Population Characteristics of Gizzard Shad Introduced into a Small Western Oklahoma Impoundment

Matthew T. Lyons
Oklahoma Department of Wildlife Conservation, Oklahoma Fishery Research Laboratory, Norman, OK 73072

Richard A. Snow
Oklahoma Department of Wildlife Conservation, Oklahoma Fishery Research Laboratory, Norman, OK 73072

Michael J. Porta
Oklahoma Department of Wildlife Conservation, Oklahoma Fishery Research Laboratory, Norman, OK 73072

Abstract: Gizzard Shad (*Dorosoma cepedianum*) are often considered a vital forage species in many aquatic systems. However, when populations of Gizzard Shad become dominated by large (> 200 mm) overabundant individuals they can have negative direct and indirect effects on sportfish populations. In September 2016, 198 Gizzard Shad were collected from Lake Carl Etling in far northwest Oklahoma to evaluate population characteristics. Total length (TL; mm) and weight (g) were recorded and sagittal otoliths were removed for aging. Gizzard Shad ranged from 56-308 mm TL with a mean age estimated at 2.63 years and a maximum age of 12 years. This Gizzard Shad population has rapid growth rates within the first year, slowing with increasing age, poor relative body condition, low mortality, and is comprised primarily of small adults. We speculate that the fast growth rate of the Gizzard Shad population may be affecting the sportfish populations in Lake Carl Etling, as indicated by low proportional size distribution (PSD) and below average relative weight (W_r) of Walleye (*Sander vitreus*) and Largemouth Bass (*Micropterus salmoides*). Information about Gizzard Shad populations in Oklahoma is limited, and this study provides baseline characteristics to which other Gizzard Shad populations in small impoundments can be compared.

Introduction

Gizzard Shad (*Dorosoma cepedianum*) are one of four clupeid species found in Oklahoma's reservoirs and rivers (Miller and Robison 2004). Gizzard Shad are widely distributed in eastern North America from the central Dakotas to Quebec, south to Florida and southwest to Texas and northeast Mexico (Page and Burr 1991, Miller and Robison 2004). The range of Gizzard Shad has expanded through anthropogenic influences (dams and canals; Miller 1957), introductions via accidental and intentional stocking (Mueller and Brooks 2004, DeVries and Stein 1990), and climate change (VanDeHey et al. 2014). However, the expansion of Gizzard Shad has slowed northward due to their critical thermal minima (4 ºC) being reached during winter months (Porath 2006).

When a population of Gizzard Shad becomes established, it can dominate the biomass of a system (Noble 1981, Stein et al. 1995). Jenkins (1949) suggested that all large Oklahoma reservoirs have Gizzard Shad populations, and are typically the most abundant species. Gizzard Shad are filter feeders that use gill rakers to strain detritus and plankton (Miller 1960, Miller and Robison 2004). This foraging behavior can influence zooplankton and phytoplankton densities, resulting in interspecific competition with juvenile and adult sportfish (Jenkins 1957, Aday et al. 2003, Michaletz 2017, Neely et al. 2018). Furthermore, Gizzard Shad can considerably increase phytoplankton, nutrient levels, and suspended solids, which may increase turbidity and ultimately impact foraging ability of piscivores (Schaus and Vanni 2000, Aday et al. 2003).

Gizzard Shad can grow very rapidly and can reach large sizes (>200 mm TL) in the first year (Michaletz 1998, Evens at el. 2014). This rapid growth limits most predators to consuming young-of-the-year Gizzard Shad (Miller 1960, Evens at el. 2014), and in some cases young-of-the-year Gizzard Shad may become too large to be utilized as prey if they outgrow predator gape limits (Cyterski & Ney 2005). Therefore, fast growth improves survival of Gizzard Shad to adulthood and minimizes the time they are vulnerable to piscivores (Evans et al. 2014). Conversely, if predator populations are in balance with Gizzard Shad prey populations and if predator size distribution is relatively even, a greater size range of Gizzard Shad can be consumed, keeping these respective populations in balance.

