Seasonal Abundance, Age Structure, and Spawning Period of Gizzard Shad in the Hydrologically Altered Upper Barataria Estuary, Louisiana

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Abstract: Gizzard shad (*Dorosoma cepedianum*) are an important component of many water bodies in the southeastern United States that contributes energy and nutrients to piscivores and impacts nutrient cycles. Spawning movements from the lower Barataria Estuary, Louisiana, into the upper reaches of the Barataria Estuary results in seasonal congregations of gizzard shad in the upper estuary. Historically, these spawning movements may have been initiated by the predictable annual Mississippi River floodpulse; however, the Barataria Estuary is currently cut off from the Mississippi River and no longer receives a predictable annual floodpulse. Gizzard shad were sampled biweekly from 22 November 2005 to 6 September 2006 using monofilament gill nets to assess gizzard shad spawning behavior, the timing of spawning, and growth rates in the altered floodplain of the upper Barataria Estuary. Catch per unit effort (CPUE; number per hour) and female gonadosomatic index peaked in March and subsequently declined. Sampling indicated that gizzard shad migrated from the lower Barataria Estuary to the upper Barataria Estuary to spawn, and spawned from April to June. The first post-spawn (spent) female was collected on 7 April 2006 and the last pre-spawn (non-spent) female was collected on 7 July 2006. Gizzard shad relative abundance was not related to changes in water level or dissolved oxygen, but appears to be related to spawning activity. Maximum age was four years for males and five years for females. Male and female gizzard shad were similar in size for ages 1 and 2, but females were larger than males for ages 3 and 4. Size at age for gizzard shad from the upper Barataria Estuary was larger than size at age reported in other studies. The lack of a predictable floodpulse in the upper Barataria Estuary did not negate gizzard shad spawning behavior and did not negatively affect growth.

Key words: gizzard shad, GSI, growth, age, floodplain, estuary

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Ecosystem productivity is a major contributing factor to gizzard shad (*Dorosoma cepedianum*) abundance (Michaletz 1997, Bremigan and Stein 2001, Vanni et al. 2005), which are a major component of fish biomass in many water bodies of the southeastern United States. Because of their low trophic level and productivity, gizzard shad abundance can be positively correlated to piscivore growth (Forney 1977, Fox 1989, Ney et al. 1990). Gizzard shad are omnivorous and can easily switch their diet pattern from planktivory to detritivory, depending on the availability of local resources (Schaus et al. 2002). As detritivores, gizzard shad can impact the total amount of sediment-based nitrogen and phosphorous released by the local fish assemblage (Sereda et al. 2008). Because nutrients released from lake sediments can stimulate primary productivity (Nowlin et al. 2005), gizzard shad can be an important link between sediment-based nutrients and water column primary production (Vanni 1996).

Gizzard shad spawning behavior is typical of most clupeids and usually involves a pre-spawn migration, which results in a large congregation of individuals at preferred spawning habitats when temperatures reach 17 to 22 C (Bodola 1964, Bremigan and Stein 1999, Zweifel et al. 2009). The initiation of spawning is probably temperature dependent as gizzard shad spawn earlier in southern latitudes than in northern latitudes (Baglin and Kilambi 1968, Willis 1987, Zweifel et al. 2009), and the spawning period typically lasts for four to eight weeks (Baglin and Kilambi 1968, Willis 1987, Jons and Miranda 1997). In large river floodplain systems, adult gizzard shad migrate from the main stem river onto floodplain habitats during flood periods (Zeug and Peretti 2009), and reproductive success can be related to the timing and duration of the river floodpulse (i.e., seasonal floodplain inundation typical of large rivers) and associated hypoxic conditions (Fontenot et al. 2001). Many large river fishes use the predictable annual floodpulse as a spawning cue (Junk et al. 1989), but it is not known if gizzard shad in large river systems rely on a predictable floodpulse as a spawning cue or if temperature is the overriding spawning cue.

