Distribution, Age Structure, and Growth of Bigheaded Carps in the Lower Tennessee and Cumberland Rivers

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Abstract - Invasive Asian carps Hypophthalmichthys nobilis (Bighead Carp) and H. molitrix (Silver Carp), collectively referred to as bigheaded carps, were introduced to the US in the 1970s to control noxious algae blooms in aquaculture ponds. Fish subsequently escaped, and by the 1980s bigheaded carps were widespread and established in the upper Mississippi River, lower Missouri River, and the Ohio River and some of its tributaries. We sampled bigheaded carps in the lowermost reservoirs on the Tennessee River (Kentucky Lake) and Cumberland River (Lake Barkley) in 2015 and 2016 using multiple gears, including gill nets, hoop nets, electrofishing, and cast nets, to describe their distribution and estimate several population attributes. Additional electrofishing samples on the Duck River, a system renowned for its diverse ichthyofauna and mussel communities, revealed that Silver Carp range extends 220 rkm upstream below the Columbia Dam. We collected a total of 737 Silver Carp and 10 Bighead Carp through the course of this study. The maximum total lengths and ages were 1385 mm and 22 years for Bighead Carp and 1005 mm and 13 years for Silver Carp. The Silver Carp populations in both reservoirs had the same pattern of strong year classes (2010, 2011, 2012, and 2015) and similar growth rates, which were faster than what has been reported for other populations around the globe. Some YOY Silver Carp were collected 180 and 110 rkm upstream in Kentucky Lake and Lake Barkley, respectively, and they may represent the first evidence of natural reproduction in those reservoirs or their tributaries.

Introduction

Hypophthalmichthys nobilis Richardson (Bighead Carp) and H. molitrix Valenciennes (Silver Carp), hereafter collectively referred to as bigheaded carps, are native to large rivers of eastern Asia and have been introduced to every continent in the world except Antarctica (Kolar et al. 2007). Bigheaded carps are popular table fare in overseas countries and have been used for their perceived ability to control zooplankton and phytoplankton production in polyculture ponds (Kolar et al. 2007). Bigheaded carps were first introduced to the US in Arkansas in the early 1970s for aquaculture purposes (Freeze and Henderson 1982). The Arkansas Game and Fish Commission subsequently propagated and stocked bigheaded carps to assess their utility as a biological control of excessive plankton and nutrients in wastewater lagoons (Henderson 1983). Soon thereafter, natural resource agencies and researchers from several other states began importing and stocking bigheaded carps to initiate

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similar studies with little regard for their potential establishment and impact on native communities and waterways (Kolar et al. 2007).

Silver Carp were reported from open waterways as early as 1975 in Arkansas, and a single Bighead Carp was captured from the Ohio River below Smithland Dam, KY, in 1981 (Freeze and Henderson 1982, Kelly et al. 2011). Reports of natural reproduction soon followed. Burr et al. (1996) captured young-of-year (YOY) Silver Carp near Horseshoe Lake, IL (an oxbow lake on the Mississippi River), and Pfieger (1997) collected young Bighead Carp from Missouri waters in 1989. Subsequently, these 2 species continued to reproduce in the wild and are now established in much of the Mississippi, Missouri, and Ohio river basins (Kolar et al. 2007). To date, Silver Carp have been reported in at least 16 states and Puerto Rico, and Bighead Carp have been found in 23 states and Lake Erie, ON, Canada (Kolar et al. 2007, USGS 2016).

Bigheaded carps are successful invaders because they tolerate a wide range of climates, are highly fecund and protracted spawners, grow quickly, and can quickly overpopulate new waters (Kolar et al. 2007). Bigheaded carps in Asia have a wide distribution (21°N to 43.5°N latitude) in areas with mean annual air temperatures that vary from -4 °C to 24 °C (Kolar et al. 2007). Although bigheaded carps can naturally occur in a wide range of habitats including large rivers, reservoirs, lakes, and ponds, they likely cannot reproduce without access to suitable riverine conditions because fertilized eggs are semi-buoyant and depend on sufficient shear velocity to keep them from settling to the bottom and suffocating (Jennings 1988, Laird and Page 1996, Verigin et al. 1978). However, recent research suggests that a reach as short as 25 rkm could allow bigheaded carp eggs to hatch given sufficient flows and optimal water temperatures (Murphy and Jackson 2013).

