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To cite this article: Christopher J. Sullivan, Carlos A. Camacho, Michael J. Weber & Clay L. Pierce (2017) Intra-Annual Variability of Silver Carp Populations in the Des Moines River, USA, North American Journal of Fisheries Management, 37:4, 836-849, DOI: [10.1080/02755947.2017.1330785](https://doi.org/10.1080/02755947.2017.1330785)

To link to this article: <http://dx.doi.org/10.1080/02755947.2017.1330785>



Accepted author version posted online: 19 May 2017.
Published online: 19 May 2017.



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ARTICLE

Intra-Annual Variability of Silver Carp Populations in the Des Moines River, USA

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Abstract

Since their introduction in the 1970s, Silver Carp *Hypophthalmichthys molitrix* have spread throughout the Mississippi River basin. Management of any species relies on an accurate understanding of population characteristics and dynamics. However, Silver Carp seasonal sampling variation is unknown. Sampling during periods of peak catch rates would facilitate Silver Carp assessment and management, improving monitoring and removal techniques. The objective of this study was to evaluate adult Silver Carp seasonal sampling variation with boat electroshocking and trammel nets. Silver Carp were collected monthly (April–October) during 2014 and 2015 from four locations in the Des Moines River, Iowa. Trammel nets rarely captured Silver Carp (mean \pm SE = 4.9 ± 1.6 fish/net; 60% of fish were captured in 6.3% of net sets) and therefore were not included in analyses. Electroshocking catch rates (CPUEs) exhibited a bimodal distribution, with peak CPUEs generally occurring in May, June, and September and lower catch rates observed during July and August. Catch rates were positively related to river discharge at upstream sites but not at downstream sites. Silver Carp size structure was similar among months and sites except at Cliffland, where fish were smaller during August and October compared to earlier in the year. Finally, Silver Carp condition peaked during April and May and decreased throughout the year except at Keokuk, where peaks were observed during both May and August. Although spatiotemporal variability was substantial, these results suggest that sampling of Silver Carp via electroshocking in May–June and September–October generally produces higher catch rates compared to July–August sampling and generates a more representative size structure. Using site-specific knowledge, monitoring and surveillance programs could more effectively sample during these periods of high vulnerability and densities in order to manage the spread and impacts of Silver Carp at statewide and regionwide scales.

The spread and subsequent impacts of introduced nonnative species constitute among the most serious (Mooney and Hobbs 2000) and least reversible (Kolar and Lodge 2002) human-induced changes occurring around the world. Recently, the invasion of Silver Carp *Hypophthalmichthys molitrix* throughout the Mississippi River basin (MRB) has been well publicized and has elicited substantial concern among scientists and the general public. Since their escape into central Arkansas rivers

during the mid-1970s, Silver Carp have migrated upstream throughout the MRB. As of 2016, Silver Carp had been captured in the Missouri River (Papoulias et al. 2006; Wanner and Klumb 2009; Deters et al. 2013), Illinois River (DeGrandchamp et al. 2007; Irons et al. 2007; Lamer et al. 2010; Sass et al. 2010), Ohio River (NAS 2016), and Wabash River (Coulter et al. 2013; Stuck et al. 2015) and in the upper (Lohmeyer and Garvey 2009; Tripp and Garvey 2011), middle (Williamson and

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Received December 7, 2016; accepted May 11, 2017

Garvey 2005), and lower (NAS 2016) portions of the Mississippi River watershed. Once Silver Carp are present in a system, their relative abundance can increase dramatically. For example, Silver Carp electroshocking CPUE increased from zero to nearly 36 fish/h (maximum CPUE = 76 fish/h) in the Big Sioux, James, and Vermillion rivers of southeastern South Dakota over a 4-year period (Hayer et al. 2014b). As a result, robust monitoring protocols that identify Silver Carp abundance status and trends are necessary for documenting initial introductions and subsequent fluctuations in abundance.

Although the efficiency of various gears used to assess Silver Carp populations has recently received considerable attention (e.g., daytime electroshocking, mini-fyke-netting, hoop-netting, gillnetting, pound-netting, etc.; McClelland and Sass 2008; Wanner and Klumb 2009; Collins et al. 2015), the extent to which seasonality and environmental characteristics affect capture rates has yet to be evaluated. Identification of seasonal sampling variation is important because the capture rates and size structure of fishes captured in sampling gears can vary temporally due to movement patterns (Miller and

TABLE 1. Mean, maximum, and minimum discharge (monthly estimates obtained from U.S. Geological Survey gauging stations), water temperature, and conductivity values measured during April–October 2014 and 2015 at four Silver Carp sampling sites in the Des Moines River.

Variable	Des Moines River site			
	Eddyville	Cliffland	Keosauqua	Keokuk
Discharge (m ³ /s)				
Mean	419.5	435.2	462.1	462.1
Maximum	628.6	775.9	843.8	843.8
Minimum	36.5	24.4	38.2	38.2
Water temperature (°C)				
Mean	20.7	20.4	20.8	20.7
Maximum	25.9	26.5	26.9	28.3
Minimum	9.1	11.8	11.0	11.7
Conductivity (μS/cm)				
Mean	531.4	553.4	508.7	522.9
Maximum	706.0	732.0	781.0	710.0
Minimum	426.0	398.0	361.0	323.0

