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GIZZARD SHAD STOCK ESTIMATE FOR LAKE APOPKA, FLORIDA, 1996

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Executive Summary

Gizzard shad *Dorosoma cepedianum* have achieved a large biomass in Lake Apopka, Florida. Removal of a large portion of this biomass will remove significant amounts of phosphorus in this highly eutrophic lake and help create conditions more conducive for establishing desirable sportfish populations. Under the direction of the St. Johns River Water Management District, 249,748 kg of gizzard shad were harvested from Lake Apopka during March-May 1996. Evaluation of this restoration method requires determining the proportion of the total gizzard shad population harvested. This report provides population estimates of gizzard shad prior to the harvest and evaluates methods used to produce the population estimates.

Population estimates were calculated by change-in-composition, depletion (Leslie estimate), and Baranov's catch equation methods. Input data for these calculations included harvest and fishing effort for the duration of the subsidized commercial fishery (7 March-23 May 1996); age, length, weight, and gender of fish in experimental gill net (6.4-12.7 cm square mesh) samples collected before and after the commercial fishery and monthly during the commercial fishery; and fish length and weight in subsamples of the commercial gill net catches during January-May 1996. Age was determined by analysis of sagittal otoliths obtained from the sampled fish. Validation of otoliths for ageing gizzard shad was constrained by lack of otoliths collected throughout the year; however, marginal increment analysis of otoliths collected during January-June suggested otoliths provided accurate ages of gizzard

shad in Lake Apopka. We assumed the ages of gizzard shad assigned by otolith analysis were accurate and used these ages in population estimation calculations.

The change-in-composition method estimated the population of Lake Apopka gizzard shad age-1 and older in February 1996 was 726,228 fish (95% confidence limits [CL] = 718,706 and 733,750 fish) weighing 245,683 kg (95% CL = 243,138 and 248,228 kg). The estimate for the total population (all ages) was 2,019,268 fish weighing 458,129 kg.

The depletion method estimated the population of age-1 and older gizzard shad in February 1996 was 899,681 fish (95% CL = 732,753 and 1,288,907 fish) weighing 375,527 kg (95% CL = 305,851 and 537,990 kg). The depletion method estimated the total population was 2,200,192 fish weighing 589,201 kg.

The catch equation method estimated the population of age-1 gizzard shad in January 1995 was 2,073,744 fish (95% CL = 1,947,327 and 2,204,113 fish) weighing 1,174,361 kg (95% CL = 1,102,771 and 1,248,189 kg). Expanding the estimate to the entire population resulted in an estimated 6,455,109 fish weighing 1,917,002 kg.

We consider all three methods appropriate for the population estimated and the data available. Therefore, the best estimate of the total gizzard shad population is 2,019,268-6,455,109 fish weighing 458,129-1,917,002 kg. This estimate equates to a density of 162-518 fish/hectare and a biomass of 37-154 kg/hectare which is lower than expected for hypertrophic Lake Apopka.

In January-April, 1995, the subsidized commercial fishery harvested 281,198 kg of gizzard shad; estimated exploitation rates, based on three population estimates for January

1995 were 24-43%. During March-May 1996, the subsidized commercial fishery harvested 249,748 kg of gizzard shad; this harvest amount was 67-102% of the estimated harvestable population weight in February 1996.

While the comparison with other biomass estimates and high exploitation rates suggest the population estimates are low, several population variables support high exploitation rate and, hence, relatively small population size. First, gizzard shad in Lake Apopka had rapid growth rate and recruited to the commercial fishery at age-1; new recruits are a large portion of the commercial landings. Second, high exploitation rates are expected to result in overfishing. The lower estimated population in 1996 than in 1995, the decline in mean weight of fish captured by the experimental gill nets from 1995 (Schramm and Pugh, 1996) to 1996, and the decline in mean weight of fish in each age class from February 1996 to May 1996 indicate overfishing occurred.

We conclude that the population estimates provided in this report are reasonable. Based on these estimates, the harvest of gizzard shad during 1995 and 1996 substantially reduced the Lake Apopka gizzard shad population.

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Gizzard Shad Stock Estimate for Lake Apopka, Florida

Gizzard shad *Dorosoma cepedianum* have achieved a large biomass in Lake Apopka, Florida. Removal of a large portion of this biomass will remove significant amounts of phosphorus in this highly eutrophic lake and may provide a gizzard shad population more conducive for establishing desirable sportfish populations. Under the direction of the St. Johns River Water Management District, commercial gill netters removed 249,748 kg of gizzard shad from Lake Apopka during 7 March-23 May 1996. The purpose of this project is to estimate the stock of gizzard shad prior to the harvest and to evaluate methods used to provide the stock estimates.

Methods

Fish Sampling

The subsidized Lake Apopka gizzard shad commercial fishery began 7 March 1996 and continued until 23 May 1996. Commercial harvest of gizzard shad was allowed before and after the subsidized fishery. Gill nets used by commercial fishers had mesh size of 10.2-cm to 11.4-cm square mesh. Weights of landings, yards of nets, and hours fished were recorded daily for each fisher.

Three samples of gizzard shad were collected with standard experimental gill nets by the Florida Game and Fresh Water Fish Commission (FGFWFC) and Mississippi State University (MSU) 20 February 1996 prior to the beginning of the subsidized commercial fishery. The experimental gill nets were 90-m long and consisted of six, 15-m long panels of 6.4-cm to 12.7-cm stretch mesh. Gill nets were fished until a minimum of 100 fish was obtained for each of three replicate samples. Using the same experimental gill nets, samples of gizzard shad were obtained by FGFWFC 26 March and 25 April. Three replicate samples of gizzard shad were collected 29 May (after the commercial fishery terminated) with standard experimental gill nets by FGFWFC and MSU. Gill nets were fished until approximately 100 fish were obtained for each of three replicate samples. Total length (TL, mm), weight (g), and gender were recorded and sagittal otoliths were removed from all fish in all samples. Otoliths were sent to MSU for age analysis.

Random samples of commercial gill net catches in January, March, April, and May 1996 were obtained by FGFWFC. Total length and weight were measured for gizzard shad in these samples.

Otolith Analysis

Gizzard shad were aged by analysis of sagittal otoliths. Except for otoliths of small (<250 mm TL) gizzard shad, opaque bands were not visible in whole view and sectioning otoliths was necessary to count opaque bands. Otoliths were prepared for analysis using methods similar to those evaluated by Benton et al. (1995). Whole otoliths were ground to make a thin dorso-ventral cross section that included the nucleus. Large otoliths (generally from fish larger than 300 mm TL) were held with a forceps to grind the anterior end of the otolith to near the nucleus. The partially ground otolith was mounted ground face down on a glass slide with thermoplastic cement. The posterior end was then ground leaving a thin (usually less than 0.5 mm), cross section of the otolith containing the nucleus. Smaller otoliths were mounted vertically (anterior end up) on a glass slide with thermoplastic cement and the anterior end ground in a dorso-ventral plane to approximately the nucleus. The thermoplastic cement was heated to loosen the partially ground otolith, and the otolith recemented with the ground face on the slide. The posterior end was then ground as for larger otoliths. All otoliths were ground with a wet grinder until opaque bands were visible. Otoliths were then polished by wet-sanding with extra-fine, wet-dry sandpaper.

Sectioned and whole otoliths were viewed using compound and dissecting microscopes. Immersion oil was applied to the mounted otoliths to improve clarity. Opaque bands appeared as dark bands when viewed with transmitted light (cross sections viewed with a compound microscope) and as white bands when viewed with reflected light (whole otoliths and cross sections viewed with a dissecting microscope). Two readers independently aged all otoliths. Differences in interpretation were discussed and resolved. Agreement was reached on assigned age for all fish.

Although otoliths have been demonstrated to provide accurate ages for a variety of freshwater fishes, otoliths have not been validated (*sensu* Beamish and MacFarlane 1983) as accurate ageing structures for gizzard shad. Marginal increment analysis (Schramm and Doerzbacher 1983; Casselman 1987) was performed to provide presumptive validation of Lake Apopka gizzard shad. Opaque bands (presumptive annuli) are initially formed at the surface of an otolith and would be visible in whole or cross-sectional views as an opaque zone at the otolith margin. An opaque band (annulus) is considered formed when a translucent or hyaline zone is visible distal to the opaque band. The hyaline zone distal to the most recently formed opaque band is called the marginal increment. In the case of a recently formed opaque band, the marginal increment would be narrow and a small proportion of the otolith radius. In the case of an opaque zone at the otolith margin, the marginal increment is zero. For relatively fast-growing and short-lived species such as gizzard shad, a marginal increment less than 5% of otolith radius may indicate the presence of a recently formed opaque band. If marginal increment analysis indicates that opaque bands are formed only once a year and during a relatively brief time period, the opaque bands can be considered valid annuli. Marginal increment analysis of Lake Apopka gizzard shad was conducted for fish collected during January-June 1995. All otoliths were inspected for the presence of opaque zones at the otolith margin and their presence noted. Marginal increment as a proportion of otolith radius (R_x/OR) was calculated for all fish.