Bigheaded carps are exhibiting rapid population growth in some US watersheds, and predators are not impeding the invasion because both carp species quickly outgrow native piscivore gape limitations (Kolar et al. 2007, Schrank and Guy 2002). For instance, Bighead Carp increased exponentially in Navigation pool 26 of the Mississippi River near St. Louis, MO, from 1992 to 2001 (Chick and Pegg 2001). Likewise, Silver Carp increased exponentially in the La Grange Reach of the Illinois River from 1990 to 2008 (Irons et al. 2011, Sass et al. 2010) and accounted for nearly a quarter of the total fish biomass in the Illinois River in 2007 (McClelland and Sass 2008). It is difficult to estimate the extent to which these invasive species have impacted ecosystem structure and function because relatively little is known about the ecology of native fish and plankton communities in large river systems (Dettmers et al. 2001). Nevertheless, there is growing evidence that bigheaded carps have the ability to influence water quality, alter plankton communities, compete with native planktivores, displace native fish from optimal habitats, and transmit diseases (Kolar et al. 2007).

Bigheaded carps can induce a trophic cascade that shifts zooplankton communities towards smaller individuals (Kolar et al. 2007). Such a trophic cascade could negatively affect native planktivorous fishes that prey on large zooplankton. Sampson et al. (2009) concluded that Bighead Carp diets overlapped with those of Dorosoma cepedianum Lesueur (Gizzard Shad) and Ictiobus cyrinellus...
Valenciennes (Bigmouth Buffalo), and the condition of those 2 native species declined in the Mississippi River and Illinois River after bigheaded carps became established (Irons and Sass 2007). Although Sampson et al. (2009) did not observe substantial overlap in the diets of Bighead Carp and adult Polyodon spathula Walbaum (Paddlefish), age-0 Paddlefish grew slower when age-0 Bighead Carp were present (Schrank et al. 2003). Virtually all fishes during their larval stage feed on similar food resources as bigheaded carps (Chick and Pegg 2001). Therefore, bigheaded carps could have negative consequences for entire fish communities.

Bigheaded carp are highly mobile in open systems due to their migratory nature; thus, coordination between states and in some cases national boundaries is necessary for effective management of these species (Conover et al. 2007). In 2015, the USFWS hosted an inter-agency meeting for states within the Ohio River basin (Illinois, Indiana, Kentucky, New York, Pennsylvania, Tennessee, and West Virginia) called the Ohio River Asian Carp Management Meeting. The purposes of the meeting were, in part, to foster inter-agency collaboration for planning and reporting, funding strategies, and implementation of management plans. However, a fundamental understanding of regional population characteristics is critical to the strategy of such plans (Conover et al. 2007).

By the early 2000s, the leading edge of the bigheaded carp invasion in the southeast US was in the Tennessee River and Cumberland River drainages (Kolar et al. 2007). Recent reports by anglers and biologists revealed that bigheaded carps are advancing in Tennessee waters. However, bigheaded carp populations had not been studied or systematically sampled throughout Kentucky Lake and Lake Barkley, the lowest reservoirs on each river system. The objectives of this study were to (1) document their distribution in the lower Tennessee and Cumberland rivers, (2) describe the age- and size-class structures of those populations, and (3) estimate their growth rates.

**Study Areas**

Kentucky Lake is a mainstem reservoir of the Tennessee River managed by the Tennessee Valley Authority (Fig. 1). The reservoir filled after the construction of Kentucky Dam in 1944 at river kilometer (rkm) 35 (measured from the confluence of the Tennessee River and Ohio River). Kentucky Dam was constructed for power generation, navigation, flood control, and recreational purposes. Barges and boats pass through the Kentucky Dam lock on a daily basis. Kentucky Lake flows northerly and spans 298 rkm from Pickwick Dam, near the Mississippi border, to the western tip of Kentucky. Water levels vary 1.5 m between winter and summer pools, and the reservoir has 3322 km of shoreline that encompass ~64,800 ha (Lake Productions 2017). Kentucky Lake is a run-of-the-river reservoir having a lacustrine downstream and riverine upstream. The lacustrine portion of Kentucky Lake has many embayments and backwater areas and is characterized as eutrophic (KDFWR 2016).

