Floodplain Wetlands as Nurseries for Silver Carp, *Hypophthalmichthys molitrix*: A Conceptual Model for Use in Managing Local Populations

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PURPOSE: This study summarizes recent observations of silver carp, *Hypopthalmichthys molitrix*, in small wetlands of the Lower Mississippi River and suggests management actions for their control based on wetland hydrology and pattern of fish movements.

BACKGROUND: The history and biology of silver carp in North America have been summarized previously by Robison and Buchanan (1988), Pflieger (1997), and Ross (2001). In 1973, the species was brought to the United States from Asia by a private fish farmer to control algae blooms in Arkansas aquaculture ponds. By the late 1970s, silver carp were cultured or stocked at 10 facilities in the state, and by 1980 were reported in natural waters presumably from flooding. The fish now inhabit the Mississippi River and its tributaries from Illinois to Louisiana. In their natural range, silver carp spawn at temperatures of 18 °C, during rising water, in large rivers, with high velocities (>70 cm/s), and extensive free-flowing reaches (100 km). In the United States, spawning occurs in large rivers and flooding allows silver carp to move freely from one location to another. Under some circumstances, silver carp can become isolated in smaller water bodies when low-water stages strand them in off-channel habitats. Silver carp inhabit river channels, backwaters, lakes, reservoirs, and open waters. Self-sustaining populations were discovered in 1995 with the capture of young-of-the-year specimens in Illinois. Silver carp may compete for food with native fishes, including young of most species utilizing zooplankton as a primary food source during critical early development (Ross 2001). Silver carp larvae and young-of-year, 12-300 mm total length (TL), feed on zooplankton and, at subsequent life stages, food preference changes to detritus and algae. Adult silver carp are capable of filtering at a rate of 18.3 L/hour.

In the Upper Mississippi River Basin, the population increased from 5,000 in 1991 to 50,000 in 1994 (Chick and Pegg 2001). Other large Asian minnows have been detrimental to native fish communities in small water bodies (Day et al. 1996), and silver carp could have similar impacts particularly considering their rapid development. Growth of silver carp is rapid and substantial, reaching 1.8–2.3 kg within the first year and maximum weights up to 27 kg (Ross 2001). *Hypophthalmichthys molitrix* mature between the ages of six and eight years and on average measure 61 cm total length (TL). Mature females can produce up to 500,000 eggs (Pflieger 1997), which are semi-bouyant and can hatch within two days after spawning (Pflieger 1997, Ross 2001). In Asia, large lakes and stretches of the Yangtze River have been identified as critical nursery habitats of silver carp (Lu and Bernatchez 1997). In the United States, however, nursery grounds have been poorly documented or are unknown, especially in the Lower Mississippi River Basin (Robison and Buchanan 1988).

STUDY AREA: Study was conducted in a floodplain reach of the lower Mississippi River (708 rkm to 748 rkm) near Eagle Lake, north of Vicksburg, Mississippi. Four different water bodies were studied, including three floodplain pools and one chute (Figure 1). Floodplain pools close to the river are fed by overbank flow, but floodplain pools farther from the river (i.e., those closest to the levee) typically are fed by backwater flow. There are two principal basins along this reach that account for backwater flow: Halpino Lake and Lake Chotard. Halpino Lake floods when water from the Mississippi River backs into Forest Home Chute, fills the lake, and then overflows onto the floodplain filling small depressions, many of which are old borrow pits. Lake Chotard floods when water from the Mississippi River enters the oxbow lake, fills it, and then spills onto the floodplain. Based on observations made since 1997, flooding occurs sometime after the river reaches a stage of 39 ft National Geodetic Vertical Datum (NGVD) at the Vicksburg gage on the Mississippi River.[1]