The Barataria Estuary was once the southern-most western-bank floodplain of the Mississippi River in southeastern Louisiana and was created by alluvial deposits transported from the Mississippi River via distributaries and interdistributaries. The upper most areas of the Barataria Estuary are dominated by cypress-

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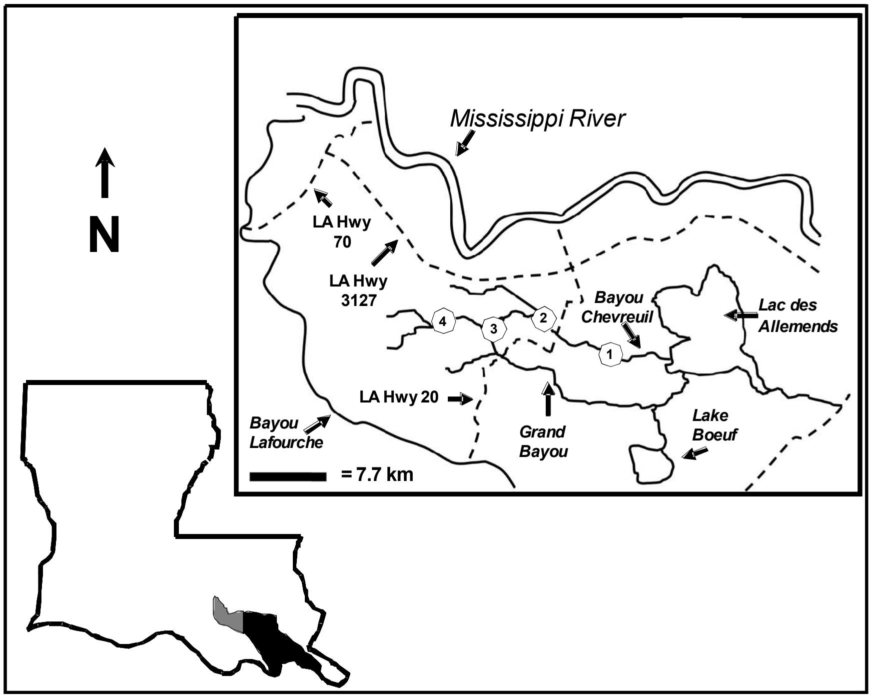

Figure 1. Location of study sites (numbers 1 – 4) in the upper Barataria Estuary (gray shaded area) sampled for gizzard shad between 22 November 2005 and 6 September 2006. Solid lines represent major water bodies and dashed lines represent major roadways.

tupelo swamps, which transform into fresh, intermediate, brackish, and then salt marsh near the coast (Braud et al 2006). Due to the closing of distributary connections and construction of flood protection levees, water from the Mississippi River only enters the Barataria Estuary through small river diversions, the Gulf Intracoastal Water Way, or indirectly from the Gulf of Mexico after passing through the mouth of the river due to strong southeastern winds (Swensen et al. 2006, Inoue et al. 2008). The overwhelming majority of water that enters the Barataria Estuary is precipitation, and precipitation amount determines water level, especially in the upper reaches of the estuary (Sklar and Conner 1979, Inoue et al. 2008). Disconnection from the Mississippi River has resulted in the loss of a predictable annual floodpulse in the Barataria Estuary.

Because the Barataria Estuary was an active Mississippi River floodplain prior to channelization, ecological processes within the Barataria Estuary probably conformed to the Flood Pulse Concept proposed by Junk et al. (1989). The transfer of energy and nutrients between the terrestrial and aquatic habitats of large river floodplains, facilitated by the predictable annual floodpulse, contributes to the relatively high biomass of fishes found in large river floodplain systems. For example, Bryan and Sabins (1979) reported 243 kg/ha of all gars (*Lepisosteus* spp. and *Atractosteus* spp.) and bowfin (*Amia calva*) in the Atchafalaya River Basin, Louisiana, which has an annual predictable floodpulse. Seasonal migrations and spawning of many fish species within large river floodplains is correlated to the annual floodplulse as many species take advantage of the inundated floodplain for foraging and spawning (Junk 1999, Snedden et al. 1999). Because some resident fish species of large river floodplains may use the floodpulse as a migratory or spawning cue (Junk et al. 1989), the lack of a predictable floodpulse may impact the seasonal movement and spawning behavior of some species in the upper Barataria Estuary.

