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Patterns of Age-0 Gizzard Shad Abundance and Food Habits in a Nebraska Irrigation Reservoir

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ABSTRACT Gizzard shad (*Dorosoma cepedianum*) are prolific spawners that can influence reservoir communities. Larval gizzard shad may compete with larval recreational fish for zooplankton resources. Therefore, it is necessary to determine larval gizzard shad dynamics and food habits to better understand their potential for competition with larval recreational fish. Our study examined age-0 gizzard shad abundance in Harlan County Reservoir during late spring/summer from 2002–2010 and food habits and prey electivity of age-0 gizzard shad during late spring/summer 2008 and 2009. The annual peak age-0 gizzard shad density from 2002–2010 ranged from 50 to 380/100 m^3, which falls within the range of values reported in other studies, but all years were considerably lower than densities reported in other studies that documented deleterious effects on zooplankton populations from gizzard shad grazing. Total length of gizzard shad was positively correlated with the number of zooplankton consumed per fish in 2008 ($r_{224} = 0.33$, $P < 0.001$) and 2009 ($r_{225} = 0.84$, $P < 0.001$) when considering shad < 30 mm total length (TL). Gizzard shad TL was also positively correlated to the size of zooplankton consumed in 2008 ($r_{224} = 0.25$, $P < 0.001$) and 2009 ($r_{225} = 0.64$, $P < 0.001$). Small gizzard shad (<15 mm TL) selected for cyclopoid copepods in 2008 (0.33 ± 0.05) and copepod nauplii (0.51 ± 0.06) in 2009 and selected against calanoid copepods in both 2008 (–0.26 ± 0.06) and 2009 (–0.35 ± 0.05). Medium sized gizzard shad (15–30 mm TL) showed selection for cyclopoid copepods in 2008 (0.17 ± 0.06) and 2009 (0.15 ± 0.08). Gizzard shad >30 mm TL reduced their consumption of zooplankton and increased consumption of algae and detritus throughout the summer. The results of this study suggest the relatively low densities of larval gizzard shad coupled with their preference for small copepods may reduce the potential for competition with larval recreational fish in Harlan County Reservoir.

KEY WORDS competition, Copepod, food habits, gizzard shad, irrigation reservoir, Nebraska, zooplankton

Although often considered a benefit to recreational fishes as a source of prey, gizzard shad (*Dorosoma cepedianum*) can impact aquatic communities through zooplankton grazing and competition with other fishes (Dettmers and Stein 1992, Garvey and Stein 1998). Gizzard shad may compete with larval recreational fishes for zooplankton at smaller sizes, thus inhibiting growth and recruitment of those species (Garvey and Stein 1998). Aday et al. (2003) showed bluegill (*Lepomis macrochirus*) growth and survival decreased in the presence of gizzard shad, and Miranda and Gu (1998) found that young gizzard shad reduced growth, survival, and abundance of other larval fish. Because of these factors, it has been suggested that gizzard shad regulate food webs via “middle-out” processes (DeVries and Stein 1992). Although uncommon, the stocking of gizzard shad to improve recreational fish growth has had unexpected negative consequences, likely due to competition among larval fish (DeVries and Stein 1990).

The degree to which middle-out food web effects by gizzard shad occur can be influenced by several factors including shad and zooplankton density (DeVries and Stein 1992), prey selectivity and diet overlap, and spawning time relative to other species (Garvey and Stein 1998, Wuellner et al. 2008). Gizzard shad have been shown to eliminate zooplankton populations in lakes and enclosure experiments with densities exceeding 600 age-0 gizzard shad/100 m^3 (Dettmers and Stein 1992, DeVries and Stein 1992). Zooplankton have been consumed most frequently by gizzard shad <30 mm in total length (Cramer and Marzolf 1970), but larger gizzard shad also fed on zooplankton when prey were abundant (Yako et al. 1996, Schaus et al. 2002). When gizzard shad are present in high densities or during times of low zooplankton abundance, there is a greater chance of negative competitive effects on other larval fish, especially when there is a high level of diet overlap (Welker et al. 1994).