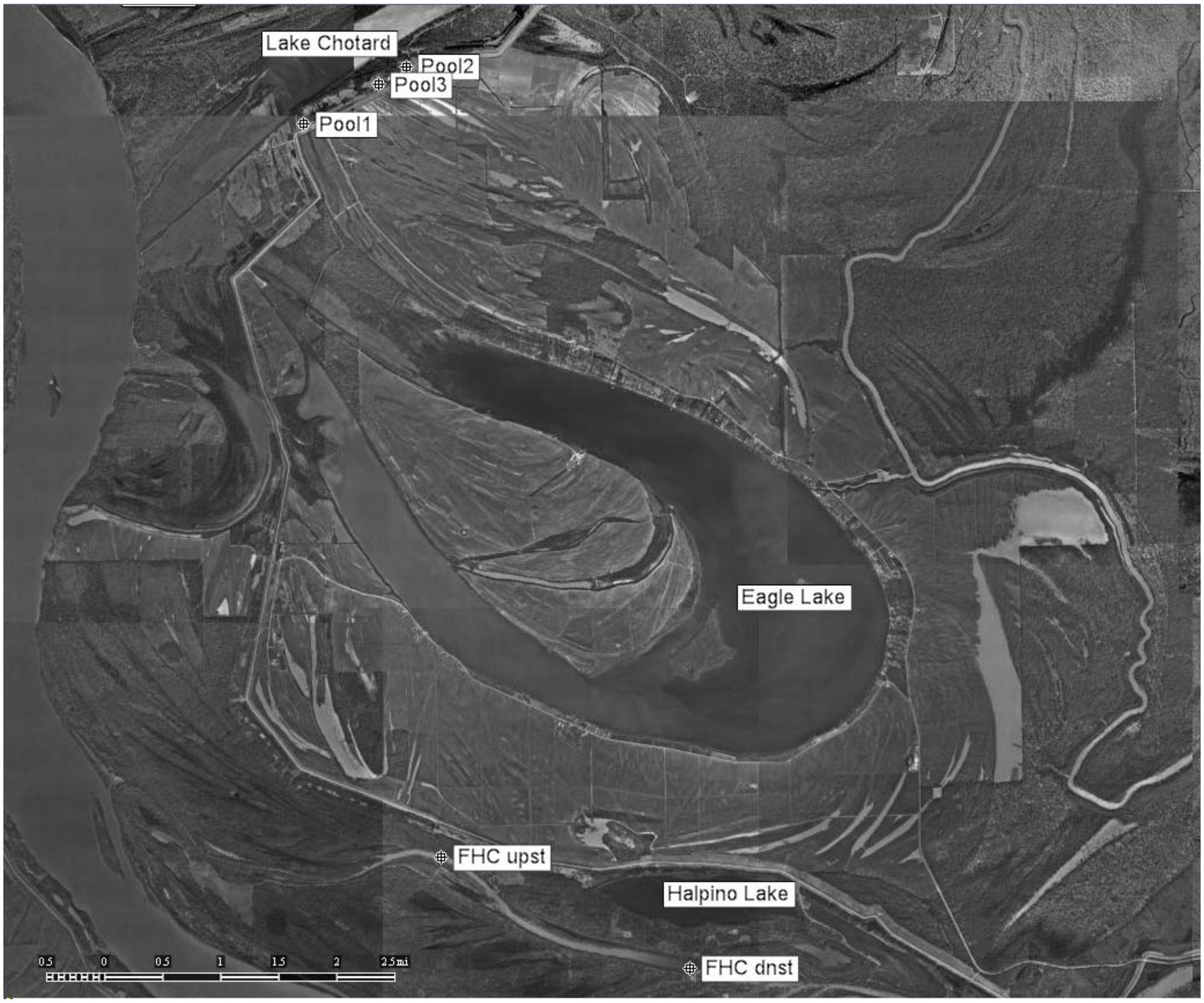

Figure 1. Study sites Forest Home Chute upstream (FHC upst), Forest Home Chute (FHC dnst) and three floodplain pools in study along with associated bodies of water (Eagle Lake, Halpino Lake and Lake Chotard).

Forest Home Chute was sampled August through December 2006. It runs parallel to the main channel of the Mississippi River just north of river km 724 to 729. At one time, it may have been part of the main channel but is now a permanent backwater, impounded in several locations by

[1] Personal Communication, 2007, Wade Creekmore, Land Owner, Vicksburg, MS.

berms with culverts, and only seasonally connected. It is completely wooded on both shorelines. Pools 1-3 were all adjacent to the levee. Pool 1 was sampled in September 2004. A thin tree line surrounded about 30 percent of the pool. Pool 2 at Ziegler Road was sampled in August 2006 and was partly wooded. Pool 3, just west of Ziegler Road, was also sampled in August 2006 and was similar to Pool 2 in that it was partly wooded but with a more discontinuous tree line.

METHODS: Hydrographs from 2003 to 2006 produced by the U.S. Army Corps of Engineers were used to determine periods of connectivity. These hydrographs allowed the authors to deduce likely time of carp introductions and to approximate residence time in wetlands.

Physical characteristics of each site were recorded while sampling. A Quanta Hydrolab™ was used to measure water temperature (°C), dissolved oxygen (mg/L), pH, and conductivity (μS/cm). Turbidity (NTU) was measured with a Hach turbidimeter. Depth was recorded at 10 equidistant points along a representative transect. Channel width and pool dimensions (along two principal axes) were measured with a laser rangefinder. Depth was measured to the nearest 0.3 m using a dash-mounted depth finder (Forest Home Chute) or surveyor stadia rod (Pools). Measurements were typically made mid-day to mid-afternoon.

Fishes were collected to determine species composition and relative abundance of silver carp. Forest Home Chute was sampled on 19 December 2006 with multiple transects made by an electrofishing boat and a single set of a 91-m, 102-mm mesh trammel net (total of 18 specimens). Electrofishing pulsed direct current voltage with an output between 6 and 8 amps. Six transects were electrofished, each at 5-minute durations. Pools were sampled with several hauls of a 3.2-m by 2.7-m seine with 5-mm mesh by picking up dead fish along the shoreline or floating in the water. Data for each methodology collected at each site were combined into a single species abundance list.

