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Long-term changes in biotic and abiotic factors influence larval gizzard shad (*Dorosoma cepedianum*) annual peak density

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ABSTRACT

Gizzard shad (*Dorosoma cepedianum*) are an influential forage fish and driver of zooplankton resources in many reservoirs. The ability to identify the biotic and abiotic factors that influence the timing of elevated gizzard shad densities can be important to better utilize this forage fish and manage sport fish. The objective of this study was to investigate which biotic and abiotic factors influence larval gizzard shad annual peak density. We used combinations of six variables (CPUE of adult gizzard shad from the prior fall, mean zooplankton density, turbidity, chlorophyll *a*, relative reservoir elevation, and water temperature) from a long-term (2003–2014) monitoring program to create 28 a-priori candidate models to assess the relative support of explanatory variables using Akaike's information criterion (AIC). During the course of our study, larval gizzard shad annual peak densities were best explained by zooplankton density and relative reservoir elevation. Zooplankton density provides greater food availability which has been shown to increase larval gizzard shad growth. Relative reservoir elevation was negatively associated with higher densities of larval gizzard shad. This study describes two important factors that may result in greater larval gizzard shad densities, which can assist managers in anticipating available forage for sport fish and identify strategies to improve system management.

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Introduction

The introduction of gizzard shad (*Dorosoma cepedianum*) into irrigation reservoirs has provided a mixed impact on fish communities. Positive impacts have been reported as providing a primary prey for sport fish (Quist et al. 2004; Olson et al. 2007; Wuellner et al. 2008) and improved growth of sport fish species (Wuellner et al. 2008). Negative impacts have been reported as competition with larval sport fish for zooplankton (Dettmers and Stein 1992; Garvey and Stein 1998; Aday et al. 2003) and directly through depression of zooplankton availability (DeVries and Stein 1992).

Because age-0 gizzard shad have been postulated to drive trophic interactions of reservoir communities through a middle-out process (DeVries and Stein 1992), it is important to understand the factors regulating density and hypothetically the associated impacts. Biotic factors that have been associated with larval gizzard shad density have included availability of adults (Willis 1987) and zooplankton prey (DeVries and Stein 1992), while a suite of abiotic factors have been associated with age-0 gizzard shad density including variables that are potentially more prominent in irrigation reservoirs. Reservoir elevation has been positively associated with increased spawning activity resulting

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in high densities of larval gizzard shad and other species (Miranda et al. 1984; Michaletz 1997; Sammons et al. 1999). Timing of water levels has shown that increases during the beginning of the spawning season have a greater effect on larval gizzard shad abundance compared to the end (Michaletz 1997). Turbidity and chlorophyll *a* levels are related to potential productivity within a reservoir and have been associated with relative abundance of higher trophic levels in reservoirs (Claramunt and Wahl 2000) and irrigation reservoirs (Olds et al. 2014). Gizzard shad have also demonstrated a sensitivity to temperature potentially related to adult overwinter survival (Porath 2006), timing and duration of spawning activity associated with temperature (Michaletz 1997) or lower survival related to lower temperatures (DiCenzo et al. 1996; Schaus et al. 2002; Vanni et al. 2005). The temperature at hatching and average temperature during the larval stage have been linked to survival of larval threadfin shad (*Dorosoma petenense*) (Betsill and Van Den Avyle 1997).

Larval gizzard shad are recognized to play an important role in irrigation reservoir communities; despite work on individual factors, a holistic study evaluating multiple factors has not been conducted. We used a 12-year data set from a Midwest irrigation reservoir to evaluate the relationship between annual peak densities of larval gizzard shad and the abundance of adult gizzard shad from the previous fall, zooplankton density, turbidity, chlorophyll *a*, relative reservoir elevation, and water temperature. The objective of this study was to determine the factors that most strongly influence larval gizzard shad annual peak density. Developing an awareness of the factors that drive larval gizzard shad density can create a better understanding of how irrigation reservoirs function and potentially allow for adaptive sport fish management practices to be employed.

