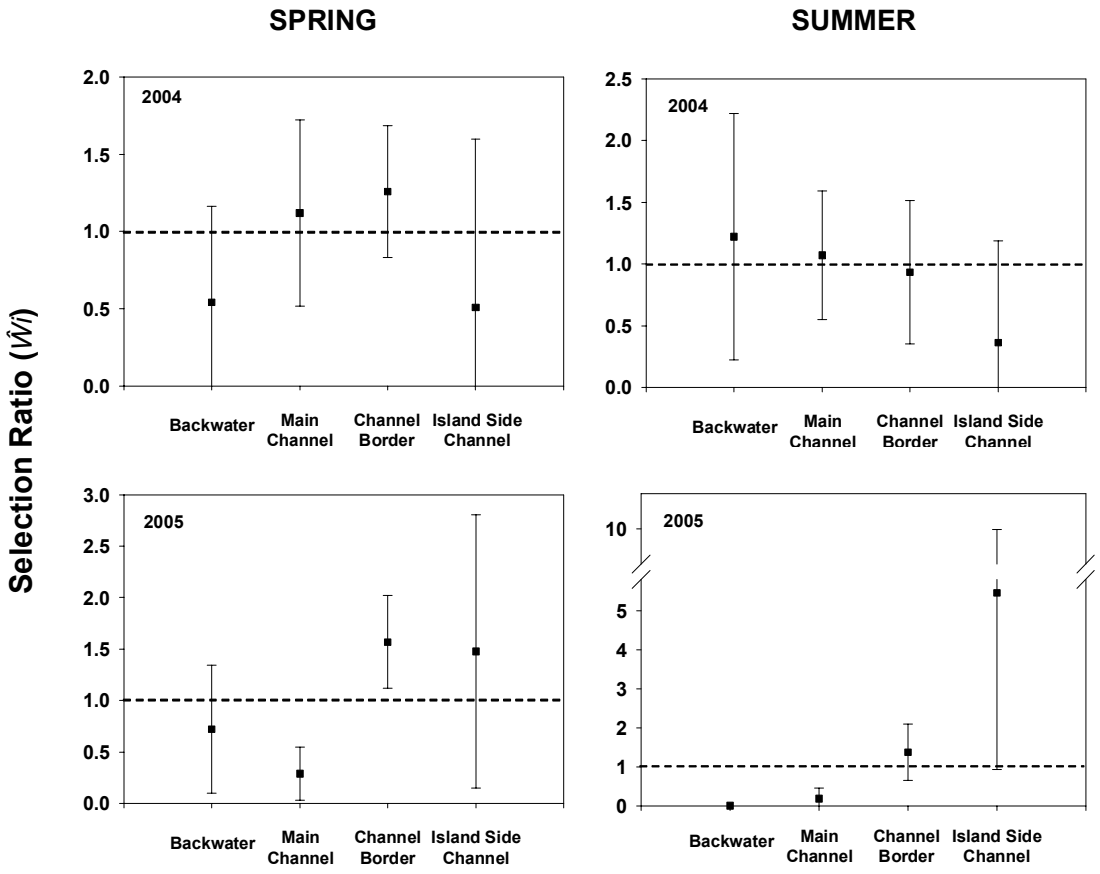

Figure 2. Mean habitat selection by silver carp in the lower Illinois River. Dotted line equals no selection. Points above line indicate selection for certain habitat type (preference); points below line indicate selection against habitat (avoidance). Error bars are ± 95% Bonferroni confidence intervals. Spring 2004, N = 15 individuals. Summer 2004, N = 12. Spring 2005, N = 16. Summer 2005, N = 12.

