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Distribution and Population Dynamics of Asian Carp in Iowa Rivers

Submitted by

Aaron J. Matthews, Nathan A. Tillotson, Michael J. Weber, and Clay L. Pierce

Department of Natural Resource Ecology and Management
Iowa State University

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Abstract

Invasive Silver Carp (*Hypophthalmichthys molotrix*) and Bighead Carp (*H. nobilis*; collectively called Asian Carp) are expanding throughout the Upper Mississippi River Basin (UMRB) and are of great concern due to their potential economic and ecological impacts. Pooled sections on the Upper Mississippi River associated with lock and dams may be poor habitats for reproduction and recruitment due to their lentic characteristics and perceived lack of adequate spawning habitat compared to more free-flowing unimpounded sections in the lower Mississippi River where evidence of reproduction has been documented. However, Iowa interior rivers connected to pooled sections of the Upper Mississippi River possess several requirements needed for successful spawning and observations of adults are becoming more prevalent. Unfortunately, little is known regarding the basic ecology and reproductive status of Asian Carp populations in these tributary systems. In order to properly make management decisions, information on reproductive success and factors that regulate populations must be understood. In this study, we evaluate 1) reproduction patterns and 2) adult population characteristics and dynamics of Asian Carp in the Mississippi, Des Moines, Skunk, Iowa, Rock, and Wapsipinicon rivers in southeastern Iowa. In 2016, 744 ichthyoplankton tows captured 26,240 eggs and 42,068 age-0 fishes from the Wapsipinicon, Rock, Iowa, Skunk, Des Moines and Mississippi rivers. The largest number of eggs collected in a sampling event occurred on May 29th and 30th 2016 when 22,689 eggs (86% of all eggs collected during 2016) were collected. The majority of eggs during this sampling event were collected from tributaries (17,509 of 22,689 eggs, 86%) compared to the Upper Mississippi River. Among tributaries, the majority of eggs were collected from the Skunk River mouth (15,553 eggs). In contrast, the majority of age-0 fish (39,700 of 42,068, 96%) were captured from the Mississippi River in 2016. Egg densities peaked in late May while age-0 fish densities were greatest during late June. Genetic analysis verified that Asian Carp eggs were captured in the Upper Mississippi River as far north as Pool 18 in addition to the Iowa and Skunk river mouths. The majority of age-0 fish were composed of Cyprinidae, Catostomidae, and Percidae. Only two Bighead or Silver carp age-0 fish were collected during two separate sampling events on June 18 and August 28. Grass Carp egg and age-0 fish were sampled four times on May 29, July 29, and August 18 and 28. A total of 186 adult Asian Carp were collected from the Mississippi, Des Moines, Skunk, Iowa, and Rock rivers during fall 2016. The majority of these fish were Silver Carp (96%) and most were collected in Pool 20 at the mouth of the Des Moines River (94%). Four Bighead Carp were collected throughout the UMRB during 2016, one at Cliffland on the Des Moines and three at the Des Moines River confluence. Additionally, two Grass Carp were collected at Cliffland on the Des Moines River.

Introduction

Background

Ecological communities worldwide are becoming more uniform through the introduction and subsequent establishment of non-native species into novel areas through anthropogenic activities (Rahel 2002). Intentional introductions commonly occur to provide societal benefits such as food, recreation, and biological control (Pimentel et al. 2000). Additionally, advancements in transportation and worldwide commerce have increased unintentional introductions (Rahel 2002). In the United States, approximately 50,000 non-native species introductions have occurred with varying success and impacts (Pimentel et al. 2005, Sagoff 2005). Nevertheless, a single non-native species can alter ecosystem structure and function and have costly economic consequences (Macisaac 1996, Pimentel et al. 2005, Weber and Brown 2009). Economic losses due to non-native introductions are estimated at US$120 billion a year; however, actual costs are likely much higher because monetary costs associated from species extinctions, loss of ecosystem services, and aesthetic values are not easily assessed (Pimentel et al. 2005). Likewise, ecological costs may be much greater than economic costs but are difficult to quantify and assess because of lag times between invasion and empirically confirmed impacts to the environment (Gido and Brown 1999, Stohlgren and Schnase 2006).

Non-native fishes are one of the most introduced groups of aquatic animals that have resulted in negative ecological effects in riverine ecosystems (Gozlan 2008). Rivers naturally provide an invasion highway for fishes to expand from the point of introduction. Furthermore, modifications to rivers for navigation have connected previously separate waterways, facilitating inter-basin movement and the spread of invaders into additional novel habitats (Leuven et al. 2009). For example, the Mississippi River Basin covers roughly 40% of the lower 48 U.S. states with thousands of river miles (USACE 2011) and connects to the previously separated Great Lakes basin via the Chicago Area Waterway System, the Ohio-Erie Canal and other man-made structures (USACE 2014).

At least 83 non-native fishes have become established in the Upper Mississippi River Basin (UMRB) as a result of dispersal from other basins or by direct introduction from anthropogenic activities (Rasmussen 2002). Two of the more recent and widely recognized invaders to the UMRB are Silver Carp (*Hypophthalmichthys molotrix*) and Bighead Carp (*H. nobilis*; collectively referred to as Asian Carp). These species have become abundant and threaten the integrity of the UMRB and any connected aquatic ecosystems (Irons et al. 2009). Asian Carp were imported during the 1970s into the United States for food consumption and biological control in aquaculture facilities (Freeze and Henderson 1982). In the 1970s, individuals thought to have escaped during flooding events were observed in several rivers within Arkansas. Due to their high reproductive capabilities and long distance migrations (DeGrandchamp et al. 2008), these fish quickly became established and now inhabit more than 20 states throughout the Mississippi, Missouri, Ohio, and Illinois river basins (Kolar et al. 2007, Baerwaldt et al. 2013, Deters et al. 2013). By the mid-1980s, Asian Carp were caught in the pooled sections of the UMRB (Kolar et al. 2007) with the first observations of Asian Carp in Iowa occurring in 1986 when Silver Carp were captured in the UMRB below lock and dam 19 (LD19) near Keokuk (Irons et al. 2009). A year later, Bighead Carp were captured near the mouth of Yellow Springs Creek north of Burlington, IA (Irons et al. 2009). Since the initial observations in Iowa, Asian Carp adults have been sighted in several additional UMRB tributaries in Iowa such as the Des Moines, Skunk, Iowa, and Cedar rivers (Bruce 1990, United Press International 2011, Irons 2012, Camacho 2016, Sullivan 2016).

Currently, southeastern Iowa appears to be on the leading edge of Asian Carp expansion in the UMRB. Substantially higher adult catch rates of both Silver and Bighead Carp occur below LD19 than above, suggesting this structure and other lock and dams on the Mississippi River may serve as a partial migration barriers (Wilcox et al. 2004). For example, the UMRB water level is regulated at each dam in order to maintain a navigation channel by reducing or eliminating the amount of water discharged, leaving passage through the locks as the only means of fish movement during low river discharge periods. However, dam gates are lifted during higher discharge events, that facilitate fish passage (Garvey et al. 2010). It is also during these high discharge events that Asian Carp exhibit some of their highest movement rates, especially during annual spring runoff and associated peak discharge events when temperatures are below or within the spawning optimum, suggesting movement may be associated with spawning migration behavior (Jennings 1988, Peters et al. 2006, DeGrandchamp et al. 2008). Furthermore, Asian Carp can quickly make long distance migrations (DeGrandchamp et al. 2008) indicating that these fish are capable of dispersal into new locations.

Although Asian Carp may be able to navigate lock and dams on the UMRB, pooled sections between these structures may provide unsuitable spawning habitats for these species. Asian Carp are highly fecund (up to 3.5 million eggs per female; Garvey et al. 2006) and have short gestation periods (Chapman and George 2011). Thus, only a few adult individuals may be needed to quickly establish an abundant population (Crawley et al. 1986). Despite adult Asian Carp being detected above LD19 up to St. Paul, MN, USA, their populations have remained low, suggesting reproduction may be limited in these reaches. Pooled sections associated with lock and dams exhibit reservoir-like characteristics that are more lentic in nature resulting in lower Asian carp reproduction than in unregulated sections where lock and dams are absent (Lohmeyer and Garvey 2009). In contrast, established Asian Carp populations in tributary systems, such as the Illinois River, can have high recruitment and adult populations have increased exponentially in abundance within a decade (Sass et al. 2010). Yet, Asian Carp abundance in the tributaries of the UMRB are much lower compared to the Illinois River and it is unknown whether or not these systems are suitable for reproduction.

Successful Asian Carp spawning depends on adults finding suitable habitat of sustained, high flow or increasing discharge when water temperatures are between 17 and 30°C (Kolar et al. 2007). Continuous river flow of at least 25 km may be necessary to suspend the semi-buoyant eggs for a 24 h period or until larvae successfully hatch (Krykhtin and Gorbach 1981, George and Chapman 2013, Murphy and Jackson 2013). In most areas of the UMRB, reaches between dams with sufficient sustained velocities of 0.3 to 3.0 m/s and turbulence to keep eggs in suspension do not exist or are poorly suited for egg survival (Lohmeyer and Garvey 2009). However, age-0 Asian Carp have been documented in tributaries such as the Cache River (a tributary to the Ohio River; Burr et al. 1996) and the Illinois River (a tributary to the Mississippi River; DeGrandchamp et al. 2007). Additionally, tributaries are known to be associated with spawning activity in their native range in the Yangtze River (Yi et al. 1988) and in varying capacities in the Missouri River (Schrank et al. 2001) and Illinois River (DeGrandchamp et al. 2007) where they are introduced. Successful establishment and reproduction in tributaries could provide sources of recruitment for pooled sections of the UMRB and other areas of poor reproduction.