Study site

Harlan County Reservoir is an irrigation reservoir built in 1952 located on the Republican River drainage in south-central Nebraska. Harlan County Reservoir covers more than 5362 ha with 121 km of shoreline with a mean depth of 4 m and a maximum depth of 18 m (Uphoff et al. 2013). Daily inflows averaged 2.6 (± 1.2) cubic meters/s and ranged from -5.3 to 9.2 cubic meters/s from 2003 to 2014 (USBR 2015). Since 2003, long-term monitoring and research at Harlan County Reservoir has provided insight on management practices primarily for walleye (*Sander vitreus*) and white bass (*Morone chrysops*) with gizzard shad providing the prominent prey base (Olson et al. 2007; Sullivan et al. 2011; Uphoff et al. 2013).

Methods and materials

Larval gizzard shad sampling

Larval gizzard shad were collected beginning at dusk using two different diameter bow-mounted ichthyoplankton push nets, 1.0 m diameter with 1.80 mm mesh and 0.5 m diameter with 0.75 mm mesh which contained a flowmeter, while boat speed was maintained at 4 km/h for 5 min in a single direction (Sullivan et al. 2011). Sampling for larval gizzard shad began in early June (2003–2004), and the last week of May (2005–2014). Sampling continued for eight consecutive weeks at standardized reservoir sites which were located using a boat-mounted GPS receiver to ensure location consistency. Sites were added as the study progressed and ranged from eight sites in 2003 and 2004, to 24–48 sites (Sullivan et al. 2012) during the remaining years (2005–2014). The collected larval gizzard shad were preserved in 70% ethyl alcohol.

Larval gizzard shad samples were enumerated and total length (mm) was measured. We counted gizzard shad < 15 mm TL from the smaller diameter net and gizzard shad ≥ 15 mm TL from the larger diameter net to avoid double counting similar-sized fish as suggested by Sullivan et al. (2011). Larval gizzard shad densities, at each site, were determined by summing the number of gizzard shad < 15 mm from the smaller diameter net and the gizzard shad ≥ 15 mm from larger diameter net and dividing by the respective volumes sampled. Larval gizzard shad density was determined per site

and averaged to determine a weekly mean. Annually, the peak week for each year was determined by selecting the largest weekly density over the sampling period. Annual peak densities were used to be consistent with methodology in similar studies (Sullivan et al. 2011; VanDeHey et al. 2012), and because an additive approach would be catching fish multiple times throughout the sampling season and catchability may vary with length. During these same years evaluated, adult gizzard shad catch rates were determined from the previous fall's standardized gill net surveys to determine abundance. Adult gizzard shad were collected overnight using four monofilament gill nets measuring 45.7 m long and 1.8 m deep. Gill nets were composed of six 7.6-m-long panels with bar mesh sizes of 19.1, 25.4, 31.8, 38.1, 50.8, and 76.2 mm following standard Nebraska Game and Parks Commission protocol (Zuerlein and Taylor 1985).

Zooplankton sampling

Zooplankton samples were collected concurrently with larval gizzard shad push net samples using a Wisconsin plankton net (0.5 m diameter with 80 μm mesh) towed vertically from the substrate to the surface. Samples were preserved in a sucrose-buffered 4% formalin solution to prevent osmotic distortion, then identified and quantified (Haney and Hall 1973). Density (#/L) of *cyclopoida* and copepod nauplii were determined for each site and averaged for the sampling date across the reservoir. These zooplankton taxa have been shown to be selected in larval gizzard shad diets (Sullivan et al. 2011).

Water quality sampling

Weekly water quality sampling was conducted to coincide with zooplankton and larval gizzard shad sampling at 15 standardized sites distributed across the reservoir, of which, all 15 were incorporated as part of the 24 larval fish push net sites. Sampling for water quality began in early June (2003–2004), and the last week of May (2005–2014). From weekly integrated water column samples at available depths of 1, 4, 7, 10, and 13 m using a Van Dorn bottle sampler, turbidity (FAU) was measured using a colorimeter and chlorophyll *a* ($\mu\text{g/L}$) measured using a fluorometer (Olds et al. 2011). Mean spring (April and May) values were used for analysis for turbidity and chlorophyll *a*. Reservoir elevation that coincided with annual peak density dates was obtained from 2003 through 2014 from the US Bureau of Reclamation website (USBR 2015). The difference of reservoir elevation (m) during the peak week relative to conservation pool (593.0 m) was used in the analysis. At the time of larval gizzard shad sampling, temperature at one meter of depth was recorded at each sampling site to coincide with the depth that larval gizzard shad were collected.