Demography of silver carp was studied by monthly sampling of the population in Forest Home Chute. Jumping fish were enumerated by four observers: one fore, one port, one starboard, and one aft. Counts were made from the downstream berm to the upstream berm, a distance of 3.8 km, as the boat traveled at a speed of 11 km/hr (previously determined to be the speed at which silver carp are stimulated to jump). Specimens that landed in the boat were measured to nearest mm (TL), weighed, and dissected to determine gender and reproductive state (two specimens on 19 December 2006) (White et al. 2003). Also, the left pectoral fin ray was excised for age and growth determination. In December, specimens collected in the trammel net were similarly processed. Because concern exists that silver carp may compete with native planktivores, paddlefish were also measured, weighed, and evaluated for robustness or condition.

RESULTS: Flood years alternated with drought years (Figure 2). Flooding from the river took place in 2003 during May through June, which was typical for many of the preceding years. Although river stages were low in 2004, most pools contained large volumes of water from local rainfall and connectivity among wetlands did occur.[1] Flooding from the river took place again in 2005 but occurred early in the year during January and February. Low river stages and local drought precluded connection and filling of most wetlands in 2006. Wetlands that had retained some water during the previous three years completely evaporated.

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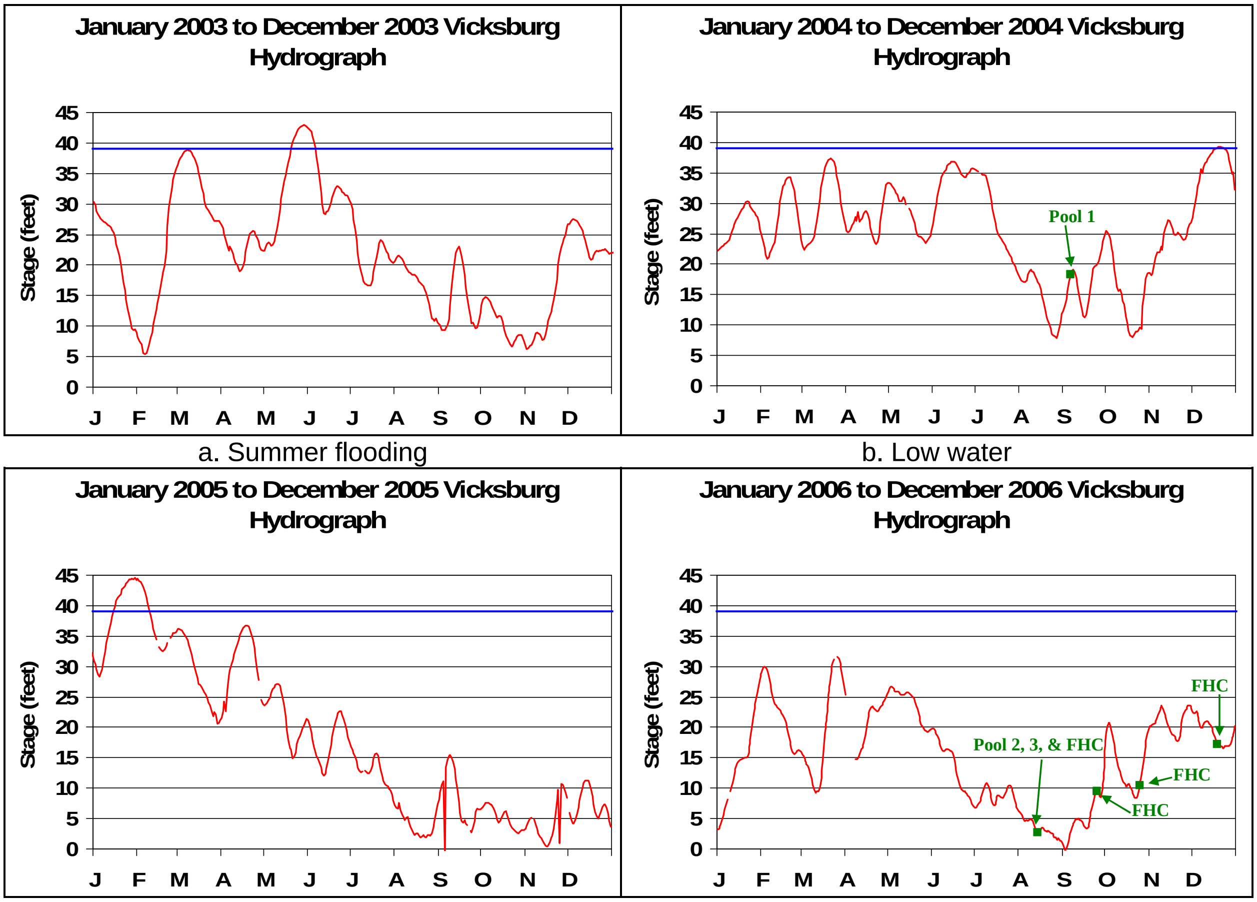
[1] Personal Communication, 2004, Jan Jeffrey Hoover, Research Fishery Biologist, U.S. Army Engineer Research and Development Center, Vicksburg, MS.



a. Summer flooding

b. Low water

c. Winter flooding

d. Low water and drought. Blue line is the controlling elevation and FHC = Forest Home Chute.

