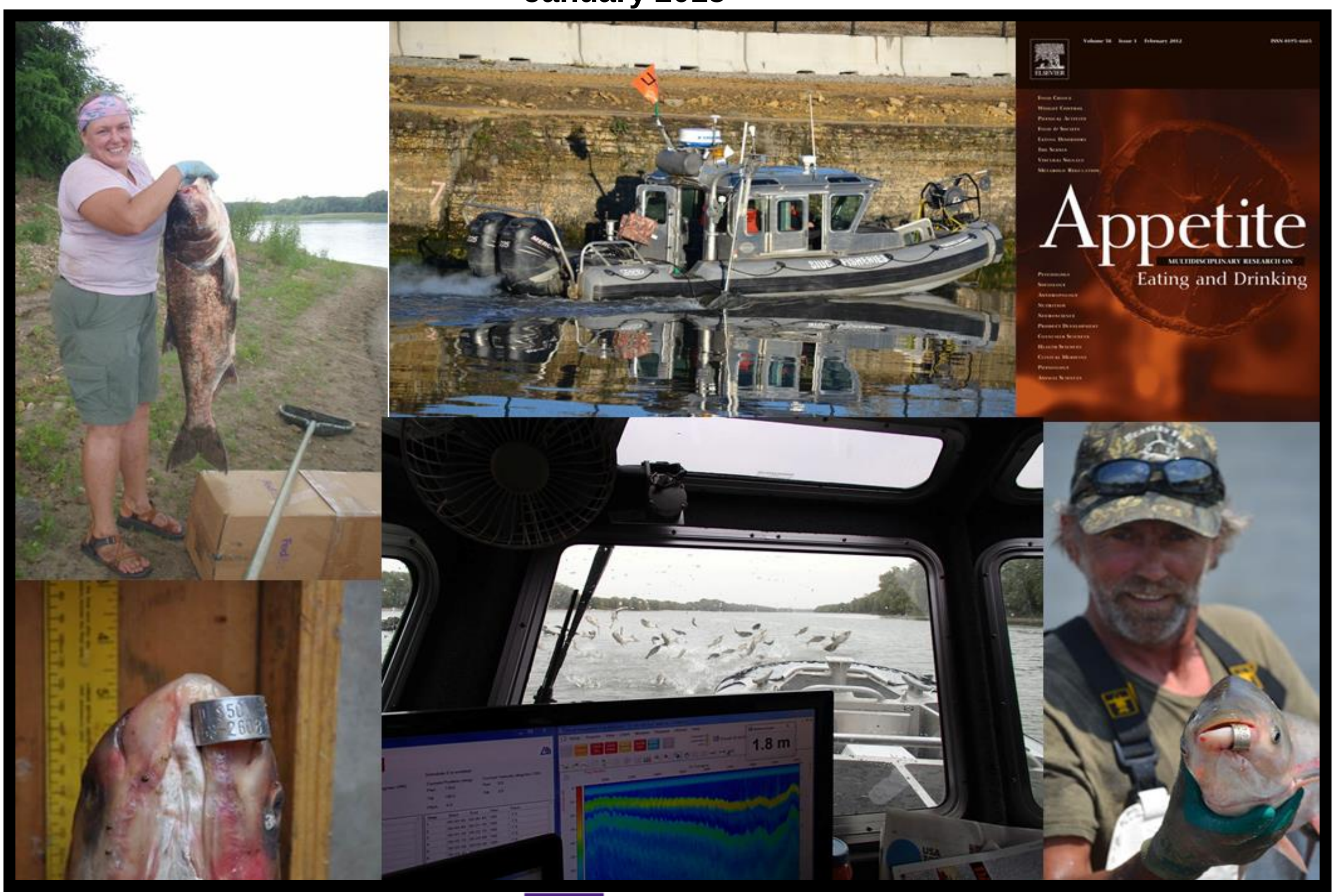
# Appendix D.

## 2014 Asian Carp Monitoring and Rapid Response Plan Interim Summary Reports

# Fishing Down the Bighead and Silver Carps: Reducing the Risk of Invasion to the Great Lakes

**A Final Report to the Illinois Department of Natural Resources by Southern Illinois University - Carbondale**

**January 2015**

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## Fishing Down the Bighead and Silver Carps: Reducing the Risk of Invasion to the Great Lakes

**FINAL REPORT**

Submitted to the Illinois Department of Natural Resources
Prepared by Marybeth K. Brey

January 2015


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# CHAPTER 1

## Executive Summary


Bighead carp and silver carp (hereafter, Asian carp) invaded the Illinois River waterway for over a decade ago. Populations of these fishes have grown dense in the lower and middle Illinois River and both species are approaching the Chicago Area Waterway System (CAWS) and the defensive electrical barrier. Without control, immigrants from the lower river will continue to migrate upstream, challenging the CAWS and ultimately the Great Lakes until they are reduced. This follows the “cockroach analogy” in that control of an insect infestation will be ineffective if only the few appearing out in the open are eliminated. Rather, effective control requires eradication at the source, such as in the cupboards or walls of an infested home. To protect the upstream CAWS and the Great Lakes while ameliorating the problem in US rivers and interior lakes, the populations of carp in the downstream reaches of the Illinois River need to be continually suppressed.

Asian carp are by far the world’s most cultured fish because they are a healthful source of protein and perhaps omega-3 fatty acids. Thus, unlike so many nuisance or invasive species, these problematic fishes in the US have one positive aspect: <u>they can be converted to desirable food for both human and nonhuman consumption</u>. The research described herein is designed with one simple idea in mind: to beat Asian carp in the Illinois River and eventually other US waterways by consuming them. Harvesting is an *immediate, revenue-positive complement* to other control efforts which may be effective but have not yet been developed.

Overharvest of Asian carp occurs in their native range and thus is possible in the Illinois River and other waterways of the US. However, several research questions must be addressed to ensure that both public and private resources are expended wisely and efficiently to effectively control these species. This report describes a multi-institution effort to quantify the abundance and ecological impact of these species in the Illinois River and then determine whether fishing is a viable option for control. Successful fishing requires an incentive on behalf of the commercial fishers and processors. Thus, marketing options need to be identified.

This report covers project findings since Fall 2010. The ecological and fish nutrition research began during fall 2010. The marketing research started in spring 2011. Funding for this research derived from Cooperative Agreement No. 30181AJ071 between the U.S. Fish and Wildlife Service and the Illinois Department of Natural Resources. **<u>Eight published journal articles have come out of this work to date</u>** (see Appendix), with many others currently in review or in the works.

**Highlights:**

- <u>Density, biomass and hydroacoustic surveys (Chapter 2):</u>
    - In 2010-2011, eight parallel hydroacoustic transects covered an estimated 0.39% of the total volume of 427.8 river km of the Illinois River. The main channel of the Illinois River from the confluence of the Illinois River and Mississippi River to Starved Rock Lock and Dam was surveyed, a total of 3,422.5 river km.

    - Protocols have been developed and refined so that surveys are analyzed in a comparable fashion, to provide replicate annual Asian carp population estimates.
    - Main channel Asian carp abundance (silver carp and bighead carp) was estimated at 743,435 (95% CI = 658,091 – 828,780) among all three lower reaches of the Illinois River combined and abundance generally declined moving upstream. Average total biomass was estimated to be 1,738 per km (95% CI = 1,538 – 1,937) and 3.30 metric tons per km (95% CI = 2.92 – 3.69).
- <u>Fishing experiment</u>. A contract was been awarded for the purchase and processing of Asian carp from the Peoria and LaGrange reaches of the Illinois River. Nearly 2 million pounds of carp were harvested from the lower river (Peoria, La Grange, and Alton pools) in 2012 (Chapters 3 and 4). Changes in Asian carp demographics were observed (Chapter 3).
- <u>Incentives</u> (Chapter 3). A program providing a training/certification program for fishermen, including vouchers for designated pounds of fish removed from the Illinois River will be implemented in September
- <u>Demographic responses to fishing (Chapter 3)</u>
    - Changes in the population size structure, relative abundance, and sex ratios were evident in 2013 relative to 2012 for silver carp in the three lower reaches of the Illinois River.
    - Young-of-year Silver carp were collected in the Alton reach (N=4) in 2013 and in large numbers in 2014. 2013 was the first time YOY Asian carp have been collected since standardized sampling began in 2011, indicating a successful spawning event in the Illinois and/or Mississippi Rivers in 2013.
    - CPUE of silver carp decreased across years for all reaches combined (overall CPUE down 42% since 2011), and for the La Grange reach in particular (CPUE down 60% since 2011), although no statistically significant difference was found.
    - There have been significant reductions in mean length-at-age across multiple age-classes from 2011 to 2012, and again from 2012 to 2013, indicating selective removal of larger individuals from the population, most likely through commercial fishing.
    - Gizzard shad overall CPUE increased from 74.6 (SE = 20) fish per hour of electrofishing in 2012, to 964.9 (SE = 274.7) fish per hour in 2013, these increases were isolated to the Alton and La Grange reaches. No differences were observed in 2014.
    - Genetic identification of carp showed 49.24% hybridization of Asian carp in the lower reaches of the Illinois River. "Pure" bighead and silver carp are still being identified. One F1 backcross (bighead carp x silver carp) was also detected in the Alton reach.
- <u>Harvest efficiency (Chapter 4)</u>:
    - Harvest efficiency was evaluated in two backwater locations commonly fished by IL DNR contracted commercial fishermen. Of the 320 Asian carp externally tagged in the HMSC backwater near Morris, IL in May 2012 a total of 167 (~52.2%) marked individuals were harvested through IDNR-contracted commercial fishing efforts by the end of December 2013. The majority these individuals (~47%) were harvested in 2012.
    - Emigration of Asian carp from the HMSC backwater appeared low in 2012, but was much higher in 2013. Thirty-two of the 39 fish (82%) that were tagged with acoustic

transmitters in 2013 left the HMSC backwater at some point, possibly decreasing susceptibility to harvest in 2013.
    - The estimated exploitation rate for this backwater area was 55% over an 82-week period for non-immigrants (89% in 2012 and 38 in 2013 ), suggesting that commercial fishing is effective at the current population size
    - However, estimates concerning the population rate of changed combined with estimated immigration in 2013 suggest that harvest was unable to outpace immigration for most of 2013 (and 2012). This suggests that continued harvest during all times of year is necessary and additional harvest from source populations (i.e., lower Illinois River) is encouraged to limit the number of immigrants to the upper river and decrease propagule pressure on the CAWS.
- Fishing estimate (model; Chapter 5). The basic harvest assessment model has been built and parameterized with data from Asian carp populations. This initial model was published in ***Fisheries*** magazine in 2013. The second version of the model is in the works with data collected over the past four years. This model will allow managers to determine the sizes and pounds of Asian carp that need to be removed from the Illinois River to suppress population growth.
- Environmental impact (Chapter 6). Contrary to initial hypotheses, our results indicated that the reduction of Asian carp through controlled commercial fishing did not significantly influence zooplankton densities, gizzard shad relative weight, or gizzard shad catch-per-unit effort in the Illinois River. Rotifers are proportionally dominant in terms of abundance in both upper and lower river sections, but they were more abundant in the lower river. Whereas cladocerans were more abundant in the upper river. As predicted, primary productivity (i.e., chlorophyll-*a* concentration) decreased from downstream to upstream and total phosphorus (mg/L) decreased from upstream to downstream.
- Movement (Chapter 7). Asian carp commonly move from the Mississippi River into the Illinois River. Approximately 30% of individuals tagged in the Mississippi River made their way to the Illinois at some point. Upstream movement tended to occur (in all years) in late March and into April. Subsequent downstream movement was typically followed (late April, early May) suggesting spawning movements. Additional movement into and out of backwater locations correlated with changes in river discharge was also documented in all years. Movement was corroborated by using otolith core Sr:Ca data. We estimated that 28-53% of adult silver carp and 26-48% of hybrids in the Illinois River were immigrants that originated in the middle Mississippi or Missouri Rivers**.** Only 5% of the fish analyzed had otolith core $\delta^{18}O$ and $\delta^{13}C$ signatures indicative of use of floodplain lake habitats during early life, consistent with data from prior years (Chapter 8).
- Nutritional content (Chapter 9). Asian carp in the Illinois River have similar protein content to fish from marine systems, although total oil content is lower. Lipid composition of the oil present is similar to that found in many marine-derived sources with 20-25% long-chain, polyunsaturated fatty acids.
- Contaminants (Chapter 10). Methylmercury and PCB concentrations were sufficiently high in some Asian carp to warrant limiting meals in sensitive human cohorts (e.g., pregnant women)

based on Illinois sportfish advisories. However, concentrations of both contaminants were well below the US FDA action levels of > 1 ppm for methylmercury and > 2 ppm for PCBs.

- Marketing summit (Chapter 11). A 2-day summit convened at the Great Rivers Research and Education Center during fall 2010. A network of experts from eight states from both private and public sectors was developed and is being used to develop economically viable ways to exploit Asian carp in the Illinois River and other river systems in the US. Summit results can be obtained at http://www.iiseagrant.org/catalog/ais/asian_carp_summit.html.
- Marketing survey (Chapter 11). A result of the marketing summit was a desire by private industry to develop domestic markets for Asian carp. A survey is being developed to determine how restaurants, the primary consumer of seafood in the US, will use Asian carp as well as the concerns of chefs about the species. Results to date suggest that the primary consumer concern is about contaminants in the fish.

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## CHAPTER 2

### Quantifying density and biomass of Asian carp in the Illinois River using Hydroacoustic Surveys

**Goals:** Estimate the abundance of Asian carp in each of the lower reaches of the Illinois River to set a baseline for assessing reductions by commercial harvesting and other eradication efforts.

**Justification:** The current density and biomass of bighead carp and silver carp in the Illinois River are unknown. Determining the standing stock of Asian carp in the Illinois River is a critical initial step in evaluating the efficacy of controlling these populations with commercial fishing, as well as to determine the potential to meet demands from various markets. Acoustic-derived density and biomass estimates will not only aid in the construction of population models to forecast exploitation effects, but will also help to identify both large-scale and microhabitat hotspots for focusing commercial fishing efforts. As commercial harvesting increases, it is essential to evaluate population responses over time, such as compensatory reproduction, to determine the effectiveness of commercial fishing as a long-term control strategy and to adapt strategies for efficiently reducing abundances of Asian carp.

**Research Approach:** To estimate the baseline density, size distribution, and biomass of Asian carp among the five lower reaches of the Illinois River we will conduct acoustic surveys using a Biosonics DT-X split-beam echosounder (200 kHz, 6.8° split) along the main channel.

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**Introduction:**

*Estimate of baseline abundance, size distribution, and biomass of Asian carp and other fishes in the Illinois River*

*General overview*

Baseline density, size distribution, and biomass of Asian carp and other fishes was estimated in the main channel among the three lower reaches of the Illinois River (i.e., Alton, La Grange, and Peoria) via a combination of hydroacoustic surveys and standardized sampling (i.e., pulsed-DC electrofishing and trammel netting). In general, hydroacoustic sampling was used to determine the total number and length-frequency distribution of all fishes within each reach. Data from standardized sampling was then used to devise total length-specific proportion of Asian carp and other fishes to distribute acoustic-derived abundance among species as a function of size. Reach-specific length-weight regressions were then determined for each group of fishes to estimate total biomass as a function of total length. Total abundance and biomass of Asian carp and other fishes was then extrapolated to the total interpolated volume based on the proportion of water volume sampled.

*Hydroacoustic sampling*

Hydroacoustic sampling was carried out in approximately 11-km stretches per day during low river stage periods using a down-looking split-beam transducer (BioSonics, Inc., 208 kHz, 6.8° 6 dB beam angle) set at 15 cm below the surface (Table 2.1). Acoustic data was collected using Visual Acquisition 6 from 1.15 to 15-m depth at a ping rate of 5 pings per second and a 0.40-ms pulse duration. Data collection was set to begin 1 m from the transducer face to account for the near-field distance (Simmonds and MacLennan 2005). Temperature was recorded and input into Visual Acquisition 6 prior to data collection to compensate for the effect of water temperature on two-way transmission loss via its effect on the speed of sound in water and absorption coefficients. The split-beam acoustic transducer was calibrated on-axis with a 200 kHz tungsten carbide sphere throughout the duration of sampling following Foote et al. (1987).

We used a stratified random sampling design for hydroacoustic surveys to compensate for the spatial distribution of Asian carp. The first two transects were conducted parallel to the shoreline following the 1.5-m depth contour of the main channel; subsequent transects were conducted at distances progressively closer to the middle of the channel (Figure 1a). Specifically, the second set of transects were conducted parallel to the first two transects ~2 m closer to the middle of the channel. The following two transects were conducted at ~4-m distance from the second set of transects. The final set of transects were conducted at 6-m distance from the third set of transects or were evenly spaced to fill in the gaps of the unsampled area for narrow stretches of river. All transects were completed by traveling downstream with the current at approximately 9.5 km/hr to limit the amount of Asian carp evasion as it relates to outboard motor noise.

*Total fish abundance and size distribution*

Echoview 5.0 was used to estimate the total number of fish and size distribution within each of the three lower reaches of the Illinois River. Data collected from the split-beam acoustics was analyzed 1 m from the transducer face (actual depth = 1.15 m) to the river bottom. Target strength (TS) was compensated for two-way signal loss as it is affected by range from the transducer, the speed of sound in water, signal absorption, and angle at which echoes were received. Background noise was filtered by removing TS-compensated acoustic signals less than -60 dB. Fish targets were determined using the split-beam single target detection algorithm (method 2) (Table 2) and size of fish targets was determined using the relationship between maximum dorsal-aspect TS and TL (Love 1971; Figure 2).

A stratified analysis was performed to determine the mean density and variance for each reach of the three lower reaches within the Illinois River following Scheaffer et al. (1996) and Parker-Stetter et al. (2009). Hydroacoustic data was separated into four strata (i.e., strata 1 = 1.5-m depth contours from both sides of the channel; strata 2-4 are progressively closer to the middle of the channel). Each 1.852 river km (i.e., one nautical mi) sampled along these strata represented replicates of strata. Strata-specific density ($\bar{\rho}_h$) and associated within-strata variance ($s^2_{\rho_h}$) was calculated using:

$$\bar{\rho}_h = \frac{1}{n_h}\sum_{i=1}^{n_h} \rho_{h,i}$$

$$s_{\rho_h}^2 = \frac{1}{n_h - 1}\sum_{i=1}^{n_h}\left(\rho_{h,i} - \bar{\rho}_h\right)^2$$

where $n_h$ is the number of one-mile replicates in stratum *h*, and $\rho_{h,i}$ is the mean density of replicate *i* within stratum *h*. The reach-specific mean density ($\bar{\rho}$) was calculated using:

$$\bar{\rho} = \frac{1}{A}\sum_{h=1}^{L} A_h \cdot \bar{\rho}_h$$

where *L* is the total number of strata, *A* is the volume of sampled water for all strata combined, and $A_h$ is the volume of sampled water for strata *h* estimated by the beam volume sum method in Echoview 5.0, such that the mean density is weighted by the sampled volume in each strata. The standard error of the estimated reach-specific mean density ($SE(\rho)$) was calculated using:

$$SE(\rho) = \sqrt{\sum_{h=1}^{L}\left(\frac{A_h}{A}\right)^2\left(\frac{s_{\rho h}^2}{n_h}\right)}$$

following the variable nomenclature defined above. Total fish abundance (*N*) was estimated by multiplying $\bar{\rho}$ by the total reach volume determined by interpolating depth contours via a triangulated irregular network in ArcMap 9.3 (Figure 1b). The standard error for total fish abundance (*SE*(*N*)) was estimated by multiplying $SE(\rho)$ by the total reach volume.

The length-frequency distribution of acoustic-detected fish was used to inform the length-frequency distribution of the extrapolated abundance within each reach. Specifically, the proportion of fish within each 1-mm interval was determined for each reach and multiplied by total estimated abundance and corresponding 95% CIs.

*Species-specific abundance, length distribution, and biomass*

Data collected from standardized sampling conducted in each reach during summer 2010 was used to inform acoustic estimates to determine species-specific abundance, length distribution, and biomass. Length-frequency distributions were determined for silver carp, bighead carp, gar *spp*., and other fishes at 20-mm TL increments. Gar *spp*. were determined separately from Asian carp and other fishes due to their morphological differences for determining biomass from length-weight relationships. The proportion of silver carp, bighead carp, gar, and other fishes was determined for each 20-mm length group; these proportions were then linearly interpolated for each 1-mm TL. The length-specific proportion of fish groups was then applied to the acoustic-derived length-frequency distribution to estimate the total number of silver carp, bighead carp, gar, and other fishes as a function of TL. Reach-specific length-weight regressions were determined for each fish group (Table 3). Length-specific biomass of each fish category was estimated by1-mm TL increments by multiplying mass determined from length-weight regressions by total estimated species-specific abundance. Total biomass was determined by summing species- and length-specific biomass. Gar *spp*. and other fishes were combined into a single category for presentation purposes.

*Asian carp spatial distribution and depth use*

Given that it is not possible to determine species composition from acoustic estimates, only a subset of fish targets that had a greater than 50% chance of being an Asian carp were used to analyze patterns of spatial distribution and depth use. Specifically, fish targets within 20-mm TL size categories that were composed of 50% or more of Asian carp were selected for analyses.

The spatial distribution of Asian carp was determined by summing the total number of highly probably Asian carp acoustic targets along each 1.6 river km in ArcMap 9.3. The cumulative proportion of Asian carp were then plotted against river km to determine the highest abundance of Asian carp as it relates to a linear spatial distribution. It is important to note that this analysis was conducted only on detected fish and not on extrapolated abundance. This approach does not account for varying sampled volumes along the river; yet, given that total number of Asian carp along the Illinois River is likely of greater importance than density for concentrated commercial fishing efforts, this analysis does provide an indication of the relative spatial abundance of Asian carp.

Depth use was determined by assigning Asian carp fish targets to depth categories at 1-m intervals. The proportion of Asian carp using a particular depth interval and associated 95% confidence intervals was determined using an intercept only model using the logistic procedure (SAS Institute 2009) for each size category and reach combination. Probabilities of Asian carp presence and 95% confidence intervals were then used to determine the potential range of abundances found at each depth interval as it is influenced by sample size and associated confidence for each reach. Densities of Asian carp were then determined by dividing depth-specific volume estimates for each reach and depth combination to construct volumetrically compensated depth use and associated confidence intervals.

**Results**

A total of eight parallel hydroacoustic transects were completed along the main channel from fall 2010 to summer 2011 along 427.8 river km of the Illinois River from the confluence of the Illinois River and Mississippi River to Starved Rock Lock and Dam for a total of 3,422.5 river km of transect distance. Overall, an estimated 0.39% of the total volume was sampled with hydroacoustics and this was fairly similar among reaches (Table 2.1). Hydroacoustic surveys took 39 days of actual sampling, not including the standardized sampling that is necessary to inform acoustic estimates on the length-specific prportion of Asian carp to other fishes.

Main channel Asian carp abundance (silver carp and bighead carp) was estimated at 743,435 (95% CI = 658,091 – 828,780) among all three lower reaches of the Illinois River combined and abundance generally declined moving upstream (Table 4). Specifically, Asian carp abundance was highest in the Alton reach ($P < 0.05$), but was not different between La Grange and Peoria ($P > 0.05$). This trend was identical for silver carp and other fishes. Bighead carp were least abundant in the Peoria reach ($P <$ 0.05), whereas abundance was not different between Alton and La Grange ($P > 0.05$).

Main channel Asian carp biomass was estimated to be 1,413 metric tons (95% CI = 1,249.3 – 1,576.7) within the main channel of the three lower reaches of the Illinois River (Table 4). Despite differences in abundance, biomass of silver carp and Asian carp collectively were not different among all reaches ($P >$ 0.05), suggesting that the average mass of Asian carp is smaller in the downstream reaches. Bighead carp biomass trends were similar to their abundance, with Peoria having substantially lower biomass than the other two reaches ($P < 0.05$). Biomass of other fishes significantly declined moving upstream ($P$ $< 0.05$).

To compensate for varying reach size, abundance and biomass was expressed on a river-km basis (Table 5). Overall Asian carp density and biomass/km among all reaches combined was estimated to be 1,738 per km (95% CI = 1,538 – 1,937) and 3.30 metric tons per km (95% CI = 2.92 – 3.69), respectively (Table 5). Asian carp density was lowest in Peoria ($P < 0.05$), but not different between Alton and La Grange ($P$ $> 0.05$); yet, Asian carp biomass/km was only different between Alton and Peoria ($P < 0.05$). Silver carp density was similar among all three lower reaches ($P > 0.05$), but silver carp biomass was highest in the Peoria reach ($P < 0.05$). Bighead carp density and biomass/km was lowest in the Peoria reach ($P < 0.05$), but similar between Alton and La Grange ($P > 0.05$). Similar to total biomass trends, biomass/km of other fishes declined moving upstream ($P < 0.05$), yet the biomass/km was not different between Peoria and La Grange ($P < 0.05$).

The length-frequency distribution of all fishes declined exponentially (Figure 2.3). It was apparent, however, that Asian carp (particularly silver carp) dominated the fish community at lengths ≥ 420-mm TL in all three lower reaches of the Illinois River. Although Asian carp made up approximately 10% of the fish community overall in terms of numerical abundance, they comprised between 60 and 100% of the fish community for TL > 420 mm and these trends were similar among all reaches (Figure 2.4). Lower proportions of Asian carp to other fishes at sizes > 420-mm TL was primarily associated with the presence of gar *spp*. A Kruskal-Wallis test indicated that the Asian carp length-frequency distribution was different among reaches ($\chi^2_2 = 13.52$, $P = 0.001$). A Wilcoxon rank sum test indicated that the Asian carp size distribution tended to be larger in Alton and La Grange compared to Peoria ($z \leq -2.93$; $P \leq$ 0.002), but was not different between Alton and La Grange ($z = 0.047$; $P = 0.48$).

In terms of biomass, Asian carp dominated biomass of fishes > 400-mm TL (Figure 2.5). However, it was clearer with biomass compared to abundance that bighead carp dominated the fish community at sizes > 800 mm-TL, particularly in the Alton and La Grange reaches. Bighead carp appear to be relatively non-abundant in the Peoria reach, which increased the average mass per Asian carp individual due to greater mass of similar-sized silver carp within the Peoria reach compared to bighead carp from Alton or La Grange (Table 3). Overall, Asian carp comprised approximately 63% of the total fish biomass in all three reaches combined. The proportional biomass composed of Asian carp as a function of size, however, indicates that Asian carp biomass dominance is restricted to sizes > 400-mm TL, ranging in dominance from 65 to 100% of the fish community in all reaches combined (Figure 2.6).

The cumulative proportion of acoustically detected Asian carp (N = 2,755) indicated that close to 30% of the total Asian carp population was located within the first 25 km of the Alton reach, near the confluence with the Mississippi River (Figure 2.7a). The fairly consistent slope of the cumulative proportion of Asian carp at distances > 25 river km, however, suggests that Asian carp are distributed fairly equally along the entire Illinois River. Yet, distinct modes in the proportion of Asian carp indicated that Asian carp were not distributed equally along the entire Illinois River. The highest proportion of acoustically detected Asian carp (N = 2725) were generally found near the downstream and upstream areas of each reach, particularly in the Alton and La Grange reaches (Figure 2.7b). However, other modes were present throughout each reach suggesting that high abundances of Asian carp may be associated with particular features of the Illinois River.

The highest proportions of Asian carp were detected at 5-m, 4-m, and between 4- and 5-m depth within the Alton, La Grange, and Peoria reaches, respectively ($P < 0.05$; Figure 2.8). However, these results closely resembled the depth-specific estimates of sampled volume. After correcting for volumetric estimates, these patterns generally held (Figure 9). In the Alton reach, the highest Asian carp densities were detected at 5 m, but it was evident that Asian carp were using depths between 4 and 8 m. The apparent high densities of Asian carp found at depths ≥ 8 m in the La Grange reach were due to low volumes of water sampled at these depths; the large confidence limits are indicative of low numbers of fish found at these depths (i.e., only 38 out of 1239 Asian carp were found at these depths). As such, Asian carp in the La Grange reach were most likely to be found between 3- and 5-m depths, with the highest probability of occurrence at 4 m when depths ≥ 8 m are ignored. Similar high variation in depth use was found at 10-m depth in the Peoria reach, which included only two out of 646 Asian carp. Thus, Asian carp in the Peoria reach were most likely to be found between 4- and 6-m depths, with the highest chance of occurrence at 4-m depth ($P < 0.05$).

**Discussion**

The results of this study indicated that the abundance and biomass of Asian carp collectively in the lower three reaches of the Illinois River (i.e., Alton, La Grange, and Peoria reaches) was 743,435 (95% CI = 658,091 – 828,780) and 1,413 metric tons (95% CI = 1,249.3 – 1,576.7), respectively. These estimates suggest that Asian carp comprise 10% and 63% of the fish community in terms of numerical abundance and biomass, respectively. Yet, Asian carp compose between 60% to 100% of the fish community at sizes greater than approximately 400-mm TL in terms of both abundance and biomass. An estimated 30% of the Asian carp population was found within the first 25 km of the Illinois River near the confluence with the Mississippi River, which is consistent with the general spatial distribution provided by Sneed (2006). At the macroscale, the spatial distribution of Asian carp was generally uniform across river distance of the three lower reaches at distances > 25 river km. Yet, distinct modes indicated that Asian carp had clumped distributions, particularly near dams, suggesting that Asian carp density may be related to particular features within the Illinois River. Further analyses with respect to relationships between Illinois River features (e.g., presence of backwaters, tributaries, availability of food resources, and refuge from flow) and Asian carp abundance relative to these data will give greater insight into factors affecting the spatial distribution of Asian carp.

The abundance and biomass estimates of silver carp and bighead carp in this study represent conservative population estimates for the Illinois River for several reasons. First and foremost, the sampled area did not include nearshore depths < 1.5 m, excludes surface volume to 1.15-m depth, and did not include backwater areas or tributaries. Sneed (2006) estimated a nearly 1:1 ratio between Asian carp density found in backwaters and the main channel (on a surface area basis), suggesting that a high proportion of Asian carp were not sampled in this study. Further, the results of this study apply to the Alton, La Grange, and Peoria reaches of the Illinois River and exclude the Starved Rock and Marseilles reaches where populations of Asian carp are known to exist. Similar hydroacoustic surveys were actually completed on the Starved Rock and Marseilles reaches during fall 2010 (an additional 75 river km, 600 km total transect distance). These data were not included in this report because standardized sampling data were not available concerning the length-specific proportional abundances of Asian carp and other fishes to inform hydroacoustic estimates, which may be available from other research institutions (e.g., Illinois Natural History Survey). The inclusion of these data would increase the estimates of Asian carp abundance and biomass for the main channel of the Illinois River.

Second, although hydroacoustics is thought to be a less biased sampling technique than other capture gears, one limitation of hydroacoustic sampling is that species-specific information cannot be determined unless there are clear spatial segregations among fish species or other classification variables of interest (e.g., age class). Thus, these estimates rely on some form of paired sampling technique to determine species composition, such that these proportional estimates can be used to inform hydroacoustic estimates. As a result, the separation of the overall size distribution determined from hydroacoustic sampling into species-specific information is inherently prone to similar gear biases from standardized sampling. Species-specific information for these results was gleaned from pulsed-DC electrofishing and trammel nets, which have known size biases. Given the elusiveness of Asian carp to capture gears, it is likely that our Asian carp abundance and biomass estimates are conservatively low in our standardized sampling and as a result hydroacoustic estimates, particularly for YOY Asian carp which were not detected with our sampling. Nevertheless, future estimates with combined hydroacoustic surveys and standardized sampling through time will allow for relative comparisons to be made concerning changes in Asian carp abundance and biomass as well as other fishes.

A third potential factor contributing to low estimates of Asian carp, specifically silver carp, is evasion from hydroacoustic gear, which was also observed by Snead (2006). Although the frequency of the hydroacoustic transducer used in this study (200,000 Hz) was much higher than the hearing capabilities of Asian carp (range = 300 Hz to 2,000 Hz; Lovell et al. 2006), silver carp were observed jumping away from the boat during hydroacoustic sampling likely due to outboard motor noise. However, it is unknown whether these fish were originally shallower than our minimum detection depth of 1.15, such that these fish would have not been detected regardless of evasion. One potential way to compensate for evasion in future hydroacoustic surveys is to conduct side-looking hydroacoustic transects to determine the density of fishes near the surface. Nevertheless, further research is needed to determine the potential effect of evasion of Asian carp on hydroacoustic estimates.

Lastly, the volume sampled with hydroacoustics represents only 0.3% of the total volume overall, despite conducting 3,422.5 river km of transect distance along the three lower reaches of the Illinois

River. The low sampled volume was most likely due to the stratified sampling design that focused on depths between 3 and 7 m rather than directly over the thalweg where the majority of the volume is located (Figures 2.1a and 2.7). Thus, despite the low estimated volume of sampled volume, the stratified sampling design focused on areas in which Asian carp are located, yet deep areas where Asian carp are less abundant were still sampled, ultimately reducing variance and providing a more precise and accurate depiction of density, abundance, and biomass in the main channel. Further, if our estimates of proportion of sampled volume were presented on an aerial basis, as done by Sneed (2006), our coverage of the Illinois River would be much higher.

To our knowledge, there have only been two previous studies conducted to estimate the abundance and biomass of Asian carp in the Illinois River for comparison purposes (i.e., Snead 2006; Sass et al. 2010). Despite the potential factors contributing to a conservative estimate, silver carp abundance in the La Grange reach, based on a mark-recapture study conducted on the La Grange reach from 2007-2008, estimated silver carp abundance to be 328,192 (95% CI = 231,226 – 484,474; Sass et al. 2010), which overlapped with our estimates. Given that our estimates pertain only to the main channel, whereas estimates provided by Sass et al. (2010) include backwater areas, indicates that the silver carp population is still increasing. Signs of reduced condition in silver carp and bighead carp from this study compared to Irons et al. (2007), however, suggest that the Asian carp population may be reaching carrying capacity. Specifically, Sass et al. (2010) used the length-weight relationship for silver carp developed by Irons et al. (2007) from data collected between 1990 to 2006 (i.e., $\log_{10}$mass = 3.122·$\log_{10}$TL – 5.294). Regression analyses indicated that both the intercept ($F_{1,580}$ = 7.33; $P$ = 0.007) and slope ($F_{1,580}$ = 10.66; $P$ = 0.001) of this relationship was higher than our estimate of the silver carp length-weight regression parameters in the La Grange reach. The intercept ($F_{1,8}$ = 30.48; $P$ = 0.0006) and slope ($F_{1,8}$ = 33.70; $P$ = 0.0004) for bighead carp from the La Grange reach determined in this study was also lower than that estimated by Irons et al. (2007) (i.e., $\log_{10}$mass = 3.122·$\log_{10}$TL – 5.294). The reduced condition of Asian carp in the La Grange reach may be responsible for our estimates of silver carp biomass being significantly lower than estimates provided by Sass et al. (2010), which was estimated to be 704.6 (95% CI = 496.4 -1,040.1). Yet, shifts in the size distribution toward smaller sizes could also contribute to lower biomass estimates, despite similar abundance estimates, in this study compared to Sass et al. (2010), which deserves further investigation.

Estimates of Asian carp (silver carp and bighead carp, collectively) abundance and biomass from a combination of side-scan sonar, mark-recapture estimates, and ratios of Asian carp to other fishes from mark-recapture surveys yielded an Asian carp abundance and biomass estimate of 865,067 (439,867 in the main channel and 425,200 in backwater lakes) and 5,425 metric tons (3,299 metric tons in the main channel and 2,126 metric tons in backwater lakes), respectively (Sneed 2006). Although these results were presented as the minimum abundance of Asian carp present in the Illinois River (from the confluence with the Mississippi River to Ottawa, IL) for similar reasons stated above, confidence limits of these estimates were not presented making it impossible to assess the precision of these estimates. Nevertheless, the upper 95% confidence interval of Asian carp abundance was significantly lower than the estimate provided by Sneed (2006). Given that Asian carp density estimates were sampled along 35 locations by Sneed (2006) and the results of our study indicated that Asian carp abundance is not equally distributed along the Illinois River, the estimates by Sneed (2006) pertaining to main channel abundance is subject to high variability in density and abundance. Therefore, if confidence limits were available for estimates of Asian carp abundance, it is highly likely that our estimates would overlap with that of Sneed (2006) specific to the main channel of the Illinois River. However, biomass estimates of Asian carp for the main channel from Sneed (2006) were 2.3 times higher than our estimates, which cannot be explained merely by variation. Estimates of Asian carp biomass from Sneed (2006), however, extrapolated the average weight of Asian carp from the main channel to the estimated abundance opposed to extrapolating size-specific biomass estimates to a length-frequency distribution as was conducted in this study and by Sass et al. (2010). Given that the size distribution of Asian carp is not normally distributed, the biomass estimates of Asian carp from Sneed (2006) were greatly overestimated.

Depth use of Asian carp was highest between 4 and 5 m, but high densities were generally found between 3 and 8 m. It is important to note that these estimates do not account for the maximum depth at which Asian carp were detected to determine whether they were more associated with the surface or bottom. In addition, each reach was sampled with hydroacoustic surveys during different time periods when Asian carp may be behaving differently; thus, depth use comparisons among reaches may not be meaningful. Repeated hydroacoustic surveys over given areas across time would be necessary to determine changes in depth use as a function of season and whether these patterns are similar among reaches.

The relationship between maximum dorsal-aspect TS and TL used in this study was developed from multiple species from several studies and includes fish that do or do not have gas bladders (Love 1971). It has been estimated that 50% of the dorsal- and side-aspect TS from a fish is generated by the gas bladder (Jones and Pearce 1958), with the skeleton and flesh (Volberg 1963) and scales (Diercks and Goldsberry 1970) reflecting the other half, listed in decreasing order of magnitude. Thus, the dorsal- and side-aspect TS of a given fish species and size is an emergent property of the size and morphology of the gas bladder, body morphology, proximate composition, and possibly the type and size of scales. Given that the gas bladder of Asian carp are much larger than the majority of fish species (personal observation), the TS threshold used in this study would likely underestimate the size of Asian carp. Therefore information concerning both the maximum side-aspect TS and dorsal-aspect TS for Asian carp and other fish species common in the Great Lakes and Mississippi River Basin would refine size-distribution estimates of Asian carp from acoustic surveys and would also help to refine the search window for detecting Asian carp for other research objectives (e.g., Asian carp detection for barrier defense operations), and may facilitate determination of species composition.

The results of this study, while conservative, suggest that the potential to commercially harvest 22,680 metric tons (50 million lb) of Asian carp per year to fulfill contract agreements between The state of Illinois, Big River Fish Corporation, and China are likely not possible. Even if our upper 95% confidence limit estimate of Asian carp biomass was doubled to compensate for the lack of sampling in backwater lakes based on the ratio of Asian carp abundance in backwater areas to the main channel, our estimate would only increase to 3,153.4 metric tons (6.95 million lb), falling well short of the contract goal. Nevertheless, future estimates of abundance and biomass of Asian carp need to address the shortcomings of this study. Specifically, future studies should attempt to include estimates of density near the surface via side-looking acoustics, which would compensate for the 1.15 m layer of unsampled volume in this study and could facilitate in reducing evasion of Asian carp during acoustic surveys. Further, an emphasis should be placed on backwater areas for two reasons. First, nearly half of the estimated Asian carp biomass was present in the backwater lakes based on a previous study conducted on the Illinois River (Sneed 2006). Second, given that these areas will likely be the most easily commercially fished areas due to difficulties associated with fishing in the main channel of the Illinois River due to flow, steep drop offs and overall greater depths than backwater areas, and barge traffic. It is unlikely that down-looking hydroacoustic surveys would be successful in backwater lakes along the Illinois River, primarily due to the shallow depths. Thus, future studies should incorporate side-looking hydroacoustic surveys and/or side-scan sonar to estimate abundance and biomass in backwater lakes.

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Table 2.1. Summary of hydroacoustics transects conducted for the Alton, La Grange, and Peoria reaches on the Illinois River. A total of eight parallel transects were conducted along each river mile section. Volume sampled was estimated with EchoView 5.0 based on the shape of the acoustic beam and depth of each ping emitted. Total volume was estimated using ArcMap 9.3 by interpolating each GPS-referenced depth from all acoustic pings (5 per second) within the main channel only via triangulated irregular networks and was not extrapolated beyond our transects (i.e., total volume does not include nearshore depths < 1.5 m and excludes surface volume to 1.15-m depth).

| River km begin | River km end | Date sampled | Volume sampled ($m^3$) | Total estimated volume ($m^3$) | Percent sampled |
|---|---|---|---|---|---|
| | | | **Alton** | | |
| 0.0 | 17.2 | 8/6/2011 | 116,983 | 21,060,499 | 0.56 |
| 17.2 | 29.3 | 8/5/2011 | 53,142 | 11,251,468 | 0.47 |
| 29.3 | 42.2 | 8/4/2011 | 30,944 | 11,071,868 | 0.28 |
| 42.2 | 52.2 | 8/3/2011 | 20,661 | 4,810,774 | 0.43 |
| 52.2 | 59.3 | 7/30/2011 | 16,620 | 5,424,036 | 0.31 |
| 59.3 | 70.4 | 7/29/2011 | 13,765 | 7,688,491 | 0.18 |
| 70.4 | 81.5 | 7/28/2011 | 20,997 | 7,962,532 | 0.26 |
| 81.5 | 92.6 | 7/27/2011 | 20,550 | 6,855,928 | 0.30 |
| 92.6 | 103.7 | 7/26/2011 | 19,217 | 6,595,422 | 0.29 |
| 103.7 | 114.8 | 7/25/2011 | 28,084 | 6,614,914 | 0.42 |
| 114.8 | 125.9 | 7/24/2011 | 16,567 | 4,519,487 | 0.37 |
| 125.9 | 137.0 | 7/23/2011 | 21,535 | 4,710,438 | 0.46 |
| 137.0 | 148.5 | 7/22/2011 | 21,778 | 5,066,111 | 0.43 |
| | | **Reach total** | **400,845** | **103,631,968** | **0.39** |
| | | | **La Grange** | | |
| 148.5 | 155.8 | 11/14/2010 | 10,570 | 4,457,211 | 0.24 |
| 155.8 | 167.6 | 11/13/2010 | 10,161 | 4,892,474 | 0.21 |
| 167.6 | 180.0 | 11/12/2010 | 13,873 | 4,603,177 | 0.30 |
| 180.0 | 191.9 | 11/11/2010 | 19,775 | 4,413,807 | 0.45 |
| 191.9 | 202.6 | 11/10/2010 | 7,627 | 3,195,897 | 0.24 |

| | | | | | |
|---|---|---|---|---|---|
| 202.6 | 215.4 | 11/9/2010 | 15,349 | 3,450,464 | 0.44 |
| 215.4 | 226.9 | 11/8/2010 | 11,228 | 3,464,060 | 0.32 |
| 226.9 | 238.0 | 11/7/2010 | 12,671 | 3,846,906 | 0.33 |
| 238.0 | 248.2 | 11/6/2010 | 5,842 | 2,308,675 | 0.25 |
| 248.2 | 259.3 | 11/5/2010 | 10,668 | 3,604,144 | 0.30 |
| 259.3 | 269.5 | 11/4/2010 | 19,992 | 3,043,250 | 0.66 |
| 269.5 | 280.0 | 10/21/2010 | 15,750 | 3,037,015 | 0.52 |
| 280.0 | 283.2 | 10/20/2010 | 19,445 | 1,047,236 | 1.86 |
| 283.2 | 291.9 | 10/11/2010 | 22,945 | 2,149,483 | 1.07 |
| | | **Reach total** | **195,896** | **47,513,801** | **0.41** |

Table 2,1, continued.

| River km begin | River km end | Date sampled | Volume sampled ($m^3$) | Total estimated volume ($m^3$) | Percent sampled |
|---|---|---|---|---|---|
| | | **Peoria** | | | |
| 291.9 | 296.7 | 4/18/2011 | 8,662 | 1,914,212 | 0.45 |
| 296.7 | 308.5 | 4/17/2011 | 23,404 | 6,391,295 | 0.37 |
| 308.5 | 320.8 | 4/16/2011 | 15,357 | 4,044,471 | 0.38 |
| 320.8 | 334.3 | 4/15/2011 | 19,246 | 4,906,887 | 0.39 |
| 334.3 | 346.3 | 4/14/2011 | 28,327 | 7,299,597 | 0.39 |
| 346.3 | 359.3 | 4/13/2011 | 27,960 | 7,448,243 | 0.38 |
| 359.3 | 370.4 | 4/12/2011 | 18,168 | 5,656,675 | 0.32 |
| 370.4 | 382.4 | 4/11/2011 | 19,689 | 6,472,205 | 0.30 |
| 382.4 | 394.5 | 4/10/2011 | 25,709 | 6,809,722 | 0.38 |
| 394.5 | 405.4 | 4/9/2011 | 21,886 | 5,583,505 | 0.39 |
| 405.4 | 416.1 | 4/8/2011 | 35,639 | 5,659,289 | 0.63 |
| 416.1 | 427.8 | 4/7/2011 | 16,908 | 4,437,282 | 0.38 |
| | | **Reach total** | **260,954** | **66,623,383** | **0.39** |
| | | **Grand total** | **857,694** | **217,769,153** | **0.39** |

Table 2.2. Values used for the single-target detection algorithm (method 2) in EchoView 5.0 during post-processing following Parker-Stetter et al. (2009). Target strength (TS) thresholds were determined based on the relationship between maximum dorsal-aspect TS and TL (Love 1971; Figure 2), and correspond to a minimum and maximum length between 59- and 1200-mm TL.

| Variable | Value |
|---|---|
| Minimum TS threshold (dB) | -50.00 |
| Maximum TS threshold (dB) | -24.64 |
| Pulse length determination level (dB) | 6.0 |
| Minimum normalized pulse length | 0.6 |
| Maximum normalized pulse length | 1.5 |
| Beam compensation model | BioSonics |
| Maximum s.d. of minor-axis angle° | 0.6 |
| Maximum s.d. of major-axis angle° | 0.6 |

Table 2.3. Reach-specific length-weight regression parameters and associated standard errors (SE) for silver carp, bighead carp, gar *spp*. and other fishes determined from standardized sampling. The functional form of the length-weight regressions was $\log_{10}\text{mass} = a' + b \cdot \log_{10}\text{TL}$, where mass is in g and TL is in mm.

| Fish category | *a*' | SE | *b* | SE | *N* | *P* | $R^2$ |
|---|---|---|---|---|---|---|---|
| | | | **Alton** | | | | |
| Silver carp | -4.94 | 0.07 | 2.98 | 0.07 | 364 | <0.0001 | 0.9702 |
| Bighead carp | -2.72 | 0.54 | 2.21 | 0.18 | 10 | <0.0001 | 0.9470 |
| Gar *spp*. | -6.34 | 0.75 | 3.30 | 0.27 | 24 | <0.0001 | 0.8709 |
| Other fishes | -5.17 | 0.09 | 3.10 | 0.04 | 137 | <0.0001 | 0.9766 |
| | | | **La Grange** | | | | |
| Silver carp | -5.09 | 0.07 | 3.03 | 0.03 | 582 | <0.0001 | 0.9538 |
| Bighead carp | -4.00 | 0.15 | 2.65 | 0.05 | 10 | <0.0001 | 0.9968 |
| Gar *spp*. | -3.78 | 1.44 | 2.34 | 0.52 | 20 | 0.0003 | 0.5248 |
| Other fishes | -4.94 | 0.12 | 3.00 | 0.05 | 115 | <0.0001 | 0.9664 |
| | | | **Peoria** | | | | |
| Silver carp | -5.44 | 0.06 | 3.16 | 0.02 | 571 | <0.0001 | 0.9753 |
| Bighead carp | -6.14 | 0.36 | 3.43 | 0.13 | 24 | <0.0001 | 0.9677 |
| Gar *spp*. | -6.14 | - | 3.21 | - | 2 | - | 1.0000 |
| Other fishes | -5.38 | 0.07 | 3.18 | 0.03 | 194 | <0.0001 | 0.9809 |

Table 2.4. Mean abundance (N) and biomass (metric tons) and associated 95% confidence intervals for silver carp, bighead carp, Asian carp combined (silver carp and bighead carp only), and all other fishes for the three lower reaches of the Illinois River. The proportion of total fish abundance composed of Asian carp among all reaches combined was 10.02% (95% CI = 10.00 to 10.04%), whereas the proportion of total fish biomass composed of Asian carp among all reaches combined was 63.47% (95% CI = 63.40 to 63.53%). Means with different letters indicate significant differences within each group of fishes at the α = 0.05 level.

| Reach | Abundance (N) | | | Biomass (metric tons) | | |
|---|---|---|---|---|---|---|
| | Mean | Lower 95% CI | Upper 95% CI | Mean | Lower 95% CI | Upper 95% CI |
| | | | **Silver carp** | | | |
| Alton | 284,817[a] | 262,093 | 307,541 | 373.7[a] | 343.8 | 403.5 |
| La Grange | 218,470[b] | 183,836 | 253,104 | 308.2[a] | 259.3 | 357.1 |
| Peoria | 180,137[b] | 159,074 | 201,200 | 393.3[a] | 347.3 | 439.3 |
| Total | 683,424 | 605,002 | 761,845 | 1,075.2 | 950.5 | 1,199.9 |
| | | | **Bighead carp** | | | |
| Alton | 26,269[a] | 24,173 | 28,365 | 177.0[a] | 162.8 | 191.1 |
| La Grange | 21,194[a] | 17,834 | 24,554 | 147.4[a] | 124.0 | 170.7 |
| Peoria | 12,548[b] | 11,081 | 14,016 | 13.5[b] | 11.9 | 15.0 |
| Total | 60,011 | 53,088 | 66,935 | 337.8 | 298.8 | 376.9 |
| | | | **Asian carp combined** | | | |
| Alton | 311,086[a] | 286,266 | 335,905 | 550.6[a] | 506.7 | 594.6 |
| La Grange | 239,664[b] | 201,670 | 277,658 | 455.6[a] | 383.4 | 527.8 |
| Peoria | 192,685[b] | 170,155 | 215,216 | 406.8[a] | 359.2 | 454.4 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Total | 743,435 | 658,091 | 828,780 | 1,413.0 | 1,249.3 | 1,576.7 |
| | | | **Other fishes** | | | |
| Alton | 2,855,671[a] | 2,627,833 | 3,083,509 | 378.1[a] | 348.0 | 408.3 |
| La Grange | 1,849,149[b] | 1,556,003 | 2,142,295 | 263.0[b] | 221.3 | 304.7 |
| Peoria | 1,971,672[b] | 1,741,125 | 2,202,219 | 172.0[c] | 151.9 | 192.1 |
| Total | 6,676,493 | 5,924,962 | 7,428,024 | 813.1 | 721.2 | 905.1 |

Table 2.5. Mean density (N/km) and biomass/km (metric tons) and associated 95% confidence intervals for silver carp, bighead carp, Asian carp combined (silver carp and bighead carp only), and all other fishes for the three lower reaches of the Illinois River. Means with different letters indicate significant differences within each group of fishes at the α = 0.05 level.

| | Density (N/km) | | | Biomass/km (metric tons) | | |
|---|---|---|---|---|---|---|
| Reach | Mean | Lower 95% CI | Upper 95% CI | Mean | Lower 95% CI | Upper 95% CI |
| **Silver carp** | | | | | | |
| Alton | 1,918[a] | 1,765 | 2,071 | 2.52[b] | 2.32 | 2.72 |
| La Grange | 1,524[a] | 1,282 | 1,766 | 2.15[b] | 1.81 | 2.49 |
| Peoria | 1,325[a] | 1,170 | 1,480 | 2.89[a] | 2.56 | 3.23 |
| Total | 1,597 | 1,414 | 1,781 | 2.51 | 2.22 | 2.80 |
| **Bighead carp** | | | | | | |
| Alton | 177[a] | 163 | 191 | 1.19[a] | 1.10 | 1.29 |
| La Grange | 148[a] | 124 | 171 | 1.03[a] | 0.87 | 1.19 |
| Peoria | 92[b] | 82 | 103 | 0.10[b] | 0.09 | 0.11 |
| Total | 140 | 124 | 156 | 0.79 | 0.70 | 0.88 |
| **Asian carp combined** | | | | | | |
| Alton | 2,094[a] | 1,927 | 2,262 | 3.71[a] | 3.41 | 4.00 |
| La Grange | 1,672[a] | 1,407 | 1,937 | 3.18[ab] | 2.67 | 3.68 |
| Peoria | 1,417[b] | 1,252 | 1,583 | 2.99[b] | 2.64 | 3.34 |
| Total | 1,738 | 1,538 | 1,937 | 3.30 | 2.92 | 3.69 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | **Other fishes** | | | |
| Alton | 19,226[a] | 17,692 | 20,760 | 2.55[a] | 2.34 | 2.75 |
| La Grange | 12,900[b] | 10,855 | 14,945 | 1.84[b] | 1.54 | 2.13 |
| Peoria | 14,504[b] | 12,808 | 16,200 | 1.27[c] | 1.12 | 1.41 |
| Total | 15,606 | 13,849 | 17,363 | 1.90 | 1.69 | 2.12 |

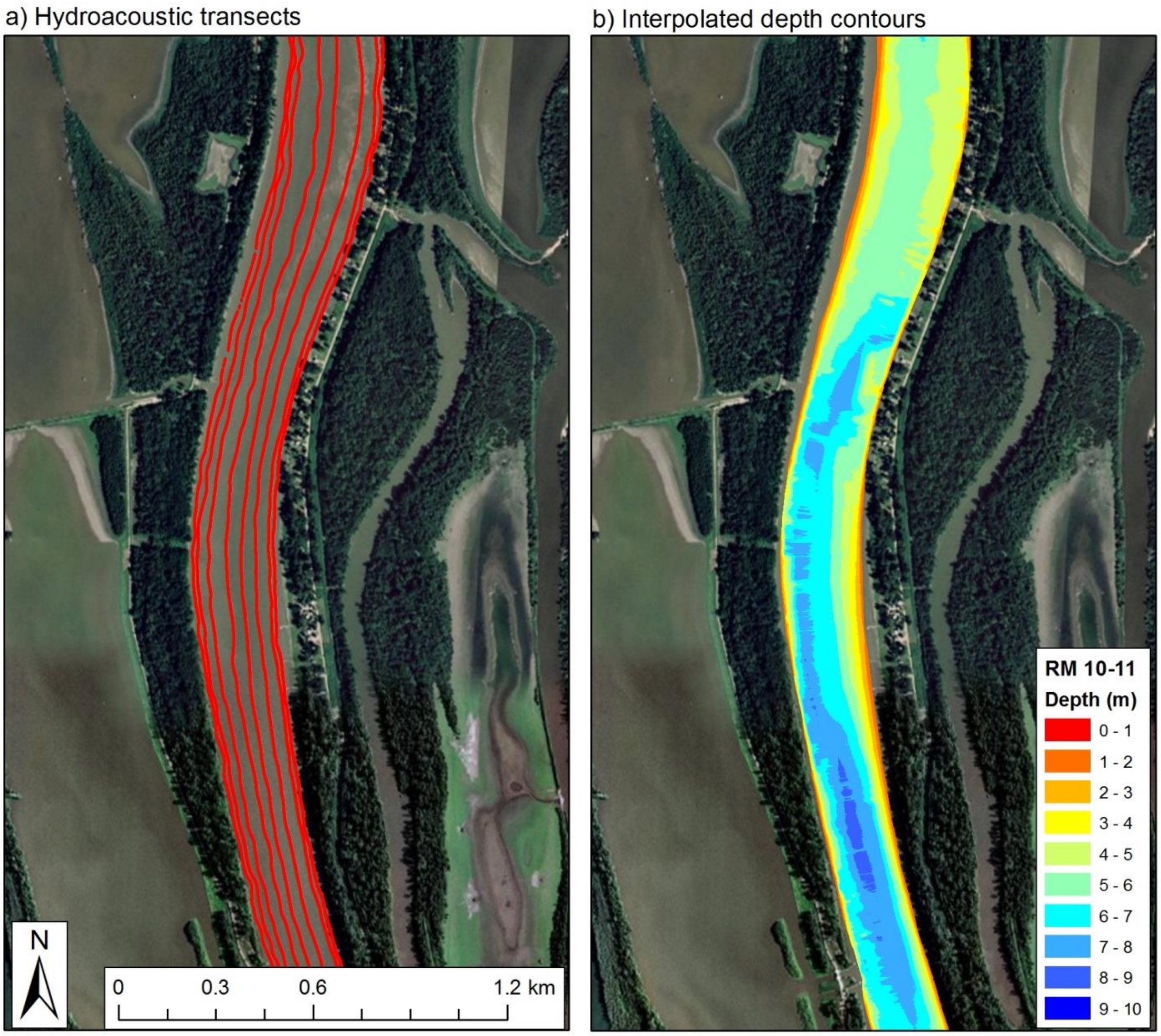


Figure 2.1. Example of a) hydroacoustic transects and b) interpolated depth contours for Alton reach river mile 10-11 (river km 18.5-20.4). Depth contours were estimated using ArcMap 9.3 by interpolating each GPS-referenced depth from all acoustic pings (5 per second) within the main channel via triangulated irregular networks and was not extrapolated beyond our transects (i.e., depth contours do not include nearshore depths < 1.5 m).

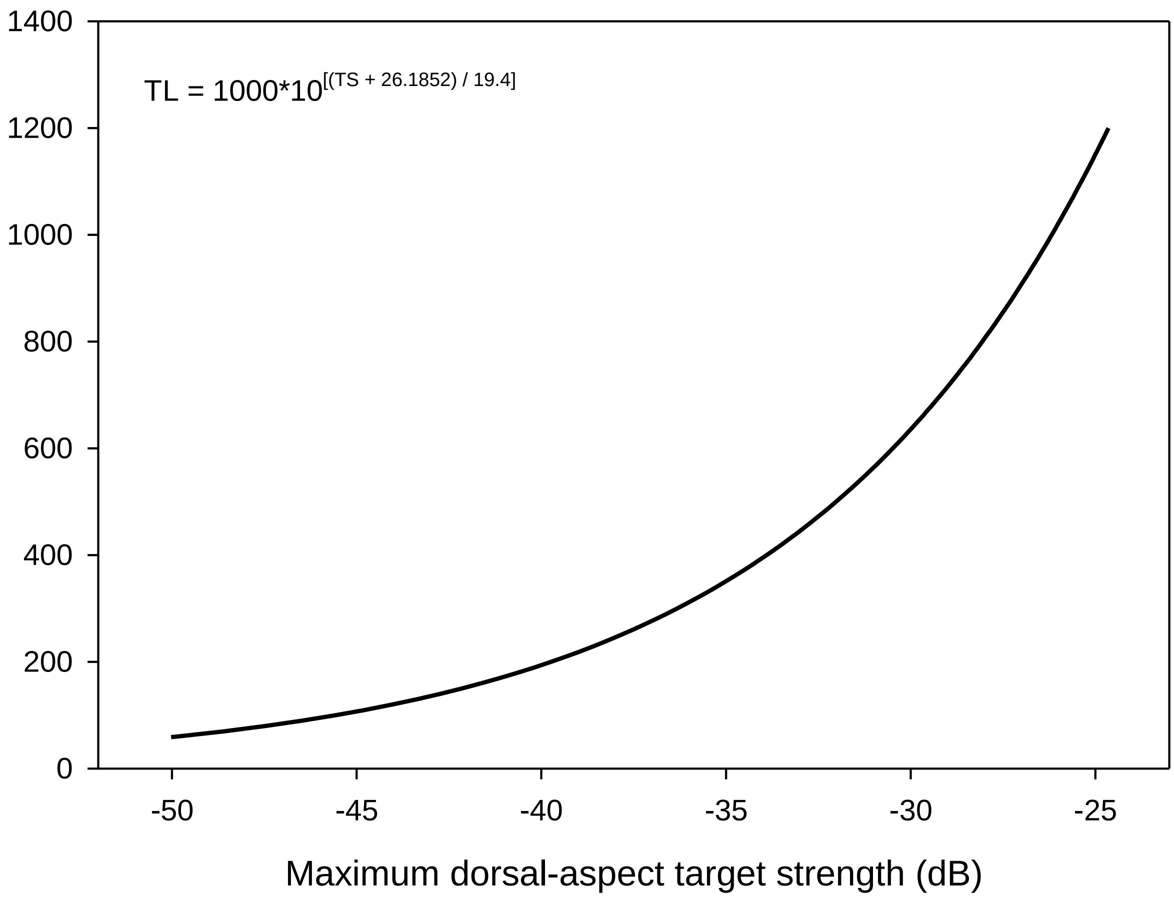


Figure 2.2. Total length plotted as a function of maximum dorsal-aspect target strength (TS) as determined by Love (1971).

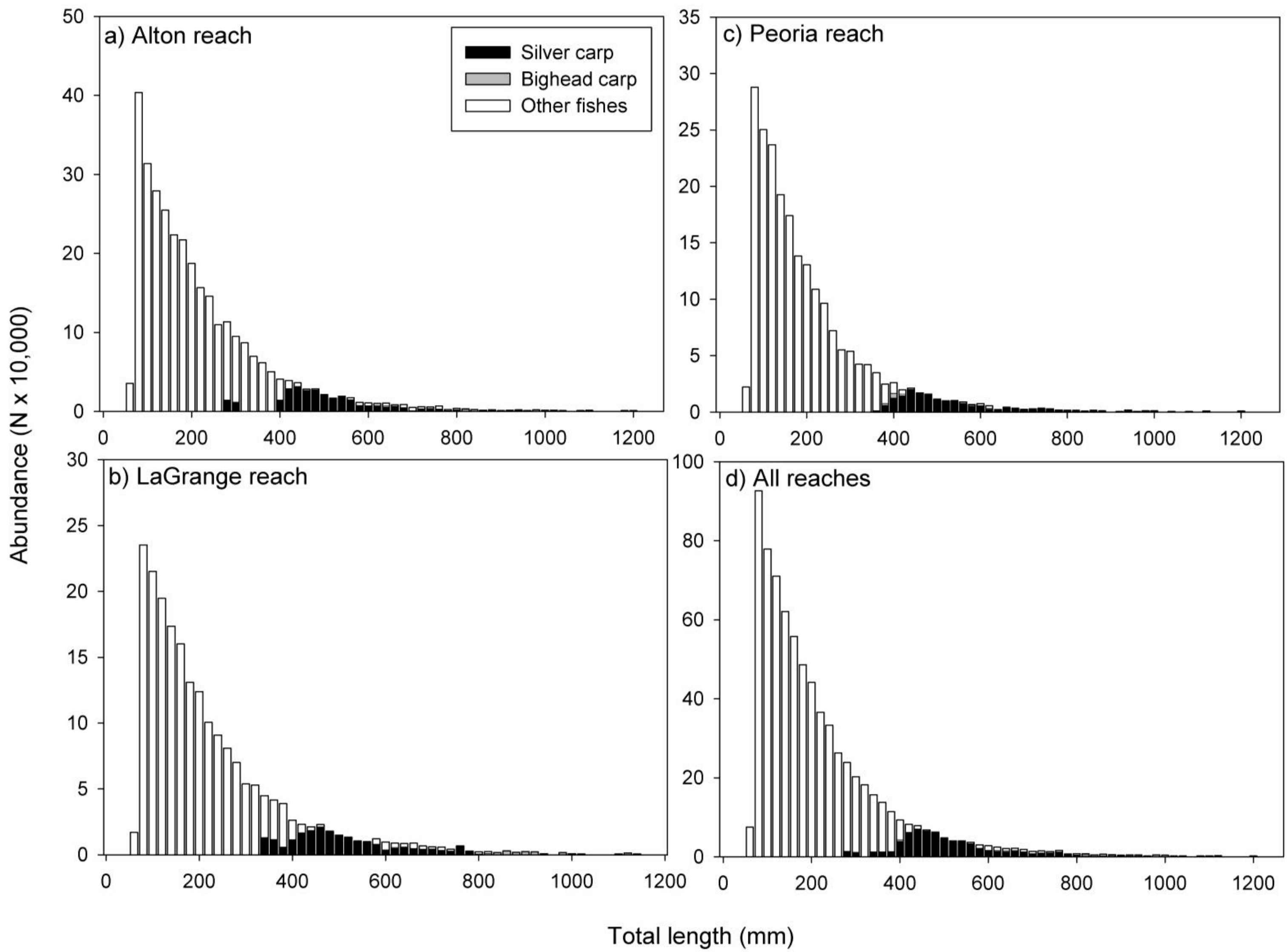


Figure 2.3. Estimated length-frequency for silver carp, bighead carp, and other fishes for the a) Alton reach, b) La Grange reach, c) Peoria reach, and d) all reaches combined for the Illinois River. Note the varying scales in abundance.

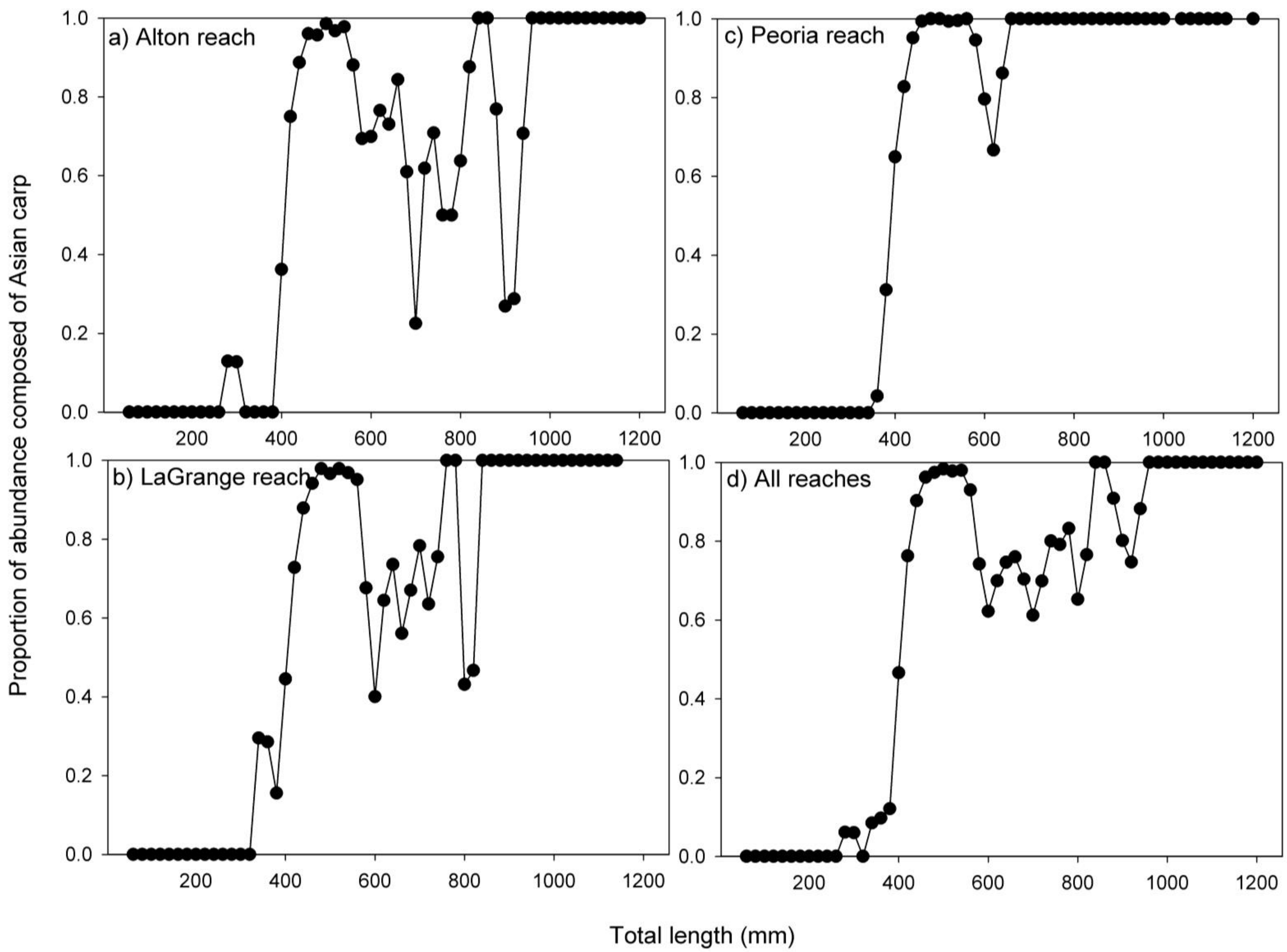


Figure 2.4. Estimated proportion of total fish abundance composed of Asian carp for the a) Alton reach, b) La Grange reach, c) Peoria reach, and d) all reaches combined for the Illinois River.

