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POPULATIONS OF LEPOMIS AURITUS (REDBREAST SUNFISH) IN A THERMALLY INFLUENCED SECTION OF THE JAMES RIVER, VIRGINIA

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Abstract

From October 1971 - September 1973, electrofishing was used to collect 1004 specimens of *Lepomis auritus* (year classes O - V) from a thermally influenced section of the James River near Bremo Bluff, Virginia. Collections of fish from the natural and heated water temperature habitats were analyzed as to year classes, season, length and sex.

Year class II comprised the greatest percentage of the total collections of fishes from the ambient temperature environment, whereas year class O was the dominant class in the heated habitat. Seasonal influence on abundance was not as pronounced in the heated habitat as in the natural environment. Seasonal composition by year classes was influenced by the reproduction and feeding activities. Male *L. auritus* had greater mean annual lengths in year classes III and IV from the ambient temperature habitat and in year classes II and III from the heated habitat. Fish in year classes O and I and males in year class II from the heated environment exhibited greater annual mean lengths than

their corresponding year classes in the ambient waters. The overall sex ratio of fish from both habitats did not differ significantly from a 1:1 ratio.

Introduction

The redbreast sunfish, *Lepomis auritus* (Linnaeus), family Centrarchidae, originally occurred in the Atlantic Coast drainages from New Brunswick to Florida and westward in the Gulf of Mexico Coastal Plain streams to Louisiana. Through introduction its range has been extended west to Texas and north in the Mississippi River Valley to southern Oklahoma (Moore, 1968). In Virginia *L. auritus* may be found in streams (primary habitat) and impoundments in virtually all geographical regions; however, it occurs more commonly in streams of the Piedmont than in any other region of the state (Shomon, 1955). In a study of the fishes in the Piedmont section of the James River, Virginia, Woolcott (1974) reported the occurrence of the redbreast sunfish in 228 of 347 collections, supporting the statement of Raney (1950) that this species is the predominant sunfish of the river drainage.

Despite the extensive geographical distribution of *L. auritus* and its popularity as a panfish, relatively few life history studies of this species have been published (Breder and Rosen, 1966). The spawning behavior, fecundity rates and food habits of the redbreast sunfish have been described by Davis (1971) and Breder and Rosen (1966). Relationships of temperature to populations of L. auritus have been reported by several authors. Breder and Nigrelli (1935) in studying prespawning behavior of adult redbreast sunfish reported that they demonstrated a primary urge to aggregate as water temperatures dropped below 5 C, dispersing as temperature exceeded 7 C. Clugston (1973) in a study of the effects of a heated effluent on fishes reported that the redbreast sunfish and two other species, Lepomis macrochirus (bluegill) and Micropterus salmoides (largemouth bass), which commonly occurred in water temperatures ranging from 35 - 41 C and 32 - 35 C, respectively, were able to sustain populations in a primary cooling pond where temperatures often exceeded 50 C. Woolcott (1974) reported finding redbreast sunfish at a temperature of 39 C in the heated discharge of an electric power station. A comparative growth study by O'Rear (1968) indicated that growth of L. auritus (year classes I and II) in thermally influenced sample areas was not greater than that of fish in ambient temperature areas.

The objective of this investigation was to determine if the seasonal structure of populations of L. auritus occurring in natural temperature habitats of the James River differed from those occurring in habitats subjected to the artifically higher temperatures in the heated effluent of an electric power station. Populations from each habitat were analyzed as to year classes present and the sex ratio and length of specimens within each year class.

Study Area

Description of the study area is taken in part from Kirk (1974) in a technical report on the influence of thermal loading by a n electric power station on the aquatic environment of the James River.

The area investigated was a 30 km section of the James River extending through the Piedmont Province from Bremo Bluff to Cartersville, Virginia. The river in this area is about 230 m wide with a rather flat channel bed. Flow is in a southeastward direction with the river forming the boundary between Buckingham and Cumberland counties on the south and Fluvanna and Goochland counties on the north (Fig. 1).