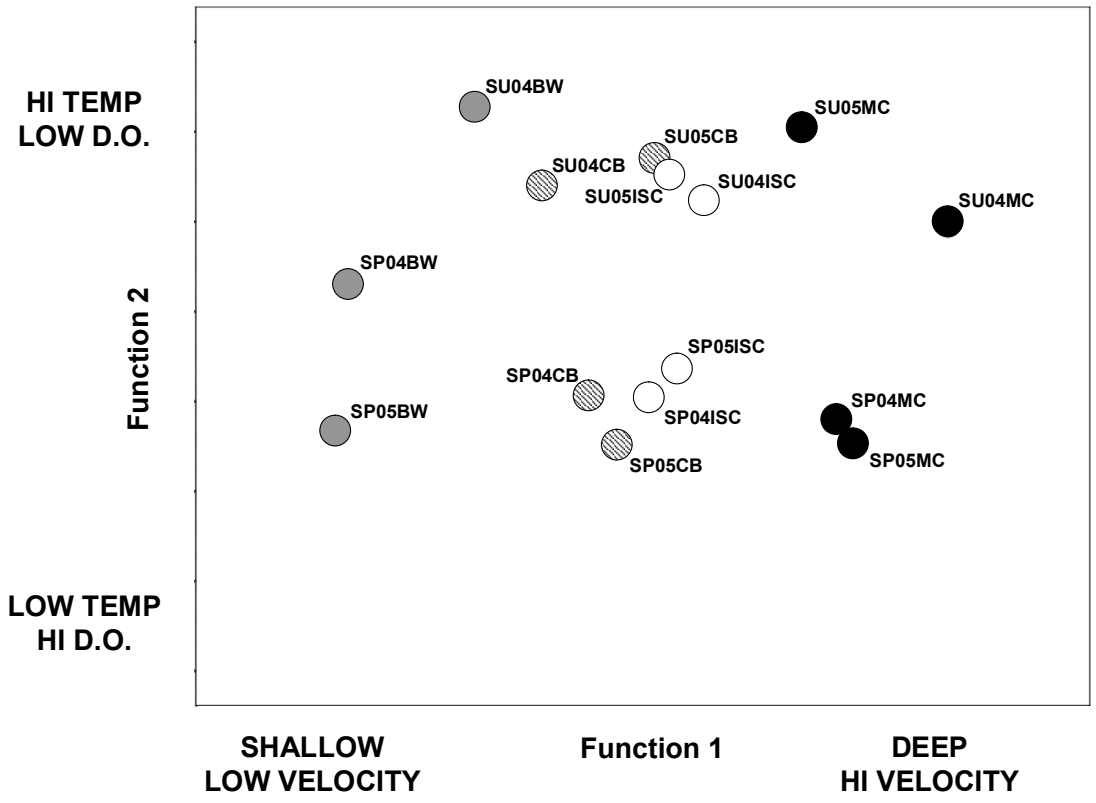

Figure 3. Discriminant function graph of four macrohabitat types in the lower Illinois River for the spring (SP) and summer (SU) of 2004 (04) and 2005 (05): backwater (BW; grey), channel border (CB; striped), island side channel (ISC; white), and main channel (MC; black). Points indicate group centroids; mean N=26 observations per centroid. N=386 observations.

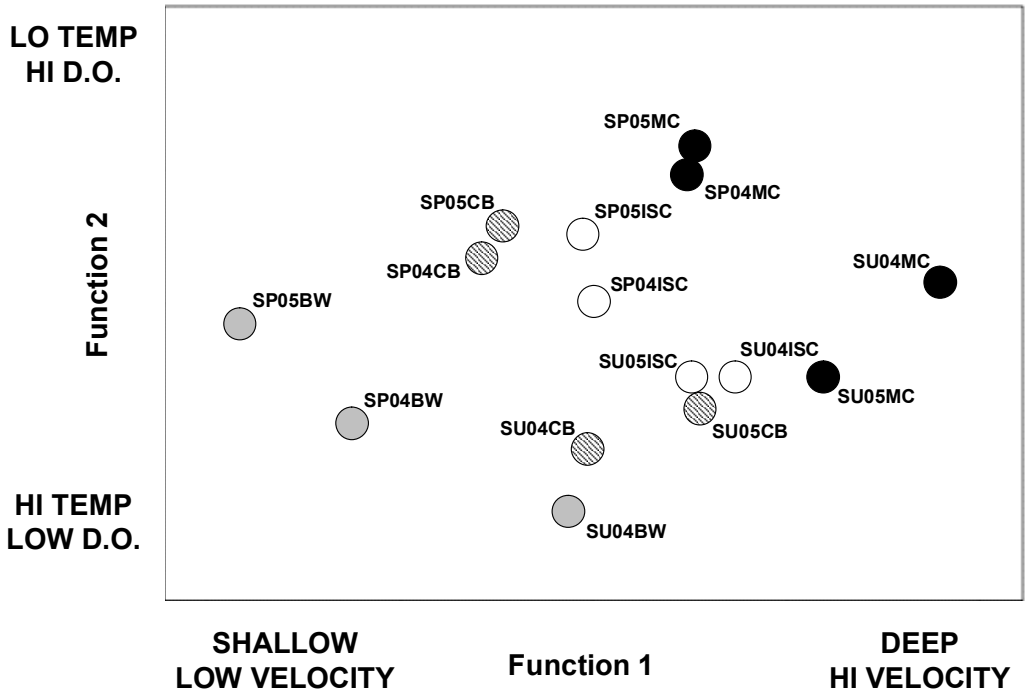

Figure 4. Discriminant function graph of bighead carp microhabitat use in the lower Illinois River for the spring (SP) and summer (SU) of 2004 (04) and 2005 (05): backwater (BW; grey), channel border (CB; striped), island side channel (ISC; white), and main channel (MC; black). Points indicate group centroids; mean N=15 observations per centroid. N=227 observations.