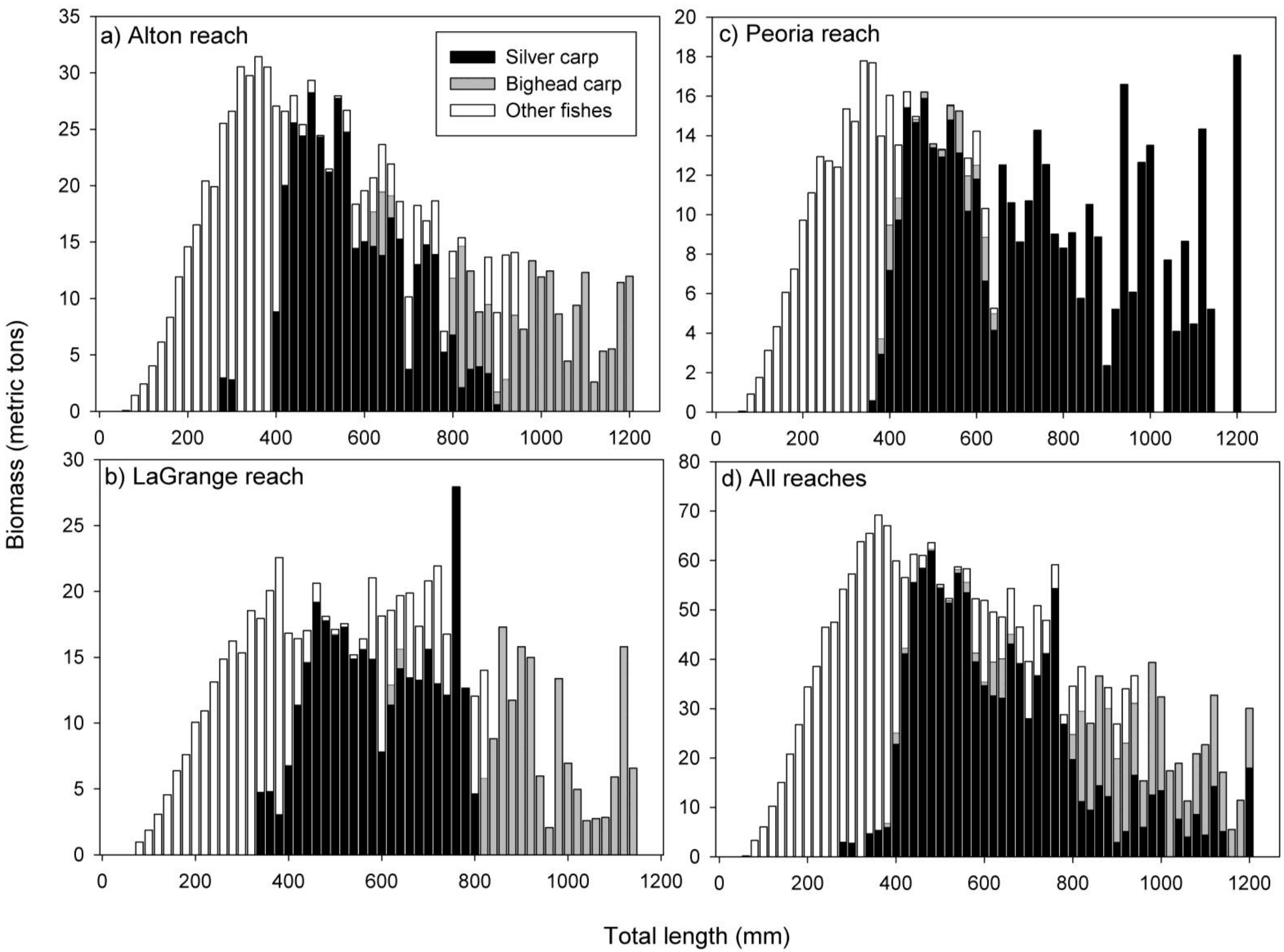


Figure 2.5. Estimated biomass of silver carp, bighead carp, and other fishes for the a) Alton reach, b) La Grange reach, c) Peoria reach, and d) all reaches combined for the Illinois River. Note the varying scales in biomass.

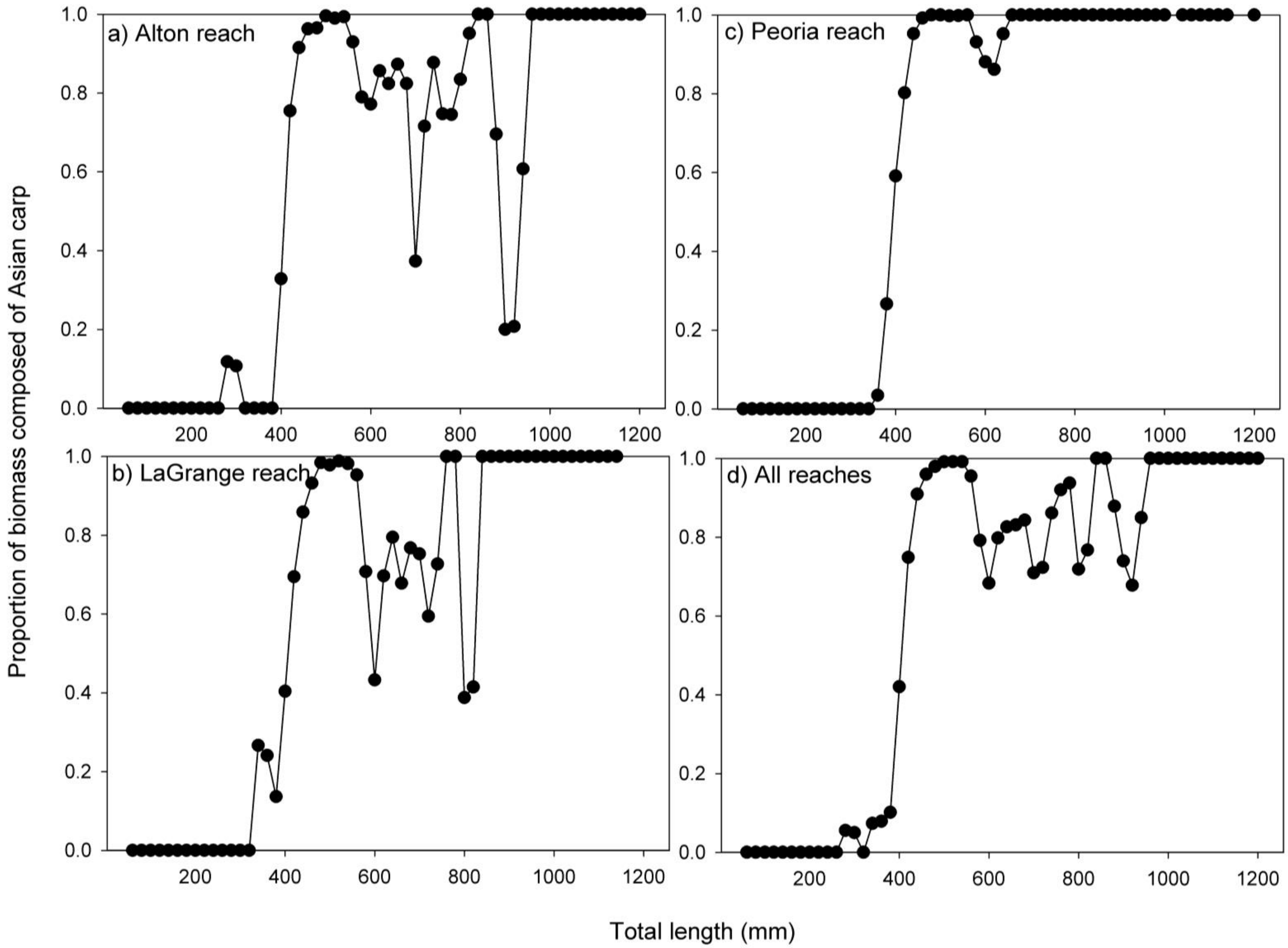


Figure 2.6. Estimated proportion of total fish biomass composed of Asian carp for the a) Alton reach, b) La Grange reach, c) Peoria reach, and d) all reaches combined for the Illinois River.

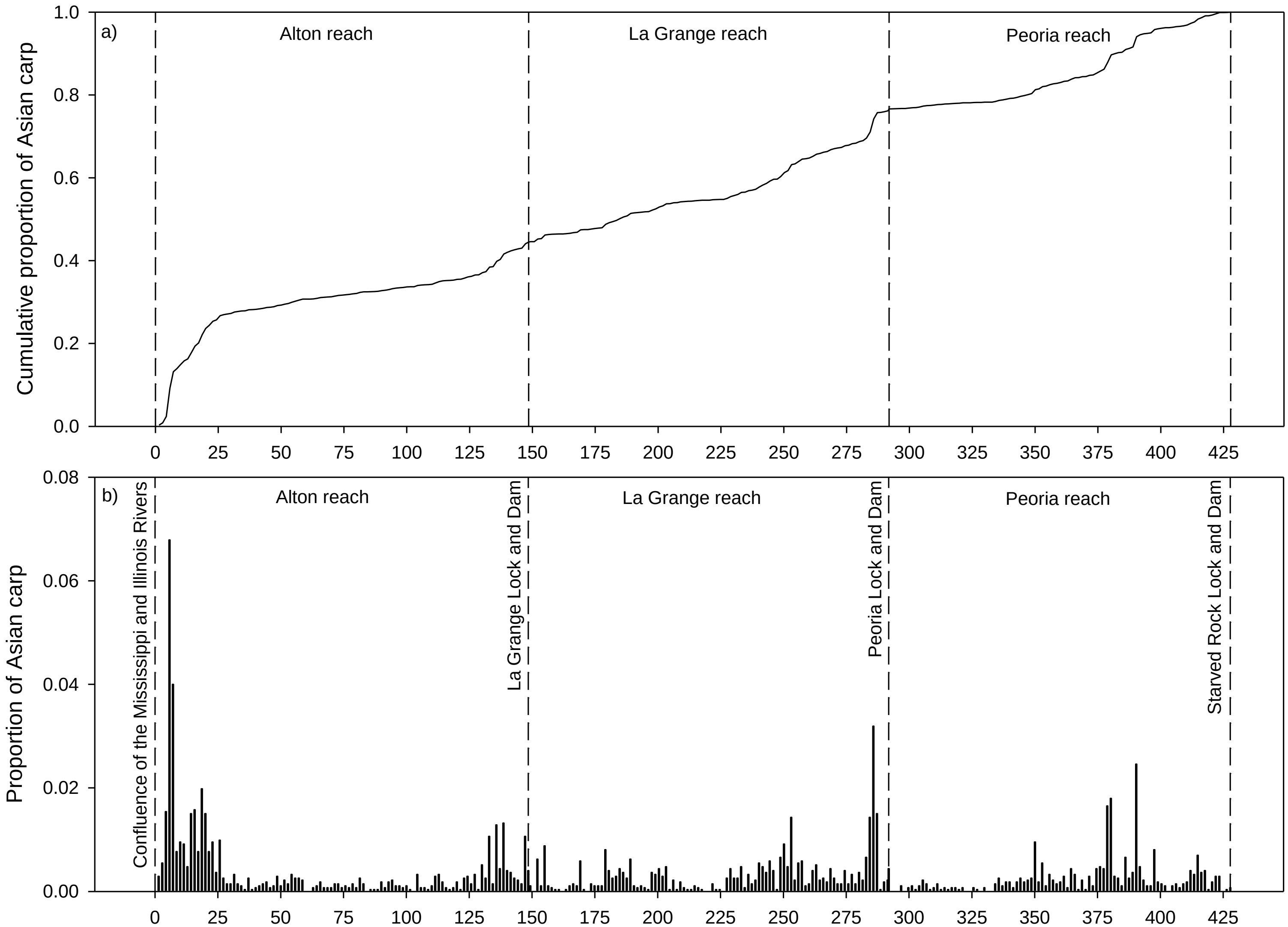


Figure 2.7. a) Cumulative proportion and b) proportion of acoustically detected Asian carp as a function of river km (N = 2,725). Vertical dashed lines indicate spatial separations among reaches. Size classes that were composed of > 50% Asian carp were used for analysis purposes.

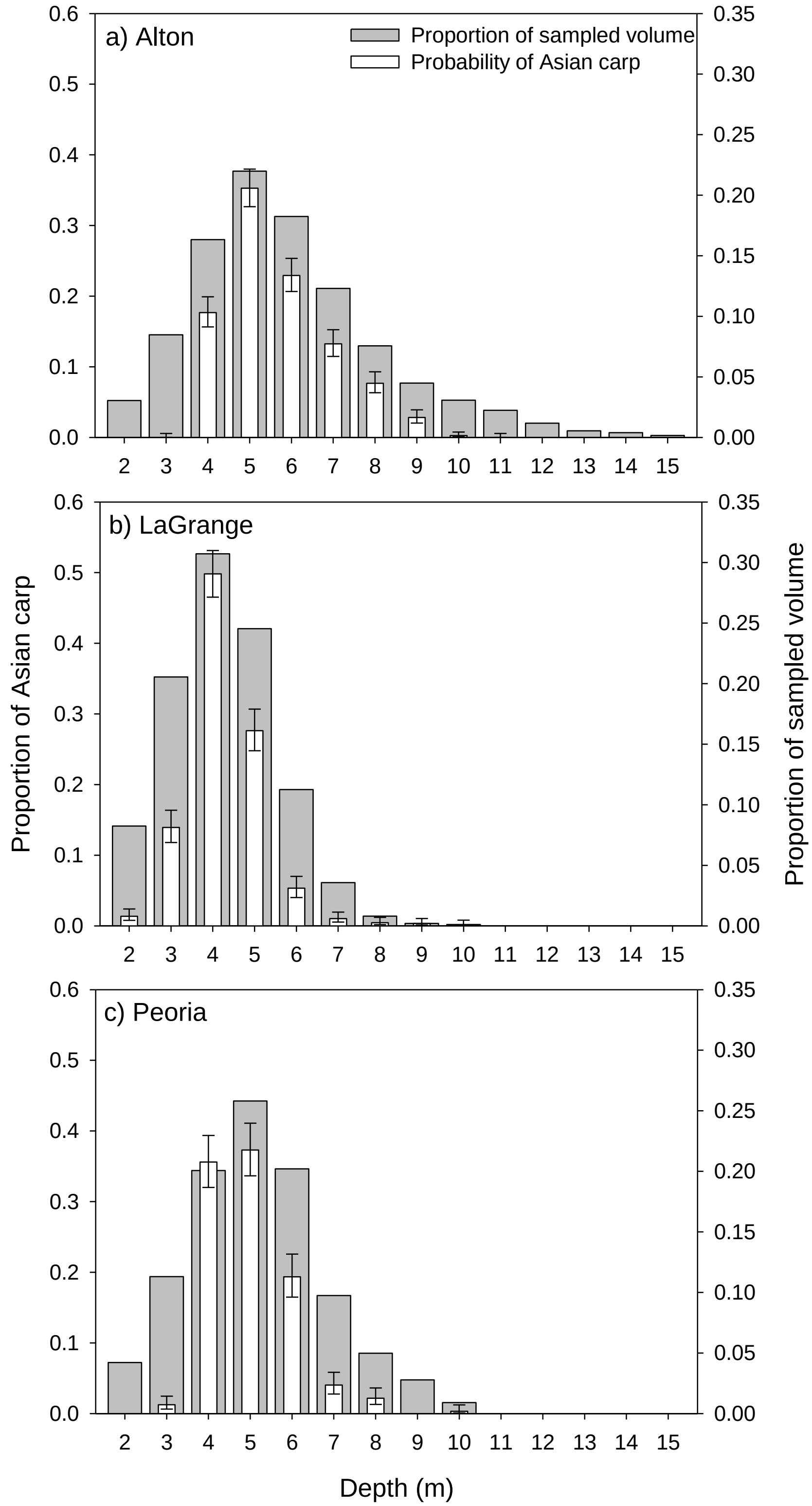


Figure 2.8. Estimated proportional frequency of Asian carp and proportion of acoustically sampled volume plotted across 1-m depth intervals for a) Alton, b) La Grange, and c) Peoria reaches of the Illinois River. Size classes that were composed of > 50% Asian carp were used for analysis purposes. Error bars represent the 95% confidence interval for proportion of Asian carp at a particular depth.

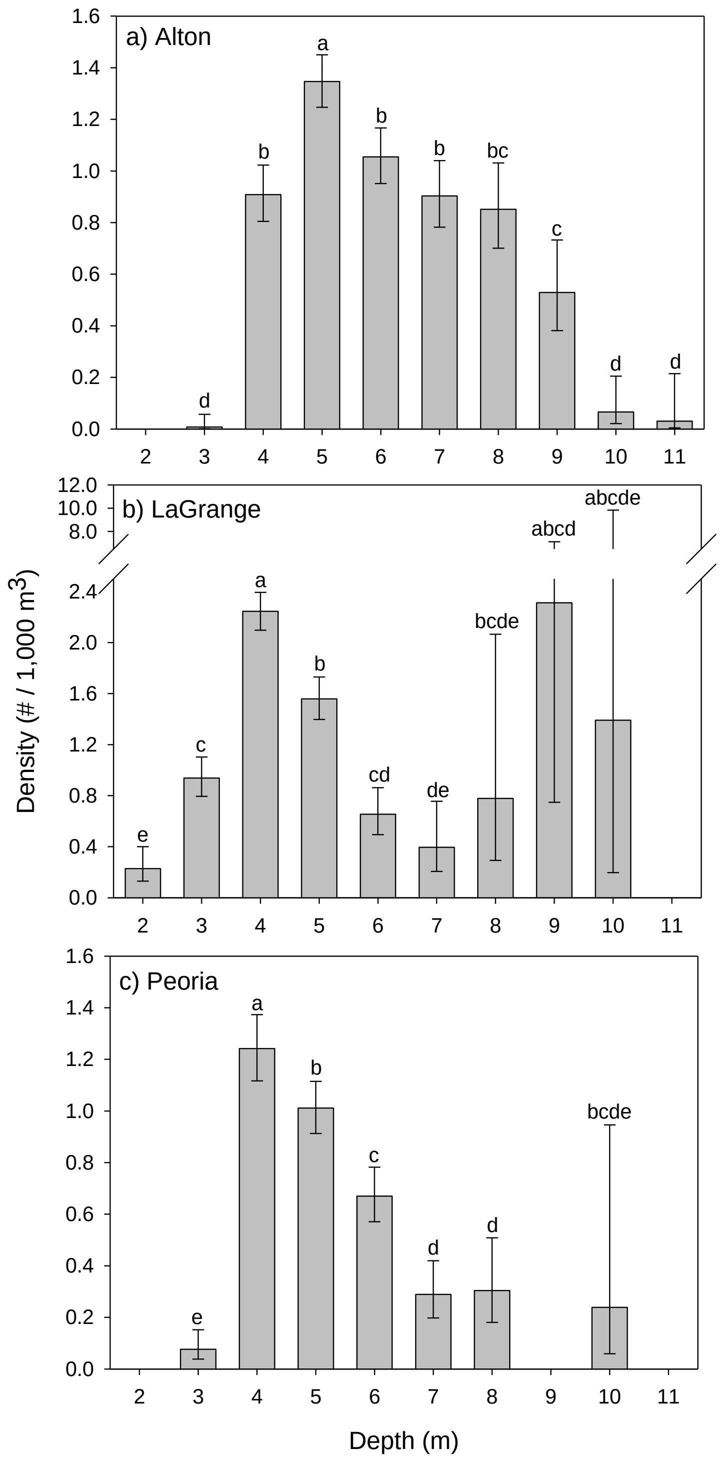


Figure 2.9. Estimated Asian carp density (#/1,000 m$^3$) and corresponding 95% confidence intervals plotted across 1-m depth intervals for a) Alton, b) La Grange, and c) Peoria reaches of the Illinois River. Size classes that were composed of > 50% Asian carp were used for analysis purposes. Bars with different letters indicate significant differences at an $\alpha = 0.05$ level.

# CHAPTER 3

## Training, certification, pilot incentive, marketing and removal research project for the long-term strategy in reducing and controlling Asian Carp populations

### INTRODUCTION

Examples of commercially valuable fish stocks being depleted through overfishing abound. Overexploitation has threatened paddlefish *Polyodon spathula* fisheries in the U.S. (Bettoli et. al 2009), destroyed the Atlantic cod *Gadus morhua* fishery of the North Atlantic (Hutchings and Myers 1994), the Pacific sardine *Sardinops sagax* fishery of California (Helfman et. al 2009), the Peruvian anchoveta *Engraulis ringens* fishery in Peru (Helfman et. al 2009), and many others. It has been estimated that over half of commercially valuable marine fisheries are in need of rebuilding (Worm et. al 2009). Inland waters are not immune to overfishing (Allan et. al 2005). Within the U.S., many historically lucrative commercial fisheries have closed due to overfishing (Quinn 2009). Our ability to decimate fisheries is well documented, but examples of using exploitative fishing practices to successfully control invasive species are less common.

Asian carp is a collective term for silver carp *Hypopthalmichthys molitrix*), bighead carp *Hypopthalmichthys nobilis*, grass carp *Ctenopharyngodon idella*, and black carp *Mylopharyngodon piceus*. These fish most likely escaped from aquaculture and sewage treatment ponds in Arkansas and elsewhere in the 1970's, the result of a misguided campaign by the Department of Agriculture to promote these fish as a non-chemical means of improving water quality. Asian carp have since spread through much of the Mississippi River basin (Tucker et. al 1996). Asian carp, primarily silver and bighead carp, became common in the Illinois River in the late 1990's (Chick and Pegg 2001). Presently, these invaders now dominate the fish community in the Illinois River (Garvey et. al 2013). Mobile hydroacoustic surveys of the Illinois River in 2011 and 2012 have conservatively estimated that Asian carp now account for more than 60% of the total fish biomass in the river system (Garvey et. al 2013).

As filter feeders, Asian carp do compete for resources with native fishes like paddlefish, gizzard shad *Dorosoma cepedianum*, and bigmouth buffalo *Ictiobus cyprinellus*, and studies have shown reduced fitness in these native species where they share habitat with Asian carp (Irons et. al 2007; Schrank et. al 2003). Perhaps of most concern is the possibility that Asian carp will migrate into the Laurentian Great Lakes via the Chicago Sanitary and Shipping Canal, a man-made connection between the Mississippi River Basin and the Great Lakes Basin. Although the impacts of Asian carp establishing populations in the Great Lakes are unknown and there is debate about whether Asian carp could establish thriving populations within the Great Lakes (e.g., Kolar and Lodge 2002, Cooke and Hill 2010, Rasmussen et al. 2011), these species could jeopardize important commercial and recreational fisheries. In addition to the ecological threats posed by Asian carp, their erratic leaping behavior (> 3 m out of the water) that is exhibited when disturbed by vibrations such as a motor boat driving by, also poses a risk to public safety.

In order to reduce Asian carp abundance, to improve conditions for native fishes, and to reduce the likelihood of Asian carp migrating towards the Great Lakes, an enhanced Asian carp commercial harvesting strategy was developed and implemented through collaborations among commercial fishermen, processors, researchers (e.g., Illinois Natural History Survey and State Universities), agencies (e.g., Sea Grant, IL Department of Natural Resources, IL Department of Economic Opportunity), and fisheries managers. Asian carp populations were monitored to provide information about the impact of commercial harvest and potential responses of the populations to increased harvest as marketing efforts are implemented.

**Component 1: Pilot training, certification, and incentive program**

To fulfill the first component of the harvesting strategy, the Center for Fisheries, Aquaculture, and Aquatic Sciences (CFAAS), Southern Illinois University, instituted a training, certification, and incentive program to support the removal of Asian carp throughout the Mississippi and Illinois River systems via Illinois licensed commercial fishermen.

**METHODS:**

A list of commercial fishermen interested in participating in an Asian carp training, certification and incentive program was developed with input from the Illinois Commercial Fishing Association (ICFA), and a lottery was used to select the finalists. The training and certification program included training on safe handling of Asian carp for consumption in foreign and domestic markets, how to properly license and safely operate a commercial fishing fleet, and how to coordinate and communicate Asian carp harvest data to other stakeholder groups.

A pilot program was completed in spring 2011 and evaluated with input from the ICFA, the CFAAS, the participant fishermen, and IDNR to develop and implement a full incentives program for fishing Asian carp that began in summer/fall 2011. Following training and certification, those fishermen who proved to be the most proficient at removing Asian carp became eligible for incentives to aid them in quickly and efficiently meeting growing market demand. For participating fishermen enrolled in the incentives program, the cost of membership to the ICFA, the commercial fishing license fee, certification training fee, and commercial fishing tag fees were all waived. Furthermore, participating fishermen were given a $1,000 bonus to help pay for fuel and net costs after they removed 50,000 pounds of Asian carp, and another bonus of $3,000 after 100,000 pounds of Asian carp were removed. Commercial fishermen enrolled in the incentives program were issued a handheld GPS device and were required to report to CFAAS the locations from which the Asian carp were being removed.

**RESULTS AND DISCUSSION:**

The pilot training and certification program successfully identified a group of ten commercial fishermen and their deckhands who were most proficient at harvesting Asian carp. These fishermen were then chosen to participate in the full incentives program that began in the Summer of 2011. Although the fishermen were successful in removing Asian carp from the Illinois River, the data collection goals of the incentives program were not fully achieved. Specifically, commercial fishermen were wary to report to CFAAS important data such as fishing location (GPS coordinates), despite their eligibility for cash incentives, and despite knowing before they joined the incentives program what their obligations would be. It is suspected that these fishermen ultimately placed a greater value on their proprietary information (i.e. fishing locations and methods) than what they could gain from the incentives by fully participating in the program, suggesting that the incentives package was too low to achieve full compliance.

Of the ten commercial fishermen enrolled in the incentives program, harvest data was collected from only five fishermen, of which only three fully participated. These three fishermen provided GPS locations and dates of their fishing efforts, harvested a combined total of 496,859 pounds of Asian carp from the Illinois River, and received a total of $8,000 in incentive payments (Table 3.1). Although these three fishermen technically fulfilled the obligations of the incentive program, review showed the GPS coordinates provided by the fishermen were typically those of the boat access ramp at which they launched, delivering little if any information to managers on specific removal locations. The other two fishermen for which data was available harvested a total 97,343 lbs. of Asian carp, but no GPS coordinates were provided. Overall harvest of Asian carp by fishermen enrolled in this program was 594,202 lbs., and was composed of approximately 83% silver carp and 17% bighead carp.

If future incentives programs are considered, better communication must be established between the commercial fishermen and the data collecting agency to ensure that participating fishermen know and fulfill their obligations. It may also be necessary to increase incentive amounts to make participation more attractive to commercial fishermen for full program compliance.

Table3.1. Commercial fishermen who fully participated in the incentive fishing program including harvest information, processor information, and fishing coordinates. Bolded row indicates when harvest requirements were met for incentive payments.

| Fisherman | License # | Processor | Delivery Date | lbs SVCP | lbs BHCP | lbs total | GPS N | GPS W |
|---|---|---|---|---|---|---|---|---|
| O. Briney | 945 | Schafer | 11/01/11 | 6389 | 753 | 7142 | 41.06.648 | 89.21.113 |
| O. Briney | 945 | Schafer | 11/02/11 | 8202 | 190 | 8392 | 40.45.234 | 89.33.505 |
| O. Briney | 945 | Schafer | 11/04/11 | 4528 | 377 | 4905 | 40.45.228 | 89.33.879 |
| O. Briney | 945 | Schafer | 11/07/11 | 4209 | 100 | 4309 | 40.45.223 | 89.33.520 |
| O. Briney | 945 | Schafer | 11/08/11 | 5004 | 3350 | 8354 | 40.06.444 | 89.21.367 |
| O. Briney | 945 | Schafer | 11/09/11 | 5315 | 561 | 5876 | 40.42.059 | 89.34.305 |
| O. Briney | 945 | Schafer | 11/11/11 | 6438 | 1193 | 7631 | 41.06.495 | 89.21.365 |
| **O. Briney** | **945** | **Schafer** | **11/14/11** | **5038** | **330** | **5368** | **40.45.225** | **89.33.516** |
| O. Briney | 945 | Schafer | 11/15/11 | 1989 | 1336 | 3325 | 40.01.450 | 89.24.894 |
| O. Briney | 945 | Schafer | 11/16/11 | 7002 | 1085 | 8087 | 41.06.650 | 89.21.107 |
| O. Briney | 945 | Schafer/B.R. | 11/21/11 | | | 5479 | 41.01.502 | 89.24.893 |
| O. Briney | 945 | Schafer | 11/22/11 | | | 0 | 41.01.502 | 89.24.887 |
| O. Briney | 945 | Schafer | 11/23/11 | 11464 | 4386 | 15850 | 41.06.495 | 89.01.367 |
| **O. Briney** | **945** | **Schafer** | **11/25/11** | **15536** | **2219** | **17755** | **41.064.492** | **89.21.362** |
| O. Briney | 945 | Schafer | 11/28/11 | 4138 | 35 | 4173 | 41.06.495 | 89.21.331 |
| O. Briney | 945 | Schafer | 11/30/11 | 8891 | 1931 | 10822 | 41.06.500 | 89.21.336 |
| O. Briney | 945 | Schafer | 12/06/11 | 5809 | 1907 | 7716 | 41.06.502 | 89.21.337 |
| O. Briney | 945 | Schafer | 12/07/11 | 7671 | 2410 | 10081 | 41.06.500 | 89.21.35 |
| O. Briney | 945 | Schafer | 12/08/11 | 10185 | 1745 | 11930 | 41.06.502 | 89.21.337 |
| O. Briney | 945 | Schafer | 12/08/11 | | | | 41.06.500 | 89.21.337 |
| O. Briney | 945 | Schafer | 12/09/11 | 4361 | 850 | 5211 | 41.06.502 | 89.21.337 |
| Fisherman | License | Processor | Delivery | lbs | lbs | lbs total | GPS **N** | GPS **W** |

| | # | | Date | SVCP | BHCP | | | |
|---|---|---|---|---|---|---|---|---|
| O. Briney | 945 | Schafer | 12/12/11 | 8182 | 1252 | 9434 | 40.45.221 | 89.33.575 |
| O. Briney | 945 | Schafer | 12/09/11 | 4361 | 830 | 5191 | 41.06.502 | 89.21.337 |
| O. Briney | 945 | Schafer | 12/13/11 | 11317 | 94 | 11411 | 40.54.919 | 89.28.967 |
| O. Briney | 945 | Schafer | 12/14/11 | 3029 | 511 | 3540 | 40.42.047 | 89.34.310 |
| O. Briney | 945 | Schafer | 12/15/11 | 5162 | 434 | 5596 | 40.42.066 | 89.34.300 |
| O. Briney | 945 | Schafer | 12/19/11 | 8033 | 77 | 8110 | 41.06.500 | 89.21.335 |
| O. Briney | 945 | Schafer | 12/20/11 | 7922 | | 7922 | 41.06.500 | 89.21.335 |
| O. Briney | 945 | Schafer | 12/22/11 | 5836 | 2564 | 8400 | 41.11.282 | 89.977 |
| O. Briney | 945 | Schafer | 12/26/11 | 9536 | 813 | 10349 | 39.52.225 | 90.32.981 |
| O. Briney | 945 | Schafer | 12/28/11 | 4341 | 941 | 5282 | 41.06.497 | 89.21.335 |
| O. Briney | 945 | Schafer | 12/29/11 | 1785 | 1556 | 3341 | 41.06.497 | 89.21.335 |
| O. Briney | 945 | Schafer | 12/29/11 | 4804 | 1653 | 6457 | 41.06.497 | 87.21.335 |
| L. Gregerson | 4037 | Big River | 10/31/11 | | | 1552 | 40.00.956 | 90.26.510 |
| L. Gregerson | 4037 | Big River | 11/05/11 | | | 2446 | 40.19.094 | 90.03.647 |
| L. Gregerson | 4037 | Big River | 11/12/11 | | | 2957 | 40.03.831 | 90.25.593 |
| L. Gregerson | 4037 | Big River | 12/05/11 | | | 11424 | GPS error | Bath, IL |
| L. Gregerson | 4037 | Big River | 12/10/11 | 4316 | 1598 | 5914 | 40.11.490 | 90.09.734 |
| L. Gregerson | 4037 | Big River | 12/12/11 | | | 6922 | 40.05.879 | 90.25.387 |
| L. Gregerson | 4037 | Big River | 12/17/11 | 3137 | 825 | 3962 | 40.11.526 | 90.08.703 |
| L. Gregerson | 4037 | Big River | 12/19/11 | 4690 | 760 | 5450 | 40.05.878 | 90.25.387 |
| D. Riley | 217 | Schafer | 11/04/11 | 4528 | 377 | 4905 | 40.45.228 | 89.33.879 |
| D. Riley | 217 | Schafer | 11/07/11 | 4209 | 100 | 4309 | 40.45.223 | 89.33.520 |
| D. Riley | 217 | Schafer | 11/08/11 | 5004 | 3350 | 8354 | 40.06.444 | 89.21.367 |
| D. Riley | 217 | Schafer | 11/09/11 | 5315 | 561 | 5876 | 40.42.059 | 89.34.305 |
| D. Riley | 217 | Schafer | 11/14/11 | 5038 | 330 | 5368 | 40.45.225 | 89.33.516 |

| Fisherman | License # | Processor | Delivery Date | lbs SVCP | lbs BHCP | lbs total | GPS **N** | GPS **W** |
|---|---|---|---|---|---|---|---|---|
| D. Riley | 217 | Schafer | 11/15/11 | 1989 | 1336 | 3325 | 40.01.450 | 89.24.894 |
| D. Riley | 217 | Schafer | 11/16/11 | 7002 | 1085 | 8087 | 41.06.650 | 89.21.107 |
| D. Riley | 217 | Schafer/B.R. | 11/21/11 | | | 5479 | 41.01.502 | 89.24.893 |
| **D. Riley** | **217** | **Schafer** | **11/23/11** | **11464** | **4386** | **15850** | **41.06.495** | **89.01.367** |
| D. Riley | 217 | Schafer | 11/25/11 | 15536 | 2219 | 17755 | 41.06.492 | 89.21.362 |
| D. Riley | 217 | Schafer | 11/28/11 | 4138 | 35 | 4173 | 41.06.495 | 89.21.331 |
| D. Riley | 217 | Schafer | 11/30/11 | 8891 | 1931 | 10822 | 41.06.500 | 89.21.336 |
| **D. Riley** | **217** | **Schafer** | **12/01/11** | **6389** | **753** | **7142** | **41.06.648** | **89.21.113** |
| D. Riley | 217 | Schafer | 12/06/11 | 5809 | 1907 | 7716 | 41.06.502 | 89.21.337 |
| D. Riley | 217 | Schafer | 12/07/11 | 7671 | 2410 | 10081 | 41.06.500 | 89.21.35 |
| D. Riley | 217 | Schafer | 12/08/11 | 10185 | 1745 | 11930 | 41.06.502 | 89.21.337 |
| D. Riley | 217 | Schafer | 12/12/11 | 8182 | 1252 | 9434 | 40.45.221 | 89.33.575 |
| D. Riley | 217 | Schafer | 12/13/11 | 11317 | 94 | 11411 | 40.54.919 | 89.28.967 |
| D. Riley | 217 | Schafer | 12/14/11 | 3029 | 511 | 3540 | 40.42.047 | 89.34.310 |
| D. Riley | 217 | Schafer | 12/15/11 | 5162 | 434 | 5596 | 40.42.066 | 89.34.300 |
| D. Riley | 217 | Schafer | 12/16/11 | 4903 | 245 | 5148 | 41.01.501 | 89.24.891 |
| D. Riley | 217 | Schafer | 12/19/11 | 8033 | 77 | 8110 | 41.06.500 | 89.21.335 |
| D. Riley | 217 | Schafer | 12/20/11 | 7922 | | 7922 | 41.06.500 | 89.21.335 |
| D. Riley | 217 | Schafer | 12/22/11 | 5836 | 2564 | 8400 | 41.11.282 | 89.977 |
| D. Riley | 217 | Schafer | 12/26/11 | 9536 | 813 | 10349 | 39.52.225 | 90.32.981 |
| D. Riley | 217 | Schafer | 12/28/11 | 4341 | 941 | 5282 | 41.06.497 | 89.21.335 |
| D. Riley | 217 | Schafer | 12/29/11 | 4804 | 997 | 5801 | 41.06.497 | 89.21.335 |
| D. Riley | 217 | Schafer | 12/30/11 | 3516 | 3112 | 6628 | 40.03.876 | 90.25.627 |
| Total | | | | 388369 | 72231 | 496859 | | |

**Component 2: Population Metrics of Commercially Caught Asian Carp, the Ecological Effectiveness of Asian Carp Removal and the Commercial Suitability of Carp Meal.**

The second commercial harvest component was conducted independently of the certification and incentives project and fishermen were not eligible for harvest incentives. The second component was a targeted, research-oriented fishing effort to understand the ecological effectiveness of Asian carp harvest, and to determine the commercial suitability of Asian carp fish meal for inclusion in aquafeeds. Prior to the implementation of this harvest component, CFAAS initiated an ongoing standardized sampling program in the Illinois River that includes electrofishing, trammel netting, and split-beam hydroacoustic surveys, allowing comparisons of Asian carp population metrics in the river pre- and post-harvesting efforts (Garvey et al. 2013).The Asian carp removed through this research component were processed into fish meal that was delivered to CFAAS. Portions of this meal were used in feed inclusion experiments and remaining fish meal was sold to private markets, with revenue generated used for the express purpose of conducting further research or aiding in Great Lakes restoration (Appendix).

The taxonomic, seasonal, and geographic variation in nutritional composition of bighead and silver carp were determined to assess their suitability for rendering and subsequent use as a protein source in aquafeeds. This data has since been published in peer-reviewed literature (Bowzer et al. 2013; Appendix).

**METHODS:**

Through a competitive bidding process, Big River Fish Company, a processing plant in Pearl, IL, was selected to hire and pay licensed Illinois commercial fishermen to harvest at least one million pounds of Asian carp from the lower three reaches of the Illinois River (Alton, La Grange, and Peoria). Researchers from the CFAAS visited the processing plant approximately every two weeks from 1 February 2012 thru 8 May 2012 while fishing was occurring, and collected data from harvested bighead and silver carp. During each visit, up to 100 silver carp and 100 bighead carp from each IL river reach were randomly selected from the delivered commercial harvest. Fish were weighed and measured, additionally, post-cleithra for age determination, sex, and gonad weights were collected from a subsample of up to five fish of each species and each reach within 50-mm total length group intervals.

*Mean length-at-age*

Post-cleithra were sectioned transversely across the center with a Buehler 1.5 amp diamond-blade low-speed isomet saw following Johal et al. (2000). Sections were read by two independent readers using side illumination from a Dolan-Jenner MI-150 fiber optic light; if disagreements between readers could not be resolved the age was omitted from analyses. Age distributions were developed for the entire sample using an age-length key. Silver carp and bighead carp mean length-at-age was compared among reaches using a two-way analysis of variance (ANOVA). Comparisons were made for age classes 2.5 through 8.5 for silver carp and 2.5 through 11.5 for bighead carp. If the $F$-test detected significant differences, post-hoc $t$-tests were conducted to determine where differences existed. A two-way ANOVA was also used to compare mean length-at-age between silver carp harvested by commercial fishermen and silver carp collected by electrofishing in 2012 (Garvey et al. 2013).

*Length-weight relationships*

Length-weight relationships were developed for commercially caught silver and bighead carp within each reach as well as all reaches combined after $\log_{10}$-transforming weight and total length data. Outliers within the data were identified and removed if they could not be rectified from original data sheets and were not biologically reasonable. The slope and intercept parameters of the length-weight relationships were then compared among reaches using an analysis of covariance (ANCOVA).

*Mortality*

The types of commercial gears used by commercial fishermen were varied and generally not reported. Examination of the catch data appeared to show gear selectivity towards larger individuals. Because the statistical models used to estimate mortality assume the sampling gear adequately represents the standing length distribution of the population, an accurate estimate of mortality could not be developed from commercially harvested Asian carp data (Miranda and Bettoli, 2007).

*Indices of spawning condition*

Commercially harvested Asian carp were collected before the spawning period. As such, we tested for changes in gonadosomatic index (GSI) as a function of TL for female silver and bighead carp using a two-dimensional Kolmogorov-Smirnov test (Garvey et al. 1998) to determine the size at which variation in GSI increases such that the probability of having a higher GSI increases, which is indicative of the potential size at maturation.

*Sex ratio of Asian carp*

Sex ratios of commercially harvested Asian carp were investigated within and among reaches. A chi-squared goodness of fit analysis was conducted to determine whether overall sex ratios differed from 1:1, and a chi-squared test of independence tested whether the sex ratios differed spatially among reaches. All statistical analyses were conducted using SAS 9.2. (SAS Institute 2009).

**RESULTS AND DISCUSSION:**

The initial goal of harvesting 1 million pounds of Asian carp to be processed into fish meal was quickly surpassed, and by the completion of this component, nearly 3 million pounds of Asian carp were removed and processed. Between 25 January 2012 and 11 June 2012, commercial fishermen harvested 1,776,656 pounds of Asian carp from the Alton reach, 493,636 pounds from the La Grange reach, and 609,708 pounds from the Peoria reach, for a total of 2.88 million pounds (Figure 1).

Researchers from CFAAS weighed and measured 2,778 Asian carp (1,761 silver and 1,017 bighead). Of these fish, 662 were sexed, and GSI's were calculated for 298 fish. Post cleithra were removed and aged from 292 fish (133 silvers, 159 bighead).

*Mean length-at-age*

Mean length-at-age for silver carp harvested by commercial fishermen differed significantly among reaches for most age classes (*P* < 0.05; Figure 3.2). Mean length-at-age was significantly higher than all other reaches for fish harvested from the Peoria reach for age classes 2.5, 3.5, and 4.5. In age classes 5.5, 6.5, and 7.5, mean length-at-age tended to be highest in the Alton reach. Mean length-at-age was actually quite homogenous for fish harvested from the Peoria reach, ranging from 613-694 mm TL across all sampled age classes, indicating a bias in commercial gears towards larger fish.

Comparisons of mean length-at-age from commercially harvested silver carp and those collected from electrofishing in 2012 further demonstrated the size selectivity of commercial gears. Commercially harvested fish had significantly greater mean lengths-at-age compared to silver carp collected with electrofishing for all age classes and reaches (*P* < 0.05) except for age-6.5 in the Peoria and La Grange reaches, where although mean TL was larger in commercially caught fish, it was not significant (Figure 3).

Due to low sample sizes of bighead carp collected during standardized sampling, we did not compare their mean length-at-age to commercially caught bighead carp. Comparisons of mean length-at-age of commercially harvested bighead carp among reaches showed harvested bighead carp tended to have greater mean TL from the Alton pool up to age 7.5,with no differences among reaches observed after age 7.5 (Figure 3.4).

*Age and length frequency of harvested Asian carp*

Over 25% of commercially harvested silver carp were age 5.5 and older, compared to just over 7% of silver carp collected during standardized electrofishing (Figure 3.5). The length frequency histogram comparing commercial harvest to standardized sampling shows a bimodal distribution of commercially caught silver and bighead carp for most reaches and for all reaches combined (Figure 3.6). This suggests that not only are commercial fishermen harvesting more larger, older fish, compared to our standardized sampling, but they are also harvesting the largest fish within younger age classes. This is supported by the lack of a bimodal distribution in the age-frequency histogram of commercially harvested fish (Figure 3.5).

These data indicate that commercial fishermen are successfully removing larger and older individuals from the population. While standardized sampling does not collect as many of these larger fish, the length-frequency histograms developed from that sampling are likely a better representation of the population size-structure as a whole. Continued monitoring of the age and length-frequency of commercially harvested fish and continued standardized sampling in the IL River will further help us to determine the efficacy of electrofishing as a tool for estimating size structure of Asian carp populations, and the efficacy of commercial fishing in controlling the Asian carp population as a whole. Commercial harvest modeling has suggested that in order to deplete Asian carp populations in the IL River, all age classes must be targeted for removal (Tsehaye et al. 2013). Currently, it does not appear that commercial removal of smaller Asian carp is occurring.

*Length-weight relationships*

Analysis of covariance indicated that the intercept and slope of the length-weight relationships were significantly different among reaches for commercially caught silver carp (slope: $F_{2, 1752} = 90.76$; $P < 0.0001$; intercept: $F_{2, 1752} = 90.74$; $P < 0.0001$), and bighead carp (slope: $F_{2, 1006} = 0.077$; $P < 0.0001$; intercept: $F_{2, 1006} = 0.078$; $P < 0.0001$; Table 1). Specifically, silver carp length-weight relationship parameters were different among all reaches ($P < 0.05$), with smaller TL silver carp in the Alton and Peoria reaches being generally heavier than those in the La Grange reach, and longer TL silver carp being heaviest in the La Grange reach, and least heavy in the Alton reach. These same differences in length-weight relationships by reach were also observed in the 2012 standardized sampling data (Garvey et al. 2013). Bighead carp length-weight relationship parameters differed among Alton and Peoria reaches, but not between Alton and La Grange, or between La Grange and Peoria. Specifically, smaller TL bighead carp tended to be heavier in the Peoria reach compared to the Alton reach, while larger TL bighead carp were heavier in the Alton reach compared to the Peoria reach (Table 1). Comparisons of bighead carp length-weight trends in commercial catches to standardized sampling was not attempted due to low sample size. Future research may want to investigate habitat or forage differences among reaches that may better explain the observed differences in fitness between different size classes of silver and bighead carp among reaches

*Indices of spawning condition*

The size at which variation in commercially harvested female silver carp GSI increased, such that the probability of having a higher GSI increased, was 506-mm TL for the Alton reach ($P = 0.026$), and was indicative of the size at maturity. Based on our age-length key, these estimates correspond to an age-at-maturity between age 3 and 4. For the Peoria and La Grange reaches, female silver carp variation in GSI was statistically homogenous across TL ($P = 0.09$; 0.671) respectively. This could be an artifact of low sample size and a lack of GSI values for multiple size classes of fish (in the Peoria reach, GSI values were only available for female silver carp >700 mm TL). Mean GSI of commercially harvested female silver carp ranged from 0.016 (SE = 0.0033) to 0.022 (SE = 0.0054) among reaches (Table 3.2). Mean GSI for female silver carp from 2012 standardized sampling ranged from 0.0017 (SE = 0.0028) to 0.0064 among reaches. These fish were collected post-spawn, which is reflected in their lower GSI values. However, the estimated size at maturity for commercially caught silver carp, pre-spawn, was comparable to the estimates made for fish collected during standardized sampling, post-spawn (Garvey et al. 2013).

The size at which variation in female bighead carp GSI increased, such that the probability of having a higher GSI increased, was 674-mm TL for the Alton reach ($P = 0.002$), and 636-mm TL for the La Grange reach ($P = 0.001$) and was indicative of the size at maturity. Based on our age-length key, these estimates correspond to an age-at-maturity between age 3 and 4. For the Alton reach, female bighead carp variation in GSI was statistically homogenous across TL ($P = 0.209$) potentially due to small sample size (N = 15) and lack of small, immature individuals in which we would expect to see low GSI values with low variation. Mean GSI for female bighead carp ranged from 0.0142 (SE = 0.0042) to 0.0149 (SE = 0.0049) among reaches (Table 3.5). Standardized sampling activities have not historically collected enough female bighead carp to make comparisons of GSI to the commercial catch.

Future efforts should include increasing our sample size and our confidence in these values. Continued monitoring of GSI in Asian carp populations in the Illinois River will be important in determining trends in reproductive success.

*Sex ratio of Asian carp*

Sex ratios were not significantly different from 1:1 for commercially harvested silver carp when all reaches were combined (217 females, 236 males; $\chi^2_1$ = 0.80; $P$ = 0.398) but did differ from 1:1 when reaches were treated separately ($\chi^2_2$ = 12.68; $P$ = 0.002). Specifically, the Alton and La Grange commercial catches were composed of roughly 55% males and 45% females, whereas the Peoria reach was 63% male and 37% female for a 1.73:1 ratio.

Sex ratios of commercially harvested bighead carp also did not differ from 1:1 when all reaches were combined (95 females, 114 males; $\chi^2_1$ =1.727; $P$ = 0.213). Bighead carp sex ratios did not significantly differ from 1:1 among reaches ($\chi^2_2$ = 4.67; $P$ = 0.099) although there tended to be more females harvested in the Alton reach, and more males harvested in the La Grange and Peoria reaches. Given the tendency for commercial gears to harvest larger fish, it was counter to our expectations that commercial catches did not harvest proportionately more females, particularly larger females from younger age classes. It will be important to continue monitoring sex ratios in the future to make inferences about the potential intrinsic rate of increase of Asian carp abundance.

*Catch per unit effort pre- and post-harvest*

We observed a 33% reduction in silver carp electrofishing CPUE for the three lower reaches of the Illinois River combined, from 151.9 fish/hour (SE = 19.7) in summer 2011 (before harvest component 2) to 102.1 fish/hour (SE = 22.8) in summer 2012, after the harvest component ($P$ = 0.0027; Figure 3.7). By reach, silver carp mean CPUE was significantly reduced from 2011 to 2012 in the Alton reach by more than half ($P$ = 0.0007), but was not different between years for the La Grange reach ($P$ = 0.07) or the Peoria reach ($P$ = 0.59) despite a trend of lower CPUE in both of these reaches. The reduction in CPUE may indicate that commercial removals are lowering silver carp abundance in the Illinois River. Reduced abundance of silver carp may also be related to water level fluctuations in the Illinois River over the last two years. Specifically, the summer of 2011 was characterized by above-average precipitation and high water levels. In contrast, 2012 was an abnormally dry year, and water levels on the Illinois River were significantly lower, which could have triggered an emigration of silver carp out of the system.

Electrofishing CPUE for bighead carp was not different from 2011 to 2012 for the lower three reaches of the Illinois River combined or among reaches ($P \geq 0.28$). Despite the lack of statistical difference between years, overall bighead carp CPUE was reduced from 2.9 fish/hr in 2011 to 0.3 fish/hr in 2012 among all reaches. The relatively low abundance of bighead carp along with the variability in catch rates, to some extent due to our inefficiency at capturing bighead carp, is likely the reason for not detecting differences in CPUE between years. Specifically, of the 2.88 million lbs. of Asian carp harvested in the three lower reaches of the Illinois River in Spring 2012 for conversion to fish meal, 45% was composed of bighead carp. As such, we would have expected strong declines in relative abundance of bighead carp. Additional analyses regarding total catches from commercial fishermen brought to processing plants, and continued monitoring by our standardized sampling program may provide a better indication of whether declines in bighead carp and silver carp abundance are occurring, or will continue to occur.

*DISCUSSION POINTS*

While a limited number of commercial fishermen reported using seines, which would harvest all sizes of Asian carp, the majority of fishermen used gill or trammel nets to target larger fish (personal communication). This selectivity for larger fish was apparent when comparing age frequencies, length frequencies, and mean length at age of commercially caught Asian carp to those caught by electrofishing during standardized sampling. Standardized sampling is limited in its ability to collect as many large fish as commercial gears, but the data that is collected is likely more representative of the population as a whole. Additional monitoring may be necessary to determine whether larger fish in the population are underrepresented in our standardized sampling regimen, and to investigate whether the lack of strong recruitment in recent years could also have facilitated some of our observed results. Continued population and harvest monitoring will help us to determine what compensatory responses Asian carp populations may experience as a result of ongoing fishing pressures.

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Table 3.1. Parameter values from the length-weight relationships ($\log_{10}$mass = $a' + b \cdot \log_{10}$TL) for commercially caught silver carp and bighead carp from the lower three reaches of the Illinois River, 2012. Parameter estimates with different letters indicate significantly different values among reaches at the $\alpha = 0.05$ level, as determined by ANCOVA.

| Reach | *a*' | SE | *b* | SE | $R^2$ | *P* | *N* |
|---|---|---|---|---|---|---|---|
| | | | **Silver carp** | | | | |
| Alton | -4.552[a] | 0.101 | 2.845[a] | 0.036 | 0.91 | <0.0001 | 646 |
| La Grange | -5.806[b] | 0.074 | 3.294[b] | 0.027 | 0.96 | <0.0001 | 580 |
| La Grange* | -5.294 | - | 3.122 | - | - | <0.001 | 1,451 |
| Peoria | -3.237[c] | 0.173 | 2.374[c] | 0.061 | 0.74 | <0.0001 | 526 |
| | | | **Bighead carp** | | | | |
| Alton | -4.123[a] | 0.104 | 2.688[a] | 0.036 | 0.94 | <0.0001 | 338 |
| La Grange | -4.723[ab] | 0.074 | 2.889[ab] | 0.026 | 0.97 | <0.0001 | 382 |
| La Grange* | -4.838 | - | 2.952 | - | - | <0.001 | 73 |
| Peoria | -3.878[b] | 0.164 | 2.592[b] | 0.057 | 0.88 | <0.0001 | 286 |

* Results from Irons et al. (2007) for comparison purposes to data collected from the La Grange reach from 1990-2006.

Table 3.2. Mean gonadosomatic index (GSI) for commercially harvested bighead carp and silver carp by reach and sex in the Illinois River, 2012.

| Species | Sex | *N* | Mean GSI | SE |
|---|---|---|---|---|
| | | **Alton** | | |
| Bighead carp | F | 32 | 0.0148 | 0.0034 |
| Bighead carp | M | 30 | 0.0019 | 0.0003 |
| Silver carp | F | 38 | 0.0160 | 0.0033 |
| Silver carp | M | 23 | 0.0042 | 0.0018 |
| | | **La Grange** | | |
| Bighead carp | F | 20 | 0.0142 | 0.0042 |
| Bighead carp | M | 36 | 0.0019 | 0.0003 |
| Silver carp | F | 26 | 0.0165 | 0.0042 |
| Silver carp | M | 20 | 0.0042 | 0.0019 |
| | | **Peoria** | | |
| Bighead carp | F | 15 | 0.0149 | 0.0049 |
| Bighead carp | M | 26 | 0.0019 | 0.0003 |
| Silver carp | F | 7 | 0.0220 | 0.0054 |
| Silver carp | M | 24 | 0.0043 | 0.0018 |

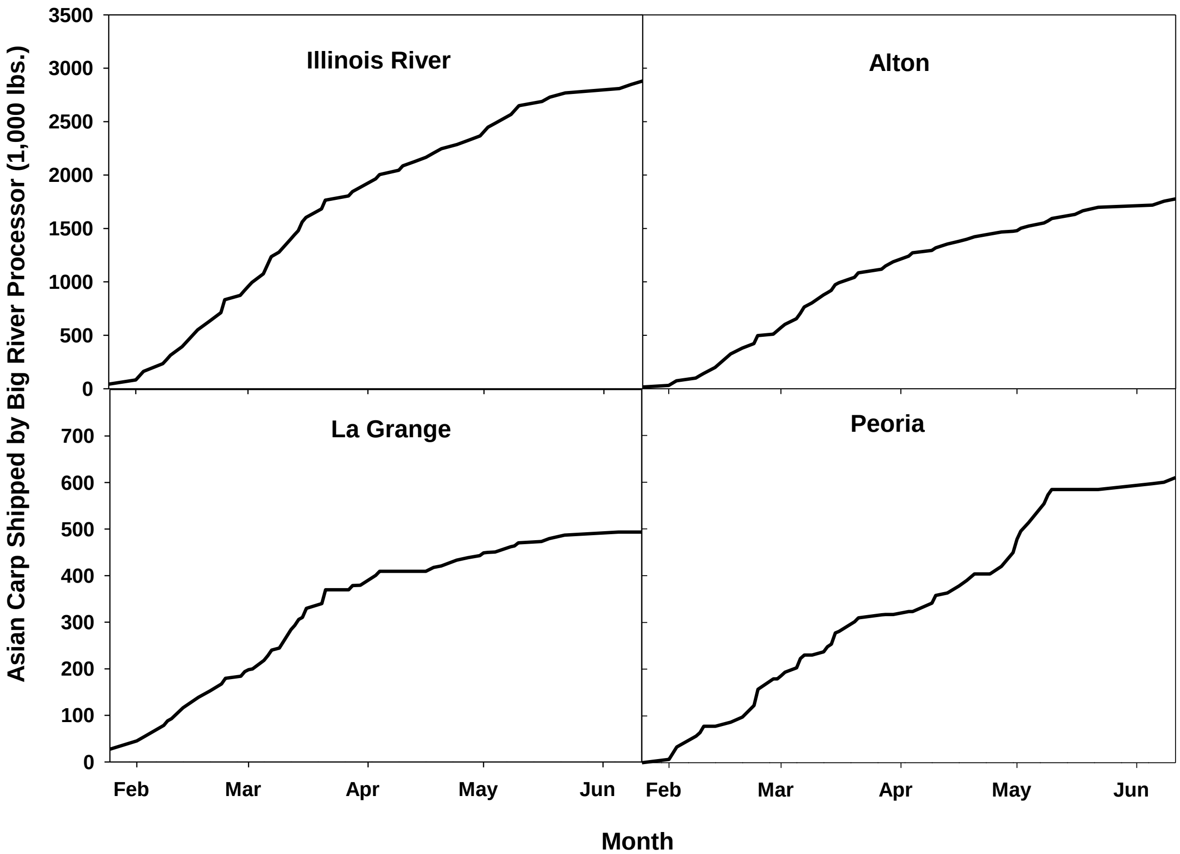


Figure 3.1. Cumulative commercial harvest of Asian carp for fish meal production by reach and month, IL River, 2012.

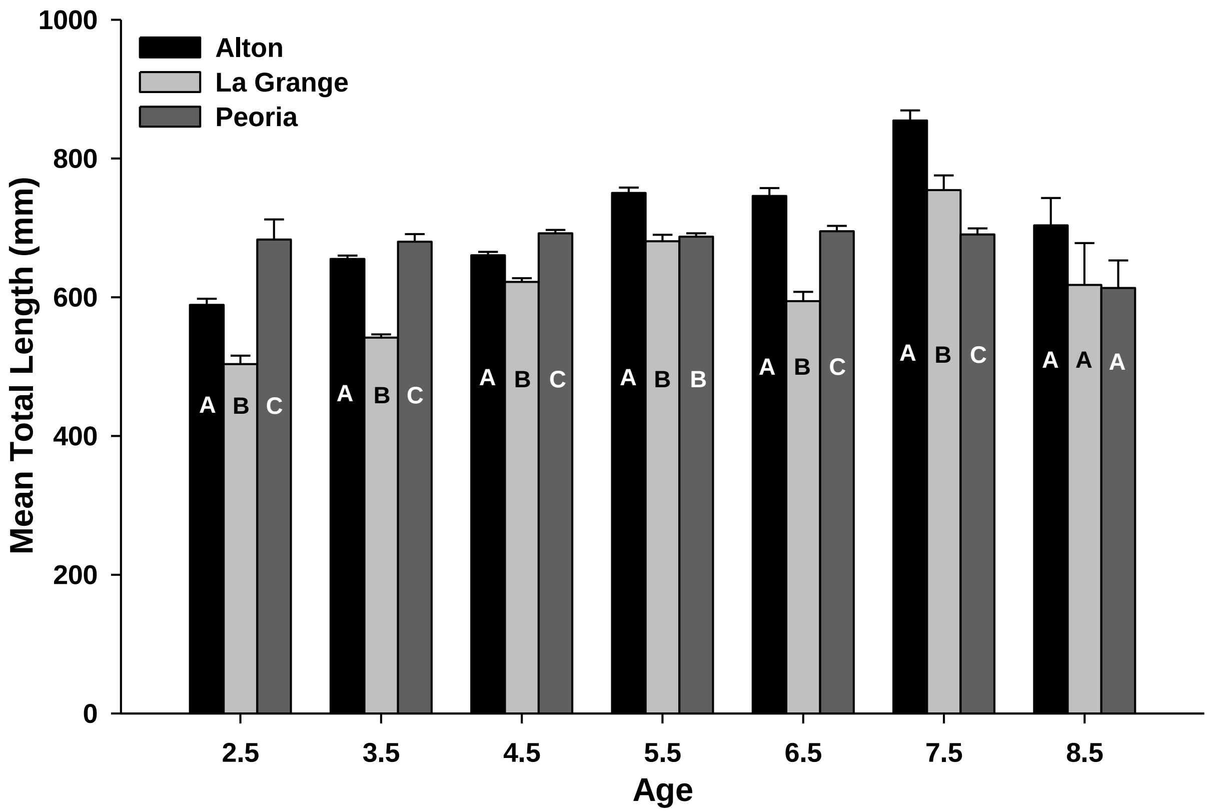


Figure 3.2. Mean length-at-age with associated standard error for commercially caught silver carp in the three lower reaches of the Illinois River; different letters indicate significantly different mean total lengths among reaches (*P* ≤ 0.05), as determined by a two-way ANOVA.

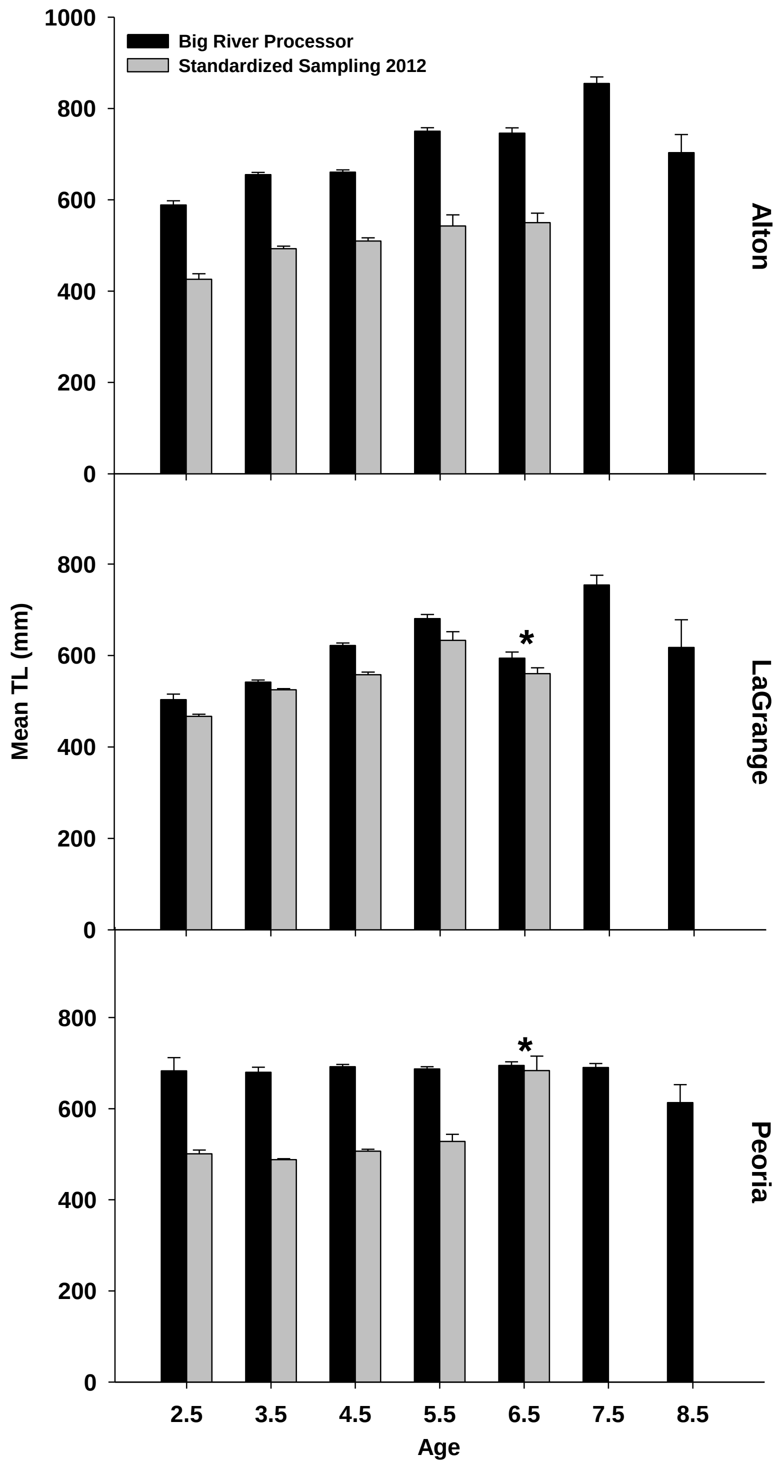


Figure 3.3. Mean length-at-age and associated standard error of commercially harvested silver carp, and silver carp collected by electrofishing during standardized sampling, IL River, 2012; Asterisk denotes a nonsignificant difference in mean total length ($P \leq 0.05$), as determined by a two-way ANOVA.

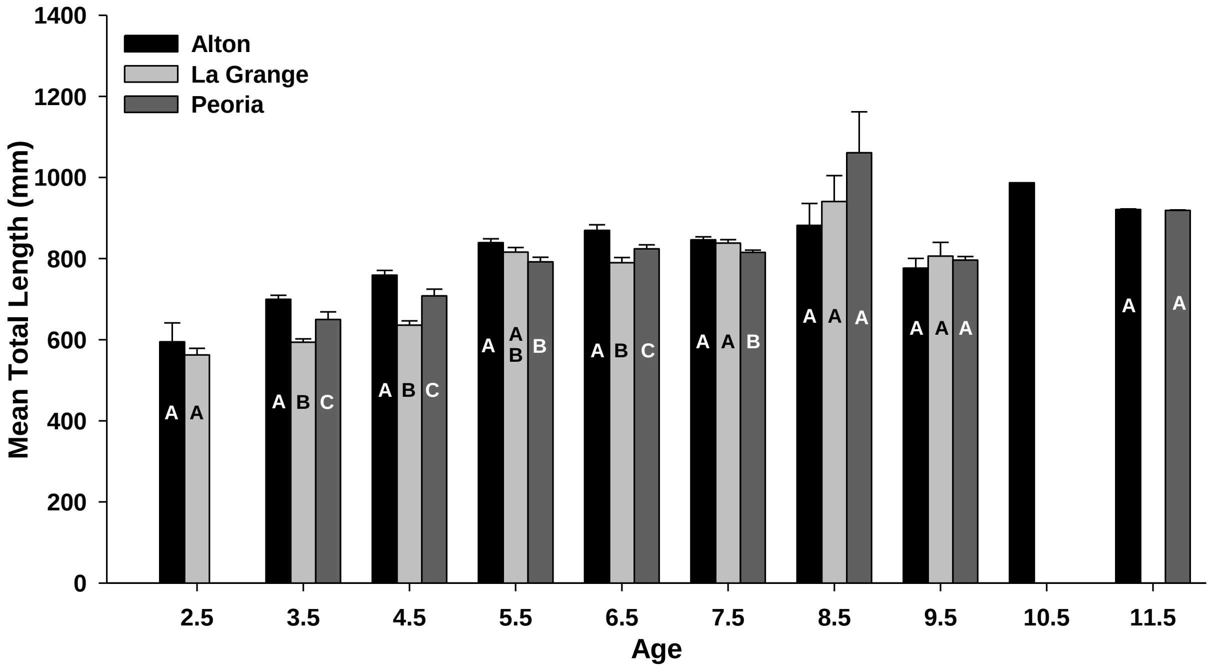


Figure 3.4. Mean length-at-age with associated standard error for commercially caught bighead carp in the three lower reaches of the Illinois River; different letters indicate significantly different mean total lengths among reaches ($P \leq 0.05$), as determined by a two-way ANOVA.