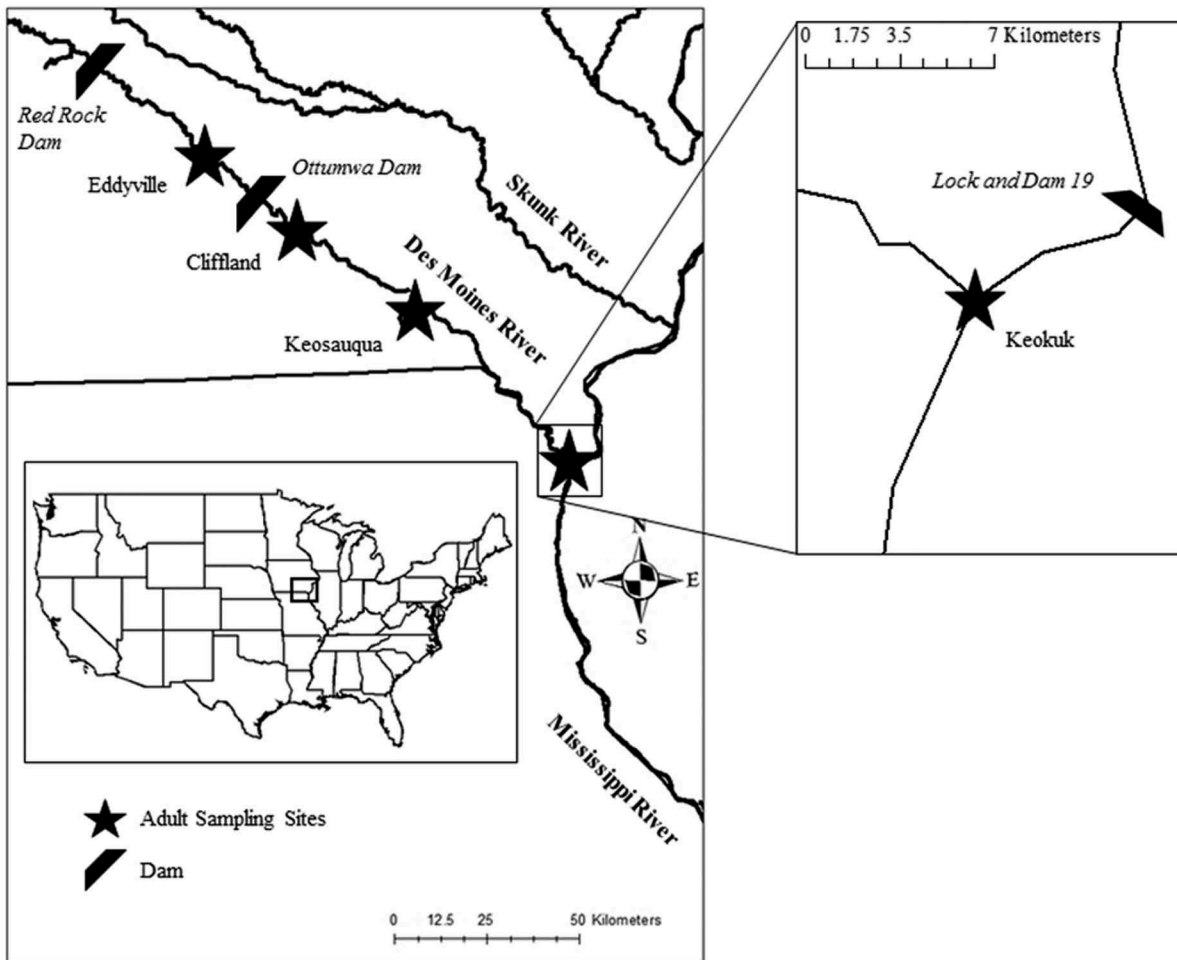


FIGURE 1. Locations of the four Des Moines River (Iowa) sites used to assess Silver Carp seasonal sampling variation.

Scarnecchia 2008; Béguyer-Pon et al. 2015), spawning migrations (Herbst et al. 2015), local environmental conditions (Cowley et al. 2007; Jones and Stuart 2009; Muhlfeld et al. 2012; Gardner et al. 2013), prey availability (Bowlby and Hoyle 2011), and the annual flux of young-of-the-year fish recruiting to sampling gears (Bacula et al. 2011; Neal and Prchalová 2012). In lakes, seasonal sampling variation has been attributed to surface water temperatures (e.g., Bacula et al. 2011) and spawning activity (e.g., Lott 2000; McKibbin 2002; Herbst et al. 2015). In contrast, seasonal sampling variation in rivers is more complex due to the aforementioned variables (Miller and Scarnecchia 2008; Zimmer et al. 2010; Muhlfeld et al. 2012; Gardner et al. 2013) in addition to variable river flow (Cowley et al. 2007) and temporary floodplain connectivity (Jones and Stuart 2009), potentially influencing fish sampling success.

Seasonal sampling variation has been documented for various freshwater fishes, with higher catches generally reported during spring and fall in response to environmental conditions (Pope and Willis 1996). Substantial research has been devoted to documenting Silver Carp expansion and subsequent increases in density (e.g., Irons et al. 2007; Hayer et al. 2014a). However, information on Silver Carp seasonal sampling variation in relation to environmental conditions is lacking. Within Mississippi River tributaries, Silver Carp movements increase during the spring and early summer, when fish generally migrate upstream in response to increasing river flow and water temperatures (DeGrandchamp et al. 2008; Coulter et al. 2016). Additionally, Silver Carp can migrate more than 3 km daily (>400 km over 2 years; DeGrandchamp et al. 2008) while frequently moving upstream (Calkins et al. 2012). Collectively, the spatiotemporal variability of environmental variables and the associated behavioral characteristics of Silver Carp (i.e., timing and extent of spawning movements) can alter this species' distribution locally and regionally, potentially influencing population indices (i.e., relative abundance, size structure, and condition) and the perception of population status.

Monitoring the population characteristics of invasive fishes can provide valuable insights into the cumulative interactions of dynamic rates (i.e., recruitment, growth, and mortality) and their influence on population structure. Most natural resource agencies recognize the importance and necessity of collecting basic information on Silver Carp populations and its value in managing and monitoring the spread of these populations (Conover and Simmonds 2007). However, sampling protocols that consider the potential spatiotemporal sampling variation in Silver Carp have yet to be developed. Therefore, the objective of this study was to evaluate potential spatial and temporal variation in Silver Carp catch rates, size structure, and relative weight (\bar{W}_r) by sampling via electroshocking and trammel-netting.

METHODS

Study site.—The Des Moines River originates in Lake Shetek, Minnesota, and flows 845 km to the confluence of the Mississippi River at Keokuk, Iowa. The Des Moines River drains an area of 40,940 km², with a mean daily discharge of 232 m³/s (USGS 2013). An array of anthropogenic alterations has been completed along the river, including dams, levees, and submerged weirs. The river is channelized and subject to rapidly changing hydrographs (Table 1). Specifically, the Des Moines River contains three dams that mitigate flood damage in adjacent cities: Ottumwa Dam (near Ottumwa, Iowa), Red Rock Dam (near Pella), and Saylorville Dam (near Des Moines). Additionally, Lock and Dam 19 (Keokuk, Iowa), which is located approximately 6 river kilometers (rkm) upstream from the Des Moines River–Mississippi River confluence, restricts the upriver movement of fish into higher reaches of the Mississippi River (Tripp et al. 2013).

Field sampling.—Adult Silver Carp were sampled once per month from April to October 2014 and 2015 at four sites in the Des Moines River (Figure 1) by using daytime boat electroshocking and stationary trammel nets. Low water levels and ice cover precluded sampling during the winter months (November–March). Sampling locations were selected based on the locations of access points, logistical constraints, agency interests, and the desire to spread sampling effort throughout the Des Moines River between Red Rock Dam and the Mississippi River confluence. Red Rock Dam, situated approximately 250 rkm upstream from the confluence, prevents fish from moving further upstream (Figure 1). Ottumwa Dam is a hydroelectric dam located approximately 70 rkm downstream of Red Rock Dam (Figure 1). However, fish are believed to be able to pass Ottumwa Dam under most river conditions except during low-flow periods (J. Euchner, Iowa Department of Natural Resources [IDNR], personal communication).

Silver Carp are difficult to capture (Williamson and Garvey 2005; Bouska et al. 2017) and have been sampled by using a variety of gears, with variable success (Koel et al. 2000; Hayer et al. 2014b; Collins et al. 2015). However, a wide array of Silver Carp sizes appear to be effectively captured with boat electroshocking (e.g., McClelland and Sass 2008; Sass et al. 2010; Stuck et al. 2015), whereas larger Silver Carp are more commonly captured by use of passive gears (e.g., trammel nets; Wanner and Klumb 2009). Consequently, both boat electroshocking and trammel-net sets were used and compared for their ability to sample Silver Carp. Both gears were deployed in areas of low velocity (<1.0 m/s; e.g., eddies, dike pools, inside river bends, etc.) within habitats less than 4 m deep (DeGrandchamp et al. 2008). Three 15-min daytime transects with a boat electroshocker (Smith-Root; 4–13 A, 100–500-V DC, 25% duty cycle, 25% frequency, 60 pulses/s; with two netters) were conducted parallel to the shoreline at fixed stations each month. To effectively

TABLE 2. Total effort, mean effort per transect, and total number of Silver Carp captured (*N*) for boat electroshocking and trammel-net surveys conducted in the Des Moines River.

