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# Asian Carp in the Missouri River: Analysis from Multiple Missouri River Habitat and Fisheries Programs

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**Asian Carp in the Missouri River: Analysis from Multiple Missouri River Habitat and Fisheries Programs**

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*Abstract*.— Bighead carp *Hypophthalmichthys nobilis*, silver carp *H. molitrix*, black carp *Mylopharyngodon piceus*, and grass carp *Ctenopharyngodon idella*, collectively referred to as Asian carps, are invasive species that were either accidentally or intentionally introduced into the Mississippi River basin. The expansion of Asian carp into the Missouri River is not well understood and knowledge of population characteristics within this river were lacking. The objectives of this study were to describe the relative abundance, size structure, and spatial and temporal trends of Asian carp using multiple gears from three long-term fish community monitoring programs in the Missouri River downstream of Gavins Point Dam, South Dakota and Nebraska from 2003 to 2007. A total of 1,307 bighead, 1,280 silver, 624 grass, and 0 black carp were captured. The majority of adult bighead carp were captured in overnight hoop nets (38%) and adult silver (14%) and grass carp (23%) were most commonly caught in overnight experimental gill nets. Mini-fyke nets captured almost exclusively, young of the year Asian carp (≤ 80 mm), while gill, trammel, and hoop nets collected a wide length range of fish (81 – 1,200 mm). The relative abundance of all three Asian carp species did not significantly differ among years; however, spatial trends were found as relative abundance was highest in the Missouri River downstream of the Platte River. Short Asian carp weighed less in the Gavins Point reach compared to downstream of the Grand River in Missouri. Conversely, long Asian carp in the Gavins Point reach attained greater weights than fish of similar length downstream. We found that multiple sampling gears are necessary to monitor Asian carp population characteristics in the Missouri River. Asian carp populations appear to be well established in the Missouri River and it is increasingly important to understand the affects these invasive species have on the native fish community.

## Introduction

Asian carp were introduced to the United States as a biological tool by natural resource agencies and aquaculturists. Bighead carp *Hypophthalmichthys nobilis* and silver carp *H. molitrix* were first introduced to a private fish farm in Arkansas in 1972 to improve water quality (Conover et al. 2007). Later in the 1970's bighead and silver carp were researched by natural resource agencies and aquaculturists to improve water quality in lakes, aquaculture ponds, and wastewater systems. By the early 1980's bighead and silver carp appeared in Arkansas rivers (Freeze and Henderson 1982) and evidence of natural reproduction was found in the Missouri River in 1989 (Kolar et al. 2005). Bighead carp are also sold live as a food fish in specialty ethnic markets (Kolar et al. 2005); however, silver carp are not cultured in the United States and are now listed under the "injurious wildlife provision" of the Lacey Act (Fowler et al. 2007). Because both bighead and silver carp feed on plankton, they may have adverse affects on native fish, mussels, and zooplankton at all life stages. Schrank et al. (2003) reported dietary overlap between age-0 bighead carp and paddlefish *Polyodon spathula* in laboratory studies. Sampson et al. (2009) reported bighead carp dietary overlap with gizzard shad *Dorosoma cepedianum* and bigmouth buffalo *Ictiobus cyprinellus* in the Illinois and Mississippi rivers and condition of these two native species has declined since establishment of Asian carps (Irons et al. 2007).

Black carp *Mylopharyngodon piceus* were intentionally imported into the United States to control snail populations in aquaculture ponds. Adult fish were reported in 1994 to have escaped from an aquaculture facility in Missouri into the Osage River, a tributary to the Missouri River (Nico et al. 2005). Since then, black carp have been collected in the Mississippi River in Illinois, the Atchafalaya and Red rivers in Louisiana, and the White River in Arkansas (Nico et al. 2005). Black carp feed primarily on mollusks and snails (Nico et al. 2005). Nearly 70 percent of North American native mussels are either extinct, endangered, threatened, or a species of concern (U. S. Fish and Wildlife Service 2005) and predation by black carp poses an additional risk to persistence of native mussels. There is also potential for competition between black carp and native fish that feed on mussels such as freshwater drum *Aplodinotus grunniens*, redear sunfish *Lepomis microlophus*, several catfishes (Ictalurids), and redhorses *Moxostoma spp.* (Nico et al. 2005).

Grass carp *Ctenopharyngodon idella* were introduced to the United States by federal and state researchers to investigate biological controls of aquatic vegetation (Avault 1965; Mitchell and Kelly 2006). Natural resource agencies and private pond owners have distributed grass carp throughout the United States starting in the 1970's (Pflieger 1978; Guillroy and Gasaway 1978). Triploid carp are authorized for stocking in 38 states, while an additional 10 states allow diploids to be stocked (Dauwalter and Jackson 2005). Grass carp have the potential to alter habitats, affect native communities through competition with other fish and invertebrates, disrupt food webs, and increase eutrophication (Conover et al. 2007).

The establishment of Asian carp in the Missouri River could potentially cause great ecological harm. Asian carp are mobile, long-lived, tolerate a broad range of climates, have opportunistic food habits and have high reproductive capabilities, population densities, and growth rates (Cudmore and Mandrak 2004; Kolar et al. 2005). Mean fecundity of female bighead carp in the Missouri River was 226,213 eggs and bimodal egg diameters in the ovary indicated potential for protracted spawning (Shrank and Guy 2002). Silver carp also have protracted spawning periods with some fish spawning multiple times within a year (Papoulias et al. 2006). By age-3, bighead carp and silver carp attained total lengths > 500 mm (Johal et al. 2001; Shrank and Guy 2002), which likely precludes these species from predation by native

Missouri River piscivores. With these life history traits, Asian carp will likely change the aquatic environment, to the detriment of native aquatic organisms.

Further understanding of Asian carp population characteristics are needed in the Missouri River. Knowledge of Asian carp populations is critical to their control and management in the Missouri River. The Asian Carp Working Group, made up of state and federal natural resource agencies, universities, aquaculturists, non-profit organizations, and various stakeholders, recommended research that would identify Asian carp population characteristics including relative abundance and size structure and identifying habitats used by Asian carp (Conover et al. 2007). The development of baseline data is critical to monitoring and early detection of Asian carp in high risk areas for introduction and expansion, such as in Lewis and Clark Lake, just upstream Gavins Point Dam, South Dakota and Nebraska. To date, no Asian carp have be have been captured in the Missouri River upstream of Gavins Point Dam (Kaemingk 2007; Shuman et al. 2008).

The objectives of this study were to assess relative abundance, size structure, and spatial and temporal trends of Asian carp in the Missouri River using data collected through a standardized long-term fish community monitoring program (Drobish 2008a), habitat assessment monitoring program (HAMP), and a fish and wildlife mitigation program. This study compared the size structure of Asian carp captured among various standardized gears, relative abundance among years and river reaches, and length-weight comparisons among river reaches. Understanding spatial patterns and the establishment of baseline relative abundance data through systematic monitoring is essential to measuring fish population responses to river management.

**Study Area**

Our study area was the Missouri River from Gavins Point Dam near Yankton, South Dakota (river kilometer [rkm] 1,305) to its confluence with the Mississippi River near St. Louis, Missouri (rkm 0). Gavins Point Dam is the furthest downstream mainstem dam on the Missouri River. The Missouri River was divided into segments based on hydrological characteristics and large tributary influences (Drobish 2008a) (Figure 1). Segment 7 extends from Gavins Point Dam to Ponca, Nebraska (rkm 1,212), is a highly braided reach of the Missouri River. However, this reach is highly influenced by an unnatural hydrograph due to releases from Gavins Point Dam. Segment 8 extends from Ponca, Nebraska to the confluence of the Platte River (rkm 958) and has been channelized with a highly degraded streambed. Segments 7 and 8 are defined as the "Gavins Point" reach because of the dam effects on the Missouri River. Segment 9 extends from the Platte River to the confluence of the Kansas River (rkm 708) and has a more natural hydrograph due to tributary discharges and distance from Gavins Point Dam. The remaining segments in the state of Missouri are delineated by major tributaries. Segment 10 extends from the Kansas River to the Grand River confluence (rkm 250). Segments 9 and 10 are defined as the "Platte-Kansas" reach due to the effects of the large tributaries, which flows across highly erodible lands and carry high sediment loads into the Missouri River. Segment 13 is the Grand River to the Osage River (rkm 130), and Segment 14 is the Osage River to the mouth of the Missouri River. This furthest downstream reach with large tributaries, Segments 13 and 14, is defined as the "Interior Highlands" reach.

Mitigation sites along the Missouri River were acquired as a result of the Water Resources Development Act of 1986 and 1999 to mitigate for habitat loss that resulted from the Missouri River Bank Stabilization and Navigation Project (U. S. Army Corps of Engineers

2003). The mitigation sites have developed new chutes and backwater areas to improve fish and wildlife habitat. These sites include Tieville-Decatur Complex (rkm 1,117 to 1,104), Louisville Bend (rkm 1,101), Tyson Island site (rkm 1,052), California Bend (rkm 1,046), Tobacco Bend (rkm 948), Upper Hamburg Bend (rkm 897), Lower Hamburg Bend (rkm 891), Upper Kansas Bend (rkm 880), and Upper Deroin Bend (rkm 838).

## Methods

*Pallid Sturgeon Population Assessment Program (PSPAP)*

Standard operating procedures (SOP) for sampling and data collection were developed to assess the pallid sturgeon *Scaphirhynchus albus* population and the associated fish community, hereafter referred to as the Pallid Sturgeon Population Assessment Program (PSPAP). The PSPAP was initiated in Segments 9, 13, and 14 in 2003 (Figure 1) (Drobish 2008a). Full implementation of PSPAP has occurred throughout the Missouri River downstream of Gavins Point Dam since 2005 (Segments 7-10 and 13-14).

All river bends in the study area were numbered prior to sampling. River bends were then randomly selected for monitoring each year. All macrohabitats and mesohabitats were identified within each selected bend. Eight macrohabitats identified in the Missouri River included, outside bend, inside bend, channel crossover, river confluence, braided channel, large secondary connected channel ($\geq$ 50 m wide), small secondary connected channel (< 50 m wide), and secondary channel non-connected (Drobish 2008a). Within each macrohabitat, mesohabitats were defined as sandbar pool, sand bar, island tip, thalweg, and channel border (Drobish 2008a). All available habitats were sampled within each randomly selected bend.

Fish sampling occurred during two defined seasons. The sturgeon season or winter season focused on the assessment of sturgeon species, although data was collected on all fish captured. The sturgeon season began in the fall when water temperatures reached 12.8 °C and continued through 30 June. The fish community season or summer season (1 July to 31 October) placed additional emphasis on collecting data on young-of-the-year (YOY) and small-bodied native Missouri River fishes. Detailed guidelines for design and deployment of standardized and non-standardized sampling gears used for PSPAP are described in Drobish (2008b). Some of these gears included overnight gill, hoop, mini-fyke nets, drifted trammel nets, towed or pushed trawls, electrofishing, trot or set lines, and seines.

*Habitat Assessment Monitoring Program (HAMP)*

The main objective of the Habitat Assessment Monitoring Program (HAMP) was to characterize biological responses to main channel habitat creation activities conducted on the Missouri River (Sampson and Cox 2007). The HAMP program adopted many methods and gears from the PSPAP (Drobish 2008a). The study design, a modified before-after/control-impact (BACI) design, was used to infer response variables with respect to treatment types and could evaluate pre- and post impacts from habitat modification projects (Sampson and Cox 2007). River bends were classified based on the presence or absence of dikes or on the anticipation of dike modifications. Bends were also classified by their radius ($25^{th}$ and $75^{th}$ percentile) and length. The HAMP program used three treatment types that included: 1) control bends that have not and will not be modified in the near future, 2) before/after bends are areas scheduled to be modified in the future by either creating notched dikes or chevrons, and 3) modified bends were areas modified prior to the start of the HAMP program and are being monitored to understand the potential of the modifications to improve fish habitat. Fish sampling gears and methods used for HAMP were identical to the ones used in the PSPAP with the addition of bag seines (Drobish 2008b).

*Missouri River Fish and Wildlife Mitigation Project (Mitigation Project)*

The Mitigation Project monitors and evaluates biotic responses of off-channel aquatic habitats along the Missouri River (Sterner and Bowman 2006). The Mitigation Project adopted many of the same gears and methods used in the PSPAP (Drobish 2008a). All mitigation sites were sampled monthly from April to October from 2005 to 2007. Each mitigation site was divided into 16 equal length “chute” segments. At each mitigation site, fish sampling occurred in eight chute segments that were randomly selected each month. Fish sampling gears used for the Mitigation Project were similar to ones in the PSPAP with the addition of smaller hoop and larger mini-fyke nets and different mesh sizes used in trawls (Drobish 2008b).