Data analyses

A set of 28 a-priori candidate models were established to assess the relative support of explanatory variables using Akaike's information criterion (AIC; Akaike 1987). Due to small sample size relative to model parameters, second-order Akaike's information criterion (AIC_c) was used to more conservatively rank competing models (Table 1; Burnham and Anderson 2002). Models with the lowest difference between AIC_c values (Δ_i) and highest model weight (W_i) were chosen for model inference. Model averaging was used across all candidate models with associated standard error. Relative variable importance was calculated by summing AIC_c weights for all models containing that predictive variable (Burnham and Anderson 2002). Variables with the largest relative variable weight are considered to be more important relative to other variables (Burnham and Anderson 2004).

Table 1. Minimum, mean, and maximum values for each variable used to explain larval gizzard shad annual peak density from Harlan County Reservoir, Nebraska, during 2003–2014.

Variable	Description	Minimum	Mean	Maximum
AG	CPUE (#/net night) of adult gizzard shad from the prior fall	1.3	8.0	26.6
CL	Mean chlorophyll <i>a</i> ($\mu\text{g/L}$) values during spring	30.0	91.3	159.5
RE	Relative reservoir elevation (m) compared to normal conservation pool during the larval gizzard shad peak week	-5.8	-1.9	0.8
TB	Mean turbidity (FAU) values during spring	10.0	26.5	57.9
Z	Mean zooplankton density of <i>cyclopoida</i> and copepod nauplii (#/L) during the larval gizzard shad peak week	12.6	28.8	62.0
WT	Mean first meter water temperature for the larval gizzard shad peak week	20.2	21.9	23.5

Results

Between 2003 and 2014, larval gizzard shad annual peak densities averaged $2.4 (\pm 0.5)/\text{m}^3$ and varied from 0.6 to $5.6/\text{m}^3$ (Figure 1). On average, peak weeks occurred during week three (mid-June) of the eight-week sampling period during our study. Adult gizzard shad averaged $8.0 (\pm 2.3)$ per net night during 2003–2014 and varied from 1.3 to 26.6 per net night. Zooplankton varied from 12.6 to 62.0 L^{-1} with a mean of $28.8 (\pm 4.5) \text{ L}^{-1}$ from 2003 through 2014. Chlorophyll *a* varied from 30.0 to 159.5 mg/L with a mean of $91.3 (\pm 11.4) \text{ mg/L}$ while turbidity varied from 10.0 to 57.9 FAU with a mean of $26.5 (\pm 3.6) \text{ FAU}$ from 2003 to 2014. Relative reservoir elevation (m) varied from -5.8 to 0.8 with a mean of $-1.9 (\pm 0.7)$ from 2003 to 2014. Water temperature within the first meter of the water column varied from 20.2 to $23.5 \text{ }^\circ\text{C}$ with a mean of $21.9 (\pm 0.3) \text{ }^\circ\text{C}$ from 2003 to 2014.

The best supported model ($W_i = 0.65$) included two variables (zooplankton and relative reservoir elevation) which were both correlated to (Figures 2 and 3) and explained 75% of the annual variability (Table 2) in larval gizzard shad annual peak density. The second best supported model ($\Delta_i = 2.49$, $W_i = 0.19$) included zooplankton and explained 55% of the variability in larval gizzard shad annual peak density. Other models evaluated were not supported by the data (i.e. high Δ_i and