Clearly, the presence of Gizzard Shad in aquatic systems has both negative and positive effects on sport fisheries. Information about Gizzard Shad population characteristics in Oklahoma is limited. Furthermore, previous Gizzard Shad studies relied on scale-based ages to describe population characteristics. It is well established in the literature that scales ages are less precise when compared to otolith estimated ages. This has been observed for many freshwater fish species including Largemouth Bass (*Micropterus salmoides*), Spotted Bass (*Micropterus punctulatus*), Smallmouth Bass (*Micropterus dolomieu;* Long and Fisher 2001), Bluegill (*Lepomis macrochirus;* Edwards et al. 2005), Walleye (*Sander vitreus;* Kocovsky and Carline 2000), Saugeye (*S. vitrues x S. Canadensis*; Koch et al. 2017), Yellow Perch (*Perca flavescens;* Niewinski and Ferreri 1999), and White Crappie (*Pomoxis annularis;* Boxrucker 1986). Imprecise age estimates can result in biased population parameters, leading management biologists to make misguided management decisions that may negatively impact those fisheries. Therefore, the objective of this study was to assess age (using sagittal otoliths), as well as growth, mortality, condition, and size structure of Gizzard Shad collected from Lake Carl Etling, Oklahoma.

Methods

Sample Area – Lake Carl Etling was formed in 1958 by impounding South Carrizo Creek, a tributary of the Cimarron River (Snow et al. 2017) in the far northwestern tip of Oklahoma in Cimarron County. Lake Carl Etling is 159 acres at normal pool with 8 kilometers of shoreline. It is a hyper-eutrophic system with a mean depth of 1 meter and maximum depth of 5.5 meters (Snow et al. 2017). Water temperature can range from 1.6 - 33.4ºC depending on time of the year. Lake Carl Etling is a turbid system with mean secchi depth measuring 23.4 cm (Snow et al. 2017). The reservoir is managed by the Oklahoma Department of Wildlife Conservation and is surrounded by Black Mesa State Park.

Sampling – Ten Gizzard Shad per 10-mm length group were collected in September 2016 using boat electrofishing (pulsed DC, high voltage, Smith Root 7.5 GPP) to ensure that all size and age classes were represented in the sample (Michaletz 1994, DeVries et al. 1995, DiCenzo et al. 1996, Michaletz 1998, Aday et al. 2003, Wuellner et al. 2008, Michaletz 2017). During these efforts, the entire shoreline was sampled. Fish were placed on ice immediately after capture, and processed at the Oklahoma Fishery Research Laboratory in Norman, Oklahoma. Fish were measured for total length (TL; mm), weight (g) and sagittal otoliths were removed for aging.

Otolith aging - After otoliths were removed they were allowed to dry for at least 24 hr before mounting. Clayton and Maceina (1999) validated that one annulus forms yearly (via marginal increment analysis) in Gizzard Shad otoliths and that fish <3 years old can be estimated using whole otoliths, however, otoliths from fish age 3 and older require sectioning in the sagittal plane for precise age estimation. Sagittal otoliths of Gizzard Shad are very delicate and require embedding in epoxy prior to sectioning. Otoliths were embedded by placing them in a 21-cell latex mold (12 mm x 5 mm x 6 mm; Electron Microscopy Sciences, Hatfield, PA), then immersed in West Systems epoxy (105 resin and 206 harder; Gougeon Brothers Inc., Bay City, Michigan). After the epoxy cured, otoliths were sectioned in a sagittal plane using a low speed Buehler IsoMet® saw (127 mm x 0.4 mm diamond wafering blade) and polished using 2000-grit sandpaper, as described by Maceina (1988). Otoliths were positioned polished-side up in modeling clay and covered with water to reduce glare.

To estimate ages, otoliths were viewed with a dissecting microscope (3.6-90x) using a fiber optic light and a reflective light source when needed. Annuli, which appeared as opaque bands on a light background, were counted to assign an age estimate to each fish. Each otolith was evaluated in random order by two independent readers (Hoff et al. 1997). When there was a disagreement on an estimated age, a concert reading was conducted by both readers and a final age estimate was determined.