*Statistical analysis*

Analysis of variance (ANOVA) was used to compare mean length for each species of Asian carp among gears. First, Asian carp length data were checked for normality for five gears: overnight gill, hoop, and mini-fyke nets, drifted trammel nets, and electrofishing. Length data was combined from all three Missouri River programs and from 2003 to 2007 to increase sample size. Additionally, ANOVA was used to compare mean length among four gill net panels. When differences in mean lengths were found among gears or gill net panels, a Tukey-Kramer multiple range test was used to determine which means varied significantly. All Asian carp were measured to total length.

Mean catch per unit effort (CPUE) was calculated for each Asian carp species to study temporal and spatial abundance in the Missouri River. Mean CPUE analyses were only tested using data from the PSPAP because of the randomized design of selecting river bends within river segments. Mean CPUE for gill nets was calculated as number of fish/30.5 m gill net-night, number of fish/net-night for hoop and mini-fyke nets, and number of fish/100 m for each drifted trammel net. The mean CPUE data were checked for normality with probability plots and if not normally distributed; were $\log_{10}$ (CPUE+1) transformed. A two-way ANOVA was used to compare mean CPUE among years and Missouri River reaches. If a significant interaction term (year X reach) was found, then mean CPUE among years and reaches were tested separately with a one-way ANOVA. A significant interaction term indicates that mean CPUE may be changing in two areas, suggesting that an interaction of years and reaches may occur (Quinn and Keough 2002). When differences were found in mean CPUE among years or reaches, a Tukey-Kramer multiple range test was used to determine which means varied significantly. Two-way ANOVA tests were performed only when sampling occurred in all river segments during the same year (gill nets from 2004 to 2007 and trammel nets from 2005 to 2007). The mean length and CPUE analyses were performed with Number Cruncher Statistical Software (NCSS) 2000 (Hintze 2006). In all comparisons, significance was determined at $\alpha = 0.05$ and was adjusted accordingly for multiple comparison tests.

Linear regression was used to describe the $\log_{10}$length-$\log_{10}$weight relationship for each species of Asian carp. Due to the low numbers of Asian carp weighed, all length-weight data was combined among the three monitoring programs from 2003 to 2007 for each species. Comparisons were made only between two reaches, Gavins Point (upstream) and Interior Highlands (downstream), since there was a minimal number of Asian carp weighed in the Platte-

Kansas rivers reach. 95% confidence intervals around the estimated parameters (intercept and slope) were used to assess the differences in condition between the two reaches for each Asian carp species.

Analysis of covariance (ANCOVA) was also used to assess potential differences in condition between the two reaches for each Asian carp species with $\log_{10}$length set as the covariate. A general linear model (GLM; Hintz 2006) was first run, in which the dependent variable ($\log_{10}$weight) was modeled as a function of the treatment variable (reach), covariate ($\log_{10}$length), and their interaction. The interaction term tested for homogeneity of slopes and if not significant, the reduced model (without the interaction) was run to test for differences in the intercepts. If the treatment variable was not significant, then intercepts were not different and would suggest that the Asian carp in the two river reaches gained weight incrementally with increasing length in a similar fashion.

**Results**

A total of 1,307 bighead, 1,280 silver, 624 grass, and 0 black carp have been captured in the Missouri River among the PSPAP, HAMP, and Mitigation programs from 2003 to 2007. Each Asian carp species was predominately captured with a different gear (Table 1). Most bighead carp were captured in hoop nets (HN; 38%), then min-fyke nets (MF; 16%), trammel nets (TN; 6%), and gill nets (GN; 5%). The majority of silver carp were captured in push trawls (31%), gill nets (14%), then mini-fyke nets (7%), and electrofishing (EF; 6%). Grass carp were evenly caught between gill nets (23%) and trammel nets (22%), then hoop nets (16%), and electrofishing (15%). Gears such as bag seines, set lines, trot lines, beam trawls, and otter trawls rarely captured any Asian carp. Bighead and silver carp catches were patchy with high incidences of zero catches. A total of 50 bighead carp were caught in a mini-fyke net and 30 silver carp were captured in a push trawl. The highest catch for grass carp was four in a mini-fyke net.

Asian carp collected in four mesh sizes of experimental gill nets varied for bighead carp from 531 to 827 mm, silver carp from 557 to 789 mm, and grass carp from 621 to 833 mm and mean length of Asian carp generally increased as the mesh size increased (Figure 2). Mean length significantly differed among gill net mesh sizes for bighead ($F = 20.07$; $df = 3$; $P < 0.001$), silver ($F = 23.09$; $df = 3$; $P < 0.001$), and grass carp ($F = 15.80$; $df = 3$; $P < 0.001$). For bighead carp, Tukey-Kramer multiple comparison tests revealed that mean lengths were significantly shorter in the 5.1 cm mesh compared to 3.8, 7.6, and 10.2 cm mesh. Silver carp mean lengths were significantly shorter in the smallest mesh (3.8 cm) compared all other mesh sizes and grass carp mean lengths were significantly longer in the largest mesh (10.2 cm) compared to all other mesh sizes.

Asian carp young of the year (YOY) were captured with one passive and one active gear. Mini-fyke nets captured almost exclusively, young of the year Asian carp with a few adult grass carp (Figure 3). All silver carp captured in push trawls were young of the year based on length (range = 17 – 80 mm). Gill nets, trammel nets, hoop nets, and electrofishing captured few to no Asian carp YOY.

Gill nets, trammel nets, hoop nets, and electrofishing all captured a wide length range of adult bighead (Figure 4), silver (Figure 5), and grass carp (Figure 6). Mean length did significantly differ among gears for bighead ($F = 119.033$; $df = 3$; $P < 0.001$), silver ($F = 3.83$; $df = 3$; $P = 0.01$), and grass carp ($F = 3.45$; $df = 3$; $P = 0.02$). In the multiple comparison tests, bighead carp captured by hoop nets had significantly shorter mean lengths when compared to all other gears and electrofishing and gill net mean lengths were shorter than trammel nets (Figure 4). Mean length of silver carp collected in hoop nets were significantly shorter than silver carp captured in gill nets (Figure 5). Grass carp captured by electrofishing had significantly shorter mean lengths compared to the other three gears (Figure 6).

Bighead carp (Table 2) were captured in nearly every river segment, in every year (Figure 7) by all three Missouri River monitoring programs. Significant interaction terms were found at least once for each species in the two-way ANOVA comparing Asian carp gill and trammel net mean CPUE among years and river reaches (Table 5). No significant differences were found in gill net mean CPUE among years or river reaches for bighead carp ($P \geq 0.273$). However, bighead carp trammel net mean CPUE differed among years ($F = 10.04$, df = 2, $P < 0.001$), with significantly higher relative abundance in 2006 compared to 2005 and 2007. Trammel net mean CPUE also differed among reaches ($F = 8.49$, df = 2, $P < 0.001$) with significantly higher catch rates in the Platte-Kansas river reach compared to the Gavins Point and Interior Highlands reaches (Figure 7).

Silver carp were captured in all segments but were most common in the downstream reaches of the Missouri River (Table 3). Silver carp gill net mean CPUE differed among reaches ($F = 51.40$, df = 3, $P < 0.001$ ); no silver carp were captured in gill nets in the Gavins Point reach with significantly more fish caught downstream in the Interior Highlands reach compared to the Platte-Kansas reach (Figure 8). However, no significant differences were found in silver carp gill net mean CPUE among years ($F = 1.02$, df = 3 $P = 0.381$) or trammel net mean CPUE among years or river reaches ($P \geq 0.108$) (Figure 8).

Grass carp have been found in all Missouri River segments each year but were not captured in the Osage River (Table 4). Significant differences in grass carp mean CPUE were found among river reaches for gill nets ($F = 8.46$, $df = 2$, $P < 0.001$), with lowest catches in the Gavins Point reach compared to the other two reaches. While grass carp mean CPUE in trammel nets had the equivocal result of significantly higher capture rates ($F = 5.42$, $df = 2$, $P = 0.004$) in the Gavin Point and Platte-Kansas rivers reaches compared to the furthest downstream reach. No differences in mean CPUE were found among years ($P \geq 0.131$) for grass carp (Figure 9).

The relationship between $\log_{10}$length-$\log_{10}$weight was derived for each Asian carp species in two reaches of the Missouri River, the Gavins Point and Interior Highlands, using linear regression (Figures 10-12). For each Asian carp species, the 95% confidence intervals for both the estimated intercept and slope parameters for the two Missouri River reaches overlapped (Table 6). Additionally, at least one confidence interval of a reach encompassed the intercept and slope estimates of the other reach. This indicates that the intercepts and slopes are not significantly different or that weight gain as the fish grows is similar between the two Missouri River reaches.

Based on ANCOVA, interactions were significantly different between the Gavins Point and Interior Highlands reaches as bighead carp $\log_{10}$length was a covariate affecting $\log_{10}$weight, but were not significant for silver and grass carp (Table 7). Additionally, intercepts were not significantly different between the river reaches for both silver and grass carp (Table 8). Therefore, silver (Figure 10) and grass carp (Figure 11) in the Gavins Point and Interior Highlands reach gained weight incrementally in a similar fashion, while differences were found for bighead carp (Figure 9). Bighead carp at shorter lengths attained less weight (lower condition) in the Gavins Point reach compared to downstream in the Interior Highlands reach. Although not significant, this trend held true for all Asian carp species. Conversely, as Asian carp attained greater lengths in the Gavins Point reach, they then tended to increase condition than the fish in the Interior Highlands reach.

## Discussion

Asian carp have proven to be difficult to capture with traditional fish sampling gears (Conover et al. 2007; Stancill 2003). The lack of captures increases the difficulty to monitor Asian carp population characteristics such as relative abundance, size structure, and condition. Collectively, over 50,000 deployments using 19 passive and 22 active gears during 2003 – 2007 were conducted in the three Missouri River monitoring programs. Although the monitoring programs on the Missouri River were designed to target pallid sturgeon and the associated benthic fish community, this high level of effort illustrated the difficulty of capturing Asian carp. Even when surrounding observed groups of bighead and silver carp with nets and electrofishing gears have proven ineffective at capturing Asian carp (Personal communication, D. Chapman, U. S. Geological Survey). Nevertheless, non-traditional methods such as bowfishing may be one of the most effective and efficient methods of capturing adult bighead, silver, and grass carp (Conover et al. 2007). Standardizing bowfishing methods would prove difficult to monitor Asian carp relative abundance and would likely only collect adults. Silver carp YOY exhibit the same jumping behavior as adults when approached by boats (personal communication, Duane Chapman, U.S. Geological Survey). For adult and juvenile silver carp, visual counts of jumping fish along transects may provide a useful index of relative abundance. However, monitoring programs such as in the Missouri River that use multiple gears may be the most reliable source for monitoring Asian carp population characteristics, while concurrently monitoring native fish populations.

Black carp are benthic, feeding primarily on mollusks (Nico et al. 2005). Given these life history traits, black carp should have been captured given the design of most Missouri River monitoring gears targeting the benthic fish community. Conover et al. (2007) suggested that the most appropriate gear and habitat to capture black carp would be to use large hoop nets in deep water. Hoop nets were used and no black carp were captured throughout all three Missouri River monitoring programs over the five year study; therefore, either black carp are in such low abundance and avoid detection or have not established any viable populations in the Missouri River. Thus far, wild-caught black carp have only occurred in the Mississippi, Red, White, and Atchafalaya rivers (Conover et al. 2007) and likely established throughout the lower Mississippi Basin (Nico et al. 2005).

Gears used in the Missouri River monitoring programs captured a wide length range of Asian carp. Among the standardized gears, experimental gill nets generally captured the widest length range for all three Asian carp species with incremental increases in mean length with larger mesh sizes. Hoop nets captured shorter adult bighead and silver carp while electrofishing captured shorter grass carp. For all three Asian carp species, only mini-fyke nets were effective at capturing small, young of the year fish. We estimated that these were young of the year based on their lengths and back-calculated lengths of bighead carp (Schrank and Guy 2002) and silver carp (Williamson and Garvey 2005). Additionally, Koel et al. (2000) reported that over 69% of the Asian carp <200 mm captured in a long-term monitoring program in the Mississippi River were captured with mini-fyke nets reaffirming that mini-fyke nets may be the best gear to sample for small Asian carp. A thorough analysis of the size structure of any Asian carp population will likely require multiple gears that target juvenile and adult life stages.