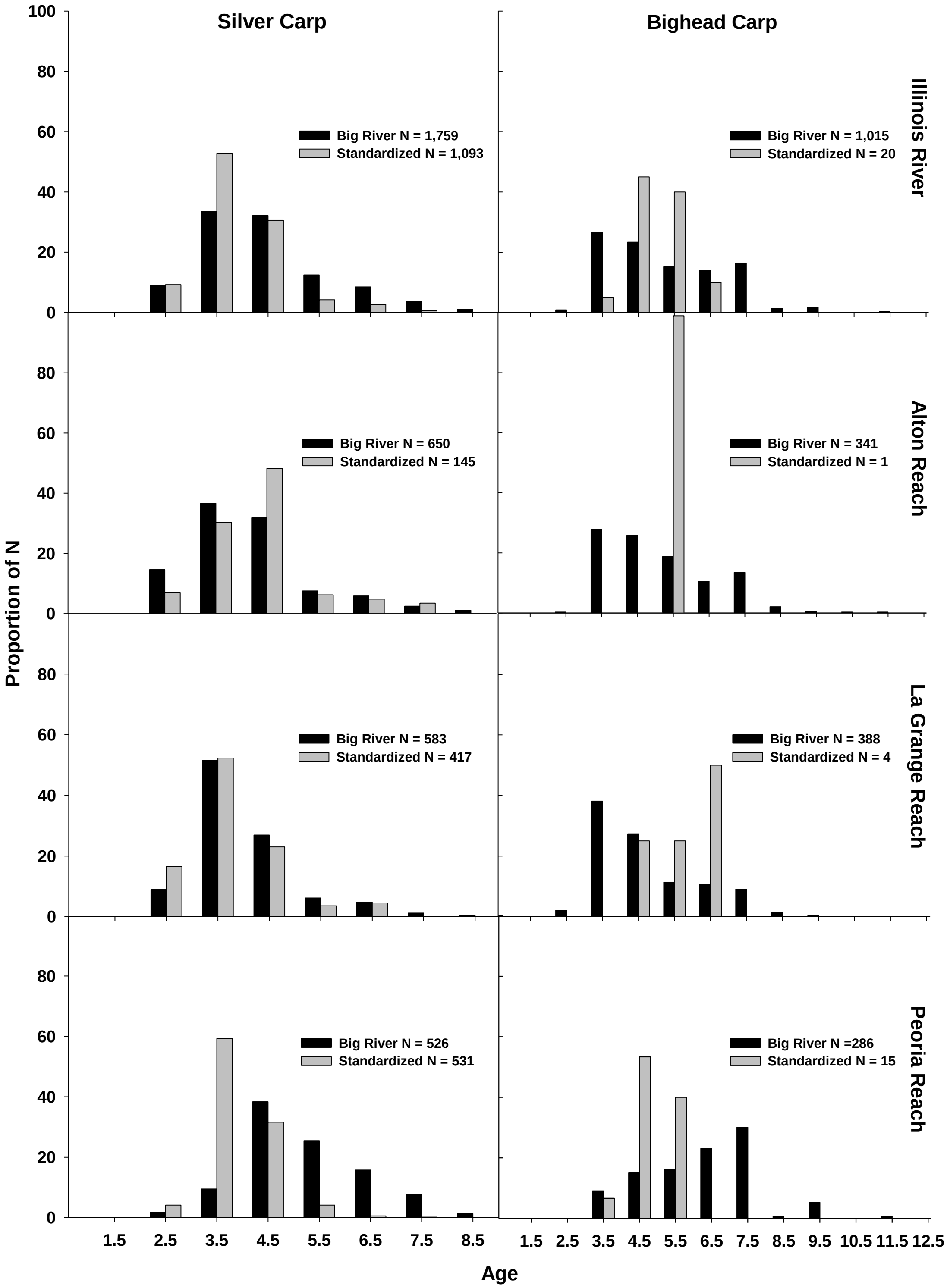


Figure 3.5: Age frequency of commercially harvested silver and bighead carp compared to carp collected during standardized sampling, IL River, 2012.

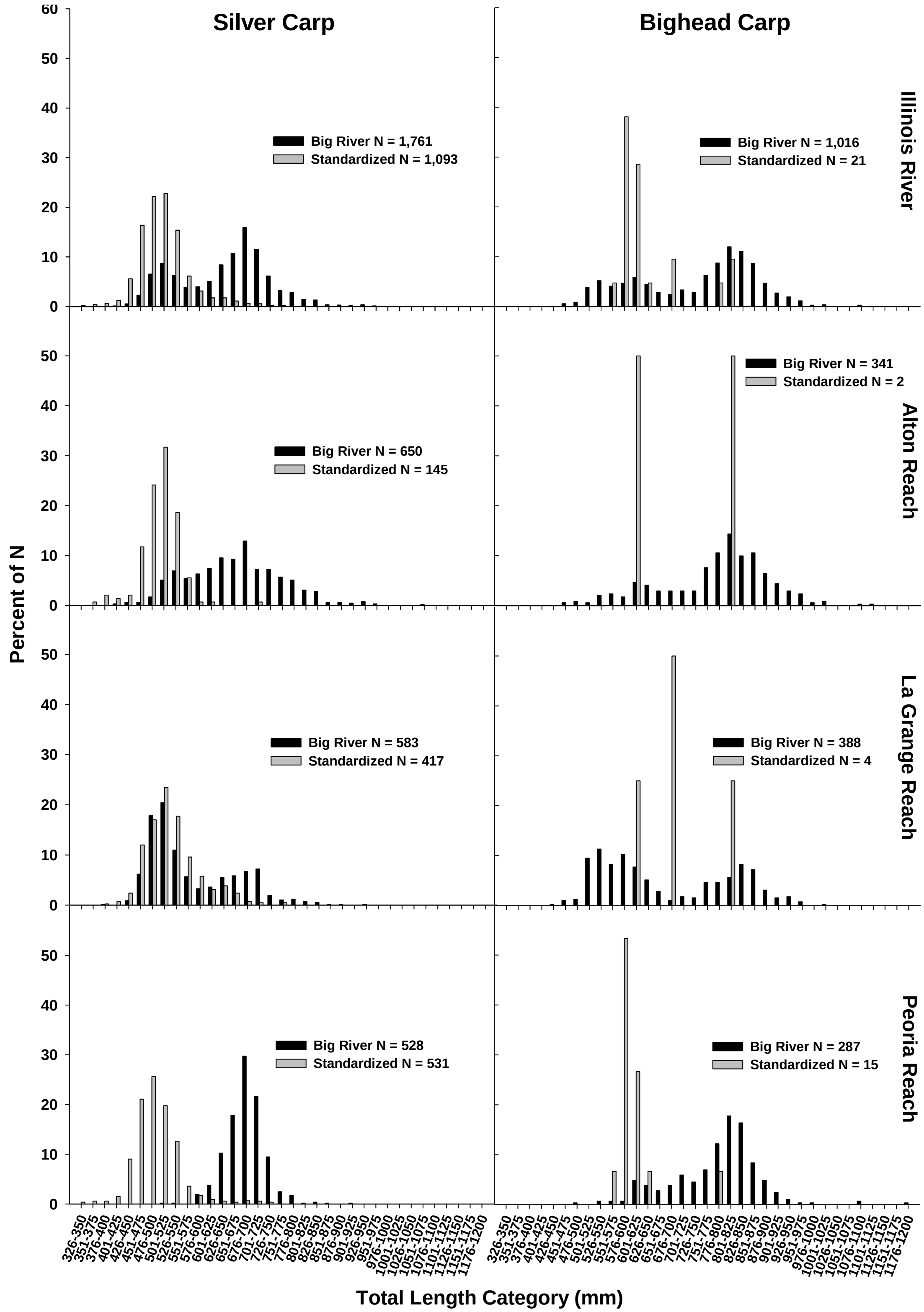


Figure 3.6: Length frequency of commercially harvested silver and bighead carp compared to carp collected during standardized sampling, IL River, 2012.

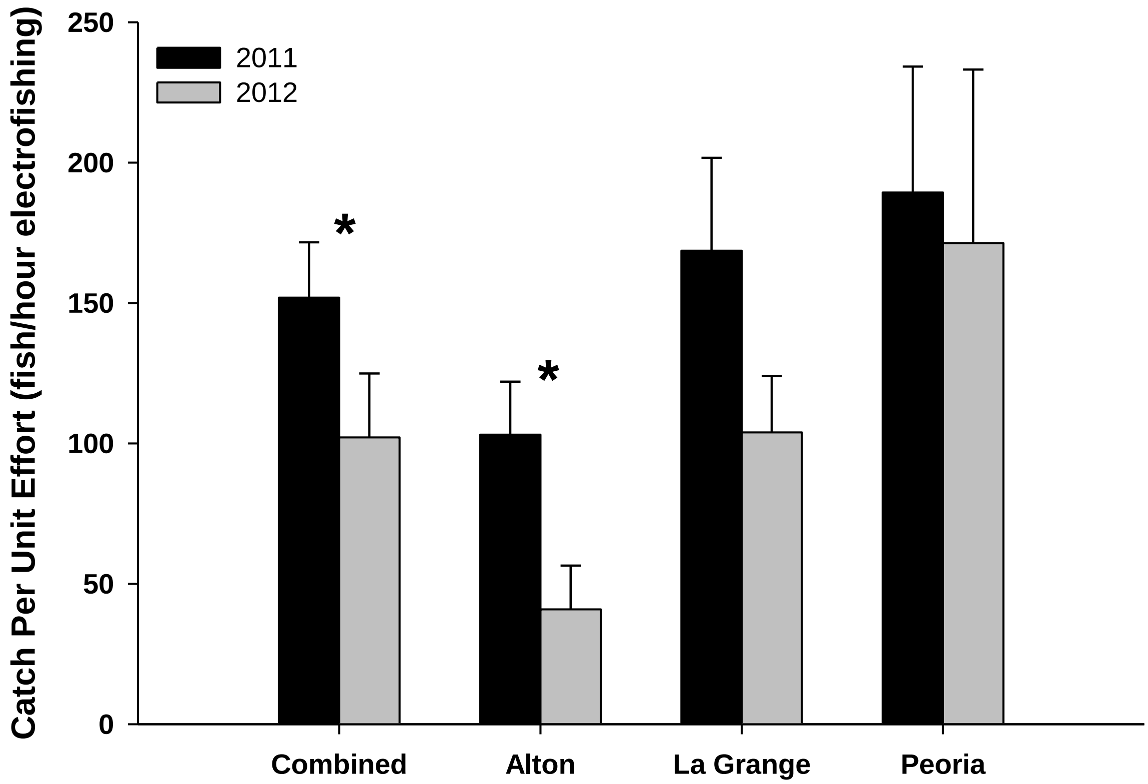


Figure 3.7. Electrofishing catch per unit effort from standardized fish sampling conducted in 2011 (pre-harvest) and 2012 (post-harvest) for the lower three reaches of the Illinois River combined and for each reach; asterisk indicates a significant difference in CPUE among years ($P \leq 0.05$).

# CHAPTER 4

## Evaluating the Efficiency of Harvest

**Introduction:** Harvest efforts in the upstream portions of the Illinois River, initiated in 2011, have continued to be part of an integrated control strategy for reducing the risk of Asian carp from gaining access to the Great Lakes. In 2011, Illinois Department of Natural Resources (IDNR)-contracted commercial harvest resulted in the removal of 351.6 tons of Asian carp from the Dresden, Starved Rock, and Marseilles reaches, eliminating the possibility that those fish will progress any further upstream toward the Chicago Area Waterway System (CAWS). In 2012, the number of Asian carp harvested dropped to 284.53 tons, even though fishing effort was similar.

In addition to declines in harvest, three separate hydroacoustic surveys, conducted by Southern Illinois University Carbondale (SIUC) in 2011, indicated a rapid decline in total fish abundance from 300,250 to 198,090 fish in the Hanson Material Service Corporation (HMSC) east pit. These pits are located on the Marseilles reach near Morris, IL and are fished as part of the Barrier Defense Asian carp Removal project. The declines in abundance were consistent with a reduction in CPE observed in that area, yet harvest alone could not account for the decline in total fish abundance. In this study, we sought to better understand how other factors, such as emigration from the study area, could help explain Asian carp population dynamics in these upstream areas.

In 2013, we built on the information gained in 2011 and 2012 and continued to monitor the efficiency of upstream harvest of Asian carp in the upper reaches, but most closely in the HMSC backwater of the Marseilles Reach. This information is important for determining the efficacy of harvest in these upper reaches of the Illinois River, defining the role of immigration from the lower river to the upper reaches, and ultimately reducing propagule pressure of Asian carp on the Great Lakes.

**Methods and Materials:** SIUC initiated a mark-recapture study (320 Asian carp were tagged) in spring 2012 within the HMSC east and west pits to estimate population size, movement patterns, and exploitation rates for Asian carp. In 2013, another mark-recapture study was initiated to bolster mark-recapture information from 2012. With the assistance of IDNR contracted commercial fishermen, an additional 276 fish (92 bighead carp, 148 silver carp, and 36 hybrid Asian carp) were captured with gill nets and tagged in the HMSC east pits on 7 April 2013. Using the same protocol as in 2012, fish were weighed (nearest g), TL measured (nearest mm), tagged with individually numbered reward jaw tags (aluminum, size 1242-9C, National Band and Tag Co.), and released at the site of capture. To better estimate exploitation, survival, and immigration to the upper reaches of the Illinois River, SIUC also initiated a mark-recapture study in the Starved Rock pool in 2013. On 8 May 2013, 263 Asian carp (43 bighead carp, 211 silver carp, and 9 hybrid Asian carp) were jaw tagged in the Sheehan Island backwater of the Starved Rock pool (near Buffalo Rock) following the same protocol used in the Marseilles backwater. Recoveries of tagged fish from both areas were recorded from contracted commercial fishermen throughout the Barrier Defense Asian Carp Removal Project. Fliers were provided to IDNR personnel, contracted commercial fishermen, bow fishing groups, and fish processing plants to increase awareness of the mark-recapture study and to provide reporting instructions. The jaw tag number, "REWARD," and contact information for SIUC were clearly marked on each jaw tag.

A Link-Barker Jolly-Seber mark-recapture model (Link and Barker 2005) for open populations was employed in Program MARK® to calculate an overall survival rate (ϕ), capture probability (*p*), and immigration rate (*f*) for all available commercial fishing periods (30 April 2012 – 17 November 2013) as well as weekly estimates of survival, exploitation, rate of population change, and immigration for 2012 and 2013 independently. For annual mark-recapture models, ϕ, *p,* and *f* were allowed to vary temporally (between sampling periods). For the combined 2012-2013 model, ϕ, *p,* and *f* were held constant to decrease the parameters in the model and increase precision of the estimates.

Immigration and emigration rates throughout the Illinois River, as well as movement between the east and west gravel pits of the HMSC backwater, are also being estimated with acoustic telemetry. To date, with assistance from IDNR-contracted commercial fishermen and Illinois Natural History Survey (INHS), 691 acoustic transmitters have been implanted in Asian carp in the Illinois River or Pool 26 of the Mississippi River. In addition to the 354 fish that were tagged in 2012, 337 Asian carp were tagged with Vemco® acoustic transmitters (v16, v13, v9, or v6 transmitting at 69 KHz) in the Illinois River in 2013 (Table 1). A total of thirty-six fish were tagged in the Dresden Island pool, with10 fish being released in Rock Run Rookery and 28 released near the confluence with the Kankakee River. In the Marseilles pool, 96 fish were tagged with transmitters; 56 were released in the main channel at the Morris boat ramp, and 38 were released in the HMS pits (21 in the west pit, 17 in the east pit). In the Starved Rock pool, 54 fish were tagged and released at the Starved Rock Marina. To determine the amount of movement between pools in the lower Illinois River and Upper Illinois River, additional fish were tagged in the Peoria (51 fish near Lacon, IL), La Grange (54 fish near Havana, IL) and the Alton pools (46 fish near Hardin, IL).

A network of 30 Vemco® VR2W receivers was deployed in the Illinois River by SIUC in 2012 to monitor movement of acoustically tagged Asian carp (Alton = 9, LaGrange = 7, Peoria = 6, Starved Rock = 4, and Marseilles = 4). This network has been continuously monitored and VR2Ws downloaded every 2-4 months to record fish detections. Receivers have been placed in and around each lock chamber and near major tributaries to track large-scale movements within and among reaches, though three receivers were specifically placed within the HMSC gravel pits to better understand the factors affecting Asian carp immigration and emigration within this area (Figure 4.1). All fish with acoustic transmitters were also tagged with individually numbered $50 reward jaw tags (aluminum, size 1242-9C, National Band and Tag Co.) to provide incentives to fishermen not contracted by the IDNR to return transmitters. IDNR-contracted fishermen have been instructed to return healthy fish back to the water as soon after capture as possible. Temperature loggers (HOBO Pendant® model UA-002-64) were deployed with all receivers to examine how this may influence movement of Asian carp. Please see Chapter 3 for more details concerning acoustic telemetry.

**Results and Discussion:**

*Harvest*

IDNR contracted commercial fishermen harvested a total of 16,025 Asian carp (6,756 bighead carp, 9,223 silver carp, 46 grass carp) from the east and west pits of the HMSC during the 2013 Barrier Defense Asian Carp Removal Project. This was slightly fewer fish (~14%) than the total number harvested in 2012 (18,712 bighead and silver carp). Although fewer fish were removed from the HMSC pits in 2013 there was no significant difference (ANOVA; $P < 0.001$) in commercial fishing effort (catch per effort; CPE (fish/1000 yards of gill net)) between 2012 (61.4 $\pm$ 0.4 fish/1000 yards) and 2013 (52.7 $\pm$ 0.4 fish/1000 yards), suggesting that Asian carp numbers have declined or are declining in this backwater. Average CPE for 2013 in the Starved Rock pool (277.3 $\pm$ 28.9 fish/1000 yards) was significantly greater (ANOVA; $P<0.001$) than for either year in the HMSC pits.

*Mark-recapture*

Of the 320 Asian carp externally tagged in the HMSC gravel pits in 2012, a total of 156 marked individuals were harvested (49%) during 2012. By December of 2013, only 11 additional carp from this tagging cohort were harvested (total of 167 carp, 52.2%). To date, 71 out of 276 fish (25.6%) from the 2013 tagging cohort have been harvested. This is a significantly smaller proportion of the tagged population than was recaptured during the 2012 mark-recapture study. Assuming that natural mortality has been constant, this suggests that fish have either moved out of areas where commercial fishing is taking place (but still within the backwater) or that they have moved out of the HMSC pits entirely. Not surprisingly, a much lower recapture rate was observed for fish tagged in Starved Rock pool. Not including three fish that were harvested by bow fishermen, 32 of the 263 fish tagged (~12.2%) were harvested by commercial fishermen over a 30-week period (5 May 2013 – 7 December 2013).

Only two individuals (tagged in the HMSC pits) were recaptured outside of the backwater where they were tagged. One was captured in nearby Peacock Slough and another in Sheehan Island in the Starved Rock Pool. This number is similar to the number of jaw tagged fish detected outside of their tagging location in 2012 (three fish), suggesting that emigration rates of Asian carp (outside their original pool) were very low, which increased their susceptibility to harvest. Acoustically telemetered fish, however, indicated that movement in and out of this area is relatively high with 57% of fish tagged in the HMSC pits moving out at some point in 2012. Data are still being processed for August – December 2013; however, when telemetry data are combined with estimated immigration rates from 2012 and 2013 (through 14 August 2013), a positive correlation exists ($R = 0.57$) between the number of fish moving into the HMSC pits and the estimated mark-recapture immigration rate. Combining these data suggests that Asian carp are residents in the backwater, make short forays into the main channel, but eventually may return to this backwater, and that additional immigration may be occurring more frequently than just the spring and fall movement periods. Further analyses should be conducted to test the significance of this relationship.

Excluding the three Asian carp that were caught outside of the HMSC backwater in 2012 and 2013 and the 15 that were recaptured during the USGS water gun experiments in this area, the estimated exploitation rate for this backwater area for the 2012 commercial fishing period (30 weeks; 7 May 2012 – 3 December 2012) was 0.89 (95% CI = 0.86 -0.91) for non-immigrants (i.e., the fish present at the beginning of the mark-recapture study). Immigration rates during this time period were very low (close to zero), likely contributing to the high exploitation rate. In 2013 the estimated immigration rate rose to 0.22 individuals per individual in the population (Table 4.1), contributing to a much lower exploitation rate. It should be noted that although this rate is lower, a 0.38 exploitation rate is still respectable for the goal of carp removal in this backwater. When data from 2012 and 2013 were combined, the estimated exploitation rate was 0.55. In addition, in 2012 and 2013, CPE of Asian carp declined at a slower rate than the proportion of marked individuals (Figures 4.2a and 4.2c), suggesting that immigration into this backwater increased at a faster rate than those removed through harvest. In fact immigration estimates from Link-Barker mark-recapture models indicated that immigration into the HMSC pits was cyclic (Figure 4.2b, Figure 4.3d), with more immigration occurring during spring and early summer in 2012 and 2013 (Figure 4.2b, Figure 4.3d)

Estimates from Link-Barker mark-recapture models indicated that the rate of population change was greater than one for half of the sampling periods. It is likely that pulses of commercial harvest allowed the population growth rate to dip below one for periods of time throughout the year. It appears that early spring and fall are two time periods when harvest was able to outpace the lower immigration rates (Figure 3). Harvest may be particularly necessary during these time periods to keep population rate of change below one. In *annual* mark-recapture models the rate of population change decreased from increased from 2012 to 2013, exhibiting a downward trend (Figure 4.2b), suggesting that fish were still being removed faster than they immigrated. However, more immigration in 2013, as indicated by mark-recapture estimates and telemetry data, may have kept the population growth rate greater than one for periods in July and October. This suggests that continued harvest throughout the year may be necessary to keep Asian carp populations at bay, and increased harvest during the fall and spring may allow commercial fishermen to more significantly lower carp numbers.

Because confidence intervals were extremely wide for annual mark-recapture models where capture probability ($p$), immigration ($f$), and survival probability ($\phi$) varied with time, these variables were held constant and one estimate of p,f, and $\phi$ were calculated for each year (Table 4.2). The rate of population change was still estimated for each sample period (Figure 3b). Exploitation rate decreased to 0.38 in 2013 from 0.89 in 2012, signifying that any fish present at the beginning of the study (in 2013) had a 38% chance of mortality (if they did not emigrate) if they remained in the HMSC backwater. Thus, commercial fishing seems largely effective, especially against resident fish in the backwaters. However, estimates of immigration rate increased in 2013 to 0.08 fish per fish in the population per week, from nearly zero in 2012. This may be a function of the high water and increased flow in 2013, attracting fish into the backwaters.

*Telemetry*

Continued analysis of telemetry data indicates that movement into and out of the HMSC pits from the Marseilles main channel, and from the east pit to the west pit, is high and likely correlates with river discharge and temperature (during spawning periods; Figure 4.5). However, movement in the reverse direction, between the HMSC west to the east west pits was relatively low. Of the 22 fish that were tagged with acoustic transmitters in the HMSC west pit in 2013, 4 (~18%) were detected in the east pit, but 22 fish that were tagged outside the west pit (either in the Marseilles main channel, in the east pit, or in another pool) were detected in the west pit.

Asian carp movement into and out of the HMSC pits seems to correspond with changes in river discharge (Figure 4.4). In the spring, movement increased starting in early march and continued until early June, when river discharge increased. In the fall, Asian carp movement increased in early September and ceased by December. Increased commercial fishing prior to and during times of peak movement may target individuals emigrating out of or immigrating into the HMSC pits, thus targeting transient fish.

**Modelling Summit and Spatially Explicit Model:** A spatially explicit model that incorporates movement among reaches is currently underway. This model will help us better understand these population dynamics and to determine how immigration and emigration affect these estimates. A modeling summit was held in St. Louis in February 2013 to discuss modeling approaches. More information about the model and the modeling summit can be found in Chapter 5.

**Recommendations:** Although overall return rate was exceptionally high for a mark-recapture study, weekly estimates of exploitation and population rate of change had extremely high standard errors due to a small proportion of tagged individuals in the population. Adding additional fish in 2013 helped slightly, but we recommend putting more faith in the annual model estimates (i.e., estimates with very tight 95% CI) than the weekly estimates. Using the trends we observed this year, an increase in the number of tagged individuals is still warranted. Nearly 1000 fish should be tagged to yield more precise weekly estimates of survival and population growth rate. In addition, instead of removing tagged individuals from the population each week, it would be helpful for commercial fishermen to return all tagged fish to the water. This should increase the number of fish available for capture each week, thus decreasing the error in our models.

We also assumed that tag loss was negligible for these analyses and could therefore have affected these results. We know that some fish that were tagged on the upper jaw early in the season had some tag loss. We modified our tagging technique so that all fish are tagged, tightly, on the lower jaw. Given that estimates of emigration appeared to be exceptionally high due to the declining proportions of marked individuals harvested, determining tag loss is still needed.

Immigration, at least to the HMSC pits, seems to be the driving factor keeping the population growth rate above one in this area. Estimates concerning the population rate of changed combined with estimated immigration in 2013 suggest that harvest was unable to outpace immigration for most of 2013 (and 2012) even though CPE decreased as effort remained the same. This suggests that continued harvest during all times of year is necessary, and additional harvest from source populations (i.e., lower Illinois River) is encouraged, to limit the number of immigrants to the upper river and decrease propagule pressure on the CAWS

**Project Highlights:**

- Of the 320 Asian carp externally tagged in the HMSC backwater near Morris, IL in May 2012 a total of 167 (~52.2%) marked individuals were harvested through IDNR-contracted commercial fishing efforts by the end of December 2013. The majority these individuals (~47%) were harvested in 2012.
- Estimates of the population rate of change in the Asian carp population in the HMSC pits using mark-recapture models still indicate a declining population, suggesting commercial fishing is effective at the current population size.
- Emigration of Asian carp from the HMSC backwater appeared low in 2012, but was much higher in 2013. Thirty-two of the 39 fish (82%) that were tagged with acoustic transmitters in 2013 left the HMSC backwater at some point, possibly decreasing susceptibility to harvest in 2013.
- Of the 22 fish that were tagged with acoustic transmitters in the HMSC west pit in 2013, 4 (~18%) were detected in the east pit during 2013. Only one fish tagged in the east pit moved to the west pit, but 22 fish that were tagged outside the west pit (either in the Marseilles main channel, in the east pit, or in another pool) were detected in the west pit.
- The estimated exploitation rate for this backwater area was 100% over an 82-week period for non-immigrants (i.e., the fish present at the beginning of the mark-recapture study in 2013 and 89% in 2012, suggesting that commercial fishing is effective at the current population size.
- Estimates concerning the population rate of changed combined with estimated immigration in 2013 suggest that harvest was unable to outpace immigration for most of 2013 (and 2012). This suggests that continued harvest during all times of year is necessary and additional harvest from source populations (i.e., lower Illinois River) is encouraged to limit the number of immigrants to the upper river and decrease propagule pressure on the CAWS.

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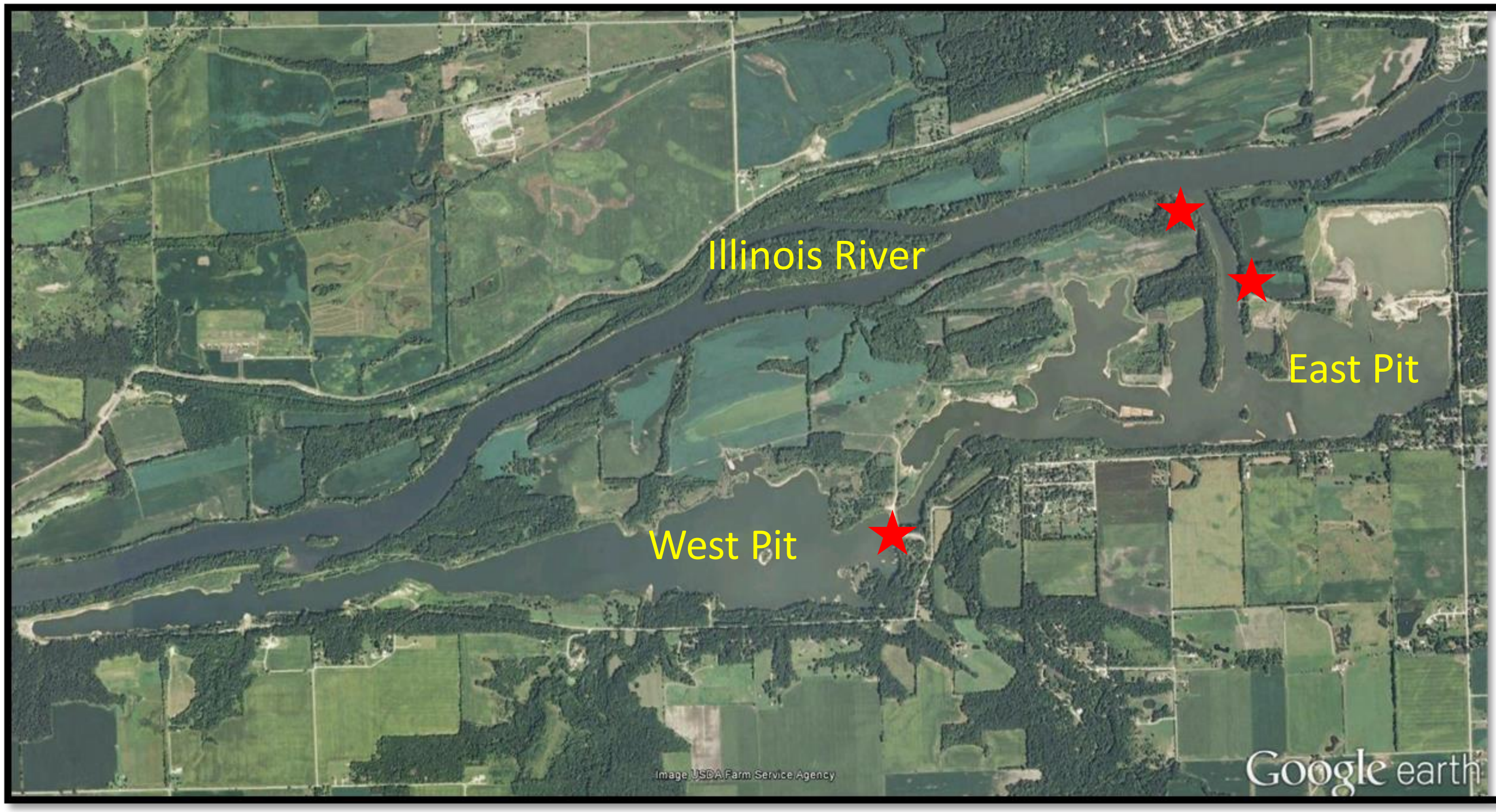


Figure 4.1. Map of Hanson Material Services Corporation backwater near Morris, IL indicating locations of VR2 receivers to quantify movement in/out of this backwater and between the west and east pits.

**Table 4.1.** Link-Barker mark-recapture estimates and 95% confidence intervals (95% CI) of weekly exploitation rate (1-ϕ) and immigration rate (*f*) for the HMSC pits in 2012 and 2013, run on an annual basis (30 weeks; ϕ(.)*p*(.)f(.)) for each year (reported as weekly rates), for the HMSC pits with both years combined (82 weeks).

| | HMSC 2012 | | HMSC 2013 | | HMSC 2012-2013 combined | |
|---|---|---|---|---|---|---|
| | Estimate | 95% CI | Estimate | 95% CI | Estimate | 95% CI |
| Exploitation rate | **0.89** | 0.86 - 0.91 | **0.38** | 0.27- 0.52 | **0.55** | 0.555 -0.557 |
| Immigration rate | **$3.4 \times 10^{-9}$** | $1.4 \times 10^{-13}$ - $9.4 \times 10^{-7}$ | **0.22** | 0.23 - 0.27 | **$7.9 \times 10^{-64}$** | 0.154-0.181 |

**Table 4. 2.** Number of bighead and silver carp tagged with acoustic transmitters per pool or backwater of the Illinois River in 2012 and 2013.

| 2012 | Bighead carp | Silver carp | Total |
|---|---|---|---|
| Pool 26 | 19 | 129 | 148 |
| Dresden | 8 | 5 | 13 |
| Marseilles | 33 | 1 | 34 |
| Starved Rock | 56 | 103 | 159 |
| Total | 116 | 238 | 354 |

| 2013 | Bighead carp | Silver carp | Total |
|---|---|---|---|
| Rock Run Rookery | 10 | | 10 |
| Dresden | 26 | 2 | 28 |
| Marseilles | 2 | 54 | 56 |
| HMSC Pits | 19 | 19 | 38 |
| Starved Rock | 8 | 46 | 54 |
| Peoria | 6 | 45 | 51 |
| La Grange | 21 | 33 | 54 |
| Alton | 13 | 33 | 46 |
| Total | 105 | 232 | 337 |

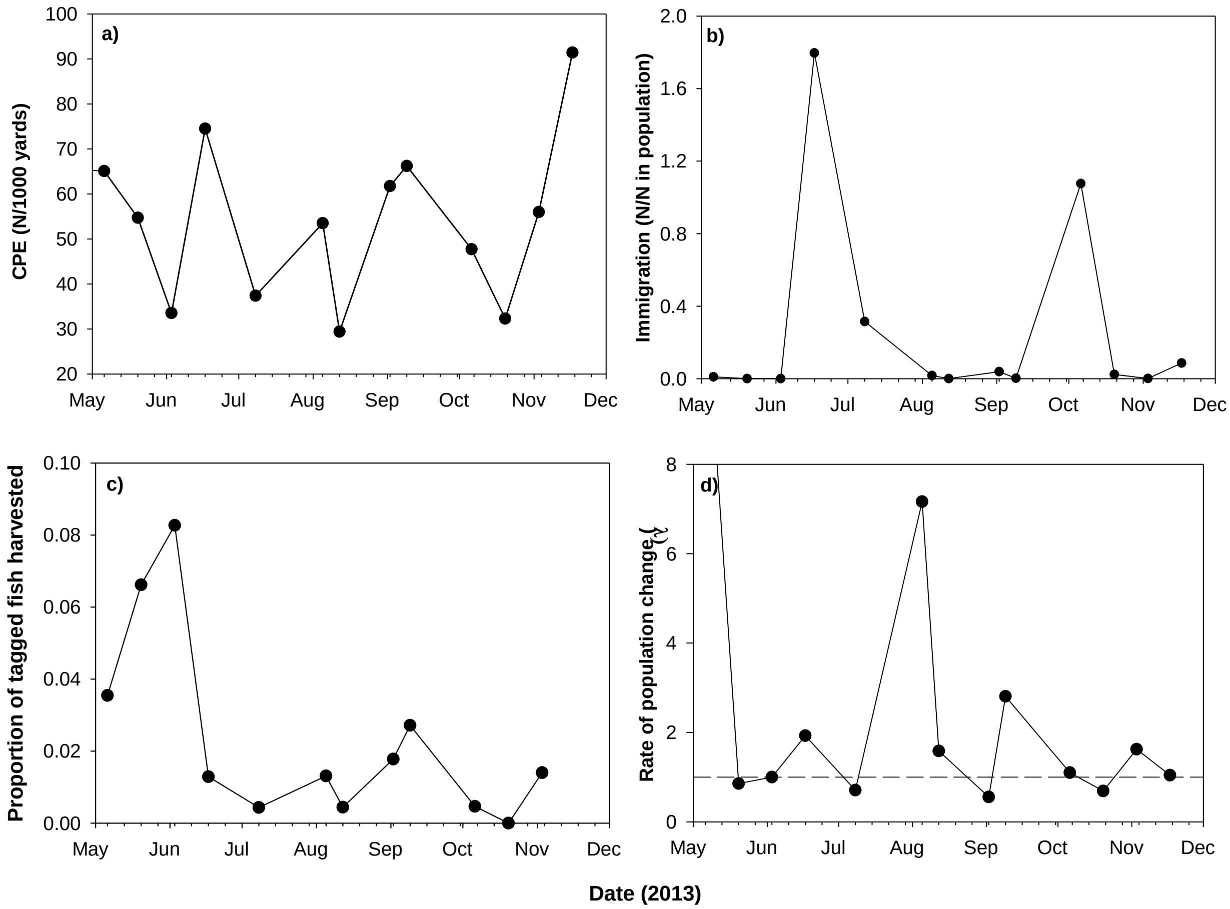


Figure 4.2. a) Catch per effort (CPE) of Asian carp from IDNR-contracted commercial fishermen in 2013 for the time-period fish were tagged, b) immigration (number of fish entering per fish in the HMSC pits) estimated by Link-Barker mark-recapture model for 2013 data only, c) proportion of tagged Asian carp recaptured correcting for those previously removed (only for fish tagged in 2013), and d) rate of population change with values near one indicating no population change.

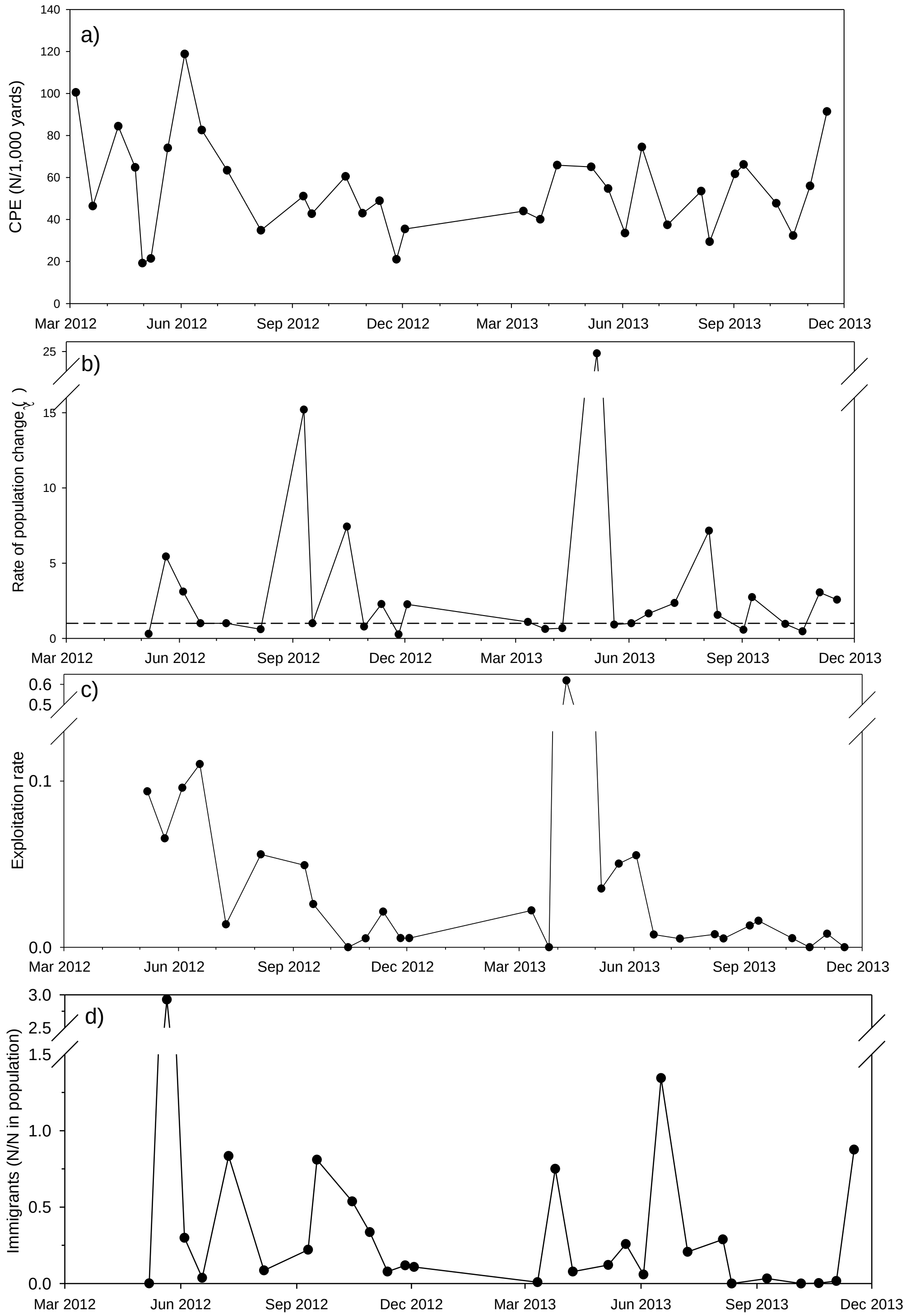


**Figure 4.3.** a) Catch per effort (CPE) of Asian carp from IDNR-contracted commercial fishermen, b) estimated weekly rates of population change with values near one indicating no population change, c) exploitation rate as a function of time, and immigration (N/N in population) for the HMSC pits in 2012 and 2013 (82-week model with all available data).

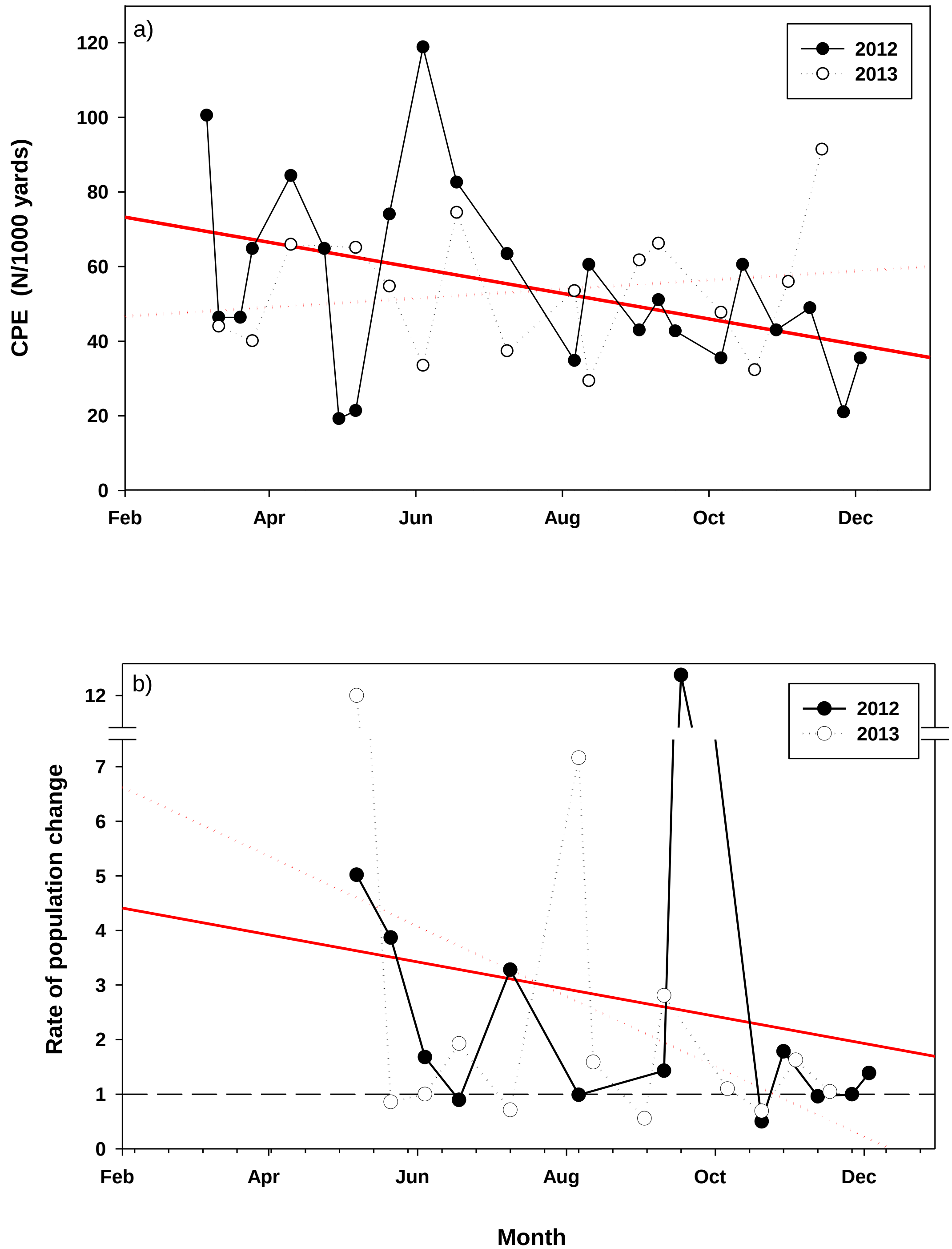


Figure 4.4. A comparison of a) CPE (number of fish per 1000 yards of gill net) and b) the rate of population change (values below one represent a declining population), between 2012 and 2013. Solid lines show the linear regression for 2012 and dashed lines represent the linear regression for 2013.

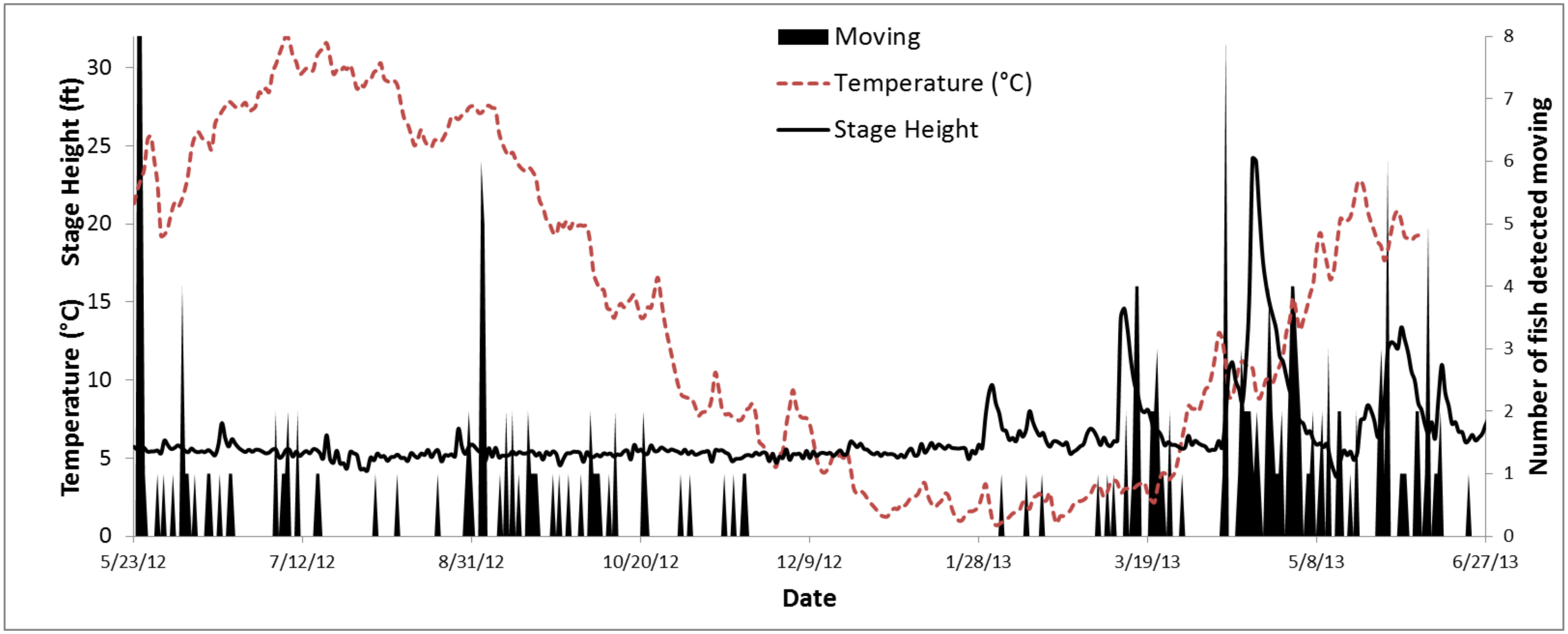


Figure 4.5. Asian carp movement, into or out of the HMSC backwater, as a function of water temperature (°C) and river stage height. The most movement is observed in the spring and early fall.

# CHAPTER 5

## Modeling Asian carp population responses to harvest in the Illinois River

**Goal:** Our goal was to develop a stock assessment framework capable of testing how the Asian carp population would respond to commercial harvest in the Illinois River.

**Justification:** Commercial harvest in the Illinois River has unknown repercussions on the Asian carp population therein. Our model will be able to determine how varying harvest rates will affect the abundance and size distribution of Asian carp species in the immediate and long-term future. This exercise is necessary to understand how harvest affects Asian carp populations and to develop predictions of harvest rates necessary to reduce propagule pressure into Lake Michigan.

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**Publications (Appendix):**

**Tsehaye, I., Catalano, M., Sass, G., Glover, D., & Roth, B. (2013). Prospects for fishery-induced collapse of invasive Asian carp in the Illinois River. *Fisheries*,*38*(10), 445-454.**

**Introduction:** An initial study was conducted to explore prospects for the "collapse" of Asian Carp in the Illinois River through intensive fishing. Based on a meta-analysis of demographic data, we developed a dynamic simulation model to compare the performance of existing and alternative removal strategies for the Illinois River. The initial model projections suggested that Asian Carp in the Illinois River are un-likely to collapse if existing harvest rates are kept below 0.7 or fishing continues to be size selective (targeting only fish >500 mm or <500 mm) or species selective (targeting mostly Bighead Carp), although their biomasses could be greatly reduced. We argue that it would still be possible to achieve fishing effort targets predicted by our model to collapse the Asian Carp populations if efforts to expand commercial fishing are combined with economic incentives to improve size selectivity and species targeting. A second model is now being developed with additional data to better determine exactly what amount of fishing is needed to decrease upstream Asian carp movement and decrease population numbers.

During two days of February 2013, fisheries investigators with broad experience in marine and freshwater systems convened to discuss ways to model the populations of Asian carps (bighead and silver) in the Illinois River, with particular focus on the potential for these species to increase densities in proximity to the electrical barrier in the Chicago Sanitary Ship Canal (CSSC) within the Chicago Area Waterway System (CAWS). Contracted harvest is occurring in the upper Illinois River to reduce the potential "propagule pressure" of Asian carp on the CSSC. We identified two modeling approaches. The first (Version 1.0) is a stochastic, stage-structured model exploring the impact of size-dependent harvest on the population trajectory of both species in the Illinois River. The model was developed as part of a research effort conducted during 2010-2011 and is coded in statistical modeling software (see results in Garvey et al. 2012 and Tsehaye et al. 2013). The output of Version 1.0 showed that the response of the population to fishing pressure is highly variable, with the conclusion that harvest must occur on all sizes of Asian carp with a high exploitation rate (> 70%) to cause the mean population growth rate to decline.

Although the current model structure and approach are sound, the output might not be all that useful to managers interested in assessing "risk" of the population reaching the barrier system. Thus, a model Version 2.0, which does not yet exist, will need to be constructed. The group agreed that this model must start from "scratch" and will require a significant amount of data. Importantly, the currency of the model needs to be decided and kept consistent. <u>The critical output of the model will be the probability that carp will establish in the proximity of the electrical barrier in the CAWS.</u> Different management strategies will be incorporated into the model to assess the change in this probability from a strategy of no control. Contracted fishing in the upper Illinois River is removing up to 1.5 million pounds annually. In the lower river, commercial fishing is occurring. The model will allow us to assess what would happen to the population in proximity to the CSSC if current harvest strategies are stopped or redistributed throughout the Illinois River. Management strategies such as size-selective control, reduction in reproductive output, and selective barriers may also be built into the model.

**Model Structure (Figure 5.1):**

- The model will be spatially explicit. Responses near the barrier will depend on control efforts both in the upper river (defined as above Starved Rock Lock and Dam) and in the lower river.
- The model will allow managers to forecast population dynamics and "risk" to the barrier for 50 years.
- The approach will generally be Eulerian in design. Rather than following individuals, population dynamics will be divided into temporally and spatially discrete cells. The distribution of responses will be followed within those cells and they will interact.
- Recruitment needs to be understood with research and incorporated as an independent process. Fish produced will be distributed throughout the lower river where recruitment is known to occur.
- The "Adult" component of the population model will have explicit temporal and spatial components.

**Data Collection and Parameterization:** Data for Version 2.0 are being collected and exist in the literature. The group agreed that building a model skeleton with place-holder variables is possible within a few months, but the challenge will be assembling data and getting them into the proper currency for the model. Data needed include larval growth and survival, spatial distribution of larval settling sites, density-dependent demographic relationships for adults, and dependence of movement on hydrology, density, and size (Figure 5.1). Simulations of the Version 2.0 will provide a response surface by which management strategies will be assessed.

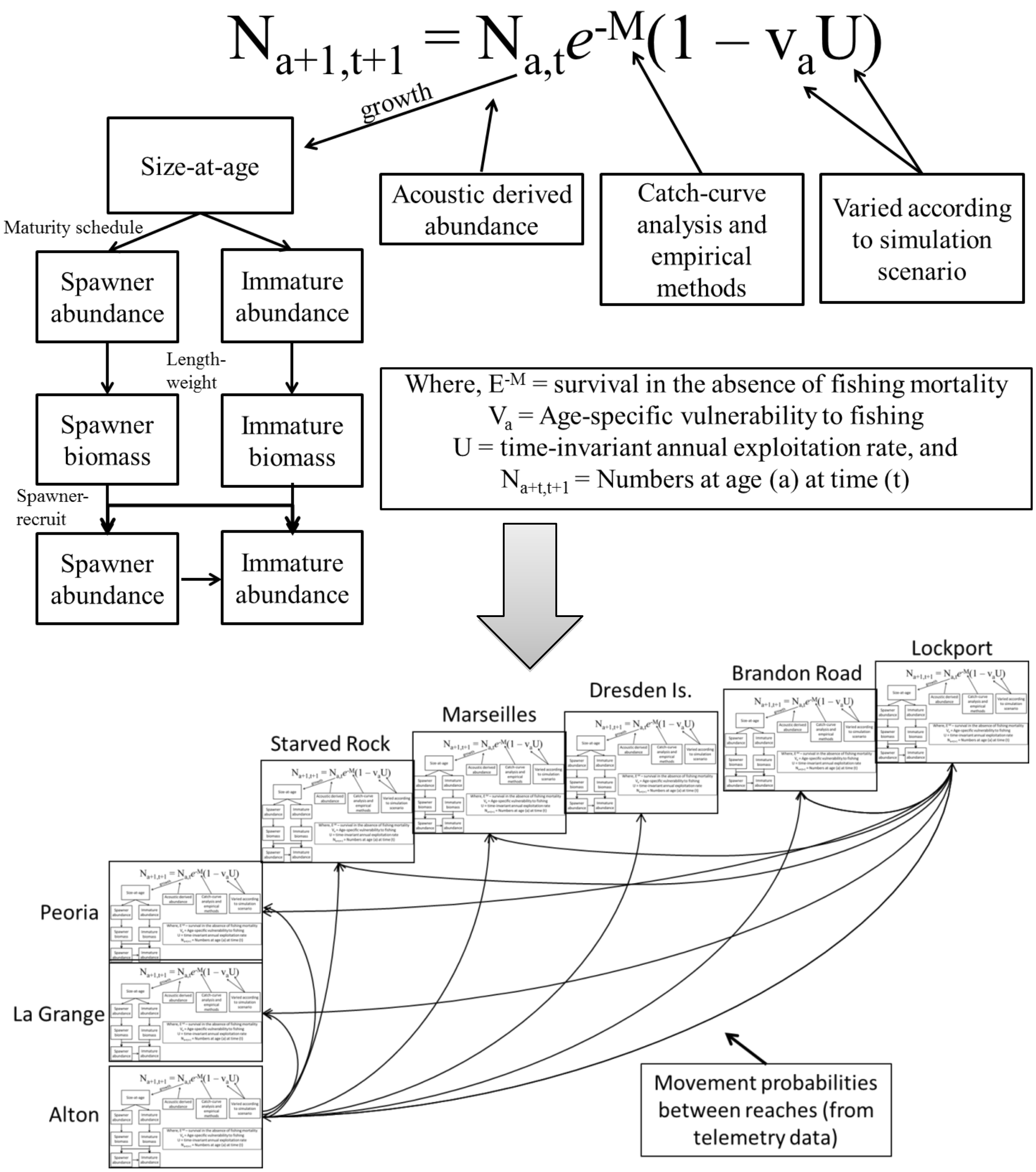


**Figure 5.1.** Structure of model Version 2.0

# CHAPTER 6

## Ecosystem responses to a large-scale reduction of Asian carp in the lower Illinois River

**Goal:** To quantify pre-Asian carp reduction effort chlorophyll *a* and nutrient concentrations, zooplankton community composition and concentration, and fish community characteristics among six reaches of the Illinois River. Identical sampling efforts will be conducted during the Asian carp eradication effort to test for ecosystem responses.

**Justification:** Due to their planktivorous feeding behavior and miniscule filtering capacities, Asian carp have been shown to alter phytoplankton and zooplankton community composition and concentrations. Changes to these lower trophic levels as a consequence of Asian carp may negatively influence native fishes that require these resources during certain life stages or throughout their entire lives. In the Illinois River, rotifer concentrations are positively correlated with Asian carp abundances. Prior to the Asian carp invasion, the zooplankton community of the Illinois River was dominated by cladocerans and copepods. We will test for changes in chlorophyll *a* and nutrient concentrations, zooplankton community composition and concentrations, and the native fish community in response to the Asian carp reduction effort.

**Research Approach:** Chlorophyll *a*, nutrient, and zooplankton samples are being collected biweekly in six reaches of the Illinois River using standard methods. The fish community is being assessed by two separate long-term fish population monitoring programs on the Illinois River. These attributes of the Illinois River will be assessed pre- and post-Asian carp reduction.

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### Introduction

Controlled commercial fishing for the reduction of Asian carp (*Hypothalmychthyes* spp.) was instituted during 2010 in an attempt to reduce migration pressure on the Dispersal Barrier and thus reduce the risk of Asian carp entering the CAWS and Lake Michigan (see Barrier Defense Asian Carp Removal Project Description/Chapter). High densities of Asian carp are believed to exert a strong direct impact on ecosystem structure and function, primarily by the consumption of plankton. Thus, it is plausible that Asian carp reduction efforts (i.e. commercial fishing) may produce detectable responses in variables such as zooplankton community structure, density, and productivity. Short-term changes in these direct response variables could provide insight into any of Asian carp's lagged impact on the native fish community. Monitoring of zooplankton response has been conducted since 2009 and riverine fish monitoring has been conducted by the Long-Term Illinois, Mississippi, Ohio, and Wabash River Fish Population Monitoring program (LTEF) since 1989. The results of these surveys are presented with the objective of increasing our understanding of the ecosystem responses that may have occurred as a result of Asian carp removal efforts.

### Methods

Plankton sampling occurred monthly (May-Oct) at 18 sites throughout the Illinois Waterway (Alton, La Grange, Peoria, Starved Rock, Marseilles, Dresden) from May thru October of 2011-2013 and at a subset of 6 sites during 2009 and 2010. At each site-date combination, three vertically-integrated 55-µm 30-L sample replicates were obtained by pumping water through 55-µm mesh. Zooplankton were preserved in the field using a 12% sugar-buffered formalin solution with Rose Bengal stain added after returning to the laboratory. For microscopic analyses, samples were concentrated to a known volume from which a homogenized 5 mL subsample was transferred to a counting wheel with a Hensen-Stemple pipette. Zooplankton were identified to the lowest possible taxonomic unit using a dissecting scope and the resulting densities are given as the number of individuals per liter of water sampled. Productivity was evaluated by measuring total phosphorus and chlorophyll *a.* Two replicate water samples were collected 0.5 m below the surface at each site-date combination. Chlorophyll-*a* concentrations were estimated by acetone extraction using standard fluorometric techniques. Total phosphorus concentrations were estimated by the ascorbic acid method after digestion with persulfate under acid conditions (Soballe and Fischer 2004).

Asian carp reduction activities through commercial fishing occurred predominately in the upper river section (Starved Rock, Marseilles, and Dresden reaches). During 2010, removals were limited to only the Marseilles and Dresden reaches, whereas from 2011 to 2013 they occurred in all three upper reaches. Removals from the lower river section (Alton, La Grange, and Peoria reaches) only occurred once during 2012. Based on the distribution of commercial fishing pressure, river geomorphology, and natural differences in ecology, we grouped sites into upper and lower river sections (Theiling 1999, McClelland et al. 2006).

*Analyses*

To investigate how the reduction through commercial fishing affected measured ecosystem responses, we only considered the upper section of the river where most of the reduction activities have occurred. Zooplankton density was evaluated using mixed model one-way ANOVA with commercial fishing (presence/absence) as the fixed effect, and site and year as random effects (2009 and 2011-2013, respectively). We indexed zooplankton density as the mean of three replicate samples taken during June of each year. We only considered June zooplankton data because a complete set of all site-month data was not available for all years.

Although Asian carp now comprise the greatest proportion of planktivore biomass in the Illinois Waterway, native planktivores are still important components of the aquatic food web. Therefore, we also included an analysis of the effect of Asian carp reductions on gizzard shad, as gizzard shad can be an indicator for other native plankton-feeding fishes. Gizzard shad (*Dorosoma cepedianum*) are a dominant water column planktivore within the Illinois Waterway and have previously been shown to exhibit reduction in body condition in relation to Asian carp establishment (Irons et al. 2007). If Asian carp can out-compete gizzard shad for plankton, then gizzard shad and the species that utilize them may be indirectly impacted. Thus in an effort to determine if reductions of Asian carp are having a positive effect on gizzard shad, we evaluated gizzard shad abundance and condition using mixed model one-way ANOVA with commercial fishing as the fixed effect, and site and year as random effects. Condition was indexed as relative weight ($W_r$; see Irons et al. 2007) and abundance was indexed as catch-per-unit effort ($CPUE_n$).

Independent of commercial fishing, mean annual zooplankton densities and mean annual productivity (chlorophyll *a* and total phosphorus) were compared by section and year using mixed model, two-way ANOVA with section (upper/lower) and year as fixed effects and site as a random effect. Zooplankton density was indexed as the mean of three monthly replicate samples averaged among the six months sampled each year. Similarly, productivity was indexed as the mean of the two monthly replicate samples averaged among the six months sampled each year. Data from 2009-2010 could not be included with data from 2011-2013 because the same site-date combinations were not sampled during each period. In addition, three other sites were excluded from the analysis because they only occurred in one reach (La Grange) and were deemed different enough from the more standard main channel conditions and would therefore obscure results. These included two backwater sites and one side channel site.

**Results – Effects of Asian Carp Reduction on Ecosystem Responses**

The presence of commercial fishing did not significantly influence rotifer ($f = 0.20$, $p = 0.70$), cladoceran ($f = 0.54$, $p = 0.54$), copepod ($f = 3.31$, $p = 0.21$), nauplii ($f = 0.22$, $p = 0.68$), or total zooplankton densities ($f = 0.22$, $p = 0.69$; Figure 6.1). Furthermore, there were no statistically significant effect of reduction activities on gizzard shad condition ($f = 0.65$, $p = 0.42$) or abundance ($f = 0.06$, $p = 0.94$; Figure 6.2).

**Results – Ecosystem Variability in Relation to River Mile**

Independent of commercial fishing, rotifer density and total zooplankton density varied by year and river section ($p < 0.02$ and $p < 0.001$, respectively), with rotifers tending to be proportionally more abundant in the lower section (Table 6.1; Figures 6.3 and 6.4). There was also a significant year by section interaction for both rotifer and total zooplankton density (both $p < 0.01$), likely a result of high rotifer densities in the upper section during 2012 (Figure 6.4). Cladoceran density varied by river section ($p = 0.03$) as they tended to be more abundant in the upper river and by year ($p = 0.002$) with 2012 significantly different from 2011 and 2013. Nauplii density differed by year ($p = 0.05$) and there was a significant year by section interaction ($p = 0.01$) as higher nauplii abundances were observed in the lower river during 2013(Figure 6.4). Only copepod density did not differ between river section and year.

Chlorophyll-*a* concentration differed by river section ($p < 0.001$). Trends indicate chlorophyll-*a* concentration tended to decrease from downstream to upstream, primarily a consequence of dramatic decreases within the upper river (Figure 6.5). Conversely, total phosphorus tended to be progressively greater upstream and was significantly different between river section and year (both $p < 0.001$; Figure 6.6) with 2012 significantly different from 2011 and 2013.

**Discussion**

Based on our analysis, we were unable to detect an influence of controlled commercial fishing of Asian carp on those ecosystem responses measured during the course of the study. However, several factors aside from commercial fishing pressure on Asian carp, may explain our findings. These include:

- The inherent biotic and abiotic differences that exist between the upper and lower river sections regardless of the establishment of Asian carp (Theiling 1999, McClelland et al. 2006). The lack of a significant response suggests that the differences we observed in productivity and zooplankton communities should not be directly attributed to commercial reductions of Asian carp.
- The relative paucity of zooplankton data collected prior to the onset of Asian carp reduction efforts in 2009. Moreover, small-sample sizes and ineffective sampling designs may have failed to detect year-to-year or site-to-site variation and could obscure broader patterns that may have emerged with additional pre-reduction data.
- In addition to the lack of a plankton response, there was also no response of gizzard shad abundance ($CPUE_n$) or condition ($W_r$). This lack of response could be attributed to a possible lagged response due to longer generation times of fishes.

Aside from these results, several other notable conclusions may be reached.

- While small-bodied rotifers dominated the zooplankton community, they were more abundant in the lower section of the Illinois River where Asian carp densities are highest. In a previous study, increasing densities of silver carp lead to significant reductions in larger bodied plankton like cladocerans and to a lesser extent copepods, but had no effect on rotifer densities (Domaizon and Dévaux 1999). These patterns may be attributed to the lower prey escape ability of cladocerans in conjunction with longer generation times making them more susceptible to suppression by planktivory and competition (Domaizon and Dévaux 1999, Lu et al. 2002). Therefore, higher rotifer concentrations coinciding with higher carp densities may be an indication of greater Asian carp foraging. Additionally, cladocerans were observed to be more abundant in the upper river, which may be a function of both reduction efforts and/or lower ambient Asian carp densities of the upper river.

- In terms of productivity, total phosphorous and chlorophyll-*a* concentrations did not appear to be correlated; total phosphorous increased upstream while chlorophyll *a* decreased upstream. However, it is worth noting general upstream decreases in the chlorophyll-*a* concentration are largely driven by a greater magnitude of decrease in the upper river.

**Recommendations**

Monitoring of productivity and zooplankton should continue to contribute to a better understanding of the long-term ecosystem effects of controlled commercial removal of Asian carp. Removals could be conducted in intermediate connected backwaters that isolate from the main river during low water to increase the ability to detect ecosystem responses to removal efforts. After colonization during high water, reductions could occur during periods of isolation to account for immigration and emigration. Concurrent ecosystem monitoring could also be conducted at more frequent and specific time intervals coinciding with removal events. *In situ* experimental enclosures or experimental ponds may also be beneficial to manipulate carp densities and initial ecosystem parameters (e.g. zooplankton, phytoplankton, nutrients).

**Project Highlights:**

23 March 2015

- Reduction of Asian carp through controlled commercial fishing did not significantly influence zooplankton densities, gizzard shad relative weight, or gizzard shad catch-per-unit effort
- Rotifers are proportionally dominant in terms of abundance in both upper and lower river sections
    - Rotifers tended to be more abundant in the lower section when compared to the upper section
    - Cladocerans tended to be more abundant in the upper section when compared to the lower section
- Primary productivity (i.e., chlorophyll-*a* concentration) decreased from downstream to upstream
- Total phosphorus (mg/L) decreased from upstream to downstream.

