TENNESSEE VALLEY AUTHORITY

River Basin Operations
Water Resources

STATUS OF THE WHITE CRAPPIE POPULATION IN CHICKAMAUGA RESERVOIR
FINAL PROJECT REPORT

Prepared by
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Norris, Tennessee

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Thomas A. McDonough
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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EXECUTIVE SUMMARY

This is the final report of an investigation conducted by the Tennessee Valley Authority (TVA) from 1986 through 1989 to determine the status of white crappie in Chickamauga Reservoir. In 1986 the Tennessee Division of Water Pollution Control (TDWPC) and the Tennessee Wildlife Resources Agency (TWRA) expressed concern to TVA over declining populations of white crappie, sauger, white bass and channel catfish in Chickamauga Reservoir. The state agencies were concerned that operation of TVA's Sequoyah Nuclear Plant (SQN) was a contributing factor in the decline of these species. The possibility of future combined impacts from operation of Watts Bar Nuclear Plant (WBN) was also addressed in a letter of concern from TWRA.

This investigation was designed to determine the current status of the white crappie population in Chickamauga Reservoir. During this investigation, various methods were used to sample all life stages of crappie. Statistical analyses were applied to current as well as historical data. Findings relative to specific objectives are summarized below.

Cove rotenone and creel data indicate the adult white crappie population in Chickamauga Reservoir has declined in recent years and the trend appears to be continuing.

Crappie spawning is concentrated in large embayments such as Wolftever Creek and smaller tributaries throughout the reservoir. Overbank habitat along the main channel appears to be insignificant for crappie spawning. Spawning success as estimated by annual larval densities and survival through early life history stages was not found to be a major factor in the overall population decline.

An increasing trend in densities of young-of-year white crappie in cove rotenone samples documented good survival through the early juvenile stage. Year-class success and adult densities were found to be determined by survival rate of juvenile fish through their second summer. Factors found to be correlated with increased mortality of young crappie during this critical period include: increased area of aquatic vegetation, increased numbers of young-of-year and yearling sunfish and largemouth bass, and increased numbers of adult largemouth bass and gizzard shad.

Differences in food habits and preferred habitats may be responsible for a dramatic shift in dominance from white to black crappie observed in Chickamauga Reservoir. Young black crappie are reported to prefer heavy vegetation and feed more readily on organisms associated with it. Increased aquatic vegetation in Chickamauga Reservoir, especially during the period of drought (1985-88), has likely had a negative effect on white crappie and favored dominance by black crappie.

Increased harvest of black crappie may compensate for decreased harvest of white crappie. Catch rates for both species were low relative to catch rates in the early 1970s, but were higher than most other Tennessee reservoirs in 1988 and 1989. Assuming present trends continue, it remains to be seen if an increased population of black crappie in Chickamauga Reservoir will compensate for the declining population of white crappie in terms of fisherman harvest.

Historical data and results of this investigation indicate no or minimal potential impacts to white crappie from operation of SQN and WBN. Monitoring results have shown low entrainment and impingement of crappie at SQN and no concentration of fish or increased fishing pressure has been observed near the SQN thermal plume during winter. Also since both SQN and WBN discharges are restricted to the main river channel and do not effect crappie spawning habitat, early spawning due to elevated thermal regimes does not represent a potential impact. Therefore, the current declining trend for white crappie in Chickamauga Reservoir cannot be correlated with any present effect of SQN operation or potential effect of WBN operation.

INTRODUCTION

White crappie (*Pomoxis annularis*) in combination with its nearest relative, the black crappie (*Pomoxis nigromaculatus*), rank either first or second in popularity among sport fishermen in the Tennessee Valley region and thus, are economically important to the recreational industry of the area. Creel surveys conducted by the Tennessee Wildlife Resources Agency (TWRA) have shown wide fluctuations in annual harvest of white crappie from Chickamauga Reservoir during the period 1972-88 (TVA 1989). A declining trend, however, in both harvest and catch rate was observed during the period 1982 through 1985. Similar declining trends for numbers and biomass of both intermediate and adult white crappie in Chickamauga Reservoir were observed in cove rotenone data collected by the Tennessee Valley Authority (TVA) from 1982 through 1987 (TVA 1989).

As a result of this apparent decline in sport fisheries, and perhaps other factors, TWRA and the Tennessee Division of Water Pollution Control (TDWPC) described the aquatic system of Chickamauga Reservoir as "stressed" from a water quality standpoint. Sauger, white bass, and channel catfish were listed along with white crappie as species with declining populations. TWRA also expressed specific concern that operation of SQN might aggravate any already "stressed" situation in the reservoir and that the potential combined effects created by the future operation of Watts Bar Nuclear Plant (WBN) should also be considered. In 1986, TVA began an investigation to address these concerns for the white crappie population in Chickamauga Reservoir.

The predominant objective around which the investigation was designed was to determine the status of, and any trends in, the white crappie population of Chickamauga Reservoir. More specific objectives were to: (1) identify important spawning areas and quantify annual abundance (densities) of crappie larvae; (2) measure survival through the juvenile stage to determine relative year-class success; (3) examine factors influencing year-class success and survival of crappie, including potential influence of SQN and WBN; (4) determine the interspecific relationship and trend in dominance between white and black crappie; and (5) evaluate whether the populations of both white and black crappie are adequate to support normal fishing pressure.

METHODS

Larval Fish Sampling

During the period 1973-85, as part of pre-operational and operational monitoring at SQN, larval fish samples were taken on a weekly or bi-weekly basis each year (except 1978) in the vicinity of SQN. These historical data were used in conjunction with rotenone data to describe relationships with other environmental parameters to explain white crappie mortality and recruitment. For a more detailed description of procedures and areas sampled during this period see TVA (1978, 1985). The following summarizes the methods and procedures used during this investigation.

1986 - Initial sampling for this project consisted of four weekly surveys to collect larval crappie from April 29 through May 20, 1986. A total of sixteen 10-minute samples was collected each week using a 0.5 m^2 push-net. Two transects located at Tennessee River Mile (TRM) 480.9 (Dallas Bay) and TRM 482.6 (Diffuser) with two stations each were sampled on the reservoir and four stations were sampled in Wolftever Creek embayment (TRM 478.5). The net was towed obliquely through the water column to sample the desired stratum, usually either from near bottom to surface or from near bottom to mid-depth and then mid-depth to surface. All samples were ten minutes in duration and collected during daytime. Samples were placed in labeled jars and fixed with 10 percent formalin.

1987 - Push-net sampling for crappie larvae began on April 21, 1987, and continued weekly through May 29, 1987. Sample methods were similar to those described above. In some shallow overbank areas containing aquatic vegetation, samples consisted of towing the net immediately below the surface for the entire 10-minute run. All push-net sampling in 1987 was conducted between TRMs 502.9 and 511.5 in the general vicinity of Armstrong Bend and at two stations (Hiwassee River Miles (HRMs) 3.4 and 7.9) in the Hiwassee River.

Also in 1987, weekly sampling with light-traps in Wolftever Creek embayment was initiated on June 9 and continued through July 15. Samples were collected from both shallow (1-2 m) and deeper (3-7 m) overbank areas as well as channel areas (9-11 m).

Light-traps consisted of PVC pipe cylinders with four Plexiglas "windows", Plexiglas light-tubes, and catch-cups. Light-traps were set at night, with one or two chemical light-sticks placed in the light-tube, then retrieved after two to four hours. Samples were rinsed into labeled jars and fixed with ten percent formalin.

1988 - Sampling for larval crappie began on April 26 and continued through June 17. Sample methods were the same as those described for 1987. All samples were collected from the Armstrong Bend area of Chickamauga Reservoir (TRMs 502-511) using both push-nets and light traps. Weekly daytime push-net sampling began on April 28 and continued through May 24. Sample depths ranged from just below the surface to approximately three meters, depending upon bottom depth and macrophyte concentration. Light-traps were fished weekly at night from April 26 to June 17 in the same general areas that were sampled with push-nets, except that some light traps were set in and adjacent to macrophyte beds where push-nets could not be used. Depths at which light-traps were fished ranged from just below the surface to 7.3 meters. All push-net samples were 10-minutes long and light-traps were fished for approximately three hours per sample.

1989 - Push-net sampling began on May 2 and continued biweekly through July 11. Two areas of the reservoir were sampled. Eight samples were collected from the same three transects sampled in 1986 (Dallas Bay, SQN Diffuser, and Wolftever Creek embayment), and eight samples were collected from three transects in the Armstrong Bend area of Chickamauga Reservoir. These transects were located at Armstrong Slough (TRM 503), Richland Creek (TRM 504.3), and Gillespie Slough (TRM 506). At each transect, samples were taken from the river channel (upper and lower strata) and from either an adjacent slough, tributary creek, or shoreline/overbank area. A total of 39 light-trap samples was collected in 1989. Traps were set in the same general areas where push-net samples were taken on June 13, June 27, and July 12.

Analysis of Historical SQN Larval Monitoring Data

Larval fish densities through the period 1973-85 were examined using stepwise multiple regression to identify environmental factors determining larval crappie abundance. The dependent variable used in this analysis was the logarithm of numbers of 5 mm crappie larvae per 1000 m^3. Since larval densities of zero were included, one was added to the density values prior to transformation.