The Virginia Electric and Power Company operates a 210 MW fossil fueled power station located on the north side of the river at Bremo Bluff, Virginia. The plant utilizes from 2 - 13% of the river water for cooling purposes depending on the operational demand and the flow (m^3/sec) of the river. Discharged water had a Δ t of 4 - 13 C and could be identified as a narrow plume extending approximately 23 m outward from the north shore at the outfall and downstream for approximately 8 km.

The Hardware River and the Slate River, which receives a discharge from the Solite Corporation, enter the James River 9.6 km and 2.3 km, respectively, above Bremo Bluff. The Rivanna River empties into the James 16.1 km downriver from Bremo Bluff. None of these rivers contributed significant amounts of pollution to the area. Other tributaries in the study area include a small creek (mouth 4.6 m wide) on the southside which enters 8 km downriver from Bremo Bluff and a scattering of several smaller streams.

Similar vegetation existed on both banks immediate to the river with farmlands of cultivated fields and pastures prevalent in the background. *Celtis occidentalis* (hackberry) was the predominant tree species along the banks followed in order of abundance by *Platanus occidentalis* (sycamore) and *Acer rubrum* (red maple). Trees found in irregular distribution were *Fraxinus* sp. (ash), *Betulia nigra* (river birch) and *Salix* sp. (willow). The more abundant herbs included *Rhus radicans* (poison ivy), *Calystigia* sp. (bendweed), *Impatiens* sp. (waterweed) and *Passiflora* sp. (passion flower vine). Only one rooted plant species, *Justica americana* (water willow), occurred in the water.

Habitats sampled varied with river discharge. At high water (river discharge over 275 m^3/sec) shoreline collecting sites were associated with a mud and debris substrate. All areas had mixed rubble, sand and debris substrates and were in moderately flowing water (approximately 45 cm/sec) when intermediate volumes (120 - 275 m^3/sec) were recorded. The low water levels (discharge less than 120 m^3/sec) resulted in the most diverse conditions revealing riffles, slow moving pools (approximately 15 cm/sec), weedbeds of *J. americana* and boulders at specific areas. The substrates consisted mostly of rubble mixed with sand and debris.

Methods and Materials

Specimens of *Lepomis auritus* used in this study were collected during an investigation of the influence of thermal loading by the Virginia Electric and Power Company's Bremo Power Station on a Piedmont section of the James River (Woolcott, 1974). Water temperatures and river discharge figures used in the analyses of data were also from that study.

Nine transects, each with a collecting station on the north and south sides of the river, were established. Collecting sites of each transect were paired with regard to most environmental factors except those associated with the heated discharge (northside). The control transect (A) was located 1.2 km above the power station discharge. Transect B included the point of discharge and the area immediately downstream; the remaining transects C-I were 0.8, 1.6, 4.0, 5.6, 8.0, 16.0 and 30.0 km, respectively, downriver from the discharge tunnel. Both collecting sites of transect A and all southside stations provided natural (ambient) temperature habitats. Only northside stations B-G were considered artificially heated environments as the thermal plume usually was not identifiable beyond station G (Woolcott, 1972). After the first seven months of the study sampling was discontinued at transects E, F, H and I.

Fishes were collected by electrofishing (220 volts, 1 - 3 amps, D.C.) from October 1971 - September 1973 on an approximate bi-monthly basis. Collections were made by wading (October 1971 - March 1972 only) in shallow areas with electrodes, and from a 4.8 m (16 ft) boat with trailing cathode electrodes and an anode dipnet (5 mm^2 mesh). A second dip-net, without current, aided in netting stunned fish. Distance from shore during collections varied from 0.6 - 9.0 m, varying with river flow; shocking time was 20 minutes at each station, which allowed approximately 200 m of shoreline to be sampled. Fish were preserved in 10% formalin for a week, rinsed with water and stored permanently in 40% isopropyl alcohol.