To further evaluate the validity of otoliths for ageing gizzard shad, we conducted marginal increment analysis for gizzard shad collected from Aliceville Lake, Mississippi. Analysis was performed for gizzard shad collected during January-May 1995.

Weight-Length Relationships

Weight-length relationships were developed for gizzard shad collected with experimental gill nets in February 1996. Differences between male and female weight-length relationships were tested by analysis of covariance. All statistical analyses were performed using SAS (1990).

Population Estimation

Population size was estimated by the change-in-composition (dichotomy) method, depletion (Leslie) method, and Baranov's catch equation method. Computations for all methods follow Ricker (1975).

Change-in-Composition Method

This method can be used to estimate population size if there are two types of fish in a population and the abundance of one type can be altered differentially from that of the other type. Growth rate of female gizzard shad in Lake Apopka was greater than growth rate of male gizzard shad (Benton et al. 1995; Schramm and Pugh 1996). As a result of faster growth rate, the larger female fish would be more vulnerable to the large-mesh commercial gill nets and, therefore, removed at a greater rate than would males.

Given that N is the number of gizzard shad, N_m is the number of male gizzard shad, and N_f is the number of female gizzard shad at $t=1$ (i.e., before the commercial fishery began), maximum likelihood estimators of N, N_m, and N_f are, after Chapman (1955):

$$N_m = \frac{p_1(C_m - p_2C)}{p_1 - p_2},$$

$$N = \frac{C_m - p_2C}{p_1 - p_2}, \text{ and}$$

$$N_f = N - N_m;$$

where:

$p_1 = m_1/n_1,$

$p_2 = m_2/n_2,$

n_1, n_2 are the size of samples taken at the beginning ($t=1$) and end ($t=2$) of the harvest period,

m_1, m_2 are the number of males in samples n_1, n_2,

f_1, f_2 are the number of females in samples n_1, n_2,

C_m = number of males caught during the harvest period (between $t=1$ and $t=2$),

C_f = number of females caught during the harvest period (between $t=1$ and $t=2$),

$C = C_m + C_f.$

Confidence limits for N were calculated from the variance of N by

$$Var\ (N) = \frac{N^2\ Var(p_1) + (N\text{-}C)^2\ Var(p_2)}{(p_1 - p_2)^2}$$

where:

$$Var\ (p_1) = \frac{p_1(1\text{-}p_1)(1\text{-}n_1/N_1)}{n_1 - 1}$$

$$Var\ (p_2) = \frac{p_2(1\text{-}p_2)(1\text{-}n_2/N_2)}{n_2 - 1}$$

N_1 = the estimated number of fish at time 1

N_2 = the estimated number of fish at time $2 = N_1 + C$

(Everhart and Youngs, 1981).

The proportion of males (m_1, m_2) and proportion of females (f_1, f_2) at the beginning and end of the harvest period were obtained from the experimental gill net samples before (26 February) and after (29 May) the harvest period. The number of males caught during the harvest period (C_m) was obtained by summing the products of the proportion of males in commercial gill nets (estimated from catches in experimental gill nets, see below) multiplied by the estimated number of fish landed during three time periods in the commercial fishery (27 February-26 March, 27 March-25 April, and 25 April-29 May 1996). (Note: We included commercial landings from several days before the beginning of the subsidized fishery and several days after the end of the subsidized fishery, because these harvests affected the change in sex ratio measured 26 February to 29 May 1996.) Similarly, summing the mean proportion of females in a sample multiplied by the estimated number of fish landed in the corresponding time period for the three time periods provided an estimate of C_f.

The proportion of males and females for each sample was estimated from the experimental gill net samples obtained at the end of each time period; e.g., the 26 March sample was used to estimate the sex ratio of landings during 26 February-26 March. Length data for fish caught by commercial gill nets in 1995 indicated gizzard shad recruited to the commercial gill nets at 300 mm (Schramm and Pugh 1996). In 1996, commercial gill net length-frequency data were available for January, March, and May. These data were compared with experimental gill net catch to determine the minimum length at which gizzard shad recruited to the commercial gill nets. Fish longer than this length caught with the experimental gill nets were assumed to be representative of fish caught in the commercial gill nets. Therefore, the proportions of males and females in the commercial landings during 27 February-26 March were the numbers of males and females large enough to recruit to the commercial gill nets divided by the total number of fish large enough to recruit to the commercial gill nets in the 26 March experimental gill net sample. Similarly, the proportions of males and females in the 27 March-25 April commercial landings were the number of males and females large enough to recruit to the commercial gill nets divided by the total number of fish large enough to recruit to the commercial gill nets in the 25 April experimental gill net sample. The proportions of males and females in the 26 April-29 May commercial landings were the number of males and females large enough to recruit to the commercial gill nets divided by the total number of fish large enough to recruit to the commercial gill nets in the 29 May experimental gill net sample. The numbers of fish landed during the 27 February-26 March, 27 March-25 April, and 26 April-29 May time periods were estimated by dividing the weights landed during these time periods by the mean weights of fish large enough to recruit to the commercial gill nets in the experimental gill net samples obtained 26 March, 25 April, and 29 May, respectively. Mean weight for the May sample was calculated from the mean weights of the three replicate samples; mean weights for the March and April samples (no replicates) were the average weight of fish caught in each sample.

The numerical population estimate and 95% confidence limits were converted to weight by multiplying by average weight of fish in the February experimental gill net sample.

The change-in-composition method estimated the number of gizzard shad in the population effectively sampled by the standard experimental gill nets in February 1996 (essentially age-1 and older fish). We estimated the number of fish not recruited to the experimental gill nets (age-0 fish) from the total mortality estimate from the January 1995 catch curve and the February 1996 population age structure. The total mortality estimate from the January 1995 catch curve was used because it was a better estimate of natural mortality than was the February 1996 mortality estimate, which included fishing mortality; age-0 fish were affected principally by natural mortality, whereas fishing mortality affected age-1 and older fish. This estimation procedure required the assumption that mortality of age-0 fish was the same as the mortality of fish in the sample used to estimate Z (ages 1-5 fish). The number of age-1 fish was estimated from the population estimate times the proportion of age-1 fish in the February 1996 experimental gill net sample. Dividing the estimated number of age-1 fish by the annual survival rate (S, $S = e^{Z}$) provided an estimate of the number of age-0 fish. Confidence limits for the estimate of age-0 fish were obtained by dividing the number of age-1 fish by S calculated from the upper and lower 95% confidence limits for Z in January 1995.

The total number and weight of the Lake Apopka gizzard shad population in February 1996 was estimated by adding the number and weight of age-0 fish to the number and weight of fish estimated by the change-in-composition method. Because the total population estimate was based on a biological assumption (*viz.* that survival of age-0 fish was the same as age-1 and older fish), statistical confidence limits were not calculated for the total population estimates.

Depletion Method

This method estimates the size of the population from the equation that represents the relationship between catch/effort (C/f) and cumulative catch (K) (Ricker 1975):

$$C/f = a + q(K);$$

where:

a is the y-intercept of the regression equation, and

q is the slope of the regression equation.

The initial population (N_0) was estimated by substituting $C/f = 0$ into the equation and solving for K; at $C/f=0$, $K = a/q = N_0$.

The relationship between C/f and K was obtained by linear regression of the commercial gizzard shad landings. Catch rate (C/f) is expected to be highly variable due, possibly, to changes in efficiency of the gear with weather and changes in the behavior of the fish that would affect catchability. In an attempt to reduce some of this variation and provide a regression model that best fit the data, separate regressions were performed using average daily C/f, average weekly C/f, and average biweekly (2-week time periods) C/f for the period of commercial harvest (5 March - 29 May). In the above regressions, f was defined as (1) 100 yards of net multiplied by hours fishing and (2) 100 yards of net. Therefore, a total of six regression equations were calculated.

Confidence limits for the depletion estimates were estimated by solving for N (using the upper and lower values from the quadratic equation as upper and lower confidence limits) in the formula provided by DeLury (1951):

$$N^2(q^2-t_p^2s_{yx}^2c_{22})-2(q^2N_0-t_p^2s_{yx}^2c_{12})N+(q^2N_0^2-t_p^2s_{yx}^2c_{11})=0$$

where:

q = catchability coefficient, slope of regression,

N_o = estimated population at $t=0$,

s^2_{yx} = variance of the points of the regression line,

c_{11} = $\Sigma X^2/n\Sigma x^2$, where X is K and Σx^2 is sum of squares of K, $\Sigma K^2-(\Sigma K)^2/n$,

c_{12} = $\Sigma X/n\Sigma x^2$.

$c_{22} = 1/\Sigma x^2.$

t_p = the *t*-statistic corresponding to a given probability *P* for *n* - 2 degrees of freedom,

n = the number of fishing periods.

The depletion method estimated the initial population before the commercial fishery began (i.e., in February 1996) in weight (calculations were made with pounds data). Estimated population and 95% confidence limit weights were converted to numbers of fish by dividing the mean weight of all fish in the February experimental gill sample that were considered recruited to the commercial gill nets (see Change-in-Composition Method) into the estimated population and 95% confidence limit weights.