Environmental parameters were examined for three time periods: one week prior to spawning, spawning to hatching (incubation), hatching to 5 mm (larval stage). Siefert (1968) reported white crappie incubation periods ranging from 42 to 103 hours, decreasing with higher temperature. We assumed an incubation period of three days. At hatching, larval crappie are 2 to 3 mm in total length (TL) (Hogue et al. 1976). Larval growth rate was estimated by calculating the mean julian date (consecutively numbered days from January 1) for each millimeter size-class. This procedure was used by DeAngelis et al. (1980) for white crappie in Pickwick Reservoir. Growth averaged approximately 0.5 mm per day. Five days from hatching to 5 mm TL was assumed.

Environmental variables included in this study were water temperature, surface elevation, and discharge (flow) from Chickamauga Dam. Means, minimum values, maximum values, variability (standard deviations), and daily changes during the three time periods were included in this analysis. Quadratic terms were evaluated because biological responses to environmental variables are frequently curvilinear in nature.

Life History

During November 1987, random (qualitative) electrofishing was conducted on four separate days (November 3, 9, 11, and 13) in Wolftever Creek embayment to collect crappie for life history information. Length and weight data were recorded and scales and otoliths from both white and black crappie were collected for age and growth analysis.

During August and September 1989, a 15.2-m-long (50 ft) bag seine was used to sample for juvenile crappie on Chickamauga Reservoir. Six to ten sites each were seined in the upper and lower sections of the reservoir. In the upper area, seine samples were collected in Grasshopper and Sale Creek embayments and from the main channel shoreline in the vicinity of TRMs 493.5-495.0. In the lower portion of the reservoir, samples were collected from Wolftever Creek and Dallas Bay embayments and the reservoir shoreline between TRMs 478-483. Also, on September 6 and 7, four seine samples were collected in Sewee Creek embayment and two from the shoreline at TRM 526 on the extreme upper end of Chickamauga Reservoir. Each seine sample consisted of anchoring one end of the seine at the shoreline and then stretching the seine to its full length perpendicularly out from the shoreline. Then one person pulled the outside end back to shore, while the other end was held stationary or only pulled a short distance. Thus, the area sampled consisted of one-fourth of the area of a circle with a radius of 15.2 m (50 ft).

Wisconsin-type trap nets (1.22 m deep) were used for one week each during November and December 1989 to collect crappie in upper and lower Chickamauga Reservoir. On November 6, 1989, a total of ten trap nets was set in Wolftever Creek and Dallas Bay embayments and near the shoreline on the river channel between TRMs 478 and 480. The nets were fished for two days and lifted on November 8, reset, then lifted and removed on November 10. Ten nets were also set on December 4, 1989, in Grasshopper and Sale Creek embayments near TRM 495. These nets were lifted on December 5, reset, then lifted and removed on December 7. All crappie were weighed and measured, and a sample of young-of-year and yearling specimens preserved for life history information and stomach content analysis.

Laboratory Analysis

Larval Fish Samples--Samples were processed by removing all *Pomoxis* sp. (black crappie and white crappie) and *Morone* sp. (white bass and yellow bass). These specimens were identified to species where possible, a function of specimen size and developmental stage (approximately 10 mm TL).

Age and Growth--Scales and otoliths removed from black and white crappie collected by electrofishing and trap netting in 1987 provided data on age composition and annual growth. Fish length at formation of each annulus was estimated using the formula:

$$L_n = A + S_n(L_c - A) / S_c$$

Where L_n = length at annulus formation,
L_c = length at capture,
S_n = scale or otolith measurement to a given annulus,
S_c = measurement to the margin,
A = correction factor.

A standard correction factor (body-scale regression intercept) of 35 mm standard length was used as recommended by Carlander (1977). Back-calculated lengths at annulus formation were compared to historic mean values for other mainstream reservoirs. Comparisons were also made with white crappie age and growth data from Chickamauga Reservoir for 1970 through 1979.

Stomach Content Analysis-- Specimens of both black and white crappie collected from electrofishing and trap-netting in Chickamauga Reservoir during 1989 were preserved for analysis of stomach contents. Fish were selected from a length range representing young-of-year and yearling crappie to determine important food organisms utilized during this period of their life. Stomach contents from 65 white crappie 63-174 mm TL, and 109 black crappie from 60-193 mm TL were examined. Parameters recorded for each specimen included: fish length (TL) and weight (grams); fullness of stomach (percent); condition of contents (excellent, good, poor, bad) based on stage of digestion; and number of food organisms identified to lowest practical taxon, usually order or family. Percent composition by taxon of food organisms was calculated for each 25 mm TL increment for both species of crappie.

Cove Rotenone Sampling and Analysis

TVA has conducted cove rotenone sampling on Chickamauga Reservoir as part of both preoperational and operational nonradiological monitoring programs since 1970 to determine trends in standing stock (numbers/ha and kg/ha) of game, prey, and commercial fish species. Cove rotenone data provide estimates of reproductive success, year-class strengths, and relative fish stock sizes in a given year. In 1970, 12 coves were sampled. The sampling regime was standardized in 1971, with four coves (figure 1) sampled each year during late August or September. The same coves were used each year; however, two sites were relocated (once in 1977 and again in 1987) because of housing development. Standardized rotenone field procedures are summarized in detail by TVA (1983). Standing stocks of young, intermediate, and adult size classes of white and black crappie (as well as other species) were analyzed using a linear regression model to determine statistically significant trends over the period 1970 through 1989.

An index of adult crappie was developed based on year-class abundance of age 2 through age 4 white crappie for a given year. Age 5 and older crappie were not included since few individuals survive beyond age 4. The index was based on densities of yearling white crappie during the previous three years. It also accounted for the decline in numbers of each cohort due to mortality. Annual mortality of age 1 and older white crappie was estimated to be 50 percent. The index developed to describe age 2 and older abundance was:

$$H_t = I_{t-1} + 0.5\ I_{t-2} + 0.25\ I_{t-3}.$$

Where H_t is the calculated index of age 2 and older abundance, and I_t is yearling density in a given year. A similar index was developed by Mitzner (1981) to predict crappie harvest rates based on juvenile densities.

Relationships of total densities and harvest rates, and densities and mortality, to selected environmental parameters were examined for each size class of white crappie using correlation analysis. Parameters included in this analysis were area of aquatic vegetation; total annual fishing pressure; dissolved oxygen (DO) concentration at a depth of 3 m; and densities and biomass of largemouth bass, sunfish, threadfin shad, gizzard shad, and combined threadfin and gizzard shad. Total, young-of-year, intermediate, and adult size class density and biomass were included for the four taxa examined with correlation analysis.

Length frequency analysis and age and growth data were used to assign white crappie to the age groups young-of-year, yearling, and age 2 and older. Instantaneous mortality rates were computed based on these age groupings. Mortality between young-of-year and yearling was computed as:

$$ZY = -[\ln(I_{t+1}) - \ln(Y_t)],$$

Where Y_t is the number per hectare of young-of-year and I_{t+1} is the number of yearling white crappie the next year. Instantaneous mortality of yearling and older fish was computed as:

$$ZA = -[\ln(A_{t+1}) - \ln(I_t + A_t)],$$

Where I_t and A_t are, respectively, yearling and older densities in a given year, and A_{t+1} is age 2 and older density the next year.

Relationships between density and mortality of young white crappie to selected environmental variables were examined using correlation analysis. Independent variables chosen for these analyses included area (hectares) of aquatic vegetation, annual fishing pressure, and density and biomass of young-of-year threadfin shad.

Creel Surveys

Fishing pressure and catch rate data for white and black crappie in Chickamauga Reservoir were obtained from TWRA. Reservoir-wide creel surveys have been conducted by TWRA since 1972. Procedures have followed a design by Dr. D. W. Hayne of the Institute of Statistics at Raleigh, North Carolina. These procedures are described in more detail in TVA (1986).

Annual creel estimates from 1972 through 1984 were based on a period of time beginning July 1 each year and ending June 30 the following year. Creel data from 1985 through 1989 were summarized on a calendar year basis. Catch rates per hour (all anglers) were also examined.

RESULTS AND DISCUSSION

Larval Fish Sampling

Push-nets--Densities (number/1000 m^3) of larval crappie were estimated from push-net samples collected during the period 1986-89 in

Chickamauga Reservoir. Number of samples and sample locations varied from year to year because efforts were made to sample various areas and habitats within the reservoir.

In 1986, 932 larval crappie were collected in 64 push-net samples taken during the four week period April 29-May 30. Total length ranged from 4 to 10 mm. Annual mean density was 104 per 1000 m^3 (table 1).

In 1987, 119 push-net samples were collected during the period April 21-May 29. No crappie larvae were collected on the first sample date (April 21) when mean water temperature was 19.2 $^{\circ}C$. On the remaining three sample dates, 2859 larval crappie were collected in 104 samples. Total length ranged from 4 to 13 mm, although 94 percent (2688) were 4-6 mm TL. Annual mean density was 191 per 1000 m^3.

In 1988, 4179 crappie larvae ranging from 4 to 14 mm TL were collected in 83 push-net samples during the five week period April 26-June 17. A peak density of 506 per 1000 m^3 was recorded on May 10. Eighty-eight percent of all crappie collected in push-nets were 4-6 mm TL. Annual mean density was 389 per 1000 m^3.