One thousand and four specimens were measured (mm, S.L.) with a drafting compass and a calibrated metric steel rule. Sex was determined either by gross examination or microscopic inspection of the gonads. Scales used in determining age were removed from the left side of the fish just posterior to the opercle and below the lateral line following the method used by Lagler (1956). When scales from this area were not readable, those from the corresponding area on the right side were used. After removing the epidermis by scrubbing the scale with 5% KOH, the scales were either mounted dry or in glycerine on standard glass microscope slides. A microprojection apparatus (10 X objective) attached to a slide projector provided an enlarged image (340 X and 1000 X) for reading the dry mounted scales; glycerine mounts were viewed under a dissecting microscope (40 X and 80 X). When two of three separate counts of annuli were in agreement the reading was accepted. Where annuli were difficult to interpret, verification of age was made by others with experience in scale reading.

Insufficient data due to periods of flooding and the absence of L. auritus in certain collection periods precluded statistical analysis by individual stations and seasons of two separate years. Therefore all stations, depending on their relation to the thermal plume (i.e. non-heated and heated), were grouped into one natural and one heated environment and the corresponding calendar seasons of two years were combined. Within each environment, year classes were analyzed for length by season and sex. Total and seasonal population compositions (% of year classes) were determined and the ratios of male to female were tested by year class and season. Comparison of year classes across environments was made for length by season and sex and ratios of male to sample population were compared seasonally.

Length data were analyzed using a two factor analysis of variance test (Steele and Torre, 1960) and an unpaired t-test (Hayslett, 1968). The chi square formula (Bishop, 1966) and a Z-formula (Walpole and Meyers, 1972) were used for analysis of abundance and sex ratio data. In all statistical test differences were considered to be significant at the .95 confidence level. The terms average and mean were used interchangeably throughout.

Results

Considerable variation in the production and dissipation of heat at steam electrical generating stations is to be expected with variation in electrical output and environmental conditions (Parker and Krenkel, 1969). The Bremo Power Station, a swingload facility, varied its electrical output from a low of approximately 110 MW in the late night and early morning hours as consumer demand was reduced, to a peak output of 210 MW usually during late afternoon or early evening hours. This pattern of production caused considerable diurnal fluctuation in heat loading to the river from day to day (Kirk, 1974). Also seasonal variation in consumer electricity demand was reflected in an increased plant production, thus increasing release of heated effluent, during the hot months of summer.

Ambient water temperature on collection dates ranged from a seasonal average of 6 C in winter to 24 C in summer. In the heat influenced habitat seasonal temperature means varied from a low 10 C in winter to a high 30 C in summer (Table 1). The greatest increase in thermal plume temperature was 13 C above ambient water temperature (recorded December 8, 1972 and June 4, 1973). The Δt values downstream from the point of discharge were directly related to the combined effects of power station operation and riverflow. Generally Δt values were higher and extended further downriver when periods of peak plant production occurred simultaneously with low river discharge. Twice during this study flooding halted plant operation, resulting in a temporary disappearance of the thermal plume. During those periods only fish from the ambient temperature water (southside stations and station A) were used for analysis of data.

River discharge during the two year period ranged from a monthly mean of 48 m^3/sec in September 1973 to 496 m^3/sec in April 1973 (Table 2). Daily mean flow varied from 39 m^3/sec in September of 1972 and 1973 to 2005 m^3/sec in October 1972. In general, discharge volumes were lowest during June, July and August.

A total of 1004 L. auritus (Fig. 2) were collected, 736 from ambient temperature and 268 from heated stations. Size of collections of fish could be correlated with seasonal temperature and river discharge. Frequency of occurrence was approximately equal in both habitats for each season (Table 3). During colder months, fall and winter, abundance per collection was greater in the heated water for both high ($> 275\ m^3/sec$) and low ($< 120\ m^3/sec$) river discharges. For the warmer months, spring and summer, however, natural temperature habitats registered a greater abundance per collection for the higher and lower river discharges. Within each habitat the trend was toward a greater frequency of occurrence and abundance per collection during low river discharges throughout the year.

Using the scale reading technique (Fig. 3) six distinct year classes (O - V) were identified which were corroborated by length frequency measurements. All year classes were represented in both habitats. Year Class II comprised the largest number (206; 27.5%) of fish in the natural habitat and year class O was the largest group (109; 40.5%) in the heated water. In both environments year classes O, I and II accounted for relatively high percentages of the total population when compared with those of year classes III, IV and V (Fig. 4).