The depletion method estimated the population size recruited to the commercial gill nets (essentially age-1 and older fish). We estimated the numbers and weights of fish not recruited to the commercial gill nets (age-0 fish) and the total population by the same procedure as for the change-in-composition method.

Baranov Catch Equation

Total instantaneous mortality (*Z*) is the sum of instantaneous fishing mortality (*F*) and instantaneous natural mortality (*M*) (Ricker 1975):

$$Z = F + M.$$

Z is the negative slope of the regression of ln(*N*) on age (catch curve). This estimation of *Z* assumes recruitment and mortality are constant for a time period at least equal to the life span of the fish. Because the catch curve is based on age measured in years, *Z* is an "annualized" rate; i.e., the reduction in the abundance of fish from age 2 to age 3 is assumed to occur in one year. There is no sport harvest of gizzard shad in Lake Apopka. Total mortality before the commercial fishery begins ($F = 0$) is natural mortality. Assuming natural mortality (M) remains constant, the difference between total mortality after 1 year of commercial harvest (Z_2) minus total mortality at the beginning of the commercial fishery (Z_1) is fishing mortality:

$$Z_2 - Z_1 = F.$$

From estimation of Z and F, population size (N) can be calculated by Baranov's catch equation (Ricker 1975):

$$C = \frac{FAN}{Z} = uN,$$

where:

C is total catch (fish harvested during January-April 1995)

$A = 1 - e^{-Z}$, actual total (annual) mortality

$u = \frac{FA}{Z}$, exploitation rate for a Type 2 fishery (fishing and natural mortality operate concurrently)

Z_1 was estimated from the catch curve prior to the 1995 commercial gizzard shad harvest (i.e., from the age frequency of fully recruited fish in the 11-12 January 1995 experimental gill net catch)

Z_2 was estimated from the catch curve 1 year later (i.e., from the age frequency of fully recruited fish in the 26 February 1996 experimental gill net catch).

No formula exists for the variance of N estimated by the catch equation. Confidence limits for catch equation estimation of N were developed from the pooled variance of Z_1 and Z_2. Confidence limits were calculated by substituting the upper and lower 95% confidence limits and the corresponding values for A (calculated from the upper and lower confidence limits of Z) in the catch equation. The confidence limits of Z were calculated from the pooled variance of $Z_1, Z_2 \times t_{df,\,0.025}$.

The catch equation method estimated the number of fish fully recruited to the experimental gill net in January 1995. Estimated population size in numbers of fish was converted to weight by multiplying the estimated number of fish by the mean weight of fish fully recruited to the experimental gill net in January 1995.

The catch curves were calculated for age classes fully recruited to the experimental gill nets (age-1) fished in January 1995 and May 1996. We estimated the numbers and weights of age-0 fish and the total population by the same procedure as for the change-in-composition method, except the number of age-1 fish was estimated from the population estimate times the proportion of age-1 fish in the January 1995 experimental gill net sample.

Results

Otolith Analysis and Validation

The age-length frequency (Figure 1) and mean lengths of age classes (Table 1) indicated fish with more opaque bands (i.e., were aged as older fish) were larger.

Of 391 gizzard shad collected 26 February 1996, otolith analysis was completed for 335 fish; otolith analysis was not possible for 56 fish because otoliths were broken or mounting and grinding did not result in an otolith preparation that allowed ageing. Of these 335 fish, 3 fish (2 age-2 and 1 age-3) had opaque bands at the otolith margin and 0-100% of fish had a marginal increment ≤10% of the otolith radius (Table 2). Of 322 gizzard shad collected 29 May 1996, otolith analysis was completed for 257 fish. Of these 257 fish, 3 age-1 fish had opaque bands at the otolith margin and 0-42% had the most recently formed opaque band relatively close (≤10% of otolith radius) to the otolith margin (Table 2).

Analysis of gizzard shad collected from Aliceville Lake, Mississippi, also indicated few fish formed opaque bands during January-June 1995 (Table 3). No fish had an opaque band at the otolith margin (marginal increment 0.000) and mean marginal increment remained relatively high. A few older fish had marginal increments less than 5% of otolith radius. As in Lake Apopka, small marginal increments were found on older fish, which are expected to have the smallest growth increment. Small (≤5% of otolith radius) marginal increments were relatively common in the January sample compared to February-June. The prevalence of small marginal increments in January compared to February-June may have resulted from the smallest amount of growth since the time of last annulus formation.

Fish with a high percentage of small marginal increments had 3 or 4 opaque bands on their otoliths (presumptively age-3 or age-4). This is attributable to slow growth in length (and in otolith radius) of older and larger fish (i.e., only a small increase in otolith radius since the formation of the last opaque band). The low frequency of otoliths with opaque bands at the otolith margin suggests that opaque bands had not formed on the gizzard shad otoliths during February-May in Lake Apopka (Table 2) or during January-June in Aliceville Lake (Figure 3). However, the increase in length with increase in number of opaque bands suggests an opaque band forms at some time during the year. The presence of opaque zones at the otolith margin of relatively high percentages of gizzard shad collected in Lake Apopka in June 1995 and the scarcity of small marginal increments during January-June suggests that opaque bands are just beginning to form in June (Schramm and Pugh 1996). Unfortunately, samples were not obtained during June-December to determine the time when opaque bands form and, therefore, verify that opaque bands form only once a year. The consistent decrease in mean length of Lake Apopka gizzard shad in each presumptive age class between February and May (Table 1) could result from some fish forming an opaque band during February-May. We believe this decline in mean length in each presumptive age class between February and May resulted from overfishing the gizzard shad population (see Discussion). For the purpose of this report, the number of opaque bands on gizzard shad otoliths will be considered accurate ages of Lake Apopka gizzard shad. It is important to recognize that very few Lake Apopka gizzard shad had formed an opaque band during February-May. Therefore, ages were assigned uniformly to year classes during the investigation period; e.g., 1994 year-class fish collected in February-May all would have one opaque band on their otoliths.

Weight-Length Relationships

Weight (*WT*) and total length (*TL*) were measured for 391 gizzard shad collected with experimental gill nets in February. Mean length of fish collected was 313.2 mm (*SE* = 1.92, range = 205-420 mm) and mean weight was 338.3 g (*SE* = 10.8, range = 73-788 g). The weight-length relations for Lake Apopka gizzard shad did not differ (P=0.237) between male and female fish. The weight-length relation for Lake Apopka gizzard shad was:

all fish: $log_{10}(WT) = -5.5393 + 3.2224\ log_{10}(TL)$

$N = 391,\ R^2 = 0.9426.$

Female gizzard shad growth rate was faster than male gizzard shad (Table 1). The difference in growth rate between genders was significant in May (P=0.014) but not in February (P=0.325). The lack of significant difference between genders in February was influenced by the collection of a single, relatively large age-4 male and two, relatively small age-4 females.

Commercial Harvest

After the termination of the 1995 subsidized commercial fishery ended, small weights of gizzard shad were harvested from Lake Apopka during July 1995-February 1996 (Table 4). Landings substantially increased during the 1996 subsidized commercial fishery (7 March-23 May), and then declined to low catch rates through September 1996.

Change-in-Composition Estimate of Population Size

The Lake Apopka gizzard shad population was 37.46% males in February (Table 5). Females were a larger percentage of the harvest than males. In May, the population was 54.83% males.

Sex ratio data for the commercial landings were estimated from experimental gill net catches of fish large enough to recruit to the commercial gill nets. Comparisons of samples of fish from the commercial landings and experimental gill net catches indicated gizzard shad were fully recruited to the commercial gill nets at 310 mm in January (Figure 2), at 330 mm in March (Figure 3) and 300 mm in May (Figure 4). Schramm and Pugh (1996) concluded that gizzard shad recruited to the commercial gill nets fished in Lake Apopka in 1995 at 300 mm. Considering both 1995 and 1996 data, 300 mm was chosen as the minimum length of shad fully recruited to the commercial gill nets in 1996. Therefore, we estimated the sex ratio of fish in the commercial landings from fish longer than 300 mm caught by the experimental gill nets. Mean percentages of male gizzard shad longer than 300 mm in experimental gill nets catches were 42.86% in March, 31.25% in April, and 37.79% in May (Table 5).

Mean weights of fish in the commercial gill net landings for each time period were also based on fish longer than 300 mm caught with experimental gill nets at the end of each time period (Table 5). Total landings during the three harvest periods ranged from 51,284-114,644 kg and 164,425-300,981 fish (Table 5).

By calculation, the pre-commercial harvest population of gizzard shad was:

males (N_m) = 272,016 fish

females (N_f) = 454,212 fish

total estimated population (N) = 726,228 fish; lower and upper 95% confidence limits

= 718,706 and 733,750 (Table 6).

(Note: calculations were based on greater precision than shown in Table 5.)

Average weight of fish sampled by the experimental gill nets in February was 338.3 g (N=3, standard error=10.0; Table 5). Applying this weight to the population estimation resulted in an estimated population standing stock of 245,683 kg with 95% confidence limits of 243,138 kg and 248,228 kg (Table 6).