Sampling site	Boat electroshocking			Trammel-netting		
	Total effort (s)	Mean effort (s)	<i>N</i> captured	Total effort (38.1 m of net)	Mean effort (38.1 m of net)	<i>N</i> captured
2014						
Eddyville	19,276	918	58	15	2	4
Cliffland	19,189	914	441	12	2	83
Keosauqua	18,306	915	36	1	2	0
Keokuk	19,366	922	468	12	<1	12
2015						
Eddyville	19,114	910	153	14	2	18
Cliffland	18,993	904	675	16	2	116
Keosauqua ^a	16,267	904	85	6	2	13
Keokuk	18,351	874	531	16	1	174

^aSampling did not occur at Keosauqua during October 2015 due to unsafe river conditions.

electroshock across sites, months, and years, sampling was conducted via a “standardizing by power” approach in which electroshocker settings were altered adaptively to be conducive for successful electroshocking (i.e., Miranda 2009) since Silver Carp have been noted as eluding active sampling gears (e.g., Williamson and Garvey 2005). Specifically, electroshocking outputs were altered based on environmental conditions to ensure that Silver Carp were specifically targeted and that a “standard” response (i.e., swimming toward the anodes) was consistently achieved. When river conditions allowed, stationary, multifilament trammel nets (2.4-m-deep inner wall, 1.8-m-deep outer wall, 38.1 m long, 10-cm bar inner mesh with number-9 twine, and a 9.9–12.7-mm foam float line and single lead line; see Drobish 2008) were fished in areas of low velocity. One end of the trammel net was anchored on the shore, and the remaining end was stretched toward deeper water or an opposite shore, thus restricting Silver Carp movement out of low-velocity areas. After trammel nets were set, one electroshocking transect was conducted, and the trammel nets were collected. Thus, the duration of net sets was variable but ranged between 20 and 30 min. All captured Silver Carp were weighed (g) and measured (mm; TL).

We measured thalweg water temperature (°C; Yellow Springs Instruments Model 550A) and conductivity (EC400 ExStik 2 Conductivity Meter) during each monthly sampling occasion at each site. Additionally, mean daily discharge values (m³/s) were obtained from U.S. Geological Survey (USGS) gauging stations upstream from each sampling location present at Tracy (station number 05488500), Ottumwa (station 05489500), and Keosauqua (station 05490500), Iowa. Due to the absence of a USGS gauging station in the Des Moines River immediately upstream from Keokuk, mean

daily discharge values obtained from the gauging station at Keosauqua (80 rkm upstream) were used, as they were highly correlated ($r = 0.99$, $P < 0.001$) with monthly discharge values measured during sampling events near Keokuk.

Data analysis.—Trammel-net sets were used independently of electroshocking and were conducted inconsistently due to a lack of available habitat. Thus, Silver Carp relative abundance was indexed as mean CPUE separately for daytime boat electroshocking or trammel-netting by month. Trammel-net CPUE at each site during each month was calculated as the average number of fish captured per 38.1 m of net, whereas electroshocking CPUE was calculated as the average number of fish collected per site, extrapolated to fish per hour. The CPUE data were zero-inflated (e.g., temporary absence of Silver Carp or a lack of Silver Carp capture) and overdispersed. Thus, a negative-binomial generalized linear model was used to assess differences in monthly mean CPUE of Silver Carp across sites. Modeling with a negative-binomial distribution is useful when data consist of counts (particularly small counts) and when the mean and variance are correlated (Gardner et al. 1995). The data were modeled as a count for a given amount of effort:

$$y_{ijkl} \sim \text{Negative Binomial}(\lambda_{ijl} \times \phi_{ijkl}), \quad (1)$$

where i denotes the month, j represents the location, k represents the individual trammel net or electroshocking run, and l denotes the year. In equation (1), λ_{ijl} is the Silver Carp CPUE for month i , location j , and year l , while ϕ_{ijkl} is the effort (offset) for year l , month i , location j , and net or run k . Pairwise comparisons of monthly CPUE rate ratios (proportional changes between months) were used to compare CPUE

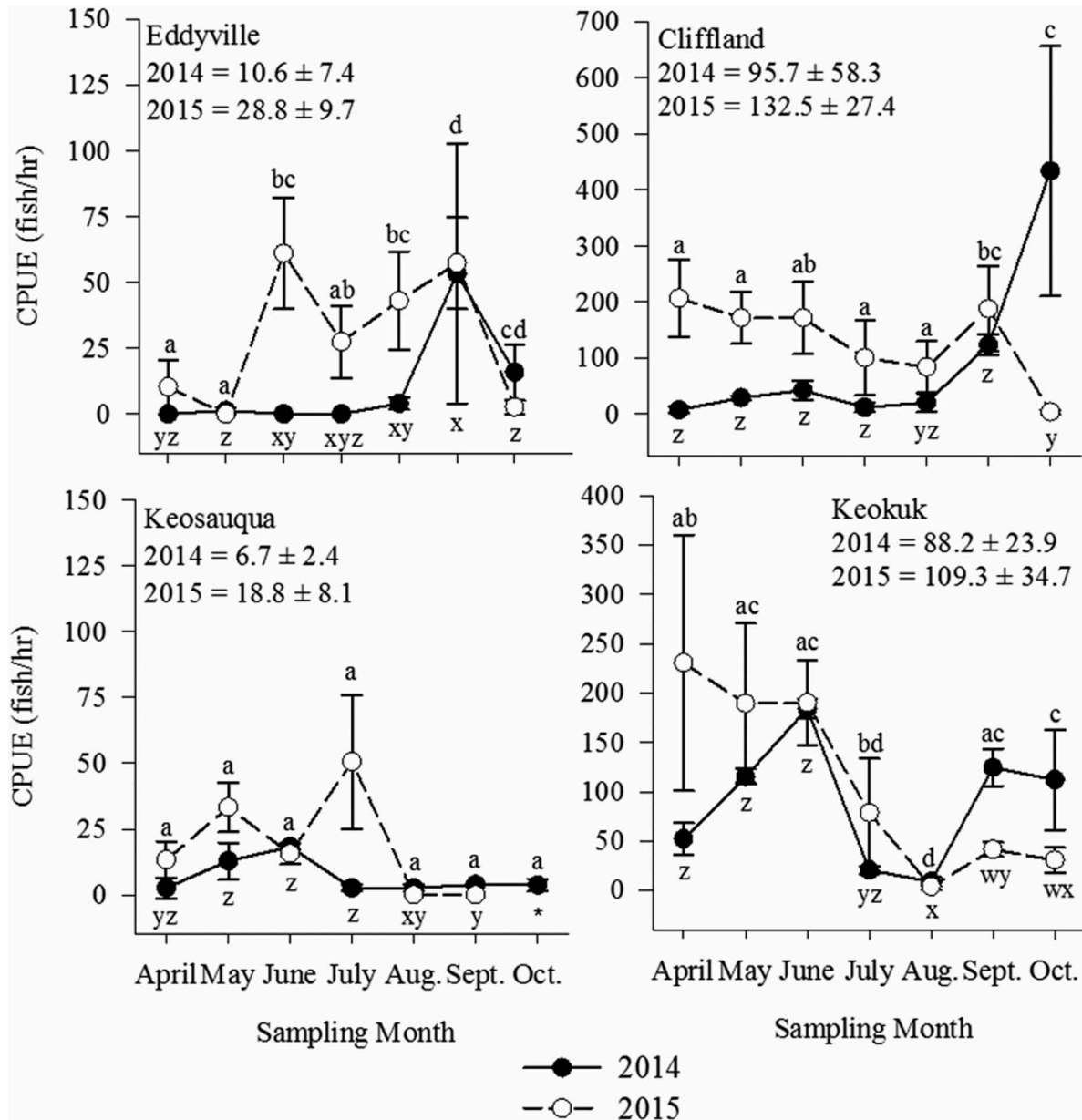


FIGURE 2. Silver Carp electroshocking CPUE (fish/h; mean \pm SE) during April–October at four Des Moines River sites in 2014 (black shaded circles) and 2015 (open circles). Points with letters in common represent CPUEs that were not significantly different ($\alpha = 0.05$) for 2014 (letters a–e) or 2015 (letters w–z).