Percentages of the total seasonal collections represented by each year class are graphically shown in Figure 5. The greatest variation (64%) for the natural habitat was found in year class O (67.5% in winter to 3.5% in summer) and the smallest variation (6.3%) was seen in year class V (6.3% in spring to 0% in winter). Year classes I - IV demonstrated fluctuations of

29.6%, 27.2%, 19.4% and 8.8%, respectively. Similarily, as in ambient temperature habitat, the greatest variation (53.9%) for the heated habitat was recorded for year class O (62.0% in winter to 8.1% in spring) and the smallest (3.7%) was observed in year class V (3.7% in summer to 0% in fall). Intermittent year classes, however, did not respond to season as did those of the natural environment. The maximum variations of these year classes were 27.8% (II), 19.9% (IV), 11.5% (III), and 10.3% (I). When the maximum variation of seasonal percentages were compared across habitats, the larger differences appeared in year classes I (difference of 19.3%), IV (difference of 11.1%) and III (difference of 7.9%).

The overall sex ratio for both populations approached a proportion of 1:1 (natural; male 337, female 339: heated; male 124, female 112); however, this was not the case in the separate year classes and seasons. Year class analysis (seasons combined) revealed a significantly higher number of females in year class I fish from ambient water and a predominant number of males in year class IV fish from both habitats (Table 4). In natural temperature waters chi square tests for seasonal variation from a 1:1 sex ratio (Table 5) showed values which significantly favored females in year class O (only 60% of specimens of this year class could be sexed) during fall (31 males, 52 females) and in year class I in the spring (9 males, 20 females). Males significantly dominated year class II in spring (48 males, 28 females) in natural waters and year class IV in summer for both natural (23 males, 5 females) and heated (10 males, 0 females) environments. Year class V fish from ambient temperature water were represented by one female collected in fall, seven males and six females in spring, and three males and one female in the summer. In the heated water one male was captured in each of the winter and spring seasons whereas two were collected during the summer.

Seasonal comparison (Z formula) of the proportion of the number of males to the total number of the seasonal population across environments proved significant only in year class II during the spring, when more females (5 males, 9 females) were collected in the heated habitat, and more males (48 males, 28 females) were captured in the ambient temperature water (Table 5).

The results of two factor analysis of variance tests (year class x season) for length of L. auritus, year classes O - IV, from both habitats are shown in Table 6. In natural temperature water, main effect year class proved significant as successive year classes (I - IV) had higher annual mean length values than did the preceeding year class. Except for year class III the results for the heated environment were the same.

A significant year class x season interaction was found in the natural temperature water (Table 6). Year class I, III and IV showed an increase in mean length from 72 to 81 mm, 129 to 145 mm and 151 to 164 mm, respectively, from fall to winter. Year class II showed a slight decrease (110 to 109 mm) whereas year class O showed a larger decrease (34 to 29 mm) during the same period. From winter to spring decreases were witnessed for mean length in year classes I (81to 60 mm), II (109 to 86 mm), III (145 to 126 mm) and IV (164 to 144 mm), and an increase was shown in year class O (29 to 34 mm). Increases were seen in year classes I (60 to 62 mm), II (86 to 101 mm), III (126 to 135 mm) and IV (144 to 149 mm), and year class O remained the same (34 mm) during the spring to summer period. The average length values of year class V were 146 mm in the fall, 157 mm in the spring and 156 mm in the summer. No fish from this year class were collected in the winter.

Interaction (year class x season) was significant for the two factor analysis of variance test for length involving L. auritus (excluding year class III) from heated water (Table 6). From fall to winter mean length increases were seen in year classes O (35 to 42 mm), I (86 to 91 mm) and IV (149 to 156 mm). Only year class II showed a decrease (117 to 110 mm) during this period. Decreases were obvious in year classes O, I, II and IV as mean length values dropped from 42 to 36 mm, 91 to 56 mm, 110 to 95 mm, and 156 to 149 mm, respectively, from winter to spring. From spring to summer the mean length values for year classes O (36 mm) and IV (149 to 148 mm) were essentially constant while year classes I (56 to 73 mm) and II (95 to 108 mm) had increased values. Seasonal average length values (O when no fish were collected) for year classes III and V were respectively 130 mm and O in the fall, O and 162 mm in winter, 126 mm and 146 mm in spring, and 122 mm and 158 mm in summer. As main effect season was a combination of both environmental conditions, it was not considered in this study.

