Prolonged Spawning of Adult Threadfin Shad and Contribution of Age-0 Threadfin Shad as a Brood Source of Summer Larval Presence in Hugo Reservoir, Oklahoma

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Abstract: Larval threadfin shad (*Dorosoma petenense*) collected in August trawl samples from Hugo Reservoir raised questions about the spawning potential of the parental fish population. Adult threadfin shad were collected weekly from 24 March to 25 August 1999 to determine their reproductive state. Gonadal somatic index (GSI) values for medium and large size classes increased until mid-May, and then steadily decreased. However, in spite of decreasing GSI values, mature ova (greater than 0.53 mm in diameter) were present in ovaries through mid July. It is likely that threadfin shad were capable of prolonged spawning throughout the spring and summer. A small proportion (4%) of age-0 threadfin shad matured within two to three months of hatching and served as a brood source for the summer larval production.

Key words: threadfin shad, ova, reproduction, gonadal somatic index, otolith

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Threadfin shad (*Dorosoma petenense*) have been widely introduced into reservoirs in the southern United States as forage for piscivorous game fishes. Threadfin shad meet several biological and ecological criteria of ideal prey. They are prolific, vulnerable to predation in all stages of life, and a good energy transfer vessel (Ney 1981, Noble 1981, DeVries and Stein 1990). Although winterkill occurs when water temperatures reach 5 C (Noble 1981), threadfin shad are able to rebound quickly because of high fecundity and prolific reproduction (Sammons et al. 1998). The reproductive ability of this species is evident in documentation and anecdotal observations of multiple or prolonged spawns in a single year and in the possibility of rapid sexual maturation of juvenile threadfin shad.

The possibility of multiple or prolonged spawns of threadfin shad in a single year has been reported throughout the Southeastern United States and Puerto Rico (Kilambi and Baglin 1969, Noble 1981, Stancil et al. 1997). Others have shown that juvenile threadfin shad grow rapidly, reach sexual maturity, and have the potential to spawn within a few months post hatching (Kimsey 1958, Swingle 1970, Heidinger and Imboden 1974, Noble 1981). However, with the exception of the Heidinger and Imboden study (1974), this age-0 reproduction has been limited to hatchery rearing ponds. Only Heidinger and Imboden (1974) have documented spawning of age-0 threadfin shad in a reservoir. Existing literature is limited regarding multiple or prolonged spawns of threadfin shad and the potential of age-0 threadfin shad to rapidly reach sexual maturity and spawn. Given the management value of threadfin shad as an important forage species in Southeastern reservoirs, this study was conducted to confirm and enhance the existing literature.

Larval trawl sampling at Hugo Reservoir, Oklahoma, in 1998 documented a primary period of larval threadfin shad abundance in May, followed by a continual presence of larvae through September (Summers et al. 1999; Fig. 1A). Questions about the temporal progression of adult threadfin shad ovarian maturation and spawning were raised. Questions were also raised as to whether age-0 threadfin shad hatched in the spring could serve as a brood source for larvae present in late summer. The objectives of this study were to 1) determine temporal patterns of egg development in adult threadfin shad and 2) to investigate the possibility of age-0 threadfin shad reproduction.

Methods

Hugo Reservoir (completed in 1974) is a 5,362-hectare U. S. Army Corps of Engineers flood-control impoundment on the Kiamichi River in southern Oklahoma. It is a turbid (secchi disc depth average 38 cm), shallow (3.6 m mean depth), mesotrophic reservoir devoid of macrophyte vegetation but heavily timbered. The dominant predators are largemouth bass (*Micropterus salmoides*), white crappie (*Pomoxis annularis*), white bass (*Morone chrysops*), and blue catfish (*Ictalurus furcatus*).