Bighead, silver, and grass carp were captured in nearly every reach of the Missouri River downstream of Gavins Point Dam in all five years of the study. The relative abundance of all three Asian carp species did not fluctuate among years. Only the capture rates of bighead carp in drifted trammel nets were higher in 2006 compared to other years. Although not significant, it does appear that silver carp were increasing in abundance from 2003 to 2007 in the Platte-Kansas rivers reach. Chick and Pegg (2001) reported that bighead carp abundance was exponentially increasing in the Illinois River from 1991 to 2000. A benthic fish study conducted in the Missouri River downstream of Gavins Point Dam during July through October from 1996 to 1998 that used similar trammel nets, hoop nets, gill nets, mini-fyke nets, and electrofishing as in this study only captured 22 bighead, 16 grass, and no silver carp (Berry et al. 2004). Bighead carp were reported only in the states of Kansas and Missouri; no silver carp were captured and of the 22 bighead carp captured by Berry et al. (2004), 86% were captured in 1998 which was likely at the onset of that species population growth in the lower Missouri River. Therefore, it does appear that Asian carp are increasing in the Missouri River. However, based on the high variability in our mean CPUE data, driven in part by low overall catches and wariness of the fish to capture, annual point estimates of relative abundance are not adequate to detect changes in abundance of Asian carp.

Spatial trends were found as bighead, silver, and grass carp were mostly captured downstream in the Platte-Kansas and Interior Highlands reaches. Very few silver carp were collected in the Gavins Point reach throughout the study. Our data confirms what Berry et al. (2004) reported, as bighead carp were found almost exclusively downstream of the Platte River and grass carp were found throughout the Missouri River downstream of Gavins Point Dam from 1996 to 1998. Although Asian carp have the ability to move great distances (Conover 2007) and bighead carp have been reported to move 163 km upstream in a 35 d period (Peters et al. 2006), it appears that relative abundances of carp remain the highest in the Missouri River from the mouth upstream to the Platte River confluence.

Young of the year bighead, silver, and grass carp were almost exclusively captured in the Interior Highlands reach which is the furthest downstream reach in the Missouri River. Fewer young of the year were captured as we moved upstream towards Gavins Point Dam. In an attempt to specifically target young of the year Asian carp with various traps, nets, and seining, none were found within 65 rkm downstream of Gavins Point Dam (Klumb 2007). Klumb (2007) hypothesized that adult Asian carp may be moving upstream to Gavins Point Dam to feed, but were not reproducing in that reach. Bighead carp were reported to reproduce in the Missouri River with the highest densities of larval fish captured the furthest downstream (rkm 516) (Schrank et al. 2001). Although Asian carp may be spawning further upstream of the Interior Highlands reach, 1) spawning may not be as successful upstream; 2) larval and juvenile Asian carp drift great distances downstream; and 3) more nursery habitat may be available in the Interior Highlands reach.

The length-weight relationship for bighead, silver, and grass carp were compared between the Gavins Point and Interior Highlands reach. Weight gain as the fish grows was similar between the two reaches for all three Asian carp species based on 95% confidence intervals around length-weight regressions. However, ANCOVA found that there were differences in weight at given lengths (condition) for bighead carp and significantly differed between the two reaches. Differences in silver carp condition may not have been detected due to low sample size. Additionally, fish at shorter lengths attained less weight in the Gavins Point reach compared to downstream in the Interior Highlands reach for all three Asian carp species.

Conversely, as Asian carp attained greater lengths in the Gavins Point reach, they then tended to attain greater weights than the fish in the Interior Highlands reach. More young of the year Asian carp were found in the Interior Highlands reach and given the higher weights at smaller lengths; this may suggest a greater availability of food. Productivity of large rivers increases longitudinally (Vannotte et al. 1980). Increased condition may also indicate better habitat conditions (Blackwell et al. 2000) were available for small Asian carp compared to further upstream in the Missouri River.

Gonadal development, especially given the high biomass of eggs in female Asian carp (Shrank and Guy 2002; Williamson and Garvey 2005), will affect relative condition of fish. Although fish were not identified by sex and condition was not analyzed by season (Blackwell et al. 2000) during this study, more female fish may have been measured in our samples. Asian carp may have moved upstream into the Gavins Point reach during spawning, which may explain the high relative condition for large fish in this reach. Schrank and Guy (2002) reported the relationship between weight and length was highly similar between male and female bighead carp in the Missouri River; however, their sampling was not conducted during the peak spawning period, which precluded comparisons of condition between sexes of ripe fish.

Through the three long-term fish community monitoring programs, this study was able to provide insights into the relative abundance, size structure, and spatial and temporal trends of Asian carp in the Missouri River with comparisons among multiple gears. Multiple sampling gears are necessary to monitor Asian carp population characteristics in the Missouri River. To enable spatial comparisons, gear specifications and deployment methods need to be standardized as they were across multiple sampling programs along 1,416 km of the Missouri River downstream of Gavins Point Dam. Further research should develop techniques to increase sampling efficiency to improve annual estimates of Asian carp relative abundance. Bighead, silver, and grass carp appear to be increasing in abundance and successful spawning and recruitment is well documented. Asian carp populations are established and it is increasingly important to understand the affects this will have on the native fish community in the Missouri River.

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**References**

Avault, J. W., Jr. 1965. Preliminary studies with grass carp for aquatic weed control. The Progressive Fish-Culturist 27:207-209.

Berry, C. R. Jr., M. L. Wildhaber, and D. L. Galat. 2004. Fish distribution and abundance. Volume 3. Population structure and habitat use of benthic fishes along the Missouri and lower Yellowstone rivers. U. S. Geological Survey, Cooperative Fish and Wildlife Research Units, South Dakota State University. Brookings.

Blackwell, B. G., M. L. Brown, and D. W. Willis. 2000. Relative weight (*Wr*) status and current use in fisheries assessment and management. Reviews in Fisheries Science 8:1-44.

Chick, J. H., and M. A. Pegg. 2001. Invasive carp in the Mississippi River basin. Science 292:2250-2251.

Conover, G., R. Simmonds, and M. Whalen, editors. 2007. Management and Control Plan for bighead, black, grass, and silver carps in the United States. Asian Carp Working Group, Aquatic Nuisance Species Task Force, Washington, D. C. 223 pp.

Cudmore, B., and N. E. Mandrak. 2004. Biological synopsis of grass carp (*Ctenopharyngodon idella*). Canadian Manuscript Report of Fisheries and Aquatic Sciences 2705. 44 pages.

Dauwalter, D. C., and J. R. Jackson. 2005. A re-evaluation of U. S. state fish-stocking recommendations for small, private, warmwater impoundments. Fisheries 30 (8):18-28.

Drobish, M. R. (Editor). 2008a. Pallid sturgeon population assessment program, Volume 1.3. U. S. Army Corps of Engineers, Omaha District, Yankton, South Dakota.

Drobish, M. R. (Editor). 2008b. Missouri River standard operating procedures for sampling and data collection, Volume 1.3. U. S. Army Corps of Engineers, Omaha District, Yankton, South Dakota.

Fowler, A. J., D. M. Lodge, and J. F. Hsia. 2007. Failure of the Lacey Act to protect U.S. ecosystems against animal invasions. Frontiers in Ecology and the Environment 5:353-359.

Freeze, M., and S. Henderson. 1982. Distribution and status of the bighead carp and silver carp in Arkansas. North American Journal of Fisheries Management 2:197-200.

Guillory, V., and R. D. Gasaway. 1978. Zoogeography of the grass carp in the United States. Transactions of the American Fisheries Society 107:105-112.

Hintze, J. L. 2006. Quick start and help manual NCSS 2000 statistical system for Windows. Number Cruncher Statistical Software, Kaysville, Utah.

Irons, K. S., G. G. Sass, M. A. McClelland, and J. D. Stafford. 2007. Reduced condition factor of two native fish species coincident with invasion of non-native Asian carps in the Illinois River, U.S.A. Is this evidence for competition and reduced fitness? Journal of Fish Biology 71:258-273.

Kaemingk, M. A., B. D. S. Graeb, C. W. Hoagstrom, and D. W. Willis. 2007. Patterns of fish diversity in a mainstem Missouri River reservoir and associated delta in South Dakota and Nebraska, USA. River Research and Applications 23:786-791.

Koel, T. M., K. S. Irons, and E. Ratcliff. 2000. Asian carp invasion of the Upper Mississippi River system. Project Status Report 2000-05. U. S. Geological Survey, Upper Midwest Environmental Sciences Center, LaCrosse, Wisconsin. 2 pages.

Kolar, C. S., D. C. Chapman, W. R. Courtenay, C. M. Housel, J. D. Williams, and D. P. Jennings. 2005. Asian carps of the genus Hypophthalmichthys (Pisces, Cyrprinidae) – a biological synopsis and environmental risk assessment. Report to the U. S. Fish and Wildlife Service. U. S. Geological Survey, LaCrosse, Wisconsin. 184 pages.

Johal, M. S., H. R. Esmaeili, and K. K. Tandon. 2001. A comparison of back-calculated lengths of silver carp from bony structures. Journal of Fish Biology 59:1483-1493.

Mitchell, A. J., and A. M. Kelly. 2006. The public sector role in the establishment of grass carp in the United States. Fisheries 31(3):113-121.

Nico, L. G., J. D. Williams, and H. L. Jelks. 2005. Black carp: biological synopsis and risk assessment of an introduced fish. American Fisheries Society, Special Publication 32. Bethesda, Maryland.

Papoulias, D. M., D. Chapman, and D. E. Tillitt. 2006. Reproductive condition and occurrence of intersex in bighead and silver carp in the Missouri River. Hydrobiologia 571:355-360.

Peters, L. M., M. A. Pegg, and U. G. Reinhardt. 2006. Movements of adult radio-tagged bighead carp in the Illinois River. Transactions of the American Fisheries Society 135:1205-1212.

Pflieger, W. L. 1978. Distribution and status of the grass carp in Missouri streams. Transactions of the American Fisheries Society 107:113-118.

Quinn, G. P., and M. J. Keough. 2002. Experimental design and data analysis for biologists. Cambridge University Press, New York.

Sampson, S. J., and O. N. Cox. 2007. 2005 Annual Report. Missouri River Habitat Assessment Monitoring Program: Segment 8 and Segment 9. Prepared for the U. S. Army Corps of Engineers – Northwest Division. Nebraska Game and Parks Commission, Lincoln.

Sampson. S. J., J. H. Chick, and M. A. Pegg. 2009. Dietary overlap among two Asian carp and three native fishes in backwater lakes on the Illinois and Mississippi rivers. Biological Invasions.

Schrank, S. J., P. J. Braaten, and C. S. Guy. 2001. Spatiotemporal variation in density of larval bighead carp in the lower Missouri River. Transactions of the American Fisheries Society 130:809-814.

Schrank, S. J., and C. S. Guy. 2002. Age, growth, and gonadal characteristics of adult bighead carp, *Hypophthalmichthys nobilis*, in the lower Missouri River. Environmental Biology of Fishes 64:443-450.

Schrank, S. J., C. S. Guy, and J. F. Fairchild. 2003. Competitive interactions between age-0 bighead carp and paddlefish. Transactions of the American Fisheries Society 132:1222-1228.

Shuman, D. A., G. A. Wanner, R. A. Klumb. 2008. 2007 annual report. Pallid sturgeon population assessment and associated fish community monitoring for the Missouri River: Segments 5 and 6. Prepared for the U. S. Army Corps of Engineers. U. S. Fish and Wildlife Service, Great Plains Fish and Wildlife Management Assistance Office, Pierre, South Dakota.

Stancill, W. 2003. An evaluation of sampling techniques and life history information on bighead carp in the Missouri River, below Gavins Point Dam, South Dakota and Nebraska. U. S. Fish and Wildlife Service, Great Plains Fish and Wildlife Management Assistance Office, Pierre, South Dakota.

Sterner, V., and R. Bowman. 2006. Fish community monitoring of off-channel habitat at the Tieville-Decatur Bend, Louiville Bend, Tyson Island and California Bend. Missouri River Fish and Wildlife Mitigation Project, Progress Report 2006. Prepared for the U. S. Army Corps of Engineers. Iowa Department of Natural Resources, Onawa, Iowa.