In 1989, 84 push-net samples were collected bi-weekly during the period May 2-July 13. A total of 302 crappie was collected, including 288 Pomoxis sp. 4-13 mm TL, 7 white crappie 16-32 mm TL, and 7 black crappie 16-28 mm TL. This total was the lowest collected during this study (table 1) and may be due, in part, to extremely high flow conditions during the sampling period which could have scattered larval crappie earlier than normal and carried them out of the sampling area. Annual mean density was only 25 per 1000 m^3; however, the collection of 14 larger specimens (16-32 mm) could indicate greater than average survival.

Annual estimated mean densities of larval crappie were highly variable (table 1) during both the 1986-89 study and the preoperational and operational monitoring at SQN (1973-85 except 1978), but were noticeably higher during the recent study. During SQN monitoring, all samples were collected in the river channel and adjacent overbank rather than from embayments as were most samples during the present study. Analysis of samples collected in Wolftever Creek embayment and from the river channel during 1986 indicates more concentrated spawning by crappie in embayments than in channel areas of the reservoir. This could explain the lower densities of crappie larvae in table 1 prior to 1986 when samples were collected in the channel and overbank areas of the reservoir.

Light-traps--In 1987, only two crappie were collected in a total of 124 light-trap samples. Both specimens collected on July 1 were juvenile black crappie (35 and 42 mm TL). Light-traps were set too late to sample crappie larvae during their peak abundance and apparently were ineffective at sampling larger post yolk-sac larvae and juveniles.

In 1988, light-trap sampling began April 26 and ended June 17 and was more successful as a total of 691 crappie was collected. Effort consisted of 137 light-trap sets fished for a total of 199.5 hours.

Catch per unit of effort over the entire sample period was 3.5 crappie/light-trap-hour fished. Total length range for crappie in light-trap samples in 1988 was 4-25 mm.

Only three larval and three juvenile crappie were captured in 39 light-trap samples during the three sample periods in 1989. Three Pomoxis sp. 5-13 mm TL, one juvenile white crappie (27 mm TL), and two post yolk-sac larval black crappie (15 and 19 mm TL) were collected on the first sample date (June 13).

These results of push-net and light-trap sampling (especially during 1987 and 1988) demonstrate the concentration of spawning activity and abundance of larval crappie in embayments and habitats secluded from the main channel of Chickamauga Reservoir. This distribution pattern for crappie during spawning and early life history tends to isolate them from areas of potential impacts from operation of SQN and future operation of WBN, such as entrainment, impingement, and thermal effects.

Factors Determining Larval Abundance

Selected environmental factors likely to influence larval abundance were evaluated using multiple regression analysis of larval crappie densities. The regression model which best explained larval densities, having the highest correlation coefficient with the fewest independent variables is shown in table 2. This model, which included water surface elevation and water temperature one week prior to spawning and mean flow during the larval stage, explained 65 percent of variability in the data.

Larval densities were highest when mean water temperature was between 18° and $20^{\circ}C$ during the week prior to spawning (figure 2). The response surface of figure 3 shows predicted larval densities as a function of discharge and water level. Densities were greatest with higher water levels and lower flow.

Trap-netting

During November 6-10, 1989, ten trap-nets fished in Wolftever Creek and Dallas Bay embayments caught 102 white and 136 black crappie. During December 4-7, 1989, ten trap-nets fished in Grasshopper and Sale Creek embayments caught 20 black and 6 white crappie.

These samples were collected to provide species composition data and young-of-year and yearling specimens for life history information. A representative sample of these specimens was preserved for stomach content analysis, and scales and otoliths removed for age determination.

Seine Sampling for Young Crappie

During August and September 1989, 32 seine samples captured 45 black crappie and 2 white crappie. Their total length ranged from 44 to 167 mm and 56 to 114 mm for black and white, respectively. Samples (14) from the lower end of the reservoir (Harrison Bay, Dallas Bay) contained 32 black crappie while 13 samples from mid-reservoir (Grasshopper, Sale Creeks) caught only 13 black crappie. The two white crappie were collected in Sewee Creek embayment in the upper end of the reservoir.

Age and Growth

White crappie collected in Chickamauga Reservoir in 1987 were aged using both scales and otoliths. Otoliths were found to be more reliable than scales, which were difficult to read. First-year length estimates were comparable for scales and otoliths. Mean length at annulus formation (one year old) of 1987 year class white crappie from Chickamauga Reservoir was much greater (table 3) than previous data for white crappie from Chickamauga (1970-79), Fort Loudoun Reservoir (1984), or means for other Tennessee River mainstream reservoirs combined. Annual growth rate of older Chickamauga white crappie was lower than that from these other reservoirs. By age 3, mean lengths of Chickamauga white crappie were comparable to the means for other mainstream reservoirs and Chickamauga white crappie from 1970-79 collections. Mean lengths of Chickamauga white crappie (using otoliths) were greater for all five age classes than for white crappie from Watts Bar Reservoir in 1988 (Mooneyhan 1989).

Black crappie from Chickamauga Reservoir in 1987 had slightly lower growth rates than the mean for other mainstream reservoirs and for black crappie from Watts Bar Reservoir in 1988 (table 3). Growth rates of black crappie in Chickamauga were also lower than those of white crappie collected from the same locations during 1987.

Stomach Content Analysis

The primary objective of this analysis was to determine if there was a noticeable difference in stomach contents between black crappie and white crappie at this size and time of year. Analysis of stomach contents for young-of-year and yearling white crappie and black crappie from Chickamauga Reservoir in November and December 1989 revealed very similar feeding habits for all four size classes of both species (table 4). The dominant food organism consumed by both species was copepods, which comprised approximately 50 percent of the total contents, followed by cladocerans and chironomid larvae. Most of these fish were too small to have switched to a piscivorous diet which explains the lack of fish remains in the stomach contents.

Cove Rotenone Data, Mortality and Correlation Analysis

Young-of-year white crappie densities varied considerably from year to year. Correlation analysis of density versus year was used to identify statistically significant trends over the period 1970 through 1989. Both density and biomass data were analyzed, but since results were similar, only density values are presented. TVA (1989) previously reported a significant increasing trend in density of young-of-year white crappie. With inclusion of the 1989 data, these trends are no longer statistically significant (table 5). The 1989 young-of-year stocks were the lowest of any year since 1976. Significant positive correlations were found between densities of young-of-year white crappie and densities of young-of-year gizzard shad (table 6). A significant inverse correlation was found with adult threadfin shad. These correlations may not represent direct cause and effect relationships, but could result from conditions being near optimum for both species in a given year, or in the case of a negative correlation, could represent direct interspecific competition.

Young-of-year white crappie densities from rotenone samples were significantly correlated with larval densities during the same year. Figure 4 suggests this relationship is curvilinear, with density dependent factors reducing survival at higher larval densities.

Examination of larval size structure for 1977, 1981, and 1982 provides additional evidence of density dependent mortality (figure 5). Larval densities were the highest in 1981 (over 40 per 1000 m^3). Mortality was high for this year class and few larvae greater than 14 mm TL were collected. In 1977 and 1982, larval densities were the third and fourth highest. Larval mortality was lower for these year classes (figure 5), and greater young-of-year stocks were produced.

Significant decreasing trends were found for density of yearling (intermediate) white crappie from rotenone samples during 1970-89. Significant ($p < 0.05$) inverse correlations were found with each size class of sunfish (table 6). This correlation could result from direct competition for food and habitat. The relationship between yearling white crappie and the previous year's young-of-year stocks was non-significant. Further examination of this relationship (figure 6) indicated mortality between young-of-year and yearling age groups was higher since 1978 than for previous year classes. The reference line on this plot represents an 85 percent mortality rate. With the exception of 1973, all year classes prior to 1978 fell above this line, while all subsequent year classes fell below the reference line, indicating greater than 85 percent mortality.

The instantaneous mortality rate between age 0 and age 1 increased significantly through time (table 5). Factors likely to cause increased mortality of young crappie were examined using correlation analysis. Significant correlations were found with increased area of aquatic vegetation; fishing pressure; young-of-year sunfish, black crappie, and largemouth bass; and yearling sunfish, black crappie and largemouth bass (table 6).

The instantaneous mortality rate of age 1 and older white crappie also showed a significant increasing trend (table 5). High mortality between age 1 and age 2 accounted for this trend. In recent years very few age 2 and older individuals were collected in cove rotenone samples. Significant inverse correlation was also found between age 1 and older white crappie mortality and mean annual dissolved oxygen concentration at a depth of one meter. Positive correlations were found with area of aquatic vegetation, fishing pressure, and density of young-of-year black crappie and gizzard shad.

For age 2 and older white crappie, density decreased significantly between 1970 and 1989 (table 5). Significant positive correlation was found with the index based on abundance of age 2 and older white crappie (figure 7). This indicates that density and survival of yearling white crappie determine age 2 and older stocks one to three years later and that adult densities are determined by events prior to white crappie reaching age 1.

Significant positive correlation was also found between age 2 and older densities of white crappie and mean annual dissolved oxygen (DO) concentration at a depth of one meter. A report (TVA 1990) describing the effect of SQN on the DO in Chickamauga Reservoir concluded that mixing effects from the plant's underwater dam and thermal discharge increase metalimnetic and hypolimnetic DO levels. Near-surface DO levels are reduced by an average of 0.7 mg/l in the main channel downstream from the mixing zone. Based on observed temporal and spatial distribution, very few crappie would be resident in the near-diffuser area to potentially experience slightly lowered DO conditions near the surface. Those that might be there would more likely benefit from the increased DO deeper in the water column.