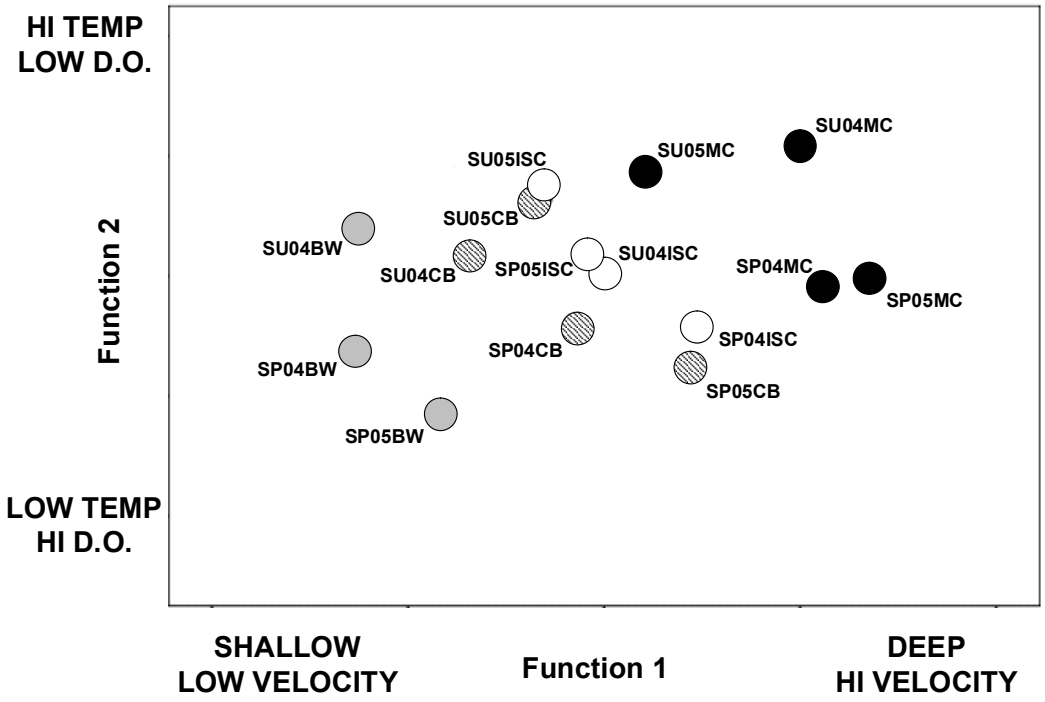

Figure 5. Discriminant function graph of silver carp microhabitat use in the lower Illinois River for the spring (SP) and summer (SU) of 2004 (04) and 2005 (05): backwater (BW; grey), channel border (CB; striped), island side channel (ISC; white), and main channel (MC; black). Points indicate group centroids; mean N=11 observations per centroid. N=159 observations.

CHAPTER TWO

MOVEMENT AND DISPERSAL OF ADULT BIGHEAD CARP AND SILVER CARP IN THE LOWER ILLINOIS RIVER

ABSTRACT

To predict the impact and potential spread of introduced exotic species, we must be able to quantify their dispersal capabilities. Asian carp have become an increasing nuisance in recent years in the Illinois River, a tributary of the Mississippi River, potentially competing with native species. I quantified the rate and extent of movement of 44 bighead carp and 41 silver carp in the lower Illinois River (Rkm 130 to Rkm 0) in 2004 and 2005. Movement between Rkm 115 to Rkm 3 was continuously monitored with stationary receivers (N=9), and supplemented with intensive mobile tracking during the spawning season. Movement was associated with the rise and fall of river stage during the spawning season of both years. Mean km/day for bighead carp and silver carp was quantified for both species (bighead carp 6.8 km/day, silver carp 10.6 km/day), demonstrating that these species disperse widely. This ability is characteristic of a species that can disperse rapidly in novel waters.

INTRODUCTION

Species invasions threaten the biological integrity of river ecosystems. Presently, at least 536 unique fish taxa have been introduced outside their native range into U.S. waters, and all 50 states have nonindigenous fish in their open waters (Fuller et al. 1999). Known impacts of these introductions include habitat alterations, competition with native

species, hybridization, and overcrowding (Taylor et al. 1984). Rahel (2000) argued that introductions of species play a greater role than extirpations in homogenizing fish faunas. No unintentional aquatic introductions have been considered beneficial (Steirer 1992). The accidental introduction of two cyprinids, bighead carp (*Hypophthalmichthys nobilis*) and silver carp (*H. molitrix)* into the Mississippi River drainage in the early 1980's after an aquaculture escapement (Freeze & Henderson 1982; Costa-Pierce 1992) have raised concern about their impact on native river species. Currently, bighead carp are present in 19 states, and silver carp occur in 12 states (Fuller et al. 1999). Both species have become ubiquitous in the Illinois River, a tributary of the Mississippi River, presenting potential problems of resource competition with native species (Schrank et al. 2003). Both bighead and silver carp have become well established in the Mississippi and Illinois River systems and their numbers have been growing exponentially in recent years (Koel et al. 2000).

Rivers have been recognized as corridors connecting patches of aquatic environments (Junk et al. 1989), and this connectivity plays an important role in facilitating the dispersal of nonindigenous species. The spread of nonindigenous species can be limited by constraints to their dispersal. The Mississippi River drainage, due to its natural connectivity with other freshwater bodies, has a relatively high number of introduced species that may result in the spread of those species to other drainages (Gido and Brown 1999). Without constraints to their dispersal, Asian carp threaten to invade connected water bodies in the Mississippi River basin.

Understanding what environmental factors serve as cues for movement and quantifying the rate of dispersal is key to developing management strategies to control

and possibly prevent future invasions of bighead and silver carp. In their native waters, a sharp rise in water levels and current velocity has been associated with spawning migrations, and shortly thereafter spawning occurs (Krykhtin and Gorbach 1981; Abdusamadov 1987). Verigin et al. (1978) documented spawning of both bighead and silver carp a few days after a sharp rise in water level, with a water temperature of 22ºC. However, it is not clear whether a rise in water levels or a rise in temperature functions as a cue for movement in North America. Although the ranges of bighead and silver carp have been increasing in recent years, rates of their dispersal have not been quantified in the Mississippi River system.