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Table 6.1. Zooplankton density (mean (± SD); individuals/L) by river section and year (May-Oct).

| Section | Year | No. Samples | Rotifers/L | Cladocerans/L | Copepods/L | Nauplii/L | Total Zoop/L |
|---|---|---|---|---|---|---|---|
| Lower | 2011 | 199 | 131.2 (133.0) | 1.9 (2.3) | 0.4 (0.7) | 2 (2.1) | 135.6 (134.5) |
| (12 sites) | 2012 | 213 | 153.9 (83.2) | 3.8 (6.0) | 0.4 (0.7) | 2.2 (2.4) | 160.3 (82.5) |
| | 2013 | 211 | 213.9 (146.1) | 2.1 (2.9) | 0.7 (1.0) | 5.7 (7.2) | 222.4 (148.1) |
| | 2011-2013 | 623 | 167.0 (128.1) | 2.6 (4.2) | 0.5 (0.8) | 3.3 (4.9) | 173.5 (129.7) |
| Upper | 2011 | 53 | 23.3 (16.5) | 2.1 (2.4) | 0.5 (0.4) | 3.5 (6.3) | 29.6 (19.9) |
| (3 sites) | 2012 | 54 | 102.7 (149.7) | 7.9 (15.8) | 0.6 (0.7) | 3.2 (3.2) | 114.4 (157.8) |
| | 2013 | 54 | 40.3 (42.5) | 4.8 (8.3) | 0.4 (0.6) | 3.0 (3.0) | 48.6 (42.2) |
| | 2011-2013 | 161 | 55.6 (96.3) | 5 (10.6) | 0.5 (0.6) | 3.3 (4.4) | 64.4 (101.5) |

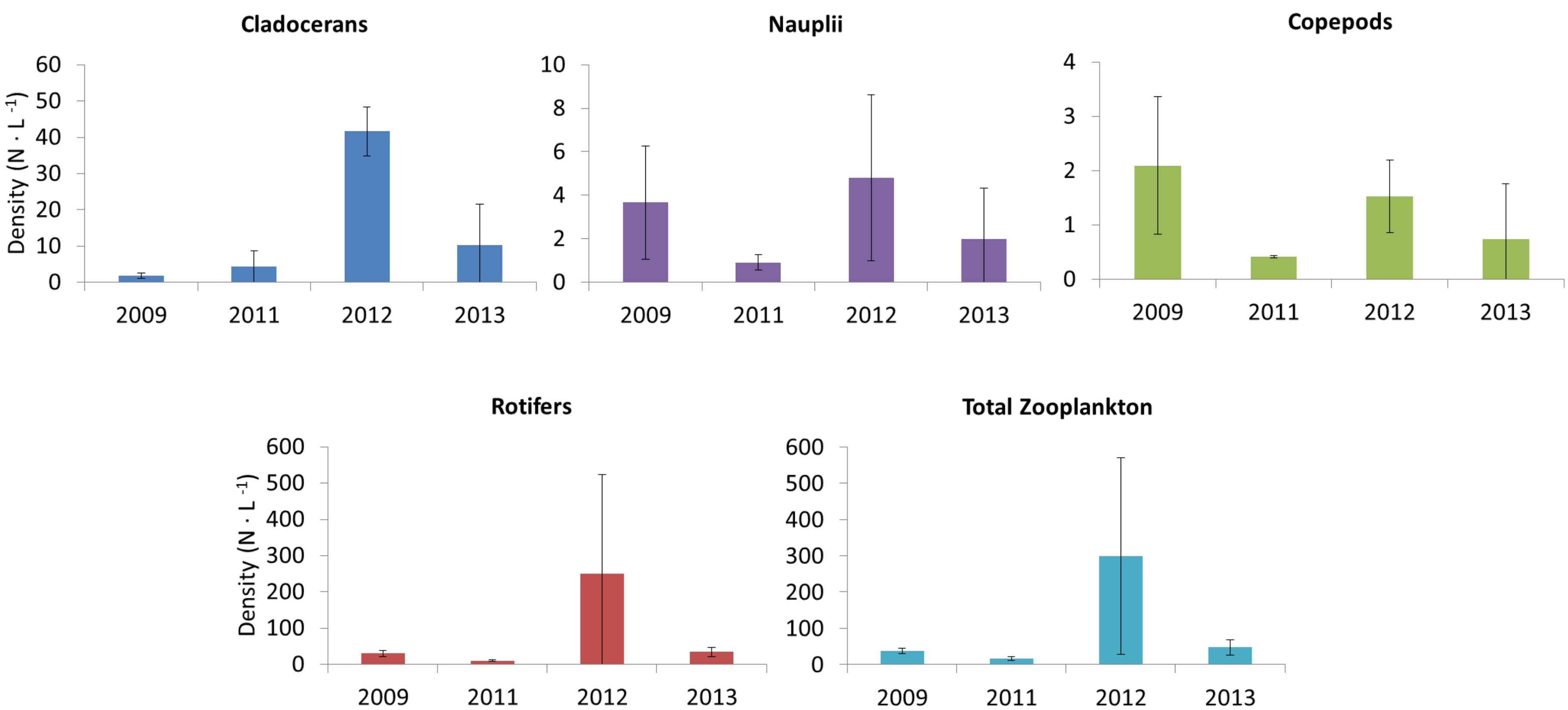



**Figure 6.1.** Mean (± SD) June zooplankton densities by year within the upper river.

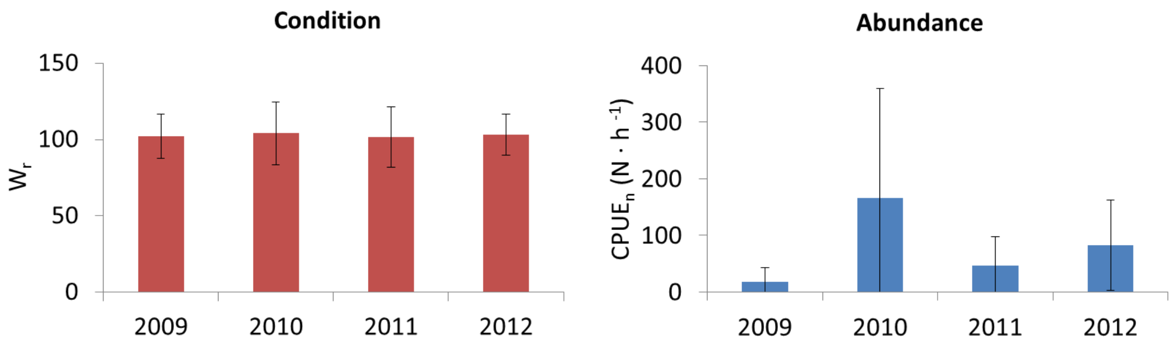
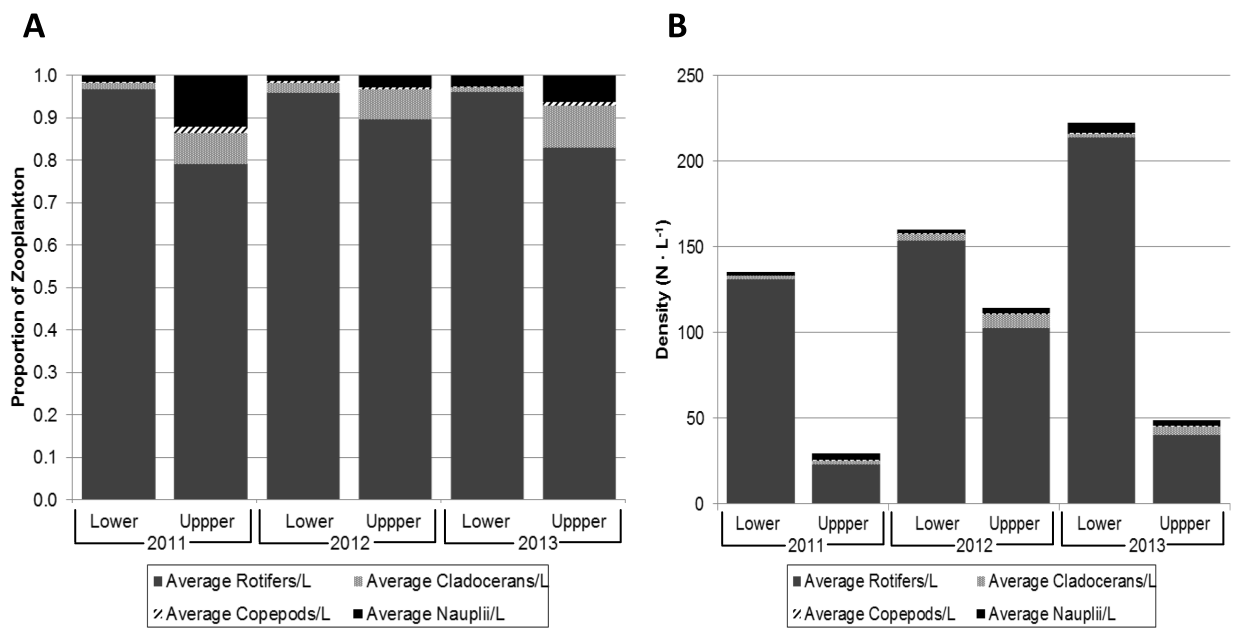



**Figure 6.2**. Condition ($W_r$; mean ± SD) and catch-per-unit effort ($CPUE_n$; mean ± SD) of gizzard shad by




year within the upper river.

**Figure 6.3. A)** Proportion of zooplankton and **B)** zooplankton density by section and year (May-Oct). Note: actual densities differ between river sections.

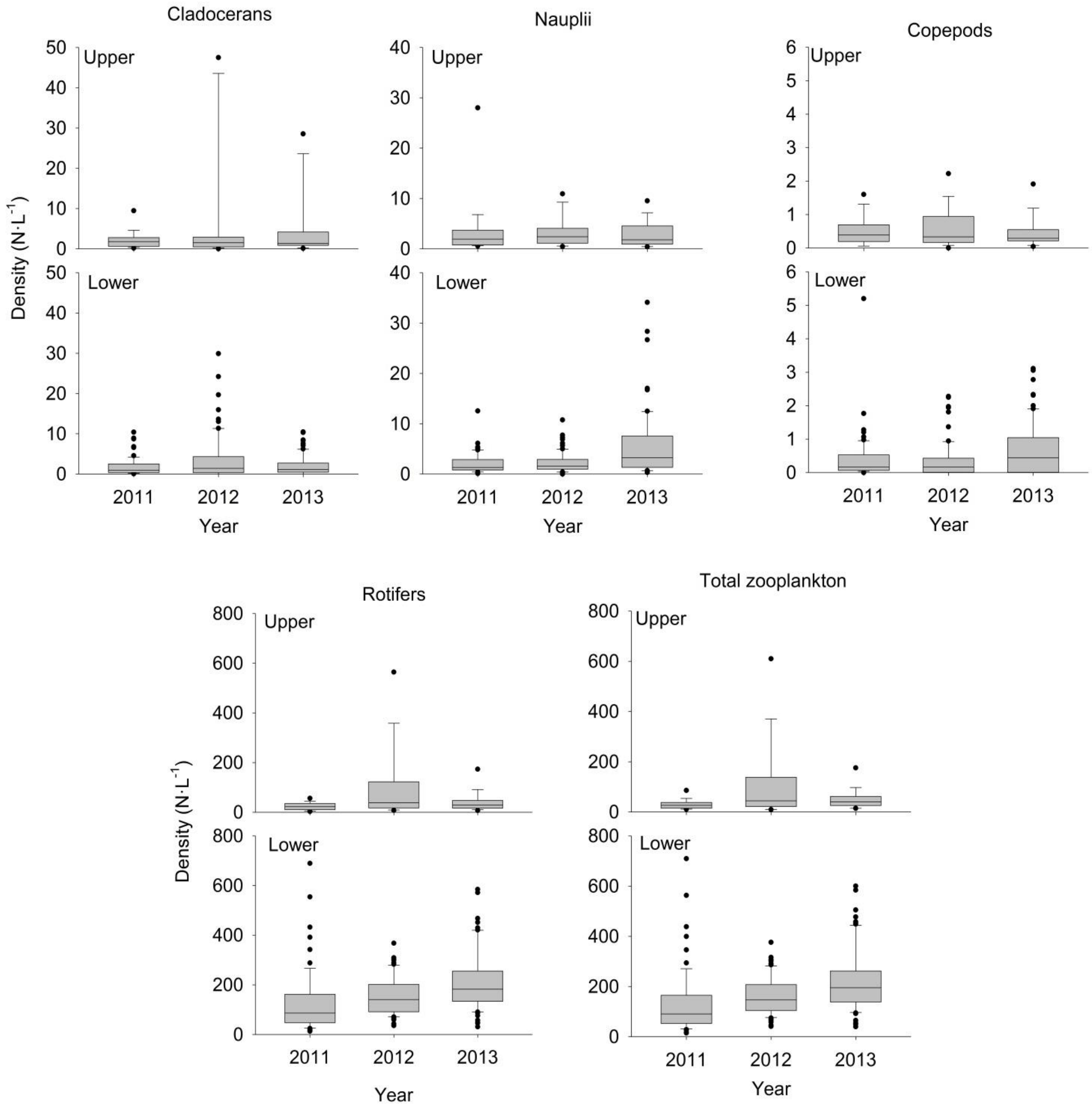



**Figure 6.4.** Density of zooplankton (May – Oct) including rotifers, nauplii, copepods, cladocerans and total zooplankton by river section and year.

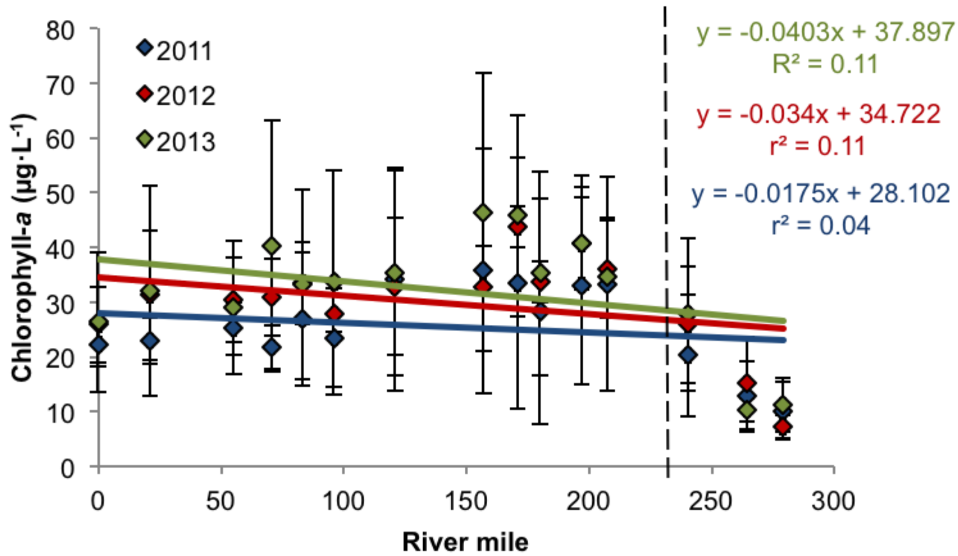



**Figure 6.5.** Mean (± SD) annual (June-October) chlorophyll *a* concentration as a function of river mile. Dashed vertical line separates river sections.

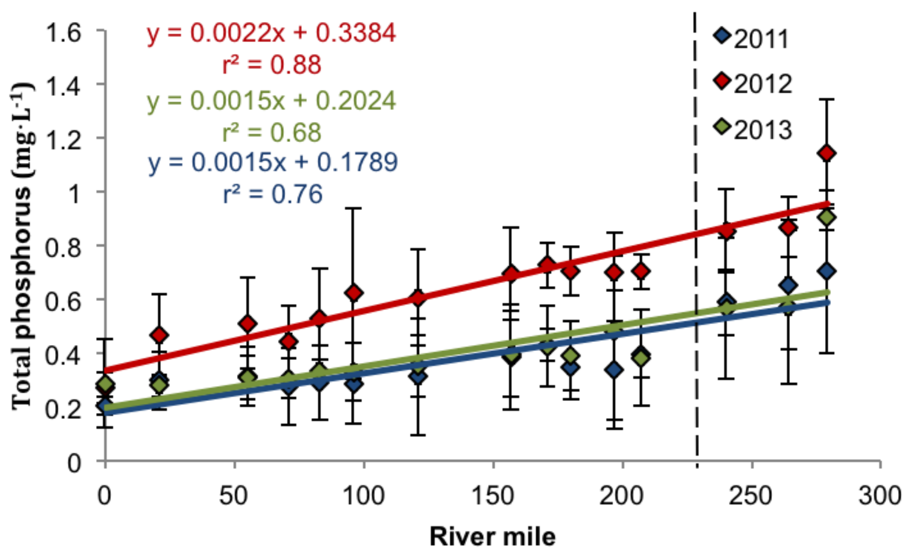



**Figure 6.6.** Mean (± SD) annual (June-Sept) total phosphorus concentration as a function of river mile. Dashed vertical line separates river section.

# CHAPTER 7

## Using telemetry to quantify movement of Asian carp

**Goal:** Effective control of Asian carp in the Illinois River requires an understanding of how many fish are immigrating from downstream reaches and the Mississippi River.

**Justification:** Asian carp invaded the Illinois River from lower reaches. The extent by which both species move upstream to contribute to the populations in the Illinois River is unknown. For harvest to be effective, the density of Asian carp removed needs to outpace the number of fish moving upstream to replace them.

**Research Approach:** Acoustic telemetry was used to track the movements of 300 adult Asian carp (150 silver carp and 150 bighead carp) tagged in the fall of 2010 in Pool 26 of the Mississippi River near the confluence with the Illinois River. Since that time the fish have been tracked using a stationary receiver array that extends from Keokuk, IA down to Caruthersville, MO in the Mississippi River and then the portion of the Illinois River downstream of Starved Rock Dam down to the confluence with the Mississippi River (Figure 7.1). In 2012, receivers were removed from the Mississippi River and relocated to the Illinois River. Currently there are over 40 stationary receivers maintained by SIU in the Illinois River (Figure 7.2).

**Abstract:** Since fall 2010, 79 Asian carp (26%) have entered the Illinois River, moving up at least 6 river miles (Table 7.1). Forty-six of those moved upriver to River mile 22.1 near Hardin, IL. Forty-two of those fish continued upriver also being detected at river mile 39.7, with 27 of those entering Apple Creek. Thirty-five carp moved above LaGrange dam, up to river mile 80.8. Six carp continued on up to river mile 161 and were detected above and below the Peoria Lock and Dam (Figure 7.1). From 2012 to 2014, 709 additional Asian carp were implanted with acoustic transmitters (2014 N = 250; 2013 N = 337; 2012 N = 372). A network of 30 Vemco® VR2W receivers was deployed in the Illinois River by SIUC in 2012 to monitor movement of acoustically tagged Asian carp. This network has been continuously monitored and VR2Ws downloaded every 2-4 months to record fish detections. Receivers have been placed in and around each lock chamber and near major tributaries to track large-scale movements within and among reaches, though three receivers were specifically placed within the HMSC gravel pits to better understand the factors affecting Asian carp immigration and emigration within this area. Immigration and emigration rates throughout the Illinois River, as well as movement between the east and west gravel pits of the HMSC backwater, are also being estimated with acoustic telemetry. To date, with assistance from IDNR-contracted commercial fishermen and Illinois Natural History Survey (INHS), 691 acoustic transmitters have been implanted in Asian carp in the Illinois River or Pool 26 of the Mississippi River.

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**Introduction:** Immigration and upstream movement of Asian carp was quantified with telemetry in 2010-2011, and indicated that 30% of Asian carp (tagged in the Mississippi River) immigrated into the Illinois River from the Mississippi River and subsequently made long distance trips up the Illinois River, but did not extend past Starved Rock Lock and Dam. Immigration and upstream movement corresponded with elevated flow in the river during spring through summer. However, Asian carp that moved upstream, returned to downstream locations as water levels dropped in late summer. Examining how immigration and movement rates of Asian carp change in relation to seasonal and annual changes in river flow as well as determining how changes in Asian carp density affect these movement rates are important considerations for forecasting population responses to removal efforts and predicting how this will affect the probability of movement toward or away from the Chicago Area Waterway System (CAWS).

Multi-year data on movement will allow us to predict the river conditions (e.g., threshold discharge, temperature) that trigger mass movement of fish in the Illinois River. Periods of mass movement might be times when removal efforts need to be increased. If removal efforts are successful and movement is density dependent, then frequency of movement of fish toward the CAWS should decline through time. Even if movement is not density dependent but related solely to temperature and river discharge, successful removal efforts would reduce the number of fish that could potential arrive at the CAWS. Tracking tagged fish over time may also allow us to locate areas that attract (or deter) Asian carp. Focus on these areas during commercial harvest events could have positive effects on decreasing the population growth rate of carp in the upper reaches.

Our data suggest that Asian carp that are resident in the upper reaches may have different movement behaviors (i.e., staying put) relative to the fish in the lower river. By dividing tagged fish between north and south river reaches, we will determine whether this is true. The alternate is that all fish in the north are transient “visitors” to the north moving downstream. This effort also will allow us to test whether Asian carp frequently move past Starved Rock Lock and Dam and whether the route of movement is through the gates or the lock. If movement is concentrated through the lock, then control efforts may be directed toward these structures in the upper river. Lastly, determining how Asian carp interact with the locks and dams of the Illinois River is an important consideration for parameterizing spatially explicit models as the type of dam (e.g., wicket dams on the lower Illinois River compared to the gated lock and dams at Brandon Road) may affect the probability for successful passage.

**Methods:**

*Acoustic transmitters—tagging*

In 2012, 372 Asian carp were tagged with Vemco® acoustic transmitters (v16, v13, v9, or v6 transmitting at 69 KHz) in the Marseilles, Starved Rock, and Dresden Pools of the Illinois River and in Pool 26 of the Mississippi River (124 bighead carp, 243 silver carp, and nine hybrid Asian carp). In early summer and late fall, when water temperatures were optimal for fish recovery, acoustic transmitters were implanted into Asian carp (77 in early summer and 296 in late fall). One hundred and sixty-four fish were tagged in the Starved Rock pool near Sheehan Island, 41 were tagged within the east pit of Hanson’s Material Services Corp. near Morris, IL, 13 were tagged in the Dresden pool near the confluence with the Kankakee River, and 155 were tagged in Pool 26 of the Mississippi near Alton, IL (see Table 1 for breakdown by species).

In 2013, an additional 337 Asian carp were tagged with acoustic transmitters in the Illinois River (Table 1). A total of thirty-eight fish were tagged in the Dresden Island pool, with10 fish being released in Rock Run Rookery, a backwater lake in the Dresden pool, and 28 fish released near the confluence with the Kankakee River. In the Marseilles pool, 96 fish were tagged with transmitters; 56 were released in the main channel at the Morris boat ramp and 38 were released in the Hanson Material Service Corporation (HMSC) pits (21 in the west pit, 17 in the east pit). In the Starved Rock pool, 54 fish were tagged and released at the Starved Rock Marina. To determine the amount of movement between pools in the lower Illinois River and Upper Illinois River, additional fish were tagged in the Peoria (N = 51 fish near Lacon, IL), La Grange (N = 54 fish near Havana, IL) and the Alton pools (N = 46 fish near Hardin, IL). For a breakdown by species, refer to Table 1.

All fish were also tagged with individually numbered $50 reward jaw tags (aluminum, size 1242-9C, National Band and Tag Co.) to provide incentives to fishermen not contracted by the IDNR to return transmitters. IDNR contracted fishermen have been instructed to return healthy fish back to the water as soon after capture as possible.

*Receivers*

A total of 36 Vemco® VR2W receivers had been deployed in the Illinois River to monitor movement of acoustically tagged Asian carp (Alton = 7, Swan Lake = 1, LaGrange = 7, Peoria = 6, Starved Rock = 7, and Marseilles = 3; Figure 6.1) in 2012. One receiver has also been placed in each lock chamber (La Grange, Peoria, Starved Rock, Marseilles, and Dresden Island) and on each upstream and downstream side of the lock and dam, with the exception of Dresden (receivers maintained by the USACE) and Marseilles (only downstream). Additional receivers are located in main channel locations as well as near major tributaries to track large-scale movements within and among reaches. Three receivers were placed within Hanson Material Service Corporation gravel pits to better understand the factors affecting Asian carp immigration and emigration within that area. Finally, active tracking by boat using a Vemco® VR100 receiver was conducted in the Sheehan Island area of the Starved Rock Pool on 21 November and 6 December 2012 and in the Marseilles reach and HMSC pits on 24 May 2013, and periodically in 2014.

*Discharge and temperature*

To relate fish movement to changes in river discharge, we needed to create discharge-gage height (or state height) relationships for each reach of the river. Discharge (Q; $m^{-1}s^{-1}$) measurements were collected using an Acoustic Doppler Current Profiler (ADCP) in the Starved Rock reach, Alton reach, and at the confluence of the Mississippi and Illinois Rivers in 2012 and 2013. Measurements were taken near Buffalo Rock (Starved Rock reach; ~RM 234) on 8 May, 17 July, 12 August, 23 October, 21 November, and 6 December in 2012 and 15 January, 13 February, 10 April, and 8 May in 2013. Discharge measurements were taken at the confluence and on the IL River at Grafton, IL on 12 July, 23 August, 26 October, 20 November, and 6 December in 2012 and the 18 January, 20 February, and 5 April 2013. Second order polynomial relationships were fit to discharge and river gage height or river stage height (depending on available data from USGS gaging stations) for these areas (Figure 6.3 and Figure 6.4). These relationships will be used to determine how change in discharge is related to fish movement.

Temperature loggers were also placed on all VR2W receivers to determine how movement relates to changes in water temperature. Movement and temperature data have been and will continue to be downloaded at 3-month intervals to determine how discharge and water temperature affect movement of Asian carp.

**Results and Discussion:**

*General movement*

Since fall 2010, 79 Asian carp (26%) have entered the Illinois River, moving up at least 6 river miles (Table 6.1). Forty-six of those moved upriver to River mile 22.1 near Hardin, IL. Forty-two of those fish continued upriver also being detected at river mile 39.7, with 27 of those entering Apple Creek. Thirty-five carp moved above LaGrange dam, up to river mile 80.8. Six carp continued on up to river mile 161 and were detected above and below the Peoria Lock and Dam (Figure 7.1).

Over 1.4 million positive (known transmitter) detections have been recorded on passive VR2W receivers from May 2012 to December 2013 on VR2W receivers located along the Illinois River (from Grafton, IL to Dresden Island Lock and Dam). From these detections, 273 individual Asian carp have been identified (including fish tagged by USACE and SIU fish tagged in 2010 with active transmitters). The redetection rate of fish tagged in 2012 was 31.2% and 27.0% in 2013 (Table 7.2).

Of the 348 Asian carp that were tagged in the Mississippi River by SIU in October/November 2010 (with active transmitters during this study), 47 were redetected in the Illinois River (Table 6.3). Five of those fish immigrated into Swan Lake, a backwater of the Alton reach located between RM 5 and RM 13. Including the fish that moved into Swan Lake, the immigration rate from the Mississippi River to the Illinois River over ~2.5 years was 13.5%. Of the fish that were tagged in the Mississippi River (Pool 26) in fall 2012 (N = 148), twelve were redetected in the Illinois River (Alton = 3, La Grange = 3, Peoria = 3, Swan Lake = 3). Including the three fish last relocated in Swan Lake, the 1-year immigration rate for 2012 carp was 8.1%. Although we do not know the number of fish that died during this time period, this is a starting point from which to parameterize spatially explicit movement models for the river and gives us an idea of the proportion of fish emigrating from the Mississippi River into the Illinois River.

*Passage through locks and dams and between reaches*

Fish detections in lock and dams increased in 2013, in part due to the additional receivers in the lock chambers. Eighty-one fish were detected in lock chambers. Two bighead carp and one silver carp were detected in the lock chamber of the Marseilles Lock and Dam. The two bighead carp (originally tagged by the USACE in the HMSC pits in October 2012) passed successfully downstream (one back upstream, then downstream again). Both were last detected moving further downstream through Starved Rock Lock and Dam into the Peoria pool in September 2013. The silver carp, which was initially tagged in the Sheehan Island backwater in the Starved Rock pool, did not successfully pass upstream through the Marseilles Lock and Dam and returned back downstream to the Sheehan Island backwater in the Starved Rock reach.

In addition to the two bighead carp that passed downstream through the Starved Rock Lock and Dam, seven additional fish attempted to pass downstream. One bighead carp successfully passed and continued to move downstream, while the other six moved back and forth near the receiver before turning back upstream to the Sheehan Island backwater area. No fish were detected moving upstream through the Starved Rock Lock chamber in 2013, although one fish (from Pool 26) was detected in the Starved Rock pool.

In the Dresden Island lock chamber, seven fish were detected, all during the months of May and June. One fish, originally tagged in the Dresden pool, successfully passed downstream (multiple attempts; 10-12 May 2013). Another moved from the HMSC pits into the lock chamber and back to the HMSC pits (25-26 June). The other five fish only show detections in the lock chamber. We do not have receivers upstream of Dresden Island Lock and Dam and therefore rely on the USACE for any detection above that area. These five fish were not detected again downstream of the dam, they likely passed upstream.

Fish tagged in the Starved Rock and Marseilles pools showed extremely high site fidelity, with 50% of all fish tagged in the Starved Rock pool relocating within that pool and 78.8% of redetected fish staying in that pool (Table 7.4). In 2012, nearly 20% (thirty-six individual fish) of the fish tagged in the Sheehan Island backwater were relocated there up to seven months post-tagging, suggesting that Starved Rock may act as a staging area (waiting area for fish until conditions become favorable for moving, either to spawn or migrate) for Asian carp and/or a natural barrier to upstream movement. The receiver in Sheehan Island has been sent to Vemco for repairs, but we suspect the number of fish redetected in that backwater is still high. Fish tagged in the HMSC pits in the Marseilles reach in 2012 also showed high site fidelity. Of fish tagged and subsequently redetected, 72.5% stayed within the Marseilles pool, 10% moved upstream, and 17.5% moved downstream (Table 7.4).

*Spawning movements*

Spawning aggregations were observed for the first time in the Marseilles reach in 2013 (22 May). Fish detections and movement in the HMSC backwater of the Marseilles reach were compared to temperature and river discharge (stage height used as a proximate measure of discharge in this reach) to determine what cues triggered spawning movements in carp. Because a receiver is located in the connecting channel between the main river channel and the backwater of the HMSC pits, we were able to tell when fish moved out of the pits, into the pits, or stayed in the connecting channel (staging). Staging fish were fish that stayed within detection range of the receiver in the connecting channel for an extended period of time without moving into or out of the pits. Fish that were “moving” were detected on both the receiver in the connecting channel and the receiver at the mouth of the pits (Figure 7.5). Staging fish were most abundant from the 1 May – 8 May, at which time fish began to move (Figure 7.6). The 8 May was the first date that water temperature rose above 18°C, a trigger for spawning movement in their native habitat (Yangtze River; Li et al. 2013). No movement and minimal staging was detected on the 9-10 May, 21 May, 28 May, or 3 June 2013. Each period of no fish detections (number of fish moving or staging is zero) is a likely spawning event when all fish were in the main channel. Each of these periods corresponded to elevated river discharge and river temperatures above 18°C, and a significant, albeit weak, positive correlation between the number of fish staging and the stage height of the Marseilles reach ($R = 0.16$; $P = 0.001$), suggesting that each rise in river stage height (elevated discharge) triggered a spawning event during this period. Although spawning aggregations were only observed during the 22 May, there were likely three additional spawning movements in the spring.

*Movement, river discharge, and temperature*

Many fish species exhibit movement related to river discharge (Taylor and Cooke 2012), and carp do not appear to be an exception. Sharp rises in river stage and current velocity have been shown to trigger movement in Asian carp in China (Wang et al. 2013). For the Illinois River, the number of unique fish moving upstream and downstream was calculated per day and a three day moving average was taken (Figure 7.7). Overall, the most movement (upstream or downstream) occurred from April to mid-July and in November. The greatest upstream movement occurred during the end of April, and the greatest downstream movement occurred during the end of May and beginning of November. Fish were possibly cuing on increased river discharge in the spring for movement. Additional analyses are being conducted to determine reach specific cues for movement.

**Recommendations:**

We were able to monitor and discern patterns of Asian carp movement throughout the entire Illinois River, showing the general time periods that fish were moving. No Asian carp were detected near the CAWS, so no fine scale movement monitoring was necessary. Additional active tracking should be conducted to locate fish tagged in the Dresden Island pool and in the Rock Run Rookery. Additional “proxy” fish should also be tagged in the upper reaches (above Dresden Island) to determine how Asian carp may respond to environmental cues in that area.

We were also able to determine differences between “immigrant” carp from the Mississippi and lower Illinois Rivers and “resident” carp in the upper Illinois River. Although fish from the Mississippi River were detected as far upstream as the Starved Rock pool, no “immigrant” fish were present further upstream. Carp from the Mississippi River are capable of making long distance migrations in a relatively short period of time (e.g., Alton pool to the Starved Rock pool in less than one month), however the immigration rate into the Illinois River was only measured at 13.5% over a 2.5-year period, suggesting that fish already present in the Illinois River are of greater concern than those in the Mississippi River. However, if the current immigration rate were to continue, there would still be a constant influx of fish from downstream reaches. An increase in downstream harvest may be necessary to ultimately decrease the propagule pressure at the CAWS.

River discharge, river gage height, and temperature in the Illinois River were related to movement patterns of Asian carp. Movement in 2013 appeared to be greater than in 2012, likely due to the increased river discharge in 2013. Temperatures over 18°C and increases in river discharge during the month of May appeared to trigger spawning movements in the Marseilles reach. Increasing fishing pressure prior to such events (April) may help to decrease the number of spawning individuals when conditions become favorable.

Although we are not yet able to relate carp movement to biomass of fish in the river due to the long processing time of our hydroacoustics data, we will continue to monitor Asian carp movement though the Illinois River in 2013 and make such comparisons as soon as data become available. We recommend increased effort to locate fish in side channels and backwater areas, as these may be important staging locations or barriers to movement for Asian carp, and more closely monitoring fine scale movements in those areas.

**Highlights:**

- In 2013, an additional 337 Asian carp were tagged with acoustic transmitters in the Illinois River (Rock Run Rookery = 10, Dresden Island = 28, Marseilles = 93, Starved Rock = 54, Peoria = 51, La Grange = 54, Alton = 46).
- Of the 348 Asian carp that were tagged in the Mississippi River by SIU in October/November 2010, 47 were redetected in the Illinois River. The immigration rate from the Mississippi River to the Illinois River over ~2.5 years was 13.5%.
- Over 1.4 million positive (known transmitter) detections have been recorded on passive VR2W receivers from May 2012 to December 2013 on receivers located along the Illinois River. From these detections, 273 individual Asian carp have been identified. The redetection rate of fish tagged in 2012 was 31.2% and 27.0% in 2013
- Fish were detected in all lock chambers in 2013. No successful upstream movement was detected through the Marseilles Lock and Dam, although attempts were made. Two fish did successfully pass downstream. This is the first record of fish moving through the Marseilles Lock and Dam.
- In the Dresden Island lock chamber, seven fish were detected, all during the months of May and June. One was confirmed passing downstream and five potentially moved upstream (awaiting USACE detection data).
- Spawning was observed for the first time in the Marseilles reach on 22 May 2013. A significant, positive correlation between the number of fish staging in the HMSC pits and the stage height of the Marseilles reach was found, suggesting that elevated discharge and temperatures above 18°C triggered multiple spawning events in May 2013.
- River-wide, the most movement (upstream or downstream) occurred from April to mid-July and in November. The greatest upstream movement occurred during the end of April, and the greatest downstream movement occurred during the end of May and beginning of November.

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Tsehaye, I., M. Catalano, G. Sass, D. Glover, B. Roth. 2013. Prospects for fishery-induced collapse of invasive Asian carp in the Illinois River. Fisheries 38(10): 445-454.

**Table 7.1.** Location data for acoustically tagged Asian carp in the Illinois Riverduring fall 2010 through summer 2011.

| River Miles Moved up the Illinois River | Number of Silver Carp | Number of Bighead Carp |
|---|---|---|
| 5.7 river miles (Grafton, IL) | 15 | 10 |
| 22.1 river miles (Hardin, IL) | 6 | 1 |
| Up to 22.1 then back down to 5.7 (38.5 total river miles) | 1 | 0 |
| 38.5 river miles (Apple Creek near Pearl, IL) | 4 | 1 |
| 39.7 river miles (Pearl, IL) | 1 | 2 |
| Up to 39.7 then back down to 22.1 (57.3 total river miles) | 1 | 0 |
| Up to 39.7 down to 5.7 then upto 84.1 (160.8 river miles) | 1 | 0 |
| 84.1 river miles (Beardstown, IL Above LaGrange Dam) | 11 | 5 |
| Up to 84.1 down to 39.7 (128.5 total miles) | 2 | 0 |
| Up to 84.1 down to 22.1 (146.1 total miles) | 1 | 0 |
| Up to 84.1 down to 5.7 (162.5 total miles) | 6 | 1 |
| 155.3 river miles (Below Peoria Lock and Dam) | 1 | 1 |
| 161 river miles (Above Peoria Lock and Dam) | 2 | 0 |
| Up to 161 down to 84.1 (235.9 total river miles) | 1 | 0 |

**Table 7.2.** The number of bighead and silver carp tagged with acoustic transmitters, the number redetected (to date), and the redetection rate by reach for 2012 and 2013.

| 2012 | Bighead carp | Silver carp | Total | Number redetected | Redetection rate |
|---|---|---|---|---|---|
| Pool 26 | 19 | 129 | 148 | 14 | 9.46% |
| Dresden Island | 25 | 20 | 45[b] | 5 | 16.67% |
| Marseilles | 48 | 16 | 64[a] | 40 | 62.50% |
| Starved Rock | 56 | 103 | 159 | 66 | 41.51% |
| Total | 148 | 268 | 401 | 125 | 31.17% |

[a] Includes 30 USACE fish tagged in the east pits.

[b] Includes 17 USACE fish tagged in the Dresden Island Pool.

| 2013 | Bighead carp | Silver carp | Total | Number redetected | Redetection rate |
|---|---|---|---|---|---|
| Rock Run Rookery | 10 | | 10 | 4 | 40.00% |
| Dresden Island | 26 | 2 | 28 | 9 | 32.14% |
| Marseilles | 2 | 54 | 56 | 0 | 0.00% |
| HMSC Pits | 19 | 19 | 38 | 25 | 65.79% |
| Starved Rock | 8 | 46 | 54 | 3 | 5.56% |
| Peoria | 6 | 45 | 51 | 1 | 1.96% |
| La Grange | 21 | 33 | 54 | 4 | 7.41% |
| Alton | 13 | 33 | 46 | 45 | 97.83% |
| Total | 105 | 232 | 337 | 91 | 27.00% |

**Table 7.3.** The number of fish tagged in the Mississippi River by SIU in October and November 2010 (with active transmitters during 2012-2013) that were redetected in the Illinois River. Numbers show the furthest upstream reach in which fish were last detected.

| | | To Illinois River Reach | | | | |
|---|---|---|---|---|---|---|
| | | Alton | Swan Lake (Alton BW) | La Grange | Peoria | Starved Rock |
| From Mississippi River Pool: (tagged 2010) | 22 | 1 | | 1 | 1 | |
| | 26 | 8 | 5 | 18 | 11 | 1 |
| | 27 | 1 | | | | |

**Table 7.4.** The probability of a detected fish being tagged in a pool (left column), and moving to another pool (top row). Only the furthest pool from the tagging location was counted (e.g., although a fish tagged in Marseilles had to move through the Starved Rock pool to reach Peoria, Starved Rock is not the final destination, so that fish would not be included in the Starved Rock count), so all probabilities will sum to one (within rounding error) per tagged pool.

| | | **Movement to:** | | | | | |
|---|---|---|---|---|---|---|---|
| | | Alton | La Grange | Peoria | Starved Rock | Marseilles | Dresden Is. |
| **Movement from:** | Pool 26 | 0.57 | 0.21 | 0.21 | | | |
| | Starved Rock | | 0.03 | 0.15 | 0.79 | 0.03 | |
| | Marseilles | | | 0.05 | 0.13 | 0.73 | 0.10 |
| | Dresden Is. | | | | | 0.40 | 0.60 |


Figure 7.1. Illinois and Mississippi River waterways. Each circle represents a stationary receiver that is in the river recording the location of acoustically tagged Asian carp continuously in 2010.

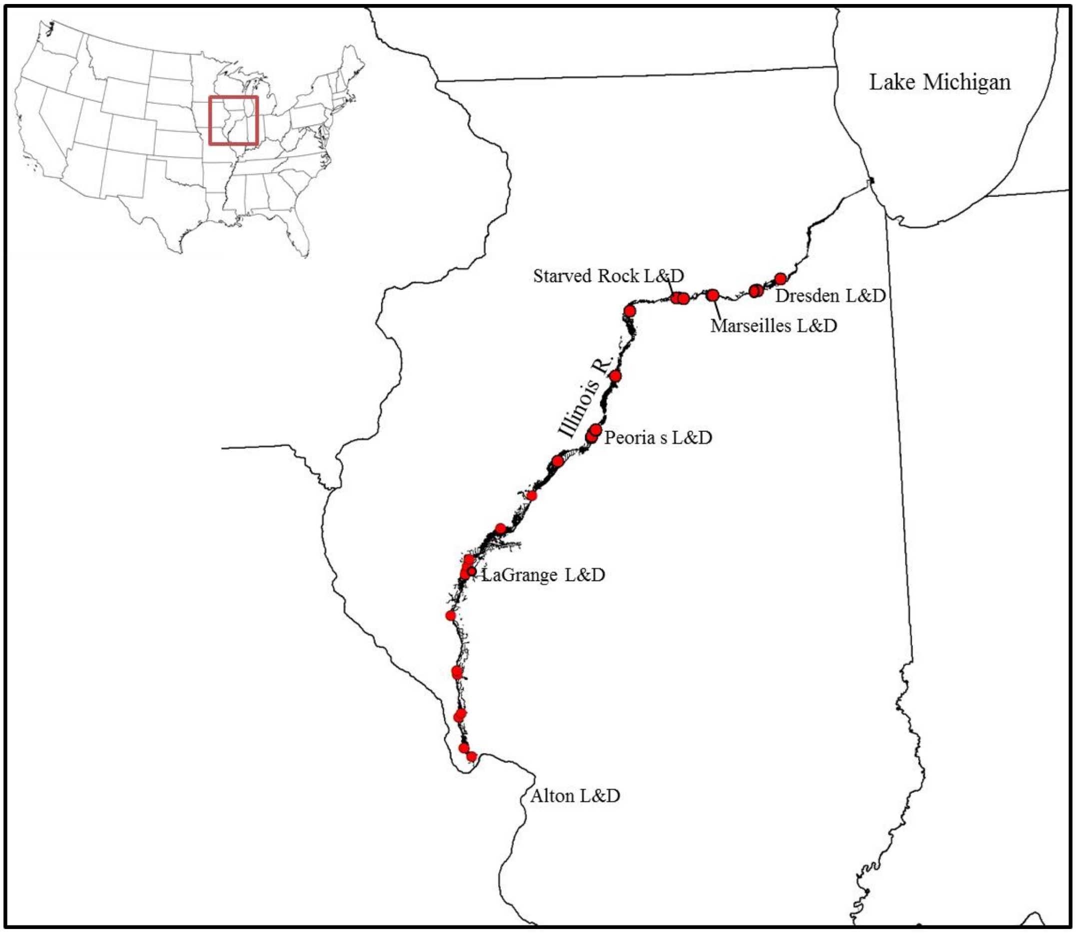


**Figure 7.2.** Locations of all active VR2W receivers along the Illinois River.

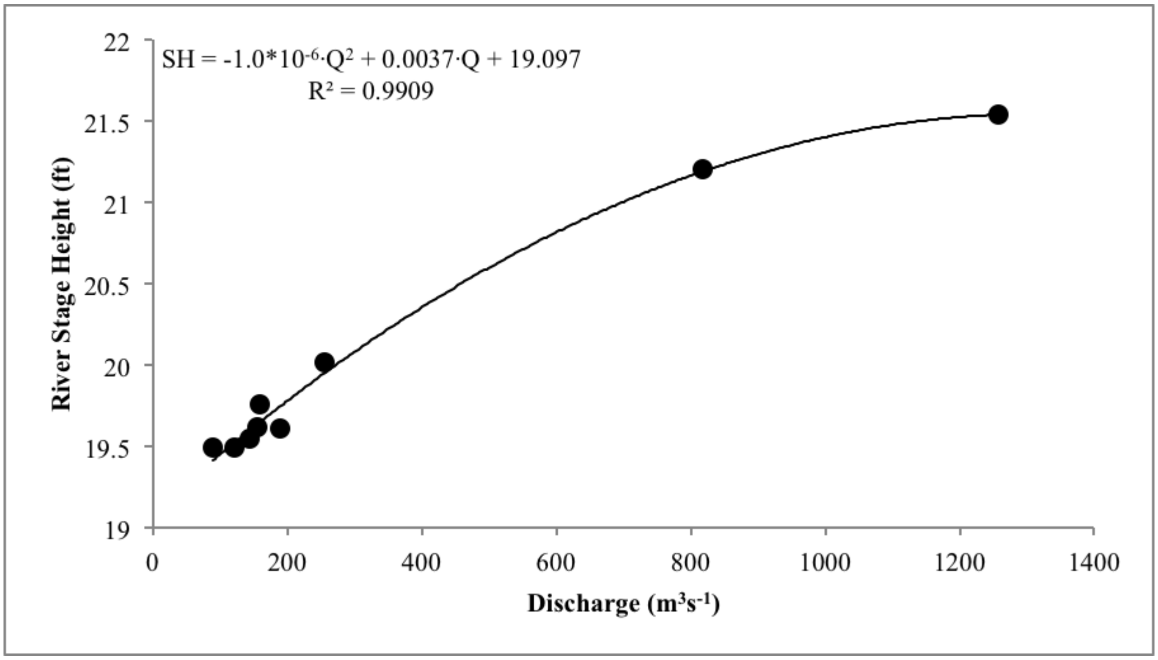


**Figure 7.3.** Second order polynomial relationship between discharge (Q; $m^3s^{-1}$) and Illinois River stage height (SH; ft.) for Hardin, IL (Alton reach) developed using Acoustic Current Doppler Profiler to measure discharge every approximately two months from spring 2012 – spring 2013 in Alton, IL. River gage height measurements were obtained from the USGS gaging station in Hardin, IL.

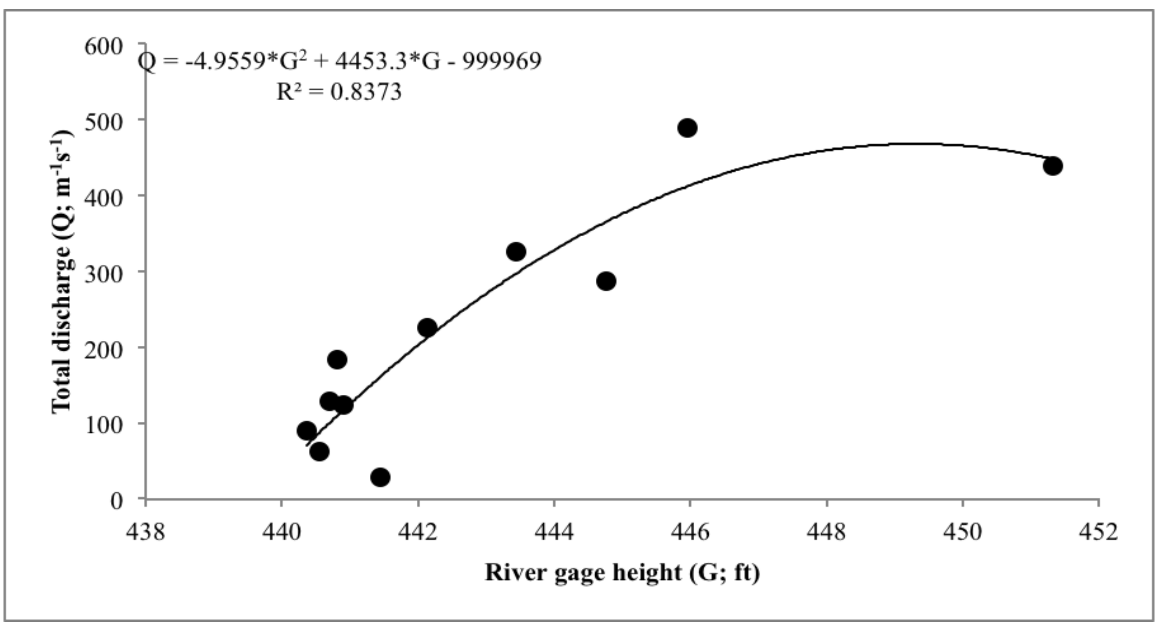


**Figure 7.4.** Second order polynomial relationship between river gage height (G; ft.) and total discharge (Q; $m^{-1}s^{-1}$) for the Starved Rock reach of the Illinois River. Discharge was measured downstream of Sheehan Island.

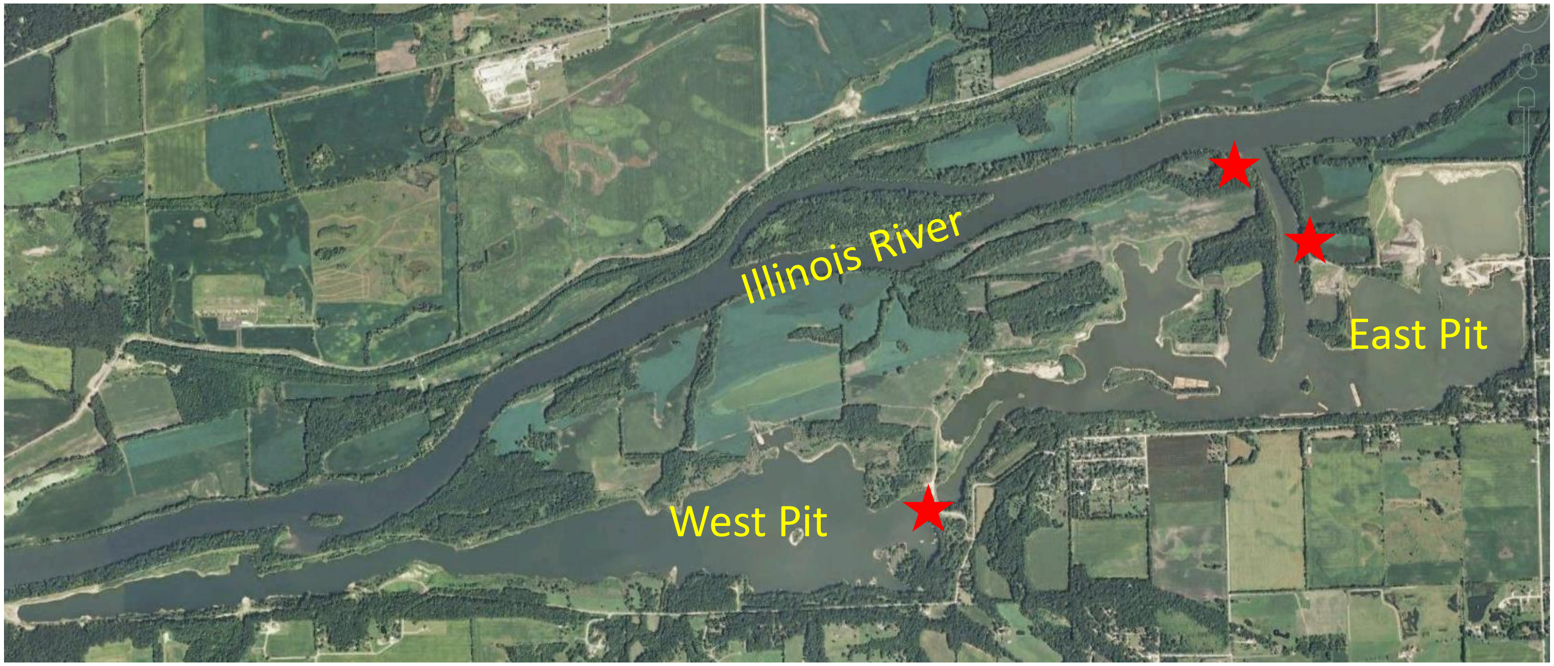


**Figure 7.5.** Map of Hanson Material Services Corporation (HMSC) backwater near Morris, IL indicating locations of VR2 receivers to quantify movement in/out of this backwater and between the west and east pits.

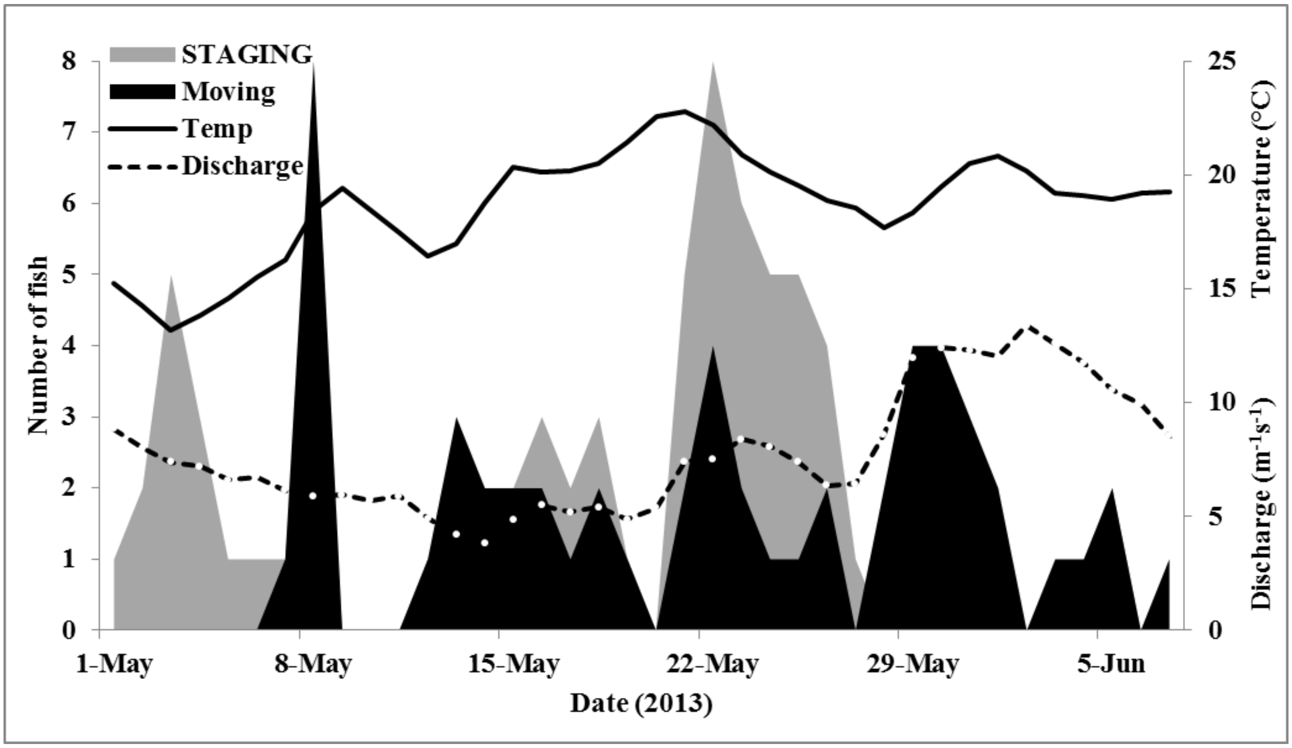


**Figure 7.6.** The number of fish detected staging in (grey) and moving to or from (black) the HMSC pits, along with corresponding river discharge and temperature over May 2013. Each period of no fish detections (number of fish moving or staging is zero) is a likely spawning event when all fish were in the main channel. Spawning was observed in the reach on 22 May.

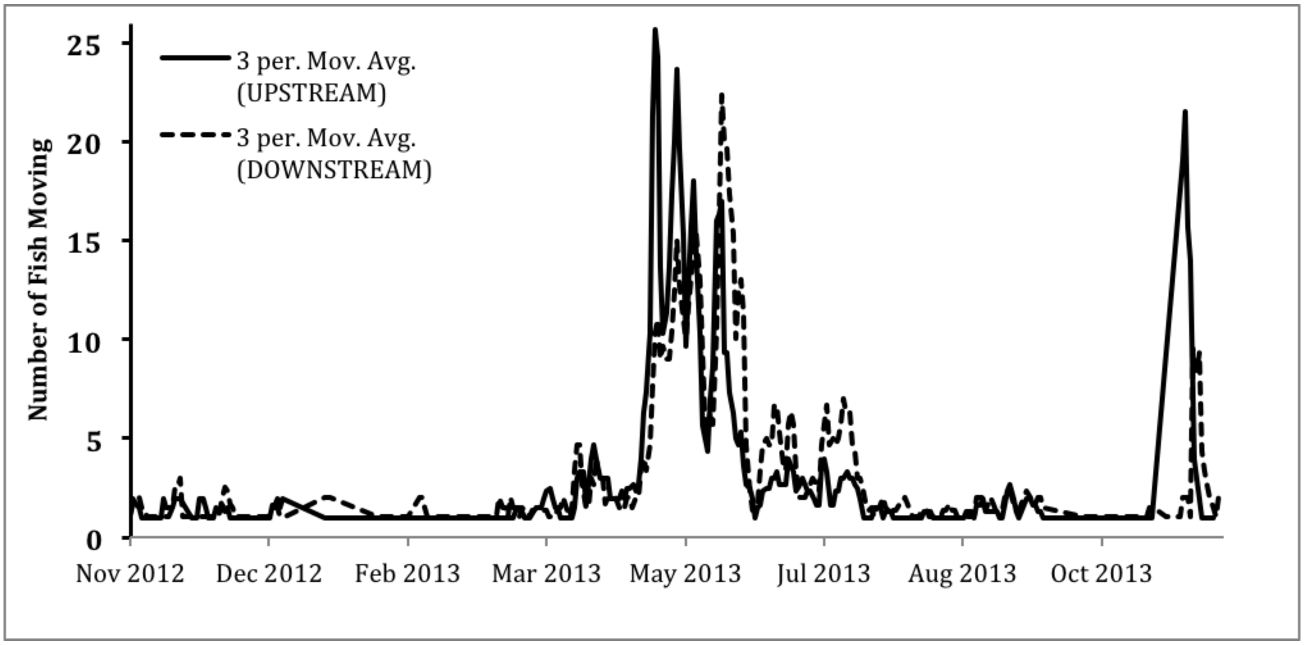


**Figure 7.7**. Three period moving averages of upstream (solid line) and downstream (dashed line) Asian carp movement by date for the entire Illinois River for all fish redetected in 2012 and 2013.

# CHAPTER 8

## Identification of natal environment of adult Asian carps in the Illinois River using otolith microchemistry and stable isotope analysis

**Goals:** Estimate the relative abundances of resident (Illinois River origin) and immigrant (Mississippi or Missouri river origin) bighead carp and silver carp in four reaches of the Illinois River (Alton, LaGrange, Peoria, and upper river). Characterize timing and patterns of inter-river movement for immigrants. Estimate the proportion of Asian carp that use floodplain lakes along the middle and lower Illinois River as larval and juvenile nursery areas.

**Justification:** Asian carps are known to be reproducing in the Illinois, middle Mississippi, and lower Missouri Rivers. However, the extent to which the Asian carp stock in the Illinois River is derived from recruits from within the Illinois River vs. immigrants from the Mississippi and Missouri Rivers is unknown. Asian carp are also known to use connected floodplain lakes during early life, but the contribution of these habitats to Asian carp recruitment in the Illinois River is also unknown. Knowledge of Asian carp recruitment sources is needed to: 1) assess the degree to which stocks of these species in the Illinois River may be replenished by immigrants from other rivers and the need to expand the geographic scope of enhanced commercial harvest efforts and 2) to direct commercial fishing and other control efforts to target locations that are supporting Asian carp populations.

**Research Approach:** Bighead and silver carps are being collected from each of four reaches of the Illinois River (Alton, LaGrange, Peoria, and upper river). Both asterisci otoliths are extracted from each fish; one otolith per fish is sectioned and analyzed for strontium:calcium ratio (Sr:Ca) using laser ablation-ICPMS and the second otolith is analyzed for stable oxygen and carbon isotope ratios (δ18O and δ13C). Sr:Ca, δ18O and δ13C of the otolith core (which reflects early life history) will be used to infer natal environment for individual fish; changes in Sr:Ca across sectioned otoliths will be used to assess timing and long-term patterns of inter-river movement.

**Abstract:** Water chemistry data continued to indicate that Sr:Ca is consistently higher in the middle Mississippi and Missouri rivers compared to the Illinois River, thus enabling use of this marker as an indicator of fish that have immigrated into the Illinois River from these other rivers. Using otolith core Sr:Ca data, we estimated that 28-53% of adult silver carp and 26-48% of hybrids in the Illinois River were immigrants that originated in the middle Mississippi or Missouri Rivers**.** Only 5% of the fish analyzed had otolith core $\delta^{18}O$ and $\delta^{13}C$ signatures indicative of use of floodplain lake habitats during early life, consistent with data from prior years. Among silver carp and hybrids that were immigrants to the Illinois River, the vast majority originated in the middle Mississippi River; only 2-8% of the total number of silver carp and hybrids captured in the Illinois River originated in the Missouri River. In contrast to silver carp and hybrids, otolith core Sr:Ca indicated that 91-98% of bighead carp analyzed originated in the Illinois River, with 2% originating in the middle Mississippi River, consistent with data from prior years.

**Contact:** Greg Whitledge, Associate Professor, Southern Illinois University Carbondale, IL; (618) 453-6089; gwhit@siu.edu

**Introduction:** Asian carps are known to be reproducing in the Illinois, middle Mississippi, and lower Missouri Rivers. Initial estimates of the extent to which Asian carp stocks in the Illinois River are derived from recruits from within the Illinois River itself vs. immigrants from the Mississippi and Missouri Rivers were obtained from otoliths collected during 2010-2011 sampling. We also estimated the contribution of floodplain lake habitats to Asian carp recruitment in the Illinois River. Asian carps are known to exhibit substantial inter-annual variation in recruitment and also within-river movement rates by adult fish. Thus, there is a need to determine whether the principle natal environments of Asian carps in the Illinois River may also differ among years. Knowledge of Asian carp recruitment sources is also needed to: 1) determine whether enhanced commercial harvest of Asian carps in the Illinois River is effectively reducing recruitment of these species within the Illinois River (as indicated by a decrease in the relative abundance of Illinois River-origin fish), 2) assess the degree to which Asian carp stocks in the Illinois River may be replenished by immigrants from other rivers (immigration rates are an important component of population models) and the potential need to expand the geographic scope of enhanced commercial harvest efforts and 3) direct commercial fishing and other control efforts to target locations that are supporting Asian carp populations.

**Objectives:** Estimate the relative abundances of resident (Illinois River origin) and immigrant (Mississippi or Missouri river origin) bighead carp, silver carp, and hybrids of these two species in four reaches of the Illinois River (Alton, LaGrange-Peoria, and upper river [upstream from Starved Rock Lock and Dam]) to assess inter-annual variability in recruitment sources of Asian carps and evaluate potential effects of enhanced commercial harvest on proportions of resident and immigrant fish. Characterize timing and patterns of inter-river movement for immigrants. Refine estimates of the proportion of Asian carp that use floodplain lakes along the middle and lower Illinois River as larval and juvenile nursery areas.

**Methods:** Adult bighead and silver carps were collected from each of three reaches of the Illinois River (Alton, LaGrange-Peoria, and upper river) during 2012-2013 by electrofishing and trammel netting. Caudal fin clips were obtained from each fish and sent to Jim Lamer at Western Illinois University for identification of bighead carp, silver carp, and hybrids. Both lapilli otoliths were extracted from each fish. One otolith per fish was sectioned and analyzed for strontium:calcium ratio (Sr:Ca) along a transect from the core to the edge of the sectioned otolith using laser ablation-ICPMS. A 250 µg subsample from the core of the second otolith from each fish was obtained using a micromill; a core subsample of this mass represents otolith carbonate deposited during age-0. The core subsample from the second otolith from each fish was analyzed for stable oxygen and carbon isotope ratios ($\delta^{18}O$ and $\delta^{13}C$) using a ThermoFinnigan Delta plus XP isotope ratio mass spectrometer interfaced with a Gas Bench II carbonate analyzer. Previously established relationships between water and otolith Sr:Ca and water and otolith $\delta^{18}O$ for Asian carps were used to characterize expected otolith Sr:Ca and $\delta^{18}O$ signatures for fish that originated in the Illinois, Missouri, and Mississippi rivers and for fish that used floodplain lake habitats during their early life history. Sr:Ca, $\delta^{18}O$ and $\delta^{13}C$ of the otolith core (which reflects early life history) were used to infer natal environment for individual fish. Changes in Sr:Ca across sectioned otoliths were used to assess timing and long-term patterns of inter-river movement for individual fish.

Water samples were collected from the Illinois River (Alton and LaGrange reaches and the upper river), five of its floodplain lakes, the upper and middle Mississippi River, and the lower Missouri River during June, August, and October 2010, 2011, 2012, and 2013 to verify persistence of distinct water chemical signatures among these locations that were observed in prior studies. Water samples were analyzed for Sr:Ca and stable oxygen isotope ratio ($\delta^{18}O$).

**Results and Discussion:** Water chemistry data continue to indicate that Sr:Ca is consistently higher in the middle Mississippi and Missouri rivers compared to the Illinois River, thus enabling use of this marker as an indicator of fish that have immigrated into the Illinois River from these other rivers. The water $\delta^{18}O$ signature of floodplain lakes frequently differs from that of the Illinois River, enabling use of $\delta^{18}O$ as a marker of Asian carp use of floodplain lake habitats during early life, although flooding can temporarily eliminate the distinct water $\delta^{18}O$ signature of connected floodplain lakes during some years.

Two hundred two adult Asian carp (59 silver carp, 70 bighead carp, 73 hybrids) collected from the Illinois River during 2012-2013 were analyzed for $\delta^{18}O$ and $\delta^{13}C$ of the otolith core. All fish identified as bighead carp based on external morphology were confirmed to be bighead carp based on genetic analysis; all hybrids had initially been identified as silver carp based on external morphology. Only 5% of the fish analyzed had otolith core $\delta^{18}O$ and $\delta^{13}C$ signatures indicative of use of floodplain lake habitats during early life, consistent with data from prior years. Limited evidence for use of floodplain lake habitats during early life may be due to the limited number and connectivity of floodplain lakes along the Illinois River or recent floods that may have temporarily eliminated the distinct signature of connected floodplain lakes. Our data indicate that most adult Asian carp in the Illinois River used river channel habitats during their first year of life, suggesting that low-velocity, near-shore areas within the river represent the predominant nursery habitat for larval and young juvenile Asian carp. Collection of some adult fish in the upper river that had used floodplain lake habitat during age-0 suggests that these fish immigrated from downriver where most of the floodplain lakes occur.

Otoliths from adult Asian carp collected from the Illinois River during 2012-2013 were also analyzed for Sr:Ca to determine river-of-origin. Forty seven percent of adult silver carp and 52% of hybrids had otolith core (first 10 µm of laser transect) Sr:Ca signatures indicative of Illinois River origin. Using otolith core Sr:Ca data, we estimated that 28-53% of adult silver carp and 26-48% of hybrids in the Illinois River were immigrants that originated in the middle Mississippi or Missouri Rivers (the range in our estimate of the percentage of immigrants reflects some uncertainty in our statistical model used to assign natal environment to individual fish). We have also observed (based on changes in Sr:Ca across sectioned otoliths) several silver carp and hybrids that entered, exited, and re-entered the Illinois River from the Mississippi River at multiple times during their life. Our estimates of percent immigrants for silver carp and hybrids were slightly higher than the estimated contribution of immigrants to the Illinois River adult silver carp stock in 2010-2011 (11-39% immigrants). Among silver carp and hybrids that were immigrants to the Illinois River, the vast majority originated in the middle Mississippi River; only 2-8% of the total number of silver carp and hybrids captured in the Illinois River originated in the Missouri River. The percentage of immigrants to the Illinois River declined from downstream to upstream reaches of the Illinois River for both silver carp and hybrids. Estimates of percent immigrants for silver carp and hybrids combined ranged from 41-75% for the Alton reach, 29-41% for the LaGrange reach, and 3-25% for the upper river. These results suggest that dams may reduce the replenishment rate of the Asian carp stock in the upper Illinois River by immigrants from the Mississippi River if control efforts are successful in reducing Asian carp abundance in the upper Illinois River. In contrast to silver carp and hybrids, otolith core Sr:Ca indicated that 91-98% of bighead carp analyzed originated in the Illinois River, with 2% originating in the middle Mississippi River, consistent with data from prior years.

**Recommendations:** Our results indicate that Asian carp stocks in the Illinois River are primarily supported by recruitment from within the Illinois River itself, suggesting that control efforts should continue to focus on the Illinois River. However, the substantial percentage of silver carp and hybrids that immigrate into the Illinois River continues to suggest that sustainable control of silver carp in the Illinois River will likely require expanding control (e.g., commercial harvest) efforts for this species to include the middle Mississippi River. Whether the higher percentage of immigrant silver carp in the Illinois River compared to prior years is at least partly due to enhanced commercial harvest or if this simply represents natural year-to-year variation is presently unclear; monitoring to determine the principle natal environments of Asian carp in the Illinois River during future years could be used to assess whether control efforts reduce recruitment of Asian carps within the Illinois River.

# CHAPTER 9

## Nutrient composition of Asian Carp harvested from the Illinois River

**Goal:** Determine the proximate and fatty acid composition of Asian carp, compositional plasticity with respect to harvest season and location, and shelf stability of Asian carp sourced from various reaches of the Illinois River in order to determine the best end-uses for meals rendered from these fish.

**Justification:** Identification of markets with great profit potential will incentivize Asian carp fishing efforts and increase the effectiveness of market-driven approaches to control Asian carp populations. A variety of potential end-uses for Asian carp have been identified, including rendering into protein meals for use as animal feedstocks, fertilizers, etc. Rendered carp meals would be similar to marine-derived fish meals, and like these products, would have lower- and higher-value uses depending on their composition. The primary determinants of fish meal/oil quality are nutrient content and composition, contaminant levels, and oxidative stability. These measures are known to vary in marine rendered products by species, season/year, and geographic location of harvest. In order to determine the ideal marketing strategies for carp products, it is necessary to quantify the pertinent compositional variability of the raw material.

**Research Approach:** Silver and bighead carps are being seasonally harvested from the Illinois River, pulverized, and processed to determine total moisture, lipid, protein, and ash content of the carcasses, as well as fatty acid composition of the lipid fraction. Subsamples of the processed carcasses are also being monitored for production of oxidative metabolites (indicators of spoilage) during refrigerated storage.