Analysis - A length-frequency histogram (for aged fish and all fish combined) and proportional size distribution (PSD, stock ≥ 180mm, quality ≥280 mm; Anderson and Gutreuter 1983) was used to visualize and quantify Gizzard Shad size structure. A $\log_{10}$ weight to $\log_{10}$ TL regression was used to describe the weight:length relationship of the population. Gizzard Shad condition was evaluated by calculating relative weight (W_r) using the standard weight equation (W_s = -5.376 + 3.170 × log10 TL) presented by Anderson and Gutreuter (1983) where 100 = the 75th percentile of the national average weight of Gizzard Shad. A von Bertalanffy growth model was used to describe growth of Gizzard Shad (Cerrato 1990) and catch-curve-regression was used to assess total annual mortality (Ricker 1975). Age-0 fish are typically not recruited to sampling gears (Miranda and Bettoli 2007), so young-of-year Gizzard Shad were not included in the catch-curve analysis. Total annual mortality was calculated by regressing the $\log_e$ number of fish caught at each age to estimate instantaneous total mortality (Z), which was then converted to total annual mortality ($A = 1 - e^{-Z}$; Ricker 1975).

Results

A total of 198 Gizzard Shad were utilized for population assessment. Gizzard Shad used for aging purposes ranged from 0 to 12 years old and 56-308 mm TL (Figure 1A). This population was dominated by sub-stock sized (< 180 mm; Figure 1B) Gizzard Shad (n=120; 61%), although stock (n=78) and quality (n=12) sized fish were collected. This resulted in a PSD of 15. The weight-length relationship of Gizzard Shad was $\log_{10}$ (W) = -4.5974+2.7872 $\log_{10}$ (TL) (R^2 = 0.98; Figure 2). This weight-length relationship results in a mean W_r of 78, which is well below the average of 100. When evaluated by size classes, W_r of stock sized

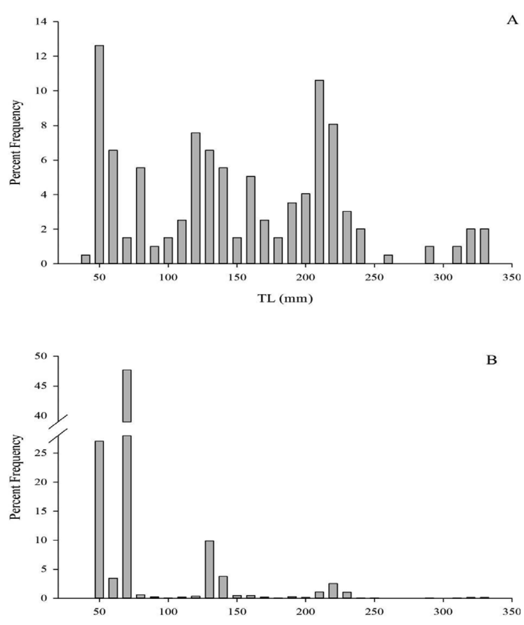

Figure 1. Length frequency histograms (10-mm bins) of (A) aged Gizzard Shad (n=198) and (B) all Gizzard Shad collected (n=2,886) collected from Lake Carl Etling, Oklahoma in September 2016.

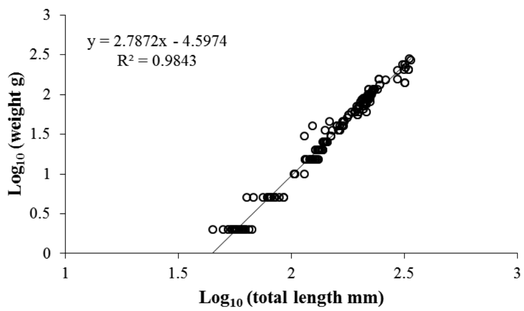

Figure 2. Weight-length relationship for Gizzard Shad collected from Lake Carl Etling, Oklahoma in September 2016. The logarithmically-transformed weight-length equation is $\log_{10}$ (W) = -4.5974+2.7872 $\log_{10}$ (TL).

Gizzard Shad was 82, however, W_r of quality sized Gizzard Shad was substantially lower at 58. The modelled von Bertalanffy growth curve indicates that Gizzard Shad approach maximum length steadily (K=0.31), with individuals in the population reaching approximately half (49%) of the predicted maximum TL by age-1 and growing to 73% of their predicted TL (L_∞ =295) by age-3 (Figure 3). The total annual mortality estimate for the Gizzard Shad population in Lake Carl Etling was 27% (Figure 4).