Figure 2. Hydrographs for the Mississippi River at Vicksburg.

Forest Home Chute (Figure 3a) provided abundant habitat (> 200 km^2) and supported a diverse fish community in addition to large numbers of silver carp. Average water depth was approximately 2 m on all dates, and water was cool (<29 °C), clear (<30 NTUs), and normoxic (>5 mg/L), although weak stratification was observed in December (Table 1). More than 20 species of fish were collected (Table 2). These were dominated taxonomically (7 species) and numerically (nearly 50 percent) by sunfishes (Centrarchidae). Some planktivores were present but none were abundant: gizzard shad, *Dorosoma cepedianum*, (9.5 percent); threadfin shad, *Dorosoma petenense*, (1.5 percent); bigmouth buffalo, *Ictiobus cyprinellus*, (5.1 percent); and paddlefish, *Polyodon spathula* (2.4 percent). Small native minnows (Cyprinidae) were very few in number and species.

Paddlefish, the largest native planktivores in Forest Home Chute, are not robust. Condition factor (KEFL), a ponderal index relating weight to body length, was low. Mean value of 1.21 (SD=0.23) for Forest Home Chute specimens was significantly, and substantially, lower than mean value of 1.70 (SD=0.10) for 101 specimens of comparable weight and length (550-920 mm EFL) collected in the Big Sunflower River, MS. Data from the Big Sunflower River, a Mississippi River floodplain system, were collected in 1993 prior to the establishment of silver carp. Length-weight regression models for the two populations indicate that disparity in condition was more pronounced in larger fish (Figure 4).

a. Forest Home Chute

b. Pool 1

c. Pool 2

d. Pool 3

Figure 3. Study areas.

Table 1
Water Quality and Physical Characteristics for Floodplain Wetlands (Average) and Forest Home Chute (Range)

Characteristic	**Forest Home Chute**	**Pool 1**	**Pool 2**	**Pool 3**
Location (Lat; Lon)	32º 45.340' N; 91º 01.440' W	32º 33.54' N; 91º 4.08' W	32º 33.9' N; 91º 3.36' W	32º 33.723' N; 91º 03.754' W
Temperature (°C)	14.33-34.30	30.46	39.57	35.47
D.O. (mg/L)	6.06-8.14	2.63	4.85	6.14
Conductivity (µS/cm)	0.346-0.377	0.254	0.118	0.212
pH	8.10-8.56	7.21	8.65	8.67
Turbidity (NTU)	17.5-30.2	271.0	685.0	946.0
Area (m^2)	232	53.7	57.2	29.8
Mean Depth (m)	1.98	0.24	0.14	0.14
Maximum Depth (m)	2.10	0.40	0.21	0.21

Table 2
Fishes Collected in Four Floodplain Wetlands of the Mississippi River

Scientific name	Common name	Forest Home Chute	Pool 1	Pool 2	Pool 3
Family Polyodontidae					
Polyodon spathula	Paddlefish	2.4			
Family Lepisosteidae					
Lepisosteus oculatus	Spotted gar	1.8		23.4 *	
L. osseus	Longnose gar	0.3			
L. platyrinchus	Shortnose gar	0.3			
Family Clupeidae					
Dorosoma cepedianum	Gizzard shad	9.5			
D. petenense	Threadfin shad	1.5			
Family Cyprinidae					
Ctenopharyngodon idella *(I)*	Grass carp		5.0	11.7*	0.5*
Cyprinus carpio (I)	Comon carp	2.7			
Hypophthalmichthys molitrix (I)	Silver carp	6.0	87.5	11.7*	3.5*
H. nobilis (I)	Bighead carp	3.0			
Opsopoeodus emiliae	Pugnose minnow	0.9		5.2	
Family Catostomidae					
Ictiobus bubalus	Smallmouth buffalo	13.7			
I. cyprinellus	Bigmouth buffalo	15.1		18.2*	0.5*
I. niger	Black buffalo	1.1			
Family Ictaluridae					
Ameiurus melas	Black bullhead				71.8
Ameiurus natalis	Yellow bullhead		2.5		
Ictalurus punctatus	Channel catfish	1.2			
Family Poeciliidae					
Gambusia affinis	Mosquitofish	+	+	18.2	18.3
Family Atherinidae					
Labidesthes/Menidia	Silverside		2.5		
Family Centrarchidae					
Lepomis spp.	Young-of-year		+		
Lepomis gulosus	Warmouth	0.6			
L. humilis	Orangespotted sunfish	3.9			2.1
L. macrochirus	Bluegill	34.0		11.7	1.4
L. megalotis/marginatus	Longear/dollar sunfish	3.0			
Micropterus salmoides	Largemouth bass	1.5			
Pomoxis annularis	White crappie	4.8	2.5		1.4
P. nigromaculatus	Black crappie	0.6			
Family Percichthydae					
Morone spp.	Yellow/white bass	0.3			
Family Sciaenidae					
Aplodinotus grunniens	Freshwater drum	1.8			
Total number of species		**24**	**7**	**7**	**8**
Total number of fish		**337**	**40**	**77**	**142**

I = Introduced species.
* = Number is represented partly or entirely by dead fish.
+ = No count data available.