To determine if the lack of a predictable floodpulse in the upper Barataria Estuary impacts gizzard shad spawning behavior and growth rates, we initiated a study to document: 1) the seasonal abundance of adult gizzard shad, 2) the timing of the gizzard shad spawning season, and 3) the growth rate of gizzard shad.

Methods

Gizzard shad were collected biweekly at four locations in the upper Barataria Estuary (Figure 1) from 22 November 2005 to 6 September 2006, using monofilament gill nets. All sites were in freshwater areas of the estuary and were not tidally influenced. Access to site 4 was not possible before 3 February 2006, due to low water levels and an abundance of submerged aquatic vegetation (*Hydrilla verticillata, Ceratophyllum demersum*). Three nets were set at a 45° angle downstream from the bank at each site between 800 and 1300 hours. Two identical nets (23 m long, 1.8 m depth, 38 mm bar mesh) and a single 23-m dual mesh net (first section: 11.5 m long, 1.8 m depth, 38 mm bar mesh; second section: 11.5 m long, 1.8 m depth, 25.4 mm bar mesh) were used at each site. Nets remained deployed for approximately two hours. Dissolved oxygen

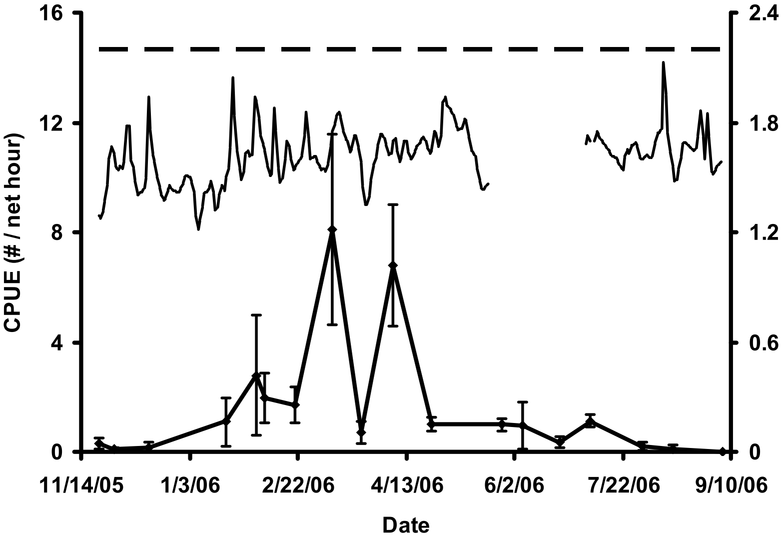

Figure 2. Mean (±SE) CPUE for gizzard shad (solid line with markers) and water level (solid line without markers) in the upper Barataria Estuary from 22 November 2005 to 6 September 2006. Water level was not determined from 21 May 2006 to 5 July 2006 or on 8 July 2006. The horizontal dashed line represents the water level at which the surrounding floodplain is inundated.

(DO; mg/L), temperature (C), and salinity (ppt) were measured with a handheld oxygen-conductivity-salinity-temperature meter (YSI 85; Yellow Springs Instruments, Yellow Springs, Ohio) 0.6 m below the surface at each site for each sample date. DO and temperature did not vary among sites (analysis of variance, $P > 0.05$), so mean (± SE) DO and temperature were calculated as the mean of all four sites for each sample date. DO levels ≤2.0 mg/L were classified as hypoxic. Mean salinity was near zero (0.2 ± 0.15), was always less than 1.0 ppt, and did not differ among sites (analysis of variance, $P > 0.05$). Because salinity was always less than one (considered freshwater), we did not include it in any other analysis. Water level was obtained from a U.S. Geological Survey continuous recorder (No. 07380401) located in St. James canal (Figure 1).