The Duck River, Kentucky Lake’s largest tributary, flows freely for 220 rkm from Columbia Dam in Columbia, TN, to Kentucky Lake. The Duck River has the
longest unimpounded reach of any river in Tennessee and is world-renowned for its diverse mussel and fish communities.

Lake Barkley is a mainstem reservoir of the Cumberland River managed by the Nashville District of the Army Corps of Engineers. The reservoir was formed by the construction of Barkley Dam in 1966 at rkm 49 (measured from the confluence of the Cumberland River and Ohio River). Lake Barkley was constructed primarily for power generation, navigation, flood control, and recreational purposes. Lake Barkley extends 119 rkm downstream from Cheatham Dam in Tennessee and flows northwesterly to the western tip of Kentucky. Similar to Kentucky Lake, Lake Barkley is a run-of-the-river reservoir with a eutrophic lacustrine downstream portion (KDFWR 2013). Lake Barkley water levels vary 1.5 m between winter and summer pools, and the reservoir has >1600 km of shoreline and ~21,000 ha of surface area (Lake Productions 2017).

**Methods**

Both Kentucky Lake and Lake Barkley were sampled systematically throughout their lengths using standardized protocols we developed to assess relative abundances. Bigheaded carp abundances (as indexed by catch-per-unit-effort [CPUE] metrics) in Kentucky Lake and Lake Barkley were similar (Ridgway

Figure 1. Locations (black dots) where 10 *Hypophthalmichthys nobilis* (Bighead Carp) were collected, 2015–2016.
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2016) and were combined to report total CPUE. Because bigheaded carps are often difficult to capture, even in areas with high densities (Hayer et al. 2014, Stancill 2003, Wanner and Klumb 2009, Williamson and Garvey 2005), we deployed additional gill nets in the reservoirs in response to commercial fisher sightings and included these data in population structure and growth analyses. Additionally, we collected electrofishing samples below Barkley Dam (10 min) and Kentucky Dam (40 min), in the headwaters of each study reservoir (i.e., below Cheatham Dam [127 min] and Pickwick Dam [60 min]), and on the Duck River below Columbia Dam [230 min] to document bigheaded carp range in the lower Tennessee and Cumberland rivers.

We deployed 1.2-m diameter hoop nets with 3.8-cm mesh (2, tied in tandem) for 3 days in a variety of habitats including backwaters, channel borders, and swift tailwaters. Hoop nets were deployed in both reservoirs in spring and summer of 2015, and the total number of tandem hoop nets fished was 48. We calculated tandem hoop net CPUE as mean number of fish collected in 3-day soaks. Experimental monofilament gill nets were 3.7 m high hobbled down to 2.4 m and fished on the substrate bottom in winter 2015, fall 2016, and winter 2016. Gangs of nets with 6 mesh sizes ranging from 76 mm to 140 mm square measure (each net consisted of 2 mesh sizes in 30.5-m panels) were fished overnight in shallow backwater areas with low water velocity. We fished a total of 48 gill net gangs and quantified catch-per-unit-effort as mean catch in a gang of nets per night. Boat-mounted electrofishing samples (n = 108) were collected in summer and fall 2015. We quantified catch-per-unit of effort as the mean number of fish captured per 10 minutes of pedal time. Data on adult and YOY Silver Carp were not combined in CPUE values to avoid inflating those estimates. We held the frequency constant at 80 pulses per second and adjusted voltage and amperage as needed to achieve a 3000-W power output (Stuck et al. 2015). Transects included a variety of habitat types (i.e., backwaters, channel borders, and swift tailwaters) typically 2 m deep. Cast nets were 2.7 m in diameter with 1-cm mesh to capture young-of-year (YOY) bigheaded carps in the summer of 2015. We threw cast nets in backwater habitats without visually targeting any fish; the total number of throws was 480. We quantified CPUE as mean number of fish captured per throw of the cast net. Complete details on the sampling design and gears we used to sample bigheaded carps are provided in Ridgway (2016).