Several potential effects to white crappie (and other species) from operation of SQN were addressed in an predictive section 316(a) demonstration for an alternative winter thermal discharge limit (TVA 1989). These included: fish concentration in the thermal plume; winter survival; fishing pressure and predation; impingement; and reproduction. No impacts to white crappie were predicted in the demonstration based, in part, on preliminary results of this investigation which began in 1986.

Inverse correlations were found between age 2 and older white crappie and increased area of aquatic vegetation; fishing pressure; density of young-of-year black crappie, sunfish, gizzard shad, and threadfin shad; and yearling stocks of sunfish and adult gizzard shad. Inverse correlations were also found for both young-of-year and adult combined gizzard and threadfin shad (table 6). It is beyond the scope of this project to completely determine the effect of each of these factors on the white crappie population in Chickamauga Reservoir. Some of the above factors such as increased fishing pressure are obvious as to their negative impact to adult white crappie, while others likely interact and result in combined and more indirect effects.

Creel

A pattern similar to the decreasing trend for ages 2 and older stocks was evident in white crappie catch rates (table 7). Harvest rates fluctuated in the 1970s and early 1980s. Strong year classes evident in the cove rotenone data (1977 and 1978) resulted in increased harvest rates when they reached harvestable size during 1980 and 1981. Catches then dropped as natural and fishing mortality depleted these year classes. Recruitment during subsequent years has been inadequate to maintain previous harvest rates. Total number of white crappie harvested did not show a significant decreasing trend. Fishing pressure increased during this period, compensating for reduced catch rates with equivalent or greater total catch. Stocks of age 2 and older white crappie were positively correlated ($r = 0.75$, $p = 0.0003$) with fisherman catch rate and inversely correlated with increased aquatic vegetation ($r = -0.56$, $p = 0.04$) and fishing pressure ($r = -0.62$, $p = 0.006$). Although white crappie catch rates have declined during 1972-89, Chickamauga ranked relatively high compared to catch rates from other Tennessee reservoirs during 1988 and 1989 (table 8).

Black/White Crappie - Species Dominance

In lakes or reservoirs where both black and white crappie occur, one species usually predominates (Ellison 1984). Generally, black crappie are more abundant in clear lakes and white crappie seem better adapted to turbid waters (Hall et al. 1954, Neal 1963, and Goodson 1966).

Prior to 1988, crappie in Chickamauga Reservoir were predominately white crappie. In rotenone samples from 1970 through 1979, black crappie averaged 1.7 percent of the total crappie population. Between 1980 and 1987, black crappie increased to an average of 8.4 percent. In 1988, black crappie outnumbered white crappie for the first time, making up 80.4 percent of the population. In 1989, black crappie increased to 85.3 percent of the population. Significant increasing trends were found for young-of-year and age 1 black crappie (table 5). This dominance of young-of-year and yearling black crappie was also evident in electrofishing, trap-net and seine samples taken since 1988 as part of this investigation. No significant trend (table 5) was found for age 2 and older black crappie, or for black crappie catch rates (table 7), although catch rates since 1987 were higher than in any previous year. The number of black crappie harvested did increase significantly (table 7) partly due to increased fishing pressure.

Since the late 1970s the area covered by aquatic vegetation in Chickamauga Reservoir has increased seven-fold. A difference in the preferred habitats of young-of-year of the two crappie species was described by Ridenhour (1960) in Clear Lake, Iowa. Young white crappie were found in large numbers in deep water, while black crappie preferred heavy vegetation along the shore. Pearse (1918) also observed association of black crappie with aquatic vegetation in Wisconsin lakes. Adult black crappie were found by Mitchell (1941), Finkelstein (1960), and Ball and Kilambi (1973) to consume less fish and more benthic invertebrates, especially insects. These organisms are found in greatest abundance in association with aquatic vegetation (Minckley 1963, Miller et al. 1989)

Aquatic macrophytes have been shown to alter aquatic habitat resulting in changes in invertebrate community structure which may favor black crappie over white crappie. It seems likely, therefore, that the increase in aquatic vegetation in Chickamauga Reservoir, particularly during the period of prolonged drought (1985-88), has favored black crappie dominance.

CONCLUSIONS

The concern expressed by TWRA and TDWPC that the white crappie population is declining in Chickamauga Reservoir is substantiated by results of this investigation. The adult white crappie population in Chickamauga Reservoir has declined in recent years, as indicated from annual cove rotenone samples and fisherman harvest rates. Spawning success and survival through early life history stages were determined not to be major factors in the overall population decline. White crappie age 2 and older were found to be significantly correlated with density and survival of yearling crappie, which indicates that densities of adults are determined by environmental factors occurring prior to white crappie reaching age 1.

Densities of adult white crappie were positively correlated with dissolved oxygen concentration and negatively correlated with area of aquatic vegetation; fishing pressure; density of young-of-year black crappie, sunfish, gizzard shad, and threadfin shad; yearling stocks of sunfish; and adult gizzard shad. Direct cause-and-effect relationships are not necessarily proposed by the above correlations in determining survival of white crappie stocks. It is more likely that a synergistic effect of several environmental variables combined with interspecific competition from one or more species is responsible for white crappie abundance.

An obvious shift in dominance from white crappie to black crappie has occurred in Chickamauga Reservoir. In 1988 and 1989, black crappie actually outnumbered white crappie, comprising 80.4 and 85.3 percent, respectively, of the total crappie collected in cove rotenone samples. White crappie, however, have continued to dominate TWRA creel data collected through 1989, although numbers of black crappie harvested have increased significantly. It would appear that, despite the declining trend in density of white crappie, the total crappie fishery has not decreased significantly due to compensating increases in the black crappie population. This is substantiated by relatively high catch rates for white crappie in Chickamauga Reservoir during 1988 and 1989 compared with other Tennessee reservoirs. Assuming present trends continue, it remains to be seen if an increased population of black crappie in Chickamauga Reservoir will compensate for the declining population of white crappie in terms of fisherman harvest.

Overall results of this investigation have determined several factors (increased aquatic macrophytes, interspecific competition, and interaction thereof) which are correlated with the population decline of white crappie in Chickamauga Reservoir. Distribution in the reservoir, lack of attraction to thermal discharges, and preferred spawning habitat away from location of SQN and WBN, all tend to minimize or negate known potential impacts to white crappie from nuclear plant operation.

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Table 1. Number collected and annual mean densities (number per 1000 m^3) of larval crappie in Chickamauga Reservoir during 1973-89 (no samples in 1978).

Year	Sample Volume m^3	Number of Crappie Collected	Annual Mean Density
1973	52,930	905	17
1974	34,160	262	8
1975	12,177	78	6
1976	16,676	112	7
1977	12,317	1,055	86
1979	27,399	397	15
1980	26,069	635	24
1981	28,930	3,960	137
1982	33,959	2,703	80
1983	30,999	733	24
1984	33,040	622	19
1985	33,018	558	17
1986	8,987	932	104
1987	14,947	2,859	191
1988	10,660	4,147	389
1989	11,924	302	25

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Table 2. Results of stepwise multiple regression analysis of 5 mm larval crappie densities with environmental variables. Includes selected parameters, regression equation, partial correlation coefficients, and significance levels.

Parameter	Regression Equation	Partial Correlation Coefficient	P
Intercept	-87.086		.0001
Water Temperature one week prior to spawning	0.273	0.09	.0013
Water temperature one week prior to spawning squared	-0.008	0.14	.0001
Discharge during larval stage prior to spawning squared	-7.823	0.08	.0023
Discharge during larval stage prior to spawning	1.068	0.07	.0046
Minimum surface water elevation one week prior to spawning	0.481	0.19	.0001
Entire model (R^2)		0.65	

0386j

Table 3. Age and growth of white and black crappie from Chickamauga Reservoir, fall 1987 compared to other Tennessee Valley Reservoirs. White crappie from Chickamauga Reservoir aged using scales and otliths, all others by scales only.

	Mean length (mm) at each age					
White Crappie — Age	1	2	3	4	5	6
Chickamauga 1987						
from scales	109	177	225	265	296	316
from otoliths	108	184	249	291	328	-
Chickamauga 1950	85	167	227	239	-	-
Chickamauga 1970-1979	77	167	237	290	325	346
Fort Loudoun 1984	70	131	178	242	272	292
Watts Bar 1988*	89	171	235	280	307	333
All mainstream reservoirs combined	84	166	227	289	337	369
Black Crappie						
Chickamauga 1987 (scales)	93	155	213	247	275	273
Guntersville 1985	86	202	263	299	318	343
Watts Bar 1988*	82	162	222	257	-	-
All mainstream reservoirs combined	98	163	215	-	-	-

* From Mooneyhan, 1989

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Table 4. Percent composition (numbers) by taxon of major food items in young-of-year and yearling white and black crappie stomachs from Chickamauga Reservoir, November-December, 1989.

Total length Class (mm)	Number* of Fish	Copepods	Cladocerans	Chironomid larvae
White Crappie				
50-75	26	.49	.33	.11
76-100	30	.54	.21	.18
101-150	6	.54	.34	.08
151-175	3	.45	.33	.04
Total	65			
Black Crappie				
50-75	13	.56	.36	.05
76-100	23	.59	.24	.14
101-150	61	.27	.57	.08
151-200	12	.47	.34	.09
Total	109			

* Includes empty stomachs

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Table 5. Correlation coefficients (Test for Temporal Trend) of white and black crappie density and instantaneous mortality by age class and harvest rates with year of sample in Chickamauga Reservoir during 1970-89.

