Steven E. Butler[1], Matthew J. Diana[1], Scott F. Collins[1], David H. Wahl[1], Clint W. Morgeson[2], Robert E. Colombo[2]

[1]Illinois Natural History Survey, Prairie Research Institute, University of Illinois
[2]Department of Biological Sciences, Eastern Illinois University

Appendix E: Investigate Enhanced Sampling with Traditional and New Gears to Assess Detectability for Asian Carp in the Illinois Waterway

2014 Annual Report

ILLINOIS NATURAL HISTORY SURVEY
PRAIRIE RESEARCH INSTITUTE

EASTERN ILLINOIS UNIVERSITY

ILLINOIS DEPARTMENT OF NATURAL RESOURCES

Great Lakes RESTORATION

Sea Grant ILLINOIS-INDIANA

Acknowledgments

This study was supported by grants from the Illinois Department of Natural Resources (ILDNR). We thank K. Irons, M. O'Hara, D. Wyffels, J. Mick, and V. Santucci for their assistance with this project. We are grateful to the numerous individuals who have provided the field and laboratory assistance to make this project possible, including the staff of the Kaskaskia, Sam Parr, and Illinois River Biological Stations, and graduate students at the University of Illinois and Eastern Illinois University.

Table of Contents

Executive Summary

Bighead carp, silver carp, and their hybrids, collectively referred to as Asian carp, are invasive fishes that have become abundant in the Illinois Waterway. Several agencies are monitoring and attempting to control populations of these fish, but the distribution of different life stages of Asian carp, the extent of Asian carp reproduction in this system, and the effectiveness of various sampling gears for capturing both juvenile and adult Asian carp are not adequately known. We have been examining patterns of larval fish abundance, evaluating catches of Asian carp and other fishes with a variety of sampling gears, and testing new gears and combination systems to assist with monitoring and control efforts. Sampling is occurring seasonally at 11 sites throughout the Illinois Waterway and at additional sites in Illinois River tributaries.

Larval fish monitoring revealed substantially higher numbers of Asian carp larvae in the Illinois River during 2014 than in previous years of sampling. Large numbers of Asian carp larvae were observed in the LaGrange and Peoria Pools, but none were observed upstream of the Peoria Pool. Asian carp appear to have had multiple spawning events in 2014, as indicated by the timing of larval occurrences. These occurrences of Asian carp larvae coincided with three distinct rises in the hydrograph that occurred between mid-June and mid-July, as well as water temperatures continuously above 23°C. The continued presence of small numbers of Asian carp larvae from mid-July to early August suggests that additional, although less prolific spawning activity continued to occur during the summer in 2014. Additional ichthyoplankton sampling occurred in four tributaries of the Illinois River during 2014. Processing and identification of tributary samples is ongoing and results will be reported once available.

The presence of large numbers of juvenile Asian carp in 2014 allowed for the assessment of sampling gears for targeting this life stage. Pulsed-DC electrofishing monitoring captured juvenile silver carp in the LaGrange and Peoria Pools, but none were observed in the Starved Rock or Marseilles Pools. Subsequent evaluation with all sampling gears captured large numbers of juveniles in the LaGrange Pool, but only a few in the Peoria Pool. Mini-fyke nets captured the highest numbers of juvenile silver carp, followed by beach seines, purse seines, pulsed-DC electrofishing, and cast nets. Gill nets failed to capture any juvenile Asian carp. Gear types targeting juvenile Asian carp were also found to capture different size distributions of these fish. Beach seines captured the smallest juvenile silver carp, whereas purse seines captured the largest average sizes. Cast nets, electrofishing, and mini-fyke nets captured intermediate average sizes. Pulsed-DC electrofishing captured adult silver carp at both upstream and downstream sites in all tributary rivers. No juvenile Asian carp were captured in tributaries during 2014. Higher numbers of male than female silver carp were observed in all tributary rivers. Silver carp GSI’s were highest in tributaries in June, and declined thereafter, although it is uncertain if any spawning actually occurred in tributaries during 2014.

Evaluation of unconventional sampling gears during 2014 included experiments testing the effectiveness of driving Asian carp into surface-to-bottom gill nets and deployment of Great Lakes trap (pound) nets in Illinois River backwaters. Drives using pulsed-DC electrofishing captured more total fish than control sets or drives using traditional pounding methods. Catch rates of silver carp were highest in electrofishing treatments, which were nearly four times higher than control sets, but similar to traditional pounding treatments. Bighead carp catch rates were highest in traditional pounding treatments, but these were not significantly different than control or electrofishing treatments. A majority of all fishes, and specifically silver carp, were captured in smaller mesh panels, particularly the 6.4 cm mesh size. Bighead carp were more vulnerable to larger mesh sizes. Very large numbers of Asian carp were captured in pound nets set in backwater habitats. Pound nets consistently captured higher numbers of fishes, including Asian carp, than concurrently set hoop nets or fyke nets. Pound nets captured larger sizes of bighead carp than other entrapment gears, although sizes of silver carp did not differ among gear types. To achieve equivalent catches of Asian carp as pound nets, considerable numbers of fyke nets or hoop nets would be required, entailing a considerably higher amount of labor hours than pound nets. Pound nets therefore appear to be a very cost-effective tool for capturing Asian carp in backwater habitats. Continued monitoring will be necessary to further evaluate the potential for Asian carp to reproduce in the upper Illinois River, examine relationships between environmental variables and Asian carp reproduction and recruitment, determine the most effective gears for sampling intermediate sizes (100 – 400 mm) of Asian carp, and further examine unconventional sampling gears and combination systems.

Introduction

Bighead carp (*Hypophthalmichthys nobilis*) and silver carp (*H. molitrix*), together referred to as Asian carp, were introduced into the United States in the 1970s and have since spread throughout the Mississippi River basin. Reproducing populations now exist in the Mississippi, Missouri, Ohio, Wabash, and Illinois River watersheds (Tucker et al. 1996, Fuller et al. 1999). In some areas where Asian Carp have invaded, their population sizes have increased exponentially (Chick and Pegg 2001, Irons et al. 2007, Sass et al. 2010), causing considerable concern about the impact these species may have on native fish communities. Due to their ability to efficiently filter large volumes of water, Asian carp may deplete plankton densities and alter zooplankton community composition (Spataru and Gophen 1985, Burke et al. 1986, Xie and Yang 2000, Lu et al. 2002, Sass et al. 2014), potentially competing with native planktivores for food resources (Schrank et al. 2003, Sampson et al. 2009). Introductions of Asian carp outside of North America have negatively affected other filter-feeding fishes and led to declines in fish diversity (Spataru and Gophen 1985, De Iongh and Van Zon 1993, Sugunan 1997). Recent evidence also indicates that Asian carp may be negatively affecting native fishes in the Illinois River (Irons et al. 2007).

The establishment of Asian carp in the Illinois River has caused additional concern due to the connection between this system and the Great Lakes via the Chicago Area Waterways System (CAWS), which includes the Chicago Sanitary and Ship Canal (CSSC) and the Cal-Sag Channel. Ecological modeling has suggested that Asian carp could potentially become established in the Great Lakes if allowed to continue their expansion (Kolar and Lodge 2002, Chen et al. 2007, Herborg et al. 2007, Kocovsky et al. 2012). The effects that Asian carp might have on Great Lakes food webs are uncertain, but their invasion of this system could threaten the commercial and recreational fishing industries of several states, tribes, and provinces. Due in part to these concerns, the U.S. Army Corps of Engineers has constructed a series of electric barriers on the CSSC near Romeoville, IL, in hopes of preventing the spread of invasive species such as Asian carp between the Mississippi River basin and the Great Lakes. The potential threat posed by Asian carp and concerns about the effectiveness of the electric barriers have also prompted debate about permanent hydrologic separation of these two basins (Rasmussen et al. 2011). However, continued uncertainty regarding the presence of Asian carp within the CAWS presents a substantial impediment to informed decision-making.

Multi-agency sampling and removal efforts are ongoing in the Illinois River and in the CAWS to monitor and control the spread of Asian carp. Asian carp have been collected in close proximity downstream of the electric barrier, and a single bighead carp was captured upstream of the barrier in 2010. However, environmental DNA technology (eDNA; Ficetola et al. 2008) has indicated that species-specific DNA from Asian carp may be present at several locations upstream of the electric barrier (Jerde et al. 2011, Jerde et al. 2013). These findings have raised numerous questions about alternative vectors for Asian carp DNA and the subsequent limitations in inference and interpretation of eDNA results, as well as the ability of traditional sampling programs to detect live Asian carp if they are indeed present in the CAWS (Darling and Mahon 2011). Because extensive sampling efforts have only been able to capture a single Asian carp where eDNA monitoring has suggested their presence above the electric barrier, some agencies have expressed concern that Asian carp DNA may be entering the system through alternative pathways (Merkes et al. 2014). Conversely, because Asian carp densities are likely very low if they are in fact present in the CAWS, and because the unique conditions found within the CAWS present numerous challenges to effective sampling with traditional fisheries gears, the probability of detecting live Asian carp in the CAWS may be marginal even at very high levels of sampling effort.

Determining methods to enhance existing monitoring programs, evaluating the effectiveness of various sampling gears to capture different life stages of Asian carp, investigating appropriate levels of sampling effort required to detect Asian carp, and testing new approaches for detecting Asian carp will help to alleviate these concerns and strengthen the ability of managers to effectively monitor and control these species. Monitoring for larval Asian carp is also needed to determine the timing and spatial extent of Asian carp reproduction in the Illinois Waterway. Reproduction and recruitment are known to be highly variable among years in the lower Illinois River (DeGrandchamp et al. 2007, Irons et al. 2011), but a system-wide assessment is needed to determine if reproduction occurs in upstream reaches, and to evaluate relationships among environmental variables and recruitment of young Asian carp. Larval fish monitoring will aid in evaluating the potential for these species to further expand their range in this system. Evaluating the effectiveness of various sampling gears for capturing Asian carp, and determining the amount of effort required to detect Asian carp when they are present at low densities, is needed to strengthen monitoring and control efforts. Additionally, testing new techniques for detecting the presence of Asian carp (Great Lakes trap nets, surface-to-bottom gill nets) is warranted in order to expand the set of tools available to managers, which will allow for customization of monitoring efforts. This report summarizes observations of larval fish abundance, Asian carp distribution, and the relative efficiency of various sampling gears for capturing Asian carp based on extensive sampling conducted throughout the Illinois Waterway during 2010-2014, focusing on results from 2014.

Study Area

The Illinois Waterway consists of the waterbodies that today form a continuous link between Lake Michigan and the Mississippi River (Figure 1). This network of waterbodies includes the Chicago Area Waterway System (CAWS), Des Plaines River, and the Illinois River. The Illinois Waterway is separated into a series of pools by 7 major navigation dams (Figure 1). These dams regulate water levels to maintain a 2.7-m deep commercial navigation channel. Two additional lock and dam structures control the flow of water from Lake Michigan into the CAWS.