Research Needs

Successful expansion and establishment of Asian Carp populations within the UMRB depends on the ability of adults to find adequate conditions of temperature and long fetches of sustained, high flow. Despite perceived poor conditions for successful Asian Carp reproduction in the Upper Mississippi River, tributaries could provide adequate conditions for reproduction, resulting in population expansion along the leading edge of the invasion. Reproductive success on an invasion front can increase exponentially through time (Chick and Pegg 2001, Sass et al. 2001) until establishment occurrs (Hayer et al. 2014). Some systems where Asian Carp are starting to establish can have sporadic reproduction (Irons et al 2011) leading to either a surge or decline in population. Although adult Asian Carp density appears low, successful reproduction of Asian Carp has been established in previous research at Iowa State within the Des Moines, Skunk, and Iowa rivers (Camacho 2016). Further evaluation of factors affecting reproduction and recruitment in Iowa tributaries of the Mississippi River in associated with annual variation in environmental conditions is needed to better understand Asian Carp population dynamics in these systems and potentially develop management strategies for these invasive fishes. By understanding more about factors affecting reproduction and recruitment within the tributaries of the UMRB, potential increases of Asian Carp presence, or newly established residence in UMR could be detected early. Spatial and temporal distribution of Asian Carp eggs and larvae will help to locate spawning habitat, help determine reproductive cues, and provide insight between environmental variables and survival of larvae and juveniles.

Objectives

The objectives of this study are to evaluate Asian Carp reproduction (egg, larval and juvenile densities) and adult population characteristics (abundance, distribution, size structure) in Pools 14-20 of the UMR with a focus on confluences with the Des Moines, Skunk, Iowa, Rock, and Wapsipinicon rivers.

Study Area

The UMR flows 2,320 river kilometers (RKM) from Lake Itasca, Minnesota to the Ohio River confluence near Cairo, Illinois. Legislative approval by US Congress in 1905 and 1935 altered the UMR by forming a series of dams, levees, wing dikes and other structures to control flooding and provide commercial navigation (Garvey et al. 2010). The UMR dams are preceded by a series of pools, starting at Pool 1 formed by Lock and Dam 1 located near St. Paul Minnesota to Pool 26 above Lock and Dam 26 near Alton, Illinois. The flows of the UMR have shifted from historically lotic to lentic in nature (Garvey et al. 2003). Despite the increase in side channels, islands and backwaters from the system of dams, they inhibit fish movements for reproduction or expanding their range (Southall and Hubert 1984, Zigler et al. 2004). At low flows when the dams close to retain water, the only passage available is through the series of locks when boats move between pools. Disruption of river continuity could affect species such as Asian Carp that require long stretches of connected habitat for one or more life stages as it does in native species. Egg and larval Asian Carp have been documented as far north as Pool 16 (Larson et al. 2017). Anthropogenic alterations also occur within the major tributaries within the Upper Mississippi River.

The Des Moines, Skunk, Iowa, and Wapsipinicon rivers all contain lowhead dams within 90 km of the confluence of the Mississippi River, potentially inhibiting reproduction within the tributaries. There are low head dams greater than 90 km from the confluence with the Mississippi River, and a split dam located within 10 km from the confluence. Catchment areas range between 6,565 km^2 for the Wapsipinicon River to 37,296 km^2 for the Des Moines River. The Des Moines River and the Rock River are the only two rivers with basins within multiple states, Iowa and Minnesota, and Illinois and Wisconsin, respectively. Previous sampling at Iowa State University has found egg and larval Asian Carp within the Des Moines, Skunk, and Iowa tributaries and adults in the Des Moines, Skunk, Iowa and Cedar rivers (Camacho 2016).

Methods

Egg and Larval Fish

Asian Carp eggs and age-0 fish were sampled from 2016 and 2017 at 18 locations (Figure 1) approximately every 10 days depending upon river conditions from the end of April until September 2016 and 2017 (14 sessions during 2016, with 54 tows per session). Sampling was not conducted when water levels were too high for safe boating or too low for boat access. Ichthyoplankton (0.5 m diameter net, 500 µm mesh) tows were conducted at the surface at a constant boat speed relative to the shoreline up to four minutes depending on debris load. A General Oceanics flowmeter (Model 2030R) was mounted in the mouth of the net to estimate volume (m^3) of water filtered during each tow. Three tows were conducted at each site parallel to river flow: the first tow was in the main thalweg for drifting eggs and larvae (<24 hours post fertilization), the second tow occurred near channel borders where water velocity is moving downstream slower than the thalweg, and the third was in an adjacent backwater area for mobile larvae (>24 hours post fertilization). After each tow, ichthyoplankton net contents were rinsed toward the cod end, placed in sample jars, and preserved in 95% ethanol.

In the laboratory, eggs and age-0 fish (larvae and juveniles) were separated from debris. Asian Carp larvae are difficult to distinguish among species and are being identified to genus using meristic and morphometric characteristic (Tweb et al. 1990, Chapman 2006, Chapman and George 2011). A portion of eggs (723 eggs) were randomly selected across sampling dates and locations and identified to species using mitochondrial DNA sequencing at University of Wisconsin-Stevens Point. Age-0 fishes were first categorized as larval or juveniles based on fin development. Fish recognized as having a full complement of fins are categorized as juvenile fish. All age-0 fish are being identified to the lowest possible taxa using morphometric and meristic characteristics described in literature (Auer 1982).

Adult Sampling

Sampling for adult Asian Carp occurred September through November in 2016 at 8 sites in the Mississippi, Des Moines, Skunk, Iowa, Rock, and Wapsipinicon rivers (Figure 1) using daytime boat electrofishing. Asian Carp are notoriously difficult to capture; however, electrofishing is more effective than trammel nets at capturing Silver Carp at these sampling locations (Wanner and Klumb 2009; Sullivan et al. 2017). Thus, electrofishing (pulsed DC; amps 4-13, voltage 100-500) was used to target channel border and backwater areas less than 4 m deep where Asian Carp have previously been shown to typically inhabit (DeGrandchamp et al. 2008). Electrofishing transects (varying effort and transect numbers) are conducted until approximately 150 Silver Carp are captured (Pool 20) or until all available habitat at the site is been sampled.

Asian Carp were identified as a Silver, Bighead, or Silver x Bighead Carp hybrid using meristic and morphometric features (Kolar et al. 2007), weighed (0.001 kg), measured (total length; 1 mm), and the first pectoral fin ray on each side and lapilli otoliths (up to 150 fish/site) were removed for age and growth analysis. Sex is determined based on visual inspection of gonads (male, female, immature, or unknown).

Lapillus otoliths were air dried at room temperature for at least four weeks following collection before being mounted in epoxy. A 1-mm thick cross section at the nucleus was cut using a Buehler Isomet low-speed saw (Isomet Corporation, Springfield, VA) with the anterior portion of the otolith oriented perpendicular to the blade. Wetted 2,000-grit sandpaper was used to polish each side of the cross section. The section was then placed in immersion oil to improve clarity and annuli viewed under a dissecting microscope with transmitted light. Lapillus otoliths were independently aged by two experienced readers with no knowledge of fish length, estimated age of other structure, or source river. If the readers disagreed, then a common age was decided in unison.

Environmental Condition Data Collection

Water temperature, discharge, and stage height were obtained from field measurements and gauging stations on each river. Discharge (m^3/s) and stage height were obtained from U.S. Geological Survey gauging stations across Iowa near Tracy, Ottumwa, Keosauqua, Augusta, Merrimac, Wapello, Iowa City, and Marengo. Water temperature (Yellow Springs Instruments 550A) and conductivity (EC400 ExStik 2 Conductivity Meter) were collected at each site in the thalweg during each sampling period. Across the UMR, river flow data were obtained from various United States Geological Survey (USGS), Advanced Hydrologic Prediction Service (APHS), and National Oceanic and Atmospheric Administration (NOAA) monitoring and gaging stations closest to sampling sites.

Chlorophyll *a* and zooplankton were collected in conjunction with each Asian Carp ichthyoplankton sampling event. Samples were collected from a stationary boat position in thalweg, side channel and backwater habitats. Triplicate zooplankton samples were collected at each site with an integrated tube sampler (5 cm diameter, 50 cm length), filtered through a 63-µm mesh sieve, combined into a composite sample, and preserved using Lugol's solution. Chlorophyll *a* was measured by filtering approximately 100 mL of water through a GF/F

Whatman© glass fiber filter (47-µm porosity) that were placed on ice in the field and frozen in the laboratory. In the laboratory, zooplankton samples were identified to suborder or family and enumerated for total density (number/L). Chlorophyll *a* was extracted with 90% acetone and quantified using an Trilogy Laboratory Flourometer (Tuner Designs) to obtain chlorophyll concentrations (µg/L).

Results

<u>*Egg and larval Fish*</u>

In 2016, a total of 744 ichthyoplankton tows were completed. Eggs were collected during every sampling session cumulating in a total of 26,240 eggs being collected across dates and sites in 2016. The largest number of eggs collected in a sampling event was during May 29th when a total of 22,689 eggs, 86% of the eggs collected in 2016, were captured (Figure 2). A total of 495 tows were taken from the Mississippi River that collected 8,731 eggs. An additional 84 tows were taken within the tributary mouths that captured 17,509 eggs: 14 eggs were collected in the mouth of the Wapsipinicon River, 174 eggs were captured in the mouth of the Rock River, 1,496 eggs were captured in the mouth of the Iowa River, 15,533 eggs were captured in the mouth of the Skunk River, 197 eggs were captured in the mouth of the Des Moines River, and 95 eggs were captured in the Des Moines River at Keosoqua. Mean egg density was highest within the Skunk River (13.52 ± 8.28 SE) and lowest at the mouth of the Wapisipinicon River (0.01 ± 0.006 SE; Figure 3). Within the Mississippi River, higher egg densities were observed below compared to above the Skunk River confluence, but densities upstream and downstream were similar at the other tributary confluences (Figure 3). Egg densities were highly variable but tended to be similar across habitats within a river during 2016 (Figure 4).