	CORRELATION COEFFICIENTS	
	White Crappie	Black Crappie
Density in Rotone Samples		
Young-of-year	0.17	0.69***
Age 1	-0.62**	0.54*
Age 2 and Older	-0.86***	0.33
Instantaneous Mortality Rate		
Age 0 to Age 1	0.70***	N/A
Age 1 and Older	0.63**	N/A
Harvest Rate		
Total per Year	-0.29	0.68**
Number per Hour	-0.67**	0.36

* = Pr from 0.05 - 0.01
** = Pr from 0.01 - 0.001
*** = Pr from 0.05 - 0.0001

NA = Trends in mortality rate of black crappie were not presented, since very few individuals were collected prior to 1988.

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Table 6. Results of correlation analyses of densities and instantaneous mortality rates of white crappie by Age class with selected environmental variables.

	Crappie Density			Instantaneous Mortality Rate	
Parameter	Young-of-year	Age 1	Age 2 and Older	Age 0 to Age 1	Age 1 and Older
Dissolved oxygen	-0.09	0.20	0.54*	-0.36	-0.70**
Area of aquatic vegetation	0.33	-0.30	-0.79***	0.60*	0.70**
Fishing pressure	0.17	-0.41	-0.74***	0.57*	0.66**
Black Crappie					
Young-of-year	0.03	-0.29	-0.63**	0.60**	0.55*
Age 1	-0.17	-0.33	-0.34	0.51*	0.21
Age 2+	0.04	-0.22	-0.18	0.12	0.24
Sunfish					
Young-of-year	0.34	-0.48*	-0.46*	0.61**	0.28
Age 1	0.11	-0.44*	-0.51*	0.56*	0.11
Age 2+	-0.18	-0.48*	-0.26	0.34	-0.10
Largemouth bass					
Young-of-year	0.43	-0.18	-0.07	0.52*	0.14
Age 1	0.37	-0.34	-0.41	0.58**	0.37
Age 2+	0.09	-0.05	-0.12	0.44	0.22
Gizzard shad					
Young-of-year	0.51*	0.04	-0.53*	0.31	0.46*
Age 1+	0.41	-0.10	-0.47*	0.43	0.23
Threadfin Shad					
Young-of-year	-0.23	-0.09	-0.50*	-0.04	0.32
Age 1+	-0.50*	-0.13	0.10	-0.42	-0.22
Combined Gizzard shad and Threadfin shad					
Young-of-year	0.01	-0.01	-0.55*	0.08	0.32
Age 1+	0.38	-0.11	-0.47*	0.41	0.22

* = P_r from 0.05 - 0.01
** = P_r from 0.01 - 0.001
*** = P_r from 0.05 - 0.0001

0385j

Table 7. Creel data including numbers, weight, fishing pressure and catch rate by year for white and black crappie from Chickamauga Reservoir from 1972-89.

Year	Hours Fished	Estimated Numbers Harvested		Estimated Biomass (kg) Harvested		Catch per hour	
		White Crappie	Black Crappie	White Crappie	Black Crappie	White Crappie	Black Crappie
72	338,935	99,838	1,874	23,764	440	.30	.01
73	252,056	143,392	2,068	33,145	474	.57	.01
74	216,868	55,873	4,215	11,441	948	.26	.02
75	463,855	66,444	4,234	13,265	1,072	.14	.01
76	412,771	64,985	6,610	16,933	1,908	.16	.02
77	273,882	85,425	1,705	23,886	517	.31	.01
78	331,987	108,716	3,313	19,080	892	.33	.01
79	416,601	87,831	4,105	16,423	974	.21	.01
80	463,683	215,764	3,204	36,765	669	.47	.01
81	491,171	136,069	4,502	28,874	1,271	.28	.01
82	454,741	50,729	3,731	14,533	1,729	.11	.01
83	523,780	35,713	2,721	10,304	997	.07	.01
84	463,795	43,515	4,504	11,428	1,206	.09	.01
85	464,658	30,468	2,736	8,003	644	.07	.01
86	612,504	63,450	5,659	13,119	1,397	.10	.01
87	689,964	77,060	18,483	21,772	5,165	.11	.03
88	742,073	126,345	17,278	+	+	.17	.02
89	640,000	58,087	13,378	+	+	.09	.02

+ data unavailable

0387j

Table 8. Sport fisheries catch rates for white crappie from Chickamauga Reservoir compared with those from other Tennessee reservoirs during 1988 and 1989.

Reservoir	Number of White Crappie caught per hour	
	1988	1989
Chickamauga	0.81	0.57
Watts Bar	0.62	0.93
Nickajack	0.24	0.09
Guntersville	0.04	-
Kentucky	0.91	0.54
Boone	0.06	-
Center Hill	0.66	0.08
Cherokee	0.16	0.42
Dale Hollow	0.68	0.31
Douglas	0.61	0.38
Normandy	0.66	-
Norris	0.39	0.21
Old Hickory	0.72	0.82
Percy Priest	0.92	0.79
Reelfoot	1.78	1.63
Woods	2.43	2.52

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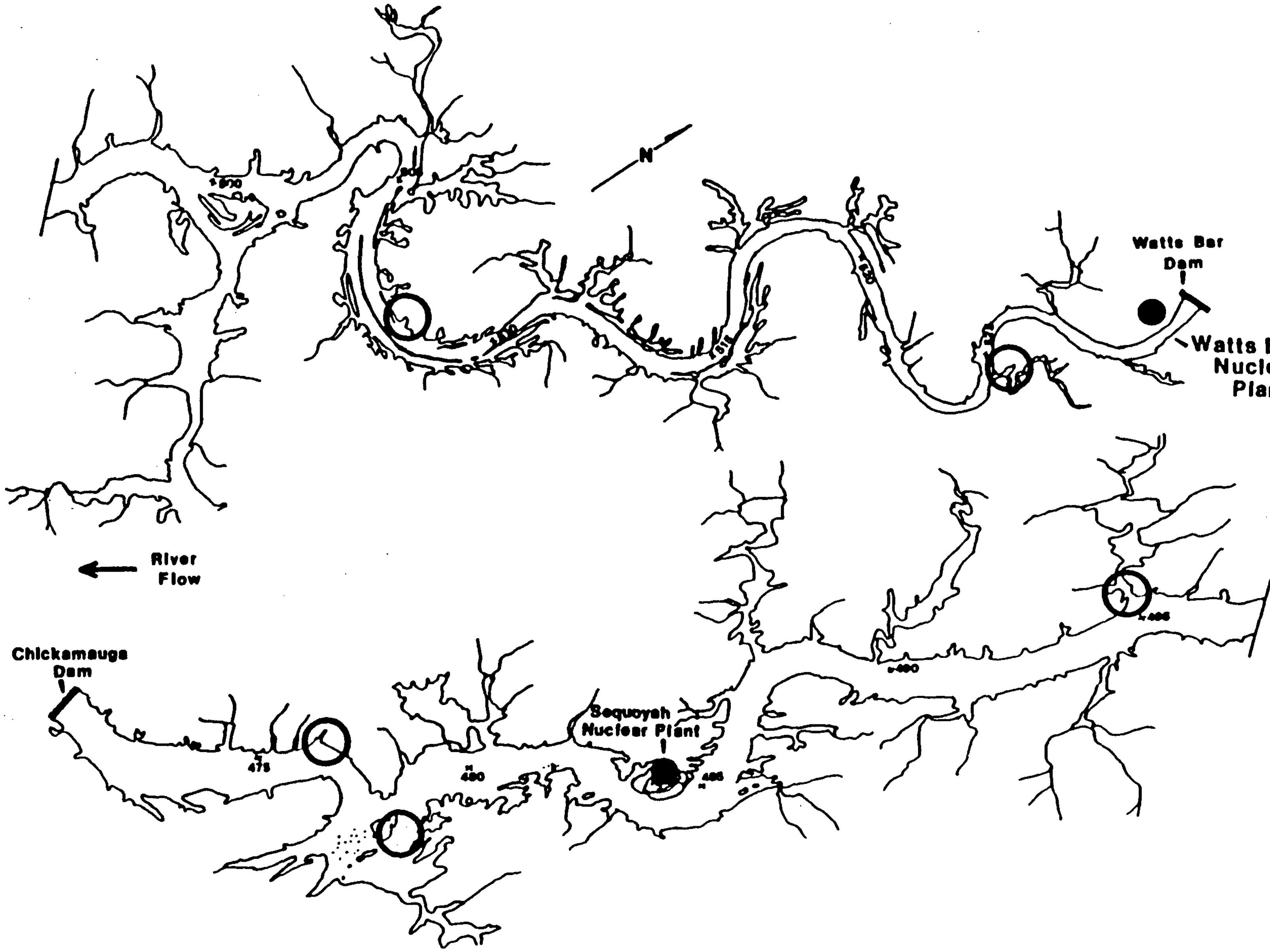

Figure 1. Map of Chickamauga Reservoir showing Sequoyah and Watts Bar Nuclear Plants and location of coves sampled with rotenone during 1971-89. Data from Sewee Creek cove (TRM 524.6) were not used in this report.