Figure 1. Map of the Illinois Waterway and major tributaries that were sampled for Asian carp, showing the location of navigation dams, the electric barrier on the Chicago Sanitary and Ship Canal (CSSC), and sites sampled as part of this study. Navigation dams are represented by squares; sampling sites on the main channel and backwaters of the Illinois Waterway are represented by circles; sampling sites in tributaries are represented by triangles.

The CAWS consists of a network of natural, man-made, and modified waterways that drain the Chicago region of northeast Illinois, southeast Wisconsin, and northwest Indiana (Figure 2). This system has been extensively modified to provide for commercial navigation and to direct wastewater away from Lake Michigan towards the Illinois River. Water now flows from Lake Michigan into the CAWS through control structures at Wilmette Pumping Station, the Chicago River Lock and Dam, and T.J. O'Brien Lock and Dam (Figure 2). The majority of the volume of flow within the system, however, is from treated wastewater and storm water discharges. Flow from the entire system eventually passes through the lower Chicago Sanitary and Ship Canal (CSSC), where the mean daily discharge (2004-2010) of all water sources combined is 84.8 m^3/s (USGS gage 5536890; Lemont, IL). The CAWS joins the lower Des Plaines River near Joliet, IL, where the navigable portion of the Des Plaines River continues downstream for another 27 km before merging into the Illinois River.

Figure 2. Map of the Chicago Area Waterways System (CAWS), showing the location of navigation dams, the electric barrier on the Chicago Sanitary and Ship Canal (CSSC), and sites sampled as part of this study. Navigation dams are represented by squares; sampling sites are represented by circles.

The Illinois River is formed by the confluence of the Des Plaines and Kankakee Rivers near Channahon, IL, and flows for approximately 440 km before joining the Mississippi River near Grafton, IL (Figure 1). The Illinois River drains an area of over 75,000 km^2, resulting in a mean daily discharge of 735.7 m^3/s in the lower reaches (USGS gage 5586100; Valley City, IL). Major tributaries of the Illinois River include the Fox, Vermillion, Mackinaw, Spoon, Sangamon, and LaMoine Rivers. The upper Illinois River flows primarily westward through a geologically young channel and is characterized by a relatively narrow floodplain, steeper gradient (≈ 20 cm/km), and rocky substrates. Near Hennepin, IL, the river turns southward and enters the pre-glacial Mississippi River valley, where it has a broad floodplain, lower gradient (≈ 2 cm/km), and extensive fine sediment deposits (Delong 2005). Numerous backwater lakes occur within the middle and lower Illinois River floodplain, although most of these lakes have been extensively altered by levees, drainage practices, and sedimentation (Mills et al. 1966, Bhowmik and Demissie 1989).

In this study, 11 sampling sites on the main channel and backwaters of the Illinois Waterway were used for data collection (Table 1). Sites were selected in the middle Illinois River (LaGrange and Peoria Pools), the upper Illinois / Des Plaines River (Starved Rock, Marseilles, Dresden Island, and Brandon Road Pools), and in the CAWS. Sites were chosen to encompass the longitudinal gradient of the Illinois Waterway, sample across a gradient of Asian carp densities, offer a variety of habitat types for testing sampling gears, and for consistency of access. Both backwater (n=2) and main channel (n=2) sites were chosen in the LaGrange Pool in order to compare abundance of larval and juvenile Asian carp among these habitats. The Hanson Material Service gravel pit at Morris was the primary location of sampling in the Marseilles Pool. Sites in all other pools were located on the main channel of the Illinois Waterway, although contiguous off-channel areas were also used for sampling with some gear types at some locations. Sampling was also conducted in four tributaries of the Illinois River (Mackinaw, Spoon, Sangamon, and Salt Fork of the Sangamon River). Each tributary was sampled near its confluence with the Illinois River and at an upstream location below the first impoundment on each river (Figure 1).

Table 1. List of sampling sites on the main channel and backwaters of the Illinois Waterway that were used for collecting data on various project components during 2014. River km is measured as distance upstream of the Mississippi River. Navigation pools are classified according to the nearest downstream navigation dam.

				Project Component		
Site	River km	Waterbody	Navigation Pool	Larval Fish	Gear Evaluations	Unconventional Gear Development
Lily Lake	133.6	Illinois River backwater	LaGrange	X	X	X
Matanzas Lake	186.7	Illinois River backwater	LaGrange	X	X	
Havana	193.1	Illinois River	LaGrange	X	X	X
Peoria L&D	251.1	Illinois River	LaGrange	X	X	
Henry	305.8	Illinois River	Peoria	X	X	X
Ottawa	386.2	Illinois River	Starved Rock	X	X	X
Morris	423.2	Illinois River backwater	Marseilles	X	X	X
I-55 / Treat's Island	447.4	Des Plaines River	Dresden Island	X		
Lockport L&D	466.7	Des Plaines River / CSSC	Brandon Road	X		
Western Ave.	515.0	CSSC	Lockport	X		
O'Brien L&D	518.2	Calumet / Little Calumet River	Lockport	X		

Larval Fish Monitoring

Background

Bighead carp and silver carp are highly fecund, with individual females capable of producing hundreds of thousands of eggs (Kolar et al. 2007, Williamson and Garvey 2005, DeGrandchamp et al. 2007). Rising water levels during periods of appropriate temperature are thought to stimulate spawning activity (Verigin et al. 1978, Schrank et al. 2001, Duan et al. 2009, Lohmeyer and Garvey 2009), although recent evidence suggests that Asian carp may exhibit more flexibility in their spawning requirements than previously assumed (Deters et al. 2012, Coulter et al. 2013). Asian carp eggs are semibuoyant and drift in river currents for approximately a day before hatching (Soin and Sukhanova 1972, Chapman 2006). Larvae settle in backwaters, creeks, and flooded areas outside of the main channel, which serve as nursery areas (Abdusamadov 1987, Pegg et al. 2002, Kolar et al. 2007). Larval and juvenile Asian carp have previously been collected in the Alton, LaGrange, and Peoria Pools of the Illinois River (DeGrandchamp et al. 2007, Irons et al. 2011, Butler et al. 2014), but the potential for Asian carp reproduction further upstream in the Illinois Waterway is unknown. Asian carp are also known to be present in several tributaries of the Illinois River, but the potential for these tributary rivers to serve as spawning locations or sources of recruitment has not previously been assessed. Additionally, recruitment in the Illinois River appears to be highly variable among years (Irons et al. 2011), possibly due to variation in discharge (Hoff et al. 2011). Assessing the timing and spatial distribution of the ichthyoplankton drift and evaluating factors affecting Asian carp reproduction and recruitment in different sections of the Illinois Waterway and its tributaries will help to improve our understanding of Asian carp population dynamics and potentially aid in development of management strategies targeting early life stages.

Methods

Larval fish sampling occurred at 11 sites throughout the Illinois Waterway (Table 1). Additional sampling was conducted in four tributaries of the Illinois River (Mackinaw, Spoon, Sangamon, and Salt Fork of the Sangamon Rivers), at downstream sites near the confluence of each tributary with the Illinois River. Sampling occurred at a minimum of bi-weekly intervals from April through October, although more frequent sampling took place during periods when Asian carp spawning activity had been observed or when larval fish or eggs were considered likely to be present. Four larval fish samples were collected at each mainstem and backwater site on each sampling date. Sampling transects were located on each side of the river channel, parallel to the bank, at both upstream and downstream locations within each study site. At tributary sites, three samples were collected on each sampling date, one near each bank and another in the center of the channel. All samples were collected using a 0.5 m-diameter ichthyoplankton push net with 500 um mesh. To obtain each sample, the net was pushed upstream using an aluminum frame mounted to the front of the boat, with the boat speed adjusted to obtain 1.0 – 1.5 m/s water velocity through the net. Flow was measured using a flow meter mounted in the center of the net mouth and was used to calculate the volume of water sampled. Fish eggs and larvae were collected in a meshed tube at the tail end of the net, transferred to sample jars, and preserved in 90% ethanol. The presence of any eggs was noted and all eggs were retained for future analyses. Larval fish were identified to the lowest possible taxonomic unit in the laboratory. Larval fish densities were calculated as the number of individuals per m^3 of water sampled.

Results

During five years of sampling, 2,694 larval fish samples were collected from main channel and backwater sites of the Illinois Waterway, capturing over 86,000 individual larval fish (Table 2). In all years, Clupeids, primarily gizzard shad (*Dorosoma cepedianum*), were the most numerous larval fish taxa captured, although Cyprinids (excluding Asian carp), Sciaenids, Catostomids, and Centrarchids were also abundant in larval fish samples. During 2014, large numbers of Asian carp larvae were observed in the LaGrange (n = 2,573) and Peoria (n = 2,658) Pools, but none were observed upstream of the Peoria Pool. The numbers of Asian carp larvae observed in 2014 were substantially higher than in previous years of ichthyoplankton sampling (Table 2), suggesting that Asian carp reproductive output was much higher in 2014 than in 2010 – 2013. Over 19,000 potential Asian carp eggs have also been tentatively identified from Illinois River samples from 2014. Subsamples of potential Asian carp eggs have been sent to the USFWS Whitney Genetics Lab for genetic confirmation and results of egg collections will be reported once questions regarding egg identification have been clarified. Sampling in tributaries collected an additional 185 ichthyoplankton samples in 2014, capturing over 4,700 larval fish and over 1,800 eggs. Processing and identification of these samples is ongoing.

Table 2. Dates, effort, and number of larval fish captured during ichthyoplankton sampling activities at main channel and backwater sites of the Illinois Waterway during 2010 – 2014.