Gizzard shad were stocked in Harlan County Reservoir as a prey source for recreational fishes, and adult gizzard shad relative abundance has increased 653% since 1980 (Olds 2007). To date, no study has attempted to understand the influence of introduced gizzard shad on the fish community in this reservoir. Walleye (*Sander vitreus*) and white bass (*Morone chrysops*) are two important recreational species that also feed on zooplankton (Beck et al. 1998), but little is known about the potential for competition between gizzard shad and these species in Nebraska reservoirs. Our objectives were to 1) document the timing and abundance of annual peak age-0 gizzard shad density, 2) determine the number and size of zooplankton

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consumed by age-0 gizzard shad, and 3) evaluate age-0 gizzard shad prey electivity.

STUDY AREA

Harlan County Reservoir is an irrigation impoundment located on the Republican River in south-central Nebraska and covers 5,362 ha at conservation pool (USACE 2010). Harlan County Reservoir was considered eutrophic to hypereutrophic, does not thermally stratify, and had a mean depth of 4 m (USBR 1996). Recreational species present in the reservoir included walleye, channel catfish (*Ictalurus punctatus*), flathead catfish (*Pylodictis olivaris*), largemouth bass (*Micropterus salmoides*), white bass, crappie (*Pomoxis* sp.), and bluegill. Non-game fish present in the reservoir included gizzard shad, freshwater drum (*Aplodinotus grunniens*), and common carp (*Cyprinus carpio*).

METHODS

Age-0 Gizzard Shad Density

We sampled age-0 gizzard shad weekly starting in early June (2002–2004) and the last week of May (2005–2010) and continued for eight consecutive weeks. We randomly selected and standardized sites through time using a GPS receiver. The number of sites increased as the study progressed and ranged from 5–7 sites in 2002–2004 to 24–26 sites the remaining years. We sampled sites starting at dusk because larval fish are more vulnerable to capture at night (Bridger 1956, Houde 1969).

We collected age-0 gizzard shad simultaneously using two different diameter bow-mounted push nets. The larger net had a 1-m diameter opening, with 1.85-mm mesh and a 0.75-mm cod-end collection cup, while the smaller net had a 0.5-m diameter opening with 0.75-mm mesh and a 0.75-mm cod-end collection cup. We attached a flowmeter (General Oceanics Inc., Miami, FL, USA) to the mouth of each net to estimate the volume of water sampled. We maintained boat speed at 4 km/h for 5 min in a single direction. We preserved captured larval fish with 70% ethyl alcohol.

We identified, enumerated, and measured [total length (TL); mm] all larval fish from each site and each net. We counted gizzard shad <15 mm TL from the small diameter net and gizzard shad ≥15 mm from the large diameter net to avoid double counting of similar sized fish. We determined size distinctions from post-hoc analysis of length frequency histograms of 2008 catch data from the large and small nets. We calculated density at each site by dividing the number of gizzard shad <15 mm collected in the small diameter net and gizzard shad ≥15 mm collected in the large diameter net by the respective volumes sampled. We then combined the large and small net gizzard shad densities to yield an overall density for the site. We averaged densities at each site for the week to estimate age-0 gizzard shad density throughout the reservoir.

Age-0 Gizzard Shad Food Habits and Prey Selectivity

We collected weekly gizzard shad and zooplankton samples from three randomly selected sites within each zone of the reservoir (e.g., riverine, transitional, and lacustrine). We standardized these three sites from which food habits data were collected throughout the study. We conducted sampling during the day to encompass primary feeding times (Dettmers and Stein 1992). We sampled larval gizzard shad using push nets deployed near the bow of the boat. Once gizzard shad grew large enough to evade the push nets (usually at about 25 mm TL in early July), we sampled them using either a 3.2-m diameter cast net with 0.95-cm bar-mesh, beach seines (50-m × 1.5-m, 2.50-cm bar mesh), or electrofishing gear. We immediately froze fish of all sizes until processed.

We divided age-0 gizzard shad into three length classes: <15 mm, 15–30 mm, and >30 mm. We selected these length classes because 14–15 mm is the length when gizzard shad have been shown to start feeding on zooplankton (Bremigan and Stein 1997), and 30 mm is the length gizzard shad have been shown to switch to a diet primarily consisting of detritus (Yako et al. 1996). Because the availability of each gizzard shad length class changed as they grew, our sample sizes varied by year and length class, but sampling occurred in June of both years. We collected gizzard shad >30 mm in July of both years.