The change-in-composition method estimated the number of fish recruited to the experimental gill nets in February 1996. Fish recruited to the experimental gill nets primarily were age-1 and older; age-0 fish were 0.60% (2 of 335) of fish in the February samples (Table 7). Therefore, the population of age-1 and older fish was 721,871 fish (726,228 x .9940) weighing 244,209 kg. Age-1 fish were 58.86% of the fish age-1 and older in the February experimental gill net sample. Therefore, the estimated number of age-1 fish was 424,893 fish. Annual survival rate, based on total mortality rate for age-1 and older fish in February 1996 (Z=1.1130, see Baranov Catch Equation Population Estimation) was 0.3286. Assuming age-0 survival rate was the same as for age-1 and older fish, the population of age-0 fish in February 1996 was 1,293,040 (Table 8). Using the 95% confidence limits for Z (Z = 1.1130 $\pm$ 0.3803, hence S_{lower} = 0.4806 and S_{upper} = 0.2246), the 95% confidence interval for age-0 fish was 884,089-1,891,777. The total population, including age-0 gizzard shad was 2,019,268 (Table 8).

Average length of age-0 gizzard shad in February was 255 mm (Table 1); from the weight-length equation for February 1996, a 255 mm gizzard shad weighed 164.3 g. Total weight of age-0 gizzard shad was 212,446 kg; the 95% confidence interval was 145,256-310,819 kg. Total weight of the entire population, including age-0 fish, was 458,129 kg (Table 8).

Depletion Estimate of Population Size

Six depletion analyses (Equations 1-6) were conducted.

Eq. 1. C/f = 27.910 - 0.0000348(K); R^2 = 0.53; N=76; slope significantly different from 0 ($P<0.01$)

C/f is mean daily catch in pounds/(100 yards net x hours fished)

N = 801,628 pounds

Lower 95% confidence limit = 707,289 pounds

Upper 95% confidence limit = 945,597 pounds

Eq. 2. C/f = 28.955 - 0.0000367(K); R^2 = 0.82; N=12; slope significantly different from 0 ($P<0.01$)

C/f is mean weekly catch in pounds/(100 yards net x hours fished)

N = 789,769 pounds

Lower 95% confidence limit = 663,660 pounds

Upper 95% confidence limit = 1,029,693 pounds

Eq. 3. C/f = 29.106 - 0.0000352(K); R^2 = 0.92; N=6; slope significantly different from zero ($P<0.01$)

C/f is mean biweekly catch in pounds/(100 yards net x hours fished)

N = 827,895 pounds

Lower 95% confidence limit = 674,286 pounds

Upper 95% confidence limit = 1,186,064 pounds

Eq. 4. C/f = 236.249 - 0.000239(K); R^2 = 0.32; N=76; slope significantly different from 0 (P<0.01)

C/f is mean daily catch in pounds/100 yards net

N = 988,489 pounds

Lower 95% confidence limit = 813,827 pounds

Upper 95% confidence limit = 1,335,309 pounds

Eq. 5. C/f = 246.957 - 0.000265(K); R^2 = 0.65; N=12; slope significantly different from zero (P<0.01)

C/f is mean weekly catch in pounds/100 yards net

N = 931,915 pounds

Lower 95% confidence limit = 710,334 pounds

Upper 95% confidence limit = 1,610,273 pounds

Eq. 6. C/f = 244.757 - 0.000247(K); R^2 = 0.81; N=6; slope significantly different from 0 (P<0.01)

C/f is mean biweekly catch in pounds/100 yards net

N = 990,918 pounds

Lower 95% confidence limit = 716,613 pounds

Upper 95% confidence limit = 2,355,018 pounds

Depletion models with C/f measured as pounds/(100 yards net x hours fished) (Equations 1-3) accounted for more variance (higher R^2) than did models with C/f measured as pounds/100 yards net (Equations 4-6). Biomass of the population estimated from pounds/(100 yards net x hours fished) ranged from 789,769 to 827,895 pounds, and the three estimates were not significantly different (all three estimates were within the 95% confidence limits for each of the three estimates). Based on the best-fit model, (highest R^2, Equation 3) the best depletion estimate was 827,895 pounds (375,527 kg) with lower and upper 95% confidence intervals of 674,286 pounds (305,851 kg) and 1,186,064 pounds (537,990 kg) (Table 6).

Fish longer than 300 mm TL were considered to be fully recruited to the commercial gill nets (from change-in-composition method, Figures 2-4). Using the February experimental gill net data, mean weight of fish longer than 300 mm was 417.4 g (N = 232, SE = 8.4). Applying this weight to the population estimate and confidence intervals from Equation 3 resulted in an estimated N of 899,681 fish with lower and upper 95% confidence limits of 732,753 fish and 1,288,907 fish (Table 6).

The depletion estimate was calculated from gizzard shad caught by commercial gill nets during March-May 1996. All fish caught by commercial gill nets were ≥ 270 mm total length and only 1 of 325 fish ≥ 275 mm sampled with experimental gill nets in February and none of 194 fish ≥ 275 mm sampled with experimental gill nets in May were age-0 fish (Figure 1, Table 7). Therefore, essentially all fish used to estimate population size by the depletion method were age-1 or older, and the population estimate did not include the number of age-0 gizzard shad in the population.

Age composition of the commercial gill net catch was not measured. The proportion of age-1 fish in the commercial gill net catch was estimated from the age composition of experimental gill net catches in February and May 1996 (Figure 1, Table 7). Age-1 gizzard shad were 55.0% of the fish ≥300 mm (the length considered fully recruited to the commercial gill nets) in February and 40.0% of the fish ≥ 300 mm in May. Using the average proportion of age-1 gizzard shad for February and May (0.475), 427,348 gizzard shad were age-1. Annual survival rate, based on total mortality rate in January 1995 (Z=1.1130) was 0.3286. Assuming age-0 survival rate was the same as for age-1 and older fish, the population of age-0 fish in February 1996 was 1,300,511; the 95% confidence interval was 899,197-1,902,707. The total population, including age-0 gizzard shad was 2,200,192 (Table 8).

Average length of age-0 gizzard shad in February was 255 mm (Table 1); from the weight-length equation for February 1996, a 255 mm gizzard shad weighed 164.3 g. Total weight of age-0 gizzard shad was 213,674 kg; 95% confidence limits were 147,738 kg and 312,615 kg. Weight of the entire population, including age-0 fish, was 589,201 kg (Table 8).

Because the commercial gill nets caught relatively few fish smaller than 300 mm, age-1 fish were not fully recruited to commercial gill nets. Hence, the proportion of age-1 fish was underestimated. Therefore, the estimate of the total population is an underestimate because (1) a portion of the age-1 cohort is not included, and (2) the underestimate of age-1 fish results in a low estimate of the number of age-0 fish.

Catch Equation Estimate of Population Size

The catch curves for January 1995 and February 1996 experimental gill net catches both showed expected declines in catch frequency with age (Figure 5) and support the assumptions of similar recruitment and similar mortality over time. By visual analysis of experimental gill net catch length frequencies, gizzard shad fully recruited to the experiment gill nets at approximately 270 mm (Figures 2-4). Comparison of age-length frequencies and mean length at age for January 1995 (Figure 1 and Table 2 in Schramm and Pugh 1996 [Appendix 1]) and February 1996 (Figure 1, Table 1) indicates gizzard shad were fully recruited to the experimental gill nets at age ≥ 1.

The catch curves for January 1995 (Equation 7) and February 1996 (Equation 8) indicated $Z_1 = 1.11303$ and $Z_2 = 1.48576$

Eq. 7. $ln(N) = 5.396 - 1.11303(\text{age}), R^2 = 0.96$

Eq. 8. $ln(N) = 7.131 - 1.48576(\text{age}), R^2 = 0.95$

By calculation, $F = 0.37273$, $A = 0.77367$, and $u = 0.19409$. Total catch during the 16 January-5 April 1995 harvest period was 402,493 fish (from change in composition calculations, Table 3 in Schramm and Pugh 1996 [Appendix 1]); therefore, $N = 2{,}073{,}744$ fish (Table 6). Pooled variance for Z_1 and Z_2 was 0.0633 and the 95% confidence limits for Z were 1.48576 ± 0.16274. Substituting these values for Z (1.32302 and 1.64850) and corresponding values of A (0.73367 and 0.80766) into the catch equation, the lower confidence limit for N was 1,947,327 fish and the upper 95% confidence limit for N was 2,204,113 fish (Table 6).

Using the January 1995 experimental gill net data, mean weight of fish longer than 280 mm was 566.3 g (Schramm and Pugh 1996). Applying this weight to the population estimation resulted in an estimated N of 1,174,361 kg with 95% confidence limits of 1,102,771 kg and 1,248,189 kg (Table 6).

Age-1 fish were 69.42% of the January 1995 gill net sample used to estimate Z_1 (i.e., fish age 1 or older, Table 7). Therefore, the population contained 1,439,593 age-1 fish in

January 1995. At Z = 1.1130, annual survival ($S=e^{Z}$) is 0.3286. Assuming age-0 survival was the same as survival from age 1 to older ages, the population of age-0 fish was 4,381,365 in January 1995; 95% confidence limits were 2,995,408 and 6,409,586 Adding these fish to the population estimate of 2,073,744 fish resulted in a total gizzard shad population of 6,455,109 fish in January 1995 (Table 8).