In three separate year classes fish from the heated environment had significantly larger annual mean lengths than their counterparts in ambient temperature waters (Table 4). Significant values were found in year class O (37 and 34 mm), males of year classes I (79 and 66 mm) and II (114 and 97 mm), and females of year class I (85 and 66 mm).

A two factor analysis of variance test (habitat x season) for length of L. auritus, year classes O - IV, indicated a greater mean length of fish from the thermal plume in year class O and I as main effect habitat was significant (Table 7).

Additional t-tests indicated that significant differences for mean length values existed in winter (43 and 29 mm) of year class O, and in fall (86 and 72 mm) and summer (73 and 62 mm) of year class I.

The average lengths of individuals in each year class from natural and heated environments are shown in Figures 6 and 7. The values are graphically reported (following the procedure of Hubbs and Hubbs, 1953) for each sex except in year class O where difficulty in determining sex of individuals necessitated combining all data. In each environment male and female fish of consecutive year classes II - IV had significantly greater annual mean lengths than specimens of the same sex of the previous year class (Table 4). Both males and females of year class I from both habitats had a significantly greater annual mean length than did fish of year class O in the corresponding habitat. In year classes III and IV from ambient temperature water annual mean lengths of males, 132.7 mm and 151.5 mm, respectively, were significantly greater than those of females, 126.1 mm and 137.7 mm, respectively. Greater annual mean length of males was also seen in year classes II (male, 114.2 mm; female, 102.9 mm) and III (male, 136.0 mm; female, 120.0 mm) in the heated water.

Discussion

The intent of this study was to characterize the distribution of _L. auritus_ from ambient and artifically elevated temperature habitats during the four calendar seasons according to age class, length and sex. Specimens used in this study were from collections made during a survey of the total fish populations of this part of the James River and not specifically for the redbreast sunfish. This possibly is related to the paucity of individuals of this species during certain seasons thereby limiting the extent of the study.

The effect of seasonal changes on the abundance of _L. auritus_ in the ambient temperature waters was pronounced as numbers of fish per collection decreased substantially in the winter and reached their greatest numbers during warmer periods. Overwintering in deeper water is less common in fishes inhabiting rivers than those inhabiting reservoirs; however, it is probable that most riverine fishes move out from the bank in winter to avoid the varying temperatures of the shallower shore region (Nikolsky, 1963). As collections were made near the shore during the present study, this could account, at least in part, for the fewer numbers in the winter collections. Warmer weather attracts fishes to the banks for reproduction and feeding activities (Breder and Rosen, 1966), making them more susceptible to collection and possibly accounting for their increase in numbers.

Seasonal influences on abundance of L. auritus were not as apparent in the artificially elevated temperature waters as they were in ambient temperature habitats. In the elevated temperature habitat, approximately equal abundance per collection was recorded in winter, spring, and summer with the only change being an increase in the fall. Although the redbreast sunfish was one of the few species found in elevated water temperatures reaching 39 C (Woolcott, 1974), it generally avoided the highest temperatures of the thermal plume during the warmer months of summer. Only during winter did the abundance per collection in the thermal plume exceed that in ambient temperature habitats. It has been proposed by several authors (Trembley, 1960; Parker and Krenkel, 1969; Gammon, 1973) that fishes are attracted to the heated effluent of power stations, during the colder periods of the year. However, in the present study, it is believed that the fish were not particularly attracted to the heated plume in the winter as there was a decline from the numbers collected in the fall, but rather that mass migrations toward the deeper water from the fluctuating shoreline temperatures of the natural habitats contributed to the difference in winter numbers collected.

Several factors probably contributed to the increase in occurrence and abundance of *L. auritus* in collection periods of low river discharge. Those considered particularly significant were reduction in the number of available habitats, shallowness and clarity of water and less chance for electrically stunned fish to be carried away by the decreased water current. Lagler (1970) states that the effectiveness of direct current electrofishing was influenced by turbidity and depth of the water, i.e. in the more turbid (although conductivity increases, specimens are more difficult to locate) and deeper water the efficiency decreased.