rates among months within each sampling location. A post hoc Tukey’s honestly significant difference test using Bonferroni corrections was used to determine which year, sites, and months differed at a significance level α of 0.05.

The relationships between the Silver Carp capture rate and mean daily discharge, water temperature, and conductivity during each day of sampling were evaluated using Pearson’s product-moment correlation coefficients (Pearson’s r). For each site and variable, a randomization test for significance involving 5,000 iterations was used to compare a generated distribution of the

calculated Pearson’s r -values. To compute a P -value ($\alpha = 0.05$), the number of generated Pearson’s r -values that were greater than the Pearson’s r obtained from the original data was divided by the number of iterations (5,000). Bonferroni-corrected P -values were used to determine significant relationships. If significant relationships were detected, linear least-squares regression was used to describe the relationship between significant pairwise comparisons.

Silver Carp size structure was calculated for each month and for each of five length-groups (250–449.9, 450–559.9,

560–739.9, 740–929.9, and ≥ 930 mm; Phelps and Willis 2013). A chi-square test for differences in probabilities was used to assess differences in Silver Carp length-group frequencies among months. If a difference was detected, individual chi-square tests were conducted to determine differences between months (Bacula et al. 2011).

Monthly body condition was indexed as W_r by using a Silver Carp standard weight (W_s) equation (J. Lamer, Western Illinois University, unpublished data) and was averaged by length-group. Length categories with fewer than five fish captured on a specific sampling date were excluded from W_r calculations. A repeated-measures ANOVA was used to test for monthly differences in W_r by length-group for each site and was blocked by year. Data were transformed when necessary to meet the normality assumptions of ANOVA. If significant differences were detected, pairwise *t*-tests with Bonferroni corrections were used to determine which groups specifically differed. All statistical analyses were conducted in R version 3.2.0 (R Development Core Team 2016), with a significance level α of 0.05.

RESULTS

Few Silver Carp were captured in trammel nets (Table 2), likely due in part to the short soak times (20–30 min/set). In addition, we were unable to set trammel nets at 47% of the sites due to a lack of suitable habitat with low flow, and most net sets did not capture Silver Carp (65.3% of total sets; see Table 2 for site effort). Six trammel-net sets (out of 95 total sets; 6.3%) accounted for 257 (60%) of the 431 Silver Carp captured with this gear (mean CPUE \pm SE in those six sets = 42.5 ± 6.3 fish/38.1 m). Incidental catch rates in the remaining trammel-net sets were extremely low (mean CPUE \pm SE = 2.0 ± 0.5 fish/38.1 m). As a result, further analyses using data collected with this gear were not conducted.

Overall, 2,476 Silver Carp were captured using daytime electroshocking in the Des Moines River from April to October in 2014 (1,014 fish) and 2015 (1,462 fish). Electrofishing effort was generally constant across sites and months (Table 2). Mean electrofishing CPUE of Silver Carp varied between years ($P < 0.001$), among sites ($P < 0.001$), and among months ($P = 0.01$), and the pairwise interactions were significant (all two-way comparisons; $P < 0.001$). During both years, Silver Carp CPUE was highly variable among sites and months (Figure 2). Monthly mean electroshocking CPUE varied temporally, ranging from 0 to 434.0 fish/h during 2014 and from 0 to 230.6 fish/h during 2015 (Figure 2). During 2014, Silver Carp CPUE at the Cliffland and Keokuk sites increased from April to June, decreased during June and August, and increased throughout September and October (Figure 2). Silver Carp CPUE at Eddyville peaked during September, as no individuals were captured during April–August. Conversely, CPUE at Keosauqua increased from

May to June and was lower during the remainder of the year. During 2015, Silver Carp CPUE at Cliffland and Keokuk peaked during April and decreased throughout the year until exhibiting a slight increase during September. In 2015, CPUE at Eddyville peaked during June and was sustained from June through September until a sharp decline occurred during October. Finally, Silver Carp CPUE at Keosauqua increased from April to July and declined markedly thereafter.

River discharge levels varied through time and among years (Figure 3) and were positively related to Silver Carp CPUE (Pearson's $r = 0.07$ – 0.75 for all sites; Figure 4). Silver Carp CPUE was significantly related to mean daily discharge at both Eddyville (Pearson's $r = 0.60$, $P = 0.004$) and Cliffland (Pearson's $r = 0.75$, $P = 0.01$), whereas it was not significantly related to CPUE at Keosauqua (Pearson's $r = 0.07$, $P = 0.23$) or Keokuk (Pearson's $r = 0.14$, $P = 0.26$). Additionally, Pearson's r -values were lower at downstream sites (Keokuk and Keosauqua) than at both upstream sites (Cliffland and Eddyville). In contrast, neither water temperature nor conductivity was related to CPUE ($P > 0.10$ for all correlations; Figure 4).

Silver Carp size structure was generally larger at downstream sites compared to upstream sites (Table 3). Silver Carp belonging to the 560–740-mm length-group composed 91% of

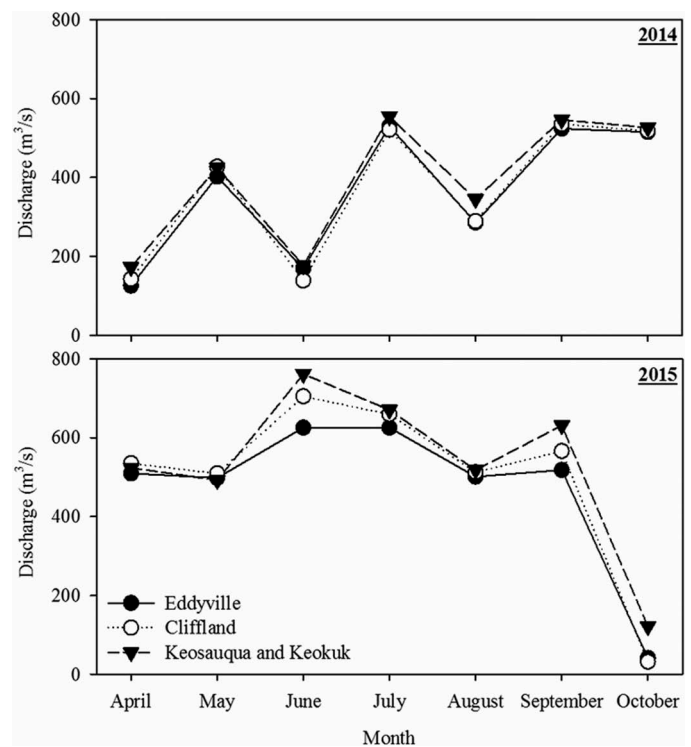


FIGURE 3. Daily discharge (m^3/s ; mean \pm SE) at four Des Moines River sites during Silver Carp sampling events in April–October 2014 and 2015. Note, error bars are not visible due to small SE values. Data were obtained from U. S. Geological Survey gauging stations upstream of each sampling location.