Gizzard shad were removed from the gill nets and kept on ice until processing. Catch per unit effort (CPUE; number of gizzard shad per net hour) was calculated as the mean of the three nets for each site, and the mean CPUE for each sample date was calculated as the mean (± SE) of all four sites as an index of relative abundance. Each gizzard shad was weighed (g), measured [total length (TL); mm] and sexed. Gonads were weighed (g) to calculate gonadosomatic index (GSI), and mean (± SE) GSI was calculated for each sample date for each sex and did not vary among sites (analysis of variance, $P > 0.05$). Each female was classified as pre-spawn (non-spent; ovary is visibly full) or post-spawn (spent; ovary is visibly devoid of eggs).

Fish were separated into 25-mm TL size groups and up to 5 fish per size group per sample date were aged (female, $n = 125$; male, $n = 119$) using annuli on sagittal otoliths examined in whole view or sectioned view (Clayton and Maceina 1999) at 40x magnification. Analysis of variance ($P \leq 0.05$) was used to compare age specific size differences (TL) between sexes (SAS 2003). A von Bertlanffy growth curve was used to separately describe growth for males and females (FAST 2.0; Slipke and Maceina 2001).

Results

A total of 239 female (332 ± 49.5 mm; 400 ± 160.9 g) and 276 male (311 mm ± 37.1; 305 ± 85.0 g) gizzard shad were collected. Gizzard shad weight (W) increased exponentially with TL for both males [$W = -5.27(TL)^{3.1}$] and females [$W = -5.56(TL)^{3.2}$]. Gizzard shad mean CPUE increased in January, peaked in March (maximum mean CPUE = 8.1), and declined to zero by September (Figure 2). Water level never inundated the floodplain and no pattern in water level was observed (Figure 2). Temperature followed the expected seasonal pattern, and with the exception of one recorded hypoxic event (14 August 2006), recorded DO remained above hypoxic levels throughout the study (Figure 3).

Mean female GSI increased through the winter, reached peak values in late March [temperature approximately 21 C (Figure 3)], and decreased through the summer (Figure 4). The first post-spawn female was collected on 7 April 2006 and the last pre-spawn female was collected on 7 July 2006 (Figure 4). All females collected after 7 July 2006 were classified as spent.

Gizzard shad ages ranged from 1–4 years for males and 1–5 years for females. There was no difference in size between males and females for ages 1 and 2, but females were larger than males for ages 3 (MSE = 278.2; $F_{1, 153} = 86.4$; $P < 0.0001$) and 4 (MSE = 450.8; $F_{1, 21} = 11.3$; $P = 0.0029$; Figure 5). The von Bertlanffy growth equation for males was $L_t = 352[1 - e^{-0.935(t-0.145)}]$ and for females was $L_t = 452[1 - e^{-0.433(t+0.258)}]$ (Figure 5).