The life expectancy of *L. auritus* in this section of the James River is in accord with that reported for other populations of this species as well as for other members of the genus *Lepomis*. The oldest specimens in this study were five years old. The only reference located that related to longevity of *L. auritus* was by Davis (1971) who reported that redbreast sunfish from rivers in southeastern North Carolina reach an age of six years. Wilbur (1968) reported that *Lepomis microlophus* (redear sunfish), a close relative of the redbreast sunfish, reaches an age of five years. In a growth study of Lepomis macrochirus (bluegill) Di Costanza (1957) found that this species attained an age of six years. Carbine and Applegate (1945) in an investigation of the fish populations of a Michigan lake reported Lepomis cyanellus (green sunfish) which reached an age of five years.

Rather than assign the cause of the sharp decline in numbers of L. auritus between year classes II and III to one or more of the usual reasons given for mortality among fishes, e.g. predation, disease, pollution, or loss of condition following the first year spawn (Paling, 1970), it is proposed that the decline is associated in part with the behavior of larger fish and the collection method employed in this study. It is probable that large redbreast sunfish do not frequent the areas near shore to the same extent that the smaller fish of the younger year classes do. Also Gammon (1975) suggested that the increased body surface of larger fishes may enable them to detect the electric field at a greater distance and thus escape before the galvanotaxic response is imposed.

High numbers of year class O fish from both habitats were attributed to the collecting procedures used during the first six months of the study when wading with electrodes in slow current backwater pools (the preferred habitat of young fishes) was used in conjunction with electrofishing from a boat. The percentage of year class O fish making up collections from the heated habitat was almost twice that of the same year class from natural habitats, although similar collecting procedures were used in both habitats. The presence of more backwater areas in the heated plume than on the ambient temperature side of the river contributed to the larger percentage of year class O fish in the heated water collections.

The seasonal composition by year class of the collections of L. auritus from both habitats of this study can be correlated with its reproduction and feeding cycles. As discussed previously, warmer weather attracts fish to the banks for breeding and feeding activities (Breder and Rosen, 1966). Davis (1971) in a study of the spawning behavior of the redbreast sunfish in North Carolina reported this species to spawn in shallow waters during late spring or early summer when water temperatures reached 22 - 26 C. Fecundity rates for fish in year classes II - VI were included in his study and as none were given for younger fish the implication is that redbreast sunfish do not reach sexual maturity until the age of two years. As most sexually mature fish of a given species have a similar breeding cycle, we could expect year classes II - V to have a similar reproduction cycle and appear in larger numbers during the spring and summer spawn and in fewer numbers during the colder months of winter, which was the case for fish in those year classes from both environments. The appearance of greater numbers of year class O fish in the fall collections from both habitats was probably due to their having attained a size large enough to be captured by the collecting gear used with the boat. Also, the previously mentioned wading method of collection in the shallower habitats during the first fall may have influenced the greater numbers of year class O during this season, just as it probably did the high percentages of this year class in the total sample populations. Sexually immature year class I fish, readily caught in the electrofishing nets, appeared in peak numbers during summer for the ambient temperature collections and during fall for those from heated water. Feeding activity near shore was considered the reason for larger numbers of this year class during those seasons. In most year classes from both habitats winter abundance was generally lowest. Exceptions to this were seen in year class V fish from the heated water where abundance was relatively low throughout the year, and in year class O fish from both habitats where fish were too small to be captured effectively with the available collection gear during the spring and summer. It would seem that even though migration is less extensive from the heated plume than from ambient temperature habitats in the winter, L. auritus generally follows a pattern of migration into deeper water during colder periods.