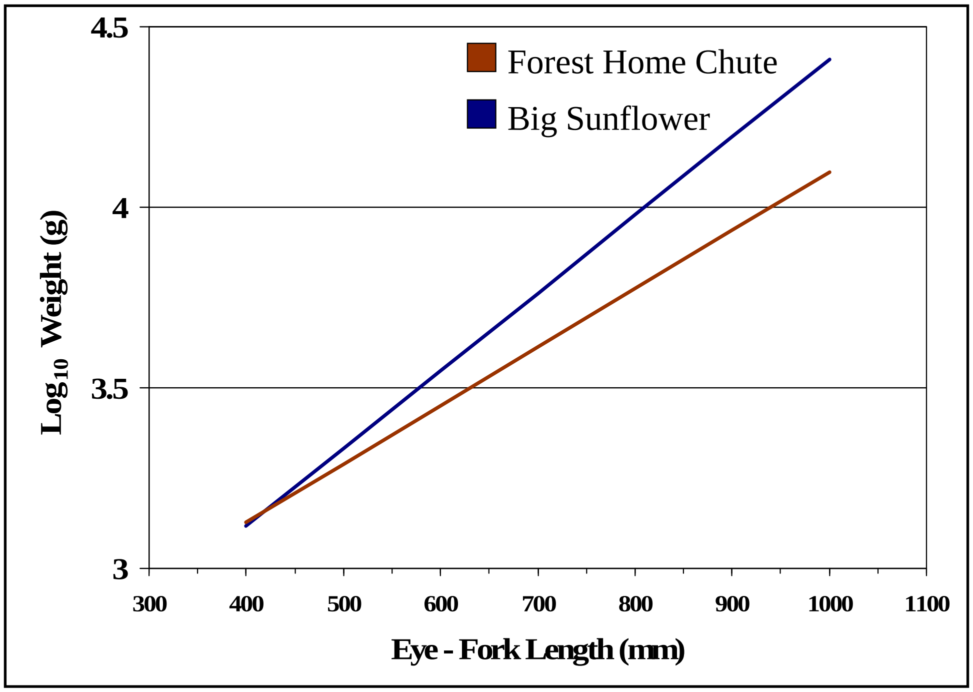


Figure 4. Length-weight relationship for paddlefish. The line is a regression model (N = 100, r^2 = 0.8599, $p < 0.0001$) for fish collected in the Big Sunflower River 1993-1994. The line is a regression model (N = 8, r^2 = 0.9498, $p < 0.0001$) for fish collected in Forest Home Chute 19 Dec 2006.

The Forest Home Chute reach was perched during each of the four sampling dates (i.e., culverts were exposed). Demographic data are probably characteristic of a small, closed population (Table 3). Numbers of jumping fish were variable among dates (46-172 fish/transect). However, other population parameters appeared less variable. Overall, and during most dates, females were slightly more abundant, larger, heavier, and more robust than males. Variation in size was only moderate. There were no small silver carp (<740 mm TL) and no large ones (>900 mm TL). For size, coefficients of variation for any single date were uniformly low (<5.0 percent), suggesting a single cohort (Figure 5). Data were supported by growth rings of the 12 spines examined, all of which were fish in their second year of life. Of the fish examined, most contained well-developed gonads, and several appeared to be maturing. Some males were running milt. None of the paddlefish collected in Forest Home Chute appeared robust. When compared with paddlefish collected from the Mississippi Delta, all were conspicuously underweight (Figure 4).

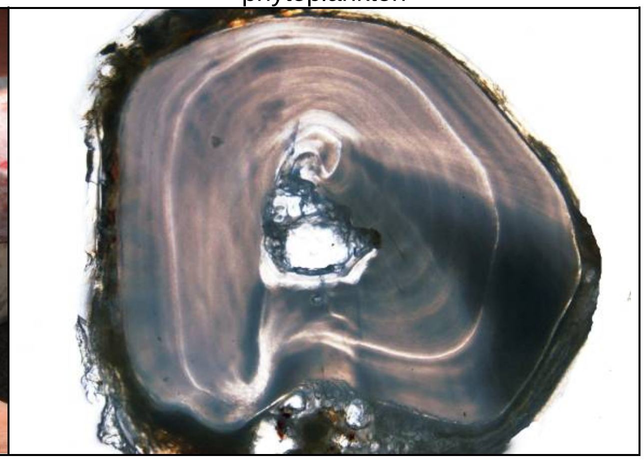
Table 3
Population Characteristics of Silver Carp in Forest Home Chute, Mississippi. Values for Total Length (TL), Weight (WT) and Condition Factor (K_{TL}) are Presented as Mean (Standard Deviation)