The mean lengths of age-0 male and female gizzard shad in January 1995 was 253 mm and 263 mm, respectively (Table 2 in Schramm and Pugh 1996 [Appendix 1]). Converting these lengths to weights with weight-length equations for fish collected in January 1995 (Schramm and Pugh 1996), average weight of an age-0 gizzard shad in January 1995 was 169.5 g. Hence, the biomass of age-0 gizzard shad was 742,641 kg; 95% confidence limits were 507,722 kg and 1,086,425 kg. The biomass for the total population including age-0 fish was 1,917,002 kg (4,226,266 pounds) (Table 8).

The above estimate of age-0 fish would be an overestimate if age-0 fish were included in the harvest with commercial gill nets. Commercial gill nets caught no gizzard shad smaller than 270 mm (Figures 2-4; Figure 4 in Schramm and Pugh 1996 [Appendix 1]). Age-0 fish were a minor component of gizzard shad larger than 275 mm in 1996 (Figure 1, Table 7). However in 1995, the harvest period used to estimate the population by the catch equation, 84 of 205 fish ≥ 275 mm collected with experimental gill nets in January and 67 of 172 fish ≥ 275 mm collected with experimental gill nets in June were age-0 (Table 7). Because age structure was not determined for gizzard shad caught by commercial gill nets, and hence the exact proportion of age-0 fish included in the landings used to estimate population size (*C* in the catch equation) could not be determined, we can only conclude that the calculated number of age-0 fish is an overestimate.

Discussion

Use of Otoliths as a Valid Ageing Structure for Gizzard Shad

Length-at-age analyses and age-length frequency distributions indicated that ages determined from opaque bands on otoliths are reasonable. Rutherford, et al. (1995), assuming otoliths provided accurate ages of gizzard shad, obtained reasonable changes in otolith growth increment of gizzard shad collected in the Mississippi River. Marginal increment analysis indicated that opaque bands did not form on gizzard shad otoliths during January-May in Lake Apopka and during January-June in Lake Aliceville. If opaque bands on gizzard shad otoliths are valid annuli, the opaque bands must form after May (Lake Apopka) or June (Lake Aliceville). From analysis of Lake Apopka gizzard shad otoliths collected in June, opaque band formation may begin in June. Therefore, it is likely that opaque bands (annuli) form on gizzard shad otoliths during the summer. The formation of more than one opaque band on the otolith between June and January is unlikely. If this were the case, opaque bands would likely appear in an irregular growth increment pattern. Although we did not measure growth increment for all opaque bands, the otoliths had regular patterns of opaque bands and, corroborating Rutherford, et al. (1995), reasonable changes in growth increment between opaque bands.

Assuming opaque bands form during the summer, it appears that Lake Apopka gizzard shad form the first opaque band (annulus) during the summer of their second year of life. Gizzard shad begin spawning in Lake Apopka in February-March (Joe Crumpton, Florida Game and Fresh Water Fish Commission, personal communication). Gizzard shad up to 250 mm long (rarely 325 mm, Figure 1) had no opaque bands on their otoliths. Comparison of gizzard shad length structure during February-May 1996 (Figures 1-4) suggest that the fish with no opaque bands on their otoliths were age-0 (i.e., 1995 year class) fish. If the 1995 year class was spawned during February-March, these fish did not form an opaque band during their first summer of life.

Otoliths have been shown to provide valid ages for another clupeid, blueback herring *Alosa aestivalis* (Schramm et al. 1992). Although marginal increment analysis did not confirm the time of annulus formation and that opaque bands form only once a year, all available evidence supports opaque bands on gizzard shad otoliths to be valid annuli.

Gizzard Shad Population Estimates

All three population estimates of the "recruited" population (fish recruited to the experimental gill nets for the change-in-composition estimate, fish recruited to the commercial gill nets for the depletion estimates, and age-1 and older fish for the catch-curve estimate) provided estimates of population size with relatively small confidence intervals. In contrast to the poor results obtained with the depletion estimate of the gizzard shad population in Lake Apopka in 1995 (Schramm and Pugh 1996), regression equations of cumulative catch on catch per effort accounted for relatively high amounts of variation for all estimators of catch per effort ($R^2 \geq 0.32$). Furthermore, each of the estimates of population size by each of the measures of catch rate were within the 95% confidence intervals of all other estimates except for the estimate using daily catch/100 yards of net x hours fished. The depletion estimate selected had the highest variance accounted for of all six depletion estimates and was within the 95% confidence intervals of all other estimates.

The change-in-composition estimate and depletion estimate of the recruited populations in February 1996 were similar. The catch-equation estimate of the recruited population in January 1995 was 2.3-2.9 times higher than the change-in-composition and depletion estimates for February 1996 (Table 6); however the catch-equation estimate for January 1995 (Table 6) was similar to the change-in-composition estimate (1,618,354 fish, 95% confidence interval 1,441,597-1,795,111 fish) and the depletion estimate (1,505,811 fish, 95% confidence interval 903,490-18,390,461 fish) for the gizzard shad population in January 1995 (Table 4 in Schramm and Pugh 1996 [Appendix 1]). (The catch-equation population estimate in Schramm and Pugh [1996] was in error because mortality was considered only for a portion of a year.) The estimates of the total population (all ages) in February 1996 from the change-in-composition and depletion methods were similar. Total population estimates were not obtained with the change-in-composition and depletion method in 1995; hence the catch-equation estimate of the total population in January 1995 can not be compared to other population estimates.

Although the amounts cannot be quantified, we recognize that the depletion method underestimated the total population size and the catch equation method overestimated population size. Because the depletion estimate is an underestimate of total population, the actual differences between the change-in-composition estimate and the depletion estimate are larger than indicated by the calculated values in Table 8. Considering that the catch equation estimate is an overestimate, the differences between the catch equation estimate and those for total population size in Janaury 1995 estimated by the change-in-composition and depletion methods would be less.

We consider all three methods appropriate for the population estimated and the data available. The best estimate of the population of gizzard shad recruited to experimental or commercial gill nets (fish age-1 and older) in January 1995 or February 1996 is 726,228-2,073,744 fish weighing 245,683-1,174,361 kg with confidence limits of 718,706-2,204,113 fish and 243,138-1,248,189 kg. The best estimate of the total gizzard shad population is 2,019,268-6,455,109 fish weighing 458,129-1,917,002 kg.

Surface area of Lake Apopka is 12,473 hectares. Lake Apopka is essentially a limnetic (open water) system and all samples and harvest of gizzard shad occurred in the limnetic portion of Lake Apopka. The range of total population estimates equate to gizzard shad densities and standing stocks of 162-518 fish/hectare and 37-154 kg/hectare. Standing stock of gizzard shad in Douglas Reservoir, Tennessee, was 10 kg/hectare in open water and 30 kg/hectare in a 47 hectare arm that included 31 hectares of open water (Haynes et al. 1967). Douglas Reservoir is a relatively deep and low trophic state reservoir. In Columbus Lake, Mississippi, average standing stock in large coves for 6 years was 38 kg/hectare (Franks 1992). Columbus Lake is a moderately fertile (mesotrophic-eutrophic) reservoir. Standing stock of gizzard shad was 255 kg/hectare in an 85 hectare arm of Barkley Lake, Kentucky, and 263 kg/hectare in the open water portion of that arm (Aggus et al. 1980). Lake Barkley is relatively shallow and moderately fertile. Lake Apopka is eutrophic (hypertrophic) and is expected to support a biomass of gizzard shad similar to or greater than that in Lake Barkley. Based on comparison with the biomass in Lake Barkley, the gizzard shad population estimates for Lake Apopka are low and appear to be underestimates.

The exploitation rate during the subsidized gizzard shad fishery also suggests the population estimates may be low. In January-April, 1995, the commercial fishery harvested 281,198 kg of gizzard shad. The estimated population biomass in January 1995 was 657,537 kg (change-in-composition estimate not expanded for age-0 gizzard shad, Schramm and Pugh 1996), 928,634 kg (depletion estimate not expanded for age-0 gizzard shad, Schramm and Pugh 1996), and 1,174,361 kg (catch-equation estimate of harvestable population, Table 8). Therefore, the exploitation rate for fish harvested during January-April 1995 was 24-43%. During March-May 1996, the subsidized commercial fishery harvested 249,748 kg of gizzard shad. This harvest amount was 102% of the harvestable population weight in February 1996 estimated by the change-in-composition method (Table 6) and 67% of the harvestable population weight in February estimated by the depletion method (Table 6).