Year	Sampling Dates	# Samples	# Larval Fish	# Asian Carp Larvae
2010	Jun 3 – Oct 2	240	2,050	78
2011	Apr 27 – Oct 13	560	7,677	2
2012	May 1 – Oct 19	722	28,274	490
2013	April 30 – Oct 9	614	30,101	327
2014	April 30 – Sep 29	558	18,572	5,231

Asian carp appear to have had multiple spawning events in 2014, as indicated by the timing of larval occurrences (Figure 3). The first observations of significant numbers of Asian carp larvae occurred at multiple sites in the LaGrange Pool on June 18. None were collected at these same sites during the week of June 23. However, at that time, high densities of Asian carp larvae appeared in the Peoria Pool. During the following week (June 30 – July 4), large numbers of Asian carp larvae were again collected from main channel sites in the LaGrange Pool, and then large numbers of Asian carp larvae appeared in LaGrange Pool backwater sites during the

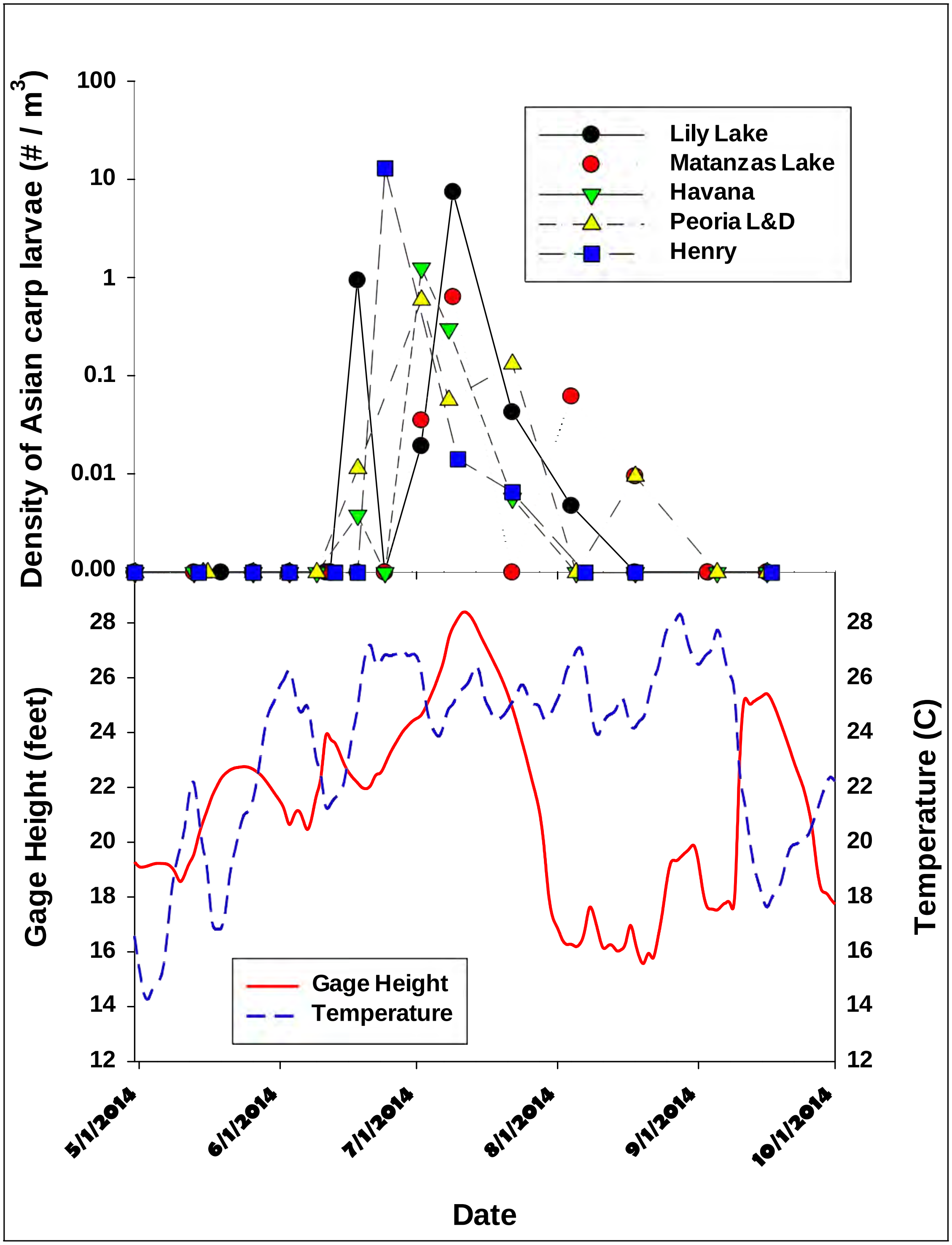

Figure 3. Mean density (number / m^3; note logarithmic scale) of Asian carp larvae collected from sites in the LaGrange (Lily Lake, Matanzas Lake, Havana, Peoria L&D) and Peoria Pools (Henry) of the Illinois River during 2014 (top panel), and mean daily gage height and water temperature of the Illinois River during this time (bottom panel). Gage height and temperature data were obtained from USGS hydrograph 5586300 at Florence, IL.

week of July 7. These occurrences of Asian carp larvae coincided with a prolonged rise in the hydrograph that occurred between mid-June and mid-July, as well as water temperatures continuously above 23°C (Figure 3). The continued presence of small numbers of Asian carp larvae from mid-July to early August in both the LaGrange and Peoria Pools suggests that additional, although less prolific spawning activity continued to occur during the summer in 2014. Few larval fish of any taxa were collected after August.

Discussion

Over five years of extensive sampling, Asian carp eggs and larvae have only been collected from the lower Illinois River (LaGrange and Peoria Pools). No Asian carp eggs, larvae, or juveniles have been identified from upstream of the Starved Rock Lock and Dam. However, silver carp spawning activity has been observed by Illinois DNR personnel in the upper Marseilles Pool, and numerous silver carp captured from the Marseilles and Starved Rock Pools during 2013 and 2014 have exhibited spawning patches, providing additional evidence that spawning activity may be occurring in these navigation pools. Asian carp eggs and larvae generally drift in the water column for considerable distances before larvae are mature enough to migrate to nursery areas (Soin and Sukhanova 1972, Krykhtin and Gorbach 1981, Chapman 2006), so the absence of eggs or larvae in samples from upstream pools may indicate that they are being rapidly transported downstream of the Starved Rock Dam following spawning events, limiting the amount of time they would be present and detectable in the water column of these reaches. Alternatively, conditions may not be suitable throughout the Starved Rock and/or Marseilles Pool to maintain eggs in suspension, leading to settling and mortality within these pools. Identifying the potential for different segments of the Illinois River to transport eggs and larvae under different discharge conditions (e.g., Garcia et al. 2013) would be useful for identifying where eggs and larvae collected in the lower Illinois River originated, and for understanding how quickly eggs produced in the upper Illinois River would be moved into downstream pools. Even if spawning occurs in these pools, if eggs are transported downstream prior to hatching and the lower river is therefore the only source of recruits into upper Illinois River pools, then restricting upstream movement of Asian carp past locks and dams could eliminate Asian carp from the upper Illinois River. However, large numbers of Asian carp larvae coupled with successful recruitment to the juvenile life stages have only been observed in one of the past five years (see Gear Evaluation section). Caution must therefore be exercised when attempting to infer spatial patterns in Asian carp recruitment from this limited pool of data, as different distributions of early life stages could be observed in future years. Continued larval fish and juvenile Asian carp monitoring will be critical for evaluating the potential for Asian carp reproduction and recruitment in the upper Illinois Waterway.

The substantial numbers of Asian carp larvae captured in 2014 contrasts with the pattern of little to no reproductive output observed in previous years of sampling. Asian carp reproduction and recruitment have previously been observed to be highly variable among years in the Illinois River (DeGrandchamp et al. 2007, Irons et al. 2011) and elsewhere in North America (Schrank et al. 2001, Lohmeyer and Garvey 2009), but few assessments of factors contributing to interannual reproductive variation have been performed. Previous analyses have suggested that recruitment in the Illinois River is related to the magnitude and variability of July river discharge (Hoff et al. 2011, Irons et al. 2011). However, DeGrandchamp et al. (2007) suggested that flow alone was insufficient to explain variation in year-class strength, arguing that some combination of maternal condition and environmental factors is likely necessary for successful reproduction. The majority of Asian carp eggs and larvae present in 2014 were collected during a period of high water temperatures (> 23°C), and a prolonged rise in water levels. This observation is generally consistent with other studies that have found spawning linked to a rising hydrograph at temperatures above 18°C (Schrank et al. 2001,Lohmeyer and Garvey 2009, Deters et al. 2012). However, small numbers of Asian carp larvae were collected through August 2014, following a large decline in water levels over several weeks. Asian carp eggs and larvae have also been collected during periods of stable or declining hydrographs in other systems (Deters et al. 2012, Coulter et al. 2013). Asian carp may be capable of multiple spawning events within a single year (Schrank and Guy 2002, Papoulias et al. 2006), and although reproductive output is almost certainly enhanced by rising water levels, spawning activity does not appear to be entirely dependent on increasing discharge. However, egg or larval densities appear to be considerably lower during periods of falling water, and the contribution of these limited spawning events to eventual recruitment is uncertain. Additionally, high and increasing discharges within the reported temperature range were observed in previous years when little to no Asian carp larvae were collected, so the conditions that contribute to successful Asian carp reproduction appear to be more complex than currently understood. Now that multiple years of ichthyoplankton sampling data is available, relationships between environmental variables (discharge, temperature, turbidity, etc.) and patterns of Asian carp reproduction can begin to be examined. However, as only one year of high larval Asian carp abundance has been observed, inferences must be appropriately limited until additional years of data, encompassing a wider range of reproductive output, have been collected.

Gear Evaluations

Background

A variety of sampling gears are being employed by various agencies to capture Asian carp, but the relative efficiency of each of these gears, and the amount of effort required to detect Asian carp when they are present in low densities, has not been evaluated. Different sampling gears may vary widely in their ability to capture fish in proportion to their abundance (i.e., catchability), and may select for different sizes of fish (Hubert 1996, Bayley and Austen 2002, Hubert and Fabrizio 2007, Neumann and Allen 2007). Estimation of catchability requires estimates of fish density, knowledge of the spatial distribution of fishes, and the sampled area into consideration (Bayley and Austen 2002, Hubert and Fabrizio 2007). Such determinations are therefore extremely difficult to obtain. However, evaluating the ability of a sampling gear to capture fish relative to other sampling gears, either in terms of total catch or catch per unit effort expended, and evaluating size selectivity, is less problematic (Casselman et al. 1990, Lapointe et al. 2006, Neumann and Allen 2007). Evaluating the ability of various methods to capture both juvenile and adult Asian carp will allow managers to customize monitoring regimes and more effectively determine relative abundances of Asian carp.

Gear evaluation sampling is also useful for characterizing the distribution of different life stages of Asian carp and other fishes within the Illinois Waterway. Asian carp are known to be less abundant in upstream pools that are closer to the electric dispersal barrier (Butler et al. 2014). Assessing the relative abundance, size distribution, and condition of Asian carp within each pool of the Illinois Waterway will provide valuable information about the demographics of these populations and the potential for these fish to continue to expand their numbers and spatial distribution within this system. Asian carp are also present in many Illinois River tributaries. Evaluating the abundance and size structure of Asian carp in these rivers will provide a more complete understanding of Asian carp populations in the Illinois River drainage as a whole and will help in determining if these tributaries serve as population sources or sinks. Understanding variation in abundance of other fish taxa across the Illinois Waterway may also provide insight into factors that influence the distribution of fishes with life histories similar to Asian carp, and may provide useful data for evaluating the effects of Asian carp on native fish assemblages.