We weighed, measured for total length (TL), sexed via internal examination, and removed the lapilli otoliths from all bigheaded carps caught. Age determination in these 2 species is challenging (Kolar et al. 2007, Schrank and Guy 2002), and various hard structures, such as fin rays, scales, otoliths, and vertebrae, have been used in previous studies (Hayer et al. 2014; Kamilov 1985, cited in Kolar et al. 2007; Kamilov 2014; Schrank and Guy 2002). At present, there is no consensus for which bony structure should be used for age estimation. Using methods described by Schnieder and Hubert (1986), Hayer et al. (2014) identified growth annuli on asteriscus otoliths, the largest of the 3 otolith pairs in cyprinids. However, Seibert and Phelps (2013) recommended using lapilli otoliths because in their opinion they provided
more reliable ages, especially for older Silver Carp. Therefore, the present study followed methods similar to Seibert and Phelps (2013) for age determination. Otoliths were held with forceps, sanded, and burnt golden brown on the reading surface using a hotplate. Under a dissecting microscope, annuli were illuminated using a fiber optic filament connected to a light source. The number of annuli in sectioned lapilli otoliths was counted independently twice; when readings disagreed, the otoliths were read a third time before a final age was assigned. If a fish was captured in the fall (October–November 2015) towards the end of the growing season, an annulus was added to the count. Those fish, and all fish captured between January and June, were included in growth analyses. Fish collected in the summer (July and August), in the middle of the growing season, were not included in the growth analyses.

We estimated Silver Carp growth in the reservoirs using the von Bertalanffy growth model:

$$L_t = L_\infty (1 - e^{-K(t-t_0)})$$

where $L_t$ is length at time $t$, $L_\infty$ is the average maximum attainable size, $K$ is the Brody growth coefficient, and $t_0$ is the age at which fish length is theoretically 0 (von Bertalanffy 1938). The growth model was fitted using nonlinear least squares in FAMS Version 1.64 modeling package (Slipke and Maceina 2014). Because YOY fish had not yet completed a full year’s growing cycle, they were not included in von Bertalanffy growth modeling. However, Tennessee Wildlife Resource Agency (TWRA) biologists collected age-1 Silver Carp from Kentucky Lake near Big Sandy embayment in May 2016 (at the start of the presumed growing season), and we included length data from those age-1 fish in the von Bertalanffy growth models.

Results

Only 10 Bighead Carp were collected throughout this study, and none were collected in Lake Barkley. Five were collected from the reservoirs using standardized sampling. Gill nets captured 3 Bighead Carp (CPUE = 0.06/net-night), and hoop nets caught 2 (0.04/three-day soak). Bighead Carp in the Tennessee River were captured below Kentucky Dam (rkm 36) up to the mouth of Big Sandy Embayment in Kentucky Lake (rkm 108), and a single Bighead Carp was collected below Barkley Dam at Cumberland River km 49 (Fig. 1).

A total of 737 Silver Carp (510 Adults and 227 YOY) were captured throughout this study. The range of Silver Carp extended throughout each reservoir and also into the Duck River below Columbia Dam at rkm 220 (Fig. 2). Of those fish, 499 were collected from the reservoirs using standardized sampling protocols. Gill nets captured 240 Silver Carp (CPUE = 5/net-night), electrofishing collected 242 (CPUE = 0.12 adult and 1.96 YOY per 10-minute runs), hoop nets caught 2 (CPUE = 0.04/three-day soak), and cast net samples totaled 15 YOY Silver Carp (CPUE = 0.03/throw of the cast net). Young-of-year Silver Carp that we (and other researchers) collected in 2015 were to our knowledge the first juveniles collected in Kentucky Lake and Lake Barkley. The furthest upstream they were collected in
both reservoirs was at rkm 219 in Kentucky Lake and rkm 166 in Lake Barkley (Fig. 3).

Bighead Carp in Kentucky Lake varied from 1010 to 1385 mm TL (mean = 1211 mm, SE = 34, n = 8); the largest weighed 35.05 kg. Silver Carp in both reservoirs varied from 96 to 1005 mm TL (mean = 655 mm, SE = 10, n = 609); the largest weighed 14.03 kg (Fig. 4). Silver Carp collected below Columbia Dam on the Duck River varied from 833 to 947 mm (mean TL = 892 mm, SE = 12, n = 10), and the largest weighed 11.17 kg.