Using ultrasonic telemetry, we monitored fish of both species in the lower reaches of the Illinois River and one of its major backwaters, the 1,100 ha Swan Lake. The Illinois River is a large, impounded river that is a tributary to the Mississippi River, and is connected via the Chicago Sanitary Shipping Canal to the uninvaded lake Michigan. This study is one of the first to quantify rates of movement and dispersal of these exotic species. The objectives of this study were to (1) determine cues for bighead and silver carp movement in the lower Illinois River and (2) quantify the rate of movement for both species.

METHODS

Study Site

The lower Illinois River extends between the La Grange Lock and Dam (River kilometer, Rkm 130) at Beardstown, Illinois to the confluence of the Mississippi River (Rkm 0) at Grafton, Illinois. Lower Swan Lake is located at the lower end of the reach,

near the confluence at Grafton, Illinois (Rkm 8). This reach of river is free flowing, but has been channelized for navigation. Despite a century of alterations due to dredging, water diversion from Lake Michigan, channelization, and levee construction, the river still retains its annual flood pulse (Karr et al. 1985; Sparks 1995). Species richness is higher in the lower Illinois River than the upper half of the river (Pegg & McClelland 2004), because the lower river is geologically older with a low gradient, characterized as an alluvial floodplain (Starrett 1971). Although the health of the entire river has improved since the Clean Water Act of 1972, leading to a shift from mostly generalist species to more specialist species, the lower Illinois was much less impacted by waste disposal activities than the upper river (Thompson 2002). This led to a less impacted fish community, with the lower river acting as a source area for numerous fish species to become established in the upper river (Pegg and McClelland 2004).

During the course of this study, there was flooding of the Illinois River and its floodplains during the late spring and summer of 2004. In contrast, 2005 was a low water year that yielded slightly warmer water temperatures than in 2004.

Surgical Procedure

Ultrasonic transmitters for remote individual identification were surgically implanted into fish of both species during spring 2004 through spring 2005. Ultrasonic telemetry is normally required in environments of high water conductivity or in applications where the water depth exceeds 10 m. During spring 2004, twenty-five bighead carp and twenty-five silver carp were tagged with transmitters. During fall 2004,

an additional fifteen fish from each species were tagged. During spring 2005, another ten individuals within each species were tagged (50 total each species).

Ultrasonic transmitters (69 kHz; 10 g in water and 65 mm in length; V16, Vemco Ltd., Nova Scotia, Canada) were less than 2% of body weight (Winter 1996). Tagged fish were ≥ 500 mm total length (TL). Each transmitter was pulse-coded, which provided unique identification numbers. The first 50 transmitters implanted into fish in the spring of 2004 had a minimum life expectancy of 570 days. The remaining 50 transmitters (fall 2004 and spring 2005) had a minimum life expectancy of 366 days. Each transmitter was tested for recognition prior to its use with a portable hydrophone and receiver (Vemco Model VH11 hydrophone, and Vemco Model VR60 receiver, respectively).

Tagged fish were collected either from the lower Illinois River, in the vicinity of Swan Lake, or from Lower Swan Lake. Trammel netting (experimental nets of 51 mm, 76 mm, 102 mm and 89 mm bar mesh panels; 3.7 m, 4 m, 4.3 m and 4 m outer wall respectively; 91.4 m in length) was the primary method of capture, but hoop nets (38 mm bar mesh, 1 m diameter fiberglass hoops), trap nets, commercial fishers, electrofishing, and fish jumping into the boat were also sources of fish.

The fish were moved to a holding tank with buffered (sodium bicarbonate) river water and carbon dioxide (CO_2) gas was diffused into the tank for anesthetization (Summerfelt and Smith 1990). When fish reached stage 3 (described as the partial loss of equilibrium; Summerfelt and Smith 1990), they were measured (total length, TL, mm), weighed (kg), and placed in a V-board. River water was circulated over their gills. Scales were removed from the ventral left area of the fish, posterior to the pelvic fin and anterior to the anal opening. For the silver carp, the surgical incision was made further

dorsally to account for the displacement of the body cavity due to the well-developed keel. After the removal of scales, the area was disinfected with betadine. All surgical utensils were sanitized in 70% ethanol.

A scalpel (no. 22) and curved hemostats were used to insert the tag and avoid damage to organs. The transmitter was pushed down and away from the incision site to alleviate any added stress on the wound. Incisions were closed with Ethilon® monofilament suture material attached to a FS-2 curved cutting needle using 5 to 7 simple interrupted sutures, as documented by Summerfelt and Smith (1990). The incision and sutures were also sealed with cyanoacrylate resin to prevent infection and to hold the wound and suture knots together securely. Immediately following the surgical procedure, fish were placed in a recovery tank supplemented with oxygen. After the fish regained control of buoyancy and orientation, they were released at the capture site. Fish were only released if they were able to swim under their own power.

Mean length and weight of tagged bighead carp were 774 mm ± 6 (SE) and 5657 g ± (SE). Total lengths ranged from 665 – 865 mm, and weights ranged from 3200 – 9500 g. Mean length and weight of tagged silver carp were 740 mm ± 13 (SE) and 5024 g ± 264 (SE). Total lengths ranged from 538 – 954 mm, and weights ranged from 1800 – 8250 g. Movement analysis was conducted on fish during the spring and summer of both years, which was considered the spawning season for Asian carp.