Deviations from 1:1 sex ratios are not uncommon in fresh water sunfishes. Uneven sex ratios with female domination have been reported by Lambou (1963) for bluegill, Wilbur (1968) for redear sunfish, and Huish (1957) for Pomoxis nigromaculatus (black crappie). In three of the four Alabama lakes studied by Schmittou (1967) females dominated the populations whereas in the fourth lake no sexual dominance occurred. He did note, however, for all four lakes that as the total number of fish in each succeeding year class declined, the percentage of males increased. Data in this study did not indicate that either sex was dominant, but L. auritus from both habitats did show similarities to the bluegill populations in the Alabama lakes in that the percentage of males tended to increase with each succeeding year class.

Small numbers of L. auritus in most seasonal collections precluded a complete analysis of sex ratio by season. Inadequate sampling is the only explanation for the absence of females (year class IV) in the heated effluent during summer. Four different year classes in three different seasons in ambient temperature waters demonstrated a significantly unbalanced sex distribution. The male dominance of year class II during spring and year class

IV in the summer was probably the result of the availability of the nest guarding males to the sampling technique. The dominance of females in year class O in the fall and in year class I in the spring is attributed to the previously mentioned tendency for females to dominate the earlier year classes and males to dominate the latter year classes.

In most temperate zone fishes growth ceases or decreases during the colder months of winter and resumes or increases in the spring (Tesch, 1970). Kilambi *et al.* (1970) stated that this seasonal growth cycle in channel catfish is dependent on the combined effects of water temperature and photoperiod, assuming adequate food is available. According to Phillips (1969), Pyle (1966) in studying growth in *Salvelinus fontinalis* (brook trout) and Gross *et al.* (1965) in a study of growth in *L. cyanellus* used water temperatures conducive to growth in association with varied photoperiods to find that greatest growth rates occurred in increasing daylengths and lowest in decreasing daylengths. Those conditions were created in a laboratory, but paralleled the temperatures and photoperiods of growing seasons in temperate zone environments. No attempt was made to determine the seasonal growth rate of *L. auritus* in the present study, however it would appear from the seasonal mean lengths of each year class of both heated and natural habitats that growth began in spring as water temperatures and daylengths increased and continued until the short daylengths and lower water temperatures of winter occurred. The tendency for mean lengths of each year class to decrease in spring is probably due to the recruitment of a new size group from the previous year class as a new annulus formed. Pronounced deviations from this tendency, for example in fish of year class O from ambient waters during spring, may have been due to the organization of the study. By dividing the year into the four calendar seasons, which may not coincide precisely with the seasonal growth pattern, it was probable that fish from the previous year's spawn had not formed their first scale annulus and therefore, even though one year old, were classified with year class O.

There was an increased mean length for fish (year classes O and I; males only in year class II) from the thermal plume over fish in the corresponding groups from the ambient waters. It has been established that temperature alters the rates of metabolic processes and may be expected to have considerable effect on the growth of poikilothermous animals (Phillips, 1969). The expected relationship between temperature and growth is that there will be little or no growth below a certain temperature; above this, the rate of growth should increase with temperature to a maximum and then decrease, perhaps becoming negative (weight) at temperatures approaching the lethal limits (Brown, 1957). According to O'Rear (1968), who studied growth in one and two year old L. auritus in an environment receiving a heated discharge, there was no increased growth seen in fish from elevated water temperature habitats when compared to those from natural waters, yet results of several authors working with other species of fishes lend support to the belief that increased temperatures do have an influence on growth rates. A review by Phillips (1969) stated that Schauperclaus (1933) found the rate of metabolic activities of fishes doubled with a 10 C rise in water temperature. Fry and Hart (1948) reported that over a range of 5 - 35 C, standard metabolism for goldfish increased to its highest value at about 30 C. It then remained steady or decreased slightly at temperatures higher than 35 C. In a study on the growth of largemouth bass fry kept at various temperatures, Strawn (1961) found that they grew at a greater rate at 27.5 C and 30 C than at temperatures above or below those.

There are several possible explanations for L. auritus from heated habitats having increased annual mean lengths only in year classes O, I and II. Schauperclaus (1933) reported that metabolic rates of small fishes are greater than those of larger fishes because of larger body surface/volume ratio. Brown

(1957) stated that when fishes spend their whole lives in one environment, their growth rates generally decline progressively as they grow older. In addition Lewis et al. (1974) gave evidence that the percentage of body weight which the stomach contents comprised in largemouth bass was greater in smaller fish than larger fish, indicating that small fish frequently consume a greater daily ration in proportion to their body weight.