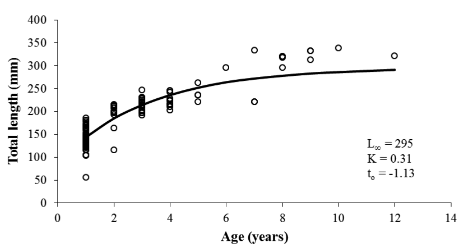

Figure 3. Von Bertalanffy growth curve calculated from otolith age estimates for Gizzard Shad collected from Lake Carl Etling, Oklahoma in September 2016. L_∞ = predicted maximum total length, K = growth constant, and t_0 = theoretical time when TL = 0.

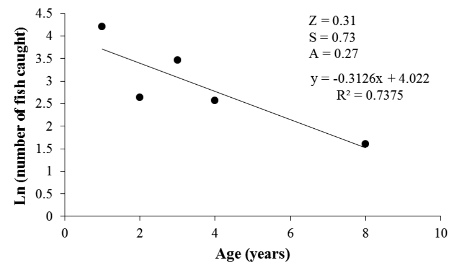

Figure 4. Catch curve regression and total annual mortality (A) for Gizzard Shad collected from Lake Carl Etling, Oklahoma in September 2016. Z = instantaneous total mortality and S = annual survival.

Discussion

To our knowledge this is the first study to use sagittal otoliths to gain a better understanding of population dynamics of a Gizzard Shad population in Oklahoma. Results suggest that Gizzard Shad from Lake Carl Etling experience fast growth in their first year, slowing as age increases, which is a characteristic of Gizzard Shad in eutrophic systems (DiCenzo et al. 1996, Michaletz 1998, Michaletz 2017). The body condition (Wr = 82-93) of Gizzard Shad from Lake Carl Etling was lower than previous studies, particularly when compared to studies from mesotrophic reservoirs (DiCenzo et al. 1996, Michaletz 1998, Michaletz 2017). Typically, in eutrophic systems W_r is stable for all size classes of Gizzard Shad (DiCenzo et al. 1996), however, condition of Gizzard Shad from Lake Carl Etling decreased as size increased. Despite poorer condition with size (and age) total annual mortality was low (27%). Michaletz (2017) reported mean annual mortality rates of 65% for small impoundments in Missouri. Using only shad > age 3, Wuellner et al. (2008) found an annual mortality rate of 27%. Gizzard Shad are characterized as a short-lived species (< 8 yrs) in eutrophic system (DiCenzo et al. 1996, Michaletz 2017), but are longer lived in mesotrophic systems (8-14 years; DiCenzo et al. 1996, Wuellner et al. 2008). We found longevity of Gizzard Shad in Lake Carl Etling to be high

(12 years) with low mortality.

The Lake Carl Etling Gizzard Shad population was composed primarily of small adults (< 180 mm). Gizzard Shad populations with low PSD values, which indicate a population dominated by small adults, often experience poor reproduction (Willis 1987). Conversely, Willis (1987) suggested that a population of Gizzard Shad with a high PSD value results in more successful reproduction and produces a greater biomass of age-0 fish. Gizzard shad populations with high PSDs are also typically in good condition (Michaletz et al. 1998). Because the Lake Carl Etling Gizzard Shad population has a low PSD and relatively poor condition, reproduction and resulting age-0 fish production may be limited. This is cause for concern because most piscivores only consume age-0 Gizzard Shad (<100 mm TL), with older shad exceeding the predators preferred size (Evans et al. 2014). Only larger piscivores can consume shad ≤ 200 mm TL (Evans at el. 2014).

Gizzard Shad are typically the main forage source for the predatory fishes in Lake Carl Etling. Black Bullhead (*Ameiurus melas*), Largemouth Bass, Walleye, Hybrid Striped Bass (*Morone saxatilis x M. chrysops*; last stocked 2010), Tiger Muskellunge (*Esox masquinongy x E. Lucius*; if present in very low numbers; Snow et al. 2017), and stocked Rainbow Trout (*Oncorhynchus* mykiss) all consume Gizzard Shad. Walleye and Largemouth Bass are known to prefer soft rayed-fishes, like Gizzard Shad, over spiny rayed-fishes (Gillen et al. 1981, Knight et al. 1984, Storck 1986, Einfalt and Wahl 1997, Shoup and Lane 2015). When Walleye are able to forage on soft rayed-fishes, growth rates are typically higher (Knight et al. 1984). We found that Gizzard Shad in Lake Carl Etling grow to almost half their full size in the first year, and by year three they approach 75% of their maximum size. This rapid growth early in life means that Gizzard Shad are only accessible by piscivores for a short period of time due to gape limitations. Because age-0 Gizzard Shad are only seasonally available due to their rapid growth, Largemouth Bass, Walleye and other piscivores may be forced to feed on less desired spiny rayed-fish, like Bluegill, which may slow piscivore growth rates.