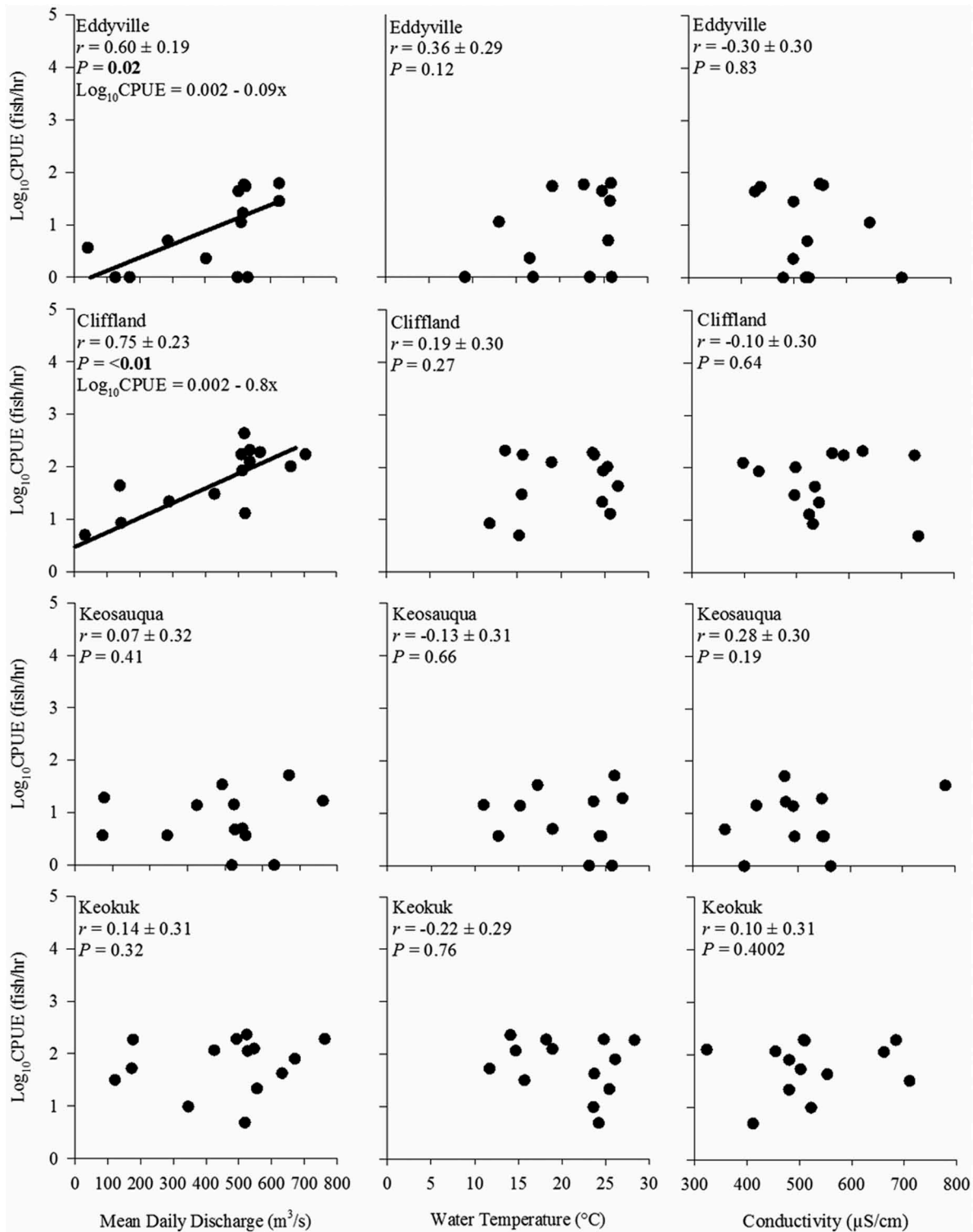


FIGURE 4. Pearson's product-moment correlations between Silver Carp monthly CPUE (fish/h; log₁₀ transformed) and mean daily discharge (m³/s), water temperature (°C), or conductivity (μS/cm) at four Des Moines River sites during 2014 and 2015.

the total catches, followed by the 740–930-mm and 450–560-mm length-groups. Size structure was similar among months at all sites except Cliffland, where a greater proportion of

450–560-mm Silver Carp was collected during August–October relative to samples collected during April–July (Figure 5).

TABLE 3. Mean (SE in parentheses), minimum, and maximum TL (mm) and weight (kg) of Silver Carp collected at four sites in the Des Moines River during 2014–2015.

Sampling site	TL (mm)			Weight (kg)		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Eddyville	641 (3)	551	826	2.6 (0.04)	1.5	6.7
Cliffland	626 (2)	450	887	2.4 (0.03)	1.0	8.2
Keosauqua	664 (7)	535	885	3.1 (0.11)	1.3	7.1
Keokuk	671 (2)	491	917	3.2 (0.03)	1.3	9.9

Silver Carp W_r varied spatially and temporally throughout the Des Moines River (Table 4). Mean (\pm SE) W_r was 91 ± 0.001 and was similar among length-groups ($F_{2, 2,315} = 0.41$, $P = 0.67$). However, there was significant between-year variation ($F_{1, 2,315} = 181.61$, $P < 0.0001$), as Silver Carp captured during 2014 had a higher W_r (mean \pm SE = 95 ± 0.004) than fish captured during 2015 (91 ± 0.003). Silver Carp W_r also varied among sites and between months, as the site \times month interaction was significant ($F_{1, 2,315} = 7.81$, $P < 0.0001$), generally peaking during April and May and decreasing in subsequent months (Figure 6). Specifically, the W_r of Silver Carp at Eddyville was higher during April and significantly decreased throughout the year. However, the W_r of Silver Carp collected during 2015 peaked during April, as Silver Carp were not captured during May. At Cliffland, Silver Carp W_r peaked during May and July and decreased throughout the rest of the year. Additionally, mean W_r of Silver Carp increased after May until peaking during July 2014 (Figure 6). At Keosauqua, only four sampling months met the sample size criterion (>5 fish) for calculation of W_r ; however, the W_r of Silver Carp captured at that site peaked during May and decreased throughout June and July. Finally, mean W_r of Silver Carp captured at Keokuk exhibited a bimodal peak, with the peaks observed during April and August 2014 (Figure 6).