We selected a maximum of 15 age-0 gizzard shad <30 mm TL from each length class, and the viscera from the gill rakers to the anus was separated from the body. We extracted and subsequently placed contents of the gut tube onto a microscope slide where zooplankton were identified to the lowest possible taxon, measured, and enumerated. For gizzard shad >30 mm TL, we processed a maximum of 15 fish from each site. We examined only contents from the foregut because differential rates of prey digestion can occur further down the digestive tract (Sutela and Huusko 2000). We used the number of each zooplankton species/group in the stomachs of all sizes of gizzard shad to calculate electivity values.

We sampled zooplankton at each of the three sites weekly starting in June when gizzard shad <30 mm TL were present (e.g., in conjunction with gizzard shad sampling) using a Wisconsin plankton net (0.5 m diameter with 80 µm mesh) deployed vertically and towed from the substrate to the surface. We preserved contents of the tow in 4% formalin sucrose solution (Haney and Hall 1973). We processed, identified, and measured zooplankton for standard length (mm) following the methods of Peterson et al. (2005). We calculated densities for the following zooplankton species and groups: *Daphnia* sp., *Bosmina* sp., copepod nauplii, and calanoid and cyclopoid copepods.

We compared the mean number and length of zooplankton consumed per fish among each gizzard shad length class using a Kruskal-Wallis Test ($\alpha < 0.05$) followed by a Dunn's post-test when significance was detected. We used Spearman's rank correlations ($\alpha < 0.05$) to test the relationship between gizzard shad length and the number and size of zooplankton consumed.

We determined the mean prey electivity for each zooplankton group present within each gizzard shad length class using Strauss' electivity index (Strauss 1979):

$$L = r_i - p_{i,}$$

where r_i and p_i represent the relative abundance of prey in the diet and environment, respectively. For each week, we determined the relative abundance of prey in the diet of gizzard shad (r_i) by dividing the number of each zooplankton group found in the stomachs of all gizzard shad processed from site *i* by the total number of zooplankton consumed at site *i*. We calculated zooplankton proportions (p_i) by dividing the density of each zooplankton group at site *i* by the total density of all zooplankton at site *i*. We averaged weekly electivity values within each year for each length class. The index value (*L*) can range from −1 (total negative selectivity) to 1 (perfect positive selectivity) for a given prey group (Strauss 1979). As per Dettmers and Stein (1992) an *L* value of ± 0.15 was selected as the cutoff to determine selectivity or avoidance. Therefore, an *L* value from 0.15 to −0.15 represented prey that was consumed in equal proportion to availability in the environment. We did not include prey electivity by gizzard shad >30 mm in the electivity analysis because of the low number of zooplankton consumed by this group.

RESULTS

Age-0 Gizzard Shad Density

The annual peak age-0 gizzard shad density from 2002–2010 ranged from 50 (2004) to 380/100 m^3 (2007), an eight-fold difference (Fig. 1). Mean peak larval gizzard shad density varied by year and occurred between May 30 and June 24, however the peak abundance may have occurred prior to our sampling efforts in 2002–2004.

Age-0 Gizzard Shad Food Habits and Prey Selectivity

The food habits of 298 and 340 age-0 gizzard shad were examined in 2008 and 2009. From the stomachs of these fish, 3,957 and 3,381 zooplankton were extracted, identified, and measured in 2008 and 2009. The mean number of zooplankton consumed by each length class differed in 2008 ($H_2 = 79.10$, $P < 0.001$) and 2009 ($H_2 = 162.31$, $P < 0.001$; Table 1). The 15–30 mm gizzard shad length class consumed the most zooplankton per fish in both years, with an average of 17.3 and 16.8 zooplankton per fish. The size of zooplankton consumed by each length class also differed in 2008 ($H_2 = 164.4$, $P < 0.001$) and 2009 ($H_2 = 221.4$, $P < 0.001$; Table 1). The <15 mm gizzard shad length class consumed the smallest prey while gizzard shad >30 mm consumed the largest prey (Table 1). The number of zooplankton consumed by the 5–30 mm length class of gizzard shad was positively correlated with gizzard shad TL in 2008 ($r_{224} = 0.33$, $P < 0.001$) and 2009 ($r_{225} = 0.84$, $P < 0.001$). Prey size also was positively correlated with gizzard shad length for 5–30 mm fish in 2008 ($r_{224} = 0.25$, $P < 0.001$) and 2009 ($r_{225} = 0.64$, $P < 0.001$). A greater number of empty stomachs were observed among gizzard shad <15 mm TL in 2009 than in 2008. No gizzard shad in the 15–30 mm and >30 mm length classes had empty guts in either year.