Evaluation of sampling gears in previous years of this study was only possible for adult Asian carp, as juvenile Asian carp were scarce or absent from the Illinois Waterway during 2011 – 2013. However, during 2014, Asian carp appear to have successfully reproduced, as large numbers of larvae were observed during early sampling (see Larval Fish Monitoring section), and large numbers of juvenile Asian carp were subsequently observed in the lower Illinois River. Sampling activities during 2014 therefore focused on evaluation of sampling gears for juvenile life stages. Identification of the most effective gears for sampling juvenile Asian carp is particularly important for establishing monitoring programs to evaluate recruitment patterns, which is critical for understanding the life history of these fishes in the Illinois Waterway.

Determining which pools of the Illinois Waterway contribute to Asian carp recruitment may be valuable for designing control strategies to limit further expansion of these species and for reducing abundances of Asian carp closer to the electric dispersal barriers. Results of this study will therefore help improve Asian carp monitoring and control efforts in the Illinois River and the CAWS, and will contribute to a better understanding of the biology of these invasive species in North America.

Methods

Sampling during 2014 was conducted at seven sites located in the LaGrange, Peoria, Starved Rock, and Marseilles Pools of the Illinois River (Table 1). Sampling at two sites (Lily Lake and Morris) occurred in both backwater and main channel locations. Following the detection of larval Asian carp by ichthyoplankton sampling, pulsed-DC electrofishing was conducted at all sites biweekly during July and August in order to determine the extent of juvenile Asian carp occurrence. Additional evaluation using all juvenile sampling gears (Table 3) then occurred during summer and fall at sites where juvenile Asian carp were found to be present (LaGrange and Peoria Pools). Additional sampling using all gear types also occurred in the Marseilles Pool, although no juvenile Asian carp were detected there during 2014. All captured fish were identified to species, and measured for total length and weight. Subsamples of juvenile Asian carp were retained for later diet and age analysis.

Table 3. List of sampling gears used during 2014 to evaluate the effectiveness of each gear for capturing juvenile Asian carp.

Gear / Method	Effort per site-visit
Pulsed-DC electrofishing	4 x 15 minute transects
Small mesh gill net – floating	4 x 4 hour sets
Mini-fyke net	8 net-nights
Small mesh purse seine	4 hauls
Beach seine	4 hauls
Cast net	4 throws
Hydroacoustics	2 x 15 minute transects

During 2014, four tributaries of the Illinois River (Spoon, Sangamon, Salt Fork of the Sangamon, and Mackinaw Rivers) were also sampled for Asian carp to assess relative abundance, demographics, and potential presence of juveniles in these waterbodies. Each tributary was sampled near its confluence with the Illinois River and at an upstream location below the first impoundment on each river (Figure 1). Pulsed-DC electrofishing (15 minutes on each site-visit) was conducted monthly at each site from April to October. All captured Asian carp were measured for total length and weight. Sex and reproductive condition were assessed, and postcleithra were removed for age analysis.

Results

Pulsed-DC electrofishing monitoring was conducted in the LaGrange, Peoria, Starved Rock, and Marseilles Pools during July and August 2014, capturing 3,730 juvenile Asian carp. Juvenile silver carp were captured in the LaGrange (n = 3,694) and Peoria (n = 36) Pools, but none were captured or observed in the Starved Rock or Marseilles Pools. Subsequent evaluation using all sampling gears resulted in the capture of 101,191 fish, including 67,882 juvenile silver carp (Table 4). The vast majority of these were captured in the LaGrange Pool (n = 67,869), with only small numbers being captured in the Peoria Pool (n = 12). No juvenile Asian carp were captured or observed by gear evaluation sampling in the Marseilles Pool. Most juvenile silver carp were captured during sampling in late July or early August (n = 67,714), with substantially lower numbers being collected during late September (n = 167), despite equivalent sampling effort. Mini-fyke nets captured the highest numbers of juvenile silver carp (n = 56,054, average = 637.0 per net-night), and appeared to be the most consistent gear type, capturing large numbers of silver carp at nearly every site (Table 4). Beach seines (n = 7,211, average = 163.9 per haul), purse seines (n = 4,063, average = 92.3 per haul), electrofishing (n = 419, average = 9.5 per 15-minute transect), and cast nets (n = 135, average = 3.1 per throw) were also effective at capturing smaller numbers of juvenile silver carp, although these gears had highly variable catches among sites. Gill nets failed to capture any juvenile Asian carp.

Gear types targeting juvenile Asian carp were also found to capture different size distributions of these fish (Figure 4). Beach seines captured the smallest juvenile silver carp (mean = 38.0 mm), and captured the highest proportion of silver carp in the 20-29 mm size range (38% of catch). Purse seines captured the largest average sizes of juvenile silver carp (mean = 52.5 mm), likely because they rarely captured any silver carp smaller than 40 mm. Cast nets (mean = 40.6 mm), pulsed-DC electrofishing (mean = 48.1 mm), and mini-fyke nets (mean = 48.6 mm) produced intermediate average sizes (Figure 4). Electrofishing, although primarily capturing 30 – 60 mm silver carp, was the only gear type that consistently captured juvenile silver carp larger than 90 mm.

During 2014, a total of 796 Asian carp (6 bighead carp, 790 silver carp) were captured during 12.25 hours of pulsed-DC electrofishing in tributary rivers. Silver carp were captured at both upstream and downstream sites in all tributaries. Bighead carp were only captured in the Sangamon (n = 3) and the Salt Fork of the Sangamon River (n = 3). The highest catch-per-unit-effort of Asian carp was obtained in the Mackinaw River (mean ± SE = 65 ± 19 per hour), whereas the lowest was from the Spoon River (48 ± 13 per hour). Only adult Asian carp (440 – 880 mm) were captured by electrofishing in tributaries. No juvenile Asian carp were captured or observed with this gear type in tributary rivers during 2014. Higher numbers of male than female silver carp were observed in all tributary rivers (Figure 5). The highest silver carp gonadosomatic indices (GSI) were observed in June and GSI declined considerably, particularly for female fish, after July (Figure 6).

Table 4. Total numbers of juvenile silver carp (≤ 161 mm) captured with each sampling gear from each site in the Illinois Waterway during 2014.

		Gear					
Site	Pool	Electrofishing	Small-Mesh Gill Nets	Mini-Fyke Nets	Small-Mesh Purse Seines	Beach Seines	Cast Nets
Lily Lake - Main Channel	LaGrange	378	0	3064	1505	6836	1
Lily Lake - Backwater	LaGrange	33	0	2568	2351	119	125
Matanzas Lake	LaGrange	0	0	1434	200	3	0
Havana	LaGrange	8	0	48977	5	253	9
Henry	Peoria	0	0	11	1	0	0
Morris - Main Channel	Marseilles	0	0	0	0	0	0
Morris - Material Service Pit	Marseilles	0	0	0	0	0	0

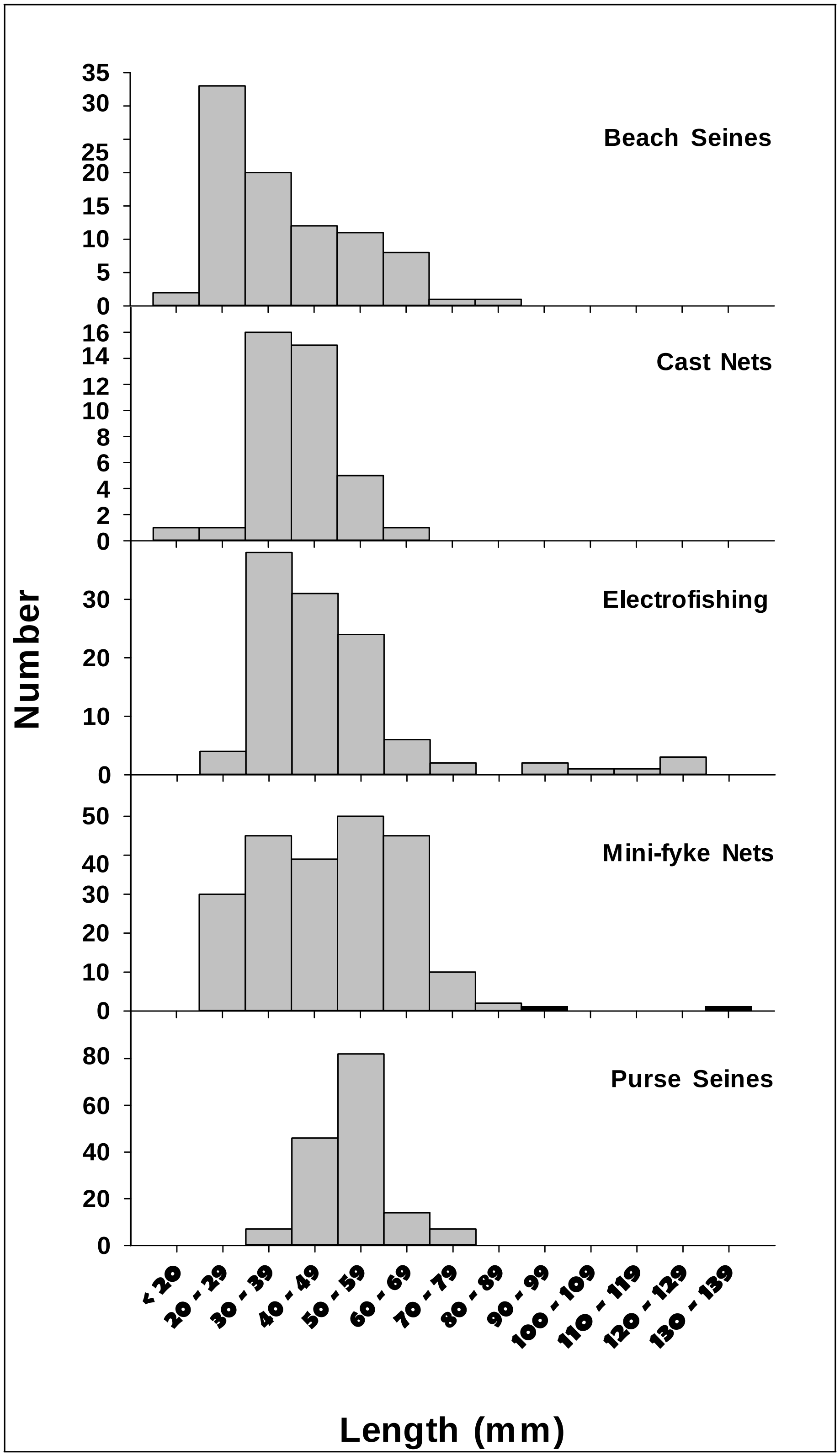

Figure 4. Size distributions of juvenile silver carp captured by different gear types from the Illinois River during 2014.