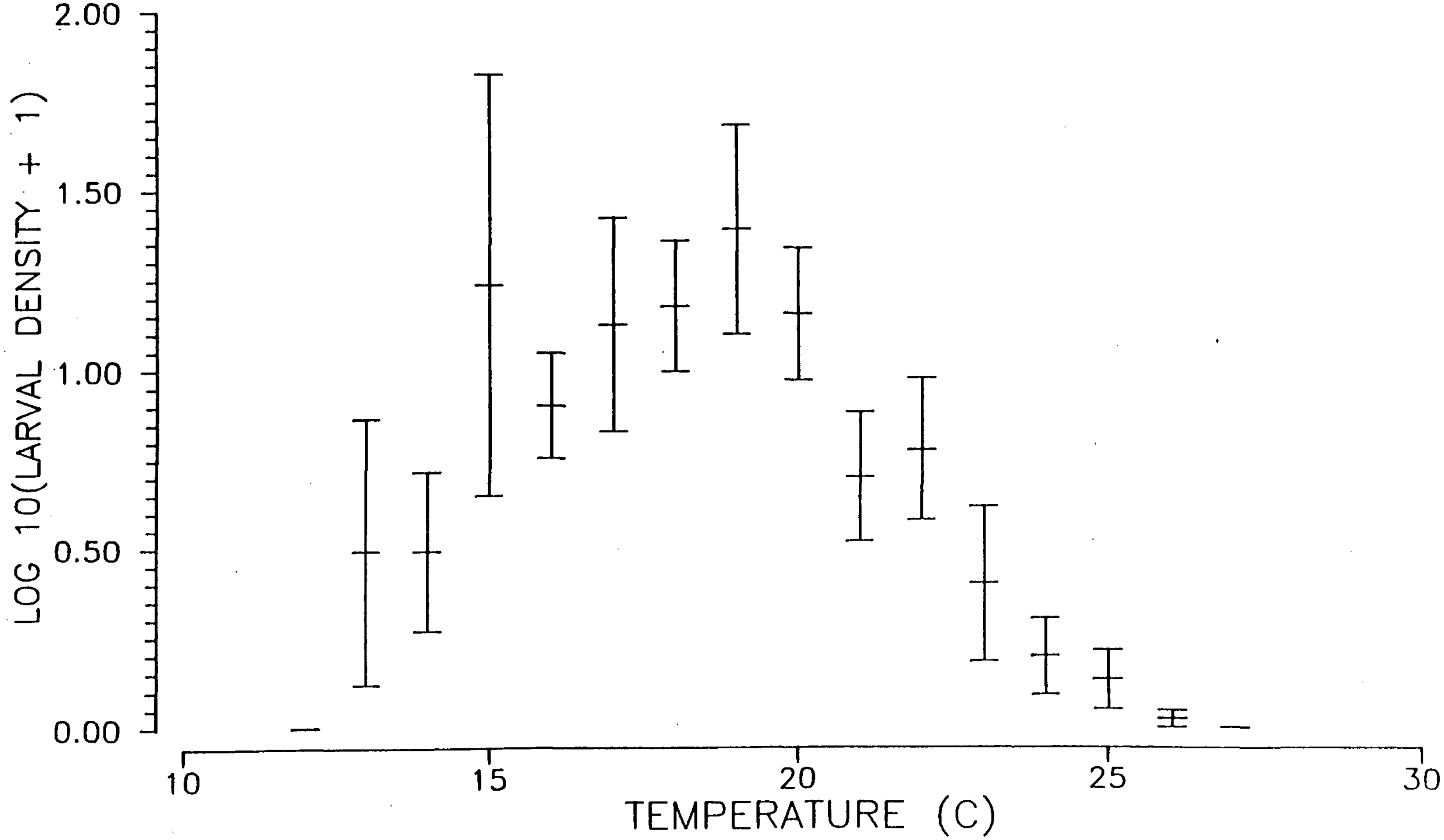

Figure 2. Mean density (plus or minus SE) of 5 mm larval crappie as a function of mean water temperatures the week prior to spawning during 1973-85 in Chickamauga Reservoir.

LARVAL CRAPPIE DENSITY AT 20 DEGREES C.

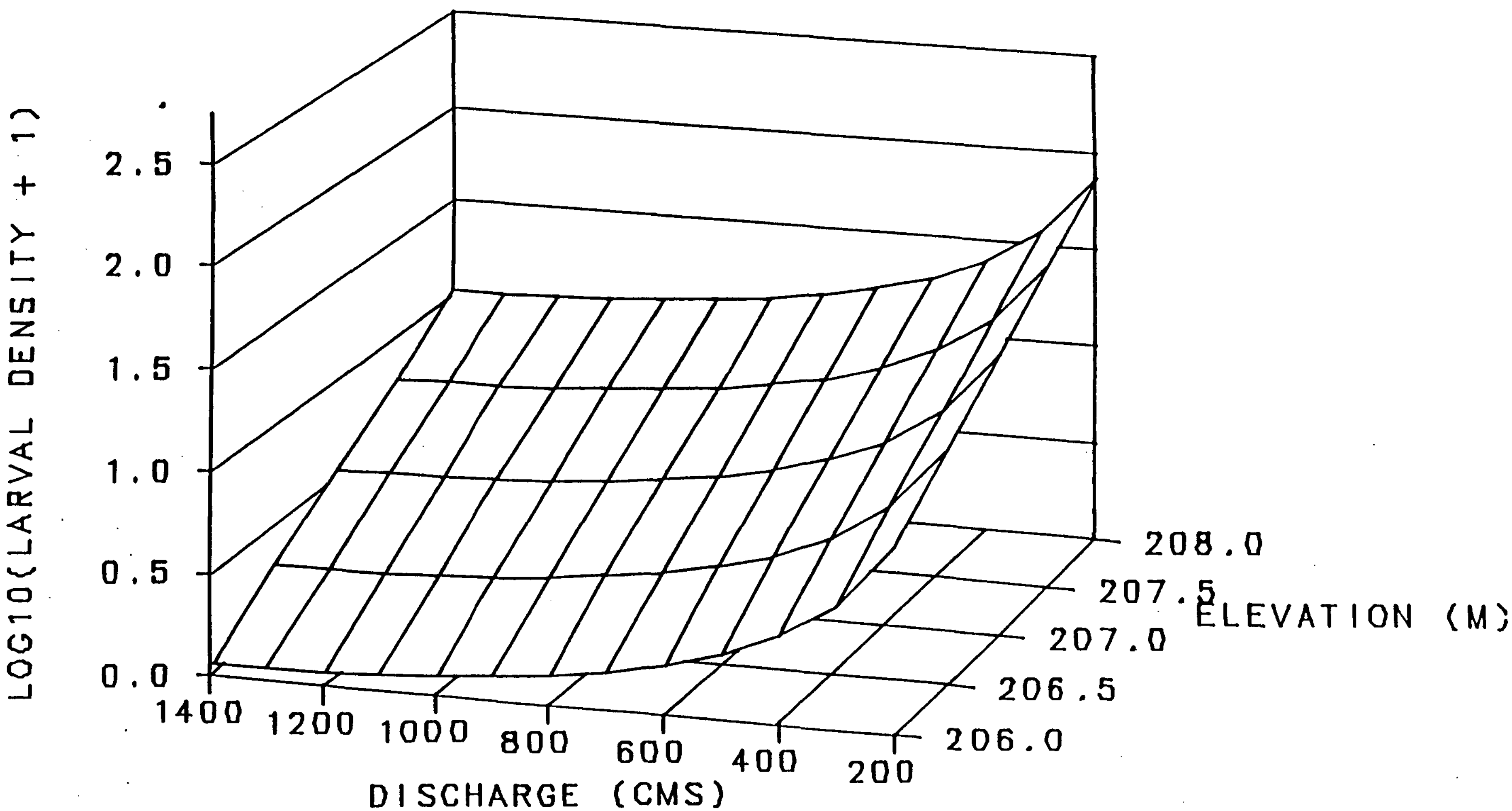

Figure 3. Predicted 5 mm larval crappie densities (number per 1000 m^3) as a function of minimum surface water elevation (during the week prior to spawning) and mean discharge from Chickamauga Dam between hatching and growth to 5 mm (assumed to be five days) when water temperature is $20^{o}C$ during 1973-85 in Chickamauga Reservoir.