U. S. Army Corps of Engineers. 2003. Final supplemental environmental impact statement, Missouri River bank stabilization and navigation project, fish and wildlife mitigation project. U. S. Army Corps of Engineers, Omaha District, Omaha, Nebraska and Kansas City District, Kansas City, Kansas.

U. S. Fish and Wildlife Service. 2005. America's mussels: silent sentinels. Available: http://www.fws.gov/Midwest/Endangered/clams/mussels.html.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37:130-137.

Williamson, C. J., and J. E. Garvey. 2005. Growth, fecundity, and diets of newly established silver carp in the middle Mississippi River. Transactions of the American Fisheries Society 134:1423-1430.

Table 1. Summary of gear numbers (N) deployed during the Pallid Sturgeon Population Assessment Program (PSPAP) from 2003 to 2007, Habitat Assessment Monitoring Program (HAMP) from 2005 to 2007, and Fish and Wildlife Mitigation Project (Mitigation Project) from 2005 to 2007 in the Missouri River and number of Asian carp captured by each gear. Only gears that were deployed at least 100 times are presented in this table. Sampling gear codes and deployment methods are described in Drobish (2008b).

| Gear | Code | N | Bighead | Silver | Grass |
|---|---|---|---|---|---|
| **Pallid Sturgeon Population Assessment Program (PSPAP)** | | | | | |
| Bag seine (6.4 mm mesh) | BS | 937 | 0 | 0 | 0 |
| Beam trawl (Faulkner) | BTF | 347 | 0 | 0 | 0 |
| Gill net (31 m; 4 panels) | GN14 | 772 | 5 | 5 | 16 |
| Gill net (61 m; 8 panels) | GN18 | 2,919 | 50 | 173 | 126 |
| Gill net (7.6 cm mesh) | GNH3 | 124 | 0 | 0 | 0 |
| Otter trawl (4.9 m; 4 mm mesh) | OT01 | 590 | 0 | 0 | 0 |
| Hoop net (1.2 m hoop) | HN | 875 | 144 | 17 | 16 |
| Mini-fyke net (3 mm mesh) | MF | 2,410 | 200 | 54 | 15 |
| Otter trawl (4.9 m; 38 mm mesh) | OT16 | 5,946 | 0 | 0 | 0 |
| Push trawl (2.4 m; 4 mm mesh) | POT02 | 483 | 0 | 0 | 0 |
| Set line | SL | 134 | 0 | 0 | 0 |
| Trot line | TL | 315 | 0 | 0 | 0 |
| Trammel net (38.1 m; 6.4 cm mesh) | TN25 | 1,302 | 0 | 0 | 0 |
| Trammel net (38.1 m; 15.2 cm mesh) | TN610 | 136 | 0 | 0 | 0 |
| Trammel net (38.1 m; 2.5 cm mesh) | TN | 6,898 | 79 | 29 | 97 |
| **Habitat Assessment Monitoring Program (HAMP)** | | | | | |
| Bag seine (6.4 mm mesh | BS | 309 | 0 | 0 | 0 |
| Gill net (61 m; 8 panels) | GN18 | 546 | 3 | 5 | 6 |
| Mini-fyke net (3 mm mesh) | MF | 736 | 0 | 1 | 2 |
| Otter trawl (4.9 m; 4 mm mesh) | OT01 | 393 | 1 | 2 | 0 |
| Otter trawl (4.9 m; 4 mm mesh) | OT04 | 1,278 | 2 | 13 | 1 |
| Otter trawl (4.9 m; 38 mm mesh) | OT16 | 2,356 | 7 | 22 | 4 |
| Otter trawl (2.4 m; 4 mm mesh) | OT08 | 161 | 0 | 3 | 0 |
| Push trawl (2.4 m; 4 mm mesh) | POT02 | 2,785 | 5 | 392 | 3 |
| Trammel net (38.1 m; 2.5 cm mesh) | TN | 1,983 | 5 | 3 | 39 |
| **Mitigation Project** | | | | | |
| Bag seine (6.4 mm mesh | BS | 755 | 0 | 0 | 0 |
| Electrofishing | EF | 1,905 | 20 | 80 | 91 |
| Fyke-net (1.9 cm mesh) | FN36 | 512 | 5 | 0 | 2 |
| Gill net (31 m; 4 panels; timed) | GN14T | 190 | 43 | 3 | 5 |
| Hoop net (1.2 m hoop) | HN | 1,335 | 349 | 13 | 68 |
| Mini-fyke net (3 mm mesh) | MF | 1,736 | 9 | 29 | 3 |
| Otter trawl (2.4 m; 4 mm mesh) | OT02 | 239 | 0 | 0 | 0 |
| Otter trawl (4.9 m; 38 mm mesh) | OT16 | 731 | 6 | 1 | 2 |
| Otter trawl (2.4 m; 4 mm mesh) | OT08 | 420 | 0 | 0 | 0 |
| Push trawl (2.4 m; 4 mm mesh) | POT02 | 869 | 0 | 3 | 0 |
| Hoop net, small (0.6 m hoop) | SHN | 1,206 | 4 | 1 | 3 |
| Trammel net (7.6 m; 2.5 cm mesh) | TN11 | 669 | 0 | 0 | 2 |
| Trammel net (15.2 m; 2.5 cm mesh) | TN50 | 405 | 1 | 4 | 6 |
| HN and SHN set in tandem | XHN | 272 | 49 | 0 | 16 |

Table 2. Bighead carp total catch from all sampling gears in each Missouri River segment during the Pallid Sturgeon Population Assessment Program (PSPAP) from 2003 to 2007, Habitat Assessment Monitoring Program (HAMP) from 2005 to 2007, and Fish and Wildlife Mitigation Project (Mitigation Project) from 2005 to 2007 in the Missouri River. Segment 28 is the Osage River, Missouri.

| | Segment | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Year | 7 | 8 | 9 | 10 | 11 | 13 | 14 | 28 | Total |
| | | | | **Pallid Sturgeon Population Assessment Program** | | | | | |
| 2003 | a | a | 9 | a | a | 221 | 66 | a | 296 |
| 2004 | 2 | a | 25 | a | a | 31 | 220 | a | 278 |
| 2005 | 0 | 6 | 5 | 5 | a | 14 | 6 | 0 | 36 |
| 2006 | 6 | 7 | 38 | 7 | 0 | 13 | 19 | 0 | 98 |
| 2007 | 5 | 4 | 4 | 3 | 2 | 4 | 0 | 1 | 23 |
| | | | | **Habitat Assessment Monitoring Program** | | | | | |
| 2005 | a | 2 | 0 | a | a | 0 | a | a | 2 |
| 2006 | a | 2 | 6 | a | a | 3 | a | a | 11 |
| 2007 | a | 1 | 1 | 0 | a | 4 | 5 | a | 11 |
| | | | | **Mitigation project** | | | | | |
| 2005 | a | a | a | a | a | 13 | 64 | a | 77 |
| 2006 | a | 60 | 6 | a | a | 11 | 11 | a | 88 |
| 2007 | a | 328 | 9 | a | a | 36 | 19 | a | 426 |
| Grand total | 13 | 410 | 103 | 15 | 5 | 350 | 410 | 1 | 1,307 |

a = No sampling occurred.

Table 3. Silver carp total catch from all sampling gears in each Missouri River segment during the Pallid Sturgeon Population Assessment Program (PSPAP) from 2003 to 2007, Habitat Assessment Monitoring Program (HAMP) from 2005 to 2007, and Fish and Wildlife Mitigation Project (Mitigation Project) from 2005 to 2007 in the Missouri River. Segment 28 is the Osage River and segment 29 is the Gasconade River, Missouri.

| | Segment | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | 7 | 8 | 9 | 10 | 11 | 13 | 14 | 28 | 29 | Total |
| **Pallid Sturgeon Population Assessment Program** | | | | | | | | | | |
| 2003 | a | a | 0 | a | a | 38 | 4 | a | a | 42 |
| 2004 | 0 | a | 4 | a | a | 27 | 267 | a | a | 298 |
| 2005 | 1 | 1 | 6 | 1 | a | 36 | 38 | 0 | 0 | 83 |
| 2006 | 1 | 2 | 10 | 9 | 4 | 21 | 40 | 2 | 0 | 89 |
| 2007 | 0 | 1 | 6 | 13 | 3 | 35 | 11 | 0 | 1 | 70 |
| **Habitat Assessment Monitoring Program** | | | | | | | | | | |
| 2005 | a | 2 | 0 | a | a | 3 | a | a | a | 5 |
| 2006 | a | 2 | 2 | a | a | 18 | a | a | a | 22 |
| 2007 | a | 0 | 2 | 3 | a | 383 | 133 | a | a | 521 |
| **Mitigation project** | | | | | | | | | | |
| 2005 | a | a | a | a | a | 9 | 19 | a | a | 28 |
| 2006 | a | 1 | 6 | a | a | 38 | 19 | a | a | 64 |
| 2007 | a | 7 | 3 | a | a | 19 | 29 | a | a | 58 |
| Grand total | 2 | 16 | 39 | 26 | 7 | 627 | 560 | 2 | 1 | 1,280 |

a = No sampling occurred.

Table 4. Grass carp total catch from all sampling gears in each Missouri River segment during the Pallid Sturgeon Population Assessment Program (PSPAP) from 2003 to 2007, Habitat Assessment Monitoring Program (HAMP) from 2005 to 2007, and Fish and Wildlife Mitigation Project (Mitigation Project) from 2005 to 2007 in the Missouri River. Segment 28 is the Osage River and segment 29 is the Gasconade River, Missouri.

| | Segment | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | 7 | 8 | 9 | 10 | 11 | 13 | 14 | 28 | 29 | Total |
| | | | | **Pallid Sturgeon Population Assessment Program** | | | | | | |
| 2003 | a | a | 13 | a | a | 29 | 4 | a | a | 46 |
| 2004 | 1 | 1 | 17 | a | a | 14 | 6 | a | a | 39 |
| 2005 | 1 | 13 | 23 | 1 | a | 30 | 18 | 0 | 0 | 86 |
| 2006 | 6 | 19 | 36 | 9 | 1 | 20 | 14 | 0 | 1 | 106 |
| 2007 | 5 | 17 | 19 | 10 | 2 | 12 | 2 | 0 | 2 | 19 |
| | | | | **Habitat Assessment Monitoring Program** | | | | | | |
| 2005 | a | 10 | 0 | a | a | 5 | a | a | a | 15 |
| 2006 | a | 15 | 16 | a | a | 1 | a | a | a | 32 |
| 2007 | a | 1 | 2 | 2 | a | 2 | 1 | a | a | 8 |
| | | | | **Mitigation project** | | | | | | |
| 2005 | a | a | a | a | a | 19 | 17 | a | a | 36 |
| 2006 | a | 23 | 29 | a | a | 22 | 7 | a | a | 81 |
| 2007 | a | 32 | 28 | a | a | 34 | 12 | a | a | 106 |
| Grand total | 13 | 131 | 183 | 22 | 3 | 188 | 81 | 0 | 3 | 624 |

a = No sampling occurred.