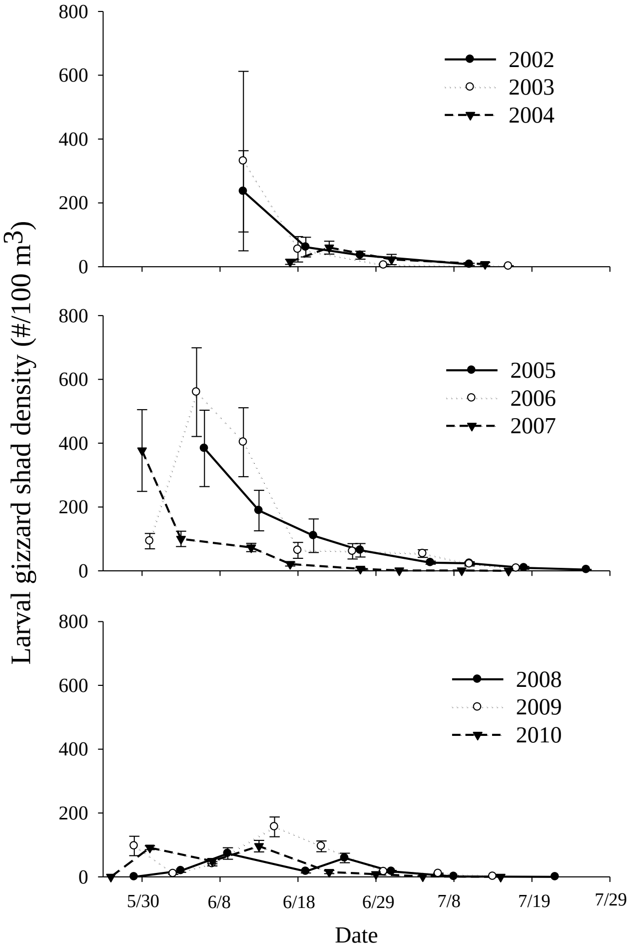

Figure 1. Weekly mean (± one standard error) age-0 gizzard shad (*Dorosoma cepedianum*) densities measured at Harlan County Reservoir, Nebraska, USA, 2002–2010.

Copepods were found in stomachs from all three gizzard shad length groups. In 2008, the most abundant prey items found in the stomachs of gizzard shad < 15 mm were copepod nauplii (48%) and cyclopoid copepods (41%), while 15–30 mm gizzard shad consumed the largest numbers of copepod nauplii (60%). Zooplankton consumed by gizzard shad >30 mm consisted of both calanoid and cyclopoid copepods which were found in equal proportions. In 2009, copepod nauplii and cyclopoid copepods were the most abundant zooplankton consumed by gizzard shad <15 mm and comprised 62% and 29% of the total number of prey, respectively. Similarly, 15–30 mm gizzard shad fed most frequently on copepod nauplii and cyclopoid copepods.

Prey electivity varied by gizzard shad length classes during both years. In 2008, gizzard shad <15 mm showed a positive preference for cyclopoid copepods and selected against calanoid copepods. Copepod nauplii, *Daphnia* sp., and *Bosmina* sp. were consumed in amounts which were proportional to those found in the environment (Fig. 2). The 15–30 mm length class of gizzard shad showed positive selection for cyclopoid copepods (Fig. 2). In 2009, gizzard shad ≤15 mm positively selected for copepod nauplii, avoided calanoid copepods and *Daphnia* sp., and showed no selection for cyclopoid copepods and *Bosmina* sp. Gizzard shad 15–30 mm in length did not show any preference for specific zooplankton and fed on all groups in proportions near those found in the environment (Fig. 2).

DISCUSSION

Our results showed that gizzard shad in Harlan County Reservoir likely did not negatively impact zooplankton communities or cause “middle-out” trophic effects in the food web as described by DeVries and Stein (1992). The annual peak age-0 gizzard shad densities varied during the study, but were similar to densities reported in other studies of gizzard shad populations in Great Plains reservoirs (Quist et al. 2004, Wuellner et al. 2008). Regardless of the variability in annual age-0 gizzard shad density, their abundance was consistently lower than densities which have been shown to significantly decrease zooplankton populations in other systems (Dettmers and Stein 1992, DeVries and Stein 1992). In enclosure experiments and at Lake Kokosing in Ohio, DeVries and Stein (1992) showed zooplankton densities were nearly eliminated when age-0 gizzard shad densities exceeded 600 individuals/100 m^3. The highest density we observed from 2002–2010 was 380 larval gizzard shad/100 m^3, indicating that competition between larval shad and other zooplanktivores may be low.