The Largemouth Bass and Walleye populations in Lake Carl Etling have poor growth rates, resulting in low PSD and below average body condition (mean W_r; Table 1, ODWC unpublished data). A combination of limited age-0 Gizzard Shad biomass and rapid growth of young Gizzard Shad (age 0-2) may be affecting predator populations that experience reduced growth rates and below-average condition. Size-specific differences in condition were apparent for Largemouth Bass in this population; as Largemouth Bass size increased, mean W_r increased (stock = 90, quality = 97, and preferred = 103). This suggests that larger Largemouth Bass may take advantage of larger bodied Gizzard Shad as forage, resulting in better body condition. Conversely, smaller Largemouth Bass had poorer condition, likely because most Gizzard Shad have outgrown the gape limits of smaller Largemouth Bass. The majority (86%) of Largemouth Bass in this population are < 300 mm TL, which have a gape width allowing them to consume shad 126 – 136 mm TL (Lawerence 1957). Similarly, previous studies that evaluated the relationship between Largemouth Bass TL and TL of Gizzard Shad consumed found that Largemouth Bass measuring 300 mm typically consume Gizzard Shad < 150 mm TL (Lewis et al. 1974, Shepherd 2008). The condition of Walleye was also well below average in Lake Carl Etling, which may also be attributed to the size of Gizzard Shad. It is not surprising that condition of Largemouth Bass and Walleye are below average in the spring. During winter, Rainbow Trout are stocked into Lake Carl Etling

Table 1. Proportional size distribution (PSD) and relative weight (W_r) of two sportfish collected from Lake Carl Etling, Oklahoma in spring 2017 (ODWC unpublished data).

Species	PSD (quality)	PSD (preferred)	W_r (stock)	W_r (quality)	W_r (preferred)	Mean W_r
Largemouth Bass	11	5	90	97	103	91
Walleye	11	N/A	85	87	N/A	85

to create an additional sport fishing opportunity. Snow et al. (*in-review*) found that Rainbow Trout consume a large portion of the age-0 Gizzard Shad biomass during winter months. During this time, Largemouth Bass, Walleye, and Rainbow Trout are all competing for the same resources. By spring, most of the Gizzard Shad remaining are too large to be consumed by the resident piscivores, likely resulting in poor body condition of the predators.

Lake Carl Etling is not well suited for Gizzard Shad, which were stocked with the intention of providing forage for sport fishes. Michaletz (1998) found that Gizzard Shad are best suited for deep clear mesotrophic impoundments and are undesirable in shallow eutrophic impoundments such as Lake Carl Etling. The Lake Carl Etling fish community is dominated by predators, which is limiting the number of age-0 Gizzard Shad recruiting to adulthood. This heavy cropping of age-0 Gizzard Shad by predators results in fast growth within the first-year allowing survival to sizes that are too large to be consumed by piscivores.

This study provides baseline population dynamics information for Gizzard Shad from a single small impoundment in Oklahoma, and it represents the first use of otoliths to derive population dynamics for Gizzard Shad in Oklahoma. Because we do not have data on other Oklahoma populations for comparison, we cannot say whether this represents a typical Gizzard Shad population in Oklahoma. However, population characteristics are important because, without these data, fisheries managers do not know if or how sport fish populations are impacted by Gizzard Shad, whether or not a small impoundment can withstand stocking of an additional predator biomass, or if the majority of fish biomass is comprised of Gizzard Shad. Future research should focus on gaining more knowledge about Gizzard Shad populations in Oklahoma reservoirs and small impoundments, as this information is lacking statewide and is critical to managing sportfish populations where shad serve as the primary forage base. We further recommend that Gizzard Shad population assessments be based on the use of sagittal otoliths.

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