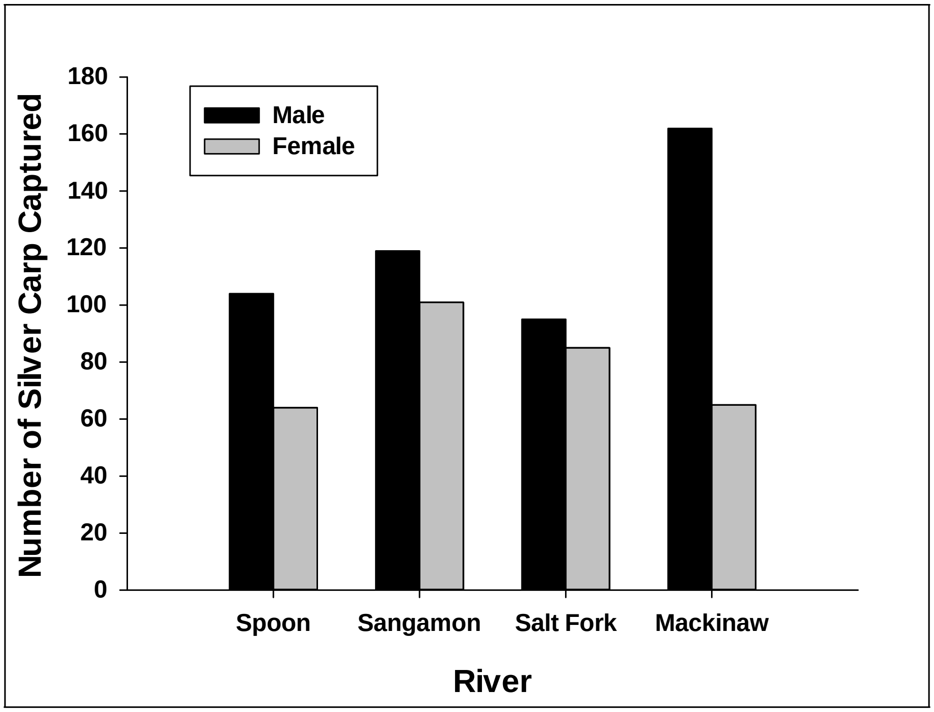

Figure 5. Numbers of male (dark bars) and female (grey bars) silver carp captured in the Spoon, Sangamon, Salt Fork of the Sangamon, and Mackinaw Rivers during 2014.

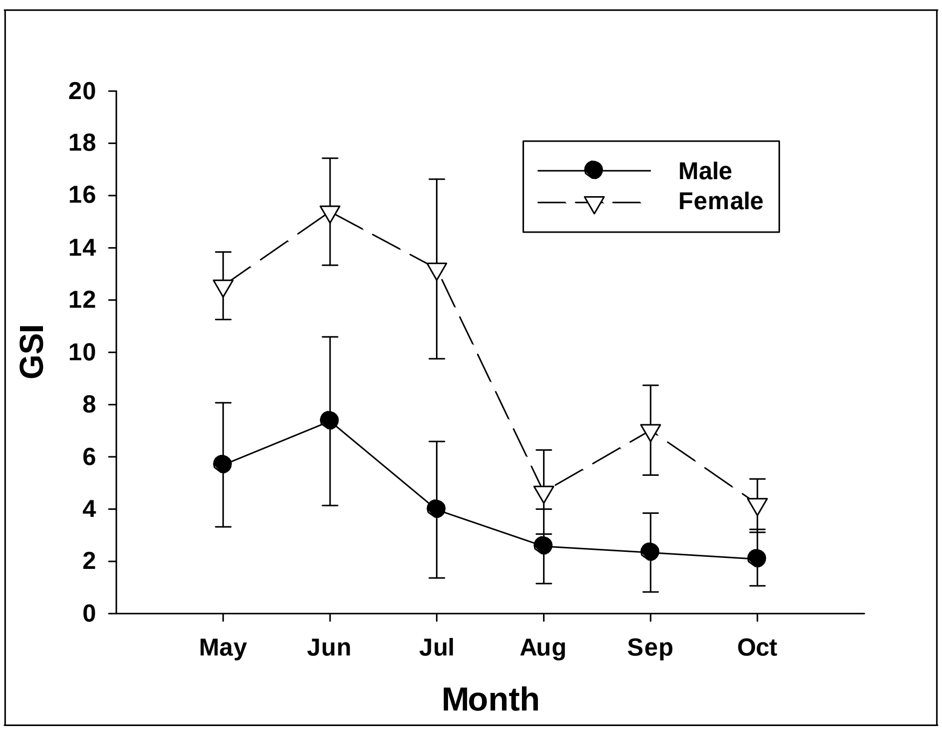

Figure 6. Mean (± SE) gonadosomatic indices for male (circles, solid line) and female (triangles, dashed line) silver carp captured in Illinois River tributaries during May – October 2014.

Discussion

The observation of large numbers of juvenile silver carp in the LaGrange Pool, but none upstream of the Peoria Pool during 2014 is consistent with findings from previous years of this study (Butler et al. 2014), as well as from other monitoring efforts occurring in the Illinois Waterway (MRWG 2014), which have found no evidence to date of juvenile Asian carp upstream of the Starved Rock Lock and Dam. Even if spawning occurs in the upper Illinois Waterway, it appears that recruitment to juvenile life stages has been limited to the lower Illinois River in recent years. Lohmeyer and Garvey (2009) found a similar pattern in the Mississippi River, with substantially higher densities of juvenile Asian carp occurring in downstream than in upstream pools. Because Asian carp eggs and larvae drift in the current for some time before they are able to actively migrate to nursery areas, it might be expected that juveniles would not be observed for some distance downstream of the uppermost spawning locations within any particular river. Additionally, backwaters, shallow creeks, and flooded off-channel areas are generally considered to be optimal nursery habitats for Asian carp (Abdusamadov 1987, Pegg et al. 2002, Kolar et al. 2007), but such areas are considerably less common in the upper Illinois Waterway than in downstream pools. Any larvae that do settle in or upstream of the Starved Rock Pool may therefore find suboptimal conditions for early growth and survival, limiting the number of recruits that would be detectable in these pools. The ability of upstream pools to serve as recruitment sources has important management implications. If Asian carp were able to successfully recruit upstream of the Starved Rock Dam, the potential for these species to sustain population growth and potentially expand their range in the upper Illinois Waterway would be much greater than if recruitment is limited to the lower Illinois River. However, if no recruitment occurs in the upper Illinois Waterway, then limiting movement of Asian carp through locks and dams, combined with continued harvest of adults in the upper pools, could substantially reduce or eliminate Asian carp from areas closer to the electric dispersal barriers, greatly decreasing the risk of invasion to the Great Lakes. Continued monitoring will be essential for determining the true spatial extent of Asian carp recruitment during years when successful reproduction occurs.

Different sampling gears varied widely in the numbers of juvenile Asian carp they captured, but catches may also reflect shifts in habitat use as Asian carp increase in size. Mini-fyke nets captured by far the highest numbers of juvenile silver carp during 2014, and collected a wide size range of individuals. Irons et al. (2011) also reported that mini-fyke nets produced the largest numbers of young-of-year Asian carp in the Illinois River. This gear type is particularly useful in near-shore areas, and is likely a useful tool for targeting the smaller size groups of juvenile Asian carp. Beach seines were also fairly effective at capturing juvenile silver carp, and may be useful for rapid monitoring purposes when overnight gear sets are not practical. However, these gear types primarily target shallow-water (< 1 m) habitats, and may not be as useful for targeting larger sizes of Asian carp as they shift to deeper-water habitats. Purse seines were effective, although highly variable, at capturing somewhat larger sizes of juvenile Asian carp in deeper-water (2 – 4 m) areas. No juvenile Asian carp were captured in gill nets during 2014, and we do not recommend this gear type for juvenile monitoring, at least for Asian carp less than 100 mm. Very few juvenile Asian carp larger than 100 mm were observed during 2014, though, and almost all of this larger size group was obtained by electrofishing. Further evaluation will be required to determine the effectiveness of these sampling gears for larger size groups of juvenile Asian carp. Additionally, all juvenile Asian carp observed during gear evaluation sampling in 2014 were identified as silver carp based on gill raker morphology, coloration, and the presence of a ventral keel. It is uncertain if bighead carp reproduction or recruitment to juvenile stages also occurred during 2014, and continued monitoring will be necessary to monitor for juveniles of this species as well as for silver carp. As only one year of sampling with gears targeting juveniles has been possible thus far, additional years of sampling when juvenile Asian carp are present will be required to answer these questions.

Asian carp appear to be present in all Illinois River tributaries sampled during 2014, and considerable numbers can be found large distances upstream from the Illinois River mainstem. The lack of bighead carp from tributary sampling efforts is likely attributable to gear bias, as only electrofishing was used to sample tributaries, but electrofishing, although highly effective for silver carp, has been found to capture very few bighead carp (Butler et al. 2014). The status of bighead carp populations in Illinois River tributaries is therefore uncertain, and additional sampling with other gear types may be necessary to adequately assess this species in these systems. The absence of juvenile Asian carp in tributaries during 2014 suggests that Asian carp either did not recruit within these waterbodies, or that recruits emigrated downstream to the mainstem Illinois River. High GSI values observed in tributaries during June, and declining thereafter, are consistent with the observation of large numbers of larval Asian carp in the Illinois River during June and July. Lower GSI's were also observed in the Illinois River during a year when higher numbers of Asian carp larvae were produced than in a year when nearly no larval production occurred (DeGrandchamp et al. 2007). However, it is uncertain at this time if Asian carp spawned in tributary rivers during 2014 or if any spawning that might have occured in these systems contributed to the populations present within these rivers or to downstream populations in the Illinois River. The large numbers of Asian carp present in these waterbodies, however, should not be ignored, and further assessment of how these fish contribute to the wider population of Asian carp throughout the Illinois River watershed should be pursued.

Unconventional Gear Development

Background

Traditional sampling gears vary widely in their ability to capture Asian carp. Additionally, the ability of some of these gears to capture Asian carp in deep-draft channels or in areas of low density is questionable. Evaluation of novel sampling gears and capture methods is therefore warranted to enhance the efficiency of monitoring programs and increase capture rates of Asian carp for control efforts. During 2014, assessment of unconventional sampling gears continued with the use of surface-to-bottom tied-down gill nets and Great Lakes style trap (pound) nets. Tied-down gill nets are used by commercial fishermen in some areas to increase catch rates relative to standard gill nets (Heard 1959, Scholten and Bettoli 2007), but no studies have assessed the effectiveness of this gear for Asian carp. Additionally, the use of fish driving methods may help to increase capture rates of Asian carp in gill nets. Driving fish into nets is an ancient method of fishing used across the world (Amarasinghe and Pitcher 1986, Minte-Vera and Petrere 2000, Okeyo 2014), and is commonly employed by commercial gill net and trammel net fishers in North America (White 1959, Vogt 1980). Verifying the utility of this method for capturing Asian carp will be informative for determining if it should be incorporated into routine monitoring programs. Pounds nets are a form of large entrapment gear commonly used in many coastal and Great Lakes fisheries (Chittenden 1991). Pound nets can be set for extended periods of time, sample a wide range of fish sizes, and have the ability to capture large numbers of fish, making them a potentially useful tool for Asian carp monitoring purposes. Capture efficiency and size selectivity of these new methods is being compared with selected traditional gears to determine the utility of these techniques for monitoring and controlling Asian carp populations.