Weekly gill-net samples were collected from 24 March 1999 through 25 August 1999 with floating, five-panel, 38.1-m experimental gill-nets to evaluate temporal patterns of ova development of threadfin shad. Gill-nets were used based on historically high catch rates of shad at Hugo Reservoir. Mesh sizes were 9.5 mm, 12.7 mm, 15.9 mm, 19.1 mm, and 25.4 mm (bar mesh), with each panel measuring 7.62 m. The nets were deployed overnight in Salt Creek cove along a steep rock and clay shoreline in 3 to 4 m of water, and retrieved after sunrise the following morning. Threadfin

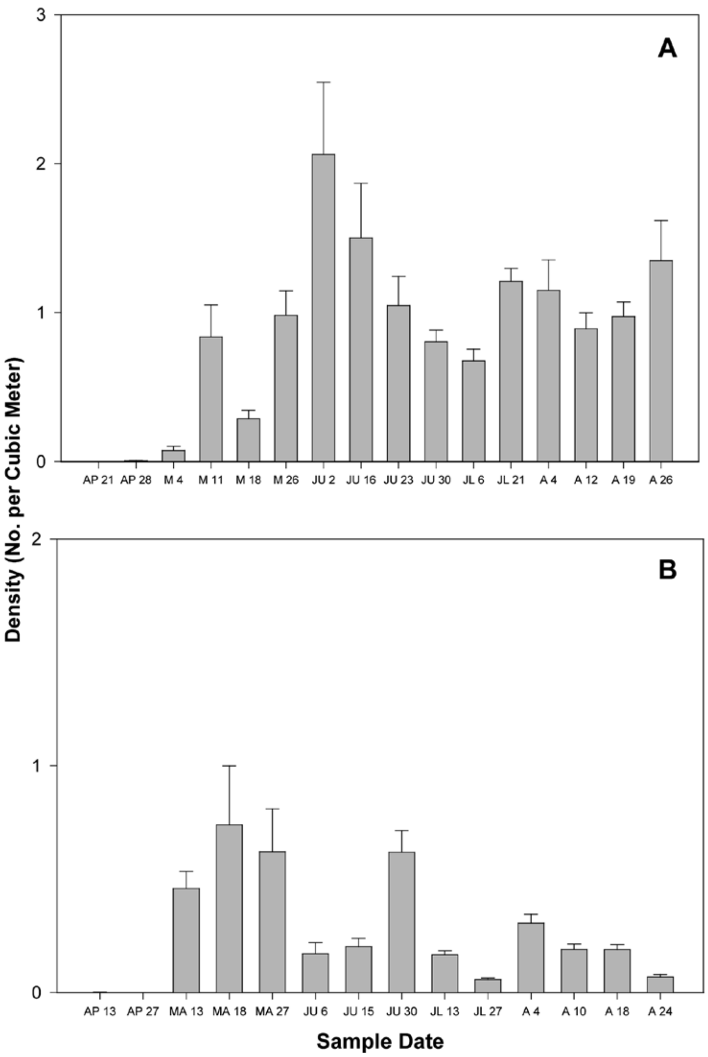

Figure 1. Larval (< 25 mm TL) threadfin shad densities (N / m^3) from Hugo Reservoir Oklahoma 1998 (A) and 1999 (B) trawl samples. Error bars represent ± 1 S.E. Data are from Summers et al. (1999).

shad were removed from the nets, immediately placed on ice, and taken to the laboratory for dissection and analysis within 12 h of capture.

Only female threadfin shad were retained for the study. Each individual was measured to the nearest mm total length (TL), and weighed to the nearest 0.01 g prior to dissection and ova examination. Fish were divided into three arbitrary length groups; small (≤ 80 mm TL), medium (81 to 120 mm TL), and large (>120 mm TL). A minimum of 10 females per length group were targeted for weekly analysis. After extraction, ovaries were blotted dry with a paper towel and weighed to the nearest 0.01 g prior to preservation in a 10% formalin solution. Saggital otoliths were removed and stored in vials containing glycerol for determination of age-0 fish and to count daily growth rings. Threadfin shad lacking an annulus on the otoliths were classified as age-0.

The Gonadal Somatic Index (GSI), a measure of sexual maturity, was calculated for each specimen as the weight of the ovaries as a percentage of the total weight of the fish prior to ovary removal (Shelton 1964, Kilambi and Baglin 1969, Heidinger and Imboden 1974, Cox and Willis 1986, Willis 1987, Buynak et al. 1992):

$$\text{Gonadal Somatic Index} = [\text{ovary weight (g)} \div \text{total body weight (g)}] \times 100$$

Monthly GSI by size class were compared chronologically using a box plot.