DISCUSSION

Our results demonstrate the high degree of seasonal sampling variability in Silver Carp populations within a major Mississippi River tributary where Silver Carp have persisted since the 1990s (NAS 2016). Seasonal trends in Silver Carp catch rates and W_r were evident, with rates being highly variable spatially and temporally. Site-specific Silver Carp capture rates were generally higher, although variable, during May–June and September–October, whereas W_r was highest during April–May in response to both spring spawning activity and fall movement patterns (Coulter et al. 2016). In contrast, size structure was similar throughout the year at three of the four sites, suggesting a lack of intra-annual variation in Silver Carp size structure. Similar seasonal variation in fish sampling dynamics has been described for a suite of freshwater species, with an emphasis on native species and sport fishes (e.g., Pope and

Willis 1996; Miller and Scarnecchia 2008; Bacula et al. 2011; Bowlby and Hoyle 2011; Muhlfeld et al. 2012; Gardner et al. 2013; Herbst et al. 2015). Temporal sampling variation can hinder accurate assessments of population structure; therefore, the present information detailing temporal variation in Silver Carp populations can aid fisheries biologists in improving sampling protocols to allow for more effective monitoring and management of these invasive populations in the Des Moines River.

Across both years, Silver Carp catch rates varied intra-annually at three (Eddyville, Cliffland, and Keokuk) of the four sites sampled in the Des Moines River; May, June, and September catch rates were generally the highest. Increases in catch rates during May and June may be attributed to upstream spawning migrations of Silver Carp. In major Mississippi River tributaries, Silver Carp movements increase during the spring with increases in temperature and flow (DeGrandchamp et al. 2008; Coulter et al. 2016). Upon making upstream migrations in spring, Silver Carp appear to congregate near dams (Calkins et al. 2012) that may have increased local abundances, resulting in higher catch rates at upstream sites. Such upstream spawning movements have also been documented for other migratory riverine fishes (e.g., Channel Catfish *Ictalurus punctatus*; Pellett et al. 1998), as environmental conditions can cue fish migrations to staging areas, temporarily increasing local abundances. Thus, the flux of Silver Carp during spring spawning migrations appears to result in higher catch rates relative to other sampling seasons.

Silver Carp catch rates were generally lowest during July and August and increased again during September and October. Silver Carp seasonal movement patterns may explain declines in catch rates during July and August. Silver Carp movement within two other Mississippi River tributaries was low during mid- to late summer, whereas increases in movements occurred during both the spring and fall periods in response to changing river temperatures (DeGrandchamp et al. 2008; Coulter et al. 2016). Thus, lower catch rates during periods of high water temperatures within the Des Moines River could be due to Silver Carp occupying habitats that were not sampled. Alternatively, declines in catch rates could be attributed to a decrease in electroshock netter efficiency. Within invaded ranges, Silver Carp leap out of the water in response to physical stimuli (e.g., sound, vibration, etc.; Kolar

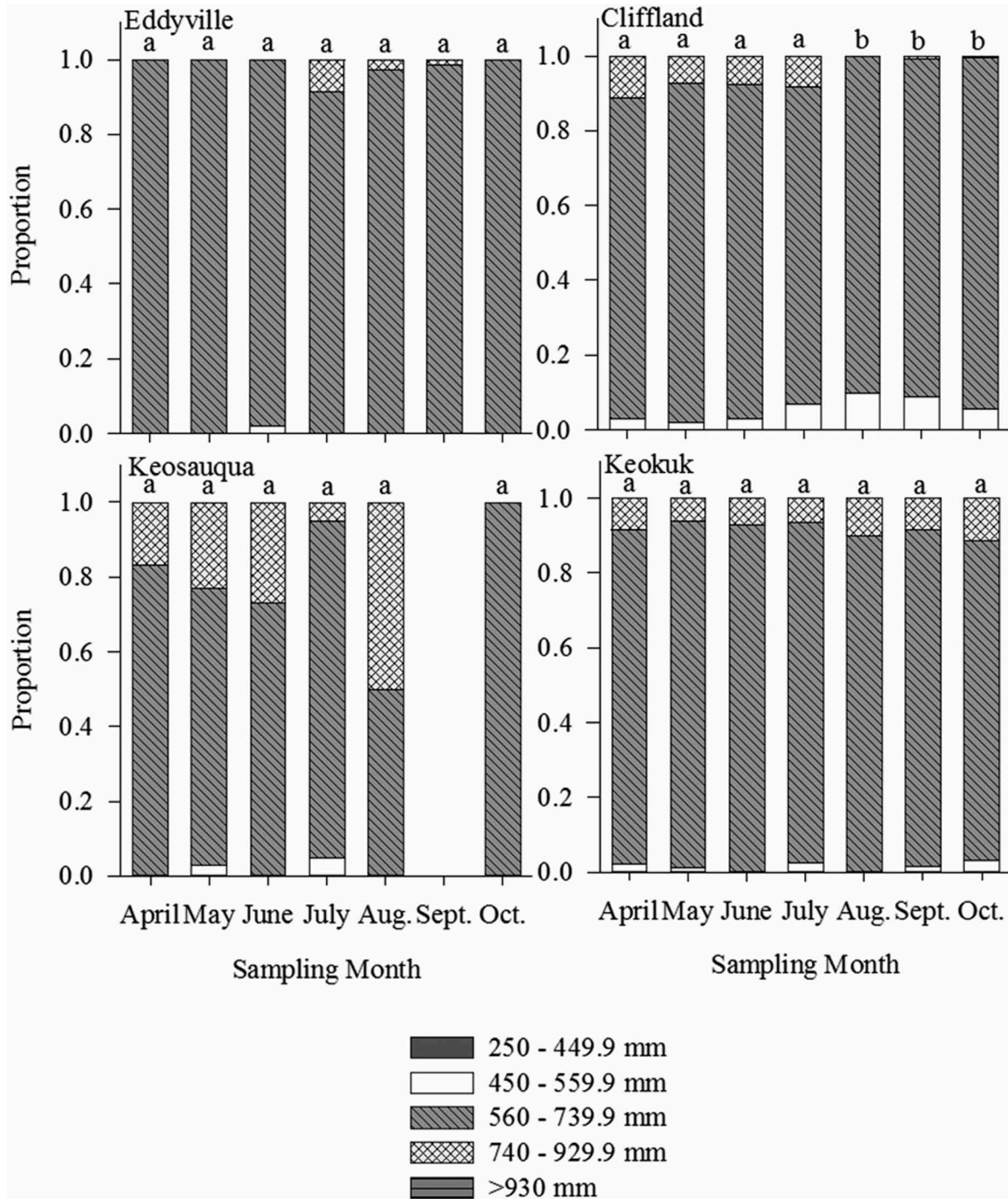


FIGURE 5. Proportional size distribution (250–449.9, 450–559.9, 560–739.9, 740–929.9, and ≥ 930 mm TL; Phelps and Willis 2013) in each sampling month for Silver Carp collected at four Des Moines River sites during 2014 and 2015. Bars with letters in common represent proportional size distributions that are not significantly different ($\alpha = 0.05$).

et al. 2007). Throughout the study, Silver Carp appeared to have a higher leaping propensity during periods of higher water temperature, potentially decreasing electroshock netter efficiency and subsequently the July and August catch rates.

Together, decreased site occupancy and increased leaping behavior may have resulted in the lower July and August catch rates relative to rates observed during May, June, September, and October.

TABLE 4. Results of repeated-measures ANOVA, testing for monthly variation in relative weight for each length-group of Silver Carp at each site blocked by year during 2014–2015 (asterisks denote significant effects at $\alpha = 0.05$).