Methods

Unconventional gears were evaluated at multiple sites in 2014 in order to evaluate their effectiveness across a range of Asian carp densities. Experiments testing the effectiveness of driving Asian carp into surface-to-bottom gill nets (91.4 m long x 8.5 m tied down to 6.1 m depth; 6.4, 7.6, 8.9, and 10.2 cm mesh panels) were conducted at four sites (LaGrange, Peoria, Starved Rock, and Marseilles Pools). Treatments included a control set, a set where fish were driven into the net with traditional pounding methods, and a set where fish were driven via a pulsed-DC electrofishing boat, each lasting 15 minutes. Five replicates of each treatment were performed at each site. All captured fish were identified to species, and measured for total length and weight. Analysis of driving experiments included data from both 2013 and 2014, comparing catch rates among treatments and among mesh sizes.

Great Lakes trap (pound) nets (100 m lead, 6.1 x 3.0 x 3.0 m pot, 7.6-9.1 m wings, 3.8-6.4 cm mesh) were deployed at the Material Service Pit (Marseilles Pool) and at Lily Lake (LaGrange Pool) for one week each during summer and fall in 2014. Pound nets were checked daily during each set, at which times all captured fish were removed from the pots for identification and measurement. Hoop nets (1.2 m x 4.8 m, 3.8 - 6.4 cm mesh) and fyke nets (15 m x 1.3 m lead, 0.9 x 1.8 m frame, 3.8 cm mesh) were also set for multiple net-nights at each site concurrent with pound nets. Comparison among pound, hoop, and fyke nets included data from 2012 – 2014, evaluating catch rates, species richness, and size distributions of Asian carp among gear types. Estimation of the amount of effort required to deploy and maintain each gear type was also used to calculate cost effectiveness of each gear in terms of amount of labor required to catch a given number of Asian carp. Two pound nets were also set for two weeks in the Material Service Pit in collaboration with USGS to test food attractants for Asian carp. The attractants were tested by deploying food on one net and using the other as a control. Results of these tests are being analyzed and will be presented by USGS.

Results

Experiments testing the effectiveness of driving Asian carp into surface-to-bottom gill nets captured a total of 80 fish in 2014, including 37 Asian carp (31 silver carp, 6 bighead carp). Analysis of combined 2013 and 2014 data indicates that drives using pulsed-DC electrofishing captured more total fish (all taxa) than drives using traditional pounding or control sets (Figure 7). Catch rates of silver carp were highest in electrofishing treatments, which were nearly four times higher than control sets, but similar to traditional pounding treatments. Bighead carp catch rates were highest in traditional pounding treatments, although these were not significantly different than control or electrofishing treatments. A majority of all fish and of silver carp were captured in smaller mesh panels, particularly the 6.4 cm mesh size (Figure 7). However, bighead carp appear to be more vulnerable to larger mesh sizes, and drives using pounding in particular captured higher numbers of bighead carp in the 10.2 cm mesh panel.

A total of 1,207 fishes were captured in pound nets at Lily Lake and Material Service Pit during 2014. Of this catch, 135 were bighead carp and 881 were silver carp. Collectively, Asian carp comprised 84% of all fishes caught during 2014 in pound nets. Analysis of combined 2012 - 2014 data indicated that catch rates of fishes, including Asian carp taxa, were consistently higher in pound nets in comparison to traditional entrapment gears (Figure 8). Average nightly catch of all fish species was, on average, 134 times higher in pound nets than in hoop nets and 5-6 times higher than in fyke nets. Overnight catch rates of bighead carp were 113 times higher in pound nets than in hoop nets, and 41 times higher than in fyke nets. Average silver carp catch rates were 3200 times higher in pound nets than in hoop nets, and 360 times higher in pound nets than in fyke nets. Overall species richness was similar between pound nets (mean = 7.4 species per net-night) and fyke nets (5.1 species per net night), whereas hoop nets only averaged one species per net-night. Pound nets tended to capture larger bighead carp (mean ± SD = 829 ± 103 mm) than hoop nets (619 ± 99 mm) or fyke nets (681 ± 140 mm). However, sizes of silver carp did not differ significantly among pound nets (582 ± 62 mm), hoop nets (572 ± 75 mm), and fyke nets (557 ± 78 mm).

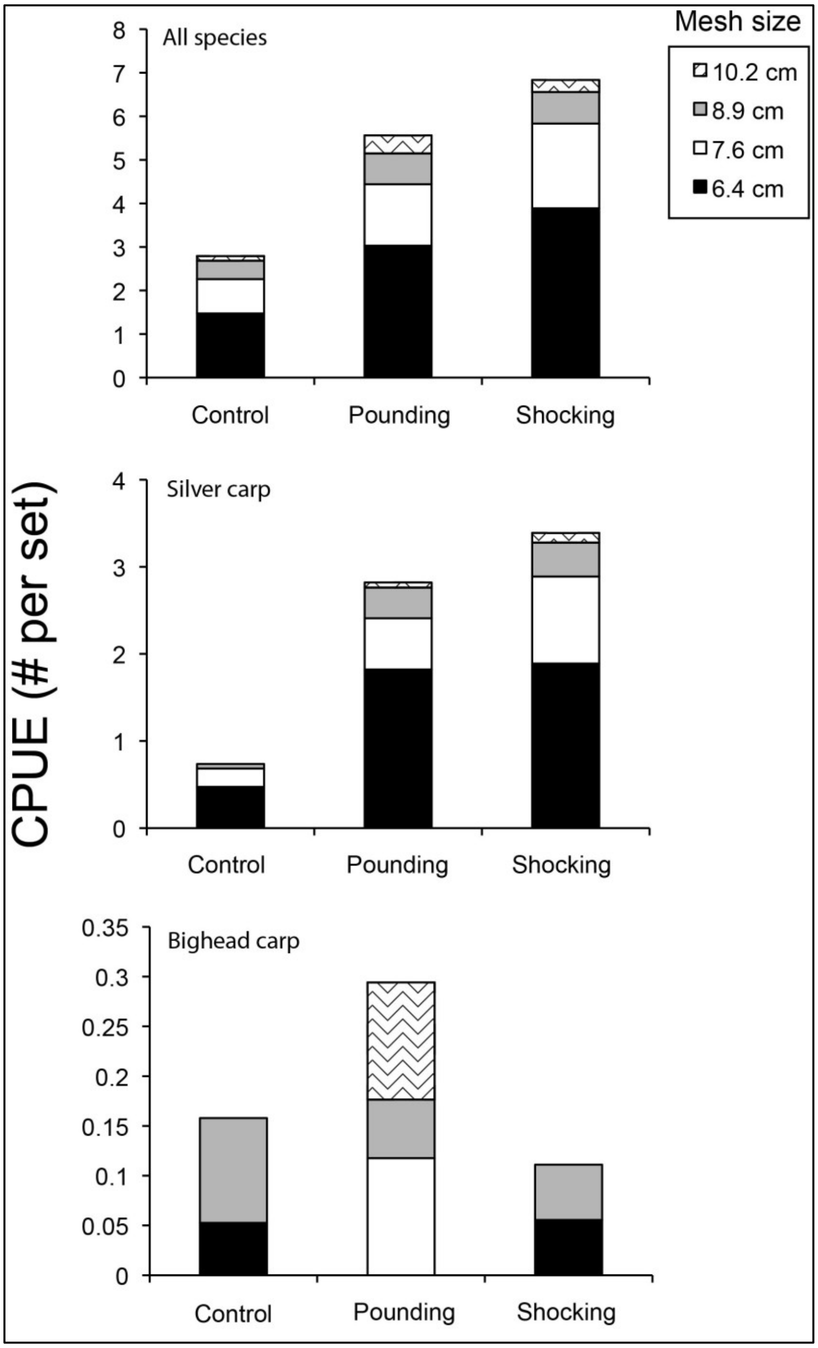

Figure 7. Mean catch per unit effort (CPUE; number / set) of all fish taxa, silver carp, and bighead carp captured in different mesh sizes (6.4 – 10.2 cm) of surface-to-bottom gill nets set for 15-minutes with a control treatment (no driving), a treatment where fish were driven into the net using traditional pounding methods, and a treatment where fish were driven into the net via pulsed-DC electrofishing.

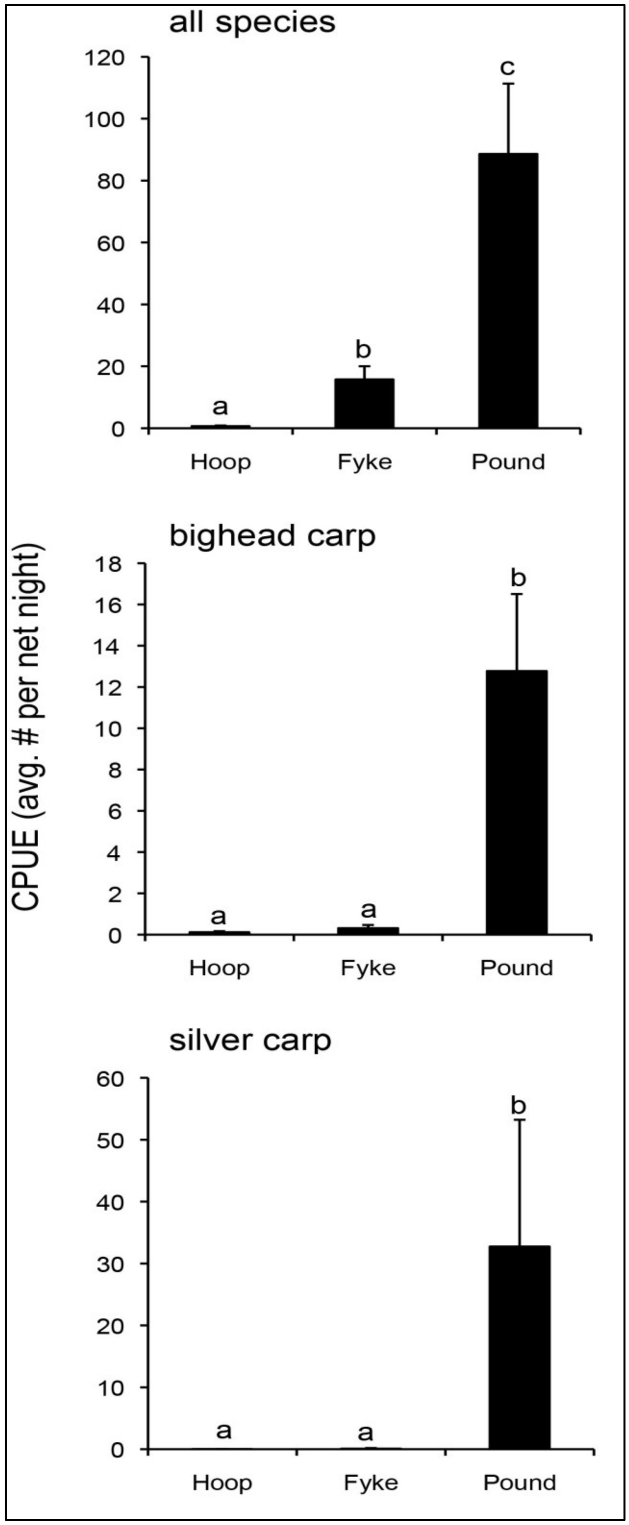

Figure 8. Mean (± SE) catch rates of all fish taxa, bighead carp, and silver carp from hoop nets, pound nets, and fyke nets set at Lily Lake and the Hanson Material Service Pit at Morris during 2012 – 2014. Letters above bars indicate significant differences among gears (Tukey's HSD, $P < 0.05$).