Genetic results from eggs collected during 2016 confirmed the reproduction of 13 different fish species, including Bighead, Silver, and Grass Carp (Table 2). Of the eggs sent for genetic identification, 31% (262 of 846) were Asian carp, comprised of 48% Silver Carp (127 of 262), 4% Bighead Carp (11 of 262), and 47% Grass Carp (124 of 262). Most Asian carp eggs identified were collected on May 29th that aligned with the highest egg densities observed during 2016 (Figure 2). The majority of Asian carp eggs (77%; 203 of 262) were found within tributaries. Of the eggs found within tributaries, the majority were collected from the Skunk River (79%; 160 of 203) with the remainder collected from the Iowa River (21%; 43 of 203). Both Bighead and Silver Carp eggs were also identified during May 29th in the Mississippi River downstream of the Skunk River. On July 29th, Silver Carp eggs also were found downstream of the Iowa River. Grass Carp eggs were also found on July 29 and August 18 and 28 within, upstream, and downstream of the Iowa and Skunk river confluences (Table 2). Most eggs were stage 1, indicating that they had been released within the previous 3 hours, but eggs up to stage 8 (33 hours) were captured (Figure 5).

A total of 42,068 age-0 fish (combination of larvae and juveniles) were captured with ichthyoplankton tows during 2016. The highest densities of age-0 fish were collected on June 28 (5.52 ± 2.33 SE, 6,828 fish) and 18 (5.30 ± 1.06 SE, 7,167 fish) following the peak in egg densities (Figure 2). The lowest density of all the sessions (0.46 ± 0.29 SE) was captured during August

28th. Age-0 fish were sampled from every river during 2016. In contrast to eggs, the majority of age-0 fish (39,700; 94%) were collected from sites within the Mississippi River, whereas only 2,368 (5%) were collected from within tributaries. However, with the exception of the Wapsipinicon River, downstream tributary sites had higher age-0 fish densities than upstream sites, suggesting a large number of age-0 fish may have originated from tributaries (Figure 3). The highest density of age-0 fish within the Mississippi River (6.88 ± 3.27 SE) were collected downstream of the Des Moines River (UMR-DNW) whereas the lowest densities were collected from WAP-MTH (0.16 ± 0.05 SE). Age-0 fish densities were highest in backwater sites at only the Rock (1.23 ± 0.59 SE) and Skunk River (0.98 ± 0.79 SE) during 2016 (Figure 4).

Several families of age-0 fish were collected during 2016, including Atherinidae, Catostomidae, Centrarchidae, Clupeidae, Cyprinidae, Hiodontidae, Ictaluridae, Lepisosteidae, Moronidae, Percichthyidae, Percidae, and Sciaenidae. During 2016, there were low age-0 fish densities (<100 larvae per 100 cubic meters) of most family groups except Catostomidae and Cyprinidae (Figure 6). Peak abundance of Catostomidae, Hiodontidae, and Percidae was earlier compared to Centrarchidae, Cyprinidae, and Lepistosidae.

Asian carp (Bighead, Silver, or Grass) eggs and/or larvae were collected at 13 out of 18 sites during 2016. In contrast to previous years, few larval Asian carp were captured during 2016. Only two yolk sac larval Bighead/Silver Carp were captured upstream of the Des Moines River confluence on June 20th and August 27th. Both Bighead/Silver Carp larvae were caught during sampling events when no eggs were genetically verified as Asian carp. Grass Carp larvae were found across several sites within the Mississippi River, including upstream of the Des Moines River, upstream and downstream of the Iowa River, downstream of the Rock River, and upstream and downstream of the Wapsipinicon River. Grass Carp larvae were also collected throughout the year from May 30th through August 27th. Grass Carp larvae were found as both yolk sac and larval stages and collected in backwater, channel border, and thalweg habitats. Densities of Asian carp larvae per 100 m^3 throughout sessions were highest (3.5± 0.3.16 SE) within the May 29th sampling event and consisted only of Grass carp larvae (Figure 7). During this session the Des Moines river sites were unable to be sampled due to boat issues. The two second highest densities of Age-0 Grass Carp larvae also included Bighead or Silver Carp larvae.

<u>Adult Asian Carp Population Characteristics and Dynamics</u>

A total of 186 Asian Carp were collected from the Des Moines, Skunk, Iowa, and Rock River sites during a total of 44.9 hours of electrofishing in 2016. The two Des Moines River sites (Cliffland and confluence) accounted for 91.9% (171 individuals) of all Asian Carp catpures, while the Skunk accounted for 6% (9 individuals), the Iowa River accounted for 1% (2 individuals), and Rock River accounted for 0.5% (1 individual). Silver Carp comprised 96% (n=179) of all Asian Carp captures in 2016, while Bighead Carp comprised 3% (n=5), and Grass Carp comprised 1% (n=2) of all captured individuals. Highest adult Asian Carp CPUE occurred at the confluence of the Des Moines River (Table 3). Confluence sites further upstream at the mouth of the Skunk, Iowa, Rock, and Wapsipinicon rivers had consecutively lower CPUE rates. Of the sites that were sampled twice (IAR-MTH and SKK-MTH), catch rates were slightly lower and the standard error increased in November compared to sampling done in September. The

Des Moines River sites were the only sites to catch Bighead, Silver and Grass Carp. Only Silver Carp were caught at the Iowa, Skunk and Rock river confluences.

The Des Moines River sites accounted for 94% of Silver Carp captures in total: 77% were captured at the Des Moines River confluence site (n=137) and 15% at the Cliffland site (n=28). The Skunk River accounted for 6% (n=12), the Iowa River accounted for 1% (n=2), and the Rock River accounted for 0.5% (n=1) of Asian Carp captures. Silver Carp ranged in size from 529 mm to 672 mm (mean = 619 mm; Figure 8) and 1.6 kg to 3.3 kg (mean = 2.3). Silver Carp size structure was smaller at Cliffland on the Des Moines River (DSM-CLF) compared to the Des Moines River confluence (Figure 8).The largest Silver Carp were captured at the the Skunk River confluence, ranging from 644 mm to 923 mm (mean = 829 mm; Figure 8) in length and 2.8 kg to 10.2 kg (mean = 6.9 kg) in weight. Silver Carp during 2016 ranged in age from 4 years to 14 years (mean = 7 years) and individuals from age 6 to 8 made up 87% (n=134) of the total number of aged fish (n=155; Figure 9). Ages were generally similar across sites in 2016 (Figure 22), but the Iowa River had the lowest mean age (5 years) and the Skunk River had the highest mean age (8 years). Length at age of Silver Carp in 2016 was variable within and across sites, and was unsuited for fitting von Bertalanffy growth curves. Therefore, growth was evaluated using mean length at age, which tended to be higher at the Skunk River than any of the other locations (Figure 10). In addition to individuals captured, 41 Asian carp jumps were observed at the Skunk River during sampling, four were observed at the Iowa River, and three were observed at the Rock River, but jumped out of range of the netters and boat.

Only four Bighead Carp were captured in 2016 at the Des Moines River confluence (CPUE = 4.3 ± 0.1; n = 3) and at the Des Moines River at Cliffland (CPUE 0.6 ± 0.6; n = 1 measuring 852 mm TL). Bighead Carp at the Des Moines River confluence had a larger size structure that ranged from 772 mm to 876 mm (mean = 832 mm) in length and 4.7 kg to 7 kg (mean = 5.9 kg) in weight (Figure 21). Bighead Carp in 2016 ranged in age from 8 years to 20 years (mean = 13 years), and ages were more variable than they were for Silver Carp (Figure 23). Only two Grass Carp were collected at the site Des Moines River at Cliffland during 2016, measuring 755 mm and 829 mm in length. No juvenile Asian carp were captured at any of our sampling locations.

Environmental Condition Data

Each of the major tributaries to the Mississippi River had consistently higher chlorophyll a throughout 2016, with the highest being the backwater of the Wapsipinicon River mouth (65.1 ± 10.4 SE), channel border of the Rock River mouth (77.3 ± 9.8 SE), backwater of the Iowa River mouth (68.0 ± 14.1 SE), backwater of the Skunk River mouth (71.1 ± 21.1 SE), and the channel border of the Des Moines River mouth (64.7 ±10.7 SE; Figure 7). Chlorophyll a concentrations were variable throughout the Mississippi River, from 14.5 ± 2.2 SE in the backwater of Pool 15 to 61.9 ± 9.7 SE in the backwater downstream of the Iowa River. Chlorophyll a within the mouths of the tributaries (Wapsipinicon, Rock, Iowa, Skunk, and Des Moines rivers) tended to be nearly three times higher compared to other sites in the Mississippi River adjacent to tributary mouths (Figure 7) indicating that these tributaries are important sources of primary production for the Upper Mississippi River.

Average monthly zooplankton densities were highest in April and May (up to 1,000 individuals/L) but were much lower from June through September (<75 individuals/L). The highest zooplankton density within sites sampled only in 2016 were found within Pool 15 of the Mississippi River during April (977 ± 337.0 SE), with the lowest density observed in the Wapsipinicon during September (18.7 ± 5.1 SE; Figure 12). For the majority of the year, there appears to be no major difference between the sites that have a high amount of Asian Carp below Lock and Dam 19, sites where Asian Carp are found in low densities above, and sites where no adults have been sampled. It is possible there could be an effect of size, or species selection between sites of various Asian Carp desnities.