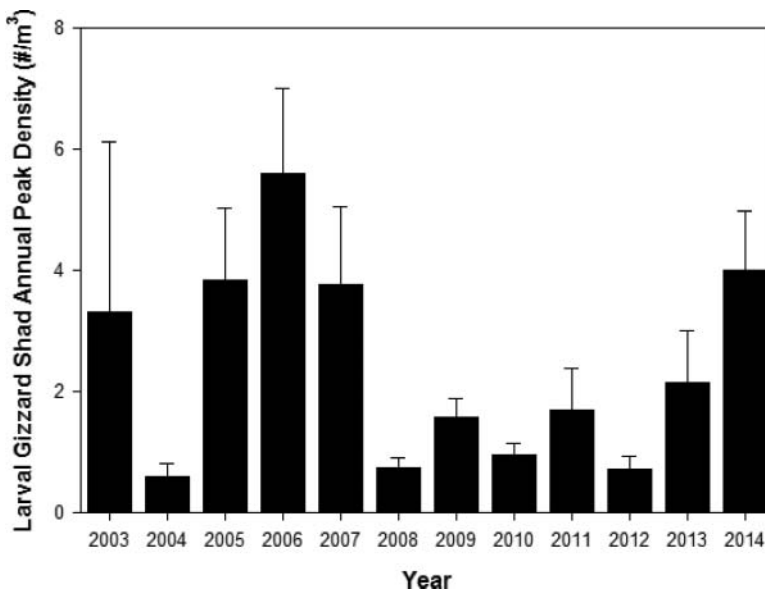


Figure 1. Larval gizzard shad annual peak density ($\#/m^3$) measured at Harlan County Reservoir from 2003 to 2014. The peak week for each year was determined by selecting the largest weekly density over the sampling period. Error bars represent the standard error of the mean.

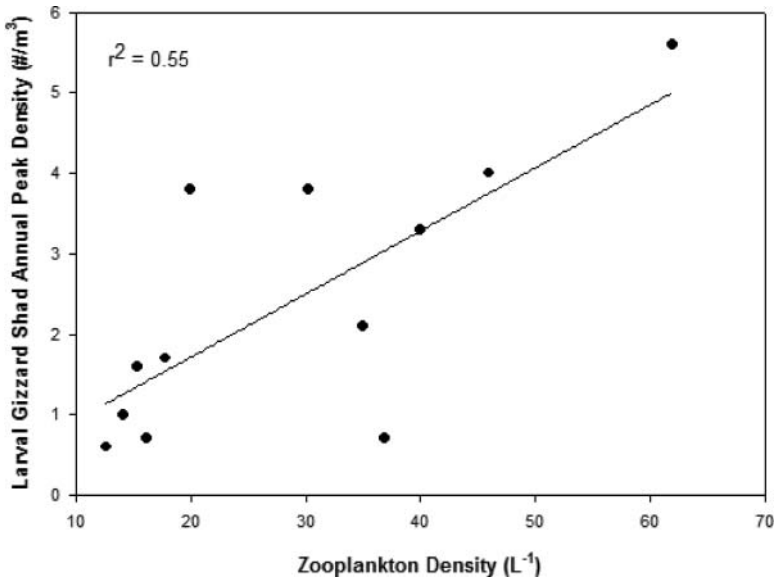


Figure 2. Larval gizzard shad annual peak densities ($\#/m^3$) from Harlan County Reservoir, Nebraska, from 2003 to 2014 compared to the zooplankton densities (L^{-1}) during the peak weeks. Zooplankton was defined by the total of *Cyclopoida* and copepod nauplii. Solid line indicates line of best fit from simple linear regression.

low W_i ; Table 2). Relative variable importance weight suggested that zooplankton had the greatest relative importance on larval gizzard shad annual peak density ($W_i = 0.95$) followed by relative reservoir elevation ($W_i = 0.69$), turbidity ($W_i = 0.09$), adult gizzard shad ($W_i = 0.06$), chlorophyll *a* ($W_i = 0.01$), and water temperature ($W_i = 0.01$) (Table 3).