**Abstract:** To date, we have quantified the proximate and fatty acid composition of silver carp harvest in the Fall of 2010 from the Alton, La Grange, Peoria, and Starved Rock reaches of the Illinois River (see Tables 8-1 and 8-2). Bighead carp appear to be less abundant than silver carp and were only caught in the La Grange and Peoria reaches during the Fall 2010 sampling season. In general, the proximate composition of silver carp (~7-25% lipid, 55-60% protein, 15-25% ash) appears to be quite suitable for rendered into protein meals for livestock feeds. Bighead carp appear to be slightly leaner than silver carp harvested from most regions (5-8% lipid, 65% protein, 24-27% ash), but would also be quite suitable for rendering into protein meals for livestock feeding. Although the ash content of these feeds is higher than what is typically reported for marine-origin fish meals, higher levels of bioavailable calcium and phosphorus might make Asian carp meals particularly attractive for plant-based aquafeeds, wherein these two macrominerals are typically limiting. The fatty acid composition of silver and bighead carp also suggests that aquaculture feeds would be an appropriate, high-value end use for rendered carp meal: Although the total lipid content of Asian carp is lower than those species typically sourced for rendering, the composition of the carp lipid is on par with most marine-origin protein and lipid ingredients (20-25% long-chain polyunsaturated fatty acids).

**Contact:** Jesse Trushenski, Assistant Professor Southern Illinois University Carbondale, 618/536-7761, saluski@siu.edu

**Publications (Appendix):**

Bowzer, J., Trushenski, J., and Glover, D. C. (2013): Potential of Asian Carp from the Illinois River as a Source of Raw Materials for Fish Meal Production, North American Journal of Aquaculture, 75:3, 404-415.

Bowzer, J., Bergman, A., and Trushenski, J. (2014) Growth Performance of Largemouth Bass Fed Fish Meal Derived from Asian Carp, North American Journal of Aquaculture, 76:3, 185-189, DOI: 10.1080/15222055.2014.893473

Bowzer, J., Trushenski, J., Rawles, S., Gaylord, T. G., & Barrows, F. T. (2014). Apparent digestibility of Asian carp-and common carp-derived fish meals in feeds for hybrid striped bass Morone saxatilis♀× M. chrysops♂ and rainbow trout Oncorhynchus mykiss. *Aquaculture Nutrition*.

Bowzer, J. and Trushenski, J. (2015) Growth Performance of Hybrid Striped Bass, Rainbow Trout, and Cobia Utilizing Asian Carp Meal-Based Aquafeeds, North American Journal of Aquaculture, 77:1, 59-67, DOI: 10.1080/15222055.2014.960117

Bowzer, J. and Trushenski, J. (2015) The Potential of Asian Carp as a Raw Material for Fish Meal Production. *Sustainable Aquaculture Digital*. In press.

Table 9.1. Proximate composition (means ± SE) of whole silver and bighead carps collected from reaches of the Illinois River Fall 2010.

| Location & Species | % DM | % Moisture | Lipid (%) | Ash (%) | Protein (%) | TL (mm) |
|---|---|---|---|---|---|---|
| Alton S | 25.6 ± 0.7 | 74.4 ± 0.7 | 11.7 ± 2.0 | 26.8 ± 1.1 | 54.8 ± 0.9 | 568 ± 16.9 |
| La Grange S | 25.5 ± 0.4 | 74.5 ± 0.4 | 17.8 ± 1.1 | 21.8 ± 0.3 | 60.0 ± 0.8 | 472 ± 6.0 |
| Peoria S | 21.7 ± 0.4 | 78.3 ± 0.4 | 7.1 ± 0.6 | 25.2 ± 1.1 | 65.7 ± 1.2 | 400 ± 12.3 |
| Starved Rock S | 27.5 ± 0.8 | 72.5 ± 0.8 | 25.0 ± 1.8 | 15.5 ± 0.7 | 55.0 ± 1.3 | 564 ± 30.8 |
| La Grange B | 20.9 ± 0.5 | 79.1 ± 0.5 | 7.9 ± 1.3 | 26.9 ± 0.9 | 67.1 ± 1.2 | 813 ± 14.1 |
| Peoria B | 18.3 ± 2.3 | 81.7 ± 2.3 | 4.9 ± 2.9 | 24.2 ± 0.8 | 66.0 ± 2.6 | 441 ± 19.0 |

S=silver carp

B=bighead carp

Table 9.2. Fatty acid composition (means ± SE) of silver and bighead carps collected from reaches of the Illinois River in the Fall of 2010.

| | Reach & Species | | | | | |
|---|---|---|---|---|---|---|
| | Alton S | La Grange S | Peoria S | Starved Rock S | La Grange B | Peoria B |
| Total SFA | 32.0 ± 0.8 | 31.6 ± 0.2 | 32.6 ± 0.4 | 28.2 ± 0.3 | 32.2 ± 0.6 | 32.1 ± 0.3 |
| Total MUFA | 32.2 ± 2.1 | 30.5 ± 0.4 | 24.7 ± 0.6 | 36.7 ± 1.2 | 29.3 ± 1.2 | 25.9 ± 2.3 |
| Total PUFA | 35.9 ± 1.6 | 37.8 ± 0.5 | 42.7 ± 0.5 | 35.1 ± 0.5 | 38.5 ± 0.7 | 42.0 ± 2.0 |
| Total MC-PUFA | 10.2 ± 0.4 | 13.3 ± 0.3 | 11.8 ± 0.5 | 11.0 ± 0.4 | 9.3 ± 0.4 | 9.3 ± 0.3 |
| Total LC-PUFA | 21.7 ± 1.6 | 21.0 ± 0.4 | 26.9 ± 0.5 | 18.2 ± 0.6 | 27.0 ± 1.1 | 30.3 ± 2.5 |
| (n-3):(n-6) | 4.0 ± 0.2 | 5.2 ± 0.1 | 4.6 ± 0.1 | 5.4 ± 0.1 | 3.2 ± 0.2 | 3.6 ± 0.0 |

S=Silver carp

B=Bighead carp

# CHAPTER 10

## Potential Contaminants in Asian Carps of the Illinois River

**Goal:** To determine if concentrations of selected contaminants in Asian carp from the Illinois River meet regulatory tolerances and guidelines for commerce as food and value-added products, and recreational fish consumption advisories.

**Justification:** Determining the safety of Asian carp for consumption by humans and food animals is critical to the development of a commercial market.

**Research Approach:** We used accepted fisheries techniques to capture edible flesh samples of 15 fish of each species from each of 4 pools for comparisons. We also received samples from 27 ground fish provided by colleagues (Trushenski/Bowzer) to examine contaminant concentrations in whole fish relative to fillets; and additional 10 samples collected in 2011 will be analyzed. All samples were analyzed by an accredited chemistry laboratory.

**Abstract:** Efforts to control invasive bighead (*Hypophthalmichthys nobilis*) and silver carp (*H. molitrix*) may include harvest for human consumption. We measured concentrations of arsenic (As), mercury (Hg), and selenium (Se) in fillets from silver and bighead carp collected from the lower Illinois River, Illinois, USA, to determine whether concentrations were of health concern and differed by species, size, and location. Concentrations of total As were below detection limits in most bighead (92%) and silver (77%) carp fillets, whereas inorganic As was below detection limits in all samples. Mean Hg concentrations were greater in bighead (0.068mgkg(-1)) than in silver carp (0.035mgkg(-1)), and were smallest in carp from the confluence of the Illinois and Mississippi rivers. Mercury concentrations in fillets were positively correlated with body mass in both species. Concentrations of Hg were below the US Food and Drug Administration's (USFDA) action level (1ppm as methyl-Hg); however, concentrations in some bighead (70%) and silver (12%) carp fell within the range that would invoke a recommendation to limit meals in sensitive cohorts. Mean Se concentrations were greater in silver (0.332mgkg(-1)) than in bighead (0.281mgkg(-1)) carp fillets, and were below the 1.5mgkg(-1) limit for an unrestricted number of meals/month. The mean molar ratio of Se:Hg in fillets was lower in bighead (14.0) than in silver (29.1) carp and was negatively correlated with mass in both species Concentrations of Hg in bighead and silver carp fillets should be considered when assessing the risks associated with the use of these species as a protein source.

**Publications (Appendix):**

**Levengood, J. M., Soucek, D. J., Dickinson, A., Sass, G. G., & Epifanio, J. M. (2013). Spatial and interspecific patterns in persistent contaminant loads in bighead and silver carp from the Illinois River. *Ecotoxicology*, *22*(7), 1174-1182**.

**Contact:** Jeff Levengood, IL Natural History Survey, University of Illinois, 1816 S Oak St, Champaign, IL 61820. 217/333-6767

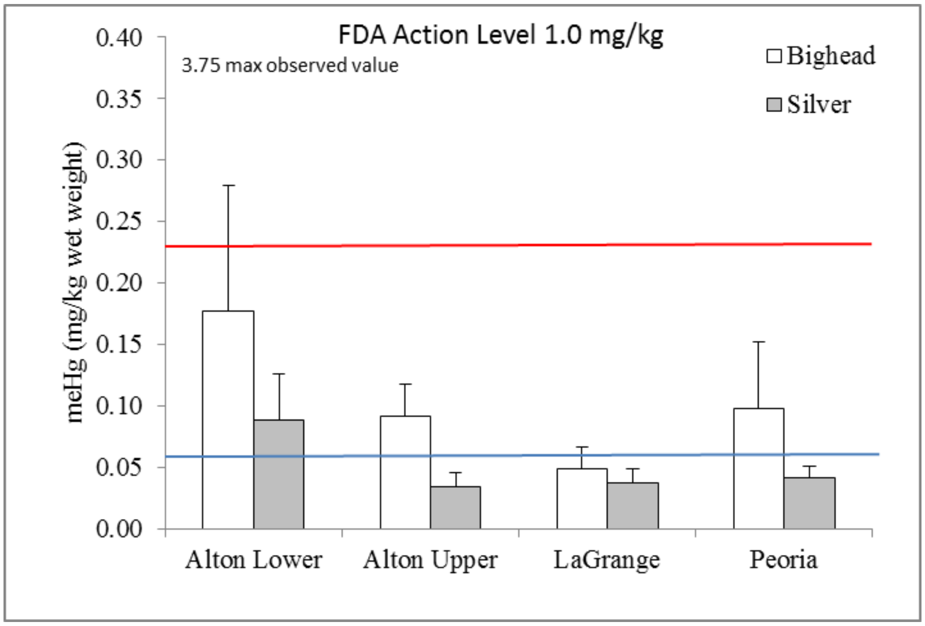


Figure 10.1. Methylmercury concentrations in fillets of Asian carps from 3 pools on the Illinois River, 2010. The blue line represents the threshold above which the most sensitive groups (women of child-bearing age and children 15 years old and younger) are advised to limit consumption to 1 meal/week. The red line represents the threshold above which the most sensitive groups (women of child-bearing age and children 15 years old and younger) are advised to limit consumption to 1 meal/month. The FDA Action Level represents the concentration at which the agency will take legal action to remove the product from the market. Sample sizes are n= 15 per species/pool.

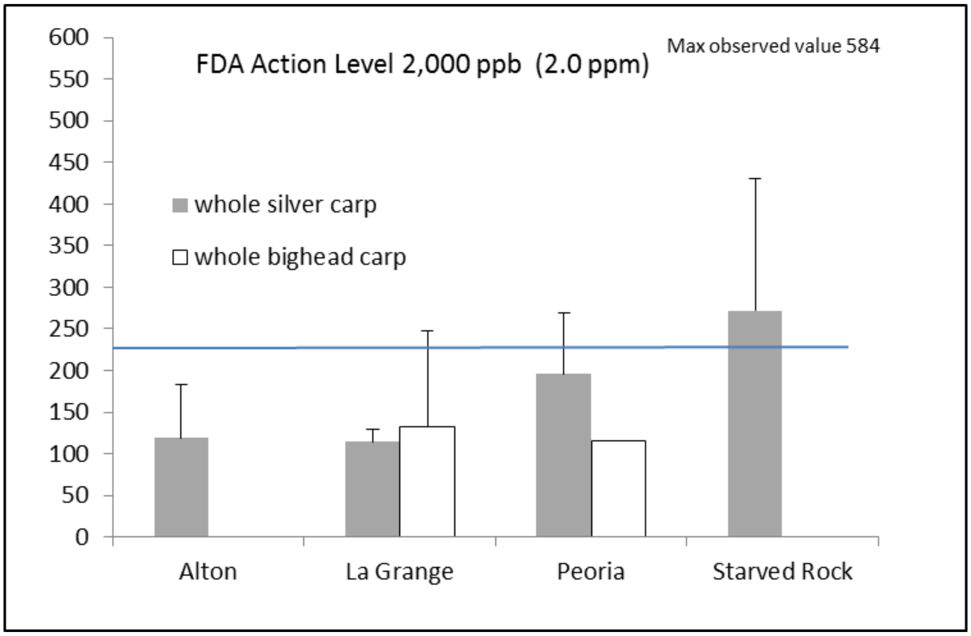


Figure 10-2. Total PCB concentrations in sample of ground, whole Asian carps from 4 pools on the Illinois River, 2010. The blue line represents the threshold above which the most sensitive groups (women of child-bearing age and children 15 years old and younger) are advised to limit consumption to 1 meal/month. The FDA Action Level represents the concentration at which the agency will take legal action to remove the product from the market. Samples size are n= 5 except n= 2 for bighead carp from Peoria pool.

# CHAPTER 11

## Increasing Commercial Harvest to Reduce Density-Dependent Effects and Movement of Asian Carp

**Goal:** Hosting a summit that brings together experts and stakeholders to explore the opportunities for and impediments to commercial harvesting of Asian carp.

**Justification:** When considering the past and present management efforts for Asian carp, one strategy that has not received widespread attention is the potential for marketing these fish commercially. Because Asian carp are relative newcomers to our waters, there has been limited effort by commercial entities in the Mississippi Basin. Likewise, because creating commercial markets to control unwanted species such as Asian carp is a non-traditional management approach, there are few examples of this strategy for managers to follow. In short, both entities are “starting from scratch.” This summit allowed for an understanding of the various issues by all stakeholders including potentially conflicting motivations and goals.

**Research Approach:** The summit was held at the Great Rivers Research and Education Center, which is located at the confluence of the Illinois, Missouri and Mississippi rivers in Grafton, IL. A summit advisory group (SAG) was established to help identify the pertinent stakeholders and to develop the agenda of the 2-day meeting, which ultimately consisted of a mixture of presentations on current state of knowledge and facilitated break-out sessions to allow for in-depth exploration of the topic. Proceedings from the summit were published and made available to the summit participants and the general public.

**Abstract:** The Asian Carp Marketing Summit brought together experts from eight states including representatives from restaurants, commercial fishing, processing and related businesses, as well as agencies, and academic institutions. Planned as a forum for stakeholders to identify obstacles and opportunities associated with commercial marketing of Asian carp as a way to reduce their numbers in the Mississippi River Basin, the summit fostered development of a thriving expert network and efforts are on track to turn the conclusions reached at the summit into action.

At the summit, participants agreed that high-value Asian carp fillets marketed to restaurants and retailers may provide the financial incentive for extensive harvesting of these fish. Looking to have immediate impact, they also recommended that whole fish be exported in high numbers to Asian markets, where these species are already popular food fish. Finally, they recommended converting Asian carp by-products into pet food or treats to eliminate waste and maximize profit opportunities. The Illinois departments of Natural Resources (IDNR) and Commerce and Economic Opportunity (DCEO) are now developing programs to help further these goals.

**Contact:** Patrice M. Charlebois, AIS Coordinator, Illinois-Indiana Sea Grant. Ph: 847-242-6441. Email: charlebo@illinois.edu.

# CHAPTER 12

## Marketing of Asian Carp

**Goal:** The goal of this project is to estimate the potential market size for Asian carp for human consumption, both as a restaurant product and for at home consumption. The size of the potential market is an important determinant of the value of the fish and it affects the net costs of the eradication efforts.

**Justification:** Though there are sporadic and isolated efforts to introduce the Asian Carp to the American consumer, particularly on the part of Chefs, a comprehensive evaluation of the market potential for the fish has never been conducted. In particular, there is no understanding of what the potential barriers to widespread consumption of Asian carp are, what preconceptions about this fish exist, what information would help in the marketing efforts for the carp, and what forms of preparation of the fish are acceptable to the public.

**Abstract:** Since a substantial portion of US consumers' fish expenditures occur at restaurants (see for example Food and Agricultural Commodity Consumption in the United States: Looking Ahead to 2020. By Biing-Hwan Lin, Jayachandran N. Variyam, Jane Allshouse, and John Cromartie, Food and Rural Economics Division, Economic Research Service, U.S. Department of Agriculture, Agricultural Economic Report No. 820), we followed a double pronged approach. We developed a survey of consumers to obtain information on the marketability of Asian Carp, and we interviewed chefs to ascertain their degree of interest in the fish and their concerns. A survey of the relevant literature was completed and a theoretical model (neophobia towards new foods was used to analyze the survey data. This is the first national survey on the attitudes of US fish consumers towards Asain carp. Contrary to the negative connotation attached to carp, most participants were willing to try a free sample of Asian carp. We also found that people would be willing to pay for it. The second approach was the Chef's component. We visited with Chefs at Kendall College's Culinary School in Chicago where they prepared carp and relayed their thoughts about the fish. Their main concerns were related to the contaminants in the carp, but they were enthusiastic about the invasivore aspect of the project. This suggests that emphasizing the low levels of contaminants of the fish will be very important for the restaurant market. In addition, Chef Philippe Parola visited Carbondale in early September 2011 and gave a demonstration on cooking the carp to community members and SIU students.

**Publication (Appendix):**

**Varble, S., & Secchi, S. (2013). Human consumption as an invasive species management strategy. A preliminary assessment of the marketing potential of invasive Asian carp in the US. *Appetite*, *65*, 58-67.**

**Contact:** Silvia Secchi, Assistant Professor, Southern Illinois University Carbondale, (618)453-1714, E-mail: ssecchi@siu.edu

Appendix 1

**Asian Carp Fish Meal Report:**

**Paul Hitchens**

**REPORT DATE: 3/4/13:**

**I. 3/4/13:**

**A. A. Current Stock of fish meal at Pinckneyville storage facility :**

| Ship Date | Delivery Date | PO# | Lbs shipped |
|---|---|---|---|
| 12/28/11 | 12/29/11 | 37498-0-7370 | 15,160 lbs (WITHOUT stabilizer added) on 9 skids BOL# 37498 |
| 02/20/12 | 02/21/12 | 103162 | 37,020 lbs Asian Carp WITH stabilizer on 14 skids on BOL# 37826 |
| 02/27/12 | 02/28/12 | 103162 | 30,860 lbs Asian Carp WITH stabilizer on 12 skids on BOL# 37881 |
| | | Total = | **83,040 Lbs.** |
| 12/6/12 | 12/7/12 | FSLC | **8,080 Lbs.** Shipped to Zeigler for Feed Preparation (from 2/28/12 delivery = Bag #'s 4, 5, & 8) |

*** 3/4/13** = Jim Berzinski, Carterville will pick up all remaining stock of carp meal = 83,040 Lbs or 41.5 Tons. Will pay 41 tons @ $350/ton = **$14,350** to SIU. Will bring check when pick up 1st load at the end of this week. Analysis of both stabilized & non-stabilized carp meal samples checked out fine(protein level = 60%).

**Total Remaining in Stock = 83,040 Lbs.**

**B. A. Current Stock of Zeigler Fish Feed with carp meal at Pinckneyville storage facility :**

| Ship Date | Delivery Date | Lbs shipped | # Pallets | Number of Bags | # Tons |
|---|---|---|---|---|---|
| 1/31/13 | 2/1/13 | 32,720 lbs | 17 | 818 | 16.36 |

- **1/31/13:** Meeting with Timpner Farm & Waeltz Farms to organize production trials in both farms for feed tesing on HSB cage culture. Explained procedures and objectives of study.
- Bags will be split up between the two HSB producers (Timpner Farm & Waeltz Farms) for production testing this starting this spring.
- Control bags for production tests have not arrived from Zeigler to date.

**II. 2/12/13: Gray Magee, Grafton - Progress Report**

1. Plan on construction of plant this March 2013.
2. Will produce fish meal only.
3. In connection with Caterpillar group in Peoria & Falcon Protein Products.
4. Will be no odor or waste.
5. Estimated production figures of 15,000,000 Lbs. of carp meal/year.
6. Will be able to process 50-60,000 Lbs./day.
7. Will E-Mail letter with further update to me & Dr. Garvey.
8. Interested in buying carp meal & will send sample for analysis.

**III. 2/13/13:**

1. Mailed Gray Magee samples for analysis.

**IV. 2/13/13:**

1. Phone conversation with Rick Smith@ **Big Rivers** concerning USDA Asian carp certification for USAID/FAS project. Retrieved data on whole fish prices, shipping, supplies, etc. Production figures from 2012
   a. Big Head & Silver = **3,110,000**

**V. 2/13/13:**

1. Called Jeff Gay for results on carp meal analysis and progress on purchasing of excess carp meal in Pinckneyville freezer unit = Does not want to buy any, due to age of the product.

**VI. 2/13/13:**

1. Phone conversation with Jill Rendleman concerning carp meal for fertilizer. Discussed price & amount for sales. Needs organic only & sample for analysis. Concern of stabilizer & excessive heat.

**VII. 2/14/13:**

1. Called Jeff Gay for results on carp meal analysis and data on processing for maximum temperatures, stabilizer ingredient, etc. for fertilizer sales.
2. Stabilizer = Ethoxyquin @ 500 ppm(I Lb./Ton) & T= 275 F.
   a. Dissipates out over time. Probably none left in product.
   b. Commonly used in Pet Foods.

**VIII. 2/15/13:**

1. Called Maschhoff for possible carp meal sale. Want sample.

**IX. 2/15/13:**

1. Phone conversation with Mike Schafer @ **Schafer Fisheries** concerning USDA Asian carp certification for USAID/FAS project. Retrieved data on processed & value added fish prices, shipping, supplies, etc. Production figures from 2012:
    a. Big Head = 1,740,045
    b. Silver = 4,382,461
    c. Grass Carp = 338,949
    d. Common Carp = 1,833,226
    **e.** Total = **8,294,681**

**X. 2/15/13:**

1. Meeting with Jill Rendleman at farm for sample delivery & sales possibilities/price.

**XI. 2/18/13:**

1. Mailed Maschhof samples for analysis.

**XII. 2/18/13:**

1. Called Jim Berzinski for possible carp meal sale in hog diets.
2. Want sample. Will meet @ freezer tomorrow to promote product & collect samples.

**XIII. 2/19/13:**

1. Met Berzinski @ freezer in P'Ville to promote product & collect samples.
2. Interested in buying all for $350/ton if analysis verifies quality. Waiting results.

**XIV. 2/20/13:**

1. Phone conversation with Rick Smith @ Big Rivers. Low fishing month for January, as Lisa McKee is out of commission from heart attack suffered over holidays. Is recovering, but slowly. Actual Lbs. of product purchased will have to wait until she gets back.
2. Griggsville packing plant is should be ready to receive product in March or April, 2013.

**XV. IATS Carp Sales for February 2013 Report = 1/31/13 through 2/28/13 :**

1. Coordinated 3 carp shipments for food fish sales to 1 Toronto buyer/hauler with Big Rivers:
2. Channel Catfish = 0 Lbs. @ $1.00/Lb.
3. Common Carp (Live) = 2,056 Lbs. @ $0.70/Lb.
4. Buffalo Carp (Live) = 0Lbs. @ $0.90/Lb.
5. Big Head (On Ice) = 11,177 Lbs. @ $0.35/Lb.
6. Grass Carp (On Ice) = 2,056 Lbs. @ $0.55/Lb.
7. Total Asian carp sold = **13,233 Lbs.**
8. Total Lbs. sold through IATS = **15,109 Lbs.**
9. IATS will receive $0.05/Lb. on brokerage fees.

APPENDIX II

PUBLICATIONS TO FOLLOW:

Bowzer, J. and Trushenski, J. (2015) Growth Performance of Hybrid Striped Bass, Rainbow Trout, and Cobia Utilizing Asian Carp Meal-Based Aquafeeds, North American Journal of Aquaculture, 77:1, 59-67, DOI: 10.1080/15222055.2014.960117

Bowzer, J. and Trushenski, J. (2015) The Potential of Asian Carp as a Raw Material for Fish Meal Production. *Sustainable Aquaculture Digital*. In press.

Bowzer, J., Bergman, A., and Trushenski, J. (2014) Growth Performance of Largemouth Bass Fed Fish Meal Derived from Asian Carp, North American Journal of Aquaculture, 76:3, 185-189, DOI: 10.1080/15222055.2014.893473

Bowzer, J., Trushenski, J., and Glover, D. C. (2013): Potential of Asian Carp from the Illinois River as a Source of Raw Materials for Fish Meal Production, North American Journal of Aquaculture, 75:3, 404-415.

Bowzer, J., Trushenski, J., Rawles, S., Gaylord, T. G., & Barrows, F. T. (2014). Apparent digestibility of Asian carp-and common carp-derived fish meals in feeds for hybrid striped bass Morone saxatilis♀× M. chrysops♂ and rainbow trout Oncorhynchus mykiss. *Aquaculture Nutrition*.

Levengood, J. M., Soucek, D. J., Dickinson, A., Sass, G. G., & Epifanio, J. M. (2013). Spatial and interspecific patterns in persistent contaminant loads in bighead and silver carp from the Illinois River. *Ecotoxicology*, *22*(7), 1174-1182.

Tsehaye, I., Catalano, M., Sass, G., Glover, D., & Roth, B. (2013). Prospects for fishery-induced collapse of invasive Asian carp in the Illinois River. *Fisheries*,*38*(10), 445-454.

Varble, S., & Secchi, S. (2013). Human consumption as an invasive species management strategy. A preliminary assessment of the marketing potential of invasive Asian carp in the US. *Appetite*, *65*, 58-67.

# Prospects for Fishery-Induced Collapse of Invasive Asian Carp in the Illinois River

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**ABSTRACT:** *Invasive Asian Carp are threatening to enter Lake Michigan through the Chicago Area Waterway System, with potentially serious consequences for Great Lakes food webs. Alongside efforts to keep these fishes from entering Lake Michigan with electric barriers, the state of Illinois initiated a fishing program aimed at reducing their densities through intensive commercial exploitation on the Illinois River. In this study, we explore prospects for the "collapse" of Asian Carp in the Illinois River through intensive fishing. Based on a meta-analysis of demographic data, we developed a dynamic simulation model to compare the performance of existing and alternative removal strategies for the Illinois River. Our model projections suggest that Asian Carp in the Illinois River are unlikely to collapse if existing harvest rates are kept below 0.7 or fishing continues to be size selective (targeting only fish >500 mm or <500 mm) or species selective (targeting mostly Bighead Carp), although their biomasses could be greatly reduced. We argue that it would still be possible to achieve fishing effort targets predicted by our model to collapse the Asian Carp populations if efforts to expand commercial fishing are combined with economic incentives to improve size selectivity and species targeting.*

## Prospectos de un colapso inducido por pesca en la carpa asiática del Río Illinois

**RESUMEN:** . *La carpa asiática amenaza con invadir el Lago Michigan a través del sistema de vías acuáticas del área de Chicago, lo cual podría acarrear serias consecuencias en las tramas tróficas de los grandes lagos. Además de los esfuerzos llevados a cabo para impedir el ingreso de estos peces al Lago Michigan mediante barreras eléctricas, el estado de Illinois ha iniciado un programa de pesca en el Río Illinois, cuya finalidad es reducir la densidad poblacional a través de una pesca comercial intensiva. En este estudio se exploran los prospectos de un colapso de la carpa asiática por medio de un régimen de pesca intensiva. Sobre la base de un meta-análisis de datos demográficos, se desarrolla un modelo de simulación dinámica para comparar el desempeño de estrategias de explotación tanto reales como alternativas para el Río Illinois. Las proyecciones del modelo sugieren que, de mantenerse las tasas de captura por debajo de 0.7 o si la pesca continua siendo selectiva a tallas (dirigiéndose a peces >500 mm o <500 mm) o a especies (carpa cabezona), entonces es poco probable colapsar la carpa asiática en el Río Illinois, aunque la biomasa se puede reducir considerablemente. Se argumenta que, pese a lo anterior, es posible lograr el nivel de esfuerzo pesquero predicho por el modelo, necesario para colapsar las poblaciones de la carpa asiática, si la pesca comercial se expande y se combina con incentivos económicos con tal de mejorar la selectividad a la talla y a las especies objetivo.*

## INTRODUCTION

Invasive species have long been recognized as a major cause of decline of native freshwater species and loss of biodiversity worldwide, with biological invasions and associated economic and ecological effects growing annually (Vitousek et al. 1997; Lodge et al. 2006; Jelks et al. 2008). At current invasion rates, nonnative species are predicted to have the most adverse effects on biodiversity in freshwater ecosystems in the next century (Sala et al. 2000). Given the serious threat that biological invasions pose to ecosystem structure and function, management agencies have developed control programs to reduce abundance or limit spread of invasive species into new systems (Lodge et al. 2006; Keller et al. 2007, 2008). For example, the National Park Service has developed a Lake Trout (*Salvelinus namaycush*) suppression program in Yellowstone Lake with the aim to rehabilitate native Cutthroat Trout (*Oncorhynchus clarkii bouvieri*; Syslo et al. 2011). Similarly, the Great Lakes Fishery Commission has implemented a binational integrated pest management program in the Great Lakes to control invasive Sea Lamprey (*Petromyzon marinus*), thereby allowing recovery of native fishes impaired by their predation (Jones et al. 2009). Because future biological invasion rates are predicted to increase (Lodge et al. 2006), similar large-scale removals of invasive species are likely to be considered for many other ecosystems (Kolar and Lodge 2002).

With many of its native populations already imperiled by nonnative species, the Laurentian Great Lakes face a new threat of invasion from Bighead Carp (*Hypophthalmichthys nobilis*) and Silver Carp (*H. molitrix*), highly efficient filter-feeding species collectively known as Asian Carp (Chapman and Hoff

2011). In light of evidence of global Asian Carp introductions leading to decreased fish diversity and abundances, an Asian Carp invasion of the Great Lakes is feared to adversely affect native populations, with potentially serious consequences for aquatic food webs and a fishing industry valued at $7 billion annually (Schrank et al. 2003; Irons et al. 2007; Southwick Associates, Inc. 2008; Sampson et al. 2009). Asian Carp were first introduced into North America in the early 1970s to control algae in aquaculture and municipal wastewater treatment facilities (Kelly et al. 2011). Shortly thereafter, they escaped confinement and established naturally reproducing populations in the Mississippi River (Chick and Pegg 2001). Since that time, their abundance has increased exponentially, and both species have migrated up the Mississippi River and its tributaries (Sass et al. 2010; Chapman and Hoff 2011; Irons et al. 2011). There are now dense populations of both species throughout the Illinois River, threatening to enter Lake Michigan through the Chicago Area Waterway System (Cooke and Hill 2010; Sass et al. 2010; Cudmore and Mandrak 2011).

Given political resistance to closure of navigation locks on the Chicago Area Waterway System, management agencies are trying to prevent invasion of the Great Lakes by Asian Carp with electric barriers built on the Chicago Sanitary and Ship Canal (Moy et al. 2011). However, these barriers may not be 100% effective at repelling Asian Carp; traces of environmental DNA have been detected in Lake Michigan, and a live Bighead Carp was captured beyond the barriers in June 2010 (Jerde et al. 2011; Mahon et al. 2011). Along with the use of electric barriers, the state of Illinois has recently developed a fishing program aimed at reducing Asian Carp densities through intensive commercial exploitation on the Illinois River, with the ultimate goal being to minimize propagule pressure on the electric barriers (Garvey et al. 2012). Pursuant to this program, the Illinois Department of Commerce and Economic Opportunity signed an agreement in 2010 to export 13.6–22.7 million kg of Asian Carp annually to the People's Republic of China, where they have more commercial value than in North America (Garvey et al. 2012). Although commercial exploitation is expected to lead to a substantial reduction in Asian Carp biomass, the fishing program was developed without adequate understanding of Asian Carp population dynamics, which is essentially a prerequisite for the development of an effective fishing policy.

Garvey et al. (2006) performed a yield-per-recruit analysis for Asian Carp in the upper Mississippi River and found that high exploitation rates targeting small (<200 mm) individuals would be required to reduce abundance by 50%. However, their analysis did not account for density-dependent effects on recruitment and uncertainty in demographic parameters, such as growth and natural mortality. In this study, we obtained improved estimates of demographic parameters with reduced uncertainties using a meta-analysis of multiple data sets on key life history characteristics of Asian Carp in the Illinois and middle Mississippi rivers. We then developed a dynamic simulation model to compare the effectiveness of various harvest policies at reducing Asian Carp biomass in the Illinois River. Finally, we explored exploitation rates necessary to "collapse" these populations and examined how size- and species-selective harvesting may affect efficacy of these removals.

## METHODS

### Population Dynamics

We assessed the population dynamics of Silver (SC) and Bighead Carp (BC) using hierarchical Bayesian meta-analyses of life history data collected from the Illinois and middle Mississippi rivers. The data were obtained from all known published and unpublished studies of SC and BC population dynamics in these systems (Table 1). The life history characteristics examined were longevity, natural mortality, growth, maturity, and the strength of compensatory density dependence in recruitment.

Longevity was assumed to be the age of the oldest individual in our data, which were derived from pectoral fin spine readings. Natural mortality ($M$) rates were estimated using four methods, including catch curve analysis (Chapman and Robson 1960) and three empirical methods relating natural mortality to demographic and/or environmental parameters (Pauly 1980; Hoenig 1983; Jensen 1996). Growth parameters ($L_\infty$, $K$, $t_0$, $\sigma^2$) were estimated by fitting hierarchical Bayesian von Bertalanffy growth models to individual length–age data from eight studies for each species, with study treated as a random effect:

$$L_{a,i} = L_{\infty,i}\left(1 - e^{-K_i(a_i - t_{0,i})}\right)\varepsilon_{a,i}, \qquad (1)$$

where $L_{\infty,i}$ is the asymptotic length (mm) for study $i$, with each study representing a unique combination of investigator, year, and location; $K_i$ is the growth coefficient, $t_{0,i}$ is the time at zero length; and $\varepsilon_{a,i}$ are age- and study-specific random errors representing individual variation in length at age. We assumed that $L_{\infty,i}$ and $K_i$ were independent and log-normally distributed across studies. For both parameters, we assumed uninformative log-normal priors (mean = 0; $\sigma^2 = 1.0 \times 10^6$). The data sets we used were uninformative on $t_0$ because few observations of age-1 fish existed, and Asian Carp grow rapidly in their first year. This lack of information resulted in unrealistically high $L_\infty$ and unrealistically low $K$ estimates. Thus, we allowed an informative prior on $t_{0,i}$. The prior was based on the mean and variance of estimates found on fishbase.org (SC: $n = 6$, mean = −0.067 years, $\sigma = 0.027$; BC: $n = 5$, mean = 0.042, $\sigma = 0.049$), which were mostly from studies within the native range of these species. Probability of maturity ($m_i$) was estimated as a function of fish length by fitting Bayesian binomial logit models to pooled female SC and BC maturity data from three studies conducted in the Illinois River:

$$\text{logit}(m_i) = C_0 + C_1 L_i, \qquad (2)$$

where $L_i$ is the observed total length (mm) of a female fish $i$, $C_0$ is the intercept, and $C_1$ is the slope. Length at 50% maturity was determined as $-C_0/C_1$. Observed maturity (1 = mature, 0 = immature) was determined from macroscopic visual inspection and the gonadosomatic index (100 × Ovary weight/Ovary-free

Table 1. Summary of data sets used for analyses of Silver and Bighead Carp life history parameters. Each data set represents a unique combination of investigator, year, and river reach. River abbreviations are as follows: IR = Illinois River, MMR = Middle Mississippi River. The sample size (*N*; number of fish examined) is indicated for each study.

| Species | Analyses | Investigator | Year | River (reach) | *N* |
|---|---|---|---|---|---|
| SC | Growth and natural mortality | 1 | 2004 | IR (Alton) | 26 |
| | | 1 | 2005 | IR (Alton) | 49 |
| | | 2 | 2010 | IR (Alton) | 102 |
| | | 2 | 2010 | IR (La Grange) | 287 |
| | | 2 | 2010 | IR (Peoria) | 233 |
| | | 2 | 2010 | IR (Starved Rock) | 14 |
| | | 4 | 2007 | IR (La Grange) | 145 |
| | | 5 | 2003 | MMR (Pool 27) | 147 |
| | Maturity | 3 | 2008 | IR (La Grange) | 187 |
| | | 1 | 2004 | IR (Alton) | 31 |
| | | 1 | 2005 | IR (Alton) | 20 |
| BC | Growth and natural mortality | 1 | 2004 | IR (Alton) | 78 |
| | | 1 | 2005 | IR (Alton) | 78 |
| | | 6 | 1998 | MMR (Pool 27) | 32 |
| | | 6 | 1999 | MMR (Pool 27) | 4 |
| | | 2 | 2010 | IR (Peoria) | 2 |
| | | 1 | 2004 | MMR (Pool 27) | 2 |
| | | 6 | 1998 | MMR (Pool 26) | 12 |
| | | 6 | 1999 | MMR (Pool 26) | 8 |
| | Maturity | 3 | 2008 | IR (La Grange) | 80 |
| | | 1 | 2004 | IR (Alton) | 81 |
| | | 1 | 2005 | IR (Alton) | 33 |

Investigators: 1. K. Baerwaldt, unpublished, Southern Illinois University; 2. D. Glover and J. Garvey, unpublished, Southern Illinois University (Garvey et al. 2012); 3. E. Trone, unpublished, Illinois River Biological Station, Illinois Natural History Survey; 4. LTRMP, Illinois River Biological Station, Illinois Natural History Survey (USGS 2012); 5. C. Williamson and D. Garvey (Williamson and Garvey 2005); 6. M. Nuevo, R. J. Sheehan and P. S. Wills (Nuevo et al. 2004).

fish weight). Females were assumed mature if the gonadosomatic index exceeded 1%, a cutoff consistent with macroscopic observations on a subset of individuals. Our analysis was based on data collected from May to August because BC gonads become very small in winter and hence are difficult to detect. Pooled data were used for maturity analysis because only three studies were available and few observations of immature fish existed for two of the data sets. All Bayesian models (growth, maturity, and catch curve) were fit using Markov chain Monte Carlo simulation using a Gibbs sampler as implemented in WinBUGS (Spiegelhalter et al. 2004). Posterior distributions of parameters were assessed after 500,000 Markov chain Monte Carlo samples and a burn-in period of 20,000, with a thinning interval of 100 samples. Convergence was assessed with the Gelman-Rubin statistic and by inspecting trace plots.

The strength of compensatory density dependence in recruitment is typically assessed by fitting stock–recruitment relationships to recruit and spawner abundance data. However, data on BC and SC in the Illinois and Mississippi rivers were not sufficient to estimate stock–recruitment relationships. Therefore, we obtained estimates of Ricker's stock–recruitment (Ricker 1954) parameters for SC and BC based on the strength of compensatory density dependence in recruitment drawn from a published meta-analysis of stock–recruit data from 208 commercially exploited fish stocks (Myers et al. 1999). More specifically, stock–recruitment parameters for SC and BC were calculated using empirical relationships that predict Ricker stock–recruitment parameters from maximum lifetime reproductive rate ($\hat{\alpha}$) adjusted for the expected lifetime spawner biomass per recruit of a population at carrying capacity (unfished) equilibrium (Walters and Martell 2004). Probability distributions of stock–recruitment parameters were obtained by calculating Ricker's $\alpha$ and $\beta$ for each of the maximum reproductive rates drawn by sampling with replacement (i.e., bootstrapping) from the meta-analysis estimates of $\hat{\alpha}$ for the 208 species. A measure of interannual recruitment variation ($\sigma_R^2$) and associated uncertainty was obtained by resampling with replacement from meta-analysis estimates of $\sigma_R^2$ for 54 commercially exploited marine fish stocks (Goodwin et al. 2006).

**Simulation Model**

To evaluate the performance of alternative exploitation rates at achieving removal targets, we constructed an age-structured dynamic simulation model that forecasted biomass and harvest of SC and BC over a 25-year time horizon in the Illinois River under different fishing scenarios. We used 10% of unfished biomass as a removal target, below which the population was considered to have collapsed (Worm et al. 2009). At 10%

of unfished biomass, recruitment is presumed to be severely reduced, and a population would no longer play a substantial ecological role (Worm et al. 2009).

Numerical recruitment to the first age-class was generated separately for each species from a Ricker stock–recruitment relationship, which included stochasticity to allow for interannual recruitment variation. The average unfished recruitment was set at an arbitrary value of 1.0 because (1) the absolute magnitude of abundance for these species was unknown for the Illinois River and (2) population scaling was not relevant to our analysis because we evaluated the effects of proportional removals on relative changes in biomass. For each species, numbers at age after recruitment were calculated over time using an accounting equation of the form:

$$N_{a+1,t+1} = N_{a,t} e^{-M} (1 - v_a U), \qquad (3)$$

where $e^{-M}$ is survival in the absence of fishing mortality, $v_a$ is age-specific vulnerability to fishing, and $U$ is time-invariant annual exploitation rate. Biomass at age was obtained by multiplying abundances by an estimate of mean individual mass at age, which was calculated as a power function of length at age obtained from the literature (Irons et al. 2007).

By incorporating $U$ and $v_a$ into the accounting equation, the simulation model allowed us to evaluate changes to the Asian Carp populations under different combinations of (a) exploitation rates (0.5 to 0.9 in 0.1 increments) and (b) vulnerability schedules (all size classes fully targeted by the fishery, only fish >500 mm targeted or only fish <500 mm targeted). We assumed that vulnerability of each species to harvest was determined solely by their respective length at age relative to the target size threshold (i.e., 500 mm) and not by any other inherent characteristic of the species (e.g., locations relative to fishing areas, commercial value). Populations of both species were modeled separately over time and aggregate Asian Carp biomass was calculated by summation. Initial species composition was assumed to be 82% SC and 18% BC based on their relative biomasses in the 2006–2010 collections of the Long Term Resource Monitoring Program (LTRMP; U.S. Geological Survey 2012) from the La Grange Reach of the Illinois River and Pool 26 of the Mississippi River. Finally, because no data existed to inform whether current population size has reached equilibrium or what current Asian Carp population size is relative to system carrying capacity, we evaluated population responses to fishing assuming that initial (i.e., current; 2012) Asian Carp biomass was (a) already at carrying capacity equilibrium; (b) 75% of carrying capacity equilibrium; and (c) 50% of carrying capacity equilibrium. The most recent biomass estimates from the three lower reaches (Peoria, La Grange, and Alton) of the Illinois River were 1,075 MT (95% confidence interval = 950–1,200 MT) for SC and 338 MT (95% confidence interval = 298–377 MT) for BC based on over 3,423 km of hydroacoustics transects, which represented about 0.39% of total river volume (Garvey et al. 2012).

We accounted for uncertainty in Asian Carp population dynamics when evaluating the performance of alternative harvest strategies by repeating the 25-year simulations for 1,000 combinations of (a) stock–recruitment parameters, (b) maturity, (c) natural mortality, and (d) growth parameters, which were taken from the Bayesian posterior distributions or bootstrapped samples of parameters from the demographic analyses and literature values. For each of the 1,000 simulated time series, we computed proportional change in biomass by dividing initial biomass (i.e., year 1) by the final biomass (i.e., year 25). The distribution of proportional biomass change across the 1,000 simulations was evaluated for each fishing scenario. The probability of collapse was then computed as the percentage of simulations in which final biomass was less than 10% of the initial. For each fishing scenario, we visually inspected time series plots of biomass to determine the number of years needed to cause population collapse.

Data from LTRMP suggest that SC constitute a larger proportion of Asian Carp biomass in the Illinois River (Sass et al. 2010). Therefore, in the absence of species-selective fishing, the response to fishing of the aggregate Asian Carp population is expected to more closely resemble the SC response to fishing. However, harvest data from the Illinois Department of Natural Resources suggest that existing fish targeting strategies are more selective toward BC than SC, with BC catches comprising nearly 90% of current commercial harvest of Asian Carp (Irons et al. 2007). The preference for BC may be due to their larger size, easier capture (i.e., trammel netting and gill netting), or perhaps a higher value. Thus, to mimic existing fisheries, we ran an additional set of simulations assuming that BC of a given age were twice as vulnerable to existing fishing methods compared to SC. These scenarios allowed for an evaluation of the efficacy of commercial removals if current species targeting practices persisted into the future.

## RESULTS

### Population Dynamics

Maximum age (longevity) estimates of wild SC and BC from outside of North America suggest that these species can reach ages of 7 to 16 years (Johal et al. 2001; Kolar et al. 2007). Despite sufficient time since colonization (late 1980s–early 1990s), the oldest fish observed in our data set were 7 years old for both species, which is close to the maximum observed age from the Mississippi River basin (Schrank and Guy 2002; Nuevo et al. 2004; Williamson and Garvey 2005). Although pectoral fin spine readings may have underestimated maximum age, this would have a minimal effect on our estimates of population dynamics parameters. Other life history parameter estimates differed between the two species (Table 2). SC reached a smaller asymptotic length than BC, but both species approached asymptotic length at nearly the same rate (Table 2). BC reached maturity at a larger size than SC, with their length at 50% maturity much higher than that for SC (Table 2). Differences in size at maturity and length at age resulted in substantial differences in maturity at age between the two species. We estimated that 38% (±20%) of age-2 and 61% (±20%) of age-3 SC were mature, whereas 3% (±4%) of age-2 and 21% (±15%) of age-3 BC

Table 2. Growth and maturity parameter and natural mortality estimates (and associated uncertainties) from meta-analyses of Bighead and Silver Carp population dynamics in the Illinois and Middle Mississippi Rivers.

| Species | Analysis | Variable | Expected value | Median | Lower 95% confidence interval | Upper 95% confidence interval | SE |
|---|---|---|---|---|---|---|---|
| SC | Growth | $L_\infty$ | 802.826 | 793.700 | 628.663 | 1,020.050 | 98.150 |
| | | $K$ | 0.445 | 0.435 | 0.255 | 0.702 | 0.109 |
| | | $t_0$ | −0.230 | −0.232 | −0.351 | −0.115 | 0.062 |
| | | $\sigma_l$ | 0.103 | 0.103 | 0.098 | 0.107 | 0.002 |
| | Maturity | $C_0$ | −6.226 | −6.104 | −9.158 | −3.734 | 1.410 |
| | | $C_1$ | 0.011 | 0.011 | 0.008 | 0.016 | 0.002 |
| | | $L_{50\%}$ | 545.341 | 548.399 | 483.881 | 590.915 | 27.452 |
| | Natural mortality | $M$ | 0.684 | 0.654 | 0.298 | 1.258 | 0.255 |
| | | Pauly | 0.363 | 0.310 | 0.093 | 0.930 | 0.226 |
| | | Hoenig | 0.733 | 0.652 | 0.243 | 1.642 | 0.402 |
| | | Jensen | 0.667 | 0.652 | 0.383 | 1.053 | 0.164 |
| | | CC | 0.984 | 0.975 | 0.778 | 1.241 | 0.121 |
| | Length–weight | $a$* | $5.082 \times 10^{-6}$ | NA | NA | NA | NA |
| | | $b$* | 3.122 | NA | NA | NA | NA |
| | Stock–recruitment | α | 19.152 | 6.716 | 0.605 | 128.51 | 45.940 |
| | | β | 2.829 | 1.313 | 0.181 | 17.205 | 5.582 |
| BC | Growth | $L_\infty$ | 982.938 | 983.250 | 890.170 | 1,086.025 | 49.071 |
| | | $K$ | 0.433 | 0.418 | 0.304 | 0.668 | 0.087 |
| | | $t_0$ | −0.015 | −0.012 | −0.202 | 0.178 | 0.097 |
| | | $\sigma_l$ | 0.104 | 0.103 | 0.094 | 0.115 | 0.005 |
| | Maturity | $C_0$ | −15.859 | −15.770 | −21.762 | −10.290 | 2.902 |
| | | $C_1$ | 0.020 | 0.020 | 0.013 | 0.028 | 0.004 |
| | | $L_{50\%}$ | 784.562 | 785.749 | 762.082 | 802.780 | 10.454 |
| | Natural mortality | $M$ | 0.654 | 0.631 | 0.293 | 1.244 | 0.239 |
| | | Pauly | 0.333 | 0.281 | 0.093 | 0.868 | 0.203 |
| | | Hoenig | 0.723 | 0.632 | 0.236 | 1.653 | 0.396 |
| | | Jensen | 0.650 | 0.626 | 0.456 | 1.001 | 0.131 |
| | | CC | 0.885 | 0.875 | 0.680 | 1.110 | 0.114 |
| | Length–weight | $a$* | $1.452 \times 10^{-5}$ | NA | NA | NA | NA |
| | | $b$* | 2.952 | NA | NA | NA | NA |
| | Stock–recruitment | α | 21.476 | 6.035 | 0.538 | 121.422 | 119.224 |
| | | β | 3.272 | 1.333 | 0.190 | 14.897 | 16.797 |
| Both | Recruitment | $\sigma_R$ † | 0.542 | 0.500 | 0.230 | 1.240 | 0.233 |

Parameter symbols: $L_\infty$ = asymptotic length; $K$ = growth coefficient; $t_0$ = time at zero length; $\sigma_l$ = standard deviation in length at age (log scale); $C_0$ = maturity intercept; $C_1$ = maturity slope; $L_{50\%}$ = length at 50% maturity ($-C_0/C_1$); $M$ = instantaneous natural mortality rate (average of four methods); $a$ = length–weight coefficient; $b$ = length–weight exponent; α = initial slope of Ricker stock–recruitment relationship; β = density-dependent parameter of stock–recruitment relationship; $\sigma_R$ = standard deviation of recruitment variability (log scale).

*Irons et al. (2007)

†Goodwin et al. (2006)

were mature. Instantaneous natural mortality rate, given as an average of estimates from the four methods, did not vary much between the two species (Table 2). Given these estimates of mortality, maturity, and von Bertalanffy growth parameters for each species, median Ricker parameters were estimated at $\alpha$ = 6.716 and $\beta$ = 1.313 for SC and $\alpha$ = 6.035 and $\beta$ = 1.333 for BC.

**Population Response to Fishing**

Although population responses to fishing were predicted to be highly variable due to high uncertainty in life history parameters for both species (especially in stock–recruitment parameters), underlying trends were evident. In general, model predictions indicated that exploitation rates must be maintained at considerably high levels to collapse the aggregate Asian Carp population. However, higher exploitation rates are required to cause the SC population to collapse, which is attributable to their earlier maturity and smaller length at age, resulting in lower overall vulnerability to fishing in the size-selective scenarios (Figure 1). When all age classes were assumed to be fully vulnerable to harvest, the SC and BC populations had a 60% and 68% probability of collapse at exploitation rates of 0.7 and 0.6, respectively (Figure 1), and the aggregate population had a 65% probability of being reduced to 10% or less of its initial biomass at an exploitation rate of 0.7. Under size-selective harvesting that targeted either small (<500 mm) or large (>500 mm) Asian Carp, both populations were less likely to collapse at an exploitation rate of 0.7, with the probability of collapse for the aggregate population estimated at 25% (Figure 1). Given the relative body sizes of SC and BC, targeting smaller fish was predicted to have stronger effects on SC than BC. With initial biomasses below carrying capacity, both SC and BC populations would continue to increase if subjected to low levels of exploitation targeting only small or large fish (e.g., when only

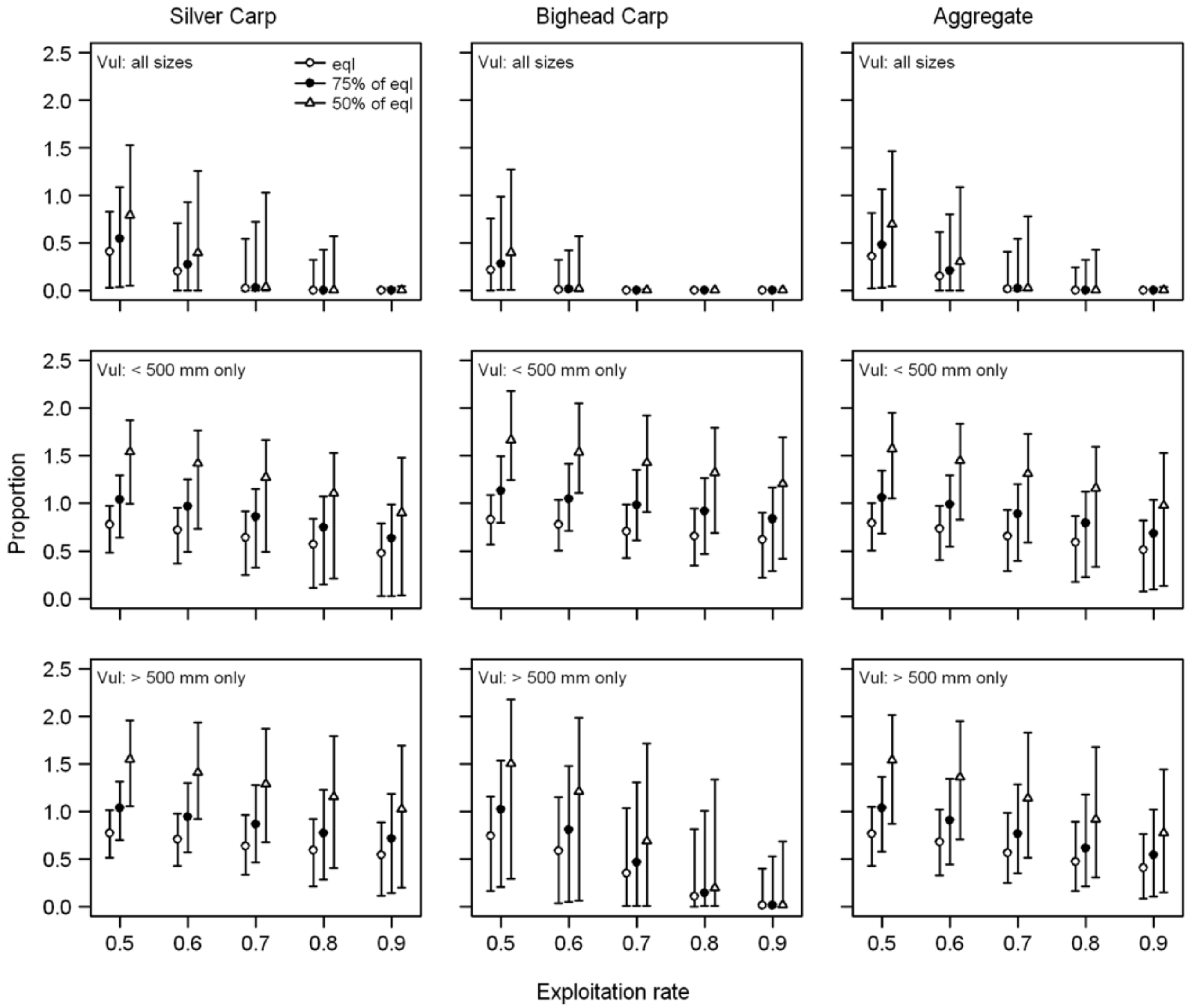


**Figure 1. Proportions (median, first, and third quartiles) of initial biomass remaining at year 25 for Silver Carp, Bighead Carp, and the aggregate Asian Carp population in the Illinois River as a function of exploitation rate under different vulnerability schedules (all size classes fully targeted, only fish >500 mm targeted and only fish <500 mm targeted) and assumptions of current population size relative to population size at carrying capacity (population at carrying capacity equilibrium, eql; population at 75% of carrying capacity equilibrium, 75% of eql; and population at 50% of carrying capacity equilibrium, 50% of eql).**

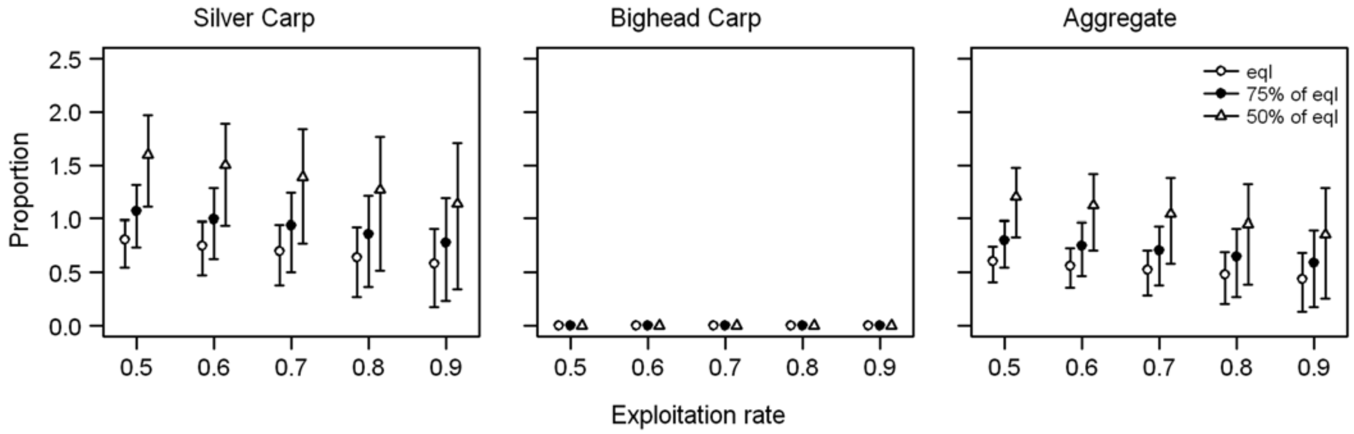


Figure 2. Proportions (median, first, and third quartiles) of initial biomass remaining at year 25 for Silver Carp, Bighead Carp, and the aggregate Asian Carp population in the Illinois River as a function of exploitation rate, assuming all size classes were equally targeted, but Bighead Carp are twice as vulnerable to existing fishing methods as Silver Carp, and under different assumptions of current population size relative to population size at carrying capacity equilibrium (population at carrying capacity equilibrium, eql; population at 75% of carrying capacity equilibrium, 75% of eql; and population at 50% of carrying capacity equilibrium, 50% of eql). (Note that all exploitation rates are in relation to aggregate population size, not individual population size; initial species composition was 82% Silver Carp and 18% Bighead Carp.)

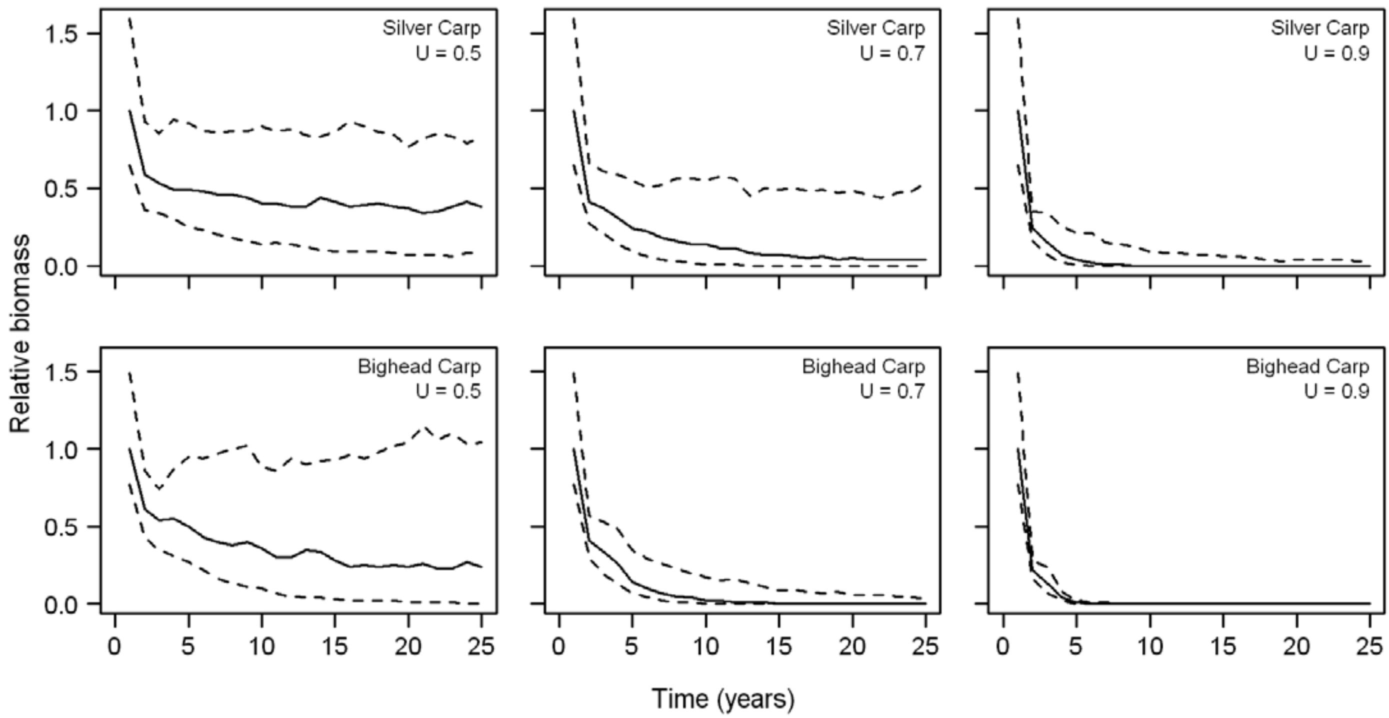


Figure 3. Silver and Bighead Carp biomass trajectories (median, first, and third quartiles) under different levels of exploitation rate (U; 0.5, 0.7, and 0.9), assuming all sizes were fully vulnerable to fishing.

fish >500 mm were targeted and $U = 0.5$; Figure 1). If all sizes were assumed fully targeted, both populations would decrease from their initial biomasses irrespective of assumptions of initial population size relative to carrying capacity.

Our results indicated that even at an exploitation rate that would collapse the BC population with a probability of almost 100%, the aggregate Asian Carp biomass could on average be reduced to at most 50% of the initial biomass, with probability of collapse less than 25% (Figure 2). Although predicted population responses to fishing varied between the two species, biomass projections indicated that the largest population responses to fishing occurred during the first few years (1–5 years after initial harvesting), with biomass stabilizing in subsequent years (Figure 3).

## DISCUSSION

Previous studies based on the LTRMP and fishery-dependent data suggest that both Asian Carp populations in the Illinois River have increased considerably in recent years (Chick and Pegg 2001; Sass et al. 2010; Irons et al. 2011). The SC population has experienced exponential growth since 2000, with the subadult and adult population size in the La Grange Reach of the Illinois River estimated at 2,500 fish per kilometer river length in the late 2000s (Sass et al. 2010). Although information on population growth of BC is limited, Illinois commercial harvest of this species suggests exponential population growth since the 1990s (Irons et al. 2007). With the exception of information on body condition of adult Asian Carp (mass at length) being lower than historically reported (Garvey et al. 2012), no data existed to inform what current Asian Carp population size might be relative to system carrying capacity. Thus, unless an effective control program is put in place, it is possible that Asian Carp densities in the Illinois River will continue to increase and raise the threat of invasions of the Great Lakes.

Although operating models have been used for several exploited fish stocks to develop policies that objectively account for uncertainty in key fishery parameters (Walters and Martell 2004), few invasive species control programs have followed a model-based evaluation of alternative removal strategies. In this study, we developed a simulation model for SC and BC that explicitly accounted for uncertainty in key demographic parameters when comparing the performance of alternative harvest polices at reducing Asian Carp biomass in the Illinois River. Based on our model predictions and evidence of Asian Carp collapse elsewhere, including in their native Yangtze River (Li et al. 1990), we argue that it may be possible to collapse the SC and BC populations in the Illinois River if efforts to expand commercial fishing of Asian Carp are combined with economic incentives to capture a wider range of fish sizes and increase targeting of SC. Our predictions showed that targeting all size classes of Asian Carp was the most effective strategy at achieving removal targets, which is consistent with results from the equilibrium yield-per-recruit analysis by Garvey et al. (2006). Although our simulation results suggested that targeting only small or large individuals would decrease the probability of achieving removal targets, size-selective fishing is the strategy that is most likely to be implemented in practice; indeed, targeting larger-sized Asian Carp is the strategy that has been proposed by the commercial fishing industry (Garvey et al. 2012). Small Asian Carp are less desirable because of their lower commercial value under current market conditions. In addition, harvest of smaller individuals could be economically less viable due to higher rates of bycatch and fouling in the smaller-mesh gears used to catch these sizes. Thus, to improve the effectiveness of existing fishing practices, strong economic incentives will be required to encourage less size-selective fishing. Economic incentives to target small fish may come from increased use of Asian Carp for fish meal, liquid fertilizer, and/or fish oil products. To test the effectiveness of such a strategy, Southern Illinois University actually initiated a pilot fishing program encouraging fishers by providing monetary incentives to harvest up to 1.36 million kg of Asian Carp of all sizes to be converted to fish meal (Garvey et al. 2012). Similar to our suggestions for improving Asian Carp removals from the Illinois River, changing the size selectivity of fishing was also recommended to increase the efficacy of Lake Trout suppression strategies in Yellowstone Lake, where targeting mature Lake Trout or undeveloped embryos was predicted to yield better outcomes (Syslo et al. 2011).

Due to their higher reproductive rate and larger population size, a higher exploitation rate would be required to achieve desired removal targets for SC than for BC. Thus, continued concentration of fishing effort on BC (for their market value or ease of capture) will undermine the prospects for achieving desired removal targets. Therefore, just as for improving size selectivity of fishing, the stronger economic incentive to target BC needs to be reversed to achieve the level of fishing effort needed to collapse the aggregate Asian Carp population, possibly through offering incentives to harvest more SC. Overall, the species- and size-selective nature of existing Asian Carp fisheries highlights the need to realign economic incentives with fishery management goals to improve the prospects for the collapse of Asian Carp in the Illinois River.

Though our Asian Carp simulation model could serve as a valuable management tool for simulating the consequences of management decisions for SC and BC removals from the Illinois River, the process of evaluating population responses to fishing could also help identify areas of critical uncertainty in the population dynamics and/or fisheries of Asian Carp. For example, our analysis showed that recruitment dynamics were a critical source of uncertainty in predicting Asian Carp population responses to fishing. Only one study to date has published a stock–recruitment relationship for Asian Carp (Hoff et al. 2011). However, the Hoff et al. (2011) study was based entirely on catch-per-effort data, which cannot be used directly for assessing recruitment dynamics without knowledge of differences in catchability among adults and recruits. It was for this reason that we employed a literature-based approach to obtain estimates of Ricker stock–recruitment parameters. Unsurprisingly, our approach resulted in a high degree of uncertainty, which appropriately reflected our level of understanding of the recruitment dynamics of these species in the Mississippi River basin.

Finally, though our population model could already be used to develop effective removal policies for the Illinois River, it could also be readily adapted to allow for the development of temporally or spatially explicit fishing policies by incorporating information on temporal and spatial distribution of Asian Carp in the river. While information on spatial distribution of Asian Carp could allow managers to improve the efficacy of existing removal strategies by directing fishing and other control efforts toward areas of fish aggregations, data on interannual variability in fish abundance could be used to vary fishing effort seasonally in order to improve removal impacts. Indeed, there are ongoing studies to gather information on the spatial and temporal distributions of Asian Carp in the Illinois River, including hydroacoustic and telemetry studies to quantify Asian Carp movement from the adjacent Mississippi River into the Illinois River and reconstruct their interannual patterns of distribution (DeGrandchamp et al. 2008; Garvey et al. 2012). By allowing us to evaluate the effectiveness of various harvest location and timing scenarios, such additional information from recent and ongoing studies could be used to develop more refined removal policies, thereby improving the prospects for the collapse of Asian Carp in the Illinois River.

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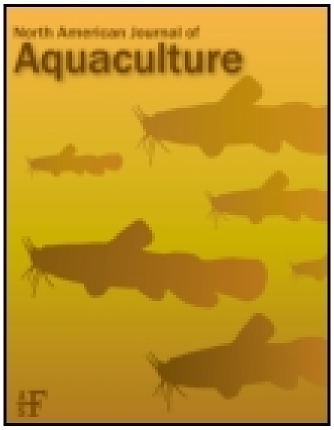
**From the Archives**

I have stated enough to show the prospects before us in the way of increasing, to an almost unlimited degree, the food resources of our country, and in rendering the productiveness of our waters, in this respect, superior, acre to acre, to that of land. Of course, time and expenditure of money will be required, but the larger the scale of operations the sooner and more effectually the result will be accomplished. There is also something still to be done by the United States in the way of extending the area of cultivation of lobsters, crabs, oysters, etc., if not by actual planting on a larger scale, yet by making the necessary experiments and supplying detailed instruction for the work. It is not impossible, indeed, that the great Salt Lake and other interior bodies of saline waters may be made the nurseries of objects such as those mentioned above.