Ova diameter frequency plots were developed from measurements of a subsample (50% of each weekly sample) of ova from each length group to monitor seasonal ovarian progression. Preserved ovaries were teased apart with a forceps to avoid damaging individual ova and positioned on a glass slide. Each dissected ovary was viewed in three distinct sections at the front, middle, and rear to best represent the entire contents of the organ. A magnified digital image of each section was captured and saved for subsequent ova diameter measurements. Each image contained about 100 ova. The EPIX X-CAP image analysis program was used to measure a random sample of individual ova diameters to the nearest 0.01 mm. No ova smaller than 0.10 mm were included in the analysis. All ova greater than 0.53 mm in diameter were considered mature (Kilambi and Baglin 1969, Heidinger and Imboden 1974).

Sexually mature age-0 threadfin shad were aged to the nearest day by counting the number of daily growth rings on the saggital otoliths with the aid of a video camera-equipped compound microscope with 500X magnification as per Adams (2000). Age-0 threadfin shad were also collected weekly from mid April through August with paired 1-m^2, 500-micron mesh and 3-mm mesh trawl nets for another portion of the Hugo Reservoir study being conducted simultaneously (Summers et al. 1999, Adams 2000). Trawl samples were preserved in a 10% isopropyl alcohol solution. Samples were iteratively split until a subsample of approximately 50 shad was achieved. All shad ≤ 20 mm TL were identified using total myomere counts, and all shad ≥ 20 mm TL were identified to species using anal fin ray counts. Catch rates were determined by dividing the number of threadfin shad in each sample by the volume of water sampled. All threadfin shad < 25 mm TL were considered larvae (Summers et al. 1999, Adams 2000).

Results

GSI Analysis

A total of 591 female threadfin shad were retained for GSI analysis. Mean GSI increased monthly through May in the large and medium length classes, followed by a steady decline (Figs. 2A, 2B). The small length class showed similar progression of GSI through