While the comparison with other biomass estimates and high exploitation rates suggest the population estimates are low, several population variables support high exploitation rate and, hence, relatively small population size. First, gizzard shad in Lake Apopka have rapid growth rate and recruit to the commercial fishery at age-1. New recruits are a large portion of the commercial landings. In 1995, age-1 fish were 69% (January) and 66% (June) of the population of age-1 and older fish (Table 7). In 1996, age-1 fish were 59% (February) and 53% (May) of the fish age-1 or older (Table 7). Second, high exploitation rates are expected to result in overfishing. The lower estimated population in 1996 than in 1995 suggest overfishing has occurred. The decline in mean weight of fish captured by the experimental gill nets from 1995 (Schramm and Pugh, 1996) to 1996 (Table 5) and the decline in mean weight of fish in each age class from February 1996 to May 1996 (Table 1) also indicates overfishing. Furthermore, the mean weight of fish in 1995 samples was higher than in 1996 samples despite a higher proportion of age-0 fish (expected to be smaller, lower weight fish) in the 1995 samples (Figures 1 and 2 in Schramm and Pugh 1996 [Appendix 1]; Table 7) than in the 1996 samples (Figure 1, Table 7). Considering that gill nets are highly size-selective, the decrease in mean weight could result from high harvest rate of the faster growing fish.

Although comparison of the gizzard shad population estimates in Lake Apopka with other lakes suggest the estimates are low, other population variables suggest the population has been overfished, that high exploitation rates are reasonable. We conclude that the population estimates provided in this report are reasonable and the harvest of gizzard shad during 1995 and 1996 substantially reduced the Lake Apopka gizzard shad population.

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Table 1. Mean total length (mm) of male and female gizzard shad, Lake Apopka, Florida, February and May, 1996. Values in parentheses are sample size, standard error.

Gender	Number of opaque bands				
	0	1	2	3	4
February 1996					
Male	205 (1,)	291 (83, 3.0)	307 (41, 4.4)		407 (1,)
Female	306 (1,)	308 (113, 2.9)	338 (81, 3.7)	384 (12, 7.5)	343 (2, 43.0)
All	255 (2,50.5)	301 (196, 2.2)	327 (122, 3.1)	384 (12, 7.5)	364 (3, 32.7)
May 1996					
Male	220 (13, 3.5)	264 (78, 3.9)	296 (46, 3.5)	326 (4, 9.1)	
Female	235 (6, 3.5)	271 (48, 6.0)	318 (54, 3.5)	387 (8, 10.7)	
All	225 (19,3.0)	267 (126, 3.3)	308 (100, 2.7)	367 (12, 11.4)	

Table 2. Occurrence of opaque bands at the margin of the otolith (marginal band, MB) and percent of fish with marginal increment ≤ 10% ($R_x/OR \geq 0.90$) of otolith radius for gizzard shad collected in Lake Apopka, Florida, 26 February and 29 May 1996. Marginal increment is measured as the ratio of the distance to the distal opaque band (R_x) to the otolith radius (OR).

Number of opaque bands	N of fish	$R_x/OR \geq 0.90$ % of fish	MB % of fish
26 February			
0	2	0	0
1	196	3	0
2	122	8	2
3	12	42	1
4	3	100	0
29 May			
0	19	0	0
1	126	10	3
2	100	8	0
3	12	42	0

Table 3. Mean, minimum, and maximum marginal increment, percent of fish with marginal increment ≤ 0.05 ($R_x/OR \geq 0.95$) of otolith radius, and ccurrence of opaque bands at the margin of the otolith (marginal band, MB) for gizzard shad collected in Aliceville Lake, Mississippi, January-May 1995. Marginal increment is measured as the ratio of the distance to the distal opaque band (R_x) to the otolith radius (OR).

Number of opaque bands	*N* of fish	Marginal increment Mean	Minimum	Maximum	$R_x/OR \geq 0.95$ % of fish	MB % of fish
January						
0	13	1.000	1.000	1.000	0	0
1	20	0.130	0.079	0.190	3	0
2	33	0.097	0.058	0.217	8	0
3	5	0.085	0.062	0.133	42	0
February						
1	2	0.292	0.288	0.296	0	0
2	9	0.160	0.075	0.382	0	0
3	7	0.106	0.083	0.158	0	0
4	1	0.048	0.048	0.048	100	0
March						
0	7	1.000	1.000	1.000	0	0
1	19	0.120	0.074	0.178	0	0
2	30	0.111	0.074	0.244	0	0
3	9	0.068	0.045	0.091	11	0
4	2	0.066	0.055	0.078	0	0
April						
0	8	1.000	1.000	1.000	0	0
1	23	0.144	0.083	0.271	0	0
2	35	0.092	0.049	0.211	3	0
3	20	0.068	0.036	0.116	35	0
4	4	0.082	0.044	0.167	25	0

Table 3. Continued.

Number of opaque bands	*N* of fish	Marginal increment			$R_x/OR \geq 0.95$ % of fish	MB % of fish
		Mean	Minimum	Maximum		
May						
0	3	1.000	1.000	1.000	0	0
1	20	0.147	0.071	0.311	0	0
2	15	0.099	0.064	0.136	0	0
	1	0.083	0.083	0.083	0	0
4	1	0.033	0.033	0.033	100	0
June						
0	17	1.000	1.000	1.000	0	0
1	23	0.148	0.077	0.206	0	0
2	12	0.090	0.036	0.133	8	0
3	1	0.055	0.055	0.055	0	0

Table 4. Reported commercial harvest of gizzard shad in Lake Apopka, Florida, April 1995-September 1996.

Time period	Number of days	Total catch, kg	Catch (kg)/day
1995			
6-30 April	25	0	0.0
1-31 May	31	0	0.0
1-30 June	30	0	0.0
1-31 July	31	1,149	37.1
1-31 August	31	17,621	568.4
1-30 September	30	26,179	872.6
1-31 October	31	19,564	631.1
1-30 November	30	8.604	286.8
1-31 December	31	2,231	72.0
1996			
1-31 January	31	6,142	198.1
1-25 February	25	8,571	342.8
26 February-4 March	8	2,613	326.6
5 March-23 May	79	249,748	3,161.4
24-29 May	6	826	137.7
29 May-30 June	33	1,796	54.4
1-31 July	31	1,834	59.2
1-31 August	31	484	15.6
1-30 September	30	4,105	136.8

Table 5. Mean proportions of male and female gizzard shad in experimental gill net samples and total catch and estimated numbers of male and female fish harvested by commercial gill nets in Lake Apopka, Florida, January-May 1996. Catch statistics for experimental gill nets during February, March, and April are for fish longer than 300 mm. Values in parentheses are sample size, standard error.

	Experimental gill net catch				Harvest			
Time period	Males, %	Female, %	Mean weight, kg	Total number of fish	Total weight, kg	Number, total	Number, males	Number, females
26 February	37.46 (3, 0.05)	62.54 (3, 0.05)	0.3383 (3, 10.0)	391				
26 March (fish ≥300 mm)	42.86	57.14	0.3821 (77, 10.3)	77				
27February- 26 March					86,760	227,061	97,312	129,749
April 25 (fish ≥300 mm)	31.25	68.75	0.3809 (48,14.0)	48				
27 March- 25 April					114,644	300,981	94,057	206,924
May 29 (fish ≥300 mm)	37.79 (3, 0.05)	62.21 (3, 0.05)	0.3119 (127, 8.0)	127				
26 April- 29 May					51,284	164,425	62,131	102,294
May 29 (all lengths)	54.83 (3, 0.02)	45.17 (3, 0.02)	0.2164 (3, 11.5)	322				
Total harvest, 27 February-29 May					252,688	692,467	253,500	438,967

Table 6. Numbers and weights of the gizzard shad population in Lake Apopka, Florida estimated by the change-in-composition (CIC) method, the depletion method, and the catch equation method.

Estimate	Method of estimation		
	CIC[1]	Depletion[1]	Catch equation[2]
Number of fish	726,228	899,681	2,073,744
Lower 95% confidence limit	718,706	732,753	1,947,327
Upper 95% confidence limit	733,750	1,288,907	2,204,113
Weight of fish (kg)	245,683	375,527	1,174,361
Lower 95% confidence limit	243,138	305,851	1,102,771
Upper 95% confidence limit	248,228	537,990	1,248,189
Weight of fish (pounds)	541,638	827,895	2,589,022
Lower 95% confidence limit	536,023	674,286	2,431,194
Upper 95% confidence limit	547,249	1,186,064	2,751,786

1 Estimate for fish recruited to experimental gill nets in February 1996; these fish primarily are age-1 and older fish.

2 Estimate for fish age-1 and older in the population in January 1995.

Table 7. Frequencies of ages and total length groups of gizzard shad collected with experimental gill nets in Lake Apopka, Florida, 1995 and 1996.

Length group, mm	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5
11-12 January 1995, total N = 272						
200	5					
225	17					
250	45					
275	39					
300	37	11				
325	5	21	4			
350	2	20	7			
375	1	18	8	2	1	
400		11	3		1	
425		3	6	1	1	1
450			1	1		
21-22 June 1995, total N = 194						
225	9					
250	13					
275	17					
300	28	6				
325	12	9				
350	9	15	2			
375	1	15	4		1	
400		18	4	1	1	
425		6	15	2		
450			6			

Table 7. Continued.