Table 5. Two-way analysis of variance testing mean catch per unit effort (CPUE) for gill nets (fish/30.5 m gill net-night) from 2004 to 2007 and drifted trammel nets (number of fish/100 m) from 2005 to 2007 among years and Missouri River reaches (Gavins Point, Platte-Kansas, and Interior Highlands). Mean CPUE was ($log_{10}$[CPUE +1]) transformed.

| Gear | Source | *F* | df | *P* |
|---|---|---|---|---|
| | | **Bighead carp** | | |
| Gill net | Year | 1.30 | 3 | 0.273 |
| | Reach | 0.71 | 2 | 0.492 |
| | Year X reach | 2.07 | 6 | 0.053 |
| Trammel net | Year | 13.07 | 2 | <0.001* |
| | Reach | 9.32 | 2 | <0.001* |
| | Year X reach | 8.24 | 4 | <0.001* |
| | | **Silver carp** | | |
| Gill net | Year | 0.12 | 3 | 0.950 |
| | Reach | 40.93 | 2 | <0.001* |
| | Year X reach | 3.23 | 6 | 0.004* |
| Trammel net | Year | 1.27 | 2 | 0.281 |
| | Reach | 2.23 | 2 | 0.108 |
| | Year X reach | 1.48 | 4 | 0.206 |
| | | **Grass carp** | | |
| Gill net | Year | 1.47 | 3 | 0.222 |
| | Reach | 5.66 | 2 | 0.004* |
| | Year X reach | 3.53 | 6 | 0.002* |
| Trammel net | Year | 1.09 | 2 | 0.335 |
| | Reach | 5.98 | 2 | 0.003* |
| | Year X reach | 0.64 | 4 | 0.633 |

Table 6. Linear regression analysis comparing the $\log_{10}$length - $\log_{10}$weight relationship for Asian carp between two reaches of the Missouri River reaches (Gavins Point and Interior Highlands). Length-weight data from all three Missouri River monitoring programs from 2003 to 2007. All regressions were significant (P <0.001).

| Reach | N | Estimated Model | $r^2$ | Intercept 95% CI | Slope 95% CI |
|---|---|---|---|---|---|
| | | **Bighead carp** | | | |
| Gavins Point | 224 | $Log_{10}$weight = -4.86 + 2.96($Log_{10}$length) | 0.98 | 0.17 | 0.06 |
| Interior Highlands | 164 | $Log_{10}$weight = -4.30 + 2.75($Log_{10}$length) | 0.80 | 0.61 | 0.21 |
| | | **Silver carp** | | | |
| Gavins Point | 7 | $Log_{10}$weight = -6.92 + 3.70($Log_{10}$length) | 0.97 | 2.08 | 0.76 |
| Interior Highlands | 68 | $Log_{10}$weight = -5.35 + 3.13($Log_{10}$length) | 0.93 | 0.59 | 0.21 |
| | | **Grass carp** | | | |
| Gavins Point | 33 | $Log_{10}$weight = -4.59 + 2.87($Log_{10}$length) | 0.97 | 0.55 | 0.19 |
| Interior Highlands | 78 | $Log_{10}$weight = -4.33 + 2.77($Log_{10}$length) | 0.88 | 0.69 | 0.24 |

Table 7. Analysis of covariance (ANCOVA) with $\log_{10}$length set as the covariate and $\log_{10}$weight as the dependent variable, to test for differences in weight-at-length (condition) data between Gavins Point (upstream) and Interior Highlands (downstream) reaches for bighead, silver, and grass carp. The complete ANCOVA model tests for slope differences.

| Source | df | Mean square | *F* | *P* |
|---|---|---|---|---|
| | | **Bighead carp** | | |
| $Log_{10}$length | 1 | 22.8870 | 6,282.78 | < 0.001* |
| Interaction | 1 | 0.0167 | 4.58 | 0.033* |
| Reach | 1 | 0.0147 | 4.05 | 0.045* |
| | | **Silver carp** | | |
| $Log_{10}$length | 1 | 0.6752 | 122.09 | < 0.001* |
| Interaction | 1 | 0.0115 | 2.65 | 0.108 |
| Reach | 1 | 0.0143 | 2.62 | 0.110 |
| | | **Grass carp** | | |
| $Log_{10}$length | 1 | 5.1320 | 1,244.07 | < 0.001* |
| Interaction | 1 | 0.0017 | 0.42 | 0.518 |
| Reach | 1 | 0.0014 | 0.35 | 0.553 |

Table 8. Analysis of covariance (ANCOVA) with $log_{10}$length set as the covariate and $log_{10}$weight as the dependent variable, to test for differences in weight-at-length (condition) data between Gavins Point (upstream) and Interior Highlands (downstream) reaches for bighead, silver, and grass carp. The reduced ANCOVA model tests for intercept differences.

| **Source** | **df** | **Mean square** | ***F*** | ***P*** |
|---|---|---|---|---|
| | | **Silver carp** | | |
| $Log_{10}$length | 1 | 5.7054 | 1,008.65 | < 0.001* |
| Reach | 1 | 0.0003 | 0.06 | 0.806 |
| | | **Grass carp** | | |
| $Log_{10}$length | 1 | 7.0015 | 1,706.52 | < 0.001* |
| Reach | 1 | 0.0126 | 3.09 | 0.081 |


Figure 1. The Missouri River from Gavins Point Dam (rkm 1,305) to its confluence with the Mississippi River (rkm 0) delineated by segments (Drobish 2008b).

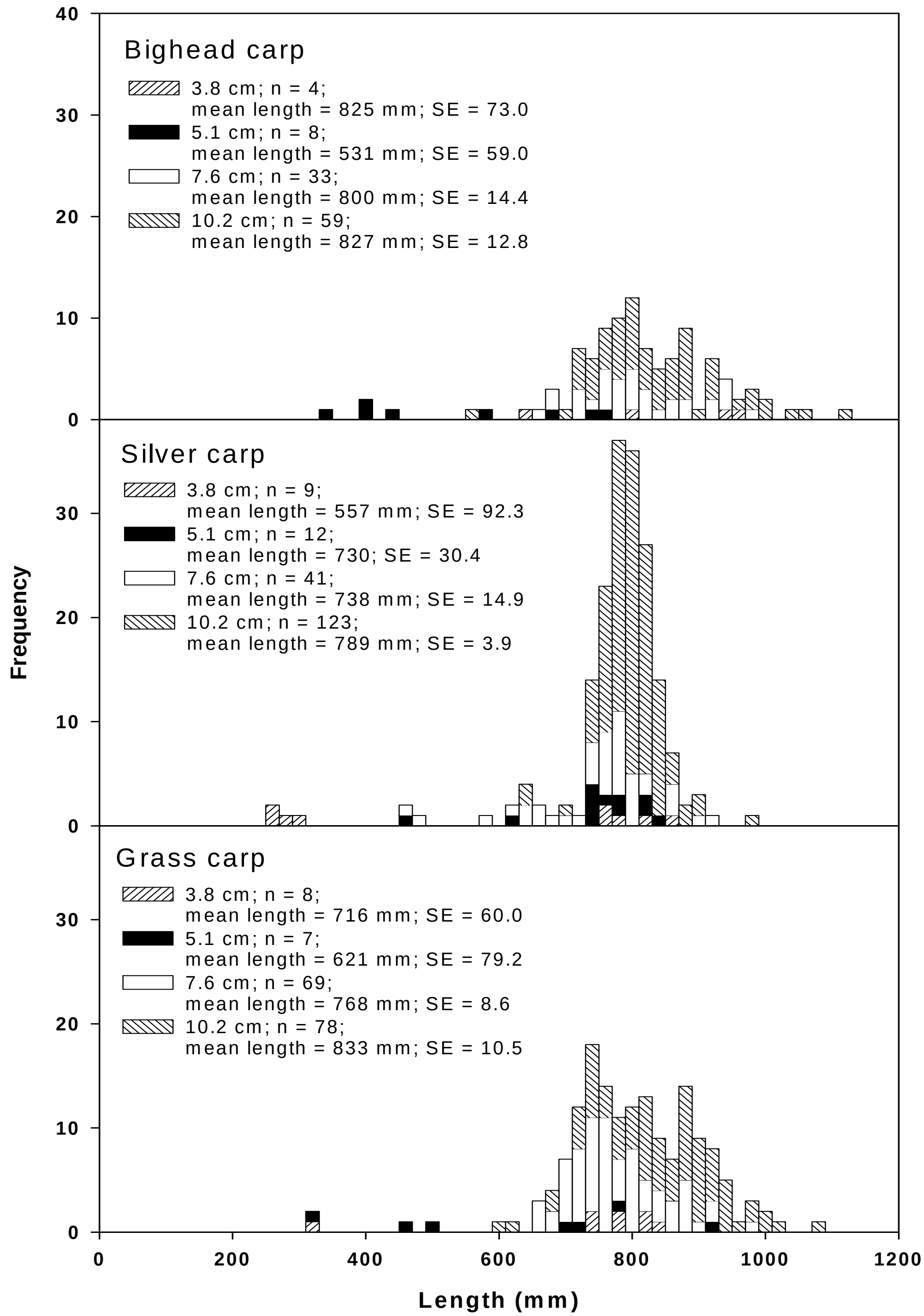


Figure 2. Length frequency distribution of Asian carp (20-cm length groups) captured in four different sized gill net mesh panels from all Missouri River monitoring programs from 2003 to 2007.

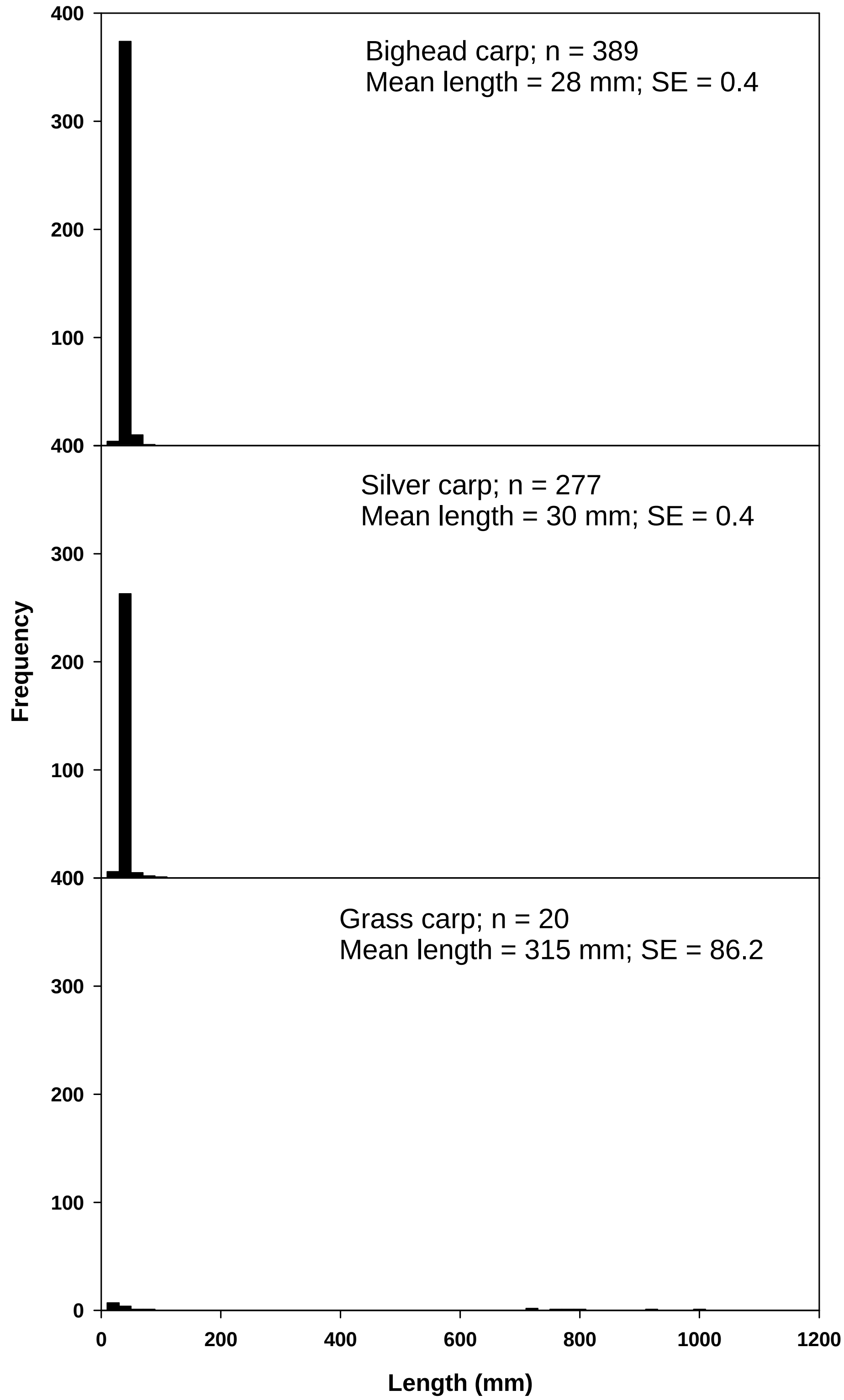


Figure 3. Length frequency distribution of Asian carp (20-cm length groups) captured in mini-fyke nets from all Missouri River monitoring programs from 2003 to 2007.