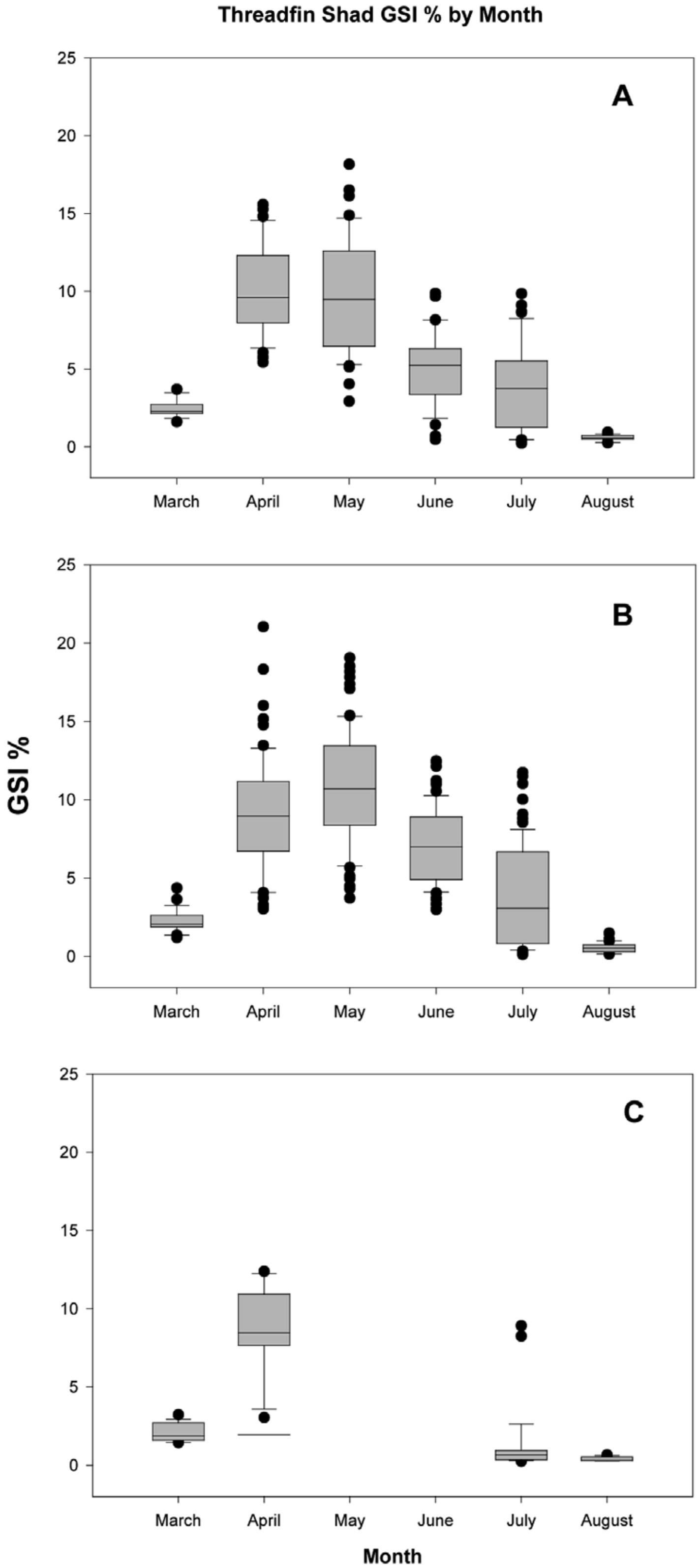

Figure 2. Threadfin shad monthly GSI box plot by size class: A—large (>120 mm TL, *N* = 172); B—medium (81–120 mm TL, *N* = 357); C—small (≤ 80 mm TL, *N* = 63). The shaded box includes GSI values between the 25th and 75th percentiles of the mean (horizontal line in the shaded box). The error bars extend to the 5th and 95th percentiles. All outliers beyond the 5th and 95th percentiles are plotted as points.

April before fish outgrew this length class (Fig. 2C). As GSI decreased in the two largest length classes, sexually mature threadfin shad were still represented in the upper portion of the shaded box (50th to 75th percentile) as well as the outlying points above the 95th percentile bar (Figs. 2A, 2B). Two individuals from the small size class in the July sample had much higher GSI than the rest of the fish in this length class (Fig. 2C). Gonadal somatic indices for all three length classes decreased to almost zero in August samples.

Ova Diameter Analysis

Ovaries from 295 fish were used in ova diameter analysis. For simplification of the results, only the first week of each monthly sample was plotted. Subsequent weekly samples of each month closely resembled the first weekly sample. Two clearly distinguishable modes of ova were present in ovaries of threadfin shad through the 1 July sample (Fig. 3). The larger mode of ova was loose within the ovarian lumen. Beginning in August, few measurable ova (>0.10 mm) were found in the ovaries (Fig. 3E). This ova diameter frequency plot for ≥ 81 mm fish is representative of all threadfin shad sampled, regardless of length class. The largest ova diameters were observed in late April and early May and measured up to 0.80 mm.

Larval Shad Presence

In 1999, Larval shad were first collected in the 13 May trawl sample, and the peak density was 0.74 / m^3 (SE = 0.26) in the 18 May sample (Fig. 1B). Trawl samples continued to collect larval threadfin shad through August 1999 (Fig. 1B).

Age-0 Spawning Potential

Only two of 53 (4%) age-0 threadfin shad collected after 25 June had developed mature ova. Both gravid specimens were captured in the 8 July sample and measured 69 mm TL with GSI greater than 8% (Fig. 2C). One fish was aged to an estimated 63 days through daily growth ring counts and had a GSI of 8.9%. The other was aged to 59 days and had a GSI of 8.3%. The ovaries of both fish contained mature ova (diameters > 0.53 mm) which were not attached to the ovarian lumen.

Discussion

The presence of larval shad in August trawl samples and the results of the GSI and ova diameter analyses indicate prolonged spawning of threadfin shad in Hugo Reservoir. A threadfin shad spawned in early July would be between 10 mm and 22 mm in length by August based on growth rates calculated for Hugo Reservoir (Adams 2000). Larval fish of this length were plentiful in