Length group, mm	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5
26 February 1996, total N = 335						
225	1					
250		8	1			
275		31	9			
300		69	21		1	
325	1	51	24			
350		25	39	1		
375		8	18	4		
400		4	8	3	1	
425			2	4	1	
29 May 1996, total N = 255						
200	1	3				
225	7	20				
250	11	19				
275		18	9			
300		46	22			
325		17	43	3		
350		2	19	1		
375		1	5	3		
400				2		
425				2		
450				1		

Table 8. Numbers and weights of age-0 gizzard shad and the total gizzard shad population (all ages) in Lake Apopka, Florida estimated by the change-in-composition (CIC) method, the depletion method, and the catch equation method.

Estimate	Method of estimation		
	CIC	Depletion	Catch equation
Age-0 gizzard shad			
Number of fish	1,293,040	1,300,511	4,381,365
Lower 95% confidence limit	884,089	899,197	2,995,408
Upper 95% conficence limit	1,891,777	1,902,707	6,409,586
Weight of fish (kg)	212,446	213,674	742,641
Lower 95% confidence limit	145,256	147,738	507,722
Upper 95% confidence limit	310,819	312,615	1,086,425
Weight of fish (pounds	468,363	471,071	1,637,244
Lower 95% confidence limit	320,234	325,707	1,119,335
Upper 95% confidence limit	685,239	689,198	2,395,157
Total gizzard population (all ages)			
Number of fish	2,019,268	2,200,192	6,455,109
Weight of fish (kg)	458,129	589,201	1,917,002
Weight of fish (pounds)	1,010,002	1,298,966	4,226,266

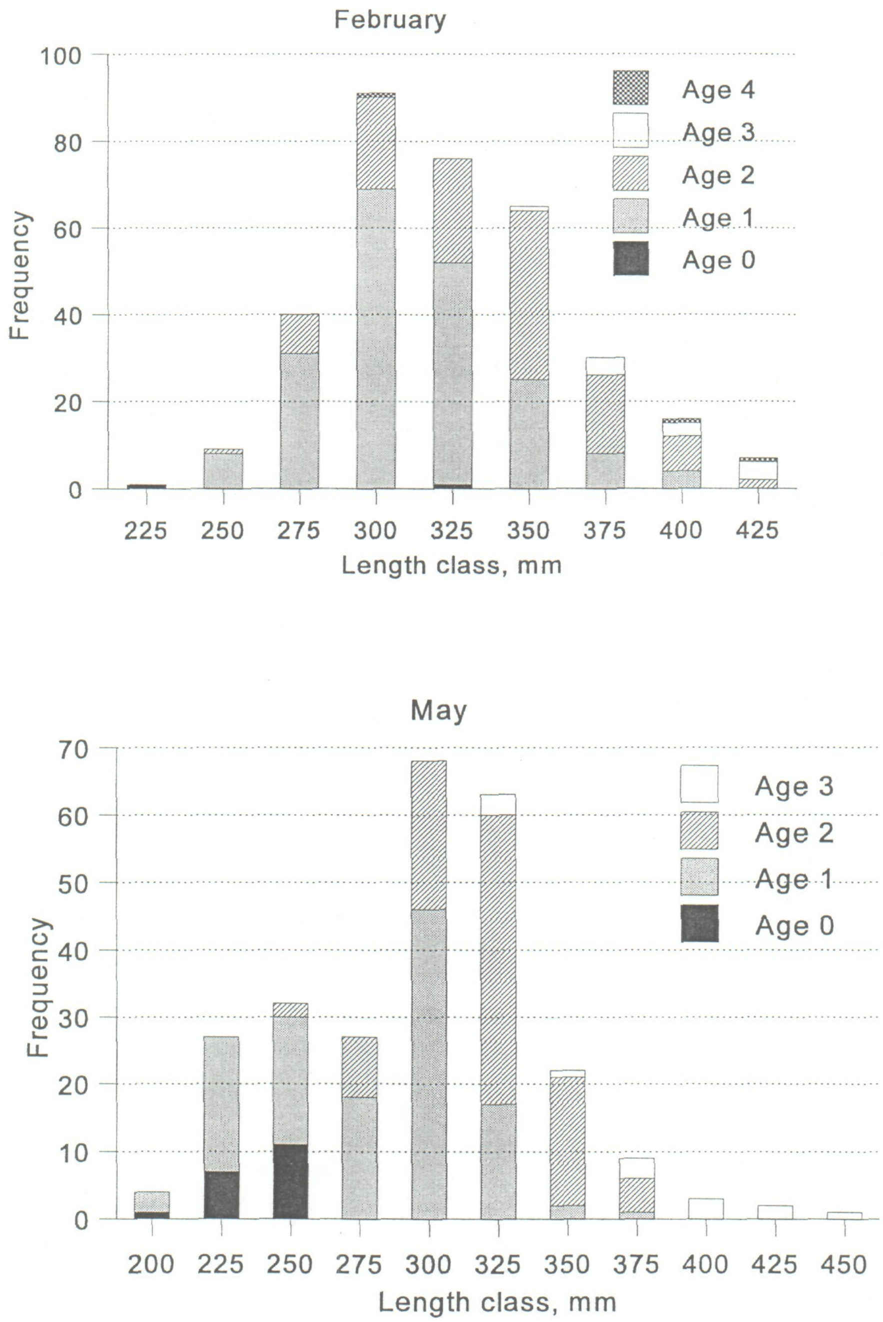

Figure 1. Frequencies of ages and lengths of gizzard shad in Lake Apopka, Florida, February and May 1996. Length class 200 includes fish 200-224 mm total length, length class 225 includes fish 225-249 mm total length, etc.

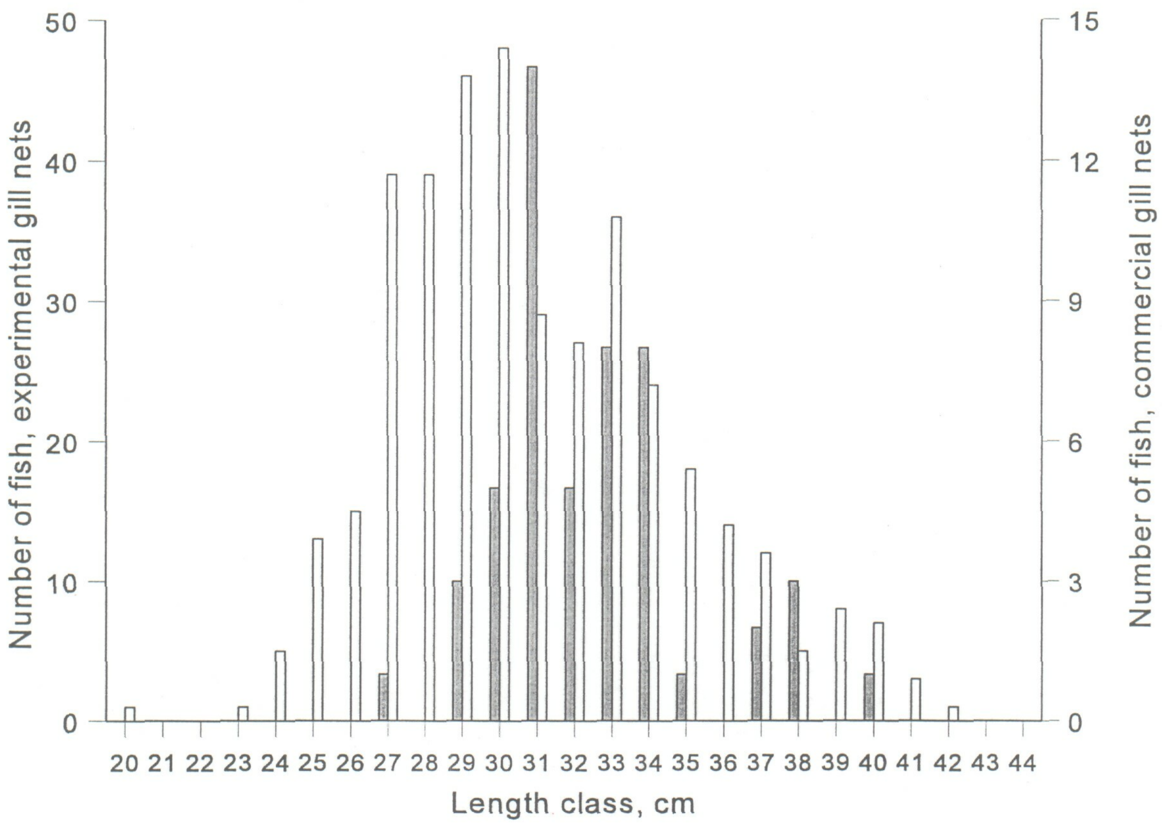

Figure 2. Frequencies of gizzard shad caught with experimental gill nets in February 1996 (open) and commercial gill nets in January (shaded), Lake Apopka, Florida.