Variable	df	F	P
Month	1, 2,315	428.91	<0.001*
Site	3, 2,315	93.03	<0.001*
Length category	2, 2,315	0.41	0.67
Year	1, 2,315	181.61	<0.001*
Month \times site	3, 2,315	7.81	<0.001*
Month \times length category	2, 2,315	1.86	0.16
Site \times length category	2, 2,315	0.77	0.46
Month \times site \times length category	1, 2,315	0.06	0.81

Mean daily discharge was positively related to Silver Carp capture rates at the two upstream-most sites, but the correlation was not significant at the two downstream sites. Silver Carp catch rates at Keosauqua were generally low and those at Keokuk were generally high across nearly all sampling occasions, regardless of discharge. The lack of a relationship at these sites could be related to the nature of the hydrograph. The Mississippi River and, hence, downstream areas of the Des Moines River sustain a relatively stable flow compared to upstream areas in tributaries, which have a larger magnitude of variation between maximum and minimum flows (Bhowmik and Adams 1986) and a higher availability of backwater habitats. The reduced variation in discharge near the Des Moines River confluence relative to upstream areas may consistently provide adequate habitat for Silver Carp, decreasing fluctuations in local population abundances and thereby negating the relationship between discharge and capture rates. In contrast, upstream sites within the Des Moines River are characterized by a deeper channel and steeper banks, creating river stretches where water velocity is more variable. Silver Carp migrate in response to dramatic increases in discharge (Zhang et al. 2000; Li et al. 2006; Wang et al. 2008); therefore, migrations from downstream to upstream habitats where velocity is higher during spawning may contribute to the fluctuating local Silver Carp abundances reflected herein. Thus, mean daily discharge may be a better predictor for capture rates at upstream sites than at downstream sites.

Intra-annual Silver Carp size structure was similar among sites except at Cliffland, where catches during April–July contained a larger proportion of 740–930-mm fish compared to August–October catches. Multiple examples of seasonal variation in size structure for a variety of freshwater species have been previously documented (e.g., Bettross and Willis 1988; Mesa et al. 1990; Lott and Willis 1991; Mero and Willis 1992). In the current study, a lack of seasonal variation in adult Silver Carp size structure could be explained by three phenomena. First, although electroshocking has been documented to capture

a wide size range of Silver Carp (e.g., McClelland and Sass 2008; Wanner and Klumb 2009; Sass et al. 2010; Stuck et al. 2015), smaller juvenile Silver Carp (<250 mm) may be more effectively captured with other passive gears (e.g., mini-fyke nets; Wanner and Klumb 2009). The inability of both gears (electroshocker and trammel nets) to capture smaller Silver Carp could have led to underrepresentation of smaller-sized fish, resulting in the lack of temporal variation in size proportions of the Silver Carp populations we sampled. Secondly, temporal variation in the size structure of Saugers *Sander canadensis* (Mero and Willis 1992), Smallmouth Bass *Micropterus dolomieu* (Mesa et al. 1990; Bacula et al. 2011), Largemouth Bass *Micropterus salmoides* (Carline et al. 1984; Bettross and Willis 1988), and crappies *Pomoxis* spp. (Boxrucker and Ploskey 1989) has been attributed to seasonal movements of adult fish between shallow and deep water and the occupation of littoral habitats by young fish during fall. However, such studies have been conducted in lentic environments, which often have greater maximum and mean depths than lotic environments. In contrast, lotic environments are often shallow and constitute a substantial amount of longitudinal and latitudinal variability in morphometric characteristics. Such differences in morphometric characteristics of lotic systems do not explain the seasonal vertical migrations observed for adult fish in lentic systems. Additionally, Silver Carp prefer open (Abdusamadov 1987), slack-water habitat (Berg 1964; Rasmussen 2002); occupy the upper layers of the water column (Shetty et al. 1989); and rarely occupy depths greater than 4 m during April–August, regardless of abiotic conditions (DeGrandchamp et al. 2008). Lastly, small sample sizes (<100 individuals; Anderson and Neumann 1996) at some site \times month combinations, particularly at Eddyville and Keosauqua, could have inhibited our ability to determine temporal variations in the size structure of Silver Carp populations at those sites. Together, the lack of deepwater habitats within sites, the tendency of Silver Carp to occupy shallow habitats throughout the year, and the small sample sizes at some sites could have led to the lack of temporal size structure variation within the Des Moines River.

Peaks in Silver Carp W_r during April and May just prior to spawning activity are typical and have been documented for a variety of other fishes (Pope and Willis 1996). Silver Carp W_r peaked at Eddyville and Keokuk during April and at Cliffland and Keosauqua during May, and these observed peaks could be attributable to reproductive activity. Silver Carp spawning occurs throughout May and June within the MRB (Kolar et al. 2007; Lohmeyer and Garvey 2009; Deters et al. 2013) and at the current study sites (Camacho 2016). After reproduction, fish tissue energy reserves are depleted, and condition tends to decline (e.g., Henderson et al. 2005). However, these trends may not apply to immature Silver Carp. Silver Carp smaller than 450 mm were absent from our collected samples, but they could display different trends in W_r compared to larger, reproductively mature fish. In rivers of eastern South Dakota, intra-annual and