We removed otoliths from 380 of 381 adult Silver Carp collected from the reservoirs, and age estimates ranged from 3 to 13 years (Table 1). Percent agreement between 2 blind readings of otoliths from 307 young (age 5 or younger) Silver Carp was 79%; percent agreement decreased to 63% for 63 older (ages 6–10) fish and 40% for the 10 oldest (age 11 or older) fish. Over all Silver Carp paired readings, 70% agreed, 22% differed by 1 year, and 8% differed by 2 years. The 8 Bighead Carp varied in age from 8 to 22 years, and percent agreement between 2 blind readings was 63%; all paired readings differed by 2 years or less. We were able to assign ages to all Silver Carp and Bighead Carp when there was a discrepancy between the first 2 readings. Strong year classes of Silver Carp were present in both Kentucky Lake and Lake Barkley in 2010, 2011, 2012, and 2015 (Fig. 5).

Figure 2. Locations where 737 *Hypophthalmichthys molitrix* (Silver Carp) were collected, 2015–2016. Three Silver Carp were observed but not captured in the Pickwick Dam tailwater.
Visual inspection of Silver Carp growth models revealed that they were nearly identical in Kentucky Lake and Lake Barkley (Ridgway 2016). Therefore, we

Table 1. Mean total lengths (TL, mm) and weights (g) by age for male and female *Hypophthalmichthys molitrix* (Silver Carp) collected in Kentucky Lake and Lake Barkley, 2015–2016. Age-1 Silver Carp (*n* = 20) were collected by Tennessee Wildlife Resource Agency biologists from Kentucky Lake near Big Sandy embayment, May 2016. Standard errors are in parentheses.

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Figure 3. A subset of *Hypophthalmichthys molitrix* (Silver Carp) locations where 227 YOY Silver Carp were collected, 2015–2016. Young-of-year Silver Carp were observed but not captured below Barkley Dam.
pooled the mean length-at-age data, and the final von Bertalanffy model was:

$$TL_t = 881 \left[1 - e^{-0.881 (t - 0.653)}\right],$$

where $TL_t$ is the predicted size for a given age of interest ($t$; $r^2 = 0.997$). The model predicted that Silver Carp reached a mean total length of 770 mm in only 3 years.

Figure 4. Total length-frequency distributions for *Hypophthalmichthys molitrix* (Silver Carp) collected using all gears in Kentucky Lake and Lake Barkley in 2015–2016.
Discussion

In the present study, Bighead Carp were collected from Kentucky Lake and below Kentucky Dam and Barkley Dam. Although we did not collect any Bighead

Figure 5. Year classes of *Hypophthalmichthys nobilis* (Bighead Carp) and *H. molitrix* (Silver Carp) collected using all gears in Kentucky Lake and Lake Barkley, 2015–2016.
Carp in Lake Barkley, they have been reported there since 2002 (Kolar et al. 2007). In 2010, a Bighead Carp was collected 1 reservoir above Lake Barkley in Cheatham Lake at Cumberland River km 239 [REFERENCE?]. Bighead Carp were collected in the Tennessee River upstream of Kentucky Lake in Lake Guntersville and Nickajack Lake as far back as 1999 [REFERENCE?]. In 2010, a single Bighead Carp was collected from Lake Chickamauga below Watts Bar Lake at rkm 853, the furthest known leading edge of the Bighead Carp invasion on the Tennessee River (USGS 2016).

Prior to this study, the leading edges of Silver Carp invasion in Tennessee waters were the tailwater below Cheatham Dam in Lake Barkley (Clark et al. 2013) and at rkm 417 below Wilson Dam in the headwaters of Pickwick Lake (USGS 2016). We documented that Silver Carp are distributed throughout Kentucky Lake and Lake Barkley, and for the first time, Silver Carp were collected below Columbia Dam at Duck River km 220. An old fish ladder on Columbia Dam improves continuity of native communities, but could also facilitate the upstream progression of the bigheaded carp invasion.

There is a paucity of information regarding the longevity of bigheaded carps (Jennings 1988, Kolar et al. 2007). In their native habitats, Bighead Carp were estimated to reach 16 years, and Silver Carp were estimated to reach 15 years in China and 20 years in Russia (Kolar et al. 2007). In 2013, a group of federal and state agencies collectively known as the Ohio River Fisheries Management Team captured and aged bigheaded carps from the Ohio River. Using otoliths as the aging structure, a single Bighead Carp was reported to be age 18 (Ohio River Fisheries Management Team 2013). In the present study, the oldest Bighead Carp was age 22, which to our knowledge is the oldest ever reported. Kolar et al. (2007) speculated that bigheaded carp longevity may be similar to that of *Ctenopharyngodon idella* Valenciennes (Grass Carp), a closely related species, which are documented to reach age 32.