Tracking

Fish were tracked using a boat with a Vemco hydrophone and receiver. Each fish location was georeferenced. Tracking intensity differed seasonally and among locations.

In spring 2004, newly tagged fish were located two weeks after the implantation between Rkm 130 to Rkm 0 and the lower and middle compartments of Swan Lake. The 130 km reach was tracked monthly during April through August (spawning season) of both years. Tracking was decreased to one entire track of the reach in the fall (October), and once more in the winter (February). Swan Lake was tracked once to twice monthly during April through August, and tracked monthly during fall and winter. Rkm 15.3 to Rkm 0 was also tracked monthly during fall 2004 through winter 2005, to monitor over-wintering activity of both species.

Stationary receivers (Vemco VR2 Single Channel Monitoring Receiver) were also used to track fish locations in the river, as well as fish movement events. In November 2004, receivers were enclosed in steel tubing that was welded to navigation buoys and placed in the main channel of the Illinois River adjacent to the main navigation channel. Buoys were painted yellow and deployed at the following river kilometers (approximately every 16 kilometers): Rkm 3.2, 22.7, 36.4, 50.7, 67.4, 84.5, and 100.4. In addition, two stationary receivers were located on each side of the Lower Swan Lake channel to document movements in and out of Swan Lake. These receivers were mounted on submerged concrete stands. Stationary receivers were checked and downloaded every three weeks to ensure functionality and data retention of the device.

Statistical Analysis

All UTM coordinates of fish locations were mapped using ArcMap, and SAS v9.1 was used to calculate distances between successive individual fish locations. Fish that were detected either by mobile tracking or by stationary receivers at least once in 90 days

were included in movement analysis. Distance between locations was measured as the shortest linear distance through water between successive fish locations, and therefore probably underestimated the actual distance traveled by individual fish. Movement of bighead and silver carp was determined by quantifying a mean km/week moved for each species in the spring and summer of 2004 and 2005. Mean daily water temperature was obtained at Rkm 34.6 with a submerged temperature logger (Vemco Minilog Temperature Data Logger). Daily river stage was obtained from the US Army Corps of Engineers, St. Louis District, river gage at Rkm 34.6.

Pearson correlation was used to test the relationship between mean weekly movement estimates and river stage levels and temperature. Bighead carp movement rates tested for correlative relationships with temperature and river stage were estimated during March 7 through September 4, 2004, and during March 6 through August 6, 2005. Silver carp movement rates were estimated during March 21 through August 21, 2004, and during March 20 through August 6, 2005. A mean was taken for distance traveled by each fish in a 14-day period.

In addition, a daily rate of movement (km/day) was quantified for individual fish during the spring and summer of both years, and a mean daily rate of movement was quantified for each species. The deployment of stationary receivers in late 2004 led to an increased detection range of tagged fish, which in turn increased the precision and accuracy of weekly and daily movement estimates in 2005. To remedy the differing daily movement rates, a truncated 32 km section of river encompassing 3 stationary receivers was selected to determine the movement rate in 2005. This daily rate of

movement was based on the passage of 20 fish (12 bighead carp, 8 silver carp) from April through June 2005.

RESULTS

In 2004, 25 bighead carp and 21 silver carp were used for quantifying movement rates. In 2005, 35 bighead carp and 32 silver carp were used in the movement analysis. During the course of the study, two fish were never found (one bighead carp and one silver carp). No distinct trend in directional upstream or downstream movements occurred for either species. For the entire 130 km study reach, daily rate of movement for bighead carp was 0.35 km/day in 2004; in 2005 this estimate increased to 3.6 km/day (Table 3). Silver carp moved 0.31 km/day in 2004 and 3.2 km/day in 2005 (Table 3). The total distance moved by each species also increased from 2004 to 2005 for the 130 km reach, with bighead traveling 172 km in 2004 and 462 km in 2005. Silver carp displayed a similar pattern with a total distance of 112 km moved in 2004 and 411 km traveled in 2005. The truncated 32 km section of river quantified the movement of both species in April through June 2005, generating higher estimates of daily movement (Table 3). Bighead carp in the partial stretch of river moved an average of 6.8 km/day, while silver carp moved 10.6 km/day.

Two major flood events occurred over the course of the study, yielding high water levels during the spawning season of 2004 and the winter of 2005; low water conditions were present during the spawning season of 2005 (Figure 6). Weekly movement estimates for bighead carp in 2004 were positively correlated with river stage ($r = 0.634$; $p = 0.0199$; Figure 7A), but unrelated to temperature ($r = -0.074$; $p = 0.8100$; Figure 7B).

In 2005, movement of bighead carp was again positively correlated with river stage ($r = 0.6197$; $p = 0.0420$; Figure 7C), and weakly negatively correlated with temperature ($r = -0.591$; $p = 0.0555$; Figure 7D). Weekly movement estimates for silver carp in 2004 were not correlated with river stage ($r = 0.2834$; $p = 0.3984$; Figure 8A), but were negatively correlated with temperature ($r = -0.652$; $p = 0.0297$; Figure 8B). In 2005, silver carp movement was positively correlated with river stage ($r = 0.747$; $p = 0.013$; Figure 8C), but unrelated to temperature ($r = -0.467$; $p = 0.1738$; Figure 8D).