Date	Observed	N	Sex Ratio Male:Female	TL, mm Male:Female	WT, kg, Male:Female	K_{TL}, Male:Female
14 Aug 06	125	12	0.5:1.0	795(34.77):807(32.56)	6.15(0.05):6.09(0.10)	1.23(0.06):1.16(0.15)
25 Sep 06	172	7	0.75:1.0	824(18.50):842(24.61)	7.71(0.04):8.96(0.06)	1.38(0.11):1.50(0.18)
25 Oct 06	78	7	1.0:0.75	802(37.06):843(28.99)	6.01(0.09):7.11(0.04)	1.16(0.10):1.19(0.02)
19 Dec 06	46	20	1.0:1.0	825(39.10):859(33.29)	5.91(0.08):7.57(0.05)	1.05(0.13):1.20(0.17)
Total	**375**	**26**	**0.73:1.0**	**812:838**	**6.62:7.39**	**1.26:1.29**

a. Silver carp

b. Long, winding intestines of a silver carp filled with phytoplankton

c. Egg mass of a mature female silver carp



d. Cross section of pectoral fin spine of a silver carp, concluding age is two years from two annuli present

Figure 5. Young-of-the-year silver carp collected at Forest Home Chute

Pool 1 (Figure 3b), a small temporary water body that dries annually, provided a stressful habitat (Table 1). Area was small (<6 km^2). Water was shallow (0.4 m), warm (30 °C), turbid (271 NTU), and hypoxic (<3 mg/L). Only seven species of fish were collected or observed (Table 2). These included grass carp, *Ctenopharyngodon idella*, yellow bullhead, *Ameiurus natalis*, and white crappie, *Pomoxis*, *annularis*, but only silver carp were abundant (Table 3). Pool 1 contained approximately 30 dead young-of-the-year and one juvenile or sub-adult silver carp. Young-of-the-year specimens preserved or measured on-site ranged from 148 to 168 mm TL. The sub-adult was 399 mm TL. This population was too small to have originated from the previous year's Mississippi River flood, but Lake Chotard did flood the pool that year, making Lake Chotard the most likely origin of the population. Two other live silver carp specimens were observed while seining. Most silver carp specimens had injuries from apparent bird predation. On the day prior to sampling, 500 to 600 wood storks (*Mycteria americana)* were seen in the pool feeding.[1]

[1] Personal observation, 2004, Jan Jeffrey Hoover, Research Fishery Biologist, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Pool 2 (Figure 3c), a semi-permanent pond, was comparable in area to Pool 1, but represented much harsher habitat (Table 1). Water was very shallow (<0.2 m), hot (>39 °C), highly turbid (685 NTUs), and borderline hypoxic (4.8 mg/L). Late night and early morning dissolved oxygen were not measured but were probably low due to high nocturnal demands on available oxygen (i.e., microbial and floral respiration). Occurrence of dead fish suggested anoxia-induced fish kills, particularly since three species found dead were active, fast-swimming fish with high metabolic demands: bigmouth buffalo, silver carp, and grass carp. Dead gar cannot be explained by anoxia since those fish can breathe atmospheric air but they may have died from stranding, heat stress, or even starvation. High levels of turbidity and low numbers of forage fish would make it almost impossible for a visual predator to feed effectively. Nine dead juvenile and sub-adult silver carp ranging from 300 to 620 mm TL were observed. Compared to the other two pools, Pool 2 contained the largest silver carp.

Pool 3 (Figure 3d), another semi-permanent pond, was smaller than Pools 1 and 2, with habitat only a little less harsh than Pool 2 (Table 1). Water was very shallow (<0.2 m), very warm (35 °C), extremely turbid (946 NTUs), but normoxic. Eight species of fish were documented, some of them represented by dead specimens (possibly due to previous thermal- or anoxia-related fish kills). Five dead silver carp measuring between 43 and 60 mm TL were observed along with grass carp and bigmouth buffalo specimens. Also observed in Pool 3 were numerous grass shrimp (*Palaemonetes sp*.). This pond differed from Pools 1 and 2 because of the greater number of divots in the soft substrate attributed to cows disturbing the habitat.

DISCUSSION: Biology of silver carp on the Mississippi River floodplain differs from other parts of the range. Native silver carp nursery grounds occur in lakes that border and drain into major rivers and in the rivers themselves downstream from main spawning grounds (Lu and Bernatchez 1997). In the lower Mississippi River, nurseries may also occur in main channel and oxbow habitats, but significant nurseries occur on the wetland floodplain, and in some cases, are remote from main channel spawning areas (Table 2). This may be due to temperature requirements of very young fish. Optimum growth temperature for silver carp larvae is 25-30 ºC or as high as 32-36 ºC just a few degrees lower than the ultimate upper lethal temperature (UULT) between 43.5 and 46.5 ºC (Opuszynski et al. 1989). Because fish are believed to migrate to different temperatures in order to optimize energy conservation and physiological processes, not necessarily to ensure survival (Eaton et al. 1995), and because extraordinarily warm temperatures occur in floodplain wetlands, silver carp may exploit unusually small and remote wetlands. This adjustment in life history is confounded by uncertainty (i.e., flood cycles, availability of suitable habitat, rainfall cycles) and, as a consequence, substantial risk (i.e., mortality, failed or delayed recruitment into river populations), but it also confers significant advantages (i.e., rapid development, refuge from big river predators). Specimens in this study varied in size and presumably age, but in all cases appeared to be from a single cohort. Also, the age and reproductive state of the specimens from this study suggest that silver carp could be maturing at a faster rate and possibly are able to reproduce outside of the presumed spawning season in the United States (April to June).