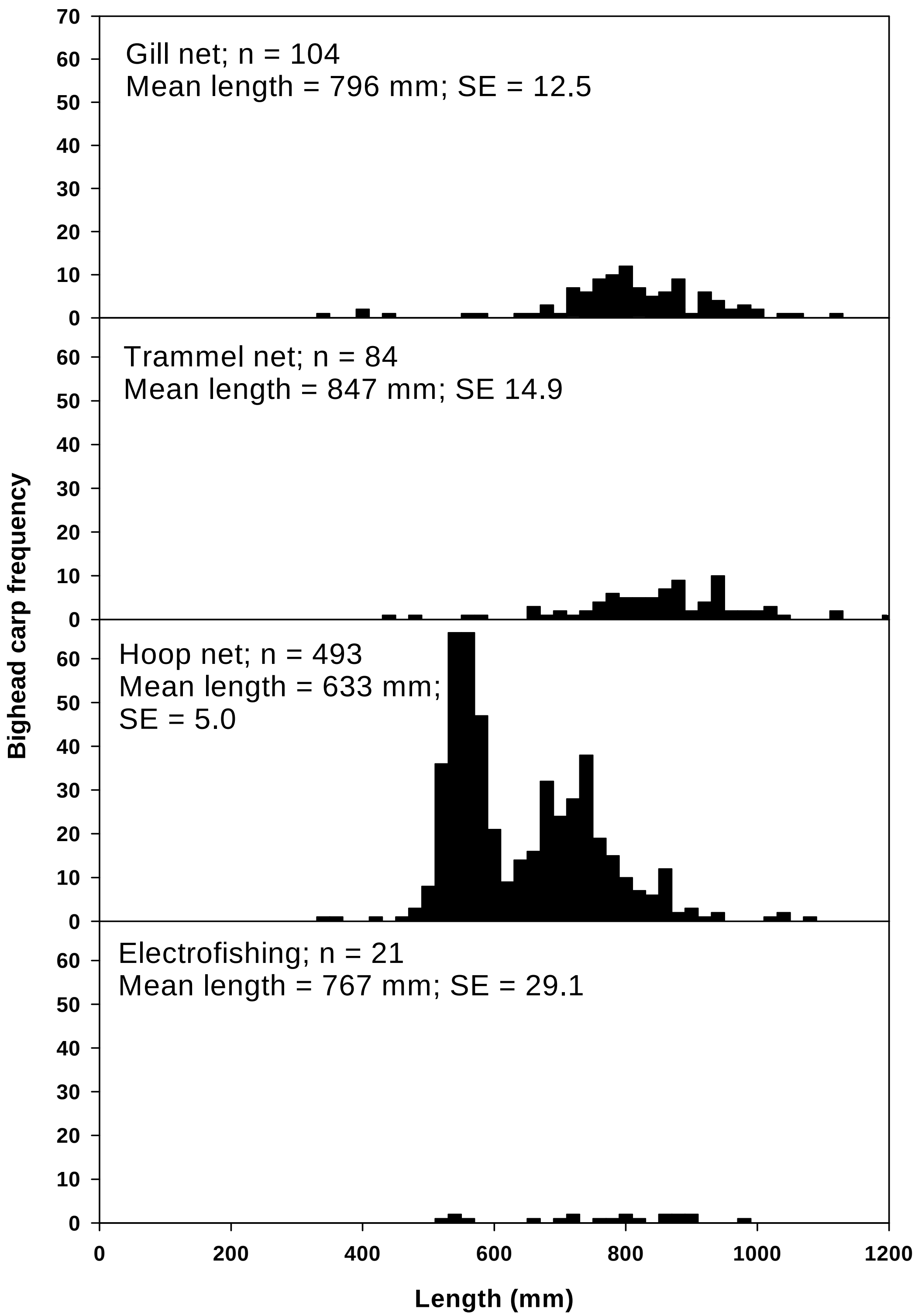


Figure 4. Length frequency distribution of bighead carp (20-cm length groups) captured in four gears from all Missouri River monitoring programs from 2003 to 2007.

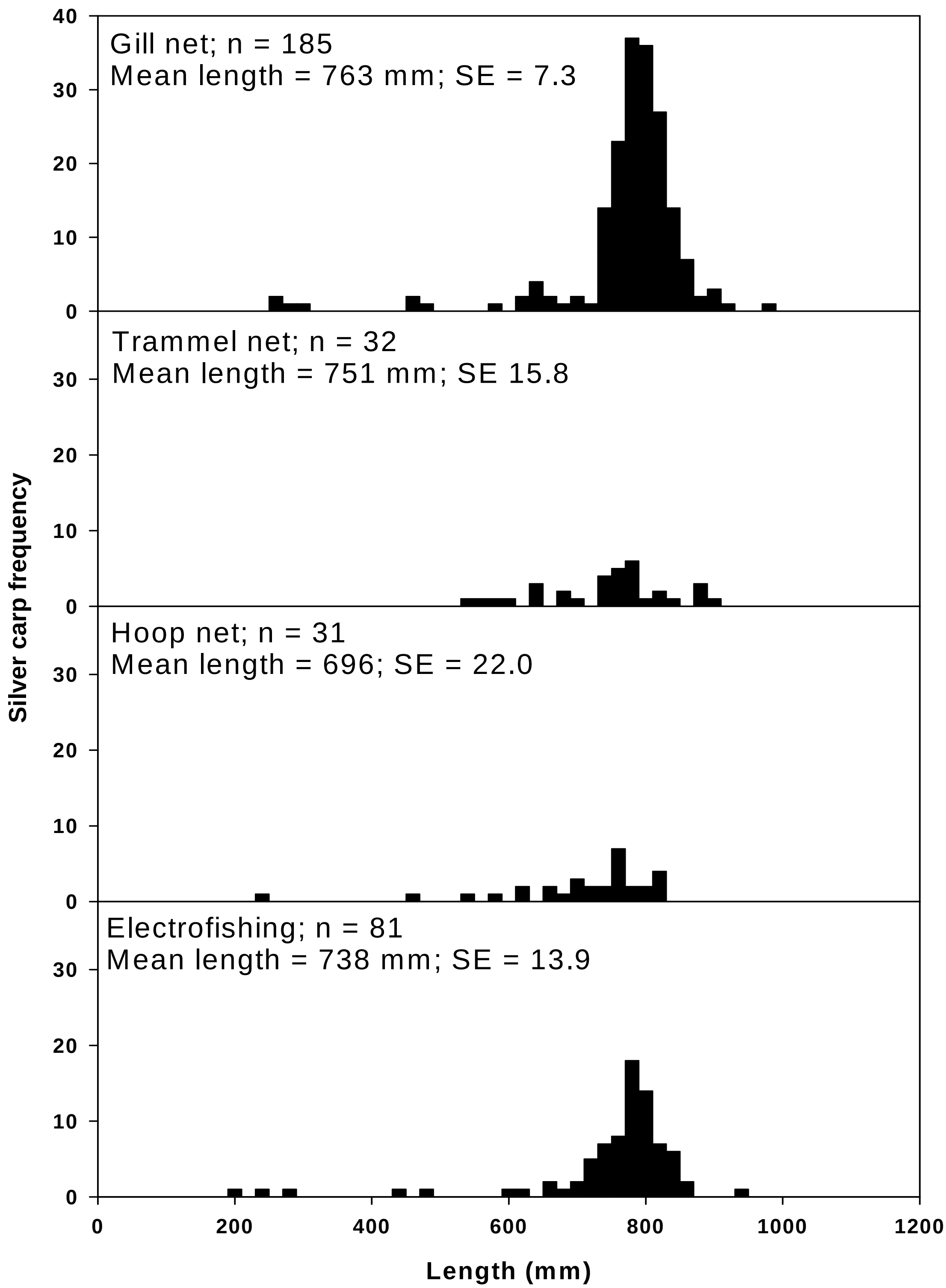


Figure 5. Length frequency distribution of silver carp (20-cm length groups) captured in four gears from all Missouri River monitoring programs from 2003 to 2007.

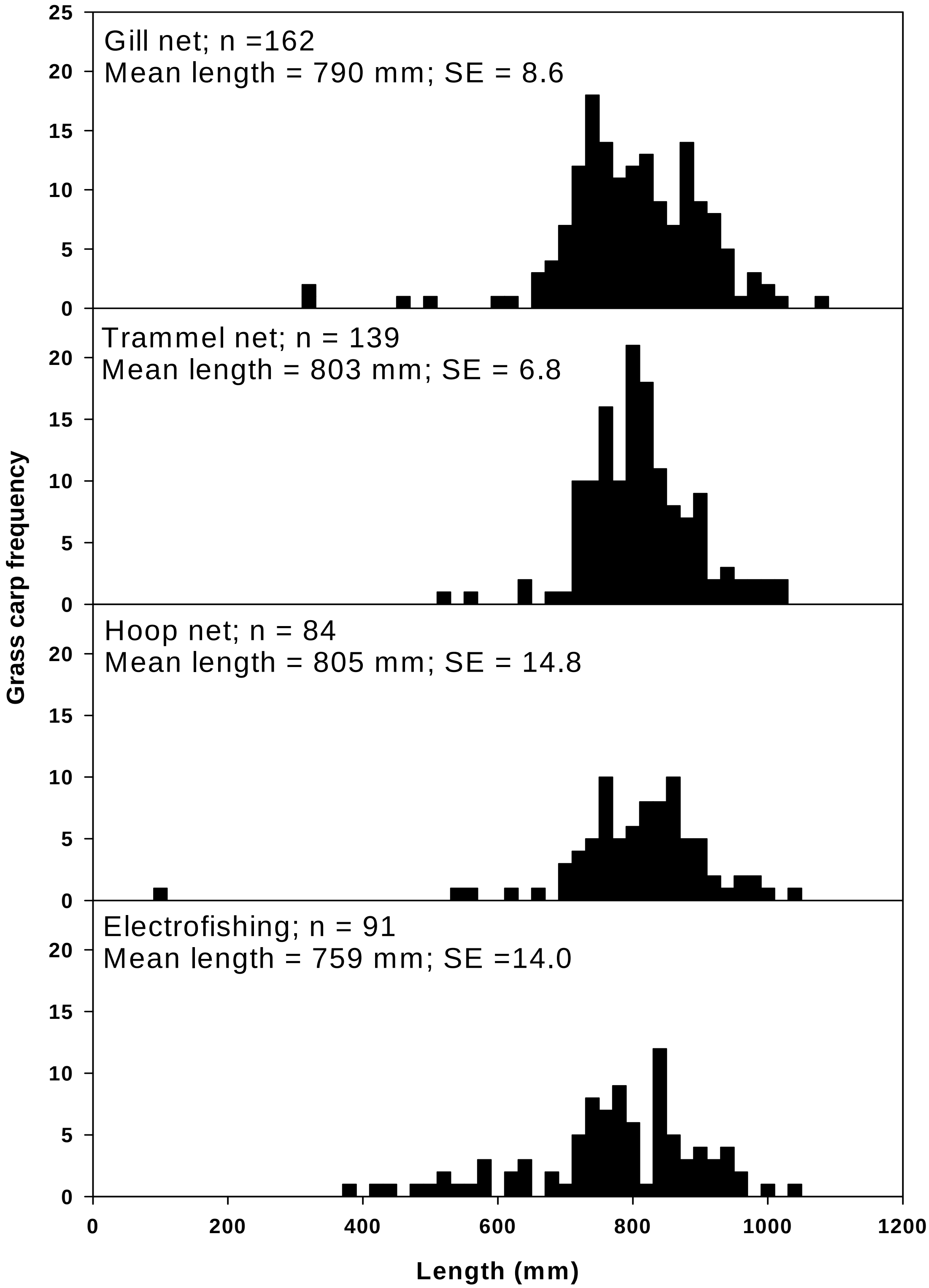


Figure 6. Length frequency distribution of grass carp (20-cm length groups) captured in four gears from all Missouri River monitoring programs from 2003 to 2007.