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Table 1. Sampling site codes for 2014-2016 sampling seasons.

*When low flows do not allow adult sampling at DSM-KQA, DSM-CLF is substituted due to being closest in proximity.

Year Sampled	Site Codes	Site Names
2016	UMR-UPW	Upper Mississippi River, Upstream of the Wapsipinicon River
	UMR-DNW	Upper Mississippi River, Downstream of the Wapsipinicon River
	WAP-MTH	Mouth of the Wapsipinicon River
	UMR-P15	Upper Mississippi River, Pool 15
	UMR-UPR	Upper Mississippi River, Upstream of the Rock River
	UMR-DNR	Upper Mississippi River, Downstream of the Rock River
	ROC-MTH	Mouth of the Rock River
	UMR-P17	Upper Mississippi River, Pool 17
	UMR-UPI	Upper Mississippi River, Upstream of the Iowa River
	UMR-DNI	Upper Mississippi River, Downstream of the Iowa River
	IAR-MTH	Mouth of the Iowa River
	UMR-UPS	Upper Mississippi River, Upstream of the Skunk River
	UMR-DNS	Upper Mississippi River, Downstream of the Skunk River
	SKK-MTH	Mouth of the Skunk River
	UMR-UPD	Upper Mississippi River, Upstream of the Des Moines River
	UMR-DND	Upper Mississippi River, Downstream of the Des Moines River
	DSM-MTH	Mouth of the Des Moines River
	DSM-KQA *	Des Moines River at Keosoqua

Table 2. Eggs of 13 fish species captured in 2016 by date and river. River abbreviations present for a species on a sampling date denotes genetic confirmation of that species collected at that location on a sampling date. W= Wapsipinicon River, R= Rock River, I= Iowa River, S= Skunk River, D= Des Moines River, U= Upper Mississippi River.

	Common Name	**Scientific Name**	4/29/2016	5/10/2016	5/19/2016	5/29/2016	6/9/2016	6/18/2016	6/28/2016	7/8/2016	7/18/2016	7/29/2016	8/9/2016	8/18/2016	8/28/2016	9/9/2016
Asian Carp	Bighead Carp	*Hypophthalmichthys nobilis*				UIS										
	Silver Carp	*Hypophthalmichthys molitrix*				UIS										
	Grass Carp	*Ctenopharyngodon idella*				UIS						UI		U	U	
Other Species	Common Carp	*Cyprinus carpio*							UW							
	Emerald Shiner	*Notropis atherinoides*				UIS	UI	URIS	UIS	USD	UR	UD	UI	UI		
	Freshwater Drum	*Aplodinotus grunniens*	U	U	UR	URID	URISD	URIS	UIS	USD	USD	UI	UD	UD		
	Goldeye	*Hiodon alosoides*		D												
	River Shiner	*Notropis blennius*							U	U			D			
	Sand Shiner	*Notropis stramineus*			UI		U	UDR			UID	UD	UI	UD		
	Shiner sp.	*Notropis sp.*								D						
	Shorthead Redhorse	*Moxostoma macrolepidotum*	D													
	Silvery Minnow	*Hybognathus nuchalis*				I										
	Speckled Chub	*Macrhybopsis aestivalis*				UIS	USD	U			UD		UD		D	

Table 3. Electrofishing catch per unit effort (CPUE, number per hour; mean ± 1 SE) of all Asian Carp species (Bighead Carp, Silver Carp and Grass Carp) caught by location and date during 2016. Sites not sample during that month are marked with a (-).

	2016		
Site	**September**	**October**	**November**
Bighead			
DSM-EDD	-	-	-
DSM-CLF	0.6±0.6	-	-
DSM-KQA	-	-	-
DSM-MTH	4.3±0.1	0	0
Silver			
DSM-CLF	16.8±16.8	-	-
DSM-MTH	215.9±64.6	-	-
SKK-MTH	3.9±3.9	-	2.8±2.2
IAR-MTH	0.7±0.7	-	0.5±0.7
UMR-P17	-	0	-
ROC-MTH	-	0.3±0.3	-
UMR-P15	-	0	-
WAP-MTH	-	0	-

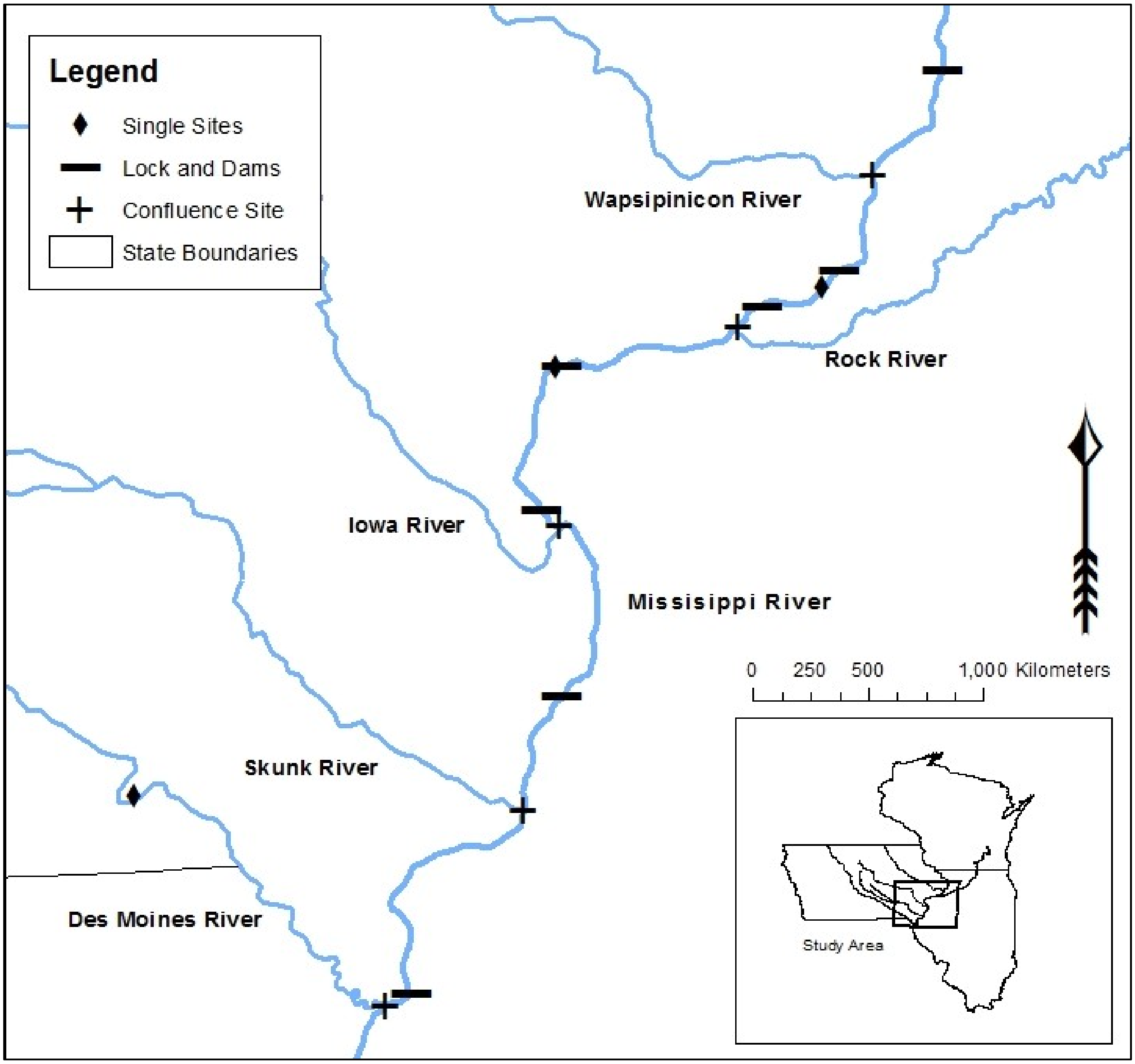

Figure 1. Approximate sampling locations ofconfluence (cross) and individual (diamond) sites and dam locations (bar) in rivers across southeastern Iowa. Confluence sites of the Wapsipinicon, Rock, Iowa, Skunk and Des Moines rivers are made up of individual sampling sites 1 km above and below the tributary within the Upper Mississippi River, in addition to a sampling site 1 km within the tributary.