DISCUSSION

Bighead and silver carp possess dispersal capabilities that enable them to rapidly move great distances. This study is one of the first to describe their behavior in a North American river system, and demonstrates the capacity of these fish to disperse and establish within recently invaded waters. Examining a behavior that can vary greatly, such as movement, at a smaller scale describes it more accurately because it accounts for individual variance, which may be missed by analyzing it at a larger scale. This is evident in the higher daily rates of movement in 2005 compared to the underestimated rates of movement for 2004. Although the deployment of stationary receivers in late 2004 expanded the detection range and was beneficial to monitor the extent of movement for each species, examining the partial stretch of river more accurately and precisely quantified daily rates of movement.

The dispersal rate and capacity of bighead and silver carp is comparable to the range and rate of movement of native Mississippi River species. Paddlefish in the upper Mississippi River travel great distances (over 400 km), including synchronized

migrations, during the spring associated with increasing water temperature and a rise in river discharge (Zigler et al. 2003). Lake sturgeon in the upper Mississippi River possess complex migratory patterns, exhibiting movement over a large geographic extent, and having highest mean movement rates in the spring and summer (approximately 0.6 km/day and 0.4 km/day, respectively) and a maximum movement rate of 17.5 km/day (Knights et al. 2002). Shovelnose sturgeon in the upper Mississippi River have been documented moving up to 11.7 km/day (Hurley et al. 1987). Pallid and shovelnose sturgeon in the Yellowstone and Missouri Rivers moved up to 15 km/day, with the highest activity in the spring and summer (Bramblett and White 2001).

River stage plays an important role in the life history of bighead and silver carp. Despite the high water during 2004 and the low water during 2005, movement was positively correlated with the rise and fall of the river during the spring and summer. The peaks in movement coinciding with peaks in river stage of each year suggest the annual rise in river stage is serving as the primary cue for small and large-scale migrations. These results are consistent with reports from their native waters in Asia, where an increase in activity and movement was associated with river stage (Krykhtin and Gorbach 1981; Abdusamadov 1987). Temperature was negatively correlated with movement estimates for bighead carp in 2004 and silver carp 2005, suggesting that both species move less with water temperatures that exceed their optimal range maximum of 26ºC (Verigin et al. 1978; Krykhtin and Gorbach 1981; Abdusamadov 1987; Jennings 1988).

The 2005 activity of these species highlights the alarming extent of dispersal of which they are capable, with one bighead carp moving over 460 km and one silver carp moving over 410 km. A conservative estimate of the environmental damage and

economic losses that nonindigenous fish species incur in the U.S. annually is in excess of $1 billion (Pimentel et al. 2000). The rapid spread of these species has triggered management strategies to impede their upstream dispersal, such as the Chicago Sanitary Shipping Canal Dispersal Barrier costing $9.1 million to construct, and $500,000 annually in maintenance costs (Moy 2005). This electric barrier, whose construction was complete in 2006, was developed to prevent Asian carp from entering the Great Lakes via the Illinois River. Wisconsin and Minnesota also have hired contractors to outfit dams on the Upper Mississippi River with electric, bubble, and sound barriers, in hopes to deter these fish from moving further north in the river system (FishPro, Inc. 2004).

Predicting movement of bighead and silver carp is imperative to developing an effective management plan. Currently, management efforts have been aimed at containing Asian carp and preventing further dispersal. Knowledge of movement cues, combined with the range and rate of movement, and habitat selectivity (see Chapter 1), can facilitate the prediction of bighead and silver carp dispersal. Targeting these species for harvest during or just before peaks in movement occur may aid in greatly decreasing biomass of these species and subsequently further invasions. Management efforts designed to target adults for removal coupled with containing current populations will likely be more effective than inhibiting further dispersal alone.

Table 3. Daily rate of movement and total range of movement for bighead and silver carp in the lower Illinois River and Swan Lake during spring and summer 2004 and 2005. River segment refers to the entire 129 km stretch of river or the partial 32 km stretch of river quantified during 2005.

Species	Year	Reach	Mean km/day (±SE)	Max km/day	Max total km
Bighead carp	2004	Entire	0.35 (±0.07)	10.0	172
	2005	Entire	3.60 (±0.75)	64.0	462
		Partial	6.83 (±1.75)	16.2	60
Silver carp	2004	Entire	0.31 (±0.05)	3.4	112
	2005	Entire	3.18 (±0.71)	64.0	411
		Partial	10.61 (±2.65)	29.7	30