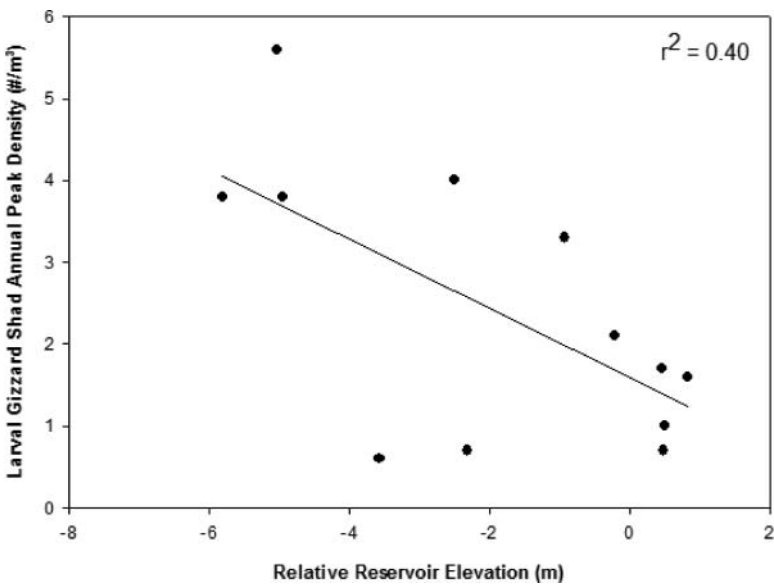


Figure 3. Larval gizzard shad annual peak densities ($\#/m^3$) from Harlan County Reservoir, Nebraska, from 2003 to 2014 compared to the relative reservoir elevation (m) during the peak weeks. Relative reservoir elevation is defined as the relationship to conservation pool during the larval gizzard shad peak week. Solid line indicates line of best fit from simple linear regression.

Table 2. Coefficient of determination (R^2), number of parameters (K), AIC_c values, difference between AIC_c values (Δ_i), and model weights (W_i) describing support of 28 models to evaluate abiotic and biotic factors influencing larval gizzard shad abundance in Harlan County Reservoir, Nebraska, during 2003–2014. These factors are mean zooplankton density of *cyclopoidea* and copepod nauplii (Z), relative reservoir elevation (RE), turbidity (TB), adult gizzard shad CPUE from the prior fall (AG), chlorophyll a (CL), and water temperature (WT).

Model	R^2	K	AIC_c	Δ_i	W_i
Z, RE	0.75	4	7.90	0.00	0.654
Z	0.55	3	10.38	2.49	0.189
TB, Z	0.61	4	13.24	5.34	0.045
RE	0.40	3	13.82	5.93	0.034
TB, Z, AG	0.75	5	14.19	6.29	0.028
Z, AG	0.58	4	14.30	6.40	0.027
TB	0.25	3	17.21	9.31	0.006
WT, TB, Z	0.65	5	18.33	10.43	0.004
CL, Z, AG	0.63	5	18.81	10.91	0.003
CL	0.11	3	19.03	11.13	0.002
AG	0.02	3	19.65	11.75	0.002
WT	0.00	3	19.89	11.99	0.002
TB, AG	0.29	4	20.41	12.51	0.001
WT, RE, Z, AG	0.79	6	21.09	13.19	0.001
WT, TB	0.25	4	21.15	13.25	0.001
TB, CL	0.26	4	22.22	14.32	0.001
CL, RE, Z, AG	0.76	6	22.64	14.74	0.000
TB, CL, RE, Z	0.76	6	22.74	14.84	0.000
CL, AG	0.13	4	22.98	15.08	0.000
WT, CL	0.12	4	23.03	15.13	0.000
TB, CL, RE	0.44	5	23.83	15.93	0.000
WT, TB, CL	0.27	5	27.19	19.29	0.000
WT, TB, CL, RE	0.44	6	32.62	24.72	0.000
WT, TB, CL, Z, AG	0.79	7	33.90	26.00	0.000
WT, TB, RE, Z, AG	0.79	7	34.29	26.39	0.000
WT, TB, CL, RE, Z	0.79	7	34.35	26.45	0.000
TB, CL, RE, Z, AG	0.78	7	34.63	26.73	0.000
WT, TB, CL, Z, AG, RE	0.82	8	80.05	72.15	0.000

Table 3. Final model averaging estimates, standard error, and relative variable importance for mean zooplankton density of *cyclopoidea* and copepod nauplii (Z), relative reservoir elevation (RE), turbidity (TB), adult gizzard shad CPUE from the prior fall (AG), chlorophyll a (CL), and water temperature (WT).

i	Parameter estimate	SE	Relative importance
Z	0.066	0.666	0.95
RE	-0.220	0.012	0.69
TB	0.004	0.018	0.09
AG	-0.004	0.000	0.06
CL	0.000	0.001	0.01
WT	-0.012	0.002	0.01