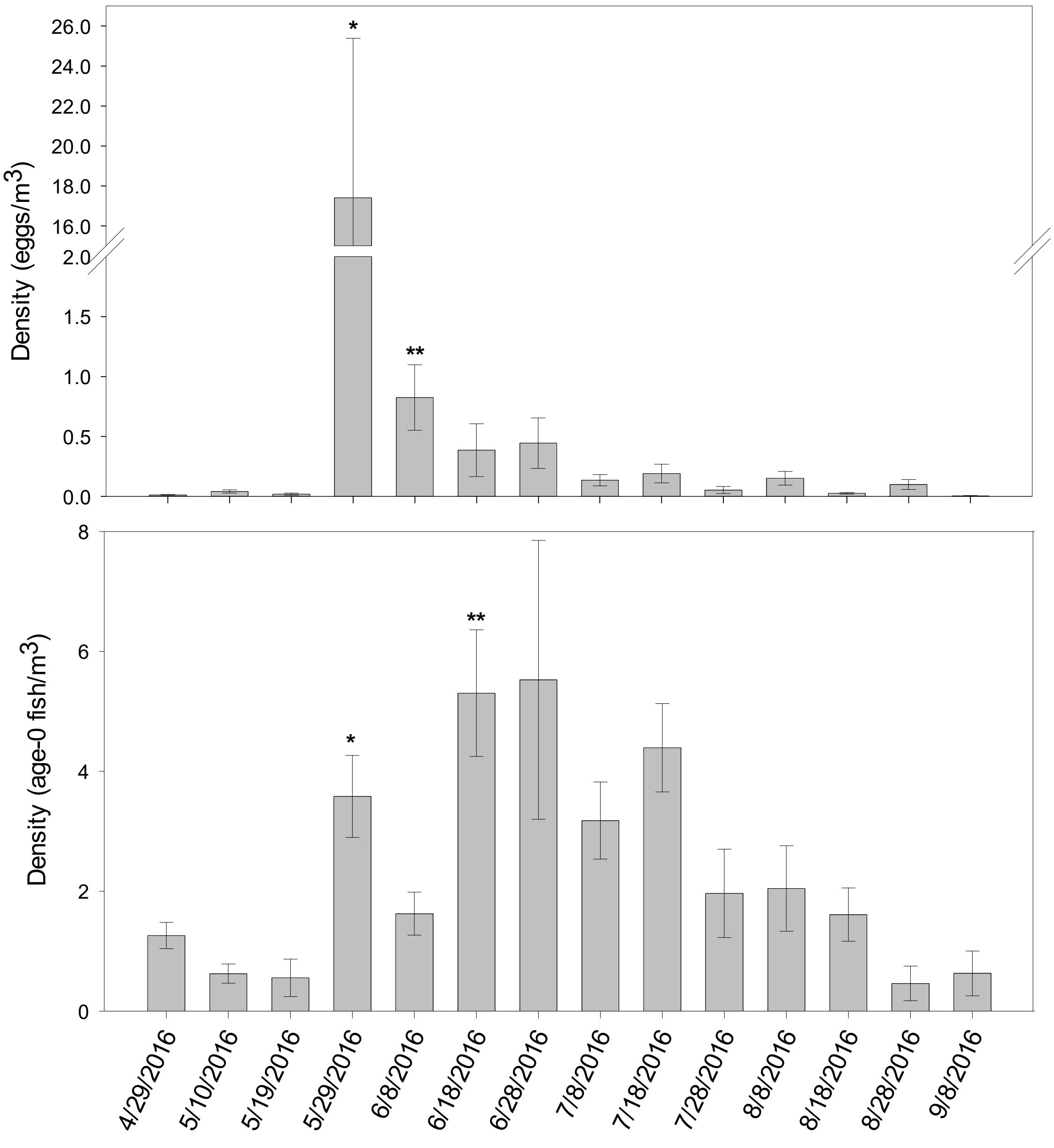

Figure 2. Density (mean ± 1 SE) of eggs (top) and age-0 fish (bottom) by sampling session collected between April 29 and September 8, 2016.
*UMR-UPD, UMR-DND, and DSM-MTH were not sampled during this session.

**DSM-KQA was not sampled during this session.

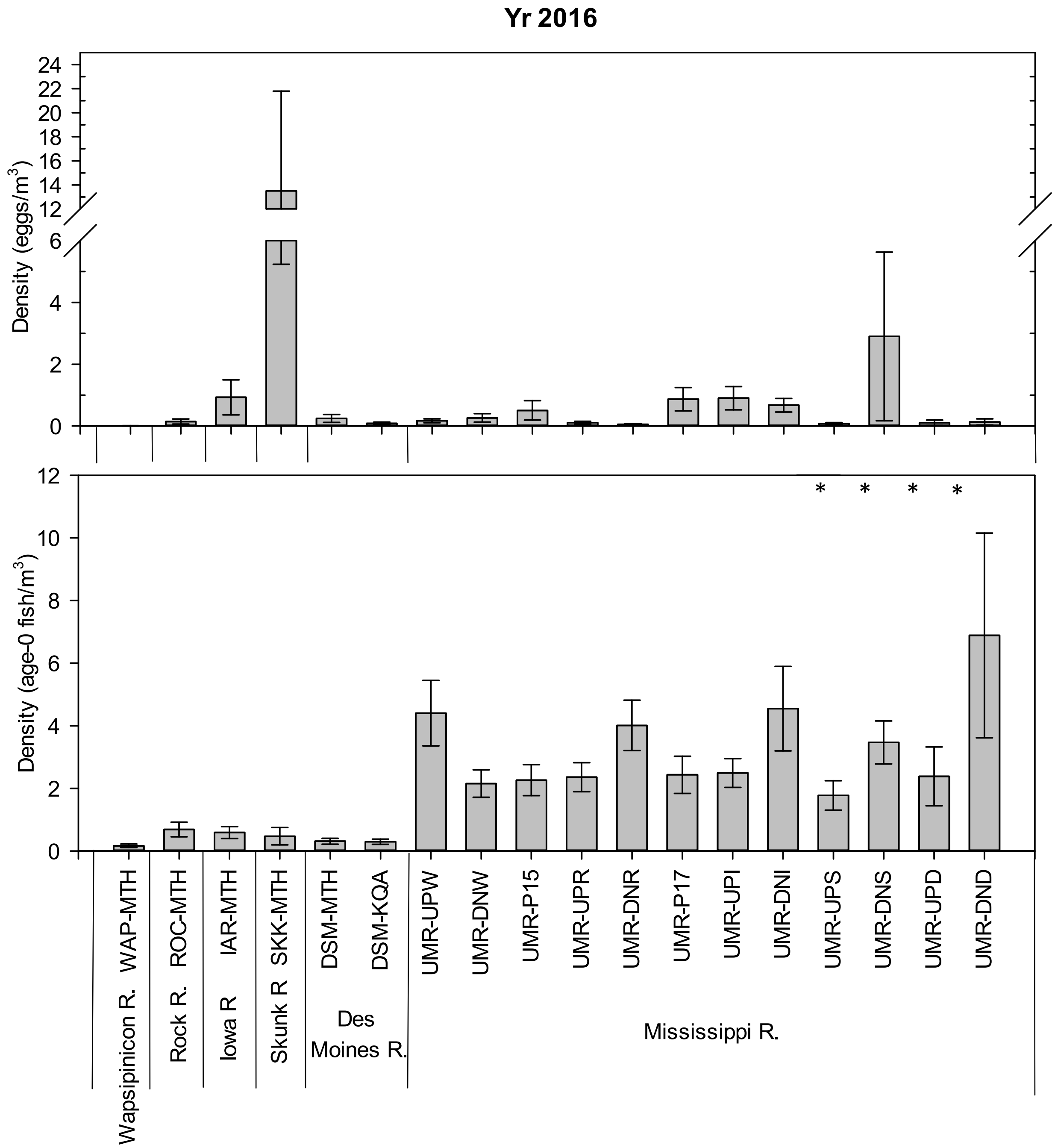

Figure 3. Densities (mean ± 1 SE) of eggs (top) and age-0 fish (bottom) by site from the Wapsipinicon, Rock, Iowa, Skunk, Des Moines, and Mississippi rivers during 2016.