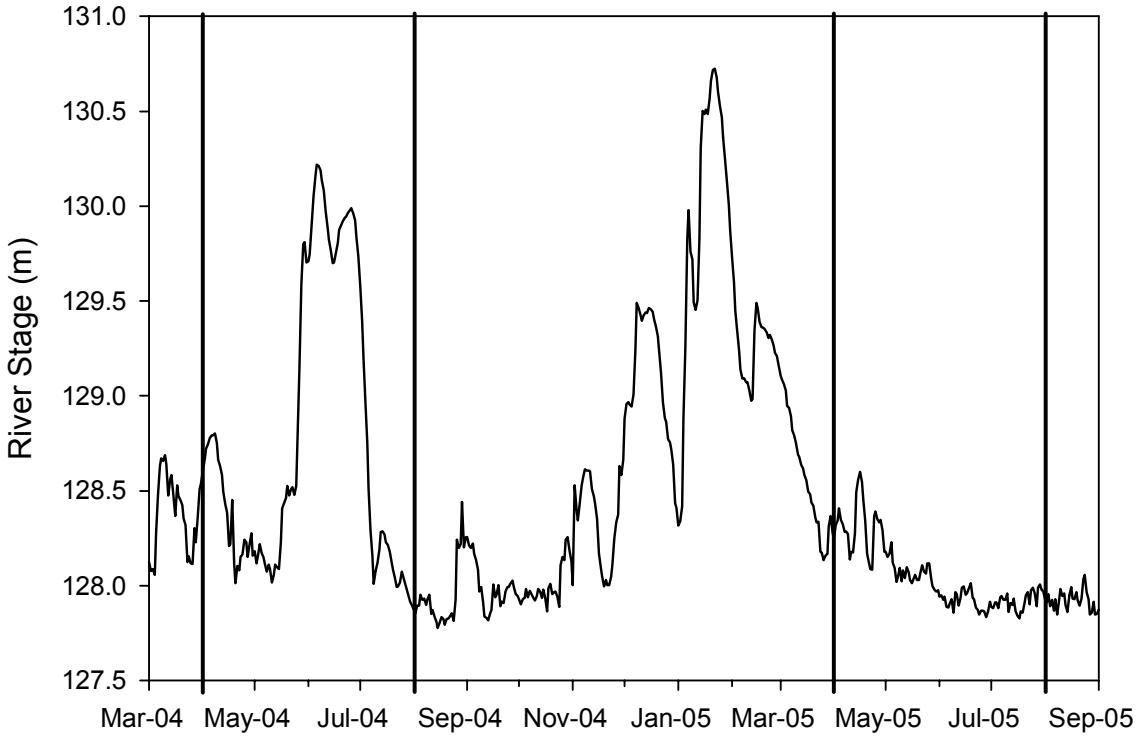

Figure 6. Daily river stage of the Illinois River recorded at Hardin, IL (Rkm 34.6). Solid bars indicate spawning period of bighead and silver carp.