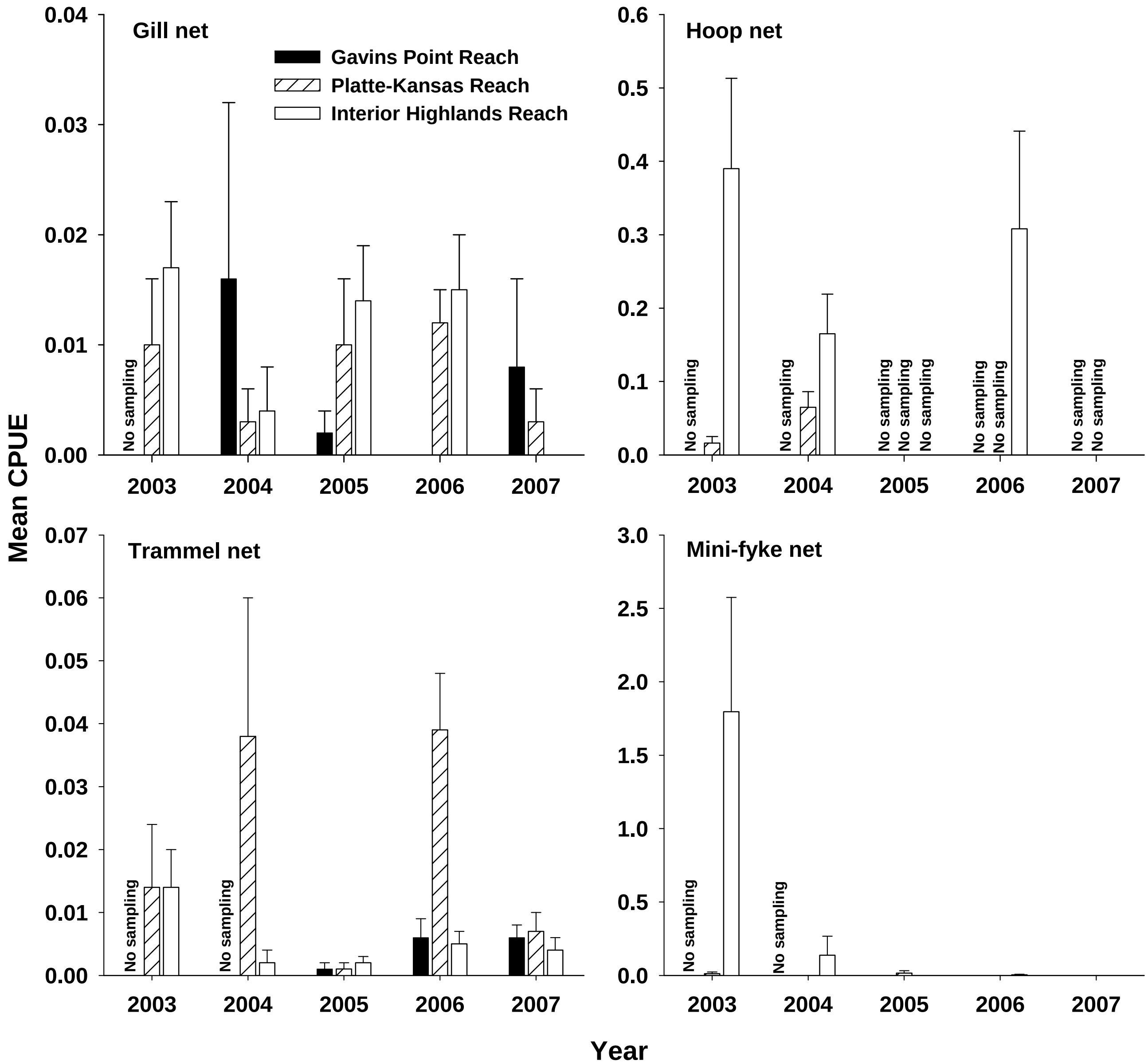


Figure 7. Bighead carp mean catch per unit effort (CPUE) for gill nets (number of fish/30.5 m gill net-night), hoop nets (number of fish/net-night), trammel nets (number of fish/100 m), and mini-fyke nets (number of fish/net-night) in the Missouri River from 2003 to 2007. Mean CPUE data presented is only from the Pallid Sturgeon Population Assessment Program because of the randomized design of selecting river bends within river segments.

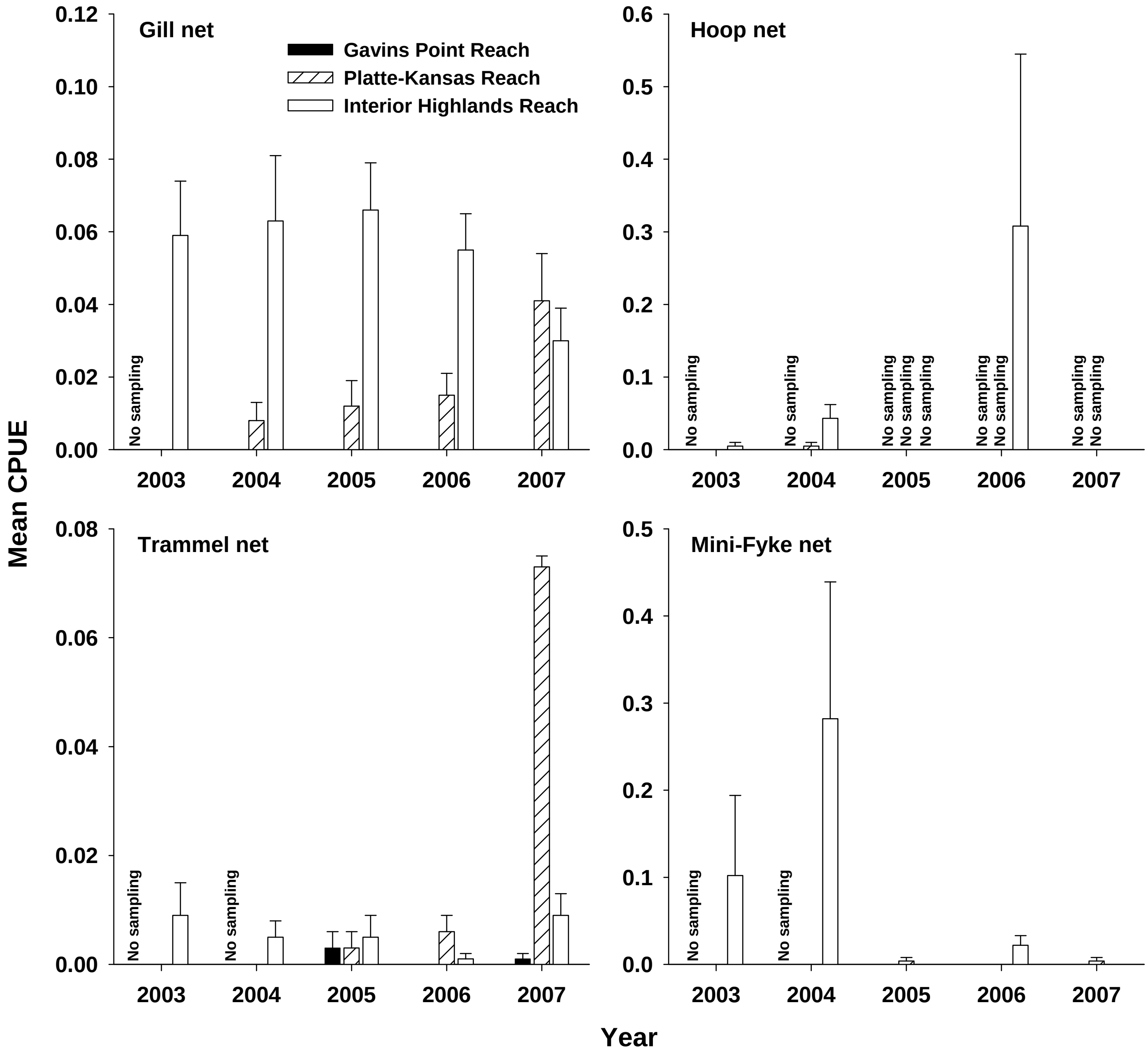


Figure 8. Silver carp mean catch per unit effort (CPUE) for gill nets (number of fish/30.5 m gill net-night), hoop nets (number of fish/net-night), trammel nets (number of fish/100 m), and mini-fyke nets (number of fish/net-night) in the Missouri River from 2003 to 2007. Mean CPUE data presented is only from the Pallid Sturgeon Population Assessment Program because of the randomized design of selecting river bends within river segments.

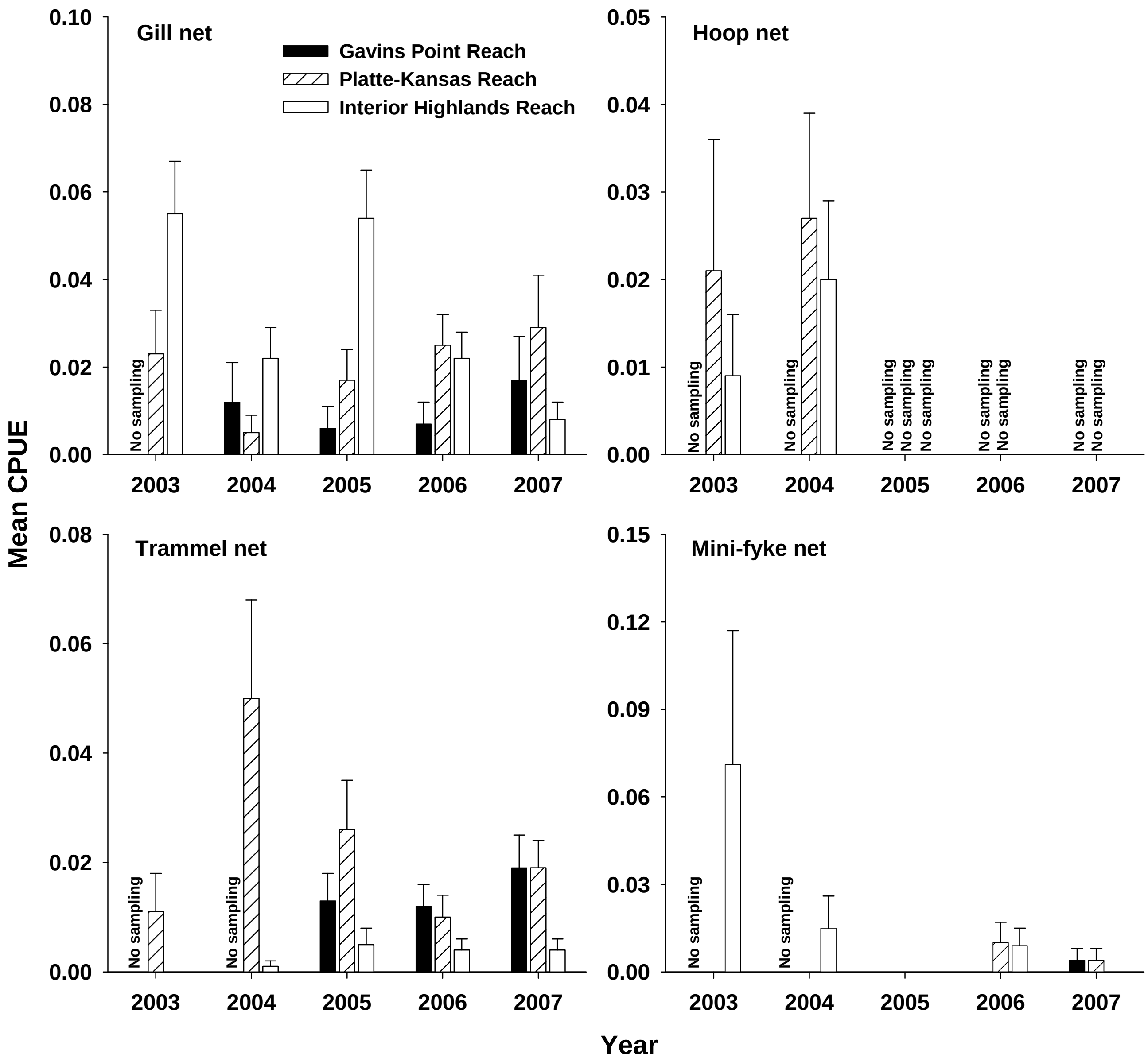


Figure 9. Grass carp mean catch per unit effort (CPUE) for gill nets (number of fish/30.5 m gill net-night), hoop nets (number of fish/net-night), trammel nets (number of fish/100 m), and mini-fyke nets (number of fish/net-night) in the Missouri River from 2003 to 2007. Mean CPUE data presented is only from the Pallid Sturgeon Population Assessment Program because of the randomized design of selecting river bends within river segments.