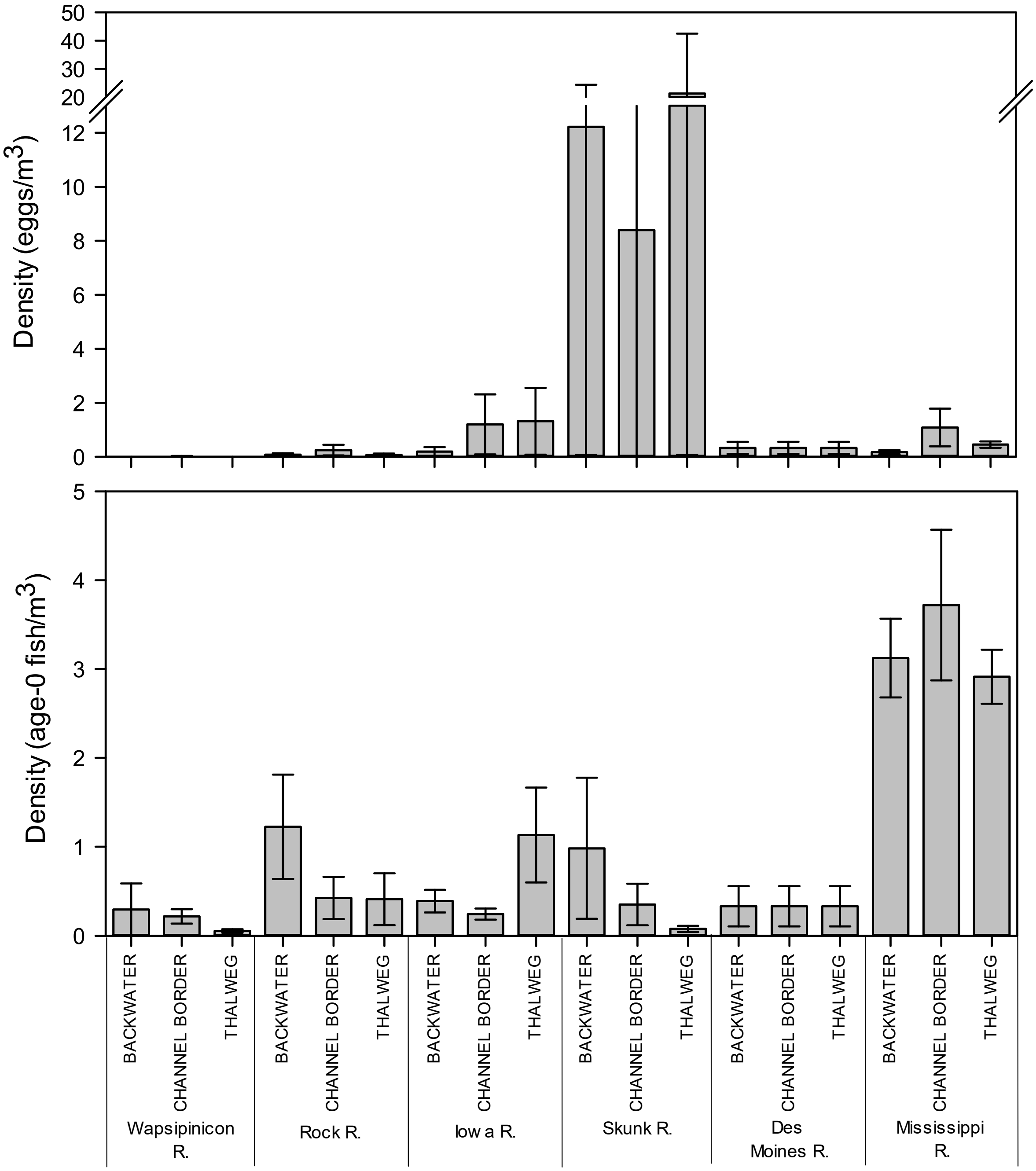

Figure 4. Densities (mean ± 1 SE) of eggs (top) and age-0 fish (bottom) by habitat from the Wapsipinicon, Rock, Iowa, Skunk, Des Moines, and Mississippi rivers during 2016.

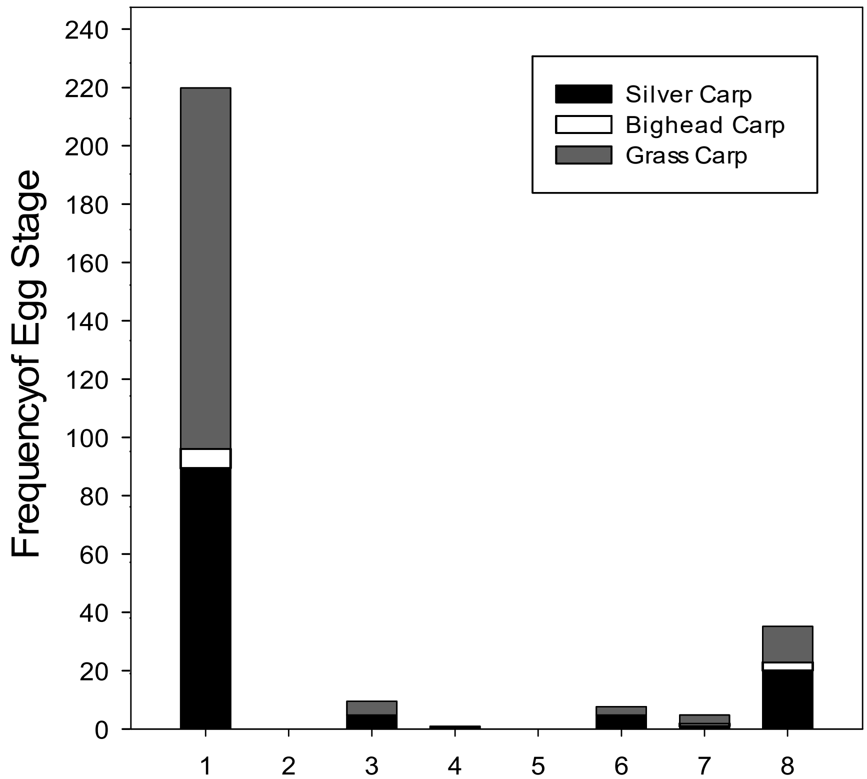

Figure 5. Asian carp (Silver and Bighead) frequency tables of egg stages during 2016. Egg stages relate to hours of development [hours:minutes]. Development times were determined from averaging the time of Bighead and Silver Carp; Stage 1= 2:25, Stage 2 = 3:59, Stage 3 = 7:00. Stage 4 = 12:04, Stage 5 = 18:05, Stage 6 = 19:15, Stage 7 = 22:00, Stage 8 = 33:00 (Chapman and George 2011).

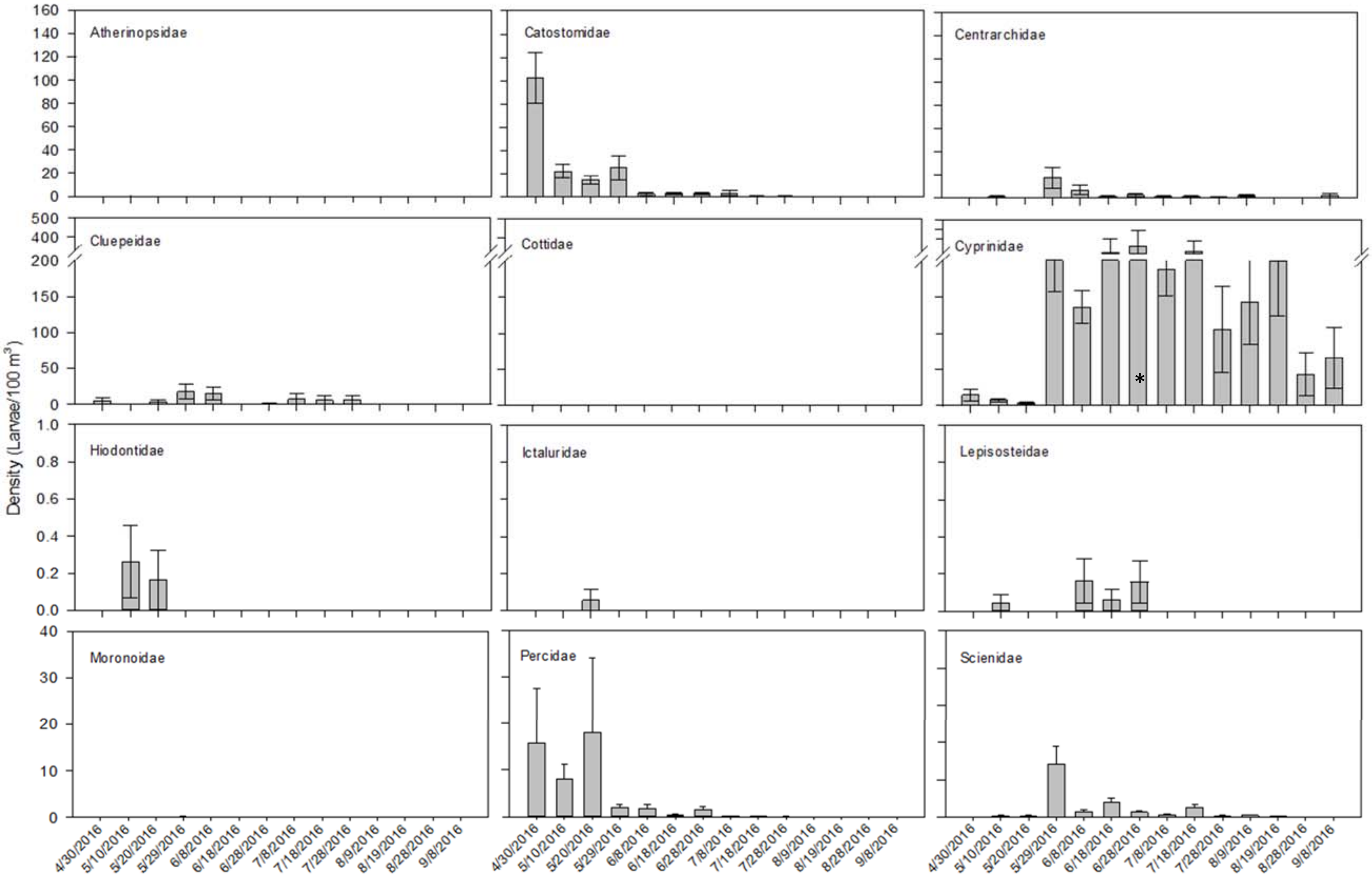

Figure 6. Densities (mean + 1 SE) of larvae identified to family from each sampling session in 2016. Only two yolk sac larval Bighead/Silver Carp captured upstream of the Des Moines River confluence on June 20th and August 27th have been identified in 2016 samples.