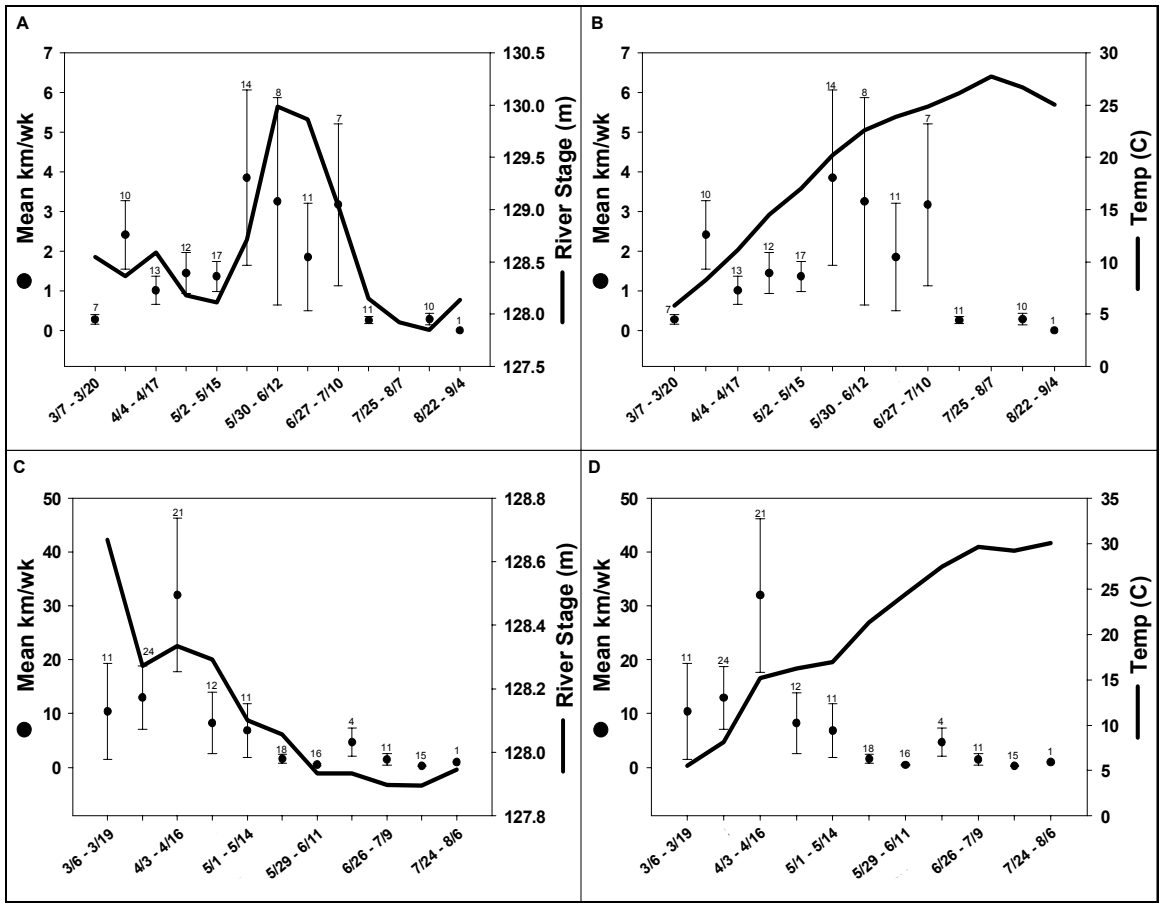

Figure 7. Mean movement of bighead carp in the lower Illinois River and Swan Lake (± 1 SE). Numbers above error bars indicate sample size for each 14-day period. (**A**) Movement with river stage during 2004; r = 0.634. (**B**) Movement with temperature during 2004; r = -0.074. (**C**) Movement with river stage during 2005; r = 0.6197. (**D**) Movement with temperature during 2005; r = -0.591.

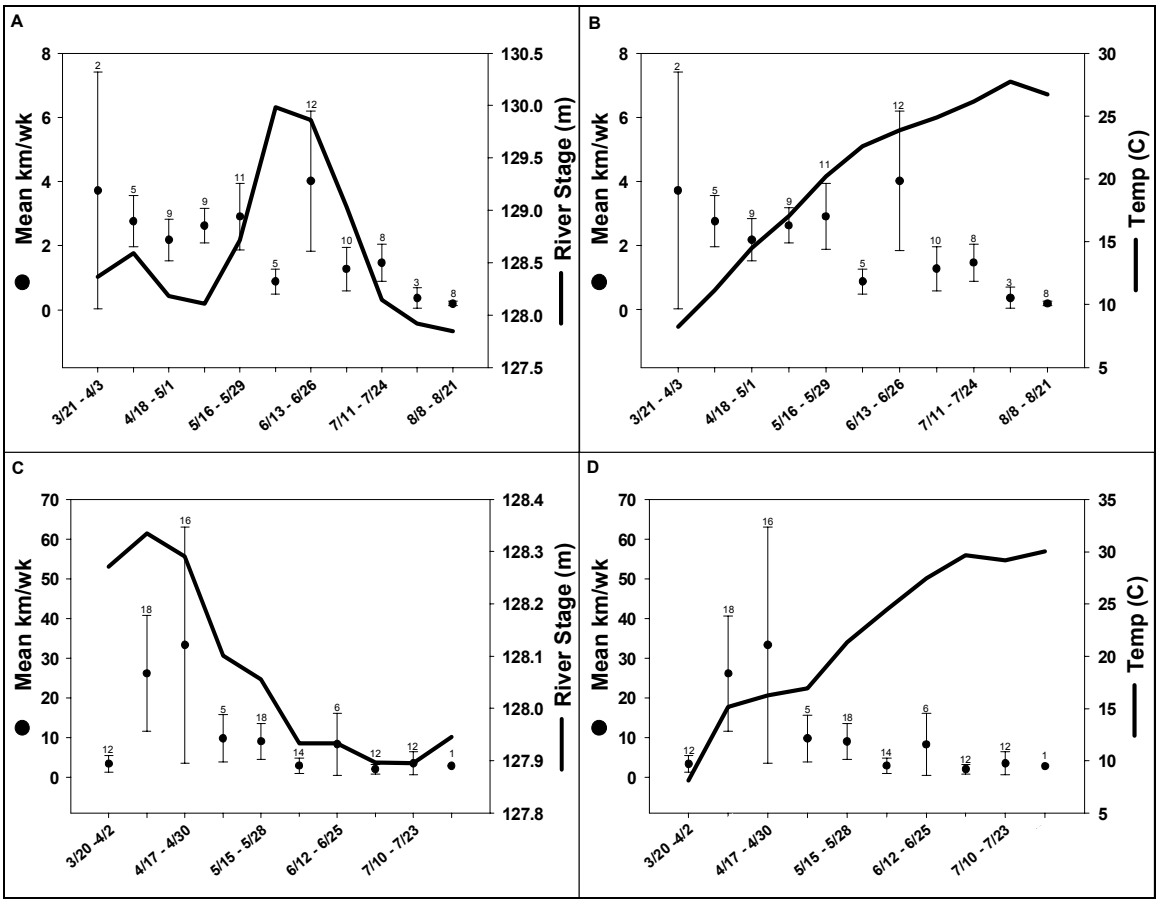

Figure 8. Mean movement of silver carp in the lower Illinois River and Swan Lake (± 1 SE). Numbers above error bars indicate sample size for each 14-day period. (**A**) Movement with river stage during 2004; r = 0.2834. (**B**) Movement with temperature during 2004; r = -0.652. (**C**) Movement with river stage during 2005; r = 0.747. (**D**) Movement with temperature during 2005; r = -0.467.

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VITA

Graduate School
Southern Illinois University

Kelly L. DeGrandchamp Date of Birth: January 14, 1981

613 N 8th Street, Eldridge, IA 52748

Michigan State University
Bachelor of Science, Zoology (Ecology, Evolution, and Organismal Biology), May 2003

Thesis Title:

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Major Professor: James E. Garvey