*Spencer F. Baird (1873): National Fish Culture, Transactions of the American Fisheries Society, 2:1, 25-32.*



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# Growth Performance of Hybrid Striped Bass, Rainbow Trout, and Cobia Utilizing Asian Carp Meal-Based Aquafeeds

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ARTICLE

# Growth Performance of Hybrid Striped Bass, Rainbow Trout, and Cobia Utilizing Asian Carp Meal-Based Aquafeeds

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*Abstract*
**Fish meal sparing is more difficult for nutritionally demanding carnivorous fishes, but economic considerations and the limited supply of fish meal continue to incentivize investigations of alternative protein sources for aquafeeds. A promising alternative to traditional, marine-origin fish meal is fish meal derived from undesirable freshwater species, such as the invasive Asian carp *Hypophthalmichthys* spp. To assess the relative value of such ingredients, we evaluated growth performance of juvenile hybrid Striped Bass (White Bass *Morone chrysops* × Striped Bass *M. saxatilis*; initial weight, 21.9 ± 0.2 g [mean ± SE]), Rainbow Trout *Oncorhynchus mykiss* (15.1 ± 0.2 g), and Cobia *Rachycentron canadum* (57.2 ± 0.5 g) reared for 8 weeks on practical diets containing different levels of menhaden fish meal (MFM), Asian carp meal (CFM), or a 50:50 blend of these ingredients such that 0, 20, 40, or 60% of the estimated digestible protein content was derived from fish meal. Growth performance was generally consistent across taxa, and weight gain tended to increase with fish meal inclusion, regardless of its origin. However, Cobia did perform better on CFM-based diets, suggesting that MFM or CFM can yield improved performance for some taxa or life stages, but these differences are likely to be marginal in most circumstances. We conclude CFM is a suitable and perhaps lower-cost alternative to MFM in feeds for carnivorous fishes.**

Feed accounts for a substantial portion of overall operating costs (40–50%) for intensive aquaculture facilities (Cheng et al. 2004). Protein is typically the most expensive component of animal feed, and this is particularly problematic in aquafeeds because fish have a much higher protein demand compared with other livestock (Keembiyehetty and Gatlin 1992). Historically, fish meal was used as a primary ingredient in aquafeeds because of its high protein density, favorable amino acid profile, and digestibility and palatability to aquatic livestock. However, fish meal inclusion rates have been declining in recent decades (Tacon and Metian 2008; Tacon et al. 2011) because it is considerably more expensive than other alternative plant- and animal-derived protein sources (Gatlin et al. 2007; Welch et al. 2010; FAO 2014). However, sparing fish meal with these alternatives can be particularly difficult for nutritionally demanding carnivorous fishes, which may not readily accept or perform as well on diets with reduced levels or free of fish meal. Fish meal has been the primary protein source for carnivorous species because it generally meets all essential amino acid requirements, is protein dense, and is highly palatable; but, due to the high cost of this ingredient and its overall high inclusion levels in the diets, there are considerable economic incentives to reduce fish meal use in aquafeeds (Watanabe 2002).

A potential alternative to traditional marine-origin fish meal is a freshwater fish meal rendered from invasive species such as Silver Carp *Hypophthalmichthys molitrix* and Bighead Carp *H. nobilis* (hereafter referred to collectively as Asian carp). Asian carp have become particularly abundant in the Mississippi River basin (McClelland et al. 2012; Tsehaye et al. 2013), and since invasive species typically have adverse effects on native populations and economically important activities (Vitousek et al. 1997; Lodge et al. 2006), a variety of control and eradication strategies have been investigated and deployed. Of these, control through increased harvest pressure is a primary focus because it

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is currently the only viable short-term control strategy (Conover et al. 2007). Considerable fishing pressure is needed to successfully control Asian carp in this system (Tsehaye et al. 2013); thus, market research and development have been undertaken to increase the demand for Asian carp (Nelson 2013; Varble and Secchi 2013). However, since Asian carp are not a preferred food fish in the United States, industrial applications, such as rendering into protein meals for livestock feeding, are considered the most promising to incentivize harvest (Conover et al. 2007; Bowzer et al. 2013).

Asian carp meal has several advantages over other alternative protein sources. Utilization of plant-origin (i.e., derivatives of oilseeds or grains) and animal-origin (i.e., by-products of livestock processing) feedstuffs in aquafeeds can be restricted by inadequate nutrient levels, digestibility, or palatability; the presence of antinutritional factors; or practical limitations to inclusion in the diet (e.g., high cost, complications related to feed manufacturing; Glencross et al. 2007). For instance, soybean meal is one of the most promising alternative protein sources (Gatlin et al. 2007), and despite its routine use in aquafeeds (Hendricks 2003) high inclusion levels can result in undesirable effects such as poor palatability (Adelizi et al. 1998), low feed conversion efficiency (Davies and Morris 1997), and gut enteritis (Heikkinen et al. 2006; Iwashita et al. 2008). Fish meals, including Asian carp meal, do not appear to present any of these challenges (Bowzer et al., in press). Furthermore, while most marine fisheries are unlikely to withstand greater fishing pressure (FAO 2012), greater harvest of Asian carp would likely improve the ecological integrity of the Mississippi River basin.

Rendering Asian carp into fish meal may increase demand and associated harvest pressure on these invasive fish, but demand for Asian carp meal is dependent on the product's quality and pricing. Current pricing estimates for Asian carp meal range from US$600–650/metric ton (P. Hitchens, Southern Illinois University Carbondale, personal communication), considerably lower than current pricing for marine-origin fish meal ($1,500–2,000/metric ton: FAO 2014). Additionally, an industry must be established to produce the product to supply the market. Given that, development of large-scale Asian carp meal production facilities has been relatively slow due to initial high risk of investment in a new product and little information regarding its nutritional value, contaminant load, or potential volume until recently. Researchers have begun to fill in many of these data gaps such as establishing that the digestibility of Asian carp meal is comparable to that of other fish meals in aquafeeds (Bowzer et al., in press), and its practical feeding value in Largemouth Bass *Micropterus salmoides* feeds is similar to menhaden fish meal (Bowzer et al. 2014). As this information has become available, interest and investment in Asian carp rendering has increased; a facility specializing in Asian carp meal production recently opened in Grafton, Illinois (Moon 2014). Therefore, Asian carp meal appears to be a promising protein source for aquafeeds, but its utilization by a range of nutritionally demanding carnivorous fish species has yet to be fully determined. Accordingly, we assessed the growth performance of hybrid Striped Bass (White Bass *Morone chrysops* × Striped Bass *M. saxatilis*), Rainbow Trout *Oncorhynchus mykiss*, and Cobia *Rachycentron canadum* fed diets containing different levels of menhaden fish meal (MFM) or Asian carp meal (CFM).

## METHODS

Fish were held in recirculating aquaculture systems with continuous aeration and mechanical and biological filtration units. Trials with hybrid Striped Bass (initial weight, 21.9 ± 0.2 g [mean ± SE]; Keo Fish Farms, Keo, Arkansas) and Rainbow Trout (15.1 ± 0.2 g; Crystal Lake Fisheries, Ava, Missouri) were conducted at the Center for Fisheries, Aquaculture, and Aquatic Sciences (CFAAS) at Southern Illinois University Carbondale, Carbondale, Illinois, while the Cobia (57.2 ± 0.5 g; Troutlodge Marine Farms, Vero Beach, Florida) trial was conducted at the Virginia Seafood Agricultural Research and Extension Center at Virginia Tech, Hampton, Virginia. Stocking density, tank size, system filtration, and water quality for each system are described in Table 1. Water temperature and dissolved oxygen were measured daily (YSI 550 temperature–oxygen meter; Yellow Springs Instruments, Yellow Springs, Ohio), whereas other water quality conditions (total ammonia nitrogen, nitrite-nitrogen, nitrate-nitrogen, alkalinity, and salinity [Cobia trial only]) were measured weekly for each system (Hach DR 2800 portable spectrophotometer, digital titrator, and reagents; Hach Company, Loveland, Colorado). Water quality conditions were maintained within suitable ranges throughout the trials (Table 1).

Practical diets were formulated to meet the known nutritional requirements of hybrid Striped Bass, Rainbow Trout, and Cobia (NRC 2011) and to contain approximately 40:12%, 42:13%, and 45:12% digestible protein : lipid, respectively (Table 2). The diets contained different levels of menhaden fish meal (MFM; Special Select, Omega Protein., Houston, Texas), Asian carp fish meal (CFM; Protein Products, Gainsville, Florida), or a 50:50 blend of these ingredients such that 0% (0 FM), 20% (20 MFM, 20 CFM), 40% (40 MFM, 40 CFM), or 60% (60 MFM, 60 CFM, 60 Blend) of the estimated digestible protein content was derived from a fish meal source. Estimates of digestible protein content were based on apparent digestibility coefficients reported for hybrid Striped Bass and Rainbow Trout (Barrows et al. 2012; Bowzer et al., in press); digestibility coefficients were not available for Cobia; therefore, these feeds were formulated using Rainbow Trout values. Errors were made in the formulation of two diets (10% lipid in 60 MFM diet versus 12% in other diets for Cobia; 45% digestible protein in 60 CFM diet versus 40% in other diets for hybrid Striped Bass). Diets were manufactured and analyzed in triplicate to determine proximate composition (Table 3) using standard methods described in detail by Rombenso et al. (2013). Minor differences resulting from the formulation errors mentioned above and/or inaccuracies in ingredient weighing or mixing were observed; however, these

TABLE 1. Recirculation system characteristics and water quality observed during feeding trials for hybrid Striped Bass, Rainbow Trout, and Cobia. Water quality values represent least-squares means ± SE.

| Parameter | Hybrid Striped Bass | Rainbow Trout | Cobia |
|---|---|---|---|
| Number of tanks[a] | 24 | 24 | 24 |
| Tank volume (L) | 150 | 190 | 300 |
| Stocking density (fish/tank) | 10 | 10 | 10 |
| Biofiltration | Trickle-down biofilter | Trickle-down biofilter | Fluidized bed biofilter |
| Mechanical filtration | Bead filter | Bead filter | Bead filter |
| Aeration | Blower/airstones | Blower/airstones | Blower/airstones |
| Temperature (°C) | 23.6 ± 1.1 | 15.3 ± 1.2 | 26.7 ± 1.1 |
| Dissolved oxygen (mg/L) | 7.7 ± 0.3 | 9.4 ± 0.5 | 6.1 ± 0.5 |
| pH | 7.7 ± 0.1 | 7.9 ± 0.3 | 7.4 ± 0.3 |
| Salinity (‰) | <5 | <5 | 24.4 ± 0.8 |
| Alkalinity (mg/L) | 181 ± 54 | 189 ± 40 | 162 ± 22 |
| $NO_3^-$-N (mg/L) | 15.6 ± 6.5 | 3.8 ± 2.8 | 17.6 ± 7.9 |
| $NO_2^-$-N (mg/L) | 0.04 ± 0.05 | 0.03 ± 0.02 | 0.16 ± 0.08 |
| Total ammonia nitrogen (mg/L) | 0.26 ± 0.15 | 0.12 ± 0.10 | 0.64 ± 0.36 |

[a]Rainbow Trout study used only 24 of 36 tanks in the system.

unintended differences did not appear substantial enough to give rise to differences in growth performance (see Results). Feeds were randomly assigned to triplicate tanks ($N = 3$), and fish were fed assigned diets once daily to apparent satiation for 8 weeks. At the end of each trial, fish were harvested, counted, and group-weighed by tank to assess growth performance in terms of the following metrics:

$$\text{Weight gain (\%)} = 100 \times \frac{\text{average individual final weight} - \text{average individual initial weight}}{\text{average individual initial weight}}$$

$$\text{Feed conversion ratio (FCR)} = \frac{\text{average individual feed consumption (dry matter)}}{\text{average individual weight gain}}$$

$$\text{Specific growth rate (SGR, \% body weight/d)} = 100 \times \frac{\log_e(\text{final individual weight}) - \log_e(\text{initial individual weight})}{\text{d of feeding}}$$

$$\text{Feed intake (FI, \% body weight/d)} = 100 \times \frac{\text{total dry matter intake}/(\text{initial individual weight} \times \text{final individual weight})^{0.5}}{\text{d of feeding}}$$

Three fish per tank were randomly selected and euthanized by an overdose of tricaine methanesulfonate (MS-222; ∼200 mg/L in culture water, fish immersed until opercular ventilation had ceased for 10 min) for individual weighing and dissection to calculate hepatosomatic index (HSI, all taxa) and viscerosomatic index (VSI, hybrid Striped Bass and Rainbow Trout only) as follows:

$$\text{HSI} = 100 \times (\text{liver weight}/\text{whole body weight})$$
$$\text{VSI} = 100 \times (\text{total viscera weight}/\text{whole body weight})$$

Data from each trial were analyzed separately by one-way ANOVA (PROC GLIMMIX) to determine the significance of differences between dietary treatments (SAS version 9.3, SAS Institute, Cary, North Carolina). Tukey's Honestly Significant Differences (HSD) pairwise comparison post hoc tests were used to compare means when omnibus tests indicated significant differences among treatment groups. Additionally, data from the MFM and CFM series (i.e., excluding the 60 Blend and 0 FM) for each study were analyzed by two-way ANOVA (PROC GLIMMIX) to determine the significance of fish meal type and inclusion level as main and interactive effects. When interactive effects were not significant, they were removed from the analysis and only the main effects were tested. All effects were considered significant at $P < 0.05$.

## RESULTS

All diets were well accepted and hybrid Striped Bass, Rainbow Trout, and Cobia performed in a manner generally consistent with our previous experience with these taxa; however, growth performance was observed to vary among dietary treatment groups (Table 4) and was influenced by fish meal type and inclusion level (Table 5), depending on the performance metric and taxon. Survival was 100% in each trial, except for two mortalities in the Cobia trial that were not related to dietary treatment.

Growth of hybrid Striped Bass varied significantly among dietary treatments and was influenced by fish meal inclusion level, but not fish meal type. Results of omnibus tests indicated final weight, weight gain, and SGR were significantly affected by dietary treatment, but pairwise comparisons did not reveal significant differences among dietary treatment groups. Growth was significantly reduced among fish fed diets containing less than 60% fish meal protein. Rainbow Trout growth did not vary significantly among dietary treatments and was not influenced by fish meal type or inclusion level, but numeric trends linking

TABLE 2. Feed formulations (g/kg, on as-fed basis) of diets where 60, 40, 20, or 0% of digestible protein consists of fish meal (Asian carp meal [CFM], menhaden fish meal [MFM], or blend) fed to hybrid Striped Bass, Rainbow Trout, and Cobia.

| Ingredient | 60 MFM | 40 MFM | 20 MFM | 60 CFM | 40 CFM | 20 CFM | 60 Blend | 0 FM |
|---|---|---|---|---|---|---|---|---|
| **Hybrid Striped Bass** | | | | | | | | |
| Menhaden fish meal | 358.7 | 239.2 | 119.6 | 0.0 | 0.0 | 0.0 | 180.0 | 0.0 |
| Asian carp meal | 0.0 | 0.0 | 0.0 | 429.3 | 286.2 | 143.1 | 215.0 | 0.0 |
| Soybean meal | 207.3 | 355.0 | 487.0 | 314.6 | 338.3 | 453.7 | 203.9 | 487.9 |
| Poultry byproduct meal | 67.0 | 120.0 | 190.0 | 135.1 | 152.6 | 232.8 | 80.0 | 399.6 |
| Wheat bran | 275.3 | 186.5 | 98.3 | 47.6 | 137.9 | 75.3 | 239.1 | 16.9 |
| Menhaden fish oil | 62.5 | 70.1 | 75.9 | 44.1 | 55.8 | 65.8 | 52.9 | 66.3 |
| Carboxymethyl cellulose | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |
| Choline chloride | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 |
| Mineral premix | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Vitamin premix | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| Stay C | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Protein (crude) | 460.0 | 474.3 | 491.4 | 551.2 | 497.9 | 507.7 | 475.8 | 531.8 |
| Protein (digestible) | 400.0 | 400.0 | 400.0 | 450.0 | 400.0 | 400.0 | 400.0 | 400.0 |
| Lipid (crude) | 120.0 | 120.0 | 120.0 | 120.0 | 120.0 | 120.0 | 120.0 | 120.0 |
| **Rainbow Trout** | | | | | | | | |
| Menhaden fish meal | 376.7 | 251.1 | 125.6 | 0.0 | 0.0 | 0.0 | 188.3 | 0.0 |
| Asian carp meal | 0.0 | 0.0 | 0.0 | 450.8 | 300.5 | 150.3 | 225.4 | 0.0 |
| Soybean meal | 200.0 | 200.0 | 200.0 | 150.0 | 200.0 | 200.2 | 200.0 | 243.7 |
| Poultry byproduct meal | 183.1 | 318.5 | 453.8 | 160.6 | 281.2 | 435.0 | 155.2 | 560.0 |
| Wheat bran | 91.7 | 85.5 | 79.3 | 108.9 | 83.2 | 78.0 | 90.0 | 55.1 |
| Menhaden fish oil | 69.3 | 65.7 | 62.1 | 50.6 | 56.0 | 57.2 | 62.0 | 62.1 |
| Blood meal | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 |
| Carboxymethyl cellulose | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |
| Choline chloride | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 |
| Mineral premix | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Vitamin premix | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| Stay C | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Protein (crude) | 517.5 | 519.2 | 520.9 | 523.0 | 522.4 | 522.5 | 519.9 | 522.0 |
| Protein (digestible) | 420.0 | 420.0 | 420.0 | 420.0 | 420.0 | 420.0 | 420.0 | 420.0 |
| Lipid (crude) | 130.0 | 130.0 | 130.0 | 130.0 | 130.0 | 130.0 | 130.0 | 130.0 |
| **Cobia** | | | | | | | | |
| Menhaden fish meal | 403.6 | 269.0 | 134.5 | 0.0 | 0.0 | 0.0 | 201.8 | 0.0 |
| Asian carp meal | 0.0 | 0.0 | 0.0 | 483.0 | 322.0 | 161.0 | 242.0 | 0.0 |
| Soybean meal | 164.5 | 263.6 | 408.2 | 158.2 | 287.8 | 370.7 | 137.9 | 358.7 |
| Poultry byproduct meal | 70.0 | 120.0 | 177.1 | 110.0 | 162.0 | 225.2 | 80.0 | 320.0 |
| Wheat bran | 248.6 | 169.7 | 84.1 | 136.8 | 86.3 | 58.2 | 199.6 | 71.1 |
| Menhaden fish oil | 39.2 | 68.5 | 76.9 | 37.8 | 52.7 | 65.6 | 49.5 | 73.9 |
| Soy protein isolate | 45.0 | 80.0 | 90.0 | 45.0 | 60.0 | 90.0 | 60.0 | 147.1 |
| Carboxymethyl cellulose | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |
| Choline chloride | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 |
| Mineral premix | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Vitamin premix | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| Stay C | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Protein (crude) | 507.6 | 517.5 | 532.2 | 543.9 | 547.0 | 550.4 | 522.1 | 556.4 |
| Protein (digestible) | 450.0 | 450.0 | 450.0 | 450.0 | 450.0 | 450.0 | 450.0 | 450.0 |
| Lipid (crude) | 100.0 | 120.0 | 120.0 | 120.0 | 120.0 | 120.0 | 120.0 | 120.0 |

TABLE 3. Analyzed composition (g/kg, on as-fed basis) of diets where 60, 40, 20 or 0% of digestible protein consists of fish meal (Asian carp meal [CFM], menhaden fish meal [MFM], or blend) fed to hybrid Striped Bass, Rainbow Trout, and Cobia.

| Parameter | 60 MFM | 40 MFM | 20 MFM | 60 CFM | 40 CFM | 20 CFM | 60 Blend | 0 FM |
|---|---|---|---|---|---|---|---|---|
| **Hybrid Striped Bass** | | | | | | | | |
| Dry matter | 943.2 | 943.7 | 941.0 | 937.8 | 941.6 | 940.1 | 936.7 | 931.8 |
| Protein (crude) | 447.1 | 456.0 | 474.5 | 574.0 | 491.1 | 491.6 | 472.6 | 525.6 |
| Lipid (crude) | 125.7 | 128.4 | 131.7 | 130.5 | 123.5 | 126.0 | 125.3 | 127.2 |
| Ash | 107.3 | 103.6 | 94.6 | 131.2 | 112.4 | 90.4 | 116.8 | 91.6 |
| **Rainbow Trout** | | | | | | | | |
| Dry matter | 940.1 | 943.2 | 941.0 | 936.7 | 937.8 | 941.6 | 943.7 | 931.8 |
| Protein (crude) | 545.9 | 568.5 | 582.2 | 552.5 | 569.8 | 571.6 | 557.1 | 574.8 |
| Lipid (crude) | 138.4 | 140.5 | 143.9 | 133.4 | 137.4 | 139.1 | 142.4 | 140.7 |
| Ash | 134.1 | 123.6 | 103.8 | 144.8 | 123.2 | 111.4 | 229.7 | 105.1 |
| **Cobia** | | | | | | | | |
| Dry matter | 940.1 | 943.2 | 941.0 | 936.7 | 937.8 | 941.6 | 943.7 | 931.8 |
| Protein (crude) | 545.9 | 568.5 | 582.2 | 552.5 | 569.8 | 571.6 | 557.1 | 574.8 |
| Lipid (crude) | 138.4 | 140.5 | 143.9 | 133.4 | 137.4 | 139.1 | 142.4 | 140.7 |
| Ash | 134.1 | 123.6 | 103.8 | 144.8 | 123.2 | 111.4 | 229.7 | 105.1 |

TABLE 4. Growth performance (final weight, weight gain, SGR, and FCR), FI, HSI, and VSI of hybrid Striped Bass, Rainbow Trout, and Cobia fed diets where 60, 40, 20, or 0% of digestible protein consists of fish meal (Asian carp meal [CFM], menhaden fish meal [MFM], or Blend). Values represent least-squared means; pooled SEs and *P*-values resulting from one-way ANOVA tests are also provided. Letters indicate significant treatment differences ($P < 0.05$).

| Parameter | 60 MFM | 40 MFM | 20 MFM | 60 CFM | 40 CFM | 20 CFM | 60 Blend | 0 FM | Pooled SE | *P*-value |
|---|---|---|---|---|---|---|---|---|---|---|
| **Hybrid Striped Bass** | | | | | | | | | | |
| Initial weight (g) | 21.9 | 22.0 | 21.9 | 21.9 | 22.0 | 21.7 | 22.0 | 21.8 | 0.2 | 0.77 |
| Final weight (g)[a] | 72.3 | 61.3 | 58.1 | 73.1 | 61.5 | 59.9 | 68.3 | 63.7 | 4.6 | 0.03 |
| Weight gain (%)[a] | 230 | 179 | 165 | 233 | 180 | 176 | 211 | 192 | 21 | 0.03 |
| SGR (% body weight/d)[a] | 2.2 | 1.9 | 1.8 | 2.2 | 1.8 | 1.8 | 2.1 | 1.9 | 0.1 | 0.04 |
| FCR | 1.1 | 1.0 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 0.1 | 0.89 |
| FI (% body weight/d) | 2.6 | 2.1 | 2.1 | 2.6 | 2.3 | 2.2 | 2.3 | 2.3 | 0.2 | 0.03 |
| HSI | 1.5 | 1.4 | 1.2 | 1.5 | 1.4 | 1.4 | 1.3 | 1.3 | 0.1 | 0.08 |
| VSI | 6.7 | 7.3 | 6.8 | 7.2 | 7.0 | 7.5 | 6.8 | 7.4 | 0.5 | 0.65 |
| **Rainbow Trout** | | | | | | | | | | |
| Initial weight (g) | 14.9 | 15.1 | 15.1 | 15.1 | 15.1 | 15.1 | 15.1 | 15.0 | 0.2 | 0.97 |
| Final weight (g) | 45.7 | 45.5 | 38.7 | 48.3 | 45.5 | 43.6 | 43.4 | 41.6 | 5.3 | 0.74 |
| Weight gain (%) | 206 | 200 | 158 | 221 | 201 | 188 | 188 | 178 | 35 | 0.75 |
| SGR (% body weight/d) | 1.8 | 1.7 | 1.4 | 1.6 | 1.9 | 1.8 | 1.7 | 1.6 | 0.3 | 0.71 |
| FCR | 1.0 | 0.9 | 1.1 | 0.9 | 1.0 | 1.0 | 1.0 | 1.0 | 0.1 | 0.65 |
| FI (% body weight/d) | 2.1 | 1.9 | 1.9 | 2.0 | 2.2 | 2.1 | 2.0 | 1.9 | 0.2 | 0.83 |
| HSI | 1.8 | 1.9 | 2.3 | 1.8 | 2.0 | 2.0 | 2.2 | 2.0 | 0.2 | 0.05 |
| VSI | 12.4 | 12.1 | 12.1 | 11.6 | 11.5 | 11.5 | 11.4 | 12.6 | 0.5 | 0.17 |
| **Cobia[b]** | | | | | | | | | | |
| Initial weight (g) | 57.2 | 57.8 | 56.9 | 57.1 | 56.8 | 57.3 | 57.3 | 57.0 | 3.8 | 0.31 |
| Final weight (g) | 217.9 zy | 221.3 zy | 203.1 zy | 249.4 z | 238.2 zy | 206.9 zy | 242.4 zy | 186.2 y | 16.9 | 0.02 |
| Weight gain (%) | 281 zy | 283 zy | 257 zy | 337 z | 333 z | 273 zy | 323 z | 227y | 26 | 0.01 |
| SGR (% body weight/d) | 2.4 zy | 2.4 zy | 2.3 zy | 2.7 z | 2.7 z | 2.4 zy | 2.6 z | 2.2 y | 0.1 | <0.01 |
| FCR | 1.7 zy | 1.6 zy | 1.8 zy | 1.5 y | 1.5 y | 1.7 zy | 1.6 y | 1.9 z | 0.1 | <0.01 |
| FI (% body weight/d) | 4.5 | 4.4 | 4.4 | 4.3 | 4.3 | 4.5 | 4.5 | 4.3 | 0.2 | 0.86 |
| HSI | 1.9 | 1.7 | 1.8 | 1.6 | 1.8 | 1.7 | 1.7 | 3.4 | 0.9 | 0.45 |

[a]Although the omnibus test indicated a significant treatment effect, the more conservative Tukey's HSD pairwise comparison test failed to identify differences among means.
[b]VSI was not assessed in Cobia.

TABLE 5. Growth performance (final weight, weight gain, SGR, and FCR), FI, HSI, and VSI of hybrid Striped Bass, Rainbow Trout, and Cobia fed diets in which 20, 40, or 60% of digestible protein consisted of fish meal provided by Asian carp meal (CFM) or menhaden fish meal (MFM), excluding the 60 Blend. Values represent least-squared means; pooled SEs and $P$-values resulting from two-way ANOVA tests are also provided. Letters indicate significance differences ($P < 0.05$). The interaction term was not significant for all parameters; it was removed from the analysis and only the main effects were tested and reported.

| | Fish meal type | | | | Inclusion level | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Parameter | MFM | CFM | Pooled SE | *P*-value | 20% | 40% | 60% | Pooled SE | *P*-value |
| **Hybrid Striped Bass** | | | | | | | | | |
| Initial weight (g) | 22.0 | 21.9 | 0.1 | 0.49 | 21.8 | 22.0 | 21.9 | 0.1 | 0.37 |
| Final weight (g) | 63.9 | 64.8 | 2.5 | 0.70 | 59.0 y | 61.4 y | 72.7 z | 3.0 | <0.01 |
| Weight gain (%) | 191 | 196 | 11 | 0.66 | 170 y | 179 y | 232 z | 14 | <0.01 |
| SGR (% body weight/d) | 1.9 | 2.0 | 0.1 | 0.62 | 1.8 y | 1.9 y | 2.2 z | 0.1 | <0.01 |
| FCR | 1.1 | 1.1 | 0.0 | 0.66 | 1.1 | 1.1 | 1.1 | 0.1 | 0.95 |
| FI (% body weight/d) | 2.2 | 2.3 | 0.1 | 0.33 | 2.1 | 2.2 | 2.6 | 0.1 | <0.01 |
| HSI | 1.3 | 1.4 | 0.1 | 0.13 | 1.3 | 1.4 | 1.5 | 0.1 | 0.08 |
| VSI | 6.9 | 7.3 | 0.3 | 0.32 | 7.2 | 7.2 | 6.9 | 0.4 | 0.79 |
| **Rainbow Trout** | | | | | | | | | |
| Initial weight (g) | 15.0 | 15.1 | 0.1 | 0.72 | 15.1 | 15.1 | 15.0 | 0.1 | 0.74 |
| Final weight (g) | 43.3 | 45.8 | 2.7 | 0.37 | 41.2 | 45.5 | 47.0 | 3.3 | 0.23 |
| Weight gain (%) | 188 | 203 | 18 | 0.41 | 173 | 201 | 213 | 22 | 0.21 |
| SGR (% body weight/d) | 1.7 | 1.8 | 0.1 | 0.51 | 1.6 | 1.8 | 1.7 | 0.2 | 0.55 |
| FCR | 1.0 | 1.0 | 0.1 | 0.68 | 1.1 | 1.0 | 1.0 | 0.1 | 0.32 |
| FI (% body weight/d) | 2.0 | 2.1 | 0.1 | 0.47 | 2.0 | 2.0 | 2.1 | 0.1 | 0.80 |
| HSI | 2.0 | 1.9 | 0.1 | 0.42 | 2.2z | 1.9 zy | 1.8 y | 0.1 | 0.03 |
| VSI | 12.2 z | 11.5 y | 0.3 | 0.02 | 11.8 | 11.8 | 12.0 | 0.3 | 0.80 |
| **Cobia**[a] | | | | | | | | | |
| Initial weight (g) | 57.3 | 57.1 | 2.4 | 0.30 | 57.1 | 57.3 | 57.1 | 2.9 | 0.82 |
| Final weight (g) | 214.1 | 231.5 | 10.2 | 0.11 | 205.0 | 229.7 | 233.6 | 12.5 | 0.08 |
| Weight gain (%) | 273 y | 314 z | 15 | 0.02 | 265 | 308 | 309 | 19 | 0.05 |
| SGR (% body weight/d) | 2.4 y | 2.6 z | 0.1 | 0.02 | 2.4 | 2.5 | 2.5 | 0.1 | 0.04 |
| FCR | 1.7 z | 1.6 y | 0.0 | <0.01 | 1.7 z | 1.6 y | 1.6 y | 0.1 | <0.01 |
| FI (% body weight/d) | 4.4 | 4.4 | 0.1 | 0.69 | 4.5 | 4.4 | 4.4 | 0.1 | 0.67 |
| HSI | 1.8 | 1.7 | 0.1 | 0.29 | 1.7 | 1.7 | 1.8 | 0.1 | 0.98 |

[a]VSI was not analyzed in Cobia.



improved growth with higher fish meal inclusion were evident. Growth of Cobia varied significantly among dietary treatment groups and was influenced by fish meal type and inclusion level. Although not statistically significant in each study, growth was generally greater among fish fed the CFM-based feeds, particularly at the higher inclusion levels. Overall, similar trends were observed among studies (i.e., better growth with higher fish meal inclusion and CFM).

For hybrid Striped Bass, FCR, HSI, and VSI did not vary among dietary treatments and were unaffected by fish meal type or inclusion level. However, FI increased with inclusion level, regardless of fish meal type. In Rainbow Trout, FCR, FI, HSI, and VSI did not vary among dietary treatments. Additionally, FCR and FI were not influenced by fish meal type or inclusion level, but Rainbow Trout HSI was significantly increased among fish fed diets with lower fish meal inclusion levels. Furthermore, although VSI was unaffected by fish meal inclusion level, it was affected by fish meal type. Rainbow Trout fed diets containing MFM had higher VSI. Cobia FI and HSI did not vary among dietary treatments and were unaffected by fish meal type or inclusion level; however, FCR was significantly reduced among Cobia fed CFM diets and diets with higher fish meal inclusion levels.

## DISCUSSION

Our results indicate that growth performance is broadly consistent among hybrid Striped Bass, Rainbow Trout, and Cobia fed MFM or CFM. This suggests that CFM (~$650/metric ton; P. Hitchens, Southern Illinois University Carbondale, personal communication) is a cost-effective alternative to traditional marine-origin fish meals ($1,500–2,000/metric ton: FAO 2014). Given that, substituting traditional fish meals with CFM in the diets of other carnivorous fishes will not likely affect growth performance negatively. Any differences in growth performance associated with utilizing CFM will likely be minimal and the result of nuances in dietary needs and formulations. Therefore, CFM appears to be a suitable, cost-effective substitute to traditional marine-origin fish meals in the diets of carnivorous fish. Published information comparing fish meal types is limited, but appears generally supportive. For example, in a similar study with juvenile Largemouth Bass fed diets containing CFM, there were no significant differences in growth performance when compared with menhaden fish meal (Bowzer et al. 2014). Kop and Korkut (2010) performed a comparable study with juvenile Rainbow Trout assessing three different marine-based fish meals: Peruvian fish meal (traditional commercial fish meal), locally produced (Izmir, Turkey) anchovy fish meal, and locally produced fish meal from the by-products of several species (Gilthead Sea Bream *Sparus aurata*, Sea Bass *Dicentrarchus labrax*, and Rainbow Trout). Their results indicated that growth performance was not influenced by fish meal type.

As long as the product used is fresh, properly stored, and of high quality, the effect of fish meal type on growth performance of fish seems minor. The level of fish meal inclusion, however, appears to have a strong influence on feed intake and growth performance. Typically, the more fish meal that is included in the diet, the better the growth. Yet, due to its variable but generally high cost, fish meal sparing is common practice in diet formulations for many species including hybrid Striped Bass (Rawles et al. 2011), Rainbow Trout (Baboli et al. 2013), and Cobia (Trushenski et al. 2013). These studies have reported success (i.e., similar growth performance among fish fed fish meal-based and alternative protein-based feeds) in partially replacing fish meal with a variety of alternative plant- and animal-based protein meals provided that some amount of fish meal was included in the diet. Correspondingly, our data suggest that some inclusion of fish meal, regardless of origin, is important to ensure rapid, efficient growth. This also implies some fish meal sparing is possible without affecting growth performance. Therefore, it is not unexpected that there were little to no significant differences in growth provided that a sufficient amount of fish meal was included in the diet.

Feed conversion and intake values were within expectations for each study. However, Cobia demonstrated better feed conversion when fed diets containing CFM and higher inclusion levels of fish meal. This better feed conversion may explain the greater growth performance observed in Cobia fed diets containing CFM and higher inclusion levels. Minor differences in feed intake can certainly influence growth performance, but given that no clear trends emerged, suggesting reduced intake occurred due to fish meal origin or lower inclusion levels, better feed conversion seems to be a reasonable explanation for the improved growth observed with CFM and higher fish meal inclusion diets in Cobia. Although the nutritional composition of CFM and MFM are relatively similar, as demonstrated by Bowzer et al. (in press), small differences in the crude protein content and amino acid profile of these meals may explain the slightly better FCR observed in this study. Additionally, better feed conversion with higher inclusion levels of fish meal in the diet is typical of many carnivorous fishes, and this was clearly demonstrated by Salze et al. (2010) who replaced fish meal with graded levels of soy protein concentrate in the diets of juvenile Cobia. Therefore, the better FCR values for diets having higher fish meal inclusion was not surprising, and the small difference between fish meal types is likely due to minor differences in the composition of the meals.

There were no apparent trends for hybrid Striped Bass or Cobia in relation to organosomatic indices, but Rainbow Trout were leaner (i.e., lower VSI) when fed CFM-based diets. Additionally, Rainbow Trout fed diets with lower inclusion levels of fish meal had slightly larger livers than fish fed diets with higher inclusion levels of fish meal. The lower fat deposition in Rainbow Trout fed CFM diets can at least partially be attributed to those diets having less crude lipid coupled with higher ash content compared with the MFM diets. These discrepancies in the diets are relatively small, but likely contributed to the minor differences in lipid deposition observed between fish meal types. It is also well documented in Rainbow Trout that liver size varies with the digestible carbohydrate content of the diet (Kaushik et al. 1989; Escaffre et al. 2007) due to an apparent inefficiency to utilize this macronutrient (Skiba-Cassy et al. 2013); however, it is not likely this is the key factor that contributed to differences in liver size in this study since the carbohydrate content remained similar among the diets. Poultry by-product was the main ingredient to replace fish meal in the lower inclusion level diets, and therefore, it is likely the key factor contributing to the variation in liver size. Steffens (1994) demonstrated that methionine and lysine supplementation was necessary to maintain proper growth in Rainbow Trout when sparing or substituting fish meal with poultry by-product. Although our diets were formulated to meet all known nutrient requirements of Rainbow Trout and were therefore not supplemented with additional crystalline amino acids, differences in essential and nonessential amino acid availability due to higher inclusion levels of poultry by-product meal may have caused the variation in liver size observed in this study (Steffens 1994).

In conclusion, CFM appears to be a cost-effective alternative protein source to traditional marine-origin fish meal in the diets of carnivorous fishes such as hybrid Striped Bass, Rainbow Trout, and Cobia. Some subtle differences in growth and organosomatic indices were observed among the taxa we investigated, but these differences were marginal. Caution should be taken when considering full-scale, commercial production given that these fish were reared under optimal conditions for only an 8-week feeding trial. Further long-term studies should be conducted under conditions typical of intensive commercial culture of these fish (i.e., temperature and oxygen fluctuations, stress, and disease), which may adversely affect growth or survival, but due to the similarity of CFM to traditional marine-origin fish meals, we believe these concerns are relatively minor. Therefore, further development of a CFM industry could not only produce a cost-effective alternative to traditional marine-origin fish meals, but also encourage harvest of invasive Asian carp in U.S. waterways.

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# Potential of Asian Carp from the Illinois River as a Source of Raw Materials for Fish Meal Production

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ARTICLE

# Potential of Asian Carp from the Illinois River as a Source of Raw Materials for Fish Meal Production

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*Abstract*
**Incentivizing overfishing through the creation of high-value markets for Silver Carp *Hypophthalmichthys molitrix* and Bighead Carp *H. nobilis* has been proposed as a management strategy for controlling Asian carp in the Illinois River. Asian carp may be rendered into a protein-dense fish meal, and one of the most attractive, high-value end uses for such a product is aquafeed manufacturing. However, the nutritional content and shelf stability of Asian carp as a raw material must be determined to assess its suitability for rendering and subsequent use as a protein source in aquafeeds, which was the focus of this study. To determine seasonal, geographical, and species variation in body composition, fatty acids, and oxidative stability, Asian carp were collected from five reaches of the Illinois River during the fall, spring, and summer (up to 12 individuals of each species per reach per season) and analyzed. Slight geographical, seasonal, and species variation exists in the body composition and fatty acid profiles of adult Asian carp from the Illinois River. There was an apparent trend of increasing lipid content from lower to upper reaches and from fall to summer. Bighead Carp tended to be leaner (higher protein, moisture, and ash content) than Silver Carp (higher lipid content). Although Asian carp generally appear to be a good source of long-chain polyunsaturated fatty acids regardless of capture location or season, the concentration of these nutrients was highest in the fall. Oxidative stability analysis indicated Asian carp meal will need stabilizers to increase shelf life. Collectively, our results suggest Asian carp-based fish meals would be nutritionally suitable for use in aquafeeds, if precautions are taken to stabilize the product during storage. Creating demand for carp meal in the aquafeed manufacturing sector may prove a valuable strategy for aiding in the control of Asian carp populations in the Illinois River.**

Following the rapid expansion of populations of Silver Carp *Hypophthalmichthys molitrix* and Bighead Carp *H. nobilis* (Chick and Pegg 2001), hereafter referred to as Asian carp, in the Mississippi River basin, a variety of management strategies aimed at controlling their movement and reducing their density have been suggested. These strategies include behavioral barriers (e.g., strobe lights, acoustic deterrents, air bubble curtains, electrical barriers), physical barriers (e.g., vertical drops, rotating drums, floating curtains), and chemical barriers (e.g., low oxygen, carbon dioxide; Conover et al. 2007; Rach et al. 2009). All of these approaches have been considered for controlling Asian carp in the Illinois River, a focal point for Asian carp control because of the hydrologic connection formed between the Mississippi River basin and the Great Lakes basin via the Des Plaines River and Chicago Area Waterway System (CAWS). A series of electrical deterrence barriers are currently in place in the CAWS (Moy et al. 2011), and an intensive surveillance program is in place to monitor the system for Asian carp (ACRCC 2012). Additional control efforts in the Illinois River are primarily focused on harvest and chemical eradication (Rach et al. 2009; ACRCC 2012). Although this "all-of-the-above" management approach appears diffuse rather than strategic, a redundant multistrategy approach is likely necessary to effectively suppress Asian carp populations in the Illinois River.

Harvest-based control efforts can be augmented by harnessing potential market forces to incentivize overfishing, but subsidies, low interest loans, or contract fisheries may be necessary until the market is fully developed (Conover et al. 2007). Asian

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carp are not favored food fish in the United States and, therefore, industrial end uses and markets are likely to generate greater demand. A considerable volume of Asian carp is currently being exported from Illinois to China for human consumption, but transportation costs and logistics limit this approach and its ability to drive harvest pressure to control carp populations. Like other fishes with limited seafood market potential (e.g., menhadens, anchovies, herrings), Asian carp can be rendered to produce nutrient-dense fish meals. Fish meals are rendered protein products derived from fish carcasses or offal. These products are primarily used as fertilizers or as feed ingredients in companion animal and livestock feeds. At this time, Asian carp are primarily processed into fertilizers, but it may be possible to target the higher value uses in the animal feeds industry, in particular aquafeeds. An Asian carp meal has several advantages over other alternative feedstuffs in aquafeed production because of its similarity to traditional, marine-origin fish meals that are considered ideal proteins in many ways. Fish meal replacement in aquafeeds presents a variety of challenges. Fish have a higher protein demand relative to other livestock (Keembiyehetty and Gatlin 1992), and protein tends to be the most expensive dietary component. Aquafeed manufacturers have relied on fish meal as a protein-dense ingredient to meet this demand, but the rising cost of fish meal has forced feed manufactures to explore alternative sources.

Fish meal replacement can be difficult depending on the qualities of the alternative feedstuff. For example, soybean meal is one of the most promising plant protein sources as a fish meal alternative because of its favorable amino acid profile and relatively protein content compared with other plant-derived protein meals (Gatlin et al. 2007). Despite the routine use of soy products in fish feeds (Hendricks 2002), high inclusion levels can confer undesired attributes to the feeds (Kaushik 2008), resulting in poor palatability (Adelizi et al. 1998), low feed conversion efficiency (Davies and Morris 1997), reduced mineral availability (Trushenski et al. 2006), and intestinal antinutritional effects (Ostaszewska et al. 2005; Heikkinen et al. 2006; Iwashita et al. 2008; Santigosa et al. 2008). In addition to soy products, a variety of other plant-based (e.g., canola, corn, wheat) and animal-based (e.g., poultry, blood, feather) feedstuffs have been explored. However, the chemical composition, digestibility, palatability, antinutritional factors, nutrient utilization, or functional inclusion of these feedstuffs pose challenges to incorporating them into aquafeeds (Glencross et al. 2007). An Asian carp meal could be an ideal alternative because it mimics traditional fish meal sources and is unlikely to exhibit the undesirable attributes of other alternatives. Furthermore, the ecological integrity of the Mississippi River basin would also benefit from the increased removal of these invasive fish.

The global supply of fish meal remains static at 5–6 million metric tons/year, and the aquaculture sector is the largest consumer (approximately 60%) of fish meal in the world, even though fish meal use in aquafeeds (in terms of dietary inclusion rates) has slowly decreased since 2006 (FAO 2012). As the aquaculture industry continues to grow, the combination of a static supply, high demand, and overdependence of aquafeed manufacturers on fish meal has led to a dramatic increase in feed cost. Fish meal prices doubled from US$694 to $1,379/metric ton between March 2007 and March 2008 (Tacon and Metian 2008), and current prices are approaching $2,000/metric ton (FAO 2013). Although the use of fish meal in aquafeeds is predicted to decrease in the future due to an improved knowledge of the digestive processes and nutritional requirements of many farm-raised fishes (FAO 2012), fish meal will continue to play a critical role in aquafeed production, particularly for carnivorous species. Thus, the aquaculture industry could benefit from an underutilized alternative fish meal source such as Asian carp.

Increased demand for fish meal developed from Asian carp would provide an incentive for commercial fishers to capture large quantities of these fishes, facilitating population control (Conover et al. 2007). Modeling predictions have suggested that harvest of both small and large Asian carp is essential to their control (Garvey et al. 2007, 2012). Given that current fishing efforts are aimed primarily at large fish for human consumption markets, Asian carp meal would also incentivize harvest of smaller and younger fish. Harvest enhancement is also attractive in that it could reduce the need for costly and unpopular chemical eradication strategies (e.g., Vasquez et al. 2012) while simultaneously revitalizing the regional commercial fishing industry. It has also been suggested that the only viable solution to control established populations of Asian carp in the short term is through enhanced harvest efforts (Conover et al. 2007). However, demand for Asian carp meal is dependent on the ability to produce a stable supply and quality rendered product. The nutritional composition and associated value of traditional reduction fisheries (i.e., fisheries that process their catch into fish meal or fish oil) landings are known to vary by species as well as harvest location and season (Bragadóttir et al. 2004; Boran et al. 2008). Furthermore, fish meal is more susceptible to oxidative spoilage than other protein meals due to its high surface-area-to-volume ratio and higher concentrations of unsaturated fatty acids (El-Lakany and March 1974; Boran et al. 2008). Therefore, the variability in nutritional value and protection against oxidation are critical factors in determining the market value of Asian carp meal as a feedstuff as well as its potential to facilitate the control of Asian carp populations and to support the aquafeed industry.

This study was designed to determine the suitability of rendering Asian carp into fish meal as a feedstuff for aquafeeds and briefly examine its potential to control carp populations through overharvest to support fish meal production. To assess the appropriateness of Asian carp as a feedstuff for aquafeed production, the species-related, seasonal, and geographic variation in body composition and storage stability were evaluated.

## METHODS

To assess taxonomic, seasonal, and geographic variation in the composition of Asian carp, Bighead Carp and Silver Carp were collected seasonally during fall (2010), spring (2011), and

TABLE 1. Numbers of Silver and Bighead carps harvested from each reach of the Illinois River in fall 2010, spring 2011, and summer 2011.

| | | Harvest location | | | | |
|---|---|---|---|---|---|---|
| Season | Species | Alton | La Grange | Peoria | Starved Rock | Marseilles |
| Fall | Silver | 12 | 12 | 12 | 12 | 0 |
| | Bighead | 0 | 2 | 12 | 0 | 0 |
| Spring | Silver | 12 | 12 | 12 | 12 | 10 |
| | Bighead | 0 | 0 | 0 | 12 | 12 |
| Summer | Silver | 12 | 12 | 12 | 12 | 12 |
| | Bighead | 10 | 10 | 12 | 12 | 12 |

summer (2011) from five reaches of the Illinois River (up to 12 fish of each species per reach per season; Table 1). The reaches were separated by lock and dam complexes, and consisted of Alton, La Grange, Peoria, Starved Rock, and Marseilles. Fish were harvested using trammel nets and pulsed DC electrofishing, and commercial fishers assisted with several collections. Fish were transported on ice to the Center for Fisheries, Aquaculture, and Aquatic Sciences at Southern Illinois University Carbondale (Carbondale, Illinois), where the carcasses were frozen (–20°C) prior to compositional analysis.

Carcasses were individually homogenized prior to analysis. Due to the large body size and thick bones of Asian carp, frozen carcasses were first cut into pieces (~5-cm cubes) using a butcher's bone saw. The partially thawed pieces were then homogenized in a knife mill (Knife Mill GM 300; Retsch, Haan, Germany). A 200-g subsample of the resulting homogenate was collected and stored frozen until compositional analysis. Some fish had to be homogenized in batches due to their large size. In these cases, batches were combined in a large bowl and mixed thoroughly by hand prior to subsample collection.

The subsamples were lyophilized (Freezone 6; Labconco, Kansas City, Missouri) to determine moisture content and subsequently pulverized using a coffee–spice grinder for determination of protein, ash, and lipid content. Total lipid was determined gravimetrically following chloroform–methanol extraction modified from Folch et al. (1957). Resultant lipid fractions were analyzed for fatty acid composition according to the procedures described by Laporte and Trushenski (2011). Briefly, samples were subjected to acid-catalyzed transmethylation performed overnight at 50°C as described by Christie (1982), and the resultant fatty acid methyl esters (FAME) were separated using a Shimadzu GC-17A gas chromatograph (Shimadzu Scientific Instruments, Kyoto, Japan) equipped with a flame ionization detector fitted with a permanently bonded polyethylene glycol, fused silica capillary column (Omegawax 250, 30 m × 0.25 mm ID, 0.25-μm film; Sigma Aldrich, St. Louis, Missouri). The injection volume was 1.0 μL, with helium as the carrier gas (30 cm/s, 205°C), and an injector temperature of 250°C. A split injection technique (100:1) was used, with a temperature program as follows: 50°C held for 2 min, increased to 220°C at 4°C/min, and held at 220°C for 15 min. Individual FAME were identified by reference to external standards (Supelco 37 Component FAME Mix, PUFAs-1, and PUFAs-3; Supelco, Bellefonte, Pennsylvania). Ash content was determined gravimetrically after incineration in a muffle furnace for 4 h at 650°C. A LECO protein analyzer (FP-528; LECO Corporation, St. Joseph, Michigan) was used to determine protein content.

To estimate oxidative stability of Asian carp fish meal, the subsamples of lyophilized, ground Asian carp were placed in a refrigerator (0, 2, 4, and 8 weeks) and analyzed for the presence of peroxides and aldehydes with Peroxysafe and Aldesafe colorimetric assay kits (SafTest, Phoenix, Arizona). The samples were stored at –80°C until analysis, and all peroxide–aldehyde concentrations were standardized for whole-body lipid content (Folch et al. 1957). These values were compared with those of a commercially available, stabilized fish meal (Special Select menhaden fish meal; Omega Protein, Houston, Texas) stored under the same conditions.

Individual fish served as the experimental units for all statistical analyses ($n = 12$). A factorial analysis was not possible due to missing combinations of independent variables as a result of incomplete sampling (Table 1). As such, a nested ANOVA design was used within the generalized linear mixed-model framework (GLIMMIX procedures) of the Statistical Analysis System version 9.2 (SAS Institute, Cary, North Carolina) to determine whether there were differences in proximate composition among locations within each season as well as among seasons within a specific location; separate species-specific models were used for moisture, protein, lipid, and ash content. These data were also analyzed using a nested ANOVA within the mixed-model framework to determine whether differences in proximate composition existed between species within a specific location and harvest season. A one-way ANOVA was used to determine differences among species across seasons and locations. Linear regression was used to determine the relationship between total length and body composition of Asian carp. Individual fish collected during the fall sample season were used to determine oxidative stability of Asian carp meals compared with that of a stabilized fish meal control using repeated-measures mixed-model analysis. In all cases, differences were considered significant at an α-level of 0.05.

TABLE 2. Proximate composition (%) of Asian carp harvested seasonally from the Illinois River (fall 2010–summer 2011) and pooled across all five harvest locations (Alton, La Grange, Peoria, Starved Rock, and Marseilles). Numeric labels indicate mean percent composition of the intact carcasses (i.e., wet matter basis); numbers may not add to 100% because of minor amounts of carbohydrate not analyzed and rounding errors. Letters indicate significant differences within species across seasons at $P < 0.05$.

| | | Seasons | | |
|---|---|---|---|---|
| Species | Composition | Fall | Spring | Summer |
| Silver Carp | Moisture | 74.9 ± 0.4 z | 71.0 ± 0.4 y | 69.2 ± 0.4 x |
| | Protein | 14.8 ± 0.8 y | 15.7 ± 0.7 z | 16.3 ± 0.7 z |
| | Lipid | 3.9 ± 1.1 y | 6.1 ± 1.0 z | 7.4 ± 1.0 z |
| | Ash | 5.6 ± 0.6 z | 6.0 ± 0.5 z | 5.6 ± 0.5 y |
| Bighead Carp | Moisture | 80.4 ± 0.8 z | 78.5 ± 0.4 z | 76.7 ± 0.3 y |
| | Protein | 13.1 ± 1.8 zy | 13.4 ± 0.9 y | 15.5 ± 0.6 z |
| | Lipid | 1.3 ± 1.5 | 2.0 ± 0.8 | 2.3 ± 0.5 |
| | Ash | 5.0 ± 1.3 z | 4.5 ± 0.7 y | 4.8 ± 0.5 y |

## RESULTS

There were significant seasonal differences in body composition (Table 2) and FAME groups (Figure 1) in Asian carp from the Illinois River. Similar trends were observed for both Silver Carp and Bighead Carp: moisture, protein, and ash decreased across harvest seasons, fall to summer, while lipid increased. Saturated fatty acids (SFAs) and monounsaturated fatty acids (MUFAs) increased over the same time period, while polyunsaturated fatty acids (PUFAs), medium-chain polyunsaturated fatty acids (MC-PUFAs), long-chain polyunsaturated fatty acids (LC-PUFAs), n-3, n-6, and the ratio of n-3 to n-6 (n-3:n-6) decreased.

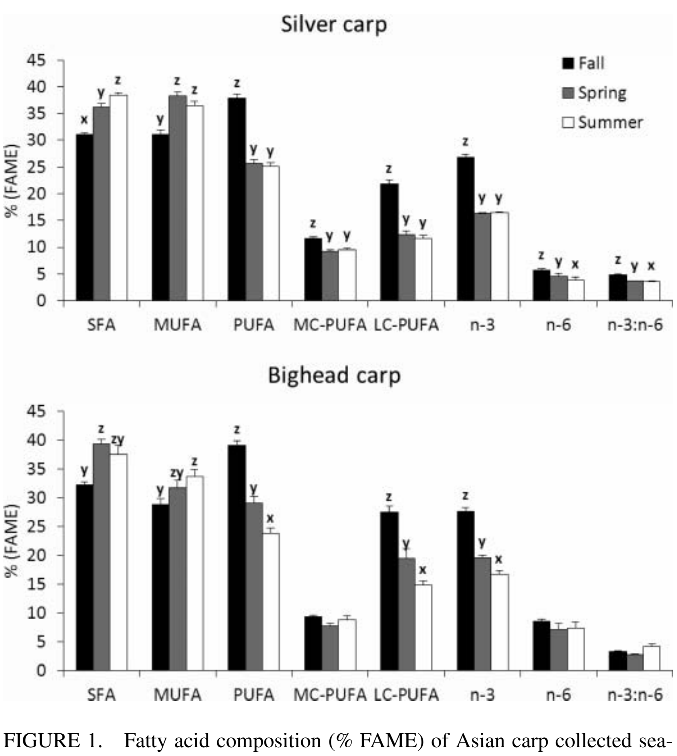


FIGURE 1. Fatty acid composition (% FAME) of Asian carp collected seasonally from the Illinois River (fall 2010–summer 2011). Data were pooled across all five harvest locations (Alton, La Grange, Peoria, Starved Rock, and Marseilles). SFAs = saturated fatty acids (no double bonds), MUFAs = monounsaturated fatty acids (one double bond), PUFAs = polyunsaturated fatty acids (two or more double bonds), MC-PUFAs = medium-chain polyunsaturated fatty acids (18 carbon atoms, two or more double bonds), LC-PUFAs = long-chain polyunsaturated fatty acids (20 or 22 carbon atoms, three or more double bonds). Different letters indicate significant differences within species across seasons at $P < 0.05$; error bars indicate SE.

Geographical differences in body composition and FAME groups within each season were also observed. Silver Carp demonstrated similar patterns among seasons in body composition: moisture and ash content of Silver Carp decreased from lower reaches to upper reaches (Alton to Marseilles), while lipid increased (Table 3). However, Silver Carp from the Peoria Reach did not follow these general trends in fall and spring. Protein content of Silver Carp within each season varied geographically with no apparent trends. The FAME groups for Silver Carp did not demonstrate any trends during fall, but spring and summer harvest periods showed similar geographic trends (Table 4). Saturated fatty acids decreased from lower to upper reaches of the Illinois River, while PUFAs, MC-PUFAs, LC-PUFAs, n-3, and n-6 increased moving up the river, peaking in Peoria before decreasing again (except for the n-6 group in spring, where there were no significant differences). Geographical differences for Bighead Carp were limited to the summer harvest period due to data gaps in fall and spring, and no trends were apparent in the body composition of Bighead Carp. However, Bighead Carp collected from the Marseilles Reach tended to be dissimilar (higher lipid content with lower moisture and ash) from the other reaches, except in protein content (Table 3). Few trends were apparent in Bighead Carp FAME groups (Table 5). Similar to Silver Carp, SFAs in Bighead Carp decreased in the upper reaches of the river. Additionally, n-3 fatty acids decreased in the upper reaches.

There were significant differences between Bighead and Silver carps within individual season–reach data sets and across all geographic locations and seasons. Overall, Bighead Carp were

TABLE 3. Proximate composition (%, mean ± SE) of Asian carp collected from the five reaches within the Illinois River (fall 2010–summer 2011). Lipid, protein, and ash are based on dry matter. Letters indicate significant geographical differences within each season at $P < 0.05$; ND = no data.

| | | | Harvest location | | | | |
|---|---|---|---|---|---|---|---|
| Species | Season | Composition | Alton | LaGrange | Peoria | Starved Rock | Marseilles |
| Silver Carp | Fall | Moisture | 74.3 ± 0.9 z | 74.5 ± 0.9 z | 78.3 ± 0.9 z | 72.5 ± 0.9 y | ND |
| | | Lipid | 11.9 ± 2.2 y | 17.8 ± 2.2 zy | 7.1 ± 2.2 y | 25.0 ± 2.2 z | ND |
| | | Protein | 54.9 ± 1.6 y | 60.0 ± 1.6 zy | 65.7 ± 1.6 z | 55.0 ± 1.6 y | ND |
| | | Ash | 27.0 ± 1.2 z | 21.8 ± 1.2 z | 25.2 ± 1.2 z | 15.5 ± 1.2 y | ND |
| | Spring | Moisture | 73.7 ± 0.9 z | 70.2 ± 0.9 zy | 73.7 ± 0.9 z | 68.7 ± 0.9 y | 68.5 ± 1.0 y |
| | | Lipid | 12.0 ± 2.2 y | 24.8 ± 2.2 z | 12.9 ± 2.2 y | 25.7 ± 2.2 z | 29.4 ± 2.5 z |
| | | Protein | 54.9 ± 1.6 | 52.8 ± 1.6 | 57.3 ± 1.6 | 51.6 ± 1.6 | 53.1 ± 1.8 |
| | | Ash | 30.1 ± 1.2 z | 18.1 ± 1.2 yx | 23.5 ± 1.2 y | 16.7 ± 1.2 x | 14.7 ± 1.3 x |
| | Summer | Moisture | 71.4 ± 0.9 z | 70.5 ± 0.9 z | 70.4 ± 0.9 z | 68.1 ± 0.9 zy | 65.6 ± 0.9 y |
| | | Lipid | 14.2 ± 2.2 y | 18.6 ± 2.2 y | 21.2 ± 2.2 y | 29.9 ± 2.2 z | 36.9 ± 2.2 z |
| | | Protein | 56.7 ± 1.6 z | 54.1 ± 1.6 zy | 53.7 ± 1.6 zy | 51.1 ± 1.6 zy | 48.8 ± 1.6 y |
| | | Ash | 25.8 ± 1.2 z | 22.4 ± 1.2 zy | 18.2 ± 1.2 y | 14.6 ± 1.2 x | 10.1 ± 1.2 x |
| Bighead Carp | Fall | Moisture | ND | 79.1 ± 0.6 | 81.7 ± 1.4 | ND | ND |
| | | Lipid | ND | 7.9 ± 1.1 | 4.9 ± 2.8 | ND | ND |
| | | Protein | ND | 67.1 ± 1.3 | 66.0 ± 3.3 | ND | ND |
| | | Ash | ND | 26.9 ± 1.0 | 24.2 ± 2.3 | ND | ND |
| | Spring | Moisture | ND | ND | ND | 79.9 ± 0.6 | 77.2 ± 0.6 |
| | | Lipid | ND | ND | ND | 4.7 ± 1.1 y | 14.4 ± 1.1 z |
| | | Protein | ND | ND | ND | 62.8 ± 1.3 | 62.0 ± 1.3 |
| | | Ash | ND | ND | ND | 24.4 ± 1.0 z | 17.8 ± 1.0 y |
| | Summer | Moisture | 77.2 ± 0.6 z | 77.9 ± 0.6 z | 76.1 ± 0.6 zy | 78.5 ± 0.6 z | 73.7 ± 0.6 y |
| | | Lipid | 6.4 ± 1.2 y | 7.5 ± 1.2 y | 9.7 ± 1.2 y | 7.2 ± 1.1 y | 18.4 ± 1.1 z |
| | | Protein | 68.2 ± 1.5 | 67.4 ± 1.5 | 63.9 ± 1.5 | 68.9 ± 1.3 | 64.5 ± 1.3 |
| | | Ash | 22.4 ± 1.0 z | 21.8 ± 1.0 z | 22.2 ± 1.0 z | 21.0 ± 1.0 z | 15.3 ± 1.0 y |

leaner (higher moisture, protein, and ash, but lower lipid content) than Silver Carp in all reaches studied, regardless of season or geographic location (Table 6). The overall fatty acid profile of Asian carp (Table 7) demonstrated that Silver Carp had higher MUFAs, MC-PUFAs, and n-3:n-6, whereas Bighead Carp had higher levels of SFAs, n-6, and LC-PUFAs. Both species had similar levels of PUFAs and n-3.

Body composition was observed to be a function of total length in Silver Carp. Lipid had a strong positive relationship with length ($r^2 = 0.38$, $P = 0.0001$). Moisture ($r^2 = 0.42$, $P = 0.0005$) and protein ($r^2 = 0.39$, $P = 0.0001$) had strong negative relationships, whereas ash had a moderate negative relationship to total length ($r^2 = 0.20$, $P = 0.0001$; Figure 2). In Bighead Carp, only protein was moderately related to total length ($r^2 = 0.13$, $P = 0.0005$).

The test of parallelism (fish meal type × time) for spoilage indicators (aldehydes $P = 0.0078$ and peroxides $P = 0.0001$) was significant. Aldehydes ($P = 0.0015$) and peroxides ($P = 0.0010$) significantly increased over time, and there were significant differences between fish meal types for the presence of aldehydes ($P = 0.0289$) and peroxides ($P = 0.0047$). The divergent trend of both carp meals from the control was apparent, and the presence of spoilage indicators was substantially higher in the unstabilized carp meals than in the stabilized menhaden meal by 8 weeks (56 d; Figure 3). Additionally, aldehydes were more prevalent in both carp meals than peroxides.

## DISCUSSION

Asian carp appear to be suitable for rendering and inclusion in aquafeeds based on their composition. Market economics and free-market access largely determine whether a fish is used for direct human consumption or rendered for feed production (Tacon et al. 2006; Tacon and Metian 2008), and given that Asian carp are not a favored food fish in the United States, this underutilized resource is better suited to other applications, including fish meal production. The proximate composition of Asian carp is similar to traditional fish meal sources such as menhaden (Rawles et al. 2010) and anchovy (IFFO 2006c; Glencross et al. 2007). However, the ash content of Asian carp is higher than traditional fish meal sources, but this may make it more attractive in aquafeeds that partially substitute fish meal with plant-based meals due to the higher levels of calcium and phosphorus in fish meals that tend to be low in plant protein sources.

TABLE 4. Fatty acid composition (% FAME, mean ± SE) for Silver Carp collected from five reaches within the Illinois River (fall 2010–summer 2011). Letters indicate significant geographical differences within each season at $P < 0.05$; ND = no data.

| | | Harvest location | | | | |
|---|---|---|---|---|---|---|
| Season | Fatty acid group | Alton | LaGrange | Peoria | Starved Rock | Marseilles |
| Fall | SFAs | 32.0 ± 0.9 zy | 31.7 ± 0.8 zy | 32.6 ± 0.8 z | 28.2 ± 0.8 y | ND |
| | MUFAs | 32.2 ± 1.3 zy | 30.5 ± 1.2 yx | 24.7 ± 1.3 x | 36.7 ± 1.2 z | ND |
| | PUFAs | 35.9 ± 1.2 y | 37.8 ± 1.1 zy | 42.7 ± 1.1 z | 35.1 ± 1.1 y | ND |
| | MC-PUFAs | 10.2 ± 0.5 y | 13.3 ± 0.4 z | 11.8 ± 0.4 zy | 11.0 ± 0.4 y | ND |
| | LC-PUFAs | 21.7 ± 0.9 y | 21.0 ± 0.8 y | 26.9 ± 0.9 z | 18.2 ± 0.8 y | ND |
| | n-3 | 24.7 ± 0.9 yx | 28.2 ± 0.9 zy | 31.3 ± 0.9 z | 23.1 ± 0.9 x | ND |
| | n-6 | 6.4 ± 0.3 zy | 5.5 ± 0.2 yx | 6.9 ± 0.3 z | 4.3 ± 0.2 x | ND |
| | n-3:n-6 | 4.0 ± 0.2 y | 5.2 ± 0.2 z | 4.6 ± 0.2 zy | 5.4 ± 0.2 z | ND |
| Spring | SFAs | 43.4 ± 0.8 z | 36.5 ± 0.8 y | 34.3 ± 0.8 yx | 32.0 ± 0.8 x | 34.4 ± 0.9 yx |
| | MUFAs | 37.1 ± 1.2 z | 41.8 ± 1.2 z | 31.9 ± 1.2 y | 40.1 ± 1.2 z | 40.7 ± 1.3 z |
| | PUFAs | 19.4 ± 1.1 w | 21.7 ± 1.1 xw | 33.7 ± 1.1 z | 28.0 ± 1.1 y | 24.9 ± 1.2 yx |
| | MC-PUFAs | 7.6 ± 0.4 y | 8.7 ± 0.4 z | 10.6 ± 0.4 z | 9.1 ± 0.4 z | 10.5 ± 0.5 z |
| | LC-PUFAs | 8.5 ± 0.8 x | 10.0 ± 0.8 yx | 18.9 ± 0.8 z | 13.4 ± 0.8 y | 12.5 ± 0.9 yx |
| | n-3 | 10.8 ± 0.9 w | 13.3 ± 0.9 xw | 23.4 ± 0.9 z | 16.9 ± 0.9 yx | 17.6 ± 0.9 y |
| | n-6 | 4.2 ± 0.2 | 4.5 ± 0.2 | 5.1 ± 0.2 | 4.0 ± 0.2 | 4.7 ± 0.3 |
| | n-3:n-6 | 2.6 ± 0.2 x | 3.0 ± 0.2 yx | 4.6 ± 0.2 z | 4.2 ± 0.2 z | 3.9 ± 0.2 zy |
| Summer | SFAs | 42.6 ± 0.8 z | 40.2 ± 0.8 zy | 36.6 ± 0.8 y | 35.7 ± 0.8 y | 36.9 ± 0.8 y |
| | MUFAs | 35.3 ± 1.2 yx | 34.3 ± 1.2 x | 30.6 ± 1.2 x | 39.7 ± 1.2 zy | 42.6 ± 1.2 z |
| | PUFAs | 22.1 ± 1.1 y | 25.5 ± 1.1 y | 32.8 ± 1.1 z | 24.5 ± 1.1 y | 20.5 ± 1.1 y |
| | MC-PUFAs | 8.7 ± 0.4 y | 10.6 ± 0.4 zy | 10.9 ± 0.4 z | 9.0 ± 0.4zy | 8.5 ± 0.4 y |
| | LC-PUFAs | 10.1 ± 0.8 y | 11.7 ± 0.8 y | 15.9 ± 0.8 z | 11.2 ± 0.8 y | 9.5 ± 0.8 y |
| | n-3 | 14.9 ± 0.9 yx | 17.8 ± 0.9 zy | 20.5 ± 0.9 z | 15.3 ± 0.9 yx | 13.5 ± 0.9 x |
| | n-6 | 3.1 ± 0.2 y | 3.8 ± 0.2 y | 5.1 ± 0.2 z | 3.8 ± 0.2 y | 3.7 ± 0.2 y |
| | n-3:n-6 | 4.8 ± 0.2 z | 4.8 ± 0.2 z | 4.3 ± 0.2 zy | 4.0 ± 0.2 zy | 3.6 ± 0.2 y |

The composition and quality of fish meal is based on fish condition at the time of harvest, which varies. The body condition of a fish and overall well-being is assumed to be adequate with sufficient lipid reserves, i.e., fish with higher fat content are in better condition (Anderson and Gutreuter 1983). The quality and chemical composition of fish meal within and among species depends on age, sex, diet, environment, and harvest season (Boran et al. 2008). Similar to many forage fish typically rendered into fish meal, we found that Asian carp carcass composition and quality varied seasonally, geographically, and by species. In general, Asian carp were leaner (low fat content) in the lower reaches of the Illinois River and during seasons with lower primary productivity such as fall. Additionally, Bighead Carp were leaner than Silver Carp across seasons and sample reaches, similar to results from the Missouri River (Orazio et al. 2011). Variation in the proximate composition of fish meal is closely related to the diet and feed intake of the species being rendered (Bragadóttir et al. 2004). Most reduction fisheries are based on plankton-eating species, such as menhaden and anchovy, which naturally experience seasonal variation in proximate body composition due to the seasonality of planktonic forage (Huss 1988). Given that Asian carp are also planktivorous (Williamson and Garvey 2005; Sampson et al. 2009), it is reasonable to observe similar seasonal variation in these species. During periods of ample food availability such as summer, protein content of the carcass will increase to a point, and then lipid deposition increases as feed intake surpasses energetic requirements, making a nutrient-rich fish for fish meal production (Bragadóttir et al. 2004; Boran et al. 2008). Following seasons with typically greater phyto- and zooplankton abundance, lipid deposition and overall body condition of Asian carp increased as well. However, seasonal availability of food does not explain all of the inconsistencies in body condition among reaches from season to season.