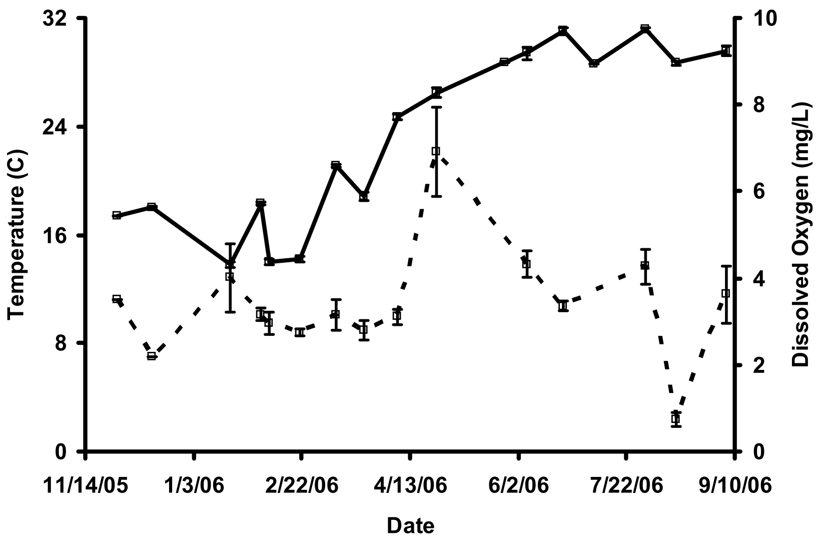

Figure 3. Mean (±SE) temperature (solid line) and dissolved oxygen (dashed line) in the upper Barataria Estuary for each sample date from 29 November 2005 to 6 September 2006.

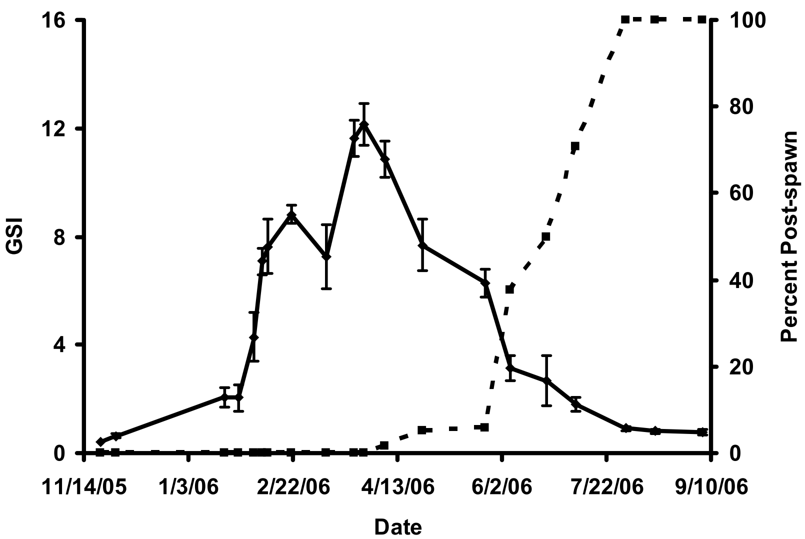

Figure 4. Mean (±SE) GSI (solid line) and percent post-spawn individuals (dashed line) for female gizzard shad collected in the upper Barataria Estuary from 22 November 2005 to 6 September 2006.

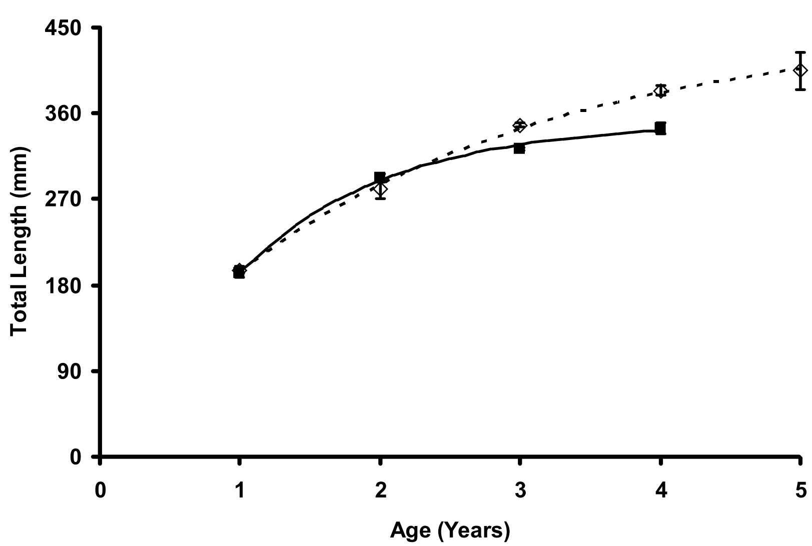

Figure 5. Mean (±SE) total length for each age class and predicted von Bertlanffy growth curves for male (solid line) and female (dashed line) gizzard shad collected in the upper Barataria Estuary from 22 November 2005 to 31 July 2006.