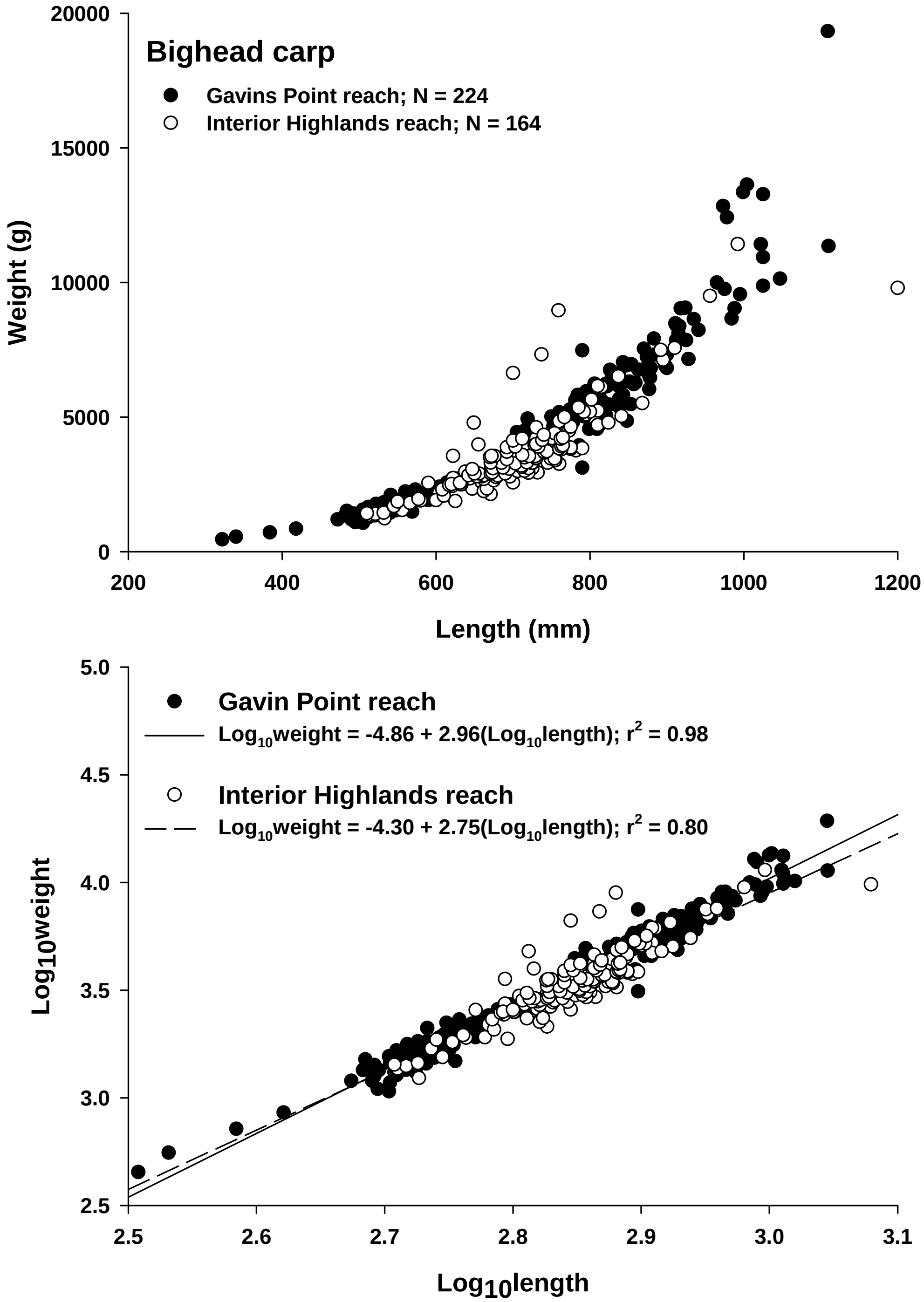


Figure 10. Weight-length relationship of bighead carp captured in the Missouri River in two reaches of the Missouri River from all monitoring programs from 2003 to 2007.

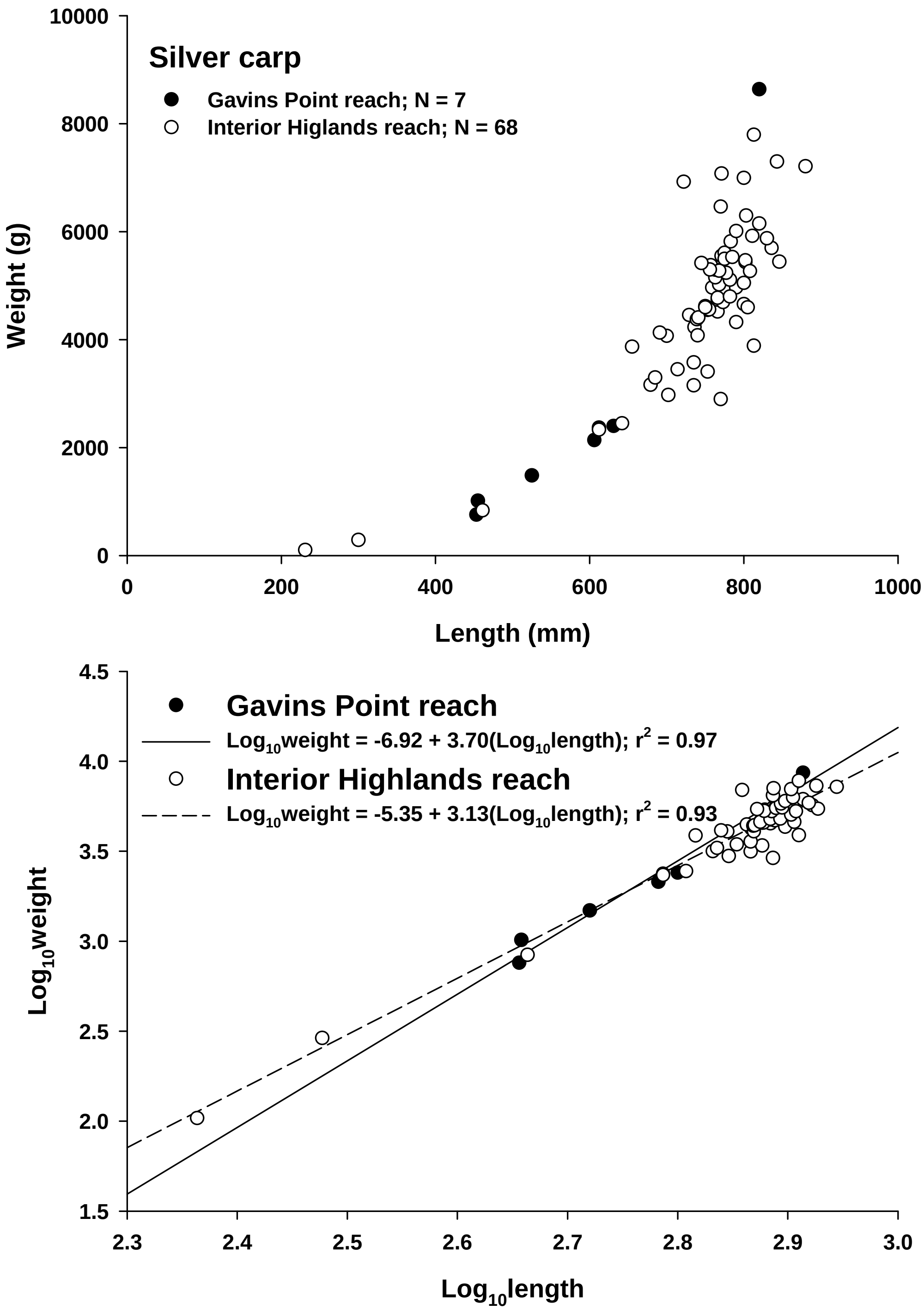


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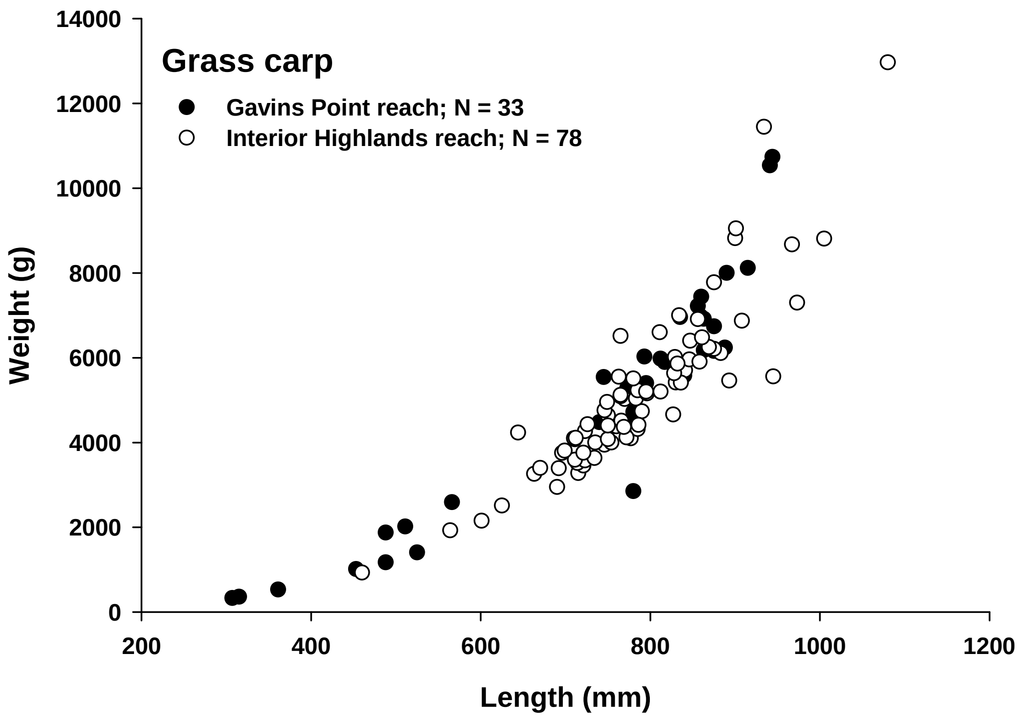
Figure 11. Weight-length relationship of Silver carp captured in two reaches of the Missouri River from all monitoring programs from 2003 to 2007.



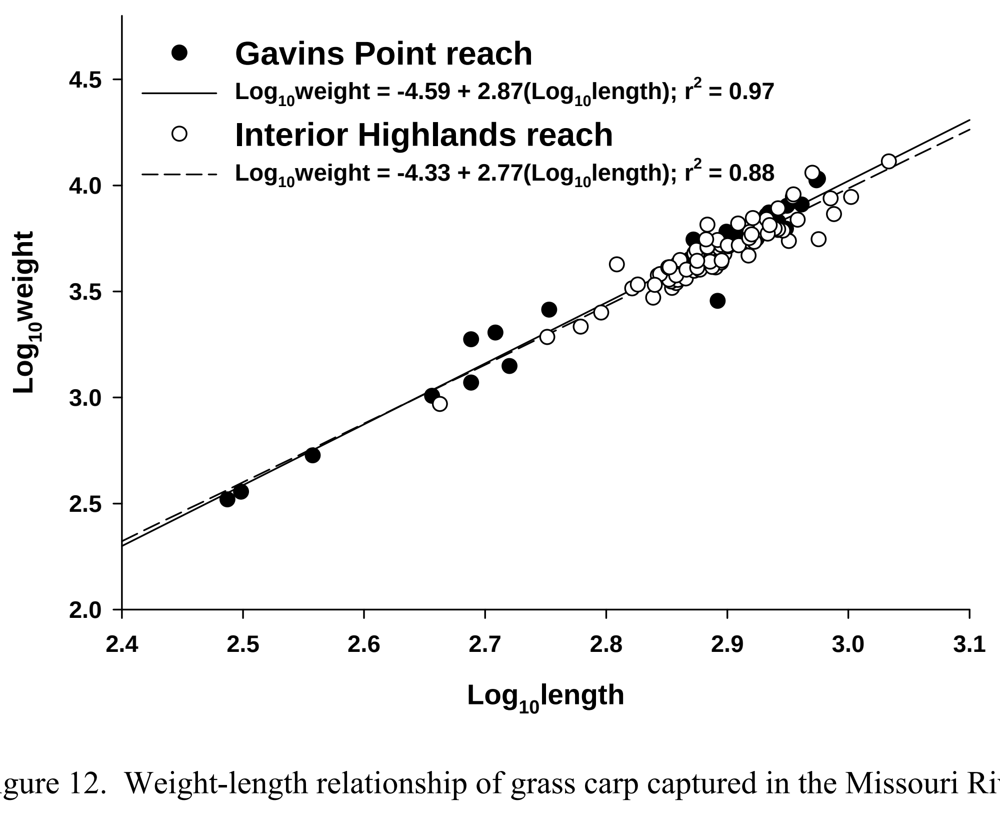




Figure 12. Weight-length relationship of grass carp captured in the Missouri River in two reaches of the Missouri River from all monitoring programs from 2003 to 2007.