Table 1. Descriptive statistics from all gizzard shad food habits sampled at Harlan County Reservoir, Nebraska from 2008–2009 where the *N* is the total number of gizzard shad sampled from each length class each year. Values presented are mean ± one standard error. Superscript letters denote significant differences among groups within a single year.

Year	Length group (mm)	*N*	Total length (mm)	% Empty stomachs	# Zoo / Fish	Zoo size (mm)
2008	<15	106	13.04 ± 0.11	1	11.43 ± 0.94^{a}	0.32 ± 0.01^{x}
	15–30	120	18.88 ± 0.16	0	17.33 ± 1.35^{b}	0.47 ± 0.02^{y}
	>30	72	98.26 ± 1.40	0	4.89 ± 0.32^{c}	1.01 ± 0.01^{z}
2009	<15	90	11.5 ± 0.20	22	1.76 ± 0.16^{a}	0.25 ± 0.01^{x}
	15–30	134	17.87 ± 0.17	0	16.81 ± 2.0^{b}	0.38 ± 0.01^{y}
	>30	116	86.76 ± 2.41	0	6.69 ± 0.63^{c}	0.92 ± 0.02^{z}

The timing of peak gizzard shad abundance varied between years and occurred between the last week in May and the third week in June in all years, which is consistent with the timing of peak age-0 gizzard shad abundance found in South Dakota (Wuellner et al. 2008) and Kansas (Quist et al. 2004) reservoirs. Since hatch timing of different larval fish species relative to each other has been shown to affect competition (Garvey and Stein 1998), the variation in the timing of peak abundance of gizzard shad observed during this study could have had positive or negative effects on other larval fish that hatched and were present in the reservoir at the same time. For instance, percids may benefit from the presence of age-0 gizzard shad due to an earlier spawn time (Quist et al. 2004), while later spawning fish such as centrarchids (Garvey and Stein 1998) may experience reduced zooplankton resources due to competition. Another possibility is that percids may hatch later or gizzard shad earlier in certain years, and species such as walleye may not be large enough to utilize gizzard shad as prey (Quist et al. 2004).

Larval fishes are gape-limited predators (Bremigan and Stein 1994), and it is not surprising that larval gizzard shad fed on larger individuals as they grew. Gizzard shad gape width increases with length (Bremigan and Stein 1994). In both years, gizzard shad length was positively correlated with both the size and number of prey consumed per fish <30 mm TL, which supported findings of previous studies that found prey size increased with gizzard shad length (Cramer and Marzolf 1970, Schael et al. 1991). Smaller gape limits likely explained, in part, the large number of copepod nauplii and copepods consumed by gizzard shad ≤15 mm TL rather than larger zooplankton such as *Daphnia* sp. and calanoid copepods. As gizzard shad reached 15–30 mm TL, they consumed more and larger zooplankton, but prey selection was not always positive for large-bodied zooplankton such as *Daphnia* sp. and calanoid and cyclopoid copepods. Mills et al. (1989) explained that although a large-bodied species may be abundant, gizzard shad need to eat less compared to small zooplankton because of the larger energy gains obtained from consuming larger individuals.