In large (>1.4 km^2), cool ($\leq$25 °C) reservoirs, silver carp reduce populations of zooplankton, diatoms, and large non-mucilaginous algae; they increase turbidity by promoting small (<10 µm) phytoplankton and large mucilaginous algae (Voros et al. 1997, Domaizon and Devaux 1999, Radke and Kahl 2002). Impacts in small (<1 km^2) warm (>25 °C) wetlands are undocumented but data indicate that they can be substantial. The large volume of plankton found in these fish (Figure 4b) indicates that shifts in plankton availability are inevitable. Water samples from Forest Home Chute in October and December contained negligible numbers of large zooplankton[1] and guts of silver carp were packed with algal material (Figure 3c). In addition to removal of certain plankton, silver carp may be selectively digesting what they eat. Inoculates of silver carp fecal material were cultivated in bottled spring water to obtain substantial blooms of planktonic algae (Figure 6), demonstrating the viability of the algae post-digestion. Reductions of zooplankton and large phytoplankton will reduce food supplies for planktivorous fishes which may explain the low numbers of shad present (Table 2) and the poor condition of paddlefish (Figure 4). The large size of even young silver carp (Table 3) make them unavailable to most aquatic predators. Large individuals may be preyed upon by alligators. Very young fish are eaten by wading birds, like the endangered wood stork, but other native wetland fishes would also be suitable prey (threadfin shad, golden shiners, bullheads) and would not become too large to eat (Table 2). Silver carp jump at the sound of propellers of motor boats and cause injuries to boaters; 12 landings of large fish in an open boat traveling 4 km demonstrates that the risk of fish-caused injuries can be substantial in backwaters (Table 3).

Figure 6. Cultured plankton from Forest Home Chute. Tube on left contains culture grown from live plankton in spring water; tube in middle contains culture grown from silver carp feces; and tube on right contains no culture in spring water (blank).

[1] Personal Communication, 2007, Clifford Ochs, Associate Professor of Biology, University of Mississippi, Oxford, MS.

Backwater wetlands are important for young-of-the-year development (Hoover et al. 2000). Silver carp require: i) seasonal connections between wetlands and the river, so that spawning adults can access wetlands; ii) appropriate geomorphology and ample rainfall, so that usable wetland habitat persists; iii) timely reconnections to the river so that grown fish can recruit to riverine populations as larger fish. If any one of these events does not take place, recruitment failure occurs. A conceptual model is presented based on the data collected with suggestions on how it may be used to prevent local recruitment of silver carp.

The model is for a single cohort of fish and based on annual hydrographic peaks, wetland geomorphology and rainfall, and sporadic or annual reconnections (Figure 7). During a 3-year cycle, silver carp from a single spawn can recruit to riverine populations as young-of-year (assuming early, sporadic reconnection during the first year), as larger juveniles (assuming persistence of suitable habitat for an entire year and reconnection the following year), or as much larger sub-adults (assuming that isolated but suitable habitats persist for a second year and reconnect during the third year or later). None of these outcomes, however, is possible if carp colonize pools that are unsuitably small and shallow (e.g., Pool 1) or which receive insufficient rainfall (Pools 2 and 3). In those cases, carp die from bird predation (Pool 1) or poor water quality (Pools 2 and 3). Hydrographs from 2003-2006 and direct observations of individual wetlands during this period[1] suggest that this is the fate of many of the silver carp in pools. Carp in backwaters, however (e.g., Forest Home Chute), persist for years and could recruit back to the river population as reproductive adults during periods of reconnection. This makes them particularly critical to managers attempting to control populations (King et al. 2003).

Strategically placed structural controls can catch silver carp during migrations to or from floodplain wetlands and could be effective in permanent backwaters. Stuart et al. (2006) constructed a cage designed to catch jumping fish. The “Williams” cage exploits the jumping behavior of carp but allows other fish species to pass through the cage without being trapped in the cage. The Williams cage may be placed at weirs and other back-water connections to contain silver carp from entering the Mississippi River and other major bodies of water. Other management plans have been proposed to attempt to control silver carp invasions. Plans include: reduction in numbers (increase of commercial and recreational harvest, biological controls, release of sterile and transgenic silver carp, application of pheromones, modification of habitat or hydrologic variables, and application of piscicides), reporting information, continuation of research, and evaluation of management and control plans (Conover et al. 2006). From this study, modification of habitat and hydrology seem to pose the most effective outcome. Flooding causes migrations to floodplain wetlands where populations are secluded from major bodies of water. With hydrological barriers (dams, wiers, culverts, etc.) present, isolation of populations of silver carp could be implemented. Once contained, other management options could be imposed and produce more effective results.