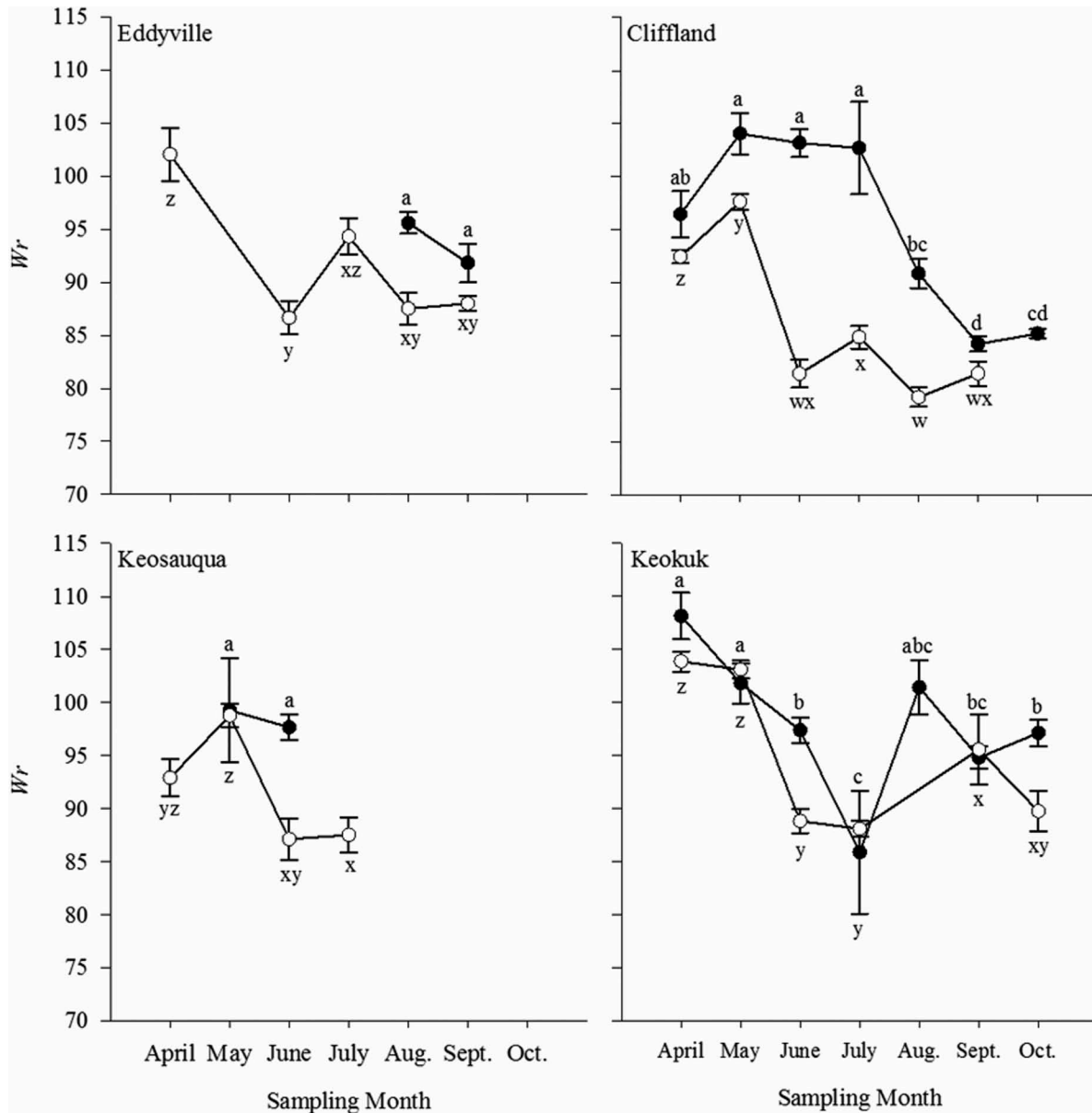


FIGURE 6. Relative weight (W_r ; mean \pm SE) by sampling month for Silver Carp collected at four Des Moines River sites during 2014 (black shaded circles) and 2015 (open circles). Points with letters in common represent W_r values that were not significantly different ($\alpha = 0.05$) for 2014 (letters a–e) or 2015 (letters w–z). Mean W_r was only calculated when more than five Silver Carp were captured in a sampling month.

interannual Silver Carp condition was stable (Hayer et al. 2014a), indicating that reproductively immature individuals may lack seasonal variability in W_r . Our results suggest that the W_r of Silver Carp larger than 450 mm varies intra-annually due to seasonal reproductive habits, and this repeatable pattern could be taken into consideration when designing sampling strategies.

Contrary to existing literature (e.g., Wanner and Klumb 2009), trammel nets in this study were unsuccessful at capturing Silver Carp and had lower catches relative to electroshocking. Electroshocking failed to capture Silver Carp on only six

occasions (3.9%), whereas 62 (65.3%) of the 95 trammel-net sets failed to capture Silver Carp. Additionally, sampling occasions where trammel-net sets had high capture rates coincided with high electroshocking catches. As such, electroshocking outperformed trammel-net sets over a wide range of Silver Carp relative abundances, suggesting that trammel nets offer either superfluous information or that they inadequately sample Silver Carp in the Des Moines River. Trammel nets were set prior to electroshocking and were immediately retrieved afterward. Throughout this process, nets were set for

less than 30 min while electroshocking was conducted in the area, potentially leading to low trammel-net captures. Conversely, long-term monitoring of fish communities on the Missouri River reported lower catches (as a proportion of total catch) of adult Silver Carp via boat electroshocking compared to passive gears (e.g., hoop net, bag seine, fyke net, etc.; Wanner and Klumb 2009). However, Silver Carp catch rates are variable across sites and, in some cases, are low (NAS 2016), potentially favoring passive gears that are employed for a longer duration relative to shorter net sets or electroshocking. Consequently, we suggest that fisheries managers consider choosing a sampling design that provides the most representative information about the fish population of interest. For established populations of Silver Carp in the Des Moines River, sampling protocols that use boat electroshocking during either May or September, when water temperatures are between 16°C and 22°C, appear to be the most effective.

Sampling sites used in the current study all exhibited varying temporal patterns of population characteristics that could influence the perceived abundance of the extant population if the trends described herein are not taken into consideration. Although not directly evaluated here, sampling site selection can also be of critical importance, even for a widespread and seemingly ubiquitous invasive species. Keokuk (located near the confluence of the Des Moines and Mississippi rivers) had high but variable capture rates that were unrelated to environmental factors; this site also exhibited bimodal peaks in Silver Carp condition. In contrast, Silver Carp capture rates were lower and more variable but were related to discharge and size structure varied temporally (only at Cliffland) at upstream sites (Cliffland and Eddyville). Silver Carp populations can vary at small spatial scales, and populations located at different site types (e.g., upstream versus downstream, channelized versus non-channelized river segments, etc.) can vary drastically. As such, the use of site-specific knowledge along with quantifying certain habitat and river morphometric variables can help managers and researchers to carefully select Silver Carp monitoring sites and time periods that allow unique, site-dependent variations in populations (e.g., bimodal peaks in W_r) to be avoided.

The dams that are prevalent in the MRB influence river hydrographs and associated fish populations. Within the Des Moines River, Red Rock Dam has altered the flow regime to create a more stable, flood-susceptible hydrograph, whereas Ottumwa Dam may restrict fish passage upstream but only during low-flow conditions. However, Silver Carp populations both above and below Ottumwa Dam were similar throughout this study; the populations therefore seemed relatively uninfluenced by temporarily impassible low-head dams. However, the Red Rock Hydroelectric Dam Project is scheduled to be completed in 2018, and the project may further alter the Des Moines River hydrograph, potentially influencing Silver Carp populations downstream of the dam. Because Silver Carp CPUEs were not influenced by river discharge downstream, future changes in dam releases may be important when

designing and implementing management strategies for Silver Carp in upstream sections of the Des Moines River.

Information provided herein will aid fisheries managers in designing methodological approaches for sampling Silver Carp. In river reaches where Silver Carp are abundant (e.g., Illinois River; Sass et al. 2010), seasonal effects could be of critical importance when implementing management strategies. Sampling for baseline population data will be most effective if carried out at times when catch rates are highest in order to obtain a sufficiently large sample size from which representative population metrics can be calculated (Anderson and Neumann 1996) and compared. In river reaches where Silver Carp have yet to become established or where they are recent invaders (e.g., upper Mississippi River), the choice of sampling season could determine whether Silver Carp are detected. Early detection and monitoring during times when detection and capture probability are highest can increase the chances of enacting effective preventative and management strategies before populations become overly abundant. Additionally, if there is a threat of Silver Carp invasion of a new river reach, diligent sampling during May, June, September, or October offers the highest probability of detectability, potentially enhancing Silver Carp preventative management strategies.

ACKNOWLEDGMENTS

We thank several technicians who were involved with data collection, and we thank Jason Euchner and Kim Bogenschutz (IDNR) for providing helpful insights about Silver Carp. We are especially grateful to Lendie Follet and Geoffrey Thompson for providing statistical consulting and to Alison Coulter and two anonymous reviewers for providing comments on earlier versions of the manuscript. This study was funded through the Fish and Wildlife Trust Fund to the IDNR. Work was performed under the auspices of Protocol Number 7-13-7599-I approved by the Institutional Animal Care and Use Committee at Iowa State University, and animals were collected under Permit SC1037 from the state of Iowa. Use of trade, product, or firm names is descriptive and does not imply endorsement by the U.S. Government.

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