The time required to deploy and reset a pound net every day over a week of sampling was estimated at 12 – 17.2 person-hours of labor. The time required to set each fyke net or hoop net each day for a week was estimated to vary between 0.83 and 1.5 person-hours. To capture the equivalent number of fish of all species as one pound net, 6 fyke nets or 134 hoop nets would be required. The overall effort required to achieve this catch would be lowest for fyke nets and highest for hoop nets (Table 5). To capture an equivalent number of Asian carp as one pound net would require 41 fyke nets or 113 hoop nets for bighead carp, and 360 fyke nets or 3,200 hoop nets for silver carp. The labor necessary to achieve these catches would be lowest with pound nets for both species (Table 5).

Table 5. Effort (person-hours) required to deploy and maintain pound, fyke, and hoop nets for one week of sampling in order to obtain equivalent catches of all fish species, bighead carp, and silver carp. Labor hours were not calculated for silver carp with hoop nets due to the extremely high number of net sets required.

Gear	All species		Bighead carp		Silver carp	
	# traps	Labor hrs	# traps	Labor hrs	# traps	Labor hrs
Pound	1	12.0 - 17.2	1	12.0 - 17.2	1	12.0 - 17.2
Fyke	6	5.0 - 9.0	41	34.2 - 61.5	360	300.0 - 540
Hoop	134	111.7 - 201.0	113	94.2 - 169.5	3200	-

Discussion

Driving fish into surface-to-bottom gill nets and use of pound nets in backwater habitats both appear to be effective methods for capturing Asian carp and other fishes under conditions appropriate for each gear type. Driving methods, either with traditional pounding or with electrofishing gear, resulted in substantial increases in catch rates over control sets. Use of surface-to-bottom gill nets in conjunction with electrofishing in particular may be a useful system for capturing Asian carp in some situations, especially where electrofishing alone is ineffective due to water depth. This combination system may also be useful for targeting both bighead carp and silver carp simultaneously, as electrofishing alone is highly effective for silver carp, but rarely captures bighead carp (Butler et al. 2014). Traditional pounding methods may still have application, though, as catch rates of both bighead carp and silver carp in pounding treatments were not statistically different than in electrofishing treatments. However, silver carp and bighead carp appear to differ in their vulnerability to various mesh sizes. This effect may be attributable to different size distributions of these two species in the Illinois River, as different mesh sizes have previously been found to target varying size groups of each species (Butler et al. 2014). Mesh size of surface-to-bottom gill nets used for monitoring or control purposes should therefore be carefully selected, multiple nets of various mesh size should be used at a given site, or experimental gill nets with panels that target a range of anticipated Asian carp sizes should be employed.

The use of pound nets in backwater habitats appears to be an effective means of capturing large numbers of Asian carp relative to conventional approaches. Pound nets captured more overall fish and higher numbers of both bighead carp and silver carp than concurrently set hoop nets and fyke nets. Overnight catches of individual pound net sets did vary considerably, likely with natural variation in Asian carp density, site-specific habitat conditions that might affect capture efficiency, and localized depletions associated with removal of captured Asian carp. However, it is apparent that pound nets are capable of capturing very large numbers of Asian carp under optimal conditions. During one overnight deployment during summer 2014, 588 Asian carp (546 silver carp, 42 bighead carp), weighing 1,058 kg, were captured. This single net-night captured more Asian carp than all hoop nets and fyke nets combined during the 2014 sampling season. The extreme difference between pound net and hoop net catch rates is likely due to the relative inefficiency of hoop nets that was observed in backwater areas as part of this study. Indeed, many hoop net sets failed to capture any fish. This contrasts with earlier findings from the Gear Evaluation study, where hoop nets were found be the most effective gear type for bighead carp and hybrid Asian carp, and the second most effective gear for capturing silver carp (Butler et al. 2014). This disparity may be due to difference in the effectiveness of hoop nets in areas with or without current, and additional analysis of previous years' gear evaluation data from both backwater and main channel sites may help to clarify the relative effectiveness of hoop nets in each habitat type. Both hoop nets and fyke nets may also be underrepresenting the size distribution of bighead carp, as pound nets tended to capture larger bighead carp than either other gear type. The mechanism responsible for this difference isn't clear, though, and this pattern appears to only be present for bighead carp, as sizes of silver carp did not vary among gear types. Additionally, no intermediate size classes of Asian carp (100 to 400 mm) were present in the Illinois River during 2014, so the ability of pound nets to capture smaller size ranges of Asian carp is still uncertain.

Pound nets appear to be a highly cost-effective tool for capturing Asian carp in backwater habitats. Management decisions must often balance a desired outcome against the costs associated with achieving it. The benefits of increasing catch rates of target fishes must therefore be weighed against the effort needed to set, maintain, and process sampling gears. In addition to capturing substantially higher numbers of Asian carp than hoop nets or fyke nets, the number of labor hours necessary to achieve equivalent catches of Asian carp with each gear type is considerably lower for pound nets. This gear type therefore appears to be an effective tool that may prove useful for Asian carp monitoring and removal purposes. However, other limitations to the use of pound nets must also be considered. The initial deployment of this gear takes considerable effort, and training and experience are required to successfully set these nets. Due to their size, storage, transportation, and limitations on where pound nets are able to be set are also concerns. Backwater areas appear to be appropriate for deployment, but use in lotic habitats would likely result in substantial complications. Gear saturation and by-catch mortality may also be concerns if pound nets are checked less than daily, so frequent maintenance of this gear type is strongly recommended.

Recommendations

Larval fish sampling should continue in future years in order to monitor for Asian carp reproduction, particularly upstream of the Peoria Pool. The high reproductive output and recruitment to juvenile stages that was observed in 2014 contrasts with the pattern of little to no reproductive output observed in previous years. The data collected in 2014 will therefore be important to eventually understanding factors that contribute to Asian carp reproduction and recruitment, but is not sufficient by itself to make strong inferences regarding these relationships. Additional sampling during other years of high reproductive output will be required to adequately understand factors that contribute to Asian carp reproduction and recruitment, and to sufficiently characterize the potential for these species to reproduce in upstream reaches. Analysis of egg and larval fish drift is also needed to determine the origin of Asian carp eggs and larvae that have been sampled from the LaGrange and Peoria Pools. Continued larval fish sampling in tributary rivers (Sangamon, Salt Fork of the Sangamon, Spoon, and Mackinaw Rivers) is warranted to examine the potential for these systems to serve as sources for Asian carp populations in the Illinois Waterway, and to evaluate the potential for similar rivers in the Great Lakes region to serve as spawning tributaries.

Evaluation of sampling gears targeting juvenile Asian carp was possible during 2014 due to high reproductive output and subsequent recruitment to juvenile stages. Continued analysis of size distributions and locations where juveniles were captured (main channel vs backwater sites) may reveal additional insight into the early life history of these species. Additional sampling for juvenile Asian carp larger than 90 mm is necessary to determine the habitats these fish associate with and the most effective gears for targeting these sizes. Additionally, as all the juvenile Asian carp observed during 2014 were silver carp, numerous questions remain concerning bighead carp reproduction and recruitment, habitat use by juvenile bighead carp, and the most effective gears for targeting juvenile bighead carp. As only one year of sampling with gears targeting juvenile Asian carp has been possible thus far, additional years of sampling will be required to answer these questions, evaluate the consistency of observed patterns, and provide sufficient data for robust detection probability analyses for juvenile sampling gears. Tributary sampling should continue to evaluate demographic characteristics of Asian carp populations within tributary rivers. Targeted sampling for juveniles within these systems should also occur to determine if recruitment occurs within tributaries.

Driving fish into surface-to-bottom gill nets and use of pound nets in backwater habitats both appear to be effective techniques for capturing Asian carp, and may be recommended for monitoring and control purposes in appropriate areas. Driving fish into surface-to-bottom gill nets may be particularly useful in deeper-water habitats where electrofishing alone is ineffective, and may allow for a better representation of bighead carp than electrofishing is capable of producing. Smaller mesh sizes (6.4 – 7.6 cm) are recommended for targeting the majority of fish species, including silver carp, whereas larger mesh sizes (7.6 – 10.2 cm) are likely to be more effective for bighead carp. Pound nets appear to be highly effective for capturing large numbers of adult Asian carp in backwater habitats with less effort than would be required using traditional entrapment gears. Daily attendance of pound nets is recommended to ensure that pound nets are fishing effectively and to minimize mortality of native species. Future evaluation of pound nets should examine their effectiveness for capturing intermediate size classes of Asian carp (100 to 400 mm), which should be present during 2015. Additionally, tests of pound nets used in conjunction with feeding attractants should be performed to continue work that began in 2014. Additional new gears or gear combinations should likewise be evaluated as they become available.

References

Abdusamadov, A.S. 1987. Biology of white amur (*Ctenopharyngodon idella*), silver carp (*Hypophthalmichthys molitrix*), and bighead (*Aristichthys nobilis*), acclimatized in the Terek Region of the Caspian basin. Journal of Ichthyology 26:41-49.

Amarasinghe, U.S., and T.J. Pitcher. 1986. Assessment of fishing effort in Parakrama Samudra, an ancient man-made lake in Sri Lanka. Fisheries Research 4:271-282.

Bayley, P.B., and D.J. Austen. 2002. Capture efficiency of a boat electrofisher. Transactions of the American Fisheries Society 131:435-451.

Bhowmik, N.G., and M. Demissie. 1989. Sedimentation in the Illinois River valley and backwater lakes. Journal of Hydrology 105:187-195.

Burke, J.S., D.R. Bayne, and H. Rea. 1986. Impact of silver and bighead carps on plankton communities of channel catfish ponds. Aquaculture 55:59-68.

Butler, S.E., M.J. Diana, J.A. Freedman, S.F. Collins, D.H. Wahl, R.E. Colombo, and T.W. Spier. 2014. Investigate enhanced sampling with traditional and new gears to assess detectability for Asian carp in the Illinois Waterway: 2013 annual report. Illinois Natural History Survey, Champaign, IL. 62 p.