Wetland restoration measures could also be implemented to reduce likelihood of recruitment. Pools created (or restored) closer to the river could be made smaller, shallower, or more densely canopied (reducing photosynthesis and availability of algae) to reduce carp carrying capacity and maximize desiccation. Pools farther from the river could be made larger, deeper, and more open since they

[1] Personal observation, 2007, Jan Jeffrey Hoover, Research Fishery Biologist, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

would flood less frequently (and be less likely to experience carp invasions) and since the native fish fauna adapted to such habitats (e.g., taillight shiner, golden topminnow, pirate perch, bantam sunfish) are self-sustaining and not flood-dependent (Baker et al. 1991).

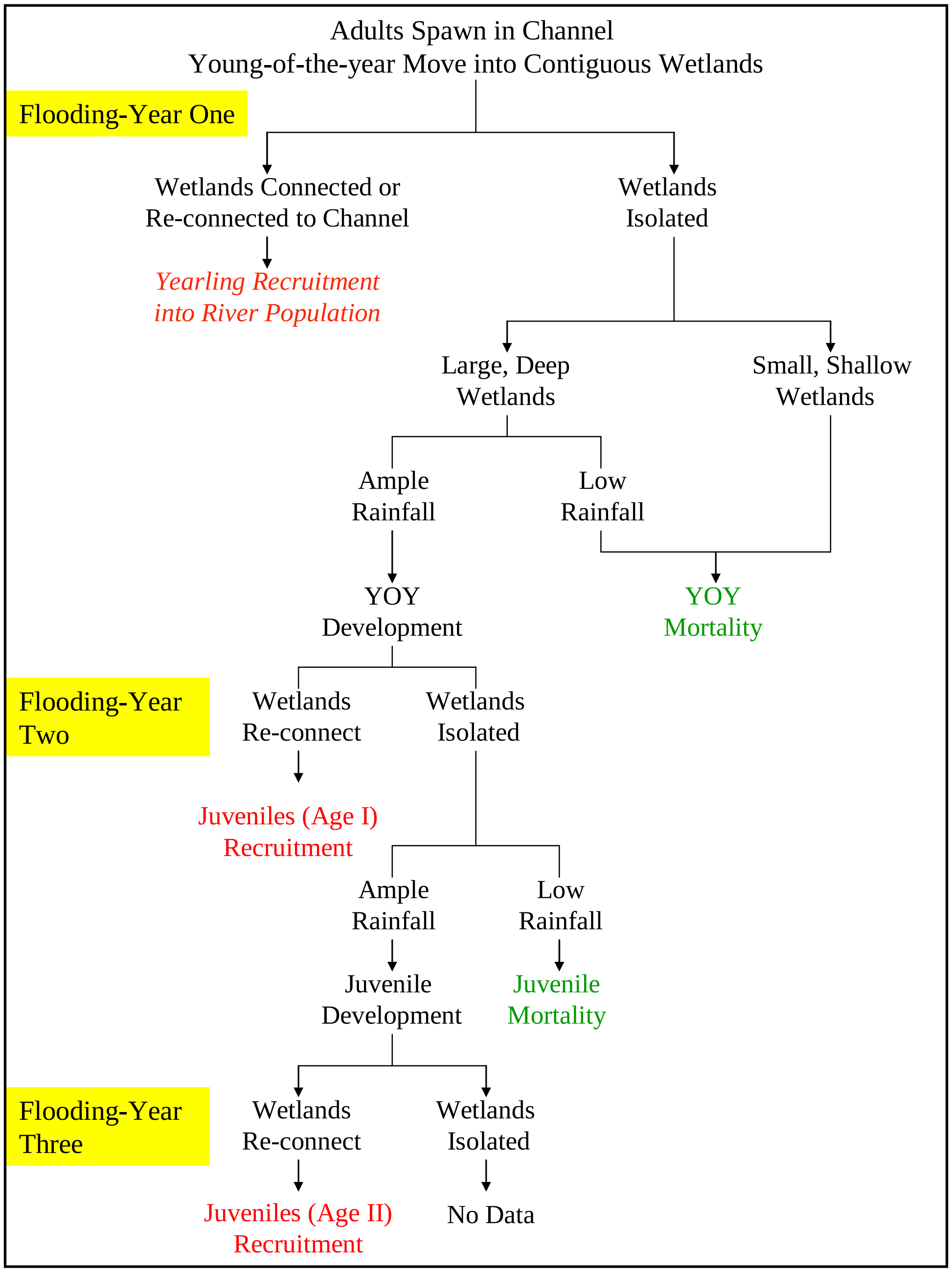


Figure 7. Conceptual model relating wetland hydrology to silver carp recruitment.

Structural and restoration-based measures of control could have significant benefits to fish communities beyond control of silver carp. Silver carp co-occur with other invasive, non-native cyprinids such as bottom-rooting common carp, herbivorous grass carp, and planktivorous bighead carp (Table 2). Successful control of silver carp populations would be likely to impact other Asian carps and benefit native aquatic plants, water clarity, plankton communities, and ultimately native fish assemblages.

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