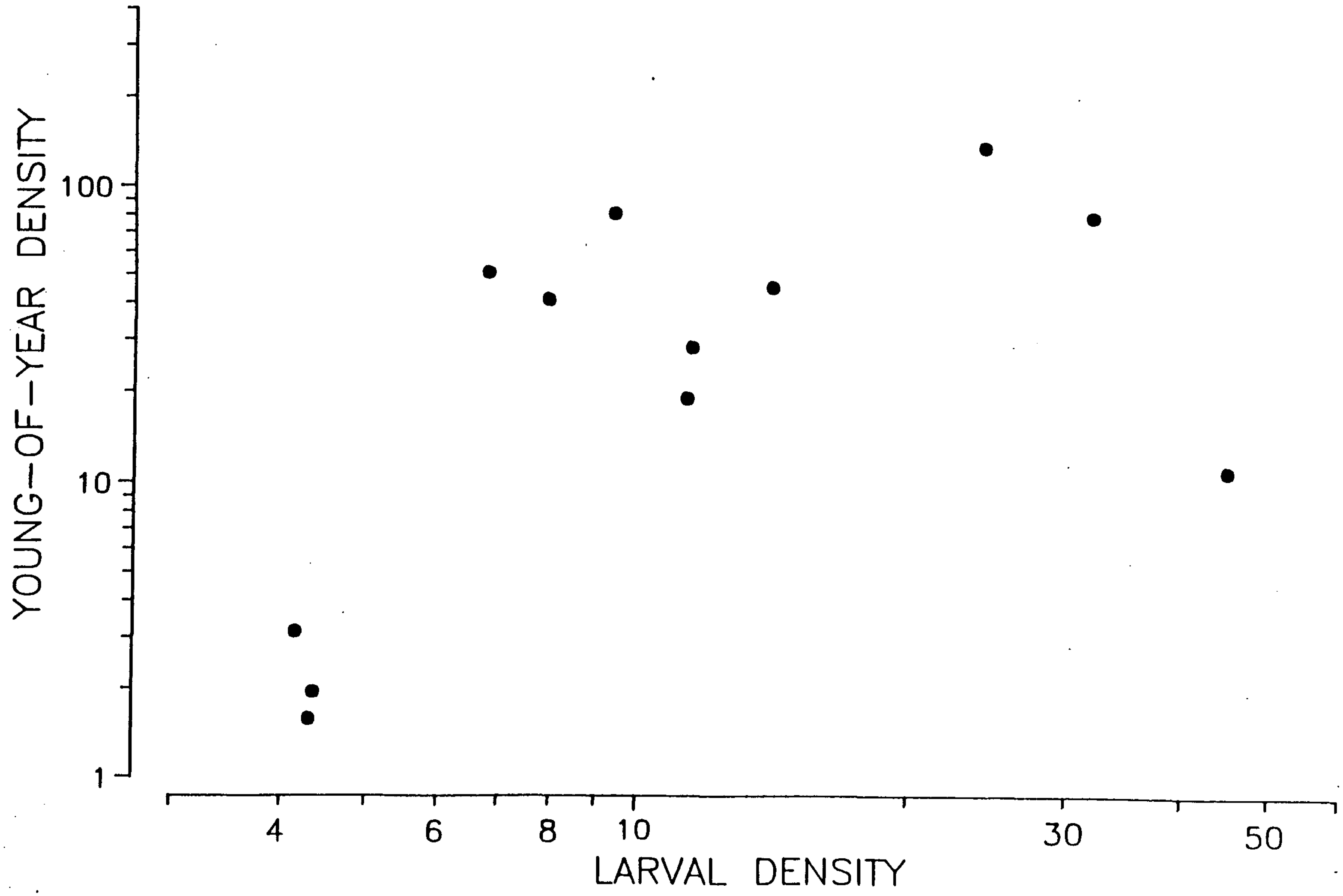

Figure 4. Young-of-year white crappie densities in cove rotenone samples (number per hectare) versus larval crappie densities (number per 1000 m^3) during the same year.

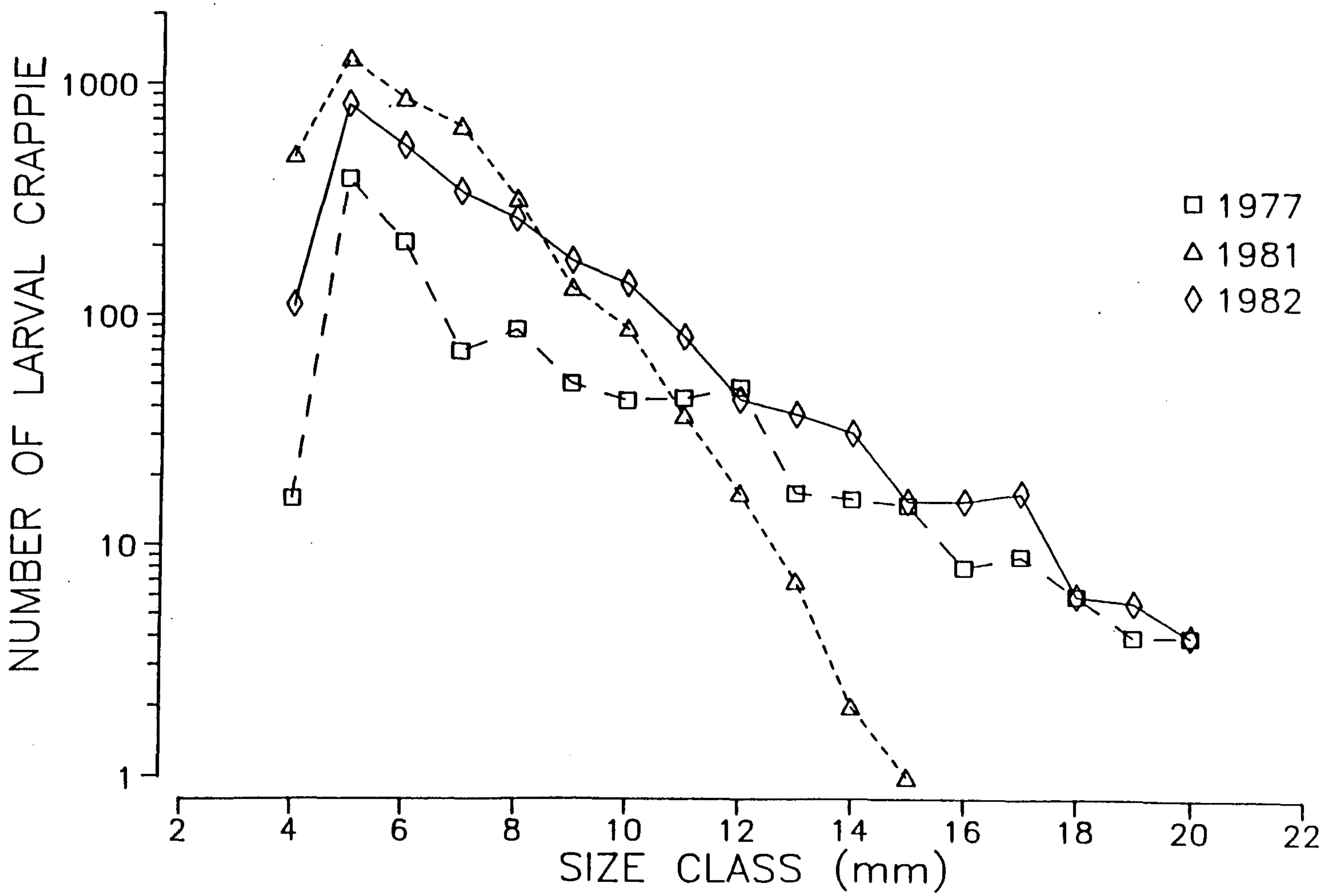

Figure 5. Length frequency distribution of larval crappie from Chickamauga Reservoir, during 1977, 1981, and 1982.

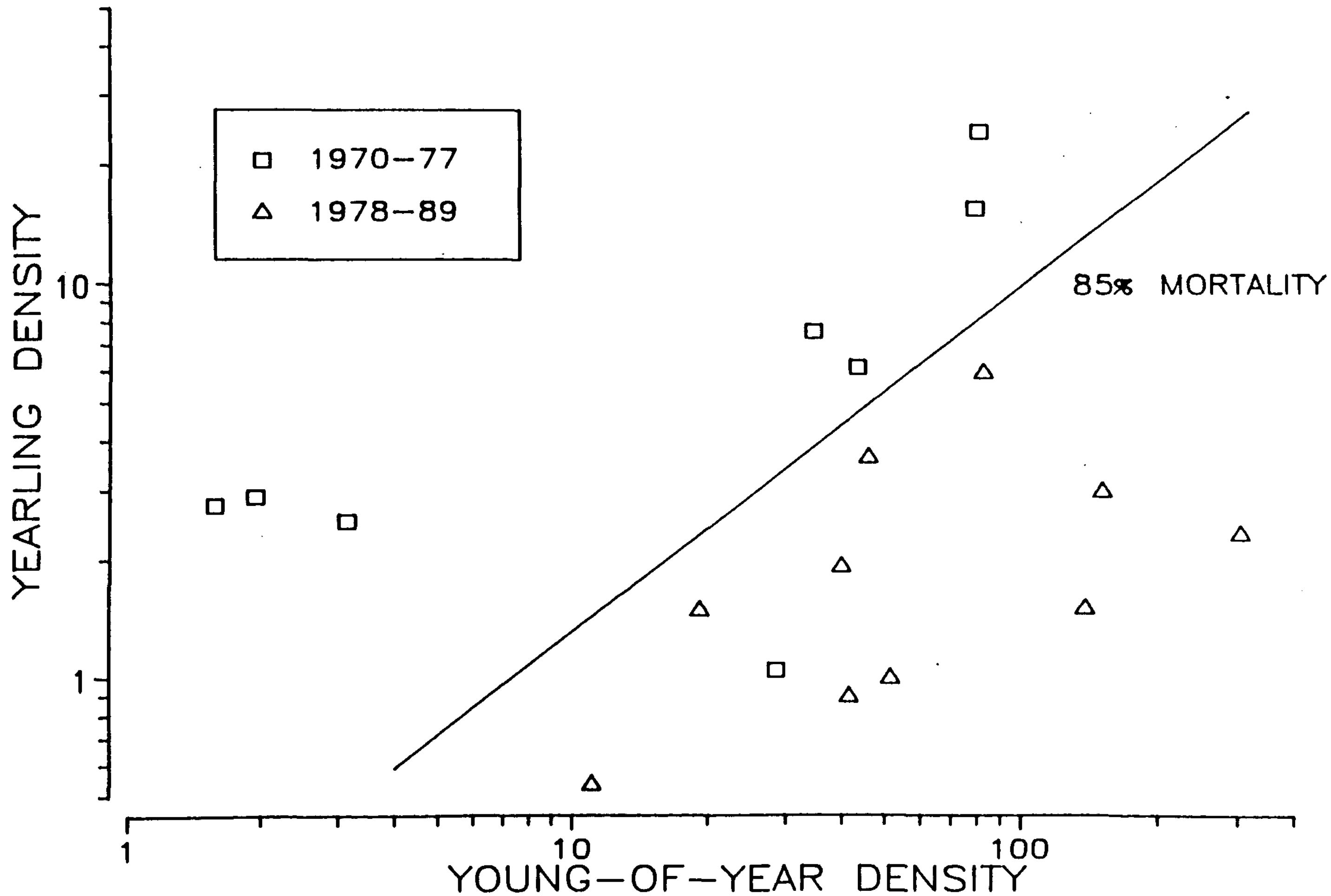

Figure 6. Young-of-year versus yearling white crappie density (number per hectare) for each year class (1970-89) in cove rotenone samples, Chickamauga Reservoir reference line represents 85 percent mortality. Year classes above this line had mortality less than 85 percent, while year classes below the line had mortality greater than 85 percent.