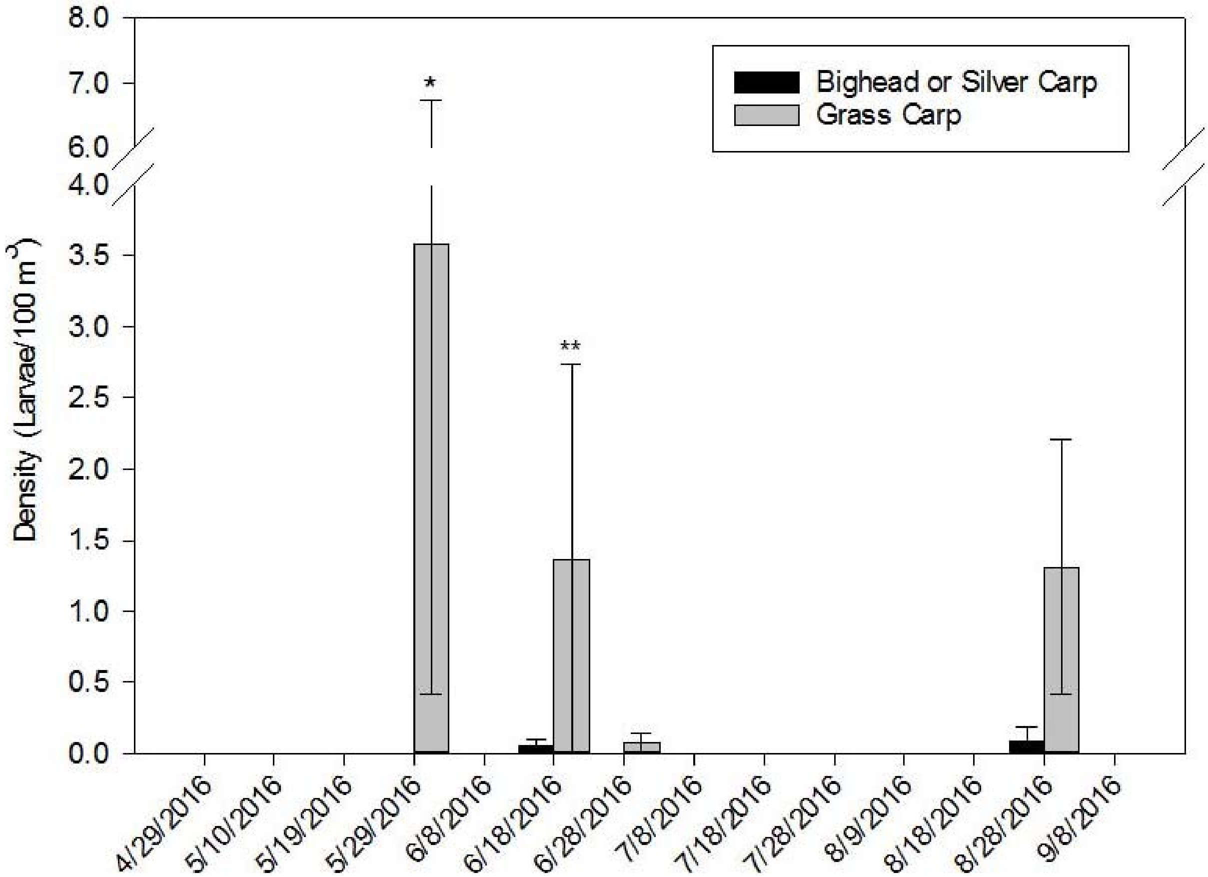

Figure 7. Density (mean ± 1 SE) per 100 cubic meters of age-0 Bighead or Silver carp, and Grass carp by sampling session.

*UMR-UPD, UMR-DND, and DSM-MTH were not sampled during this session.

**DSM-KQA was not sampled during this session

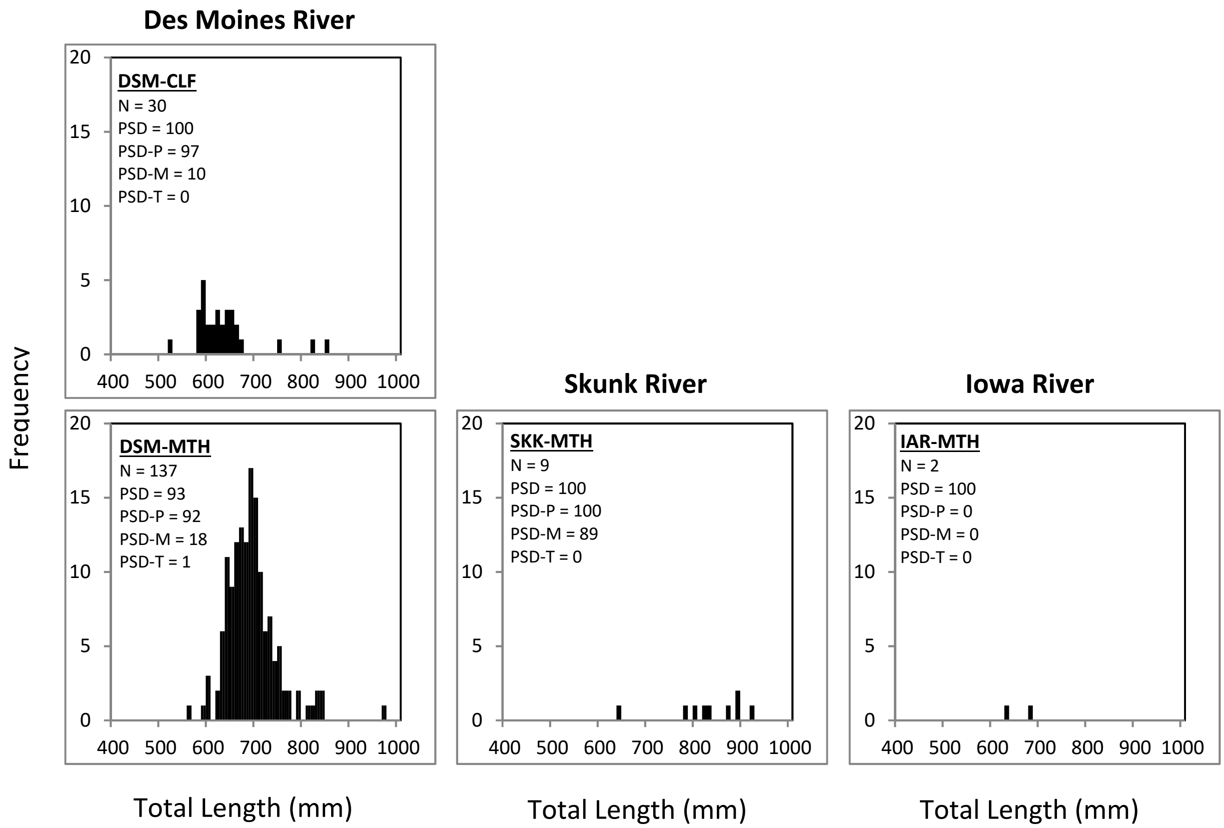

Figure 8. Silver Carp length-frequency distributions and proportional size distribution (PSD; P-Preferred, M-Memorable, T-Trophy) indices of fish collected during 2016 from the Des Moines River at Cliffland (CLF) and at the Des Moines River mouth (MTH) in addition to Iowa River and Skunk River. One Silver Carp was captured at the Rock River mouth. No Asian Carp were captured in Pool 17, Pool 15, or the Wapsipinicon River confluence.

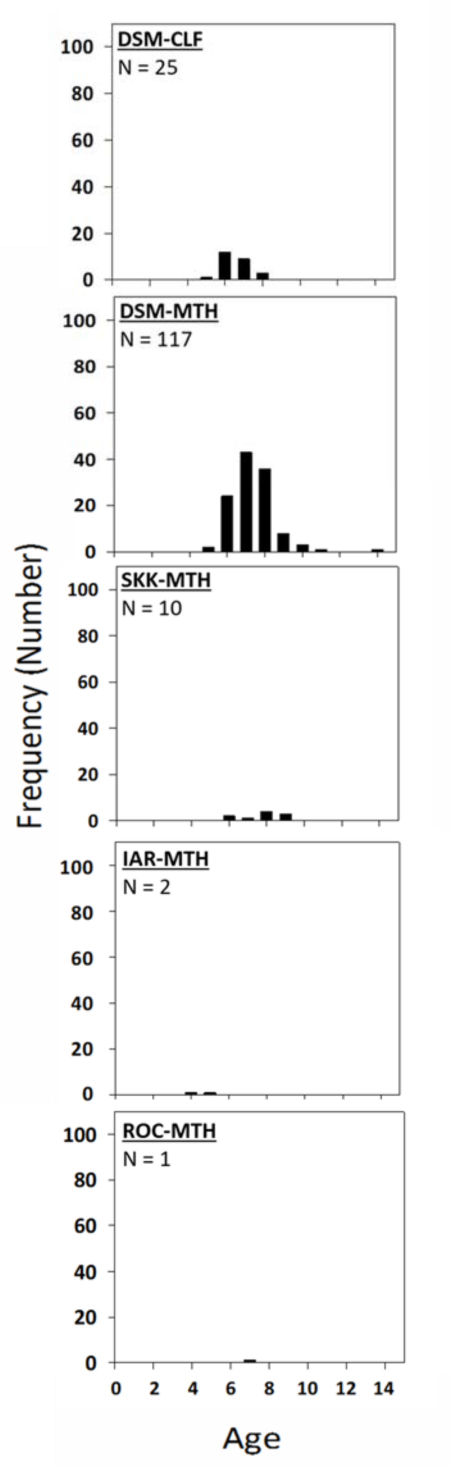

Figure 9. Age frequency of Silver Carp captured during 2014, 2015, and 2016 in the mouths of the Skunk (SKK) and Des Moines (DSM) rivers as well as the Eddyville (EDD), Cliffland (CLF), and Keosauqua (KQA) sites within the Des Moines River. N = number of aged Silver Carp captured at each site.