Discussion

The upper Barataria Estuary is a freshwater, nutrient and detritus-rich eutrophic system (Hopkinson and Day 1980, Stow et al. 1985, Conner and Day 1992) which is the type of habitat associated with high gizzard shad biomass (Michaletz 1997, Bremigan and Stein 2001, Vanni et al. 2005). Although the upper Barataria Estuary appears to support quality gizzard shad habitat, our results indicate that adult gizzard shad are not year-round residents and that relative abundance peaks in March and April. Changes in gizzard shad abundance did not relate to changes in DO or water level; however, peaks in gizzard shad abundance occurred at temperatures similar to spawning season temperatures (17–20 C) from other studies (Bodola 1964, Zweifel et al. 2009) and coincided with peak female GSI values. Gizzard shad moved into the upper Barataria Estuary from the lower estuary to spawn, and the movement was not related to a floodpulse. Based on the observations of post-spawn ovaries and GSI values, as a rough estimate of gizzard shad spawning season (Jons and Miranda 1997), we identified April through June as the gizzard shad spawning season in the upper Barataria Estuary.

The temperature regime of the upper Barataria Estuary allows for an extended growing season for gizzard shad when compared to more northern areas, which may explain the relatively large size at age. Mean total length for age 1 and age 3 gizzard shad was larger than that observed in Missouri (Michaletz 1998). Also, the mean total length for all age classes for this study was larger than found in two Tennessee River impoundments (Clayton and Maceina 2002). However, the mean size of gizzard shad in the upper Barataria Estuary for each age class was within reported ranges for New Mexico (Jester and Jensen 1972). Female gizzard shad grew larger than males by age 3 and remained larger at age 4 in the upper Barataria Estuary, similar to the findings of Bodola (1964) in western Lake Erie. Although we could not discern if the lack of a predictable annual floodpulse has a positive effect on the growth of gizzard shad, the lack of a floodpulse does not negatively affect the growth of gizzard shad in the upper Barataria Estuary.

As detritivores, gizzard shad can be an important component of the phosphorous and nitrogen cycles in eutrophic systems (Vanni 1996, Sereda et al. 2008). Because the waterways of the upper Barataria Estuary have an abundance of detritus that originates from vegetation on the adjacent floodplain (Conner and Day 1992), the seasonal abundance of gizzard shad may impact local nutrient cycles. Upstream migration of lotic fish species can be an important mechanism for upstream transfer of energy and nutrients (MacAvoy et al. 2000). In river systems of the Atlantic coast, the seasonal inland migration of clupeids can increase local ammonia levels (Browder and Garman 1994) and contribute marine-derived organic matter to resident freshwater fishes (Garman and Macko 1998). Gizzard shad that migrate to the upper Barataria Estuary to spawn make energy and nutrients garnered from the lower estuary available to upper estuary species, and may be an important component of overall estuary production. In addition, larval and juvenile gizzard shad produced by a successful spawn may contribute energy and nutrients to upper Barataria Estuary residents.

Although the upper Barataria Estuary no longer functions as a large river floodplain with regard to a predictable floodpulse, gizzard shad use the area for spawning habitat. The open connection between the upper estuary and lower estuary allows for the movement of gizzard shad and other organisms between the upper and lower estuary. Because of our limited sampling area, we were not able to determine exactly where the gizzard shad were when they were not in the upper Barataria Estuary. Also, we do not know what level of salinity limits their southernmost distribution in the Barataria Estuary. Further study on seasonal nutrient cycling and trophic dynamics may reveal the importance of gizzard shad to the productivity of the upper Barataria Estuary, which continues to be a highly productive aquatic ecosystem despite the lack of a predictable annual floodpulse.

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