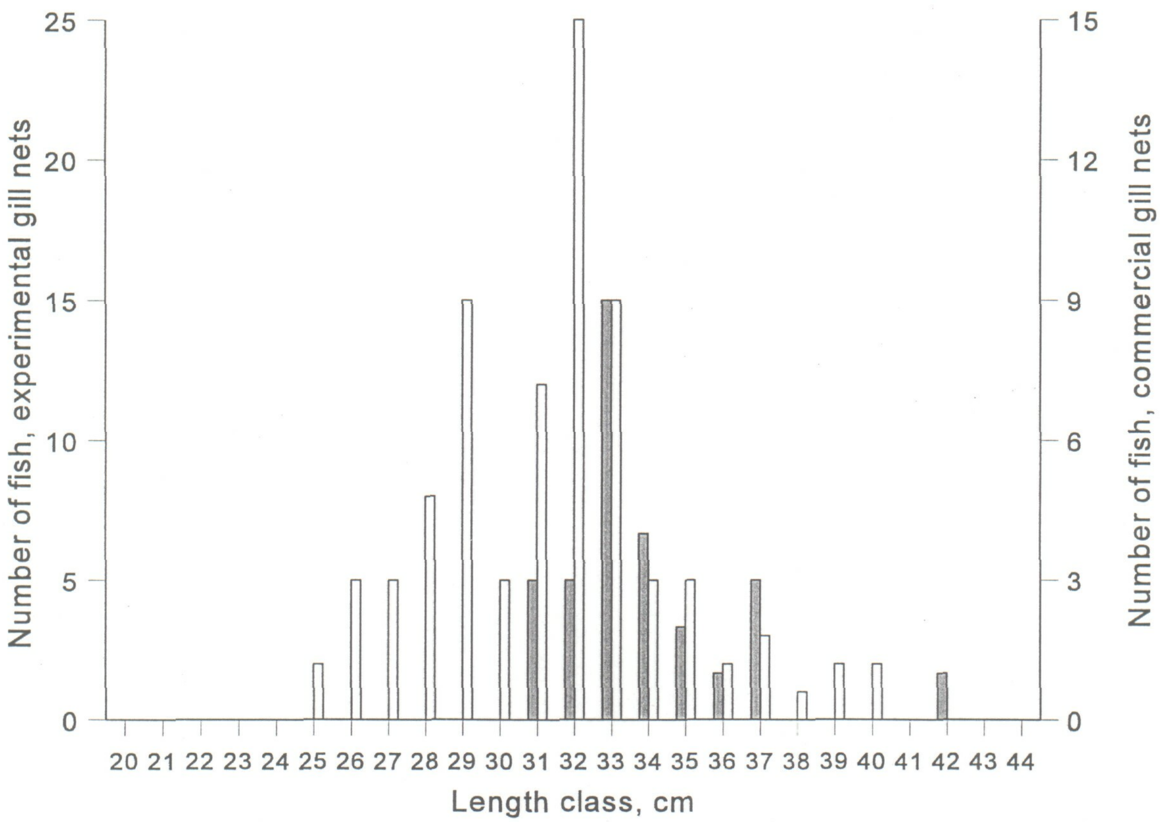

Figure 3. Frequencies of gizzard shad caught with experimental gill nets (open) and commercial gill nets (shaded) in March 1996, Lake Apopka, Florida.

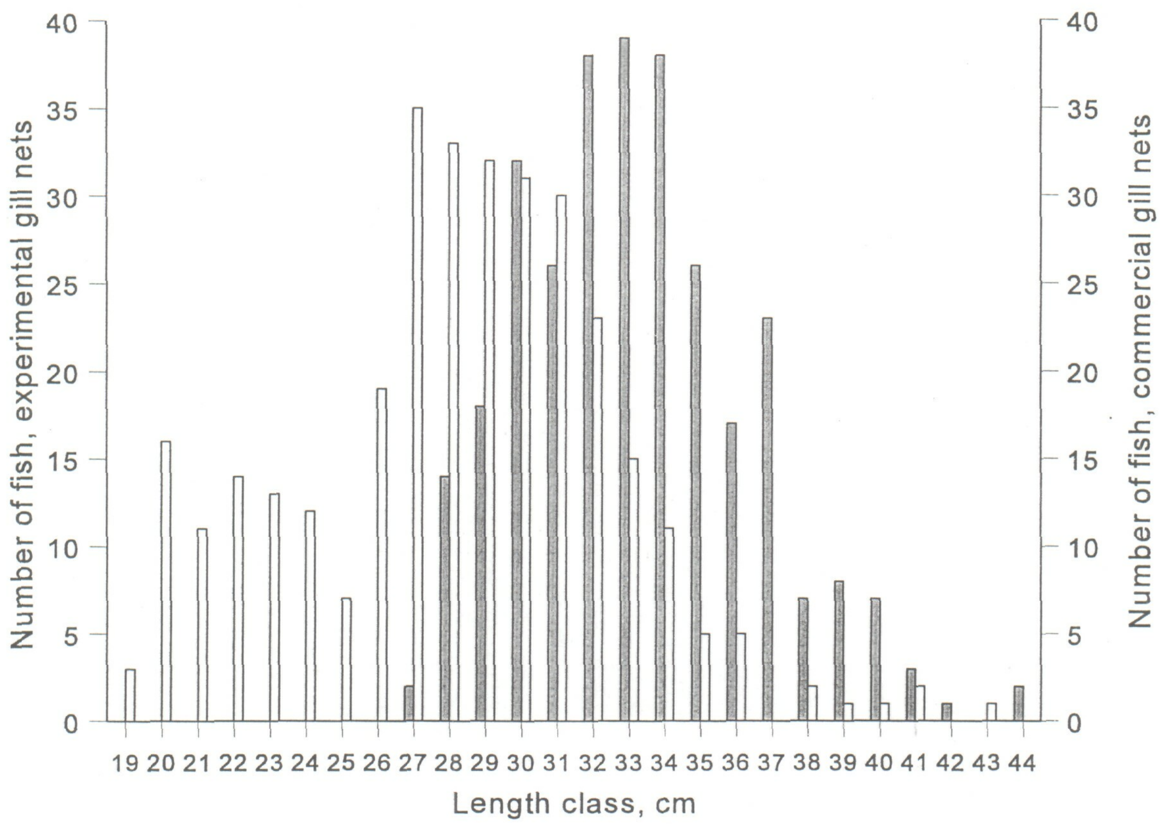

Figure 4. Frequencies of gizzard shad caught with experimental gill nets (open) and commercial gill nets (shaded) in May 1996, Lake Apopka, Florida.

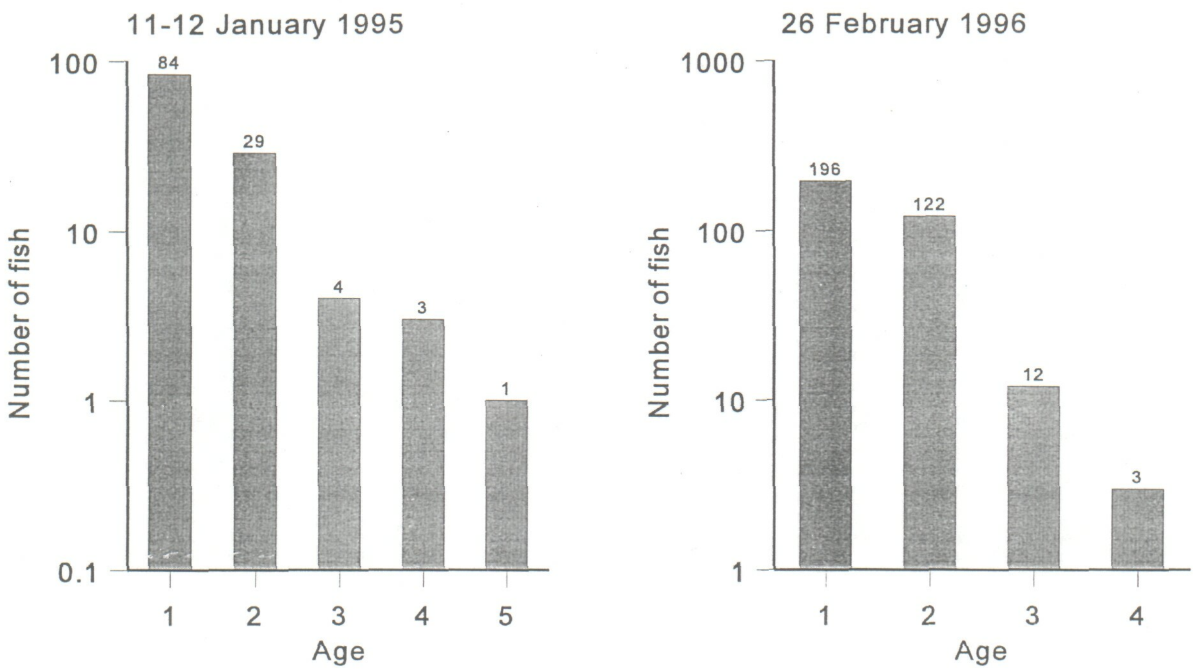

Figure 5. Age-frequency of gizzard shad sampled with experimental gill nets in Lake Apopka, Florida, 11-12 January 1995 and 26 February 1996.