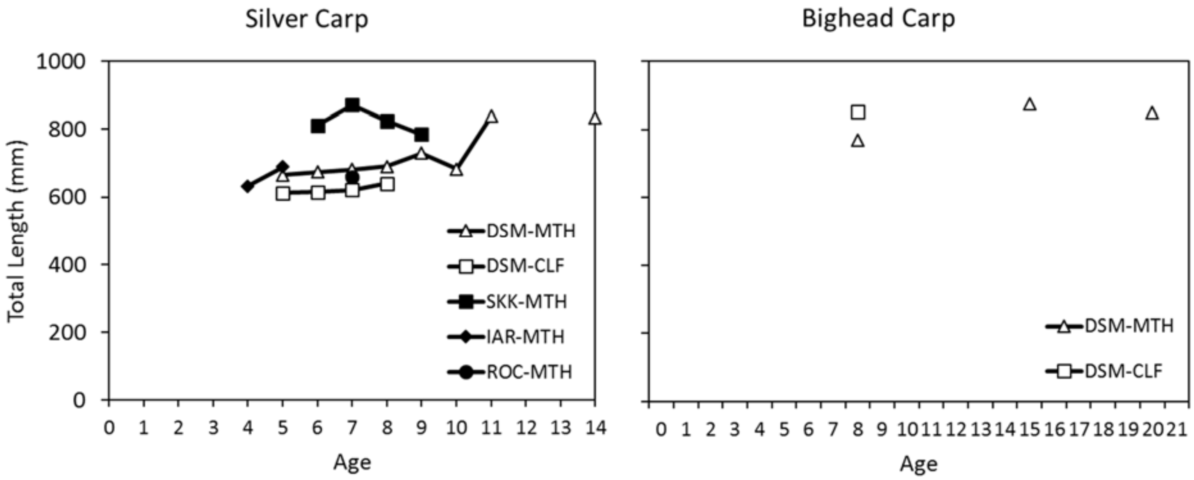

Figure 10. Mean length (mm) at age (years) for both Silver and Bighead Carp captured during 2016 in the mouths of the Rock (ROC), Iowa (IAR), Skunk (SKK), and Des Moines (DSM) Rivers as well as the Cliffland (CLF) site within the Des Moines River. Note: backcalculated length-at-age was not estimated in 2016.

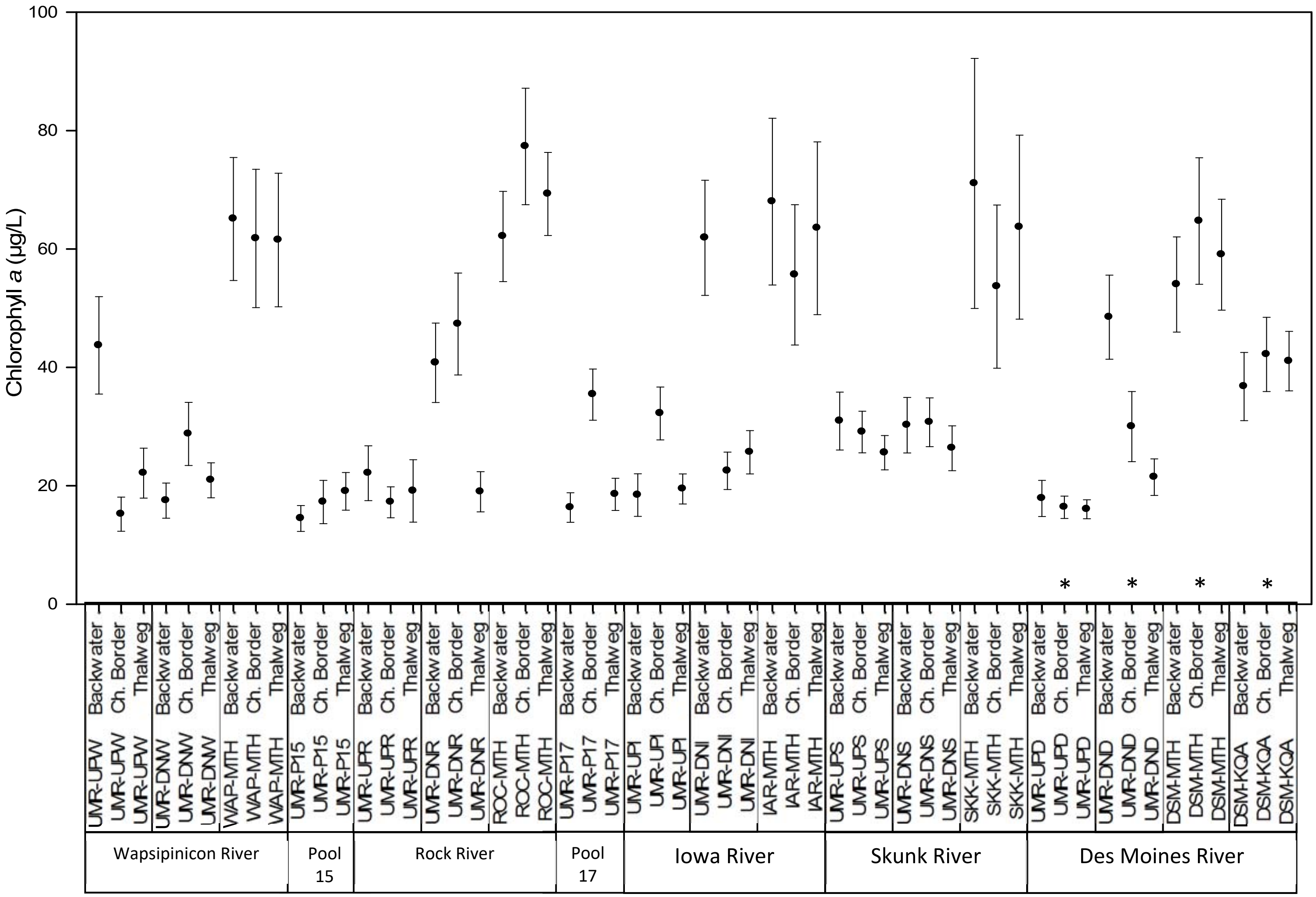

Figure 11. Chlorophyll *a* measurements (mean ± 1 SE) of each site collected between April 29 and September 8, 2016.
*Not all of the Des Moines River sites were collected on 5/19/16 and 6/8/16 due to mechanical issues and low water levels.

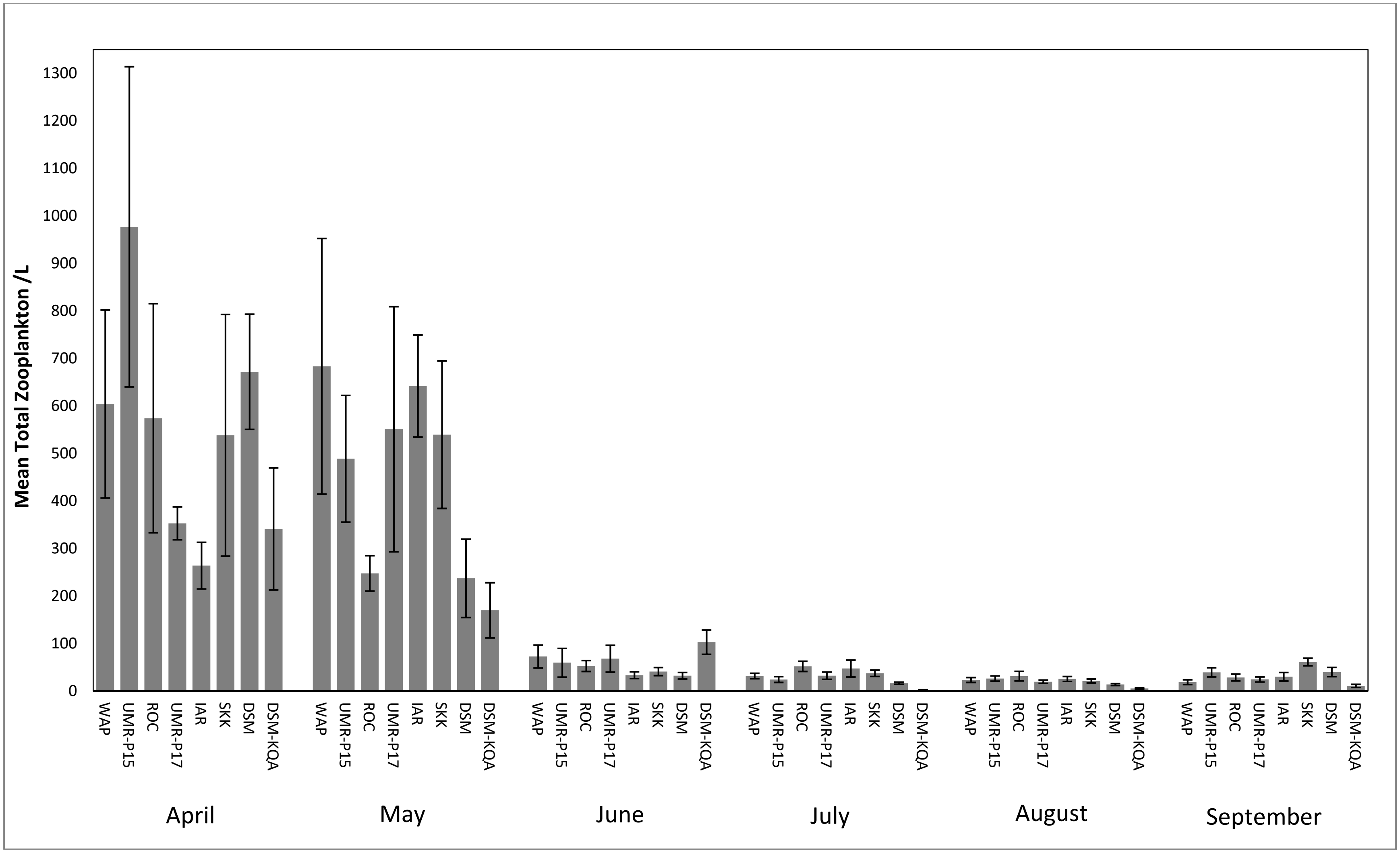

Figure 12. Zooplankton density (#/L; mean + 1 SE) by site and month during 2016. All confluence sites were averaged within another (WAP = Average of UMR-UPW, UMR-DNW, and WAP-MTH; ROC = Average of UMR-UPR, UMR-DNR, and ROC-MTH; IAR = Average of UMR-UPI, IAR-MTH, and UMR-UPI; SKK = Average of UMR-UPS, SKK-MTH, and UMR-DNS; DSM = UMR-UPD, DSM-MTH, and UMR-DND). Individual site codes are listed in Table 1.