Casselman, J.M., T. Penczak, L. Carl, R.H.K. Mann, J. Holcik, and W.A. Woitowich. 1990. An evaluation of fish sampling methodologies for large-river systems. Polish Archives of Hydrobiology 37:521-552.

Chapman, D.C. 2006. Early development of four cyprinids native to the Yangtze River, China. U.S. Geological Survey Data Series 239.

Chen, P., E.O. Wiley, and K.M. Mcnyset. 2007. Ecological niche modeling as a predictive tool: silver and bighead carps in North America. Biological Invasions 9:43-51.

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

Chittenden, M.E. 1991. Operational procedures and sampling in the Chesapeake Bay pound-net fishery. Fisheries 16(5):22-27.

Coulter, A.A., D. Keller, J.J. Amberg, E.J. Bailey, and R.R. Goforth. 2013. Phenotypic plasticity in the spawning traits of bigheaded carp (*Hypophthalmichthys* spp.) in novel ecosystems. Freshwater Biology 58:1029-1037.

Darling, J.A., and A.R. Mahon. 2011. From molecules to management: adopting DNA-based methods for monitoring biological invasions in aquatic environments. Environmental Research 111: 978-988.

DeGrandchamp, K.L., J.E. Garvey, and L.A. Csoboth. 2007. Linking adult reproduction and larval density of invasive carp in a large river. Transactions of the American Fisheries Society 136:1327-1334.

De Iongh, H.H., and J.C.J. Van Zon. 1993. Assessment of impact of the introduction of exotic fish species in north-east Thailand. Aquaculture and Fisheries Management 24:279-289.

Delong, M.D. 2005. Upper Mississippi River Basin. Pages 327-373 *in* A.C. Benke and C.E. Cushing, eds. Rivers of North America. Elsevier Academic Press, Burlington, MA.

Deters, J.E., D.C. Chapman, and B. McElroy. 2012. Location and timing of Asian carp spawning in the lower Missouri River. Environmental Biology of Fishes 96:617-629.

Duan, X., S. Liu, M. Huang, S. Qui, Z. Li, K. Wang, and D. Chen. 2009. Changes in abundance of larvae of the four domestic Chinese carps in the middle reach of the Yangtze River, China, before and after closing of the Three Gorges Dam. Environmental Biology of Fishes 86:13-22.

Ficetola, G.F., C. Miaud, F. Pompanon, and P. Taberlet. 2008. Species detection using environmental DNA from water samples. Biology Letters 4:423-425.

Fuller, P.L., L.G. Nico, and J.D. Williams. 1999. Nonindigenous fishes introduced into inland waters of the United States. American Fisheries Society, Special Publication 27, Bethesda, Maryland.

Garcia, T., P.R. Jackson, E.A. Murphy, A.J. Valocchi, and M.H. Garcia. 2013. Development of a fluvial egg drift simulator to evaluate the transport and dispersion of Asian carp eggs in rivers. Ecological Modelling 263:211-222.

Heard, W.R. 1959. The use of hobbled gill nets in a commercial fishery of Lake Carl Blackwell, Oklahoma. Proceedings of the Annual Conference of the Southeastern Association of Game and Fish Commissioners 13:90-95.

Herborg, L.M., N.E. Mandrak, B.C. Cudmore, and H.J. MacIsaac. 2007. Comparative distribution and invasion risk of snakehead (Channidae) and Asian carp (Cyprinidae) species in North America. Canadian Journal of Fisheries and Aquatic Sciences 64:1723-1735.

Hoff, M.H., M.A. Pegg, and K.S. Irons. 2011. Management implications from a stock-recruit model for bighead carp in portions of the Illinois and Mississippi Rivers. American Fisheries Society Symposium 74:5-14.

Hubert, W.A. 1996. Passive capture techniques. Pages 157-192 *in* B.R. Murphy and D.W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, MD.

Hubert, W.A., and M.C. Fabrizio. 2007. Relative abundance and catch per unit effort. Pages 279-325 *in* C.S. Guy and M.L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, MD.

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

Irons, K.S., G.G. Sass, M.A. McClelland, and T.M. O'Hara. 2011. Bigheaded carp invasion of the LaGrange Reach of the Illinois River: insights from the Long Term Resource Monitoring Program. American Fisheries Society Symposium 74:31-50.

Jerde, C.L., W.L. Chadderton, A.R. Mahon, M.A. Renshaw, J. Corush, M.L. Budny, S. Mysorekar, and D.M. Lodge. 2013. Detection of Asian carp DNA as part of a Great Lakes basin-wide surveillance program. Canadian Journal of Fisheries and Aquatic Sciences 70:522-526.

Jerde, C.L., A.R. Mahon, W.L. Chadderton, and D.M. Lodge. 2011. "Sight-unseen" detection of rare aquatic species using environmental DNA. Conservation Letters 4:150-157.

Kocovsky, P.M., D.C. Chapman, and J.E. McKenna. 2012. Thermal and hydrologic suitability of Lake Erie and its major tributaries for spawning of Asian carps. Journal of Great Lakes Research 38:159-166.

Kolar, C.S., D.C. Chapman, W.R. Courtenay, C.M. Housel, J.D. Williams, and D.P. Jennings. 2007. Bigheaded carps: a biological synopsis and environmental risk assessment. American Fisheries Society, Special Publication 33, Bethesda, MD.

Kolar, C.S., and D.M. Lodge. 2002. Ecological predictions and risk assessment for alien fishes in North America. Science 298:1233-1236.

Krykhtin, M.L., and E.I. Gorbach. 1981. Reproductive ecology of the grass carp, *Ctenopharyngodon idella*, and the silver carp, *Hypophthalmichthys molitrix*, in the Amur Basin. Journal of Ichthyology 21:109-123.

Lapointe, N.W.R., L.D. Corkum, and N.E. Mandrak. 2006. A comparison of methods for sampling fish diversity in shallow offshore waters of large rivers. North American Journal of Fisheries Management 26:503-513.

Lohmeyer, A.M., and J.E. Garvey. 2009. Placing the North American invasion of Asian carp in a spatially explicit context. Biological Invasions 11:905-916.

Lu, M. P. Xie, H. Tang, Z. Shao, and L. Xie. 2002. Experimental study of trophic cascade effect of silver carp *Hypophthalmichthys molitrix* in a subtropical lake, Lake Donghu: on plankton community and underlying mechanisms of change of crustacean community. Hydrobiologia 487:19-31.

Merkes, C.M., S.G. McCalla, N.R. Jensen, M. P. Gaikowski, and J.J. Amberg. 2014. Persistence of DNA in carcasses, slime, and avian feces may affect interpretation of environmental DNA data. PLoS ONE 9(11):e113346.

Mills, H.B., W.C. Starrett, and F.C. Bellrose. 1966. Man's effect on the fish and wildlife of the Illinois River. Illinois Natural History Survey Biological Notes 57:1-24.

Minte-Vera, C.V., and M. Petrere. 2000. Artisinal fisheries in urban reservoirs: a case study from Brazil (Billings Reservoir, São Paulo Metropolitan Region). Fisheries Management and Ecology 7:537-549.

Monitoring and Response Workgroup (MRWG). 2014. 2013 Asian carp monitoring and response plan interim summary reports. Asian Carp Regional Coordinating Committee, Council on Environmental Quality, Washington, DC.

Neumann, R.M., and M.S. Allen. 2007. Size structure. Pages 375-421 *in* C.S. Guy and M.L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, MD.

Okeyo, D.O. 2014. Artisanal and commercial fishing gear and practices in the Lake Victoria basin drainage system of Kenya: a photodiagrammatic verification. Lakes and Reservoirs: Research and Management 19:192-205.

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

Pegg, M.A., A.M. Lemke, and J.A. Stoeckel. 2002. Establishment of bighead carp in an Illinois River floodplain lake: a potential source population for the Illinois River. Journal of Freshwater Ecology 17:161-163.

Rasmussen, J.L., H.A. Regier, R.E. Sparks, and W.W. Taylor. 2011. Dividing the waters: the case for hydrologic separation of the North American Great Lakes and Mississippi River basins. Journal of Great Lakes Research 37:588-592.

Sampson, S.J., J.H. Chick, and M.A. Pegg. 2009. Diet overlap among two Asian carp and three native fishes in backwater lakes on the Illinois and Mississippi rivers. Biological Invasions 11:483-496.

Sass, G.G., T.R. Cook, K.S. Irons, M.A. McClelland, N.N. Michaels, T.M. O'Hara, and M.R. Stroub. 2010. A mark-recapture population estimate for invasive silver carp (*Hypophthalmichthys molitrix*) in the La Grange Reach, Illinois River. Biological Invasions 12:433-436.

Sass, G.G., C. Hinz, A.C. Erickson, N.N. McClelland, M.A. McClelland, and J.M. Epifanio. 2014. Invasive bighead and silver carp effects on zooplankton communities in the Illinois River, Illinois, USA. Journal of Great Lakes Research 40:911-921.

Scholten, G.D., and P.W. Bettoli. 2007. Lack of size selectivity for paddlefish captured in hobbled gillnets. Fisheries Research 83:355-359.

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

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

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

Soin, S.G., and A.I. Sukhanova. 1972. Comparative morphological analysis of the development of the grass carp, the black carp, the silver carp and the bighead (Cyprinidae). Journal of Ichthyology 12:61-71.

Spataru, P., and M. Gophen. 1985. Feeding behavior of silver carp *Hypophthalmichthys molitrix* Val. and its impact on the food web of Lake Kinnert, Israel. Hydrobiologia 120:53-61.

Sugunan, V.V. 1997. Fisheries management of small water bodies in seven countries in Africa, Asia, and Latin America. FAO Fisheries Circular 993.

Tucker, J.K., F.A. Cronin, R.A. Hrabik, M.D. Petersen, and D.P. Herzog. 1996. The bighead carp (*Hypophthalmichthys nobilis*) in the Mississippi River. Journal of Freshwater Ecology 11:241-243.

Verigin, B.V., A.P. Makeyeva, and M.I. Zaki Mokhamed. 1978. Natural spawning of the silver carp, *Hypophthalmichthys molitrix*, the bighead carp, *Aristichthys nobilis*, and the grass carp, *Ctenopharyngodon idella*, in the Syr-Dar'ya River. Journal of Ichthyology 18:143-146.

Vogt, R.C. 1980. New methods for trapping aquatic turtles. Copeia 1980:368-371.

White, C.E. 1959. Selectivity and effectiveness of certain types of commercial nets in the T.V.A. Lakes of Alabama. Transactions of the American Fisheries Society 88:81-87.

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

Xie, P., and Y. Yang. 2000. Long-term changes of Copepoda community (1957-1996) in a subtropical Chinese lake stocked densely with planktivorous filter-feeding silver and bighead carp. Journal of Plankton Research 22:1757-1778.