The pooled growth rate of Silver Carp was higher in Kentucky Lake and Lake Barkley than in North Dakota tributaries of the Missouri River (Hayer et al. 2014), the middle Mississippi River (Williamson and Garvey 2005), and the Illinois and Wabash rivers (Stuck et al. 2015) (Fig. 6). In addition, the growth rate we observed was higher than Silver Carp in India’s Gobindsager Reservoir (Tandon et al. 1993, cited in Williamson and Garvey 2005) and Russia’s Amur River (Nikolskii 1961, cited in Williamson and Garvey 2005). Reaffirming our age estimates, other researchers using a different aging structure (pectoral fin rays) reported similarly fast growth of Silver Carp in Kentucky Lake (>800 mm TL at age 3) and similar strong year classes (2010, 2011, and 2012; A. DeRose, Murray State University, Murray, KY, unpubl. data).

Although their origin is unknown, we collected YOY Silver Carp from the upper reaches of Kentucky Lake and Lake Barkley. Those YOY Silver Carp either hatched in Kentucky Lake and/or Lake Barkley, or they hatched and swam 166–219 rkm from the Ohio River to where they were captured in each reservoir. Spawning and recruitment in large rivers has been related to increases in both flow and stage
(Schofield et al. 2005, Schrank et al. 2001, Verigin et al. 1978) which are believed to keep fertilized, semibuoyant eggs suspended before hatching (Jennings 1988, Laird and Page 1996, Verigin et al. 1978). Although poorly understood, successful reproduction has been documented for introduced and native bigheaded carp populations in reservoir systems of Eurasia and Asia (Kolar et al. 2007). Given optimal temperature and sufficient flows, Murphy and Jackson (2013) predicted that bigheaded carps can spawn and successfully reproduce in just 25 km, much less than the previously reported 80–100 km (Krykhtin and Gorbach 1981, Nico et al. 2005). Both Kentucky Lake and Lake Barkley are run-of-the-river reservoirs having swift tailwaters, low retention rates, and expansive backwater embayments which could serve as nursery grounds. In addition, the lower Duck River has sufficient linear habitat (223 km) and a large backwater delta at the Kentucky Lake confluence. However, bigheaded carp egg-transport suitability (Murphy and Jackson 2013) is beyond the scope of this study and has yet to be modeled for these reservoir systems.

We are inclined to believe that they hatched in the reservoir(s) because Silver Carp larvae utilize backwaters or other flooded areas as nursery grounds (Nikolsky 1963, cited in Kolar et al. 2007). Migrating upstream through a navigation lock at an early age

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**Figure 6.** Von Bertalanffy growth curves for *Hypophthalmichthys molitrix* (Silver Carp) in Kentucky Lake and Lake Barkley (this study—observed mean lengths-at-age are shown); Middle Mississippi River (Williamson and Garvey 2005); Wabash River, IL, and the Illinois River (Stuck et al. 2015); Missouri River tributaries in South Dakota (Hayer et al. 2014); India (Tandon et al. 1993 cited in Williamson and Garvey 2005); and the Amur River, Russia (Nikolskii 1961 cited in Williamson and Garvey 2005).
life-history stage would be a heretofore unobserved phenomenon, though not impossible. Barges have the ability to entrain, retain, and even transport small fish (Notemigonus crysoleucas Mitchell [Golden Shiner] 63–122 mm TL were used as a surrogate for YOY Silver Carp) through locks (Davis et al. 2016). However, transport distances of up to only 15.5 rkm were examined in that study, and it is difficult to consider a barge transferring such a substantial number of YOY Silver Carp 200+ rkm unless YOY of incredible abundance were present below the reservoirs. Whether spawned in the Ohio River or in Tennessee waters, Silver Carp are present in Kentucky Lake and Lake Barkley across a wide range of sizes and ages.