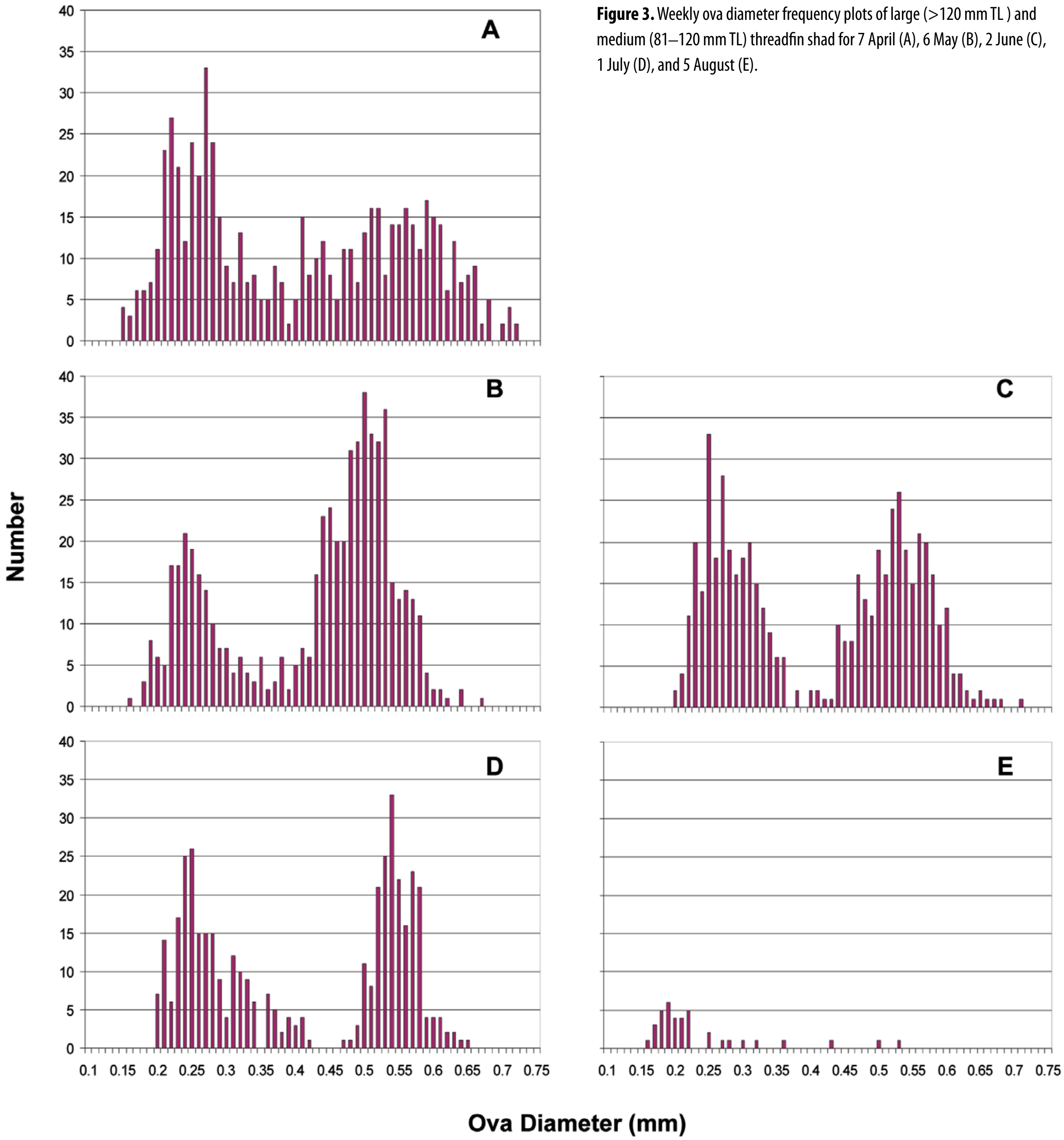

Figure 3. Weekly ova diameter frequency plots of large (>120 mm TL) and medium (81–120 mm TL) threadfin shad for 7 April (A), 6 May (B), 2 June (C), 1 July (D), and 5 August (E).

August 1999 trawl samples. Mean GSI remained at or above 5% until mid-July with many individual GSI greater than 8%, indicating that fish were sexually mature and able to release mature ova (Fig. 2). The progression of ova diameter also supports the previous observations. Mean ova diameter values of 0.55 mm or greater were reached in May and remained until mid-July (Fig. 3). Gonadal somatic indices decreased consistently following the initial peak in May, but the presence of mature ova in the ovaries restricted mean GSI from declining below 1% until mid July. The presence of mature ova in the 14 July sample but almost completely absent in subsequent weekly samples suggests that a final pulse of mature ova had been released.