It would be expected that if primary production was the dominant factor affecting the composition of Asian carp, overall body condition should not vary appreciably by reach given that the entire Illinois River is subject to the same seasonal shifts in climate and broadly similar productivity cycles (though productivity may be somewhat higher in the downstream reaches). Several reaches did not follow this pattern, indicating that other factors are contributing to the condition of these fish. Just as fish are more nutritionally valuable during periods of ample food, they will be less nutritionally valuable as a raw material

TABLE 5. Fatty acid composition (% FAME, mean ± SE) for Bighead Carp collected from five reaches within the Illinois River (fall 2010–summer 2011). Letters indicate significant geographical differences within each season at $P < 0.05$; ND = no data.

| | | Harvest location | | | | |
|---|---|---|---|---|---|---|
| Season | Fatty acid group | Alton | LaGrange | Peoria | Starved Rock | Marseilles |
| Fall | SFAs | ND | 32.2 ± 2.6 | 32.2 ± 6.0 | ND | ND |
| | MUFAs | ND | 29.3 ± 1.8 | 25.9 ± 4.3 | ND | ND |
| | PUFAs | ND | 38.5 ± 1.5 | 42.0 ± 3.6 | ND | ND |
| | MC-PUFAs | ND | 9.3 ± 1.0 | 9.3 ± 2.3 | ND | ND |
| | LC-PUFAs | ND | 27.0 ± 1.2 | 30.3 ± 2.8 | ND | ND |
| | n-3 | ND | 27.1 ± 1.1 | 30.5 ± 2.5 | ND | ND |
| | n-6 | ND | 8.6 ± 1.7 | 8.4 ± 4.1 | ND | ND |
| | n-3:n-6 | ND | 3.2 ± 0.7 | 3.6 ± 1.6 | ND | ND |
| Spring | SFAs | ND | ND | ND | 38.7 ± 2.5 | 40.5 ± 2.5 |
| | MUFAs | ND | ND | ND | 26.1 ± 1.7 y | 35.9 ± 1.7 z |
| | PUFAs | ND | ND | ND | 35.3 ± 1.5 z | 23.7 ± 1.5 y |
| | MC-PUFAs | ND | ND | ND | 5.7 ± 0.9 y | 9.7 ± 9 z |
| | LC-PUFAs | ND | ND | ND | 28.4 ± 1.1 z | 12.4 ± 1.1 y |
| | n-3 | ND | ND | ND | 24.5 ± 1.0 z | 15.8 ± 1.0 y |
| | n-6 | ND | ND | ND | 9.0 ± 1.7 | 5.6 ± 1.7 |
| | n-3:n-6 | ND | ND | ND | 2.8 ± 0.6 | 2.8 ± 0.6 |
| Summer | SFAs | 42.8 ± 2.7 z | 40.7 ± 2.7 z | 40.0 ± 2.7 z | 37.7 ± 2.5 zy | 27.9 ± 2.5 y |
| | MUFAs | 31.1 ± 1.9 yx | 27.8 ± 1.9 w | 29.9 ± 1.9 x | 38.2 ± 1.7 zy | 39.1 ± 1.7 z |
| | PUFAs | 26.1 ± 1.6 zy | 21.4 ± 1.6 yx | 30.1 ± 1.6 z | 24.1 ± 1.5 zyx | 18.1 ± 1.5 x |
| | MC-PUFAs | 8.3 ± 1.0 zy | 7.1 ± 1.0 y | 9.5 ± 1.0 zy | 7.2 ± 0.9 y | 11.9 ± 0.9 z |
| | LC-PUFAs | 16.6 ± 1.2 zy | 13.0 ± 1.2 zy | 17.8 ± 1.2 z | 15.6 ± 1.1 zy | 11.9 ± 1.1 y |
| | n-3 | 20.0 ± 1.1 z | 17.2 ± 1.1 zy | 19.7 ± 1.1 zy | 15.2 ± 1.0 yx | 12.3 ± 1.0 x |
| | n-6 | 4.3 ± 1.8 y | 4.5 ± 1.9 y | 6.5 ± 1.8 zy | 6.9 ± 1.7 zy | 13.2 ± 1.7 z |
| | n-3:n-6 | 4.7 ± 0.7 zy | 4.2 ± 0.7 zy | 3.2 ± 0.7 y | 2.2 ± 0.6 y | 6.3 ± 0.6 z |

during periods of starvation or high energy expenditure due to natural behavior (e.g., spawning, migration), stress (e.g., suboptimal temperature, low dissolved oxygen), food shortages (e.g., increased competition, reduced prey availability), and seasonal decreases in feed intake (e.g., overwintering). The lower body condition observed in Asian carp from the lower reaches of the Illinois River, and Bighead Carp in general, are likely attributed to competition. Bighead and Silver carps can have substantial diet overlap despite Silver Carp's broader feeding range, including the capacity to consume smaller food particles (Sampson et al. 2009). Additionally, Asian carp compete with native filter feeding fishes such as Gizzard Shad *Dorosoma cepedianum* and Bigmouth Buffalo *Ictiobus cyprinellus* (Irons et al. 2007; Sampson et al. 2009). Because of the similarities in diet composition among Asian carp and native planktivores within the Mississippi River basin, interspecific competition among species is highly probable in these systems (Sampson et al. 2009). Although there is no evidence of direct competition (i.e., limited food availability) in the Illinois River, the body condition of Gizzard Shad and Bigmouth Buffalo has decreased since the proliferation of Asian carp, and these changes were not strongly linked to complementary changes in other abiotic and biotic variables (Irons et al. 2007). Asian carp population densities are highest in the lower reaches of the Illinois River, particularly in Alton, LaGrange, and Peoria (Sass et al. 2010; Garvey et al. 2012), and higher densities probably contributed to lower overall body condition as a result of intraspecific competition for prey resources. This is supported by evidence that body condition improves in the upper reaches of the Illinois River as the population density of Asian carp decreases, which is contrary to expectations if productivity was the primary factor affecting body condition. Enhanced harvest of Asian carp should reduce both intra- and interspecific competition among planktivores, resulting in better body condition for Asian carp as well as native planktivorous fishes. However, gear selection and methods used to enhance harvest of Asian carp should be considered carefully to reduce the risk of native species bycatch, which may further affect the ecological integrity of the system.

Several lines of evidence suggest that Silver Carp can effectively outcompete Bighead Carp for prey resources in the Illinois River. Anecdotal evidence regarding Bighead Carp—such as the lower body condition (in this study and Orazio et al. 2011), narrower range of potential food particles (Sampson et al. 2009), lower abundance (Garvey et al. 2012), and the apparent faster

TABLE 6. Proximate composition (%) of Asian carp harvested from the Illinois River (fall 2010–summer 2011) across all five harvest locations (Alton, La Grange, Peoria, Starved Rock, and Marseilles) and seasons. Numeric labels indicate mean percent composition of the intact carcasses (i.e., wet matter basis); numbers may not add to 100% because of minor amounts of carbohydrates not analyzed and rounding errors.

| | Species | |
|---|---|---|
| Composition | Silver Carp | Bighead Carp |
| Moisture | 71.5 ± 0.3 y | 77.5 ± 0.4 z |
| Protein | 15.7 ± 0.5 z | 14.7 ± 0.6 y |
| Lipid | 5.8 ± 0.7 z | 2.2 ± 1.0 y |
| Ash | 5.8 ± 0.5 | 5.8 ± 0.6 |

rate of upstream movement (J. Garvey, Southern Illinois University Carbondale, personal communication)—compared with Silver Carp suggest they may be moving to less dense areas upstream in response to competitive exclusion. However, this hypothesis of competitive differences between these two Asian carp species needs to be explored further and is beyond the scope of this project. However, these variations in body composition have a fundamental importance to consumers, manufacturers, and wholesalers that demand a product equivalent to their expectations (Boran et al. 2008). Nevertheless, it should be noted that the geographic, seasonal, and species differences observed in this study were minor, and all size-classes of fish harvested would be deemed as valuable inputs for fish meal production.

To our knowledge this is the first attempt to process Asian carp into fish meal; these fish are typically marketed as seafood throughout the rest of the world. Much like the food fish industry, however, stabilizing the product is of critical importance. Freezing and frozen storage are important methods for preserving fish products such as fillets and fish meal (Asgharzadeh et al. 2010). One of the principal methods of predicting shelf life in processed food products is monitoring the level of lipid degradation by testing for the presence of peroxides and aldehydes (Sewald and DeVries 2012), and it is apparent that if an Asian carp meal product is to be used in aquafeed production, it will need to be stabilized to increase shelf life. The rate that spoilage occurs depends on product composition, particularly lipid composition in regards to chain length and hydrogen saturation, as well as environmental factors such as temperature, moisture, surface area, and light (Belitz et al. 2004; Sewald and DeVries 2012). Given that lipids present in fish meals contain a high proportion of unsaturated fatty acids and large surface area, they are particularly susceptible to spoilage (El-Lakany and March 1974). Silver Carp also have higher lipid content than Bighead Carp, which may make them more susceptible to spoilage. The rapid increase in the presence of peroxides and aldehydes in the Asian carp meals relative to the stable levels of the fish meal control demonstrates the need for antioxidants to increase the shelf life of an Asian carp meal product. A range of synthetic antioxidants are available and used in animal feeds, but ethoxyquin is the most frequently used synthetic stabilizer in fish meal because it is considerably more effective than other common feed additives (Lundebye et al. 2010). Given its effectiveness in other fish meals, it could easily be incorporated into Asian carp-based fish meals to extend shelf life.

TABLE 7. Fatty acid composition (% FAME, mean ± SE) of Asian carp collected from the Illinois River across all seasons (fall 2010–summer 2011) and harvest locations. Significant differences were determined at $P < 0.05$.

| Fatty acid(s) | Silver Carp | Bighead Carp |
|---|---|---|
| 12:0 | 0.15 ± 0.09 y | 0.60 ± 0.12 z |
| 13:0 | 0.06 ± 0.01 y | 0.13 ± 0.01 z |
| 14:0 | 6.53 ± 0.13 z | 5.49 ± 0.17 y |
| 15:0 | 1.04 ± 0.05 y | 1.39 ± 0.07 z |
| 16:0 | 22.10 ± 0.27 z | 20.37 ± 0.35 y |
| 17:0 | 0.50 ± 0.02 y | 0.90 ± 0.02 z |
| 18:0 | 4.93 ± 0.18 y | 8.86 ± 0.23 z |
| 20:0 | 0.25 ± 0.01 y | 0.46 ± 0.01 z |
| 22:0 | 0.02 ± 0.05 y | 0.38 ± 0.06 z |
| 24:0 | 0.01 ± 0.01 y | 0.07 ± 0.02 z |
| SFAs | 35.59 ± 0.51 y | 37.67 ± 0.67 z |
| 16:1n-7 | 14.74 ± 0.23 z | 10.61 ± 0.30 y |
| 18:1n-9 | 16.21 ± 0.47 | 15.21 ± 0.62 |
| 18:1n-7 | 3.63 ± 0.12 y | 5.61 ± 0.16 z |
| 20:1n-9 | 0.98 ± 0.03 y | 1.20 ± 0.04 z |
| 22:1n-11 | 0.01 ± 0.01 y | 0.05 ± 0.01 z |
| 22:1n-9 | 0.00 ± 0.03 y | 0.22 ± 0.04 z |
| MUFAs | 35.63 ± 0.52 z | 32.73 ± 0.68 y |
| 16:2n-4 | 1.91 ± 0.12 z | 1.39 ± 0.15 y |
| 16:3n-4 | 1.93 ± 0.05 z | 0.70 ± 0.07 y |
| 18:3n-4 | 1.07 ± 0.03 z | 0.81 ± 0.04 y |
| 18:2n-6 | 2.55 ± 0.05 y | 3.05 ± 0.06 z |
| 18:3n-6 | 0.28 ± 0.02 | 0.28 ± 0.03 |
| 20:2n-6 | 0.27 ± 0.01 y | 0.42 ± 0.01 z |
| 20:3n-6 | 0.34 ± 0.01 y | 0.44 ± 0.01 z |
| 20:4n-6 | 1.17 ± 0.11 y | 2.33 ± 0.14 z |
| n-6 | 4.61 ± 0.13 y | 6.36 ± 0.17 z |
| 18:3n-3 | 4.41 ± 0.10 z | 3.22 ± 0.13 y |
| 18:4n-3 | 1.71 ± 0.05 z | 0.94 ± 0.06 y |
| 20:3n-3 | 0.31 ± 0.08 y | 0.77 ± 0.10 z |
| 20:4n-3 | 1.65 ± 0.04 z | 1.28 ± 0.05 y |
| 20:5n-3 | 6.37 ± 0.20 | 6.35 ± 0.26 |
| 22:5n-3 | 1.57 ± 0.07 y | 2.04 ± 0.09 z |
| 22:6n-3 | 3.23 ± 0.17 y | 4.56 ± 0.23 z |
| n-3 | 19.26 ± 0.50 | 19.05 ± 0.65 |
| PUFAs | 28.78 ± 0.62 | 27.70 ± 0.81 |
| LC-PUFAs | 14.85 ± 0.51 y | 18.24 ± 0.67 z |
| MC-PUFAs | 10.01 ± 0.21 z | 8.68 ± 0.27 y |
| n-3:n-6 | 4.21 ± 0.13 z | 3.63 ± 0.18 y |

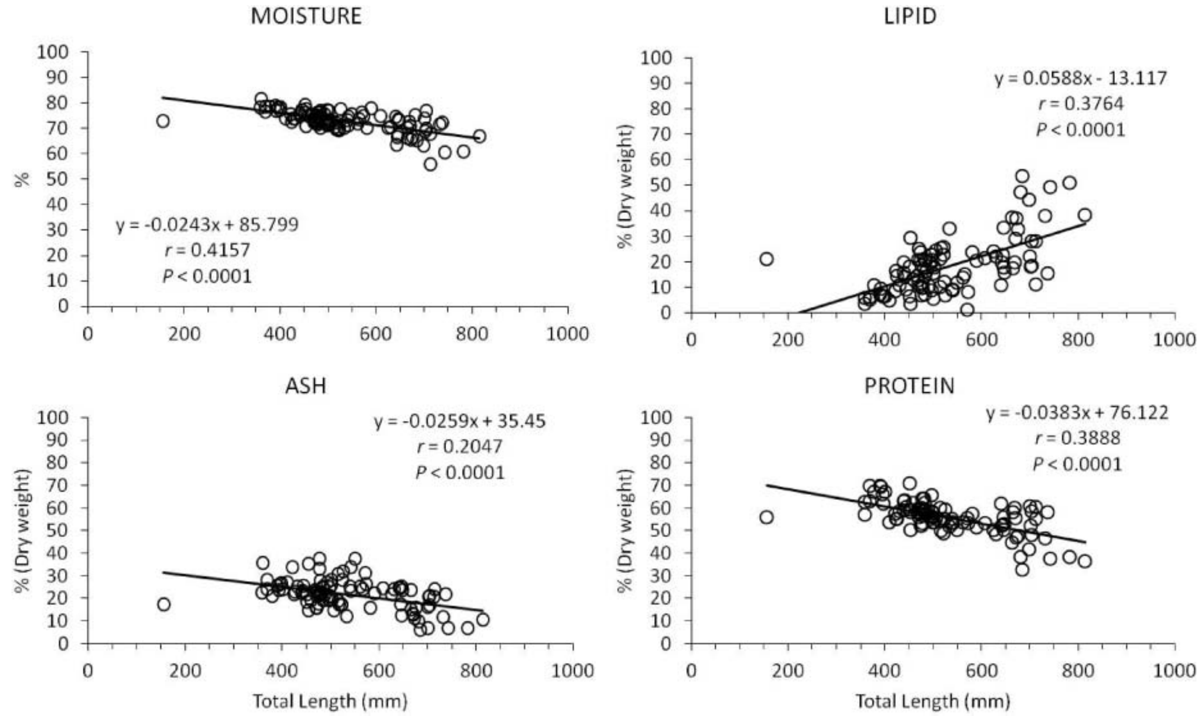


FIGURE 2. Relationship between total length and proximate composition of Silver Carp harvested from the Illinois River (fall 2010–summer 2011). Percent lipid, protein, and ash were determined on dry matter basis.

A stabilized Asian carp meal is a nutritionally suitable alternative for aquafeed production because of its similarity to traditional marine-based fish meals. The quality and concentration of essential nutrients in fish meal makes it a valuable component in the diets of most aquaculture species and many terrestrial farm-raised animals (IFFO 2006a) because it promotes normal growth, increases feed efficiency, enhances nutrient absorption, and improves palatability (Sullivan and Reigh 1995; Watanabe 2002; IFFO 2006b; Oyelese and Odubayo 2010). Additionally, the nutrients in fish meal are also effective for maintaining good health and improved disease resistance in fish through an enhanced immune response (Watanabe 2002; IFFO 2006b). One of the more important attributes of fish meal that are devoid in other alternative protein sources is the small, yet biological important, amount of LC-PUFAs (20 and 22 carbon, three or more double-bonded fatty acids). Given that many carnivorous species lack the ability to synthesize sufficient amounts of LC-PUFAs de novo, it is critical to provide LC-PUFAs in the diet. Adequate levels of LC-PUFAs are necessary for proper development and function. One of their many functions includes acting as precursors for eicosanoids that are involved in cardiovascular modulation, immunity and inflammatory response, renal and neural function, and reproduction (Sargent et al. 2002). An Asian carp-based fish meal would have similar levels of LC-PUFAs and benefits as those mentioned above from marine fish meal sources while also directing an otherwise unutilized resource to the human food chain, making it an attractive feedstuff for aquafeed manufacturers and the aquaculture industry.

Given the beneficial attributes of fish meal, feed manufacturers are willing to pay higher prices for fish meal (currently ∼\$1,900/metric ton) compared with lower quality alternative protein sources such as soybean meal (∼\$500/metric ton; FAO 2013). Currently, Asian carp meal is priced at \$600–650/metric ton (P. Hitchens, Southern Illinois University Carbondale, personal communication), and fish markets along the Illinois River pay commercial fishers approximately \$0.33/kg and \$0.40/kg for Silver and Bighead carps, respectively (Schaffer's Fish Market, personal communication). Experienced commercial fishing crews (i.e., one to two boats and three to eight fishers) can routinely harvest > 10,000 kg of Asian carp/d from the Illinois River under optimal harvest conditions (R. Smith, Big River Fish, personal communication; Irons et al. 2007). Thus, Asian carp provide another source of income for commercial fishers while also providing a cost-effective alternative feedstuff to aquafeed producers. Additionally, the National Management and Control Plan for Bighead, Black, Grass, and Silver carps in the United States indicates that harvest enhancement is the only viable short-term control strategy for Asian carp where populations are already established (Conover et al. 2007). Given that Asian carp meal is a high-quality product like traditional marine fish meals but is currently priced similarly to lower-quality alternatives, this product may become an especially attractive ingredient for aquafeed manufacturers. However, it is expected that the price of Asian cap meal will increase to similar levels of traditional marine fish meal sources if a market is established. It is unclear what effects, if any, changes in

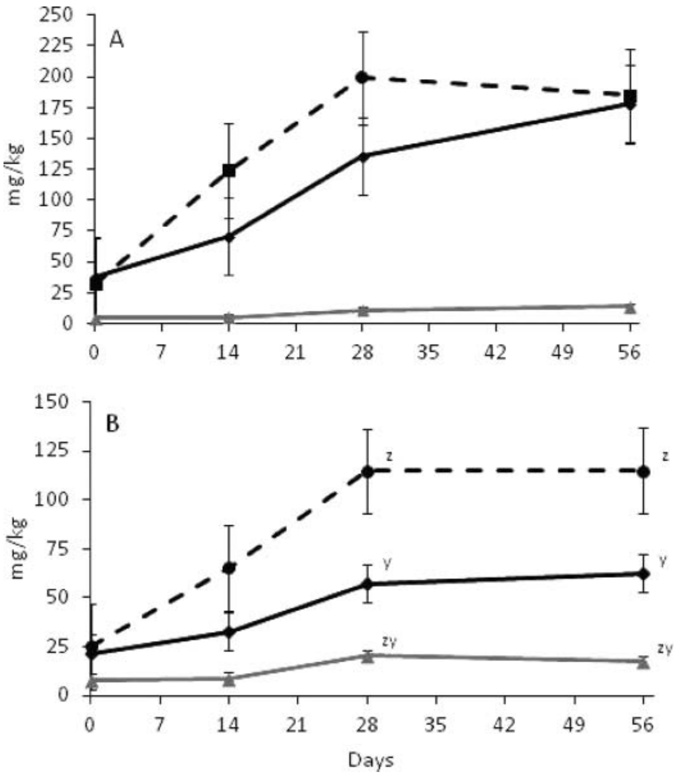


FIGURE 3. Oxidative stability of unstabilized Asian carp meals (Silver Carp = solid black line–diamonds, Bighead Carp = dashed black line–circles) compared with a commercially available stabilized menhaden fish meal control (gray line–triangles) based on the development of **(A)** aldehydes and **(B)** peroxides during refrigerated storage. Values were standardized for lipid content; error bars represent SE.

price structure may have on demand for Asian carp-derived fish meal.

The aquaculture industry continues to be the fastest-growing animal food producing sector, at a rate of roughly 8.8%/year (FAO 2012). To meet rising demand, the supply of feed inputs will also have to grow at similar rates (Tacon and Metian 2008). However, the aquaculture industry has not addressed its overdependence on fish meal in the production of aquafeeds. When the supply of fish meal became static, the aquaculture industry responded by paying higher prices and consuming larger portions of the global fish meal supply, while other industries found cheaper alternatives. The aquaculture industry now consumes the largest portion of the global supply of fish meal at approximately 60%, with little chance of consuming more of the overall supply (FAO 2012). The overdependence of aquaculture on fish meal to produce balanced and palatable aquafeeds for fishes makes them vulnerable to price fluctuations (Cheng et al. 2004). Thus, feed costs can be a significant variable cost in many aquaculture operations (Kaushik and Seiliez 2010). The industry could therefore benefit from an underutilized source of raw material such as Asian carp. An Asian carp meal is currently a more economical alternative feedstuff to marine-based fish meals and could ameliorate some of the effects of price shifts on aquafeed production while maintaining the overall quality of the feed. However, the ability of an Asian carp meal to ameliorate future price shifts maybe reduced given that its price is expected to increase because of its potential to be a high-value feedstuff.

In conclusion, reducing costs of feed can make aquaculture more profitable by substituting expensive ingredients (marine fish meal) for comparable, more cost-effective ingredients such as an Asian carp meal. The body composition and FAME profile of Asian carp from the Illinois River indicates that a rendered Asian carp meal is broadly similar to traditional marine fish meal sources but presently at a fraction of the cost. However, it is reasonable to expect that the price of Asian carp meal will increase to reflect the prices of similar products, such as traditional marine fish meal sources, but if the price does not increase to reflect this value, subsidies may be necessary to support the industry. Although subsidizing enhanced harvest to support this industry may be more cost effective than other control options. Given that the infrastructure, processing plants, transport, and commercial fishers to support an Asian carp meal industry is already being developed, a marketing strategy of Asian carp products is a logical approach to aid in the control of Asian carp populations in the Illinois River.

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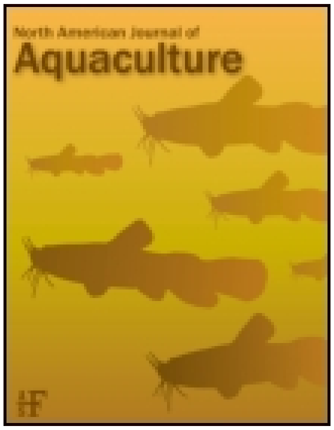


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# Growth Performance of Largemouth Bass Fed Fish Meal Derived from Asian Carp

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**TECHNICAL NOTE**

# Growth Performance of Largemouth Bass Fed Fish Meal Derived from Asian Carp

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***Abstract***
**Feeds for carnivorous fish like Largemouth Bass *Micropterus salmoides* are commonly based on marine-origin fish meal, but this ingredient is costly. Fish meal derived from undesirable species, such as invasive Asian carp *Hypophthalmichthys* spp., is a promising alternative source of protein for carnivorous fish, but information regarding its biological value as a feed ingredient is limited. Accordingly, we evaluated the growth performance of juvenile Largemouth Bass (initial weight, 11.6 ± 0.2 g [mean ± SE]) reared for 8 weeks on practical diets (∼14.5% lipid, ∼42% digestible protein) containing different levels of menhaden fish meal (MFM), Asian carp meal (CFM), or a 50:50 blend of these ingredients such that 40% (40 MFM, 40 CFM) or 60% (60 MFM, 60 CFM, 60 Blend) of the estimated digestible protein content was derived from fish meal. Weight gain (329–388%), feed conversion ratio (0.78–0.97), and specific growth rate (2.65–2.88% body weight/d) were generally consistent among treatments. Although our results suggest that performance is greater among fish fed diets with greater fish meal inclusion, regardless of its origin, this trend was not supported by clear statistical evidence. Asian carp fish meal appears to be broadly equivalent to MFM in feeds for Largemouth Bass. Development of CFM as a feed ingredient may offer producers of Largemouth Bass and other carnivorous fishes some savings in feed cost and encourage the harvest of invasive Asian carp.**

Largemouth Bass *Micropterus salmoides* is widely recognized as a popular sport fish across the United States, and their popularity continues to grow as a food fish in live markets, particularly in cities with large ethnic populations (Coursey et al. 2013). Commercial production has relied primarily on diets containing high levels of marine-origin fish meal often considered necessary to encourage feeding behavior and satisfy the dietary requirements of carnivorous fishes like Largemouth Bass. Replacement of fish meal with alternative proteins, particularly plant-derived protein meals such as soybean meal, is problematic for Largemouth Bass as they are relatively intolerant of carbohydrate-rich diets (Coursey et al. 2013). The carbohydrate content of most plant-derived protein meals exceeds 20%, which is considered too high for Largemouth Bass (Mitchell et al. 2002), rendering aggressive fish meal replacement with plant-derived protein meals impractical. Animal-derived protein meals (e.g., poultry byproduct meal, blood meal) do not present the same challenges as plant-derived feedstuffs and may be well-utilized by Largemouth Bass (Portz and Cyrino 2004; Coursey et al. 2013), but each of these products has some limitations compared with fish meal, including amino acid deficiencies and reduced palatability (Tidwell et al. 2005; Subhadra et al. 2006).

Feed costs are typically the highest production expense in aquaculture (Naylor et al. 2000) and represent approximately 50% of production costs in Largemouth Bass culture (Tidwell et al. 2000). Feed costs are greatly influenced by the price of fish meal and overreliance of feed manufacturers on this feedstuff as a primary source of protein for species like Largemouth Bass. Economic incentives to spare or replace fish meal in carnivorous fish feeds are strengthened by growing concerns regarding the sustainability and ecological effects of reduction fisheries (i.e., fisheries providing raw materials for fish meal and fish oil production) and public perception of feeding fish to fish as a practice. Concerns over costs and future supplies led the Food and Agriculture Organization (FAO) of the United Nations to describe marine-origin fish meals as the greatest market constraint to the continued growth of aquaculture (FAO 2008). The aquaculture industry would obviously benefit from the identification of effective, lower cost alternatives to fish meal.

One promising alternative to marine-origin fish meal is fish meal rendered from freshwater Silver Carp *Hypophthalmichthys molitrix* and Bighead Carp *H. nobilis* (hereafter referred to together as Asian carp). Both species are invasive in North America and are particularly problematic in the Mississippi River basin where they have become especially

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abundant (McClelland et al. 2012; Tsehaye et al. 2013). Invasive species are widely recognized for their adverse effects on native populations and industries associated with these natural resources (Vitousek et al. 1997; Lodge et al. 2006). The threat of Asian carp entering the Great Lakes and disrupting the $7 billion fishing industry centered on that system has prompted government agencies to devise and implement various control strategies (Tsehaye et al. 2013). Although an integrated management strategy is necessary to effectively control Asian carp populations, harvest enhancement is currently the only viable short-term control strategy where populations are already established (Conover et al. 2007). Although some fish are being harvested from Illinois waters for human consumption, Asian carp are not a favored food fish in the United States, and markets for industrial uses such as livestock feeding are considered the most promising for encouraging harvest (Bowzer et al. 2013). Current pricing estimates for Asian carp meal (CFM; US$600–650/metric ton: P. Hitchens, Southern Illinois University Carbondale, personal communication) are low compared with traditional marine-origin fish meals ($1,500–2,000/metric ton: FAO 2013), and previous research has demonstrated that the digestibility of CFM is comparable to that of menhaden *Brevoortia* spp. fish meal (MFM) in aquafeeds (Bowzer et al., in press). As such, CFM appears promising as an alternative to marine-origin fish meal in feeds for carnivorous fishes such as Largemouth Bass; however, the biological value of this feed ingredient has yet to be directly evaluated. Accordingly, we assessed the growth performance of Largemouth Bass fed diets containing different levels of MFM or CFM.

## METHODS

Fifteen tanks in a recirculation aquaculture system consisting of twenty-four 50-L tanks with supplemental aeration and mechanical and biological filtration units were stocked with juvenile Largemouth Bass (initial weight, $11.6 \pm 0.2$ g [mean $\pm$ SE]; 10 fish per tank). Water temperature and dissolved oxygen were measured daily (YSI 550 temperature–oxygen meter; Yellow Springs Instruments, Yellow Springs, Ohio), whereas other water quality conditions (total ammonia nitrogen, nitrite-nitrogen, nitrate-nitrogen, and alkalinity) were measured weekly (Hach DR 2800 portable spectrophotometer, digital titrator, and reagents; Hach Company, Loveland, Colorado). Throughout the trial, the photoperiod was 14 h light : 10 h dark and water quality conditions were maintained within ranges suitable for Largemouth Bass: water temperature = $24.4 \pm 1.8$°C, dissolved oxygen = $6.69 \pm 0.73$ mg/L, total ammonia nitrogen = $0.36 \pm 0.11$ mg/L, nitrite-nitrogen = $0.02 \pm 0.01$ mg/L, nitrate-nitrogen = $16.15 \pm 2.51$ mg/L, pH = $7.73 \pm 0.14$, and alkalinity = $186 \pm 59$ mg/L.

Practical diets were formulated to contain approximately 14.5% lipid, 42% digestible protein (based on apparent digestibility coefficients reported for Rainbow Trout *Oncorhynchus mykiss* by Barrows et al. 2012), and different levels of MFM (Omega Protein, Houston, Texas), CFM (Protein Products, Gainsville, Florida), or a 50:50 blend of these ingredients such that 40% (40 MFM, 40 CFM) or 60% (60 MFM, 60 CFM, 60 Blend) of the estimated digestible protein content was derived from fish meal (Tables 1, 2). Feeds were manufactured and analyzed in triplicate to determine proximate composition (Table 2) using standard methods described in detail by Rombenso et al. (2013). Feeds were randomly assigned to triplicate tanks ($N$ = 3), and fish were fed assigned diets once daily (1100 hours) to apparent satiation for a period of 8 weeks. At the end of the trial, fish were harvested, counted, and group-weighed by tank to assess growth performance in terms of the following metrics:

TABLE 1. Composition (g/kg dry matter basis) of Asian carp meal (CFM) and menhaden fish meal (MFM) in test diets for Largemouth Bass (adapted from Bowzer et al., in press).

| Composition | CFM | MFM |
|---|---|---|
| Protein (crude) | 640.1 | 687.3 |
| Lipid (crude) | 122.7 | 101.3 |
| Ash | 246.4 | 213.7 |
| Dry matter | 971.4 | 943.3 |

$$\text{Weight gain (\%)} = 100 \times \frac{\text{average individual final weight} - \text{average individual initial weight}}{\text{average individual initial weight}}$$

$$\text{Feed conversion ratio (FCR)} = \frac{\text{average individual feed consumption (drymatter)}}{\text{average individual weight gain}}$$

$$\text{Specific growth rate (SGR, \% bodyweight/day)} = 100 \times \frac{\log_e(\text{final weight}) - \log_e(\text{initial weight})}{\text{days of feeding}}$$

$$\text{Feed intake (FI, \% body weight/day)} = 100 \times \frac{\text{total dry matter intake}/(\text{initial individual weight} \times \text{final individual weight})^{0.5}}{\text{days of feeding}}$$

Three fish per tank were then euthanized with an overdose of tricaine methanesulfonate (MS-222; ~200 mg/L in culture water; fish immersed until opercular ventilation had ceased for 10 min) then individually weighed and dissected to calculate organosomatic indices as follows:

$$\text{Hepatosomatic Index (HSI)} = 100 \times (\text{liver weight}/\text{whole body weight})$$

$$\text{Viscerosomatic Index (VSI)} = 100 \times (\text{total viscera weight}/\text{whole body weight})$$

All data were analyzed by one-way ANOVA (PROC GLIMMIX) to determine the significance of differences between diets (SAS version 9.3, SAS Institute, Cary, North Carolina). Post hoc Tukey's honestly significant difference (HSD) pairwise comparison tests were used when omnibus tests

TABLE 2. Dietary formulation (g/kg, as-fed basis) and proximate composition (g/kg, dry matter basis, except dry matter) of diets based on Asian carp meal (CFM) or menhaden fish meal (MFM) fed to Largemouth Bass. Numerals in diet names indicate the percentage of digestible protein content provided by a fish meal source, i.e., 60 indicates 60%.

| Ingredient | 60 MFM | 40 MFM | 60 CFM | 40 CFM | 60 Blend |
|---|---|---|---|---|---|
| Menhaden fish meal[a] | 376.7 | 251.1 | 0 | 0 | 188.3 |
| Asian carp meal[b] | 0 | 0 | 450.8 | 300.5 | 225.4 |
| Soybean meal[c] | 183.9 | 295.9 | 126.9 | 260.1 | 198.6 |
| Poultry byproduct meal[d] | 150.0 | 250.0 | 250.0 | 250.0 | 200.0 |
| Wheat bran | 143.5 | 50.0 | 50.0 | 50.0 | 50.0 |
| Menhaden fish oil[a] | 66.7 | 73.8 | 43.1 | 60.2 | 58.5 |
| Blood meal[e] | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 |
| Carboxymethyl cellulose | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |
| Choline chloride | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 |
| Mineral premix[f] | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Vitamin premix[g] | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| Stay C[h] | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Protein (crude) | 538.9 | 515.8 | 558.7 | 525.9 | 540.9 |
| Protein (digestible) | 420.0 | 410.0 | 428.9 | 401.8 | 433.0 |
| Lipid (crude) | 130.0 | 130.0 | 130.0 | 130.0 | 130.0 |
| Analyzed composition: | | | | | |
| Dry matter | 945 | 942 | 949 | 949 | 930 |
| Protein (crude) | 526 | 548 | 596 | 563 | 571 |
| Lipid (crude) | 144 | 152 | 149 | 146 | 148 |
| Ash | 113 | 105 | 131 | 99 | 122 |

[a]Omega Protein, Houston, Texas.

[b]Protein Products, Gainsville, Florida.

[c]Seimer Enterprises, Teutopolis, Illinois (47% protein).

[d]Tyson, Robards, Kentucky (pet food grade).

[e]Darling International, Irving, Texas.

[f]Formulated to contain 24.897% zinc oxide, 14.933% ferrous sulfate, 3.470% manganese oxide, 0.967% cupric carbonate, 0.262% potassium iodide, 0.060% sodium selenate, and 0.030% cobalt carbonate in a cellulose base.

[g]Formulated to contain 25.000% L-ascorbyl-2-polyphosphate, 14.000% *RRR*-alpha tocopheryl acetate, 13.160% vitamin K, 12.500% inositol, 12.500% nicotinic acid, 7.500% riboflavin, 6.250% calcium pantothenate, 2.500% pyridoxine hydrochloride, 1.250% thiamine mononitrate, 1.000% vitamin A palmitate, 0.500% cyanocobalamin, 0.450% folic acid 0.125% biotin, and 0.010% cholecalciferol in a cellulose base.

[h]Argent Laboratories, Redmond, Washington.



indicated significant differences among dietary groups. Additionally, data from the MFM and CFM series (i.e., excluding the 60 Blend) were analyzed by two-way ANOVA (PROC GLIMMIX) to determine the significance of fish meal type and inclusion level as main and interactive effects. All differences were considered significant at $P < 0.05$.

## RESULTS AND DISCUSSION

Our results indicate that growth performance of Largemouth Bass is not influenced by the origin of the fish meal or inclusion level (Tables 3, 4). Weight gain (329–388%), FCR (0.78–0.97), and SGR (2.65–2.88% body weight/d) were generally consistent for fish among fish meal types and inclusion levels. Feed intake was highest in the 40 CFM group and lowest in the 60 Blend group, and neither group showed any obvious patterns related to fish meal inclusion level or origin. Hepatosomatic and viscerosomatic indices did not vary among treatment groups, and survival was 100% in all groups. Kop and Korkut (2010) conducted a similar experiment with juvenile Rainbow Trout fed practical isonitrogenous and isoenergetic diets utilizing three different fish meal types: Peruvian fish meal (traditional commercial fish meal), locally produced (Izmir, Turkey) anchovy fish meal, and locally produced fish meal from the by-products of several fish species (Gilthead Sea Bream *Sparus aurata*, Sea Bass *Dicentrarchus labrax*, and Rainbow Trout). Their results indicated that the origin of fish meal did not influence growth performance. Similarly, our data indicate that while some inclusion of fish meal may be important to ensure rapid, efficient growth in Largemouth Bass juveniles, traditional marine-origin fish meals such as MFM could be replaced with CFM without compromising performance.

Although there was no statistical difference in growth performance among treatments, in general diets containing higher levels of fish meal performed better, except the 60 MFM diet (Table 3). Growth with the 60 MFM diet was not significantly lower than that for any of the other fish meal diets, but it was lower than expected (i.e., higher fish meal inclusion typically

TABLE 3. Growth performance of Largemouth Bass fed diets containing Asian carp meal (CFM) or menhaden fish meal (MFM). Values represent least-squares means; pooled SE and $P$-values resulting from one-way ANOVA tests are also provided. No significant differences were observed for any parameters ($P < 0.05$).

| Parameter | 60 MFM | 40 MFM | 60 CFM | 40 CFM | 60 Blend | Pooled SE | *P*-value |
|---|---|---|---|---|---|---|---|
| Initial weight (g) | 11.7 | 11.5 | 11.5 | 11.5 | 11.7 | 0.2 | 0.64 |
| Final weight (g) | 50.1 | 52.6 | 54.3 | 53.2 | 56.9 | 2.4 | 0.15 |
| Weight gain (%) | 329 | 356 | 370 | 364 | 388 | 18 | 0.09 |
| Specific growth rate (% body weight/d) | 2.65 | 2.76 | 2.81 | 2.79 | 2.88 | 0.07 | 0.09 |
| Feed conversion ratio | 0.97 | 0.95 | 0.90 | 0.94 | 0.78 | 0.07 | 0.11 |
| Feed intake (% body weight/d) | 2.79 | 2.87 | 2.78 | 2.90 | 2.50 | 0.15 | 0.14 |
| Hepatosomatic index | 1.00 | 0.93 | 1.01 | 0.95 | 0.98 | 0.08 | 0.82 |
| Viscerosomatic index | 6.71 | 6.82 | 6.31 | 6.07 | 6.77 | 0.58 | 0.63 |



leads to better growth). Fish meal replacement studies have been successful in partially or completely replacing fish meal with a variety of alternative plant- and animal-based protein meals for many species, including Largemouth Bass (Cochran et al. 2009), hybrid striped bass (White Bass *Morone chrysops* × Striped Bass *M. saxatilis*) (Rawles et al. 2011), and Rainbow Trout (Baboli et al. 2013). Therefore it is not surprising that there were no significant treatment effects in this study. However, the lower than expected growth performance observed in the 60 MFM diet of this study can likely be attributed to the lower than intended protein content in the diet (Table 2). In general, the analyzed composition of the diets exceeded intended protein content based on their formulations, except the 60 MFM diet, which was lower than intended; the analyzed crude protein content of the 60 MFM diet was approximately 40 g (g/kg, as-fed basis) lower than intended, whereas all of the other diets were near their intended crude protein content (± 10 g/kg, as-fed basis). This suggests that some mistakes were made during feed manufacturing, which led to lower protein content and likely contributed to the reduced performance in the 60 MFM treatment. Regardless, growth performance observed in this trial was generally good and consistent with ranges reported in other Largemouth Bass feeding trials (Tidwell et al. 2005; Coursey et al. 2013). The data also suggest that some fish meal sparing with alternative plant and animal protein meals is possible without affecting growth performance.

Overall, feed conversion was exceptional in this study (FCR, 0.78–0.97). Feed intake (2.50–2.90% body weight/d) was similar among dietary treatments with no apparent trend. Although growth performance was undoubtedly influenced in part by minor differences in feed intake, no clear trends emerged, suggesting there are corresponding patterns of reduced intake in fish from the lower fish meal treatments and elevated intake in fish fed diets with higher levels of fish meal included or differential intake of diets based on one fish meal type or the other. There were no evident trends observed in HSI (0.93–1.01) or VSI (6.07–6.82), and these values are consistent with the results of previous studies (Tidwell et al. 2005; Coursey et al. 2013). Additionally, there were no mortalities during our study. Given that feed conversion was exceptional in this study and there were few differences in growth, feed intake, HSI, or VSI, Asian carp meal appears to be a suitable substitute for traditional marine fish meals.

Our study demonstrates that Asian carp meal is a suitable substitute for more expensive fish meals and some fish meal sparing is possible without compromising growth of Largemouth Bass.

TABLE 4. Growth performance of Largemouth Bass fed diets containing Asian carp meal (CFM) or menhaden fish meal (MFM), excluding the 60 Blend. Numerals in inclusion level terms indicate the percentage of digestible protein content provided by a fish meal source, i.e., 60 indicates 60%. Values represent least-squares means; pooled SE and $P$-values resulting from two-way ANOVA tests are also provided. No significant main or interactive effects were observed for any parameter ($P > 0.05$).

| | Fish meal type | | | | Inclusion level | | | |
|---|---|---|---|---|---|---|---|---|
| Parameter | MFM | CFM | Pooled SE | *P*-value | 60 | 40 | Pooled SE | *P*-value |
| Initial weight (g) | 11.6 | 11.5 | 0.08 | 0.26 | 11.6 | 11.5 | 0.08 | 0.26 |
| Final weight (g) | 51.4 | 53.7 | 1.8 | 0.23 | 52.2 | 52.9 | 1.8 | 0.71 |
| Weight gain (%) | 343 | 367 | 14 | 0.11 | 350 | 360 | 14 | 0.48 |
| Specific growth rate (% body weight/d) | 2.70 | 2.80 | 0.04 | 0.12 | 2.73 | 2.78 | 0.06 | 0.45 |
| Feed conversion ratio | 0.96 | 0.92 | 0.05 | 0.45 | 0.94 | 0.95 | 0.05 | 0.83 |
| Feed intake (% body weight/d) | 2.83 | 2.84 | 0.09 | 0.92 | 2.79 | 2.89 | 0.09 | 0.28 |
| Hepatosomatic index | 0.97 | 0.98 | 0.05 | 0.81 | 1.01 | 0.94 | 0.05 | 0.25 |
| Viscerosomatic index | 6.77 | 6.19 | 0.41 | 0.20 | 6.51 | 6.44 | 0.41 | 0.87 |

However, some caution should be taken when extrapolating to commercial-scale production since these fish were reared under optimal conditions and variations in temperature, stress, dissolved oxygen, parasites, and other challenges that are typical of intensive commercial fish culture; but, these concerns should be minimal given that Asian carp meal and traditional fish meal sources have similar proximate compositions. Therefore the production of Largemouth Bass, and likely that of other carnivorous species, could benefit from using Asian carp meal in practical diets.

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# Apparent digestibility of Asian carp- and common carp-derived fish meals in feeds for hybrid striped bass *Morone saxatilis* ♀ × *M. chrysops* ♂ and rainbow trout *Oncorhynchus mykiss*

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## Abstract

Apparent digestibility coefficients (ADCs) of nutrients (crude protein, amino acids, crude lipid, fatty acids, and minerals) were determined for fish meals derived from menhaden, Asian carp (combination of silver and bighead carps), and common carp in feeds for hybrid striped bass and rainbow trout. Extruded test diets were formulated to contain a 70 : 30 mixture of reference diet and test ingredient with yttrium oxide (1 g kg$^{-1}$) serving as the inert marker. Diets were randomly assigned to triplicate tanks and fish were fed once per day at 2% body weight. Fecal samples were collected by manual stripping. The ADCs were calculated according to standard procedures. The composition and digestibility of Asian carp and common carp meals was broadly similar to menhaden meal. Protein digestibility ranged from 86.5% (Asian carp meal) to 93.1% (common carp meal). Lipid was highly digestible with ADCs >100% for all ingredients. Although the Asian carp meal was less digestible than the other two fish meals, it was still a highly digestible ingredient. Our data suggest that fish meals derived from Asian or common carp would be valuable feedstuffs in diets for hybrid striped bass, rainbow trout, and possibly other cultured fishes.

KEY WORDS: bighead carps, fishmeal, *Hypophthalmichthys* spp., invasive species, sunshine bass

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## Introduction

Marine-origin fish meal has traditionally been used as the principal protein source in aquafeeds for carnivorous taxa because it generally meets the essential amino acid requirements of fish, it is protein dense, highly palatable, and readily accepted by tuna (Van Barneveld & Vandepeer 2007), yellowtail (*Seriola* sp.; Kolkovski & Sakakura 2007), grouper (*Epinephelus* sp.; Ottolenghi *et al*. 2004; Sim *et al*. 2005), barramundi (*Lates calcarifer*; Thongrod 2007), snapper (*Lutjanus* sp.; Tacon & Metian 2009), flounder (*Paralichthys* sp.; Tacon & Metian 2009), croaker (*Larimichthys* sp.; Tacon & Metian 2009), and pompano (*Trachinotus* sp.; Tacon & Metian 2009). Given that protein tends to be the most expensive component of fish feeds and feed typically accounts for 40–50% of operating costs of intensive fish production (Cheng *et al*. 2004), there are considerable economic incentives to reduce the aquaculture industry's reliance on fish meal as a primary dietary ingredient. The aquaculture industry continues to grow to meet the increasing demand for fisheries products (FAO 2012), but a combination of stagnant supply and high demand for fish meal has led to dramatic increases in fish meal costs. Whereas the price of fish meal from 1985 to 2000 fluctuated around $500 per metric ton, current prices exceed $2000 per metric ton (FAO 2013). Current supplies of fish meal will not be sufficient to meet the demand of future production if dietary inclusion of fish meal remains at high levels (Hardy & Tacon 2002): although fish meal has other applications, more than 70% of global production is used in the production of aquafeeds (Tacon & Metian 2011). Even though the use of fish meal in aquafeeds is expected to decline in the future due to an improved knowledge of the digestive processes and nutritional requirements of many farm-raised fishes (Food & Agriculture Organization of the United Nations (FAO) 2012), fish meal will continue to play an essential role as a dietary protein source in aquafeeds, particularly for emerging culture taxa. Finding a source of fish meal from underutilized alternative fish meal sources such as silver carp *Hypopthalmichthys molitrix* and bighead carp *H. nobilis* (hereafter referred to simply as Asian carp) as well as common carp *Cyprinus carpio* will benefit the aquaculture industry.

Asian and common carp are low value fishes with little potential as food fishes in the United States. Therefore, they are particularly suited for industrial applications such as rendering. Like traditional fish meal sources with limited seafood market potential (e.g., menhadens, anchovies, and herrings), Asian and common carp could be rendered to produce nutrient-dense meals for livestock feeds, especially aquafeeds. Common carp are abundant in many rivers and impoundments across the United States (Nico *et al.* 2013) and recently Asian carp have rapidly expanded and proliferated in the Mississippi River Basin (Conover *et al.* 2007). The abundance and wide distribution of carps make them an attractive target for new reduction fisheries. Although these fisheries do not compare in volume to traditional marine fish meal sources, they may provide a cost-effective supplement to marine harvest. However, demand for these carp meals depends on producing a quality rendered product. The nutritional compositions of fishes are known to vary by taxon as well as harvest location and season (Bragadottir *et al.* 2004; Boran *et al.* 2008).

Asian and common carp meals have advantages over other alternative feedstuffs in aquafeed production due to their similarity to traditional fish meal sources. Fish meal replacement presents a variety of challenges for nutritionally demanding carnivorous fish. Fish feeds contain higher protein levels than other livestock feeds (Keembiyehetty & Gatlin 1992), and aquafeed manufacturers have traditionally relied on fish meal to meet this demand. The rising cost of marine fish meals has forced feed manufacturers to explore a variety of plant-based (e.g., soybean, canola, corn, and wheat) and animal-based (e.g., poultry, blood, and feather) feedstuffs. However, a combination of chemical composition, nutrient utilization, digestibility, anti-nutritional factors, palatability, and functional attributes of these feedstuffs has made it difficult to create fish meal-free formulations that perform equally to formulations that include fish meal (Glencross *et al.* 2007). For example, soybean meal is a promising alternative to fish meal because of its favorable amino acid profile and relatively protein-dense content (Gatlin *et al.* 2007). Although soybean meal is routinely incorporated into fish feeds at moderate levels (Hendricks 2003), high inclusion levels have resulted in poorer fish performance, reduced diet palatability (Adelizi *et al.* 1998), higher feed conversion ratios (Davies & Morris 1997), and decreased mineral availability (Trushenski *et al.* 2006), and detrimental effects of anti-nutrients in soybean meals has been well documented on the intestine of salmonids (Ostaszewska *et al.* 2005; Heikkinen *et al.* 2006; Iwashita *et al.* 2008). Similar results have been demonstrated with other alternative feedstuffs (Subhadra *et al.* 2006; Lewis & Kohler 2008; Merida *et al.* 2010). Asian and common carp meals, on the other hand, would probably present few, if any, problems commonly associated with alternative feedstuffs.

Although numerous trials have reported the digestibility of various ingredients and feeds in fishes, such as hybrid striped bass *Morone chrysops* × *M. saxatilis* (also referred to as sunshine bass) and rainbow trout *Oncorhynchus mykiss*, digestibility data from studies utilizing extruded feeds is somewhat limited (Rawles *et al.* 2006a,b; Gaylord *et al.* 2010). As extrusion is the predominant method for the manufacture of commercial feeds used in hybrid striped bass and rainbow trout culture, the most relevant digestibility coefficients come from test diets manufactured in a similar process (Rawles *et al.* 2010; Glencross *et al.* 2011). Without data on the digestibility or availability of nutrients from the ingredients used in a formulation, one must make assumptions that may limit the ability of nutritionists and feed manufacturers to deliver high-performing diets based on alternative ingredients. Thus, in view of promising compositional data (Table 1), the potential use of Asian and common carp meals in aquafeeds will depend in part on the availability of nutrients from these products. Therefore, the objective of this study was to determine the nutrient composition and compare apparent digestibility of nutrients from fish meals derived from menhaden, Asian carp, and common carp in extruded feeds for hybrid striped bass and rainbow trout.

**Table 1** Composition (g kg$^{-1}$ dry matter basis) of fish meal sources fed to hybrid striped bass and rainbow trout

| Composition | Asian carp | Common carp | Menhaden |
|---|---|---|---|
| Protein (crude) | 640.1 | 674.6 | 687.3 |
| Lipid (crude) | 122.7 | 169.3 | 101.3 |
| Ash | 246.4 | 161.2 | 213.7 |
| Dry matter | 971.4 | 857.4 | 943.3 |
| Amino acid | | | |
| Ala | 32.1 | 36.5 | 31.3 |
| Arg | 27.2 | 30.0 | 25.8 |
| Asp | 42.8 | 36.8 | 38.2 |
| Cys | 4.0 | 2.3 | 3.8 |
| Glu | 53.3 | 47.3 | 49.9 |
| Gly | 32.7 | 49.0 | 36.6 |
| His | 10.0 | 7.0 | 9.4 |
| Ile | 21.1 | 15.6 | 18.3 |
| Leu | 36.4 | 27.6 | 32.8 |
| Lys | 36.1 | 26.5 | 31.4 |
| Met | 14.7 | 10.4 | 12.9 |
| Phe | 19.7 | 16.3 | 17.0 |
| Pro | 25.2 | 36.4 | 25.7 |
| Ser | 17.2 | 16.8 | 18.5 |
| Tau | 5.0 | 5.0 | 3.7 |
| Thr | 20.5 | 18.0 | 19.1 |
| Trp | 14.3 | 11.2 | 14.3 |
| Tyr | 15.7 | 11.1 | 12.9 |
| Val | 23.0 | 19.0 | 20.6 |

## Materials and methods

Hybrid striped bass (~140 g average weight; Keo Fish Farms Inc., Keo, AR, USA) and rainbow trout (~115 g average weight; Crystal Lake Fisheries, Ava, MO, USA) were used to determine the apparent digestibility coefficients (ADCs) of three fish meal sources: menhaden (Special Select™; Omega Protein, Houston, TX, USA), common carp (harvested from Utah Lake, Utah experimental fish meal; Northwest Fisheries Science Center, Seattle, WA, USA), and Asian carp (harvested from Illinois waterways, Protein Products, Gainsville, Florida) (Tables 1-3). The Asian carp meal was subjected to routine quality control/quality assurance tests by a commercial feed manufacturer and met typical standards for fish meal used in aquafeed manufacturing (personal communication, Scott Snyder; formerly of Zeigler Bros., Inc., Gardners, PA, USA). The Asian carp meal was derived primarily from silver carp, although some bighead carp were likely included in the rendering process. Although previous research had shown the composition of carps to vary by harvest location and season (Vujković *et al.* 1999; Steffens & Wirth 2005; Guler *et al.* 2008), previous research had indicated that both species harvested from the Illinois River had generally comparable value as raw materials for rendering into a

**Table 2** Fatty acid composition (g kg$^{-1}$ of identified fatty acids on a dry matter basis) of fish meal sources fed to hybrid striped bass and rainbow trout

| Fatty acid(s) | Asian carp | Common carp | Menhaden |
|---|---|---|---|
| 14:0 | 13.7 | 34.3 | 101.8 |
| 16:0 | 212.2 | 193.3 | 252.9 |
| 16:1n-7 | 36.0 | 97.7 | 117.3 |
| 16:2n-4 | 0.5 | 5.0 | 14.7 |
| 17:0 | 2.4 | 9.7 | 5.3 |
| 16:3n-4 | 0.0 | 2.5 | 17.0 |
| 17:1 | 0.0 | 3.8 | 0.0 |
| 18:0 | 63.9 | 42.9 | 51.9 |
| 18:1n-9 | 470.4 | 183.7 | 81.9 |
| 18:1n-7 | 23.8 | 69.6 | 32.1 |
| 18:2n-6 | 118.8 | 93.3 | 13.3 |
| 18:3n-6 | 2.1 | 1.5 | 1.7 |
| 18:3n-4 | 1.2 | 4.1 | 4.9 |
| 18:3n-3 | 8.8 | 83.9 | 9.6 |
| 18:4n-3 | 1.0 | 18.6 | 18.5 |
| 20:1n-9 | 13.2 | 10.8 | 9.6 |
| 20:2n-6 | 6.5 | 7.7 | 1.6 |
| 20:3n-6 | 7.5 | 4.2 | 2.6 |
| 20:4n-6 | 7.5 | 26.1 | 17.3 |
| 20:5n-3 | 4.2 | 56.7 | 125.8 |
| 22:5n-3 | 1.9 | 18.5 | 25.4 |
| 22:6n-3 | 4.4 | 32.1 | 95.0 |
| SFA[1] | 292.1 | 280.2 | 411.9 |
| MUFA[2] | 543.4 | 365.7 | 240.8 |
| PUFA[3] | 164.4 | 354.1 | 347.3 |
| MC-PUFA[4] | 132.0 | 201.5 | 47.9 |
| LC-PUFA[5] | 32.0 | 145.1 | 267.6 |
| n-3 | 20.3 | 209.7 | 274.2 |
| n-6 | 142.5 | 132.7 | 36.5 |

[1] SFA = saturated fatty acids (no double bonds).
[2] MUFA = monounsaturated fatty acids (1 double bond).
[3] PUFA = polyunsaturated fatty acids (2 or more double bonds).
[4] MC-PUFA = medium-chain polyunsaturated fatty acids (18 carbon atoms with 2 or more double bonds).
[5] LC-PUFA = long-chain polyunsaturated fatty acids (20 or more carbon atoms with 3 or more double bonds).

**Table 3** Mineral composition (ug g$^{-1}$ sample) of fish meal sources fed to hybrid striped bass and rainbow trout

| Mineral | Asian carp | Common carp | Menhaden |
|---|---|---|---|
| Ba | BD[1] | BD | 13.0 |
| Cu | BD | BD | BD |
| Mn | BD | BD | 64.3 |
| Ti | 42.0 | 41.6 | 44.0 |
| Ca | 61615 | 30665 | 46815 |
| Fe | 197 | 126 | 851 |
| Mg | 2340 | 1572 | 3301 |
| P | 9289 | 20711 | 15143 |
| K | BD | BD | BD |
| S | 6106 | 7231 | 8743 |
| Zn | 137 | 381 | 117 |
| Y | BD | BD | BD |

[1] BD = below detection level.

protein meal (Bowzer *et al.* 2013). The methods of Cho *et al.* (1982) and Bureau *et al.* (1999) were used to estimate the apparent digestibility of crude protein, amino acids, crude lipid, fatty acids, and minerals as described by Barrows *et al.* (2012). Yttrium oxide served as the inert maker, and the reference diet met or exceeded all known nutritional requirements of hybrid striped bass and rainbow trout (NRC 2011) (Table 4). Test diets consisted of a 70 : 30 ratio (dry matter basis) of reference diet to test ingredient.

All diets were manufactured with a twin-screw cooking extruder (DNDL-44; Buhler AG, Uzwil, Switzerland) with an 18 s exposure to an average temperature of 109 °C. The die plate (3 mm) was water cooled to an average temperature of 60 °C. Pressure varied at the die head from 18 to 29 bar, depending on the diet. The pellets were dried in a pulse-bed drier (Buhler AG) for ~15 min at 88 °C or until final moisture levels were <100 g $kg^{-1}$ as determined by microwave moisture analyzer (uWave; Omnimark, Bohemia, NY, USA). The pellets were then cooled with forced air at ambient temperatures. All added oil was incorporated in the mix rather than top coated.

Both trials followed similar procedures in comparable recirculating systems with continuous flow and aeration. Tanks were stocked with five fish and water temperatures were maintained at approximately 22 and 16 °C for hybrid striped bass and rainbow trout, respectively. The photoperiod remained 24 h light throughout both trials. Each test diet was randomly assigned to triplicate tanks ($N = 3$) and fed once per day at 2% body weight. The fish were acclimated to experimental conditions for 1 week prior to the beginning of fecal sample collection. Fecal samples were collected by manual stripping 8 h (hybrid striped bass) and 26 h (rainbow trout) postfeeding. Collection times were chosen based on previous experience with gut passage rates and fecal sample collection for these taxa. Manual stripping was accomplished by transferring fish to an aerated sedative bath [hybrid striped bass: 30 mg $L^{-1}$ and rainbow trout: 15 mg $L^{-1}$ eugenol; AQUI-S 20E (10% eugenol), Aqui-S New Zealand Ltd., Lower Hutt, New Zealand], gently drying the vent area of sedated fish, and applying pressure to the lower abdominal region to expel fecal material into a plastic tube. Precautions were taken to exclude water, urine, mucus, scales, etc. from the fecal samples. Following fecal sample collection, fish were returned to their respective tanks to recover, and normal feeding and culture conditions resumed the subsequent day. The process was repeated every 2 days, pooling fecal material by tank, until a sufficient volume of feces was obtained for analysis.

**Table 4** Composition of reference diet (g $kg^{-1}$) dry matter basis adapted from Barrows *et al.* (2012)

| *Ingredient* | |
|---|---|
| Wheat flour | 293.3 |
| Squid meal | 250.0 |
| Soy protein concentrate | 171.4 |
| Menhaden fish oil | 133.9 |
| Corn protein concentrate | 83.4 |
| Soybean meal, solvent extracted | 43.0 |
| Vitamin premix ARS 702 | 10.0 |
| Choline chloride | 6.0 |
| Taurine | 5.0 |
| Stay-C | 2.0 |
| Trace mineral premix | 1.0 |
| Yttrium oxide | 1.0 |
| Analyzed composition | |
| Crude protein | 464.2 |
| Crude lipid | 142.9 |

Dry matter analysis of ingredients, diets, and feces was performed according to standard methods (AOAC 1995). Mineral contents were quantified in ingredients, diets and feces by inductively coupled plasma atomic absorption spectrophotometry following nitric acid digestion (Anderson 1996). Crude protein (N × 6.25) was determined in ingredients, diets, and feces by the Dumas method (Association of Official Analytical Chemists (AOAC) 1995) on a Leco TruSpec *N* nitrogen determinator (LECO Corp., St. Joseph, MI, USA). Amino acid concentrations in samples were determined by high performance liquid chromatography (HP1100; Agilent Technologies, Wilmington, DE, USA) following acid hydrolysis (Association of Official Analytical Chemists (AOAC) 1995) using precolumn *o*-phthaldehyde derivatization (Fleming *et al.* 1992). Tryptophan in samples was similarly analyzed by HPLC following basic hydrolysis (AOAC 2000). Total lipid was determined gravimetrically following chloroform/methanol extraction modified from Folch *et al.* (1957). Resultant lipid fractions were analyzed for fatty acid composition according to the procedures described by Laporte & Trushenski (2011). Samples were subjected to acid-catalyzed transmethylation performed overnight at 50 °C as described by Christie (1982) and the resultant fatty acid methyl esters (FAME) were separated using a Shimadzu GC-17A gas chromatograph (Shimadzu Scientific Instruments, Kyoto, Japan) equipped with a flame ionization detector fitted with a permanently bonded polyethylene glycol, fused silica capillary column (Omegawax 250, 30 × 0.25 mm I.D., 0.25 μm film; Sigma Aldrich, St. Louis, MO, USA). Individual FAME were identified by reference to external standards (Supelco 37 Component

FAME Mix, PUFA-1, and PUFA-3; Supelco, Bellefonte, PA, USA). To calculate the ADCs of fatty acids, % FAME was converted to dry matter concentration of fatty acids in the samples using the following equation:

$$\mathrm{FA} = (x/100\mathrm{g\ sample}) \times (0.93\mathrm{g\ FAME}/1\mathrm{g\ lipid}) \times (y/100\mathrm{g\ FAME})$$

where, FA = g of the fatty acid per 100 g of sample, $x$ = g of lipid in the sample, $y$ = g of the fatty acid in the sample, ADCs of each nutrient in the test diet ($ADC_{diet}$) and ingredients ($ADC_{ingredient}$) were calculated according to the following equations (Kleiber 1961; Forster 1999):

$$ADC_{diet} = 100 - 100\{\%\mathrm{Yt\ in\ diet} \times \%\mathrm{nutrient\ in\ feces}\}/\{\%\mathrm{Yt\ in\ feces} \times \%\mathrm{nutrient\ in\ diet}\}$$

$$ADC_{ingredient} = \{(a+b)\ ADCN_t - (a)\ ADCN_r\}b^{-1}$$

where, $ADC_{ingredient}$ = apparent digestibility coefficient of the nutrient in the test ingredient, $ADC_t$ = apparent digestibility coefficients of the nutrient in the test diet; $ADC_r$ = apparent digestibility coefficients of the nutrient in the reference diet; $a = (1-p) \times$ nutrient content of the reference diet; $b = p \times$ nutrient content of the test ingredient; $p$ = proportion of test ingredient in the test diet (0.3 in the present study).

Tanks served as the experimental units for all statistical analyses ($N$ = 3). Apparent digestibility coefficients for protein, amino acids, lipid, FAME, and minerals in the test ingredients were subjected to a two-way ANOVA design within the generalized linear mixed model framework (GLIMMIX procedure) of the Statistical Analysis System, version 9.2 (SAS Institute, Cary, NC, USA) to determine whether there were differences among taxa, fish meal type, or main effect interactions. When interaction was found non-significant, the interaction term was removed from the model and only main effects were determined. Significant differences among main effect means were subjected to pairwise comparisons using Tukey's HSD test (Tukey 1953). All effects were considered significant at $P < 0.05$.

## Results

Interaction among fish taxa and meal type was not found in the digestibility data except for three response variables (16:2n-4, 18:2n-6, and glycine). Residual analysis revealed significant interactions were caused by the presence of extreme outliers in those responses. Once the outliers were excluded from analysis, no interactions were found.

### *Effect of fish meal type*

The apparent digestibility coefficients (ADCs) for crude protein were significantly lower in Asian carp meal when compared with common carp and menhaden fish meals (Table 5). Overall, amino acids in the fish meals were highly digestible (>80%), with the exception of tryptophan (68.4%) and aspartate (79.0%) in Asian carp meal. Lysine digestibility was particularly lower in Asian carp meal (82.4%) when compared with common carp (94.0%) and menhaden (98.5%) fish meals.

There were no significant differences in the ADCs of crude lipid among fish meal sources. However, individual fatty acids in Asian carp meal generally exhibited lower ADCs than those of common carp and menhaden meal (Table 6). The digestibility coefficients of saturated fatty acids (SFA), long-chain polyunsaturated fatty acids (LC-PUFA), and n-3 fatty acids in Asian carp meal were particularly lower than those in the other two fish meals. Individual fatty acids that contributed to the lower ADCs observed in the SFA lipid class included C14:0, C16:0, C17:0, and C18:0. The lower digestibility of LC-PUFA and n-3 fatty acids in Asian carp meal were primarily due to lower eicosapentaenoic acid (20:5n-3) and docosahexaenoic acid (22:6n-3) availability, approximately 30%, as compared to over 85% in the other two fish meal sources (Table 6). The n-6 fatty acid group in Asian carp meal had a much higher ADC (94.3%) than the n-3 fatty acid group (64.3%). The ADCs of all nutrients for common carp and menhaden fish meal were similar with only minor statistical differences (Tables 5 and 6).

Due to the low levels detected (<1000 ug $g^{-1}$) for many of the minerals analyzed (Table 3), ADCs were only calculated for four minerals in fish meal sources (Table 7). Calcium digestibility was below 25% in all three fish meals. Magnesium digestibility was highest in the common carp meal (75.8%) followed by Asian carp meal (69.6%) and menhaden meal (47.8%). Phosphorus digestibility coefficients were not significantly different among fish meal sources ranging between 41.8% and 45.4%. Sulfur was highly digestible (>95%) in all three fish meals.