Eight year classes of Silver Carp were observed and a boom–bust pattern of strong and weak (or absent) year classes was apparent, which is observed in many fish species. Not knowing the natal rivers of the adult Asian carp we collected prevented us from attempting to relate fluctuations in adult year-class strength to environmental variables per the methods of Maceina and Bettoli (1998). Larval fish should be sampled spatiotemporally to determine where and when reproduction is occurring. If successful reproduction varies with environmental variables such as discharge, then recruitment could be predicted and potentially controlled (DeGrandchamp et al. 2007, Hintz et al. 2017), perhaps by manipulating dam outflow above the reservoirs (Lohmeyer et al. 2009) or arranging for aggressive harvesting programs.

All of the Bighead Carp we captured were large (≥1009 mm TL) and old (age 8 or older). The absence of young fish and their low densities indicate that recruitment in Kentucky Lake and Lake Barkley by Bighead Carp is negligible. Similarly, researchers documenting the leading edges of bigheaded carp invasions in the Ohio River and tributaries of the Missouri River collected few Bighead Carp relative to Silver Carp ([PROVIDE NAME OF CONTACT], Kentucky Department of Fish and Wildlife Resources, [PROVIDE LOCATION], unpubl. data: Silver Carp = 74, Bighead Carp = 4; Hayer et al. 2014: Silver Carp = 469, Bighead Carp = 8). Long-term monitoring of Bighead Carp in the Illinois River revealed that year-class strength is highly variable, but one strong year class can quickly rebuild the population (Irons et al. 2011).

Gill-net catch data suggest Silver Carp are already a large component of the fish assemblages (Ridgway 2016). Determining the extent to which Silver Carp are increasing in Kentucky Lake and Lake Barkley requires multiple years of catch data, and this study could not address that concern. However, studies documenting the early colonization of bigheaded carps elsewhere reported exponential increases in Silver Carp (Chick and Pegg 2001, Hayer et al. 2014, Irons et al. 2011, Sass et al. 2010), and Bighead Carp (Irons et al. 2011).

Silver Carp growth rate in Kentucky Lake and Lake Barkley is remarkably fast relative to other populations, and fish are reaching harvestable size at a young age. Commercial fishers and markets prefer larger fish because payment depends on weight, not individual fish. In addition, targeting larger fish greatly reduces handling and processing effort, bycatch, and bycatch mortality when using gill nets with larger mesh (Ridgway 2016). Between 2011 and 2015, commercial fishers removed more than 750,000 kg of bigheaded carp from the reservoirs [REFERENCE?].
2013, the Kentucky Department of Fish and Wildlife Resources (KDFWR) initiated a bigheaded carp harvest program, and in 2015 began subsidizing the price of bigheaded carp to motivate commercial fishers to invest more effort. As a result, more than 360,000 kg were removed in 2015 alone. Commercial fishing tournaments hosted by KDFWR have also proved useful, removing more than 37,000 kg in just 2 days in March 2013 [REFERENCE?]. However, periodic standardized sampling is needed to determine whether removal efforts have reduced carp densities (Bouska et al. 2014).

Similar to other researchers, we found bigheaded carp to be difficult to capture using traditional techniques, which translated into low CPUE values during this study. However, 2 electrified trawling techniques (paupier butterfly frame trawl and dozer trawl) were recently developed by the Fish and Wildlife Conservation Office in Columbia, MO, to increase sampling efficiency (Doyle et al. 2015). The week of 7 November 2016, the paupier trawl sampled Big Bear Embayment of Kentucky Lake (near Tennessee rkm 11) and collected 1378 Silver Carp in 5 hours of nighttime electro-trawling pedal time ([PROVIDE NAME OF CONTACT], US Fish and Wildlife, [PROVIDE LOCATION], unpubl. data). Continued paupier monitoring in Kentucky Lake and Lake Barkley is scheduled in 2017.

The findings reported herein constitute the first study of bigheaded carps throughout Kentucky Lake and Lake Barkley systems, and there is more work to be done. Continued public education and collaboration with states within the Tennessee River and Cumberland River basins will be important to effectively control and manage bigheaded carps. Future monitoring and research in these systems should aim to deter further migrations upstream, limit natural reproduction, identify potential ecologic and economic impacts, assess new control techniques, and evaluate management success.

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Literature Cited