The minimum GSI considered to be mature were bracketed in the literature by values of 19% (Johnson 1971) and 8.8% (Heidinger and Imboden 1974). Mean GSI peaks of 10.1% in the large length group April sample, and 10.9% in the medium length group May sample were the highest mean indices in the entire sampling period (Fig. 2). The largest individual GSI recorded was 21.0%, for a 93-mm threadfin shad collected on April 28. The GSI from this study are near the lower end of published values. The mean GSI for all shad greater than 80 mm during May in this study were slightly lower than published values considered as mature (14% by Kilambi and Baglin 1969, and 12% by Shelton 1964). Gonadal somatic indices from June through August also resemble GSI trends from other studies. Johnson (1971) recorded GSI around 5% during the month of June. Heidinger and Imboden (1974) observed mean GSI of 9.6% and 8.8% in a sample of age-0 shad during July and August, respectively. Shelton (1964) recorded mean GSI between 5% and 10% for June and July samples.

The July ova diameter data also supports the hypothesis of prolonged spawning. Mature ova (> 0.53 mm in diameter) were present in ovary samples from 7 April through 1 July (Fig. 3). After mid July, the mode of mature ova was no longer observed in the samples, and few measurable ova (>0.10 mm) remained in the ovaries. When subsequent samples showed no further presence of this mode of mature ova, in conjunction with a drastic decline in GSI, it was assumed that the mature ova were released in early July spawning. Ova diameters in this study were less than those previously reported. Ova diameter modes from mature fish were at 0.75 mm and 0.35 mm in the Kilambi and Baglin (1969) study and 0.82 mm and 0.40 mm in the Johnson (1971) study. Ova diameter modes from mature ovaries in Hugo Reservoir were about 0.60 mm and 0.30 mm. In order for oviparous fishes, including *D. petenense*, to release ova, the ova must be released from the attachment to the ovary (Shelton 1978). The largest cohort of ova from this study was clearly loose in the ovarian lumen.

It is well documented that threadfin shad spawning activity occurs around sunrise (Gerdes and McConnell 1963, Lambou 1965, Shelton 1972, Heidinger 1983). Because fish were collected after sunrise, it is possible that some of the largest mature ova had already been released prior to collection. Also, mature ova may have been released when netted shad struggled against the mesh of the nets: the pressure of the mesh on the abdomen of the fish may have increased this likelihood. Despite intense summer heat, most of the shad collected were still alive when the nets were retrieved, suggesting that the majority of specimens became entangled in the nets just prior to collection.

The inconsistency of collecting threadfin shad less than 80 mm during the study may be attributed to growth during sampling. Fish from the small length group were collected for the first five weekly samples, then were absent until the 25 June sample. The threadfin shad collected in March and April may have been the smallest of the overwintered age-1 fish from the summer 1998 spawn. Since most of these threadfin shad were near the upper limit of the small length group, it is likely that they grew larger during the sampling period, and were recruited into the medium length class. The small threadfin shad that began appearing in collections in late June were the first of the age-0 fish to grow into a designated length group. The absence of annulus formation in conjunction with the small size of the otoliths of these threadfin shad confirms they were age-0 fish and only months old.

A small portion (4%) of the age-0 population had mature ova (>0.53 mm in diameter) and elevated GSI (8.9% and 8.3%) in mid-July. This observation supports Heidinger and Imboden's (1974) conclusion of age-0 threadfin shad reproduction in an Illinois reservoir and Noble's (1981) review of threadfin shad potentially spawning within months of hatching. Along with the Heidinger and Imboden (1974) study, this is the only other study to present ova diameter data and GSI data to support age-0 threadfin shad reproduction outside of hatchery rearing ponds. Although the percentage of age-0 fish capable of spawning is likely minimal (4% in this study), the total contribution to the threadfin shad population by age-0 fish cannot be disregarded. Even if just 4% of the total age-0 population serve as brood fish, their contribution to late summer larval shad densities may be significant. Further evaluation of age-0 spawning is recommended to better grasp the proportion of summer larvae produced by age-0 threadfin shad.

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