Discussion

This study investigated factors related to annual peak density of larval gizzard shad in a Midwest irrigation reservoir. Irrigation reservoirs are prone to greater oscillation in water levels as well as subject to hydrological patterns that are driven by agricultural demand rather than precipitous patterns (Olds et al. 2011). The reservoir selected for this work has an extensive 12-year data set spanning years of changing conditions which captured system variability including a complete drought cycle. Ideally, additional reservoirs could have been included to derive relationships; however, long-term data sets such as the one used are time-consuming and limited in availability; especially on irrigation reservoirs. We believe this work offers a representative case study that can provide insight into other irrigation reservoirs as well as provides an opportunity to see how gizzard shad recruitment relates to other reservoir systems. The annual peak densities of larval gizzard shad in this Midwest irrigation reservoir were representative of densities found in other lakes and reservoirs

(Matthews 1984; Michaletz 1997; Allen et al. 1999), but would be considered lower than those found in Ohio (Bremigan and Stein 2001) and greater than those reported from South Dakota (VanDeHey et al. 2012). Additionally, in this reservoir, the temporal variability in occurrence of larval gizzard shad annual peak density was consistent from 2003 to 2014 with the peak week occurring around week three (mid-June) at an average water temperature of 21.9 °C. Thus, the results produced from this modeling exercise should serve as a representative sample that can provide meaningful insight into factors associated with the annual peak density of larval gizzard shad in irrigation reservoirs.

Zooplankton was the most supported variable associated with larval gizzard shad annual peak density. Similar to other regions, larval gizzard shad annual peak density in Harlan County Reservoir was positively correlated to zooplankton density (Welker et al. 1994; Vanni et al. 2005). Greater food availability has improved growth of larval gizzard shad in mesocosms (Bremigan and Stein 1997) and the faster rate of growth can assist larval gizzard shad with their ability to escape predators through greater swimming abilities and outgrowing their gape width (Noble 1981; DeVries and Stein 1990; Fisher et al. 2000). Larval gizzard shad thrive in systems dominated by small zooplankton compared to large zooplankton (DeVries and Stein 1992; Bremigan and Stein 1994). Similarly, smaller zooplankton such as *cyclopoidea* and copepod nauplii were positively selected as prey for larval gizzard shad in this reservoir (Sullivan et al. 2011) and explain variability in peak densities.

Relative reservoir elevation was the second most supported variable associated with larval gizzard shad annual peak density. This study identified a negative association between relative reservoir elevation and annual peak density of larval gizzard shad in an irrigation reservoir. However, other studies have found that lower water was linked to lower larval gizzard shad abundance (Michaletz 1997). The nuances of water management within an irrigation reservoir most likely explain this variance of influence on observed larval gizzard shad densities. Water release from irrigation reservoirs is regulated by the amount available to supplement crops; in years that less water is available (i.e. lower relative reservoir elevation), the call for water will be delayed to ensure adequate amounts for the intense growing season later in the summer. The result is a later start for water release and subsequent entrainment loss of larval gizzard shad. Indeed, age-0 gizzard shad comprise the majority of fish identified in entrainment loss studies when they are present (Lewis and Seegert 2000; Smith and Brown 2002). Modeling exercises have shown that population abundance can be reduced due to entrainment loss (Ogawa and Mitsch 1979), but these losses may not be observed at the population level (Perry et al. 2002). Consequently, in years when Harlan County Reservoir has lower relative water elevations, we may be observing a delayed entrainment loss which could allow sport fish to use this prey resource.

Understanding the conditions related to larval gizzard shad annual peak density can assist managers by anticipating the availability of this important prey source. Because larval gizzard shad are thought to drive the trophic interactions within reservoirs from the middle-out (DeVries and Stein 1992), management can only be improved through a greater understanding. For example, potential management practices such as altering the timing or location of stocking can be linked to growth or survival of sport fish (Hoxmeier et al. 2006). Future studies should investigate the effects large-year classes of gizzard shad have on the availability of resources and the resulting impacts they have on lower trophic levels and recruitment and growth of other fish.

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Disclosure statement

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