### *Effect of taxon*

Rainbow trout had significantly higher ADCs for crude protein and most amino acids when compared with hybrid striped bass in this study (Table 5). Tryptophan availability was much higher in rainbow trout (RBT) (90.8%) than hybrid striped bass (81.3%). However, hybrid striped bass

**Table 5** Apparent digestibility coefficients for crude protein and amino acids from three fish meal sources in extruded feeds for hybrid striped bass and rainbow trout

| Protein/amino acid | Fish meal source | | | Taxon | |
|---|---|---|---|---|---|
| | Asian carp | Common carp | Menhaden | Hybrid striped bass | Rainbow trout |
| Protein | 86.5 ± 0.3*y* | 93.1 ± 0.3*z* | 92.7 ± 0.3*z* | 89.3 ± 0.2*y* | 92.2 ± 0.2*z* |
| Ala | 86.5 ± 0.4*x* | 92.0 ± 0.4*y* | 94.3 ± 0.4*z* | 90.6 ± 0.3 | 91.3 ± 0.3 |
| Arg | 96.6 ± 1.2*y* | 101.2 ± 1.2*z* | 102.3 ± 1.2*z* | 98.8 ± 0.9 | 101.2 ± 0.9 |
| Asp | 79.0 ± 0.5*y* | 89.8 ± 0.5*z* | 89.4 ± 0.5*z* | 84.4 ± 0.4*y* | 87.8 ± 0.4*z* |
| Cys | 88.9 ± 4.6 | 89.7 ± 4.6 | 97.8 ± 4.6 | 91.9 ± 3.8 | 92.4 ± 3.8 |
| Glu | 88.8 ± 0.2*x* | 93.6 ± 0.2*y* | 94.8 ± 0.2*z* | 91.8 ± 0.2*y* | 93.0 ± 0.2*z* |
| Gly | 86.0 ± 0.6*y* | 84.7 ± 0.6*y* | 90.5 ± 0.6*z* | 86.4 ± 0.5 | 87.6 ± 0.5 |
| His | 84.5 ± 0.4*x* | 87.9 ± 0.4*y* | 92.4 ± 0.4*z* | 87.3 ± 0.3*y* | 89.2 ± 0.3*z* |
| Ile | 81.2 ± 0.7*y* | 94.3 ± 0.7*z* | 95.7 ± 0.7*z* | 89.8 ± 0.5 | 91.1 ± 0.5 |
| Leu | 89.6 ± 0.3*y* | 94.4 ± 0.3*z* | 95.1 ± 0.3*z* | 92.8 ± 0.2 | 93.3 ± 0.2 |
| Lys | 82.4 ± 0.6*x* | 94.0 ± 0.6*y* | 98.5 ± 0.6*z* | 91.2 ± 0.5 | 92.0 ± 0.5 |
| Met | 85.7 ± 0.5*x* | 91.6 ± 0.5*y* | 95.4 ± 0.5*z* | 90.2 ± 0.4*y* | 91.6 ± 0.4*z* |
| Phe | 90.2 ± 0.3*y* | 94.6 ± 0.3*z* | 95.4 ± 0.3*z* | 93.3 ± 0.3 | 93.5 ± 0.3 |
| Pro | 96.3 ± 2.3 | 98.7 ± 2.3 | 95.5 ± 2.3 | 100.6 ± 1.8*z* | 93.0 ± 1.8*y* |
| Ser | 87.9 ± 0.4*y* | 89.0 ± 0.4*y* | 92.3 ± 0.4*z* | 88.7 ± 0.3*y* | 90.8 ± 0.3*z* |
| Tau | 127.0 ± 8.6 | 129.9 ± 8.6 | 116.0 ± 8.6 | 128.8 ± 7.0 | 119.7 ± 7.0 |
| Thr | 85.9 ± 0.4*x* | 91.5 ± 0.4*y* | 93.2 ± 0.4*z* | 89.4 ± 0.4*y* | 91.0 ± 0.4*z* |
| Trp | 68.4 ± 2.5*y* | 95.4 ± 2.5*z* | 94.5 ± 2.5*z* | 81.3 ± 2.1*y* | 90.8 ± 2.1*z* |
| Tyr | 89.2 ± 0.3*y* | 94.3 ± 0.3*z* | 94.6 ± 0.3*z* | 91.7 ± 0.2*y* | 93.6 ± 0.2*z* |
| Val | 85.5 ± 0.6*y* | 94.9 ± 0.6*z* | 95.6 ± 0.6*z* | 90.6 ± 0.5 | 92.1 ± 0.5 |

had significantly higher ADCs for proline (100.6%) than rainbow trout (93.0%). Although crude lipid was not significantly different between taxa, hybrid striped bass generally had slightly higher digestibility coefficients than rainbow trout for individual FAMEs. The availability of SFA was particularly higher in hybrid striped bass (87.1%) when compared with rainbow trout (71.4%). However, the overall ADCs of all nutrients in the tested fish meals were high for both taxa.

Few taxon differences were observed in mineral availability (Table 7). Rainbow trout (50.2%) had a significantly higher ADC for phosphorus when compared with hybrid striped bass (35.9%). However, hybrid striped bass (104.8%) appear to utilize sulfur better than rainbow trout (97.4%). The ADCs for calcium and magnesium were not significantly different between taxa.

## Discussion

Market and environmental factors suggest that traditional marine sources of fish meal are not capable of sustainably increasing catches to support increases in demand (Tacon & Nates 2007). Given that marine fish meal is a dominant ingredient in the diets of many cultured carnivorous fish due to the demanding nutritional needs of these taxa, nutritionists have been concerned with finding suitable alternatives. When considering potential replacements, nutrient composition and digestibility are usually evaluated first because nutrient availability is necessary for accurate and low-cost diet formulations (Rawles *et al*. 2010). Freshwater fish meal sources, such as the Asian carp and common carp evaluated in this study, are similar compositionally to traditional marine fish meal sources, particularly with respect to crude protein and amino acid content, and given that Asian carp meal is currently priced at $600-650 per metric ton (P. Hitchens, Southern Illinois University Carbondale, personal communication), carp meals are promising cost-effective alternative protein sources for aquafeed manufacturers that may be able to alleviate some of the demand on marine fish meal sources. However, it is expected that the price of Asian carp meal will more closely resemble traditional marine-origin fish meal sources once the market is established due to the similarity of the products. Even though the fatty acid profiles varied among fish meals in this study, particularly in beneficial 20:5n-3 and 22:6n-3 content, which was highest in the menhaden meal, the primary source of these nutrients in the diet typically comes from the oil source used in the formulation. Given the importance of other ingredients, such as fish oil, as sources of beneficial LC-PUFA, the fatty acid profile of fish meal is of less concern in the context of aquafeed formulation. Nevertheless, the common carp meal used in this study more closely resembled the fatty acid profile of menhaden meal. Additionally, mineral content

**Table 6** Apparent digestibility coefficients for crude lipid and fatty acids from three fish meal sources in extruded feeds for hybrid striped bass and rainbow trout

| Lipid/fatty acid(s) | Fish meal source | | | Taxon | |
|---|---|---|---|---|---|
| | Asian carp | Common carp | Menhaden | Hybrid striped bass | Rainbow trout |
| Lipid | 103.5 ± 1.1 | 100.6 ± 1.1 | 100.2 ± 1.1 | 101.3 ± 0.8 | 101.6 ± 0.8 |
| 14:0 | 49.5 ± 9.4*y* | 92.1 ± 9.4*z* | 96.6 ± 9.4*z* | 90.1 ± 7.7*z* | 68.6 ± 7.7*y* |
| 16:0 | 70.4 ± 4.1*y* | 86.8 ± 4.1*z* | 93.4 ± 4.1*z* | 89.7 ± 3.4*z* | 77.4 ± 3.4*y* |
| 16:1n-7 | 86.4 ± 1.5*y* | 96.4 ± 1.5*z* | 97.7 ± 1.5*z* | 94.5 ± 1.2 | 92.5 ± 1.2 |
| 16:2n-4 | 116.8 ± 1.0*z* | 99.6 ± 1.0*y* | 99.6 ± 1.0*y* | 99.6 ± 0.8*y* | 111.0 ± 0.8*z* |
| 17:0 | 48.5 ± 7.0*y* | 86.4 ± 7.0*z* | 89.9 ± 7.0*z* | 83.3 ± 5.7 | 66.6 ± 5.7 |
| 16:3n-4 | BD[1] | 100.0 ± 0.2 | 99.7 ± 0.2 | 100.0 ± 0.2 | 99.7 ± 0.2 |
| 17:1 | BD | 100.0 ± 0.0 | BD | 100.0 ± 0.0 | 100.0 ± 0.0 |
| 18:0 | 63.5 ± 4.7*y* | 73.3 ± 4.7*zy* | 86.2 ± 4.7*z* | 82.0 ± 3.9*z* | 66.6 ± 3.9*y* |
| 18:1n-9 | 93.6 ± 1.6 | 95.1 ± 1.6 | 95.7 ± 1.6 | 95.3 ± 1.3 | 94.3 ± 1.3 |
| 18:1n-7 | 85.2 ± 1.6*y* | 95.1 ± 1.7*z* | 96.6 ± 1.7*z* | 93.6 ± 1.4 | 91.1 ± 1.4 |
| 18:2n-6 | 95.5 ± 1.1*y* | 97.2 ± 1.1*y* | 106.4 ± 1.1*z* | 97.7 ± 0.9*y* | 101.7 ± 0.9*z* |
| 18:3n-6 | 97.6 ± 4.7 | 82.4 ± 4.7 | 98.2 ± 4.7 | 101.0 ± 3.8*z* | 84.4 ± 3.8*y* |
| 18:3n-4 | 100.0 ± 0.5 | 100.0 ± 0.5 | 99.1 ± 0.5 | 100.0 ± 0.4 | 99.4 ± 0.4 |
| 18:3n-3 | 92.9 ± 1.5 | 98.0 ± 1.5 | 98.1 ± 1.5 | 94.8 ± 1.2 | 97.9 ± 1.2 |
| 18:4n-3 | 100.0 ± 0.3 | 99.7 ± 0.3 | 99.2 ± 0.3 | 99.5 ± 0.3 | 99.7 ± 0.3 |
| 20:1n-9 | 87.4 ± 1.9*y* | 89.6 ± 1.9*y* | 98.4 ± 1.9*z* | 91.9 ± 1.5 | 91.8 ± 1.5 |
| 20:2n-6 | 93.9 ± 2.2 | 97.5 ± 2.2 | 96.9 ± 2.2 | 98.4 ± 1.8 | 93.8 ± 1.8 |
| 20:3n-6 | 91.5 ± 4.8 | 92.1 ± 4.8 | 99.2 ± 4.8 | 96.7 ± 3.9 | 91.8 ± 3.9 |
| 20:4n-6 | 76.3 ± 1.5*y* | 93.8 ± 1.5*z* | 95.2 ± 1.5*z* | 87.2 ± 1.3 | 89.6 ± 1.3 |
| 20:5n-3 | 29.8 ± 6.2*y* | 93.9 ± 6.2*z* | 98.0 ± 6.2*z* | 70.0 ± 5.0 | 77.8 ± 5.0 |
| 22:5n-3 | 76.9 ± 8.0 | 97.1 ± 8.0 | 97.8 ± 8.0 | 89.3 ± 6.5 | 91.9 ± 6.5 |
| 22:6n-3 | 29.4 ± 4.6*y* | 85.9 ± 4.6*z* | 96.1 ± 4.6*z* | 72.0 ± 3.7 | 68.9 ± 3.7 |
| SFA[2] | 67.8 ± 4.4*y* | 85.6 ± 4.4*z* | 93.2 ± 4.4*z* | 88.8 ± 3.6*z* | 75.6 ± 3.6*y* |
| MUFA[3] | 92.6 ± 1.1*y* | 95.3 ± 1.1*zy* | 96.8 ± 1.1*z* | 95.5 ± 0.9 | 94.3 ± 0.9 |
| PUFA[4] | 90.0 ± 1.0*y* | 95.6 ± 1.0*z* | 97.7 ± 1.0*z* | 94.4 ± 0.8 | 94.5 ± 0.8 |
| MC-PUFA[5] | 95.2 ± 0.7*y* | 97.6 ± 0.7*y* | 100.4 ± 0.7*z* | 97.1 ± 0.6 | 98.3 ± 0.6 |
| LC-PUFA[6] | 70.1 ± 2.4*y* | 92.7 ± 2.4*z* | 97.1 ± 2.4*z* | 86.3 ± 1.9 | 86.9 ± 1.9 |
| n-3 | 64.3 ± 3.3*y* | 95.1 ± 3.3*z* | 97.4 ± 3.3*z* | 84.5 ± 2.7 | 86.7 ± 2.7 |
| n-6 | 94.3 ± 1.0*y* | 96.3 ± 1.0*zy* | 99.9 ± 1.0*z* | 96.2 ± 0.8 | 97.4 ± 0.8 |

[1] BD = below detection level.
[2] SFA = saturated fatty acids (no double bonds).
[3] MUFA = monounsaturated fatty acids (1 double bond).
[4] PUFA = polyunsaturated fatty acids (2 or more double bonds).
[5] MC-PUFA = medium-chain polyunsaturated fatty acids (18 carbon atoms with 2 or more double bonds).
[6] LC-PUFA = long-chain polyunsaturated fatty acids (20 or more carbon atoms with 3 or more double bonds).

**Table 7** Apparent digestibility coefficients of minerals from three fish meal sources in extruded feeds for hybrid striped bass and rainbow trout

| Mineral | Fish meal source | | | Taxon | |
|---|---|---|---|---|---|
| | Asian carp | Common carp | Menhaden | Hybrid striped bass | Rainbow trout |
| Ca | 22.3 ± 3.3*z* | 10.4 ± 3.3*zy* | 9.1 ± 3.3*y* | 12.1 ± 2.7 | 15.7 ± 2.7 |
| Mg | 69.6 ± 7.5*zy* | 75.8 ± 7.5*z* | 47.8 ± 7.5*y* | 69.9 ± 6.1 | 58.9 ± 6.1 |
| P | 41.8 ± 2.5 | 42.0 ± 2.5 | 45.4 ± 2.5 | 35.9 ± 2.0*y* | 50.2 ± 7.5*z* |
| S | 108.1 ± 2.5*z* | 95.6 ± 2.3*y* | 99.7 ± 2.3*zy* | 104.8 ± 1.9*z* | 97.4 ± 1.9*y* |

was similar among the studied fish meals, although phosphorus content was slightly higher in the common carp meal.

Although the Asian carp meal in this study was generally less digestible than the common carp and menhaden fish meals, it was still a highly digestible, nutrient-dense product that could be included in feed formulations. Effective diets can still be formulated with ingredients with slightly lower ADCs, but more of that ingredient needs to be added to have the same level of digestible nutrients. Lower ADCs, however, will have an effect on the value or price of an ingredient.

Poultry byproduct meal is considered a cost-effective alternative to fish meal for many fish including hybrid striped bass and rainbow trout (Gaylord & Rawles 2005; El-Haroun *et al.* 2009; Rawles *et al.* 2010). However, the fish meals evaluated in this study had higher nutrient digestibility and availability than the poultry by-product assessed by Rawles *et al.* (2010) for hybrid striped bass and Cheng *et al.* (2004) for rainbow trout. However, we did see slightly lower protein and amino acid digestibility for menhaden meal than previous reports for hybrid striped bass using the manual stripping method (Rawles *et al.* 2010). The ADCs of common carp and menhaden fish meals were largely similar. The greatest difference between fish meals regarding digestibility coefficients was in LC-PUFA and n-3 fatty acids, particularly 20:5n-3 and 22:6n-3. The Asian carp meal had significantly lower digestibility coefficients for these lipid groups and fatty acids when compared with the common carp and menhaden meals. The lower digestibility coefficients can probably be attributed to the much lower content of LC-PUFA, n-3 fatty acids, 20:5n-3, and 22:6n-3 in the composition of the Asian carp meal. It should be noted that the nutritional composition of the carp meals is dependent on the source of the raw materials and manufacturing processes. Bowzer *et al.* (2013) demonstrated variation in Asian carp harvested from the Illinois River seasonally and geographically with bighead carp being leaner in general than silver carp. Similarly, differences in body composition have been observed in common carp (Spiric *et al.* 2010; Mraz *et al.* 2012). Others have reported Asian carp to have higher concentrations of LC-PUFA and n-3 fatty acids (Vujković *et al.* 1999; Steffens & Wirth 2005; Guler *et al.* 2008), which may be attributed to differences in harvest location and season. However, it is equally important to note that these authors reported tissue fatty acid levels, which may not be directly comparable with levels in rendered products derived from these fish.

Additionally, water pollution concerns in the aquatic environment associated with aquaculture production have increased tremendously over the last decade (Cheng *et al.* 2004). Phosphorus and nitrogen tend to be the nutrients of greatest concern. Therefore, feedstuffs that contain highly digestible protein and phosphorus at appropriate levels can reduce the processing necessary to remove these nutrients from the discharge of aquaculture facilities. Since the carp meals are highly digestible with only slightly higher (common carp meal) or lower (Asian carp meal) phosphorus levels when compared with menhaden meal, they would be appropriate alternative feedstuffs in regards to maintaining or reducing the levels of nitrogen and phosphorus in the discharge of aquaculture facilities.

In general, few differences in nutrient ADCs were observed between RBT and hybrid striped bass in the current study with high digestibility and availability observed for all nutrients tested except calcium and phosphorus. Apparent availability of calcium was generally low for both taxa as well as in each fish meal source. Although calcium availability appears low, our values are similar to Sugiura *et al.* (1998) in which a variety of protein meal sources were evaluated in rainbow trout and coho salmon *O. kisutch*. Phosphorus was moderately available to both taxa, but rainbow trout (50.2%) had a much higher apparent availability when compared with hybrid striped bass (35.9%). Phosphorus availability in this study was lower than previously reported for rainbow trout in a variety of protein meal sources (Sugiura *et al.* 1998; Cheng *et al.* 2004). However, a direct comparison of ADCs for phosphorus with other studies is difficult due to differences among and within taxa, experimental procedures, and phosphorus levels in the ingredients (Papatryphon & Soares 2001). Additionally, ADCs are influenced by interactions with other nutrients (Papatryphon & Soares 2001). Given that few studies have compared multiple taxa with the same dietary treatments, determining potential differences among taxa is difficult (Burr *et al.* 2011). Possible reasons for the higher phosphorus ADC observed in rainbow trout in this study are that the dietary phosphorus concentrations in the diets were close to the estimated requirement for rainbow trout which would maximize the ADCs when compared with hybrid striped bass (Riche & Brown 1996) or the differences in fecal collection times could have influenced the observed ADCs.

It is widely recognized that different fecal collection techniques affect digestibility estimates, making comparisons between experiments difficult (Anderson *et al.* 1995; Glencross *et al.* 2005). In the current study, manual stripping was used to collect samples. Amirkolaie *et al.* (2005) stated that the main disadvantage of this method is the removal of gut content prior to complete digestion as well as possible contamination of feces (e.g., blood, slime, semen, or eggs) which can artificially increase nutrient content resulting in underestimated digestibility. Although care was taken to minimize contamination, it has been shown that repeated handling with the use of sedation (like in the present study) during manual stripping can affect intestinal transit and lower digestibility estimates when compared with other techniques (Spyridakis *et al.* 1989). However, Stone *et al*. (2008) did not see a reduction in the ADCs of rainbow trout with repeated manual stripping. Although discrepancies exist among methods, manual stripping is still considered a preferred conservative method for determining digestibility in fish (Glencross *et al*. 2005), and our results should be considered conservative estimates. Even assuming some underestimation of digestibility, all fish meals tested were highly digestible.

In conclusion, data from the current trial suggest that Asian and common carp meals are highly digestible and nutrient-dense feedstuffs broadly similar to menhaden meal which could be used as cost-effective alternatives in aquafeeds. Even though Asian carp meal is slightly less digestible when compared with the other fish meal sources tested in this study, it is still a highly digestible and compositionally desirable when compared with other alternative protein meals. Although Asian and common carp populations are unlikely to support the volume of landings associated with traditional, marine reduction fisheries, they could be a valuable source of additional inputs for aquafeed manufacturing.

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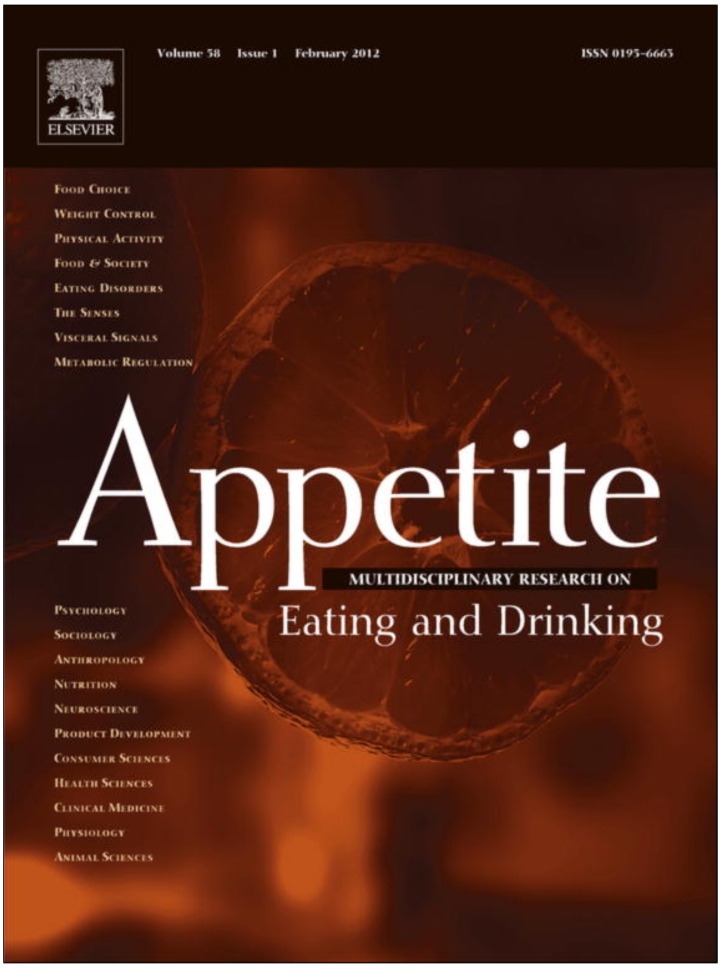


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Research report

# Human consumption as an invasive species management strategy. A preliminary assessment of the marketing potential of invasive Asian carp in the US ☆

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ABSTRACT

Over the past 20 years, Asian carp have invaded rivers and lakes in the Midwest and southern United States, with large negative impacts, such as encroachment on the habitat of native fish and mass die-off. They also respond to boat motors by jumping out of the water, which can cause harm to boaters and fishermen. Policymakers in the Great Lakes region between the US and Canada are worried about possible expansion of the Asian carp to their region and its effects on their fishing industry. A potential solution to the problem is to harvest Asian carp for human consumption. This study analyzes the results of the first national survey on the attitudes of US fish consumers towards Asian carp. We find that this is a potentially promising strategy. Most respondents would be willing to try a free sample of Asian carp and would be willing to pay for it. Because of the negative connotation attached to carp in general, this figure is encouraging. Creating demand for Asian carp could be a market based, cost-effective solution for a problem (invasive species) that is typically dealt with through command and control policies, if it is coupled with appropriate policies and safeguards to ensure the fish is eventually eradicated and not cultivated for profit after removal from US rivers and lakes.



## Introduction

Over the past 20 years, silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*Hypophthalmichthys nobilis*), collectively known as Asian carp, have invaded rivers and lakes in the Midwest and southern United States. Their widespread distribution throughout the US is shown in Fig. 1. They have had negative impacts on native fish, such as paddlefish, bigmouth buffalo, and gizzard shad, by directly competing for food and space (Irons, Sass, McClelland, & Stafford, 2007), thus, reducing native fish diversity (Chick & Pegg, 2001). Their ability to outcompete native fish results in decreased fish landings of more profitable native fish for commercial fishermen, which affects their economic welfare. Asian carp affect recreationalists through their mass die-offs and propensity to jump out of the water in response to a boat's motor (Garvey, Ickes, & Zigler, 2010). This causes dangerous and unpleasant situations for boaters, waterskiers, and recreational fishermen. In addition, their encroachment towards the Great Lakes has led to a federal lawsuit initiated by Michigan, Minnesota, Wisconsin, Ohio and Pennsylvania against the Metropolitan Water Reclamation District of Greater Chicago. The lawsuit would require the Army Corps of Engineers (a co-defendant) to build physical barriers between the Mississippi River and Lake Michigan in order to shut off all access routes (Egan, 2010). These states fear damage to a $7 billion fishing industry if Asian carp move into the Great Lakes (Asian Carp Regional Coordinating Committee, 2012). Though a Federal judge dismissed the lawsuit on December 3rd 2012, he also noted that he would reconsider the case if the plaintiffs re-filed under different grounds (Flesher & Webber, 2012). Overall, Asian carp have cost tax payers millions of dollars and caused unmeasurable damages to aquatic ecosystems. A potential solution to the problem is to harvest Asian carp for human consumption. Previous carp marketing research has focused on a specific US state and canned carp preparation (Engle & Kouka, 1995). This study analyzes the results of the first national survey on the attitudes of US fish consumers towards Asian carp.

While Asian carp have continued to increase their abundance, this trend is not common among many other fish species. Chilean seabass, Atlantic cod, orange roughy, flounder and red snapper are only a few of the numerous fish that have been overfished

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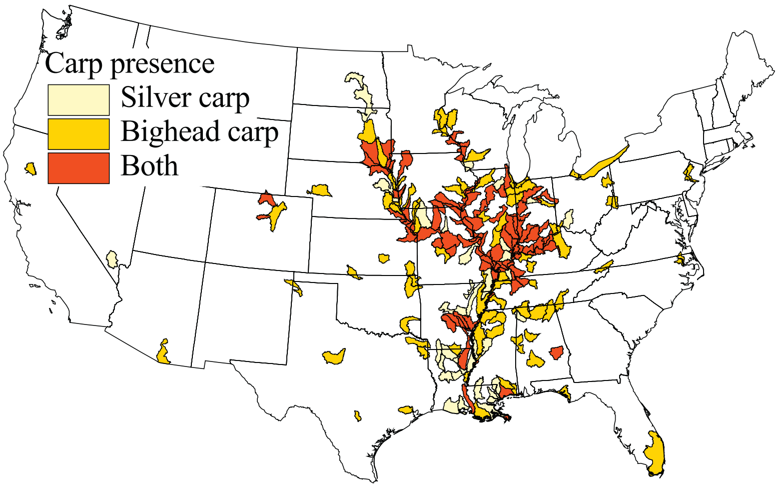


**Fig. 1.** Distribution of Asian carp in the US according to the US Geological Survey's Nonindigenous Aquatic Species database.

according to the Monterey Bay Seafood Watch (Monterey Bay Aquarium, 2012b). As researchers have touted the benefits of eating fish and a growing world population keeps demanding more protein, fish consumption has increased substantially. In the United States alone, consumption of edible fish meat has increased from 3.7 billion pounds in 1990 to 4.8 billion pounds in 2010 (Van Voorhees & Lowther, 2011), much of which is imported. US imports of edible fishery products in 2010 were worth $14.8 billion. In the US, the expansion in total consumption in the last decade has been mainly due to population growth, with flat per capita consumption. Worldwide, however, in the last 20 years there has been an increase in per capita consumption, even excluding questionable statistics from China (FAO, 2012). The increase is entirely due to aquaculture, as capture fisheries have been unable to keep up with demand. Given this overall background, a proposed solution to the Asian carp invasion is to use the meat for domestic consumption. This would alleviate the stress on America's waterways and would provide a local, plentiful supply of fish.

However, many challenges must be overcome before this solution can be implemented. On the marketing side, one of the biggest hurdles at this moment is that American consumers have a negative view of Asian carp as food. Much of this stems from the misconception that bighead and silver carp taste like their cousins, the common and grass carps. Although all of these carp originated from Asia, silver and bighead carp have a much lighter, more delicate flavor than grass or common carp (Bardach, Ryther, & McLarney, 1972). This is one of the reasons why silver and bighead carp are the most cultured fish in the world by weight (FAO, 2012).

The difference in taste is mainly due to their diet. Both bighead and silver carp are filter feeders and their diet consists of zooplankton and phytoplankton. Grass and common carp are bottom feeders (Bardach et al., 1972), which impacts the flavor of their meat. Occasionally other factors can cause off flavors, such as algae that is occasionally present in the water, which can emit toxins such as geosmin and methylisoborneol (Persson, 1984; Tabachek & Yurkowski, 1976). However, research done by Papp, Kerepeczki, Pekár, and Gál (2007) found that bottom feeding common carp had 5–10 times the amount of geosmin present in their fillets than filter feeding silver carp, concluding that the type of feeding habits affects meat flavor (Papp et al., 2007). Another issue specific to the US is that, because they are so numerous in rivers and streams in the Midwest, silver and bighead carp are considered to have little value (carp is currently selling at about 5 cents a pound), thus consumers may not be willing to pay for their meat. Further, since they will be harvested from rivers that may be thought to have water quality issues, demand for Asian carp meat may be decreased as consumers are already aware of the dangers of eating fish (Verbeke et al., 2008). On the other hand, carp would be locally harvested and processed, and this may be valued by consumers who prefer local food. Local production coupled with the fact that consuming carp is actually helping solve an environmental problem may make carp products more attractive. Indeed, in the US, proponents of the invasivore movement promote the eating of invasive species as a management strategy (Weis, 2011).

On the production side, however, there are concerns because of potential ecological and fisheries management impacts of harvesting Asian carp. From a ecological perspective, preliminary stochastic simulation modeling results suggest that fishing could collapse the Asian carp population to functional extinction if all sizes of Asian carp are harvested (Garvey et al., 2012). Specifically, the probability of collapse is much less if only small or large Asian carp are harvested. As such, a market based solely on the human consumption of large adults would also have to be combined with markets that could target smaller Asian carp, such as organic fertilizer, livestock and aquaculture feeds, and pharmaceuticals (i.e., fish oil). However, the removal of the large, fecund females could have a larger effect on population declines than predicted given that recent evidence suggests that larger females spawn earlier within a spawning season than smaller Asian carp, potentially leading to greater reproductive success of larger females (Glover, 2012). From a fisheries management perspective, there is some evidence that the harvest of Asian carp will not negatively affect the harvest of other fish in the Illinois and Mississippi rivers, and that the supply of fish is relatively unresponsive to the price of fish (Speir & Brozovic, 2006). This suggests that fishermen in the area have either limited ability to fish one specific species or are unwilling to expend the extra effort necessary to target a particular species. The main caveat is that these conclusions are based on an inventory of existing fleet and technology/gear. The fishermen included in the analysis were mostly part-timers (273 out of 320, or 85%), and used small boats (Speir & Brozovic, 2006). If Asian carp prices were to increase well above historical averages, perhaps through the use of temporary subsidies, and rents were created in the fishery, economic theory and the history of fisheries' management indicate that more fishermen, possibly with larger boats, will enter the market (Beddington, Agnew, & Clark, 2007). This is indeed the same long term conclusion reached by the authors of the Asian carp fishery management paper (Speir & Brozovic, 2006).

## Methods

Conducting a survey to determine the market potential of a "new" fish entails considering several issues simultaneously, including those mentioned above. In addition, considerations must be made for awareness of health benefits and health concerns associated with fish consumption (Verbeke et al., 2008), overfishing of wild populations, and human psychological aversion to new products of animal origin (Pliner & Pelchat, 1991). All of these variables and more must be taken into account for a full assessment to be performed. To determine the market potential of Asian carp, multiple measures were tested through a web-based, national survey, which was pre-tested with local consumers in Carbondale, Illinois. To pretest the survey, we set up a table in front of the Neighborhood Grocery Co-op and asked customers to complete the survey. Based on their answers, we edited it as necessary. Both the pretest and the final survey received approval from Southern Illinois University Human Subjects Committee, and all participants provided informed consent.

The final survey consisted of forty questions and was administered by Synovate, a market research company. A screening question, "Have you consumed fish in the last month", was sent to every member of Synovate's online panel to determine which respondents ate fish on a regular basis. The respondents who answered "yes" to the screening question were sent the final survey. Because the entire panel was only asked whether or not they had eaten fish in the last month, not the frequency of their fish consumption, we only know the frequency of consumption for the panel members who completed the survey. Over 35% of the respondents consumed fish at home once a week or more frequently, and 40% of them consumed fish at home once or twice a month. The reason behind the pre-screening of the potential respondents was to include only fish consumers, since people who do not like/do not eat fish would not likely be willing to try Asian carp, and many of our questions would not pertain to them. Based on data from the National Health and Nutrition Examination Survey III conducted by Center for Disease Control and Prevention used by the US Environmental Protection Agency (EPA), 88% of adults in the US consume fish/shellfish at least once a month and 58% consume fish/shellfish at least once a week (OEHHA, 2001). When Synovate polled their panel members, approximately 68% (15,810 out of 23,376) responded that they had eaten fish in the previous month. Once Synovate determined which respondents on their panel ate fish, the final survey was administered. The survey instrument is available from the authors upon request.

Due to our sampling procedure, and the pre-selection of fish consumers as respondents, assessment of validity is complex. There is limited available data to compare our sample with the population of US fish consumers, since the existing national surveys are conducted to assess the potential for exposure to toxic chemicals and not for marketing purposes. Therefore, data on race, income and geographical location of fish consumers is not available. In 2002, the US EPA issued a study on per capita fish consumption in the US using the 1994–1996, and 1998 USDA Continuing Survey of Food Intakes by Individuals, which are based on a representative sample of the US population and use a two non-consecutive day recall period. Of the 20,607 respondents of all ages, only 4391 (21%) had eaten fish and were part of the fish consumption analysis. Within the adult population, the respondents that had consumed fish were 28% of the sample. Women were 48% of the adult sample,[1] and people 45 and older comprised 58% of the adult consumer sample, (US EPA, 2002). In our sample, women are 51.5%, and 59.9% of the sample are 45 and older. By contrast, according to the 2010 US census, 51.7% of the adult population was over 44 years old, and 50.8% was female. It therefore appears that fish consumers tend to be older than the general population, and our sample reflects that. Compared to the general census, our sample under represents both African Americans and Latinos, but ethnicity in not available in the EPA survey of fish consumers. The geographical distribution of the sample on the other hand closely matches that of the census population (Howden & Meyer, 2012; Lofquist, Lugaila, O'Connell, & Feliz, 2012).

In the survey, willingness to try (WTT) and willingness to pay (WTP) for Asian carp meat were both measured. Because Asian carp is an exotic, novel food, consumers may not be willing to purchase it without first tasting it, therefore, WTP might not be an accurate measurement of the true market potential. Thus, we first asked respondents if they would be willing to try a free sample of Asian carp in the grocery store. Since the sample is free and the respondent does not have to invest more than their willingness to experiment, this measurement could give a better preliminary assessment. We also assessed willingness to pay because its measurement gives insight on the characteristics of respondents willing to go beyond a free taste test of Asian carp and therefore can provide initial information on what the best avenues to market Asian might currently be, prior to any large scale marketing efforts (Schupp, Gillespie, O'Neil, Prinyawiwatkul, & Makienko, 2005; Schupp et al., 2003).

Other variables measured included frequency of fish consumption in restaurants and at home, awareness of Asian carp and the problems they cause, awareness of overfishing/depleted fish stocks, health benefits and health concerns associated with consuming fish, purchase habits of new food items, interest in trying if Asian carp was locally caught and processed. The survey also included sociodemographic measures such as age, income, urban/suburban/rural residence, and education. There are several reasons why each measure was included in the survey, which will be described in detail next. The hypotheses tested and their relationships to the specific variables are described in Table 1.

### *Fish consumption – Restaurants and home*

The likelihood of a person trying a new type of fish is largely based on whether the person already consumes seafood. Based on previous research, consumers have the most aversion to foods of animal origin and are least likely to try new types of flesh foods (Pliner & Pelchat, 1991). Schupp, Gillespie, O'Neil, Prinyawiwatkul, and Makienko (2005) found a correlation between consumption of game meat and willingness to try exotic meat. Therefore, if an individual does not already consume fish, it is highly unlikely that they will try Asian carp. Higher frequencies of fish consumption, both at home and in restaurants, should lead to a higher willingness to try Asian carp.

**H1.** The higher the frequency of fish consumption in restaurants and at home, the higher the willingness to try (WTT) and willingness to pay (WTP) for Asian carp.

### *Asian carp awareness*

In previous studies about a multitude of environmental issues such as climate change (Semenza et al., 2008) and picking up litter (Brown, Ham, & Hughes, 2010), awareness of an issue often leads to action to help resolve the issue as hypothesized by Bamberg and Möser (2007), Stern (2000), and many others trying to develop models to predict determinants of pro-environmental behavior

[1] Note that EPA's definition of adults is 15 and older, slightly different from ours which is 18 and older. This likely increases the number of younger adults in the EPA sample, therefore the percentage of 45 and over would be higher than 60.1 if our definition had been used.

**Table 1**
Hypotheses with variable tested and whether it was supported by results.

| # | Hypothesis | Variable measured | Results |
|---|---|---|---|
| H1 | The higher the frequency of fish consumption in restaurants and at home, the higher the willingness to try (WTT) and willingness to pay (WTP) for Asian carp | Overall consumption | Not supported |
| H2 | The higher the awareness of problems caused by Asian carp in the US, the higher the WTT and WTP | AC | Supported for WTT |
| H3 | The higher the awareness and following of the Monterey Bay Seafood Watch, the higher the WTT and WTP | MBSW | Supported for WTP_sticks |
| H4 | Respondents aware of the health benefits of fish consumption will be more WTT and WTP than those respondents with health concerns about fish consumption | Health concerns, Health benefits | Not supported |
| H5 | Respondents who self identify themselves as product purchase leaders will be more WTT and WTP for Asian carp | Purchase Habit | Supported for all WTP |
| H6 | Locally caught and processed fish will increase WTT and WTP | Local | Supported for WTT, WTP_fillet, steak, cakes |
| H7 | Respondents with higher levels of education will be more willing to try and pay for Asian carp as will females and older respondents | Education, Gender and Age | Not supported for Education and Age, Gender supported for WTP_steak |
| H8 | Respondents with higher neophobia will be less willing to try and pay | Neophobia | Supported for WTT, WTP_fillet and steak |

(Bamberg & Möser, 2007; Stern, 2000). Thus, awareness of Asian carp and the problems they have caused in US waterways should result in an increase in willingness to try and willingness to pay for Asian carp meat as a way to combat the Asian carp invasion.

**H2.** The higher the awareness of problems caused by Asian carp in the US, the higher the WTT and WTP.

### *Awareness of overfishing and Monterey Bay Seafood Watch*

The Monterey Bay Seafood Watch (MBSW) is the oldest and most established seafood guide that helps consumers make ethical seafood choices (Jacquet et al., 2010). The MBSW lists species that are safe to eat in terms of population health and fishing practices (green list), okay to eat in moderation (yellow list), and should not be eaten at all (red list). People who follow the recommendations of the MBSW do not consume fish species that are on the red list. We chose the MBSW as our indicator because it is the oldest program of its kind, it distributes the guide to zoos and aquariums nationwide, and it is the one that other seafood lists are based on. However, there have been debates over whether it is effective and the program recently modified its sustainability assessment criteria and the frequency with which updates are made (Monterey Bay Aquarium, 2012a). The awareness of the problem of overfishing and decreased fish stock health can lead to changes in consumption behavior, as described in the section above about Asian carp awareness. When individuals are aware of the problem, behavior change can result. Thus, consumers who follow the MBSW should be more willing to try and willing to pay for Asian carp from US waterways because they are a species that are not threatened by overfishing, and depleting Asian carp fish stocks is considered to have positive environmental impacts, unlike the depletion of native fish stocks.

**H3.** The higher the awareness and following of the Monterey Bay Seafood Watch, the higher the WTT and WTP.

### *Health benefits and health concerns*

Fish consumption has gained popularity in recent years as research has revealed many positive health benefits from eating fish. These are attributed mostly to omega-3 fatty acids which are shown to decrease heart disease and arthritis, and increase brain function, especially in babies and children (Sidhu, 2003). However, eating fish also poses health risks and can be perceived as a risky behavior. Some fish bioaccumulate toxins from their habitat, which leads to toxins building up in their meat. Thus, fish meat can contain high levels of heavy metals, such as methyl mercury and cadmium, and other toxins such as polychlorinated biphenyls and dioxins (Sidhu, 2003). For years, pregnant and nursing women, children, and the elderly have been advised to only eat several species of fish in moderation, including tuna, orange roughy, shark, and tilefish, because of the presence of these toxins (NRDC, 2012).

To some, the health risks of fish consumption may outweigh the benefits provided by the omega-3 fatty acids. A survey of Belgian consumers in 2004 showed that the respondents were more aware of safety risks associated with fish consumption than health benefits (Verbeke et al., 2005, 2008). For those individuals who are more aware of safety risks, willingness to try Asian carp may be lower than those respondents aware of health benefits associated with fish consumption.

**H4.** Respondents aware of the health benefits of fish consumption will be more WTT and WTP than those respondents with health concerns about fish consumption.

### *Purchase habits*

Based on the Diffusion of Innovation Theory, rates of new product adoption vary, and only a small fraction of the population quickly adopts a new product. These individuals are identified as innovators and early adopters (Rogers, 2003). Innovators and early adopters are characterized by being more likely to take risks and more willing to try new products. Thus the respondents who identify themselves as one of the first to buy new products at the grocery store (innovators and early adopters) should be more willing to try Asian carp as they are willing to take more risks.

**H5.** Respondents who self identify themselves as product purchase leaders will be more WTT and WTP for Asian carp.

### *Locally caught and processed*

Demand for local products has risen recently as concerns over economic and environmental issues have become more widespread. These concerns include keeping jobs local to support the local economy and reducing greenhouse gas emissions through reductions in shipping. Studies of local agricultural products have shown that consumers are willing to pay more for locally produced food (Adams & Salois, 2010; Darby et al., 2008; Hu et al., 2009).

However, in our pilot survey, many individuals expressed concern over eating fish from local, Midwest rivers and streams due to the pollution. This is partly because consumers have better knowledge of their local waters than they do of overseas fisheries and aquaculture production practices. Nevertheless, the perceived health risk associated with eating polluted fish may decrease respondents' willingness to try Asian carp, as discussed earlier in the paper. Therefore, it is unknown what net effect the locally caught variable will have on willingness to try or pay for Asian carp that has been caught in Midwestern waterways. Geography may be a determining factor in whether respondents are more or less willing to try Asian carp, as respondents living outside the Midwest may not be as aware of the pollution found in Midwest waterways. However, as can be seen in Fig. 1, Asian carp have invaded waterways as far west as California and as far east as New Jersey and Florida, so they are not only a Midwest problem, but a national problem. If respondents are aware of the large spread of Asian carp populations across the US, all respondents may perceive Asian carp as "local".

**H6.** Locally caught and processed fish will increase WTT and WTP.

*Socio-demographic variables*

Socio-demographic variables are very influential in willingness to try and pay for fish and local foods. In a previous Asian carp consumption survey focused on Arkansas consumers and canned carp preparation, Engle and Kouka (1995) found that gender and age were each influential on taste preference. Older females tended to rate canned bighead carp higher in blind taste tests against salmon and tuna (Engle & Kouka, 1995). Foltz, Dasgupta, and Devadoss (1999) found that age, education level, and income were predictors of willingness to buy trout (Foltz et al., 1999). Since income is highly correlated with education level we will only use education level in our hypothesis testing.

**H7.** Respondents with higher levels of education will be more willing to try and pay for Asian carp as will females and older respondents.

*Food neophobia*

Food neophobia is a measure of a person's willingness to try different and unique foods (Pliner & Hobden, 1992). Many food neophobia studies have focused on neophobia in children (Dovey et al., 2008; Pliner, 1994). However, neophobia can last through adulthood and is important in marketing acceptance of new food products (Henriques, King, & Meiselman, 2009). The neophobia scale has also been shown to predict a person's willingness to pay (Sanjuán-López, Philippidis, & Resano-Ezcaray, 2011). In research examining acceptance of novel saffron products, Sanjuán-López et al. (2011) found that respondents who have greater food neophobia are less willing to pay to try new products.

**H8.** Respondents with higher neophobia will be less willing to try and pay.

*Dependent variables: Willingness to try and willingness to pay*

The dependent variables measured in the survey were willingness to try (WTT) a free sample of Asian carp in the grocery store, and willingness to pay (WTP) for four different preparations of Asian carp in two different settings (in a restaurant and at a grocery store). The preparations are described in Table 2, as are the numbers of respondents willing to try/pay for the carp and their percentages.

We chose these preparations because Asian carp is notoriously bony, to the extent that many recreational fishermen will not eat the meat because of the bones. However, if properly deboned and prepared, consumers will not have to be concerned with the bones when eating Asian carp. Several methods can be used to extract the bones from the meat. One method is to fillet the fish and then cook (either by steaming or baking) the meat with the bones intact (Fig. 2). Once the meat has been cooked the bones are easily removed and the meat can be fashioned into several different preparations, such as fish cakes, sticks, or reconstructed fillets. This method produces the most meat from the fish. Another method is to simply cut around the bones while cleaning the fish. With this method, only small strips of meat can be rendered from the fish

**Table 2**
Percent of respondents willing to buy Asian carp, mean price respondents are willing to pay for each preparation, and comparison between mean WTP (willingness to pay) and actual price of preparation at a grocery store/restaurant.

| | Product description | Number of respondents willing to buy (%) | Mean WTP for all respondents | Mean WTP for respondents willing to buy | Actual price for similar product available in market |
|---|---|---|---|---|---|
| Grocery store | 10-oz package of two frozen Asian carp fillets crusted with Panko bread crumbs | 138 (68%) | $3.20 | $4.70 | $6.34[a] $5.98[b] |
| | 12-oz box of 14 wild-caught, frozen Asian carp fish sticks | 134 (66%) | $3.20 | $4.80 | $3.96[c] |
| Restaurant | Asian carp fish cakes, made with bread crumbs, herbs and spices | 119 (59%) | $5.90 | $9.90 | Blue Crab Cake $7.99[d] Old Fashioned Fish Cakes $15.95[f] |
| | Asian carp steak, grilled and served with a tomato garlic sauce | 130 (64%) | $7.00 | $10.80 | Atlantic Salmon $14.25[e] Tilapia $13.50[e] Rainbow Trout $13.50[e] Cod $25.50[e] |

[a] Gorton's Garlic & Herb Seasoned Tilapia Fillets (13.3 oz).
[b] Morey's Lemon Pepper Tilapia (10 oz).
[c] Gorton's Fish Sticks (11.4 oz).
[d] Crabby Bill's Seafood Co. (various locations in Florida).
[e] Red Lobster Restaurant (Nationwide, but prices are for O'Fallon, IL).
[f] Union Oyster House (Boston, MA).

**Fig. 2.** Asian carp require extra processing due to their bone structure. *Photo credit*: Sylvia Smith, SIUC.

**Table 3**
Descriptive statistics of variables.

| Variable | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|
| WTPsticks | 0 | 10 | 3.17 | 2.81 |
| WTPfillet | 0 | 10 | 3.22 | 2.80 |
| WTPsteak | 0 | 16 | 6.95 | 5.52 |
| WTPcakes | 0 | 16 | 5.85 | 5.15 |
| WTPsticks_binary | 0 | 1 | 0.66 | 0.47 |
| WTPfillet_binary | 0 | 1 | 0.68 | 0.47 |
| WTPsteak_binary | 0 | 1 | 0.64 | 0.48 |
| WTPcakes_binary | 0 | 1 | 0.59 | 0.49 |
| WTT | 0 | 1 | 0.73 | 0.45 |
| Neophobia | 10 | 63 | 32.77 | 10.42 |
| Age | 19 | 83 | 48.50 | 16.26 |
| Education | 1 | 4 | 2.55 | 0.98 |
| Purchase Habit | 0 | 3 | 1.98 | 0.77 |
| Gender | 0 | 1 | 0.51 | 0.50 |
| Health Concerns | 0 | 1 | 0.29 | 0.46 |
| Health Benefits | 0 | 1 | 0.93 | 0.26 |
| Local | 1 | 3 | 2.32 | 0.57 |
| Overall Consumption | 1 | 8 | 3.84 | 1.42 |
| AC Awareness | 2 | 14 | 7.44 | 4.04 |
| MBSW | 2 | 14 | 5.48 | 3.16 |

and much of the meat is wasted because it is very difficult to remove the bones prior to cooking. Chef Philippe Parola, who was an early proponent of the invasivore movement and has developed several recipes for Asian carp, helped us identify the dishes used in the survey based on preparations that could potentially be found in grocery stores and restaurants that give consumers the least exposure to bones.

Though the survey asked for willingness to pay at different price points ranging from $2 to $10 for the fish sticks to be consumed at home and $8 to $16 for the fish steak at a restaurant, there was not much variation in the responses (see Table 3), therefore the WTP regressions were run as simple binary choices.

## Results

The respondents ($N = 202$) came from various backgrounds and geographic locations within the United States. The sample was evenly distributed on a gender basis, and it included a larger number of older (61% over 45), married (69%) and childless (68%) consumers (Table 4). The sample was quite evenly distributed between consumers with only some college or less and college graduates or more. Geographically, the South was slightly overrepresented and about half the sample had incomes of over $60,000/year and half below (note that not answering the income question was an option so the total of responses to this question is less than the total of respondents). The data was analyzed using SPSS software.

### *Fish consumption – Restaurants and home*

Respondents were asked when eating at a restaurant or at home, how often they consumed seafood. The answer choices were: "More than twice a week, once or twice a week, once or twice a month, once every 2–3 months, and never." The results from the survey show that the greatest number of respondents ($n = 84$, 34%) only ate fish once every 2–3 months in restaurants (coded as 1), however, 32% ($n = 81$) eat fish once or twice a month at home (coded as 2). Only slightly over 3% of respondents responded that they ate fish more than twice a week at home or in restaurants (coded as 4). These numbers are slightly lower than the statistics from the OEHHA (2001), as stated earlier. In their study, 88% of consumers eat fish once a month and 58% eat fish once a week (OEHHA, 2001). Fish consumption in both restaurants and at home were highly correlated ($p > .01$) with the Monterey Bay Aquarium Watch measures and the Asian carp awareness measures, which could mean that those individuals who eat fish are aware of issues of overfishing and ecosystem health. Home consumption and restaurant consumption were combined in the regression analysis.

### *Asian carp awareness*

The awareness of problems caused by Asian carp was determined through agreement with two statements: "I am aware of the environmental damage done by Asian carp in the United States" and "I am aware of the effort to prevent Asian carp from entering Lake Michigan". Respondents were required to determine their awareness through a seven-point Likert scale (1 = strongly disagree, 7 = strongly agree). Likert type scales have been used extensively in the literature to assess environmental awareness. Some examples of previous surveys that have used Likert scales include studies on the levels of environmental awareness in small and medium sized enterprises (Gadenne, Kennedy, & McKeiver, 2009), watershed conservation and preservation (Story & Forsyth, 2008), and individual determination of environmental concerns and behavior (Nisbet, Zelenski, & Murphy, 2009). Thirty-eight percent ($n = 77$) of respondents stated that they agreed with the first statement, and 42% ($n = 84$) agreed with the second statement. The results from each statement were combined for an overall Asian carp awareness measure in the regression analysis. The overall mean for the combined measure was 7.44 with a minimum of 2 and maximum value of 14 (Table 3). Based on this statistic, most respondents had a neutral knowledge of both statements.

### *Awareness of overfishing and Monterey Bay Seafood Watch*

Awareness of overfishing and the Monterey Bay Seafood Watch (MBSW) was measured by two questions: "I am aware of the Monterey Bay Aquarium Seafood Watch" and "I try to follow the recommendations of the Monterey Bay Seafood Watch." These were measured on a Likert-type scale from one to seven (1 = strongly disagree, 7 = strongly agree). The majority of respondents disagreed with each statement. Seventy-one percent said that they were not aware of the MBSW, and 57% did not follow it. The questions were combined for the analysis to comprise one MBSW measure. The combined MBSW mean was 5.48. Based on the mean of the combined Asian carp awareness measure and this measure,

**Table 4**
Demographics of survey respondents.

| | Total | Age | | Gender | | Marital Status | | Children | | Education | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 18–44 | 45+ | Male | Female | Single | Married/attached | Have children | No children | Some college or less | College graduate or more |
| Total respondents | 202 | 81 | 121 | 98 | 104 | 62 | 140 | 65 | 137 | 98 | 104 |
| Willing to try a free sample | 147 (73%) | 67 (83%) | 80 (66%) | 71 (72%) | 76 (73%) | 41 (66%) | 106 (76%) | 49 (75%) | 98 (72%) | 70 (71%) | 77 (74%) |
| Not willing to try a free sample | 55 (27%) | 14 (17%) | 41 (34%) | 27 (28%) | 28 (27%) | 21 (34%) | 34 (24%) | 16 (25%) | 39 (28%) | 28 (29%) | 27 (26%) |

| | Total | Income | | Region | | | |
|---|---|---|---|---|---|---|---|
| | | <$60,000 | $60,000+ | North-East | Midwest | South | West |
| Total respondents | 202 | 88 | 92 | 39 | 45 | 75 | 43 |
| Willing to try a free sample | 147 (73%) | 64 (73%) | 69 (75%) | 29 (74%) | 35 (78%) | 54 (72%) | 29 (67%) |
| Not willing to try a free sample | 55 (27%) | 24 (27%) | 23 (25%) | 10 (26%) | 10 (22%) | 21 (28%) | 14 (33%) |

there was higher appreciation among respondents of the problems caused by Asian carp than of the Monterey Bay Seafood Watch.

*Health benefits and health concerns*

Ninety-three percent of respondents stated that they were aware of health benefits (1 = aware of benefits, 0 = not aware of benefits) of eating fish, and only 29% ($n = 59$) had health concerns with eating fish (Table 3). Of those respondents who listed what health benefits they were aware of, omega-3 fatty acids was the top reason, being mentioned by 51% ($n = 96$) of respondents. The second reason (31%) was that fish is a lean meat. Forty-three people listed mercury as their top concern with fish consumption. Contaminants were the second most frequently listed reason. This is the opposite of what Verbeke et al. (2005, 2008) found. However, their survey consisted of Belgian respondents and was conducted in 2003. European respondents may have different views than Americans regarding health concerns about food. Perceptions may have also changed in the 9 years between the two surveys as much more evidence about the benefits of eating fish has been published. By contrast, in a recent survey of elderly Australian subjects, Grieger, Miller, and Cobiac (2012) found that a majority of respondents believe that fish is healthy (Grieger et al., 2012), which supports our results.

*Purchase habits*

Respondents' purchase habits were measured through the question "When thinking about buying new food products, how would you describe yourself?" with answers ranging from "As one of the first to buy" (coded as 3) through "will not purchase" (coded as 0). Twenty-six percent responded that they are product leaders, and are one of the first to buy. Forty-eight percent purchase after few others have purchased, 23% purchase after many people have purchased, and only 2% will not purchase. This question correlated highly ($p > .01$) with age (younger respondents are more likely to be product purchase leaders), and home fish consumption.

*Locally caught and processed*

Respondents were asked whether they would be more or less inclined to try Asian carp if it were locally caught and processed (coded 3 = more, 1 = less) or if it would make no difference (coded 2). This measure was highly correlated with awareness of health concerns and age. Thirty-seven percent of respondents answered that they would be more willing to try Asian carp if it were local, it would make no difference to 57%, and only 5% said that they would be less inclined to try Asian carp if it were locally caught and processed. A separate correlation found no significant link between geographical location and locally caught and processed ($r = -0.091$), which can be assumed to mean that respondents did not associate Asian carp only with the Midwest. Since aquaculture is a global endeavor and much of the fish eaten in the US is imported, as discussed earlier, simply being raised in the US may be considered "local" by many respondents.

*Neophobia*

The food neophobia scale was comprised of 10 different questions on a seven point scale determined to be effective by Pliner and Hobden (1992). The answers to the questions were summed to obtain one neophobia score. The higher the score, the more neophobic the respondent is. Possible scores could range from 10 to 70, and the mean for our sample was 32.7 with a standard deviation of 10.42 (Table 3). Since the mean was rather low, most

**Table 5**
Logistic regression of willingness to try (WTT), and willingness to pay (WTP) for sticks, fillets, steaks, and cakes.

| | WTT | | | | WTP sticks | | | | WTP fillet | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *B* | S.E. | Wald | Exp(*B*) | *B* | S.E. | Wald | Exp(*B*) | *B* | S.E. | Wald | Exp(*B*) |
| Age | −0.02 | 0.01 | 2.65 | 0.98 | −0.05 | 0.01 | 12.88** | 0.95 | −0.03 | 0.01 | 6.262** | 0.97 |
| Gender | 0.25 | 0.43 | 0.34 | 1.29 | 0.54 | 0.42 | 1.69 | 1.72 | 0.52 | 0.42 | 1.544 | 1.69 |
| Education | −0.27 | 0.22 | 1.43 | 0.77 | −0.25 | 0.21 | 1.36 | 0.78 | −0.10 | 0.21 | .212 | 0.91 |
| Purchase Habit | 0.18 | 0.32 | 0.32 | 1.19 | 0.90 | 0.32 | 8.14** | 2.46 | 0.87 | 0.32 | 7.63** | 2.39 |
| Local | 1.05 | 0.38 | 7.76** | 2.85 | 0.51 | 0.34 | 2.27 | 1.66 | 0.79 | 0.35 | 5.21* | 2.21 |
| Asian Carp Awareness | 0.14 | 0.06 | 5.37* | 1.15 | 0.07 | 0.05 | 1.70 | 1.07 | 0.09 | 0.05 | 2.643 | 1.09 |
| MBSW | −0.13 | 0.08 | 2.76 | 0.88 | −0.14 | 0.07 | 4.02* | 0.87 | −0.12 | 0.07 | 2.907 | 0.89 |
| Overall Fish Consumption | 0.05 | 0.15 | 0.10 | 1.05 | 0.20 | 0.15 | 1.74 | 1.22 | 0.16 | 0.15 | 1.037 | 1.17 |
| Neophobia | −0.11 | 0.03 | 16.38*** | 0.89 | −0.04 | 0.02 | 3.17 | 0.96 | −0.05 | 0.02 | 4.53* | 0.95 |
| Health Concerns | 0.32 | 0.46 | 0.49 | 1.38 | 0.17 | 0.43 | 0.16 | 1.19 | 0.34 | 0.44 | .612 | 1.41 |
| Health Benefits | 0.24 | 0.72 | 0.11 | 1.27 | 0.24 | 0.71 | 0.11 | 1.27 | −0.12 | 0.69 | .029 | 0.89 |
| Constant | 3.27 | 2.17 | 2.26 | 26.22 | 1.49 | 2.07 | 0.52 | 4.42 | 0.03 | 2.08 | .000 | 1.03 |
| Cox & Snell *R* Square | .273 | | | | .286 | | | | .274 | | | |
| Nagelkerke *R* Square | .395 | | | | .397 | | | | .384 | | | |

| | WTP steak | | | | WTP cakes | | | |
|---|---|---|---|---|---|---|---|---|
| | *B* | S.E. | Wald | Exp(*B*) | *B* | S.E. | Wald | Exp(*B*) |
| Age | −0.04 | 0.01 | 10.26*** | 0.96 | −0.05 | 0.01 | 15.32*** | 0.95 |
| Gender | 1.01 | 0.44 | 5.18* | 2.74 | 0.70 | 0.40 | 3.11 | 2.02 |
| Education | 0.01 | 0.21 | 0.00 | 1.01 | 0.02 | 0.20 | 0.01 | 1.02 |
| Purchase Habit | 0.61 | 0.31 | 3.83* | 1.84 | 0.68 | 0.29 | 5.39* | 1.98 |
| Local | 0.97 | 0.35 | 7.79** | 2.65 | 0.81 | 0.33 | 6.11* | 2.24 |
| Asian Carp Awareness | 0.04 | 0.05 | 0.56 | 1.04 | 0.10 | 0.05 | 3.66 | 1.10 |
| MBSW | 0.08 | 0.07 | 1.13 | 1.08 | 0.03 | 0.07 | 0.22 | 1.03 |
| Overall Fish Consumption | 0.11 | 0.16 | 0.50 | 1.12 | 0.03 | 0.15 | 0.04 | 1.03 |
| Neophobia | −0.08 | 0.03 | 9.39** | 0.92 | −0.04 | 0.02 | 3.00 | 0.96 |
| Health Concerns | −0.09 | 0.43 | 0.04 | 0.91 | 0.25 | 0.41 | 0.39 | 1.29 |
| Health Benefits | 0.89 | 0.73 | 1.49 | 2.44 | 0.47 | 0.68 | 0.47 | 1.59 |
| Constant | 0.57 | 2.12 | 0.07 | 1.77 | −0.55 | 1.94 | 0.08 | 0.57 |
| Cox & Snell *R* Square | .323 | | | | .287 | | | |
| Nagelkerke *R* Square | .444 | | | | .387 | | | |

* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

respondents were not very neophobic. Respondents who were neophobic were older, less educated, less aware of health benefits associated with eating fish, and product purchase laggards.

*Willingness to pay and willingness to try*

Examination of the responses to the willingness to try and pay questions indicates that over 70% of the sample was willing to try a free sample of the carp. The most popular preparation that respondents (68%) were willing to pay for was the fillet from the grocery store. The least popular preparation was fish cakes, with only 59% of respondents reporting they would pay (Table 2).

*Logistic regression*

*Willingness to try*

A logistic regression with WTT as the dependent variable showed that the independent variables explained between 27.3% and 39.5% of the variance (Cox & Snell $R^2 = .273$, Nagelkerke $R^2 = .395$, see Table 5). The significant variables included neophobia, Asian carp awareness, and locally caught and processed. This supports hypotheses 2, 6, and 8 (Tables 1 and 5).

*Willingness to pay*

As we note above, the willingness to pay variables were evaluated through a logistic regression. Therefore, the answers were recoded as 0 = not willing to pay, and 1 = willing to pay (depending on the preparation, the willingness to pay amount could range from \$2 to \$16). The significance of the results was similar to those of the WTT, with the lowest for the WTP for store-bought fish fillets (Cox & Snell $R^2 = .274$, and Nagelkerke $R^2 = .384$), and highest for the steak at a restaurant (Cox & Snell $R^2 = .323$, and Nagelkerke $R^2 = .444$). As shown in Table 5, age was a significant predictor in WTP for all preparations of Asian carp. Younger respondents were more likely to be willing to pay for Asian carp. Respondents who were product purchase leaders were also more likely to pay for Asian carp, which supports hypothesis five. The locally caught and processed measure was a significant predictor of willingness to pay for most preparations. Respondents who answered that they were more likely to try the carp if it was locally caught and processed, or if it made no difference to them, were more willing to pay for every preparation except fish sticks, which partially supported hypothesis six. This may be due to the fact that purchasing "local" food is not important to the segment of the population that eats fish sticks. Another explanation could be that, due to their heavily processed nature, fish sticks are not widely seen as something that could be manufactured locally. Neophobia was significant in predicting WTP for fillets and steaks. Those individuals who were more food neophobic were less likely to pay. Finally, contrary to hypothesis three, people who were more willing to pay for fish sticks were less aware of the Monterey Bay Seafood Watch and less likely to follow its recommendations.

## Discussion

Based on the results from our survey, the market potential for Asian carp meat in the United States is considerable. Most respondents said they would be willing to at least try a free sample of Asian carp, and would be willing to pay for some preparation of it. Because of the negative connotation attached to carp in general, this figure is encouraging. The willingness to pay measures were also encouraging in determining market potential. While over half of the respondents replied they would be willing to pay for different preparations of Asian carp, the respondents who were willing to pay, would be willing to pay similar or equal prices as other more popular fish on the market (see Table 2).

While 202 respondents is a relatively small sample size for evaluating market potential and obtaining target market information, the goal of our survey was to provide preliminary results on whether a market for Asian carp meat exists. The results from our survey could also provide a preliminary basis for the development of an Awareness-Trial-Repeat analysis to further examine market potential and forecasting (Narasimhan & Sen, 1983). Another avenue to pursue in terms of market potential is the Asian–American segment of the US population. Our sample only contained six respondents from Asian descent, and thus was too small to draw any conclusions about the market potential for this population segment.[2]

Creating demand for the human consumption of Asian carp in the US could be a market based, cost effective solution for a problem (invasive species) that is typically dealt with through command and control type abatement. Invasive species are a negative externatility of globalization. Asian carp, specifically, are in part a negative externality of an industry developed to try to meet the demand for consumable fish. They were originally brought into the United States as a non-chemical alternative to clean aquaculture and wastewater ponds for the production of other farm raised fish. Later they were raised as a source of fish meat. They escaped confinement in the 1970s and have since made their way up the Mississippi River (Chick & Pegg, 2001) and now constitute the highest known densities in the world in portions of the Illinois River (Sass et al., 2010). As it is obvious from Fig. 1, their distribution is widespread.

A high consumer demand for Asian carp would result in more people fishing and processing them, which would not only remove carp from waterways, but would also create more jobs. An alternative to using tax money to fight the carp invasion, consumers who buy and eat Asian carp would be paying for the removal. This strategy could be coupled with the production of fertilizer or aquaculture fish foods from small carp and parts discarded from processing. These uses would make sense economically given that the price of natural gas – a key input to fertilizer – is projected to increase and so is demand for fish (FAO, 2012; US Department of Energy Energy Information Administration, 2012). As we note in the introduction, preliminary modeling work suggests that if all sizes of carp are caught, fishing is an effective management strategy. Specifically, harvest rates (catch divided by the initial fish population) of 0.6 and above are effective in reducing fish populations (Garvey et al., 2012). Current lack of data and uncertainty on the starting population conditions mean that only relative results are available, and no absolute size of fish harvest can be determined (Glover, 2012).

Intuitively, therefore, this would seem to be a win–win strategy for ecosystems, taxpayers, consumers, commercial fishermen and processors, and recreationalists. However researchers have conflicting views and some issues remain unresolved because of the uncertainty still surrounding the Asian carp's population dynamics discussed in the introduction. Other possible limitations to this approach include changing the way people view Asian carp, from something that is unsavory to something that is appetizing and appealing. Creating the infrastructure necessary to harvest and process Asian carp is also a large financial barrier. Last but not least, there are concerns about creating a market for invasive species, whose ultimate goal is to extirpate the species and thus disappear as well. A recent article by Nuñez, Kuebbing, Dimarco, and Simberloff (2012) outlines the benefits and consequences of creating a consumer market for invasive species (Nuñez et al., 2012). Marketing efforts have already been initiated for many invasive species throughout the United States. These include kudzu, lionfish, nutria, snakehead, and garlic mustard These marketing attempts are all at different stages, though none have yet been able to successfully eradicate the target species. It is important that education be included as a key part of any invasive species marketing campaigns so that the species does not become incorporated into the local culture. This has occurred both in Hawaii and Patagonia with the wild boar and would make eradication even more difficult (Nuñez et al., 2012).

Therefore, although creating a market for invasive species may help to eliminate them from the ecosystem they threaten, it may also result in people and organizations cultivating them for profit after their removal from the specified ecosystem. This would cause additional problems including the possibility of reintroduction. Possible strategies need to incorporate research on backstop technologies such as aquaculture, and appropriate marketing, regulatory and education schemes so that the general public, the fishermen and the processors are all aware of the long term objectives of the fishery. A thorough investigation of future implications needs to be performed. This will have value for the management of other invasive species as well.

The use of fishermen to control nuisance-causing species is not entirely novel. It has been explored in the Pacific Northwest to reduce Northern Pikeminnow populations, which have been inflated by the construction of hydropower dams and which prey on juvenile salmon (Best, 2006). Many surveys and studies have focused on market potential of exotic meats (McLean-Meyinsse, 1994; Schupp, Gillespie, O'Neil, Prinyawiwatkul, & Makienko, 2005), and several papers discuss developing a market for invasives, including the already mentioned Nuñez et al. (2012) and Jojola, Witmer, and Nolte (2005), which discusses the potential for nutria management through human consumption in Louisiana. Recent literature has started exploring commercial harvest as a strategy for controlling overabundant native species such as white tailed deer in North America (VerCauteren et al., 2011). However, this is one of the first studies trying to establish market potential of an exotic invasive species for human consumption using a national survey.

To accurately assess the preliminary market potential of Asian carp, nationwide fish consumption must be measured. In this study, we performed preliminary market research to find out how many respondents eat fish before the survey was conducted. We had difficulties finding other studies that measured the national frequency of fish consumption and what percentage of the population consumes fish at all. The existing literature typically looks at fish consumption through a toxicology lens (OEHHA, 2001). This is one of few national studies examining fish consumption for market research purposes.

In summary, our survey provides a good preliminary assessment for entrepreneurs and organizations interested in developing the infrastructure necessary to create a market for Asian carp. Much work still needs to be completed, including determining if negative future repercussions may arise from developing market demand. In particular, it is critical to create bioeconomic models based on realistic carp population growth models to establish how commercial fishing will help in reducing population pressure, and whether the carp can be completely eradicated, perhaps with

[2] While we did not have enough Asian American respondents to fully test the marketing potential of this population segment, it would be beneficial to conduct a second survey to ascertain this information. Asian carp were imported from Asia, where they are considered a delicacy. Much of the Asian carp currently harvested from US waterways is shipped to China for consumption. Populations of Eastern European descent could also be potential targets, given their traditional diets.

complementary policies. If so, alternative fisheries and products will have to be developed in the long term. The eradication of the carp would open up ecological niches for other species and this should be investigated. However, based on this assessment, there is interest within US consumers for Asian carp meat.

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