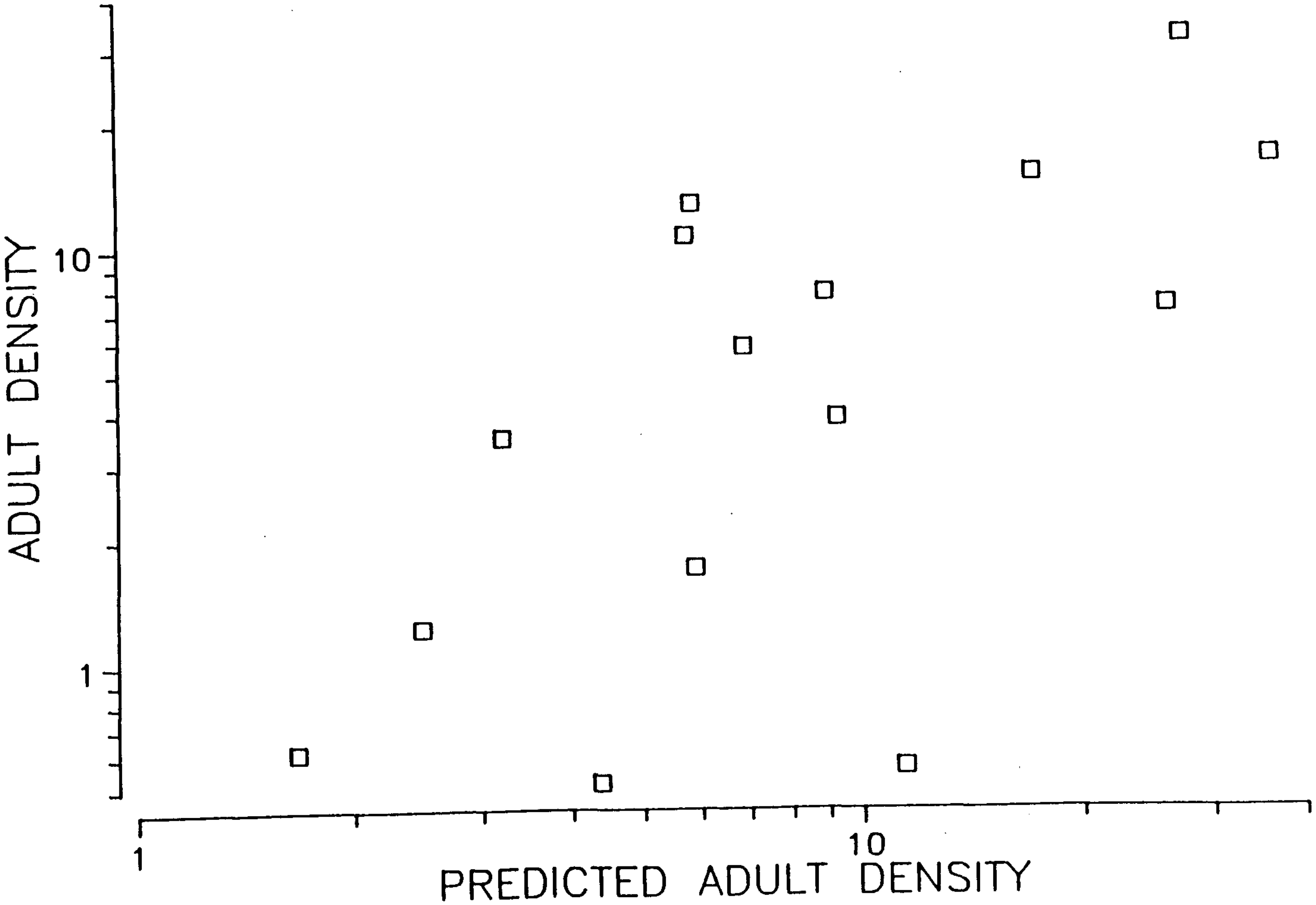

Figure 7. Adult white crappie densities versus predicted adult densities in cove rotenone samples from Chickamauga Reservoir 1970-89. Adult densities were predicted from yearling densities in cove rotenone during the previous three years assuming 50 percent annual mortality.

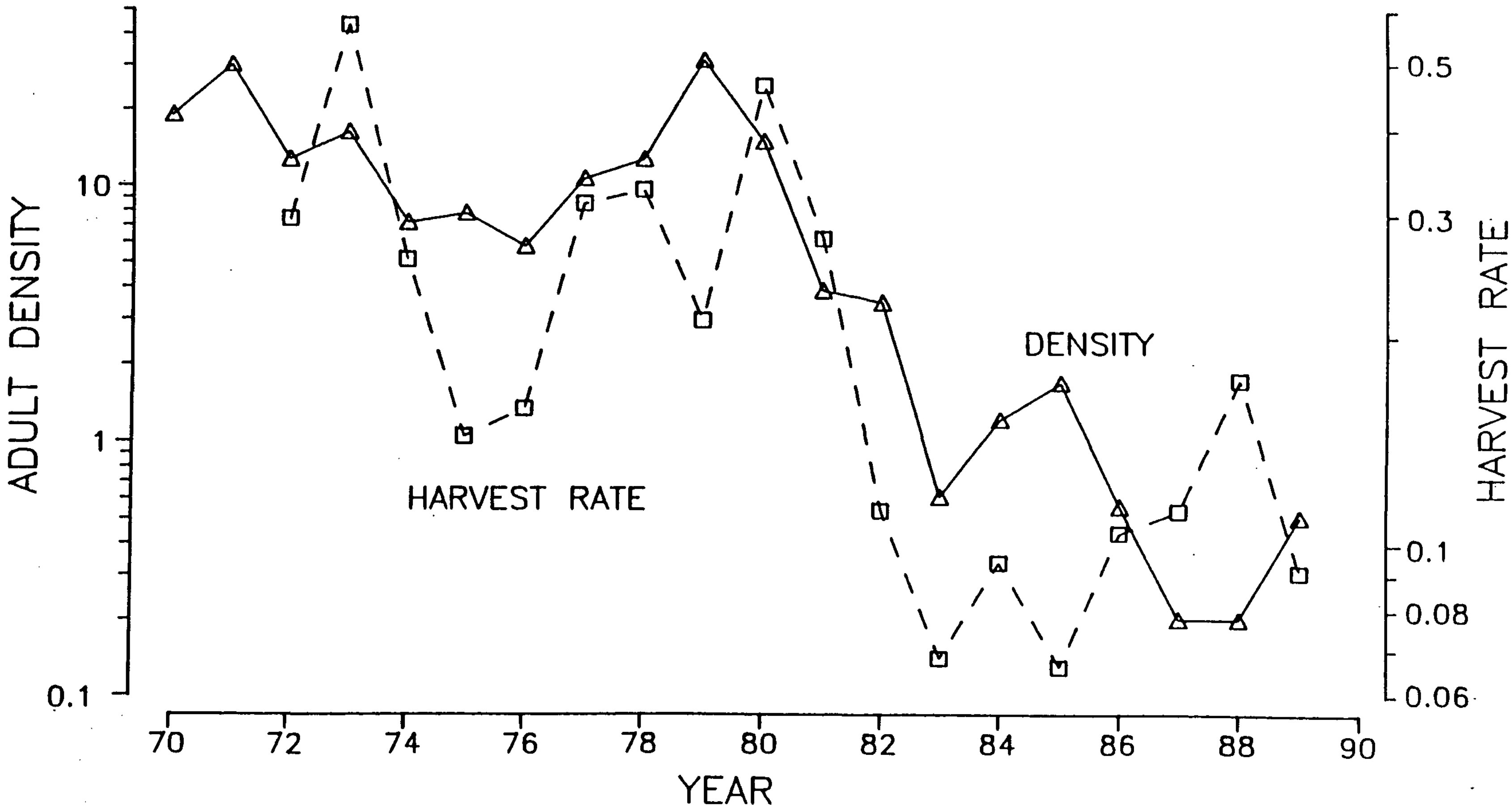

Figure 8. Density of age 2 and older white crappie (numbers per hectare) and harvest rate (number per hour) by year for Chickamauga Reservoir.