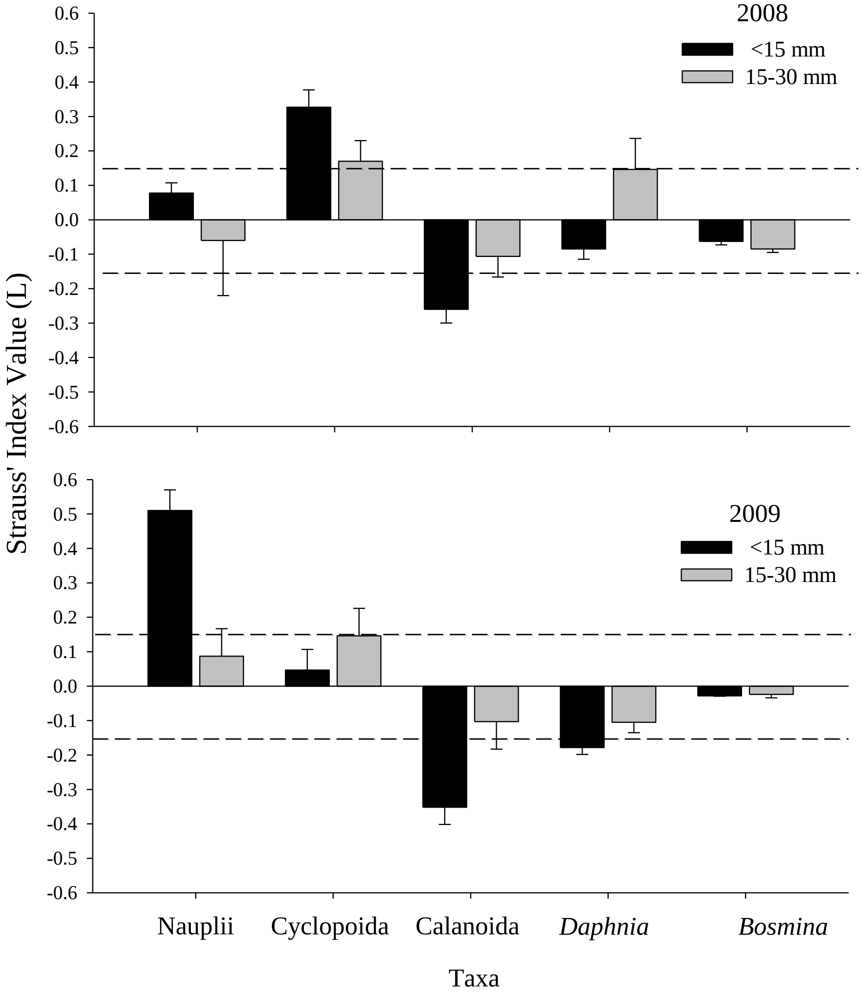

Figure 2. Strauss electivity index (Strauss 1979) values for gizzard shad (*Dorosoma cepedianum*) collected during June at Harlan County Reservoir, Nebraska, USA, 2008–2009.

Our study supported the hypothesis that age-0 gizzard shad switched from a diet of zooplankton to a diet of detritus and phytoplankton after reaching a length of approximately 30 mm (Cramer and Marzolf 1970, Drenner et al. 1982). Gizzard shad >30 mm consumed fewer zooplankton per fish than the 15–30 mm length class and likely obtained most of their energy from algae and detritus, which comprised an estimated >95 % of the material in the guts. However, it was difficult to estimate the percentages of each component in the digestive tract due to differential digestion rates of individual food items, and the prolonged evacuation rates which occured in larger individuals (Sutela and Huusko 2000).

Approximately 1% of the gizzard shad <15 mm that were sampled in 2008 and 22% of the gizzard shad from 2009 had no zooplankton in their guts. Although we sampled

21% more gizzard shad with empty guts in 2009 than 2008, it seems unlikely that limited zooplankton resources influenced this occurrence because the mean densities of all zooplankton groups except *Bosmina* sp. were higher in 2009 than in 2008. This either suggested that they were sampled during a period of the day when they were not feeding or that they consumed other food sources such as algae and detritus. Age-0 gizzard shad have been shown to feed at different rates depending on the time of day and water temperature (Salvatore et al. 1987), and this could explain the occurrence of gizzard shad with empty guts. Another possibility is that the smallest gizzard shad had not started feeding on zooplankton. Bremigan and Stein (1997) found that gizzard shad in some Ohio reservoirs did not begin exogenous feeding until they reached 15 mm TL.

Based on age-0 gizzard shad dynamics and prey electivity, low densities of gizzard shad in Harlan County Reservoir likely provide a prey base for juvenile and adult recreational fishes without eliminating or competing for zooplankton during the larval stage. Thus, the introduction of gizzard shad is likely beneficial to the food web in this system.

MANAGEMENT IMPLICATIONS

We recommend the use of long term data sets to answer ecological questions given the dynamic nature of irrigation reservoirs. Indeed, this 9 year study displayed highly variable densities of age-0 gizzard shad among years. Currently, the impact the observed range of densities may have on recreational fish growth and subsequent recruitment remain poorly understood. Additionally age-0 gizzard shad selected small bodied zooplankton during 2008 and 2009 when shad densities were low. Age-0 gizzard shad food habits during years of greater abundance should be investigated to ensure competition between shad and larval recreational fish remains low during years of higher age-0 shad densities.

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