The data indicated that male redbreast sunfish are significantly longer than females in year classes III and IV in the natural environment and in year classes II and III in the heated habitat. Unfortunately, no studies pertaining to sexually related growth rates for L. auritus could be found for comparison, and sexual growth rates reported for other Lepomis species were contradictory. Larimore (1957) reported male Lepomis gulosus (warmouth) to be larger than females in year classes I - V. Schmittou (1967) found male bluegill grew faster than females and Di Costanza (1957) reported male bluegills to be larger than females in the third and fourth years of life. Agreeing with Di Costanza, Sprugel (1954) found male bluegill grow more rapidly between the first and fourth years of life in midwestern lakes. Hubbs and Cooper (1935) pointed out that among centrarchids males usually grow faster than females. On the other hand, Beckman (1949) was unable to distinguish any significant difference in growth for either sex of bluegill, and Morgan (1951) obtained results indicating a faster growth rate for females in this species. If there is a greater growth rate for male redbreast sunfish, then this in conjunction with an increased growth rate associated with increased water temperature might account for the male length dominance showing up in an earlier year class (II) in the heated habitat. These accelerated growth rates might also account for only male *L. auritus* of year class II from heated habitats demonstrating significantly greater annual mean lengths than their counterparts in the ambient water habitats.

Summary

One thousand and four Lepomis auritus (redbreast sunfish) were collected from a 30 km section of the James River which received a thermal effluent from the power station at Bremo Bluff, Virginia. Collections of fish from the natural (ambient) and heated habitats were made by electrofishing from October 1971 - September 1973 and were analyzed as to year classes, season, length and sex.

Using the scale reading technique, six distinct year classes (O - V) were identified, in both the natural and heated environments. Year class II represented the greatest number of individuals in the ambient water collections and year class O had the greatest number in collections from the heated habitat.

Influence of the seasonal changes on abundance of this species was more evident in collections of fish from the natural habitat than those of the artifically heated one. Numbers of ambient water fish were greatest during the warmer months of summer and decreased during the colder months whereas numbers of heated habitat fish were relatively equal during the winter,

spring and summer seasons with an increased change in the fall. Seasonal abundance per collection for the heated environment was greater than that of the natural habitat only in winter.

Seasonal composition by year class was related to the reproduction and feeding cycles of this species in both habitats as peak abundance of the sexually mature fish showed up in the spring and summer in association with spawning activities. Peak numbers of sexually immature individuals were associated with feeding activities and selectivity of the collection methods.

Length analysis of sex per year class showed males to have significantly greater annual mean lengths than females in year classes III and IV for the ambient habitat and year classes II and III in the heated habitat. This may be due to an increased growth rate associated with males of other centrarchid species.

Fish in year class O, males in year classes I and II, and females in year class I from the heated environment exhibited significantly greater annual mean lengths than their corresponding groups in the ambient temperature. These increased mean lengths for fish of the artificially heated plume were believed to be influenced by increased growth rates associated with increased water temperature.

The overall sex ratio of fish from these two habitats did not significantly differ from 1:1. Analysis by year class and season indicated, however, a predominance of females in the younger year classes (O and I) and a greater number of males in the year class IV.

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Table 1. Seasonal temperature (C) range and average for natural and heated water environments in the James River near Bremo Bluff, Virginia (October 1971 - September 1973).

	Natural Environment Temperature		Heated Environment Temperature	
	Range	$\overline{X}$	Range	$\overline{X}$
Fall	6-23	13	6-35	17
Winter	2-12	6	4-20	10
Spring	10-26	18	10-37	23
Summer	20-28	24	22-39	30

Table 2. Monthly discharge rates for the James River near Bremo Bluff, Virginia for the period from October 1971 - September 1973. Values reported to nearest m^3/sec.

Month	Mean	High	Low
1971			
October	328	809	85
November	115	122	110
December	357	560	239
1972			
January	119	131	99
February	229	286	185
March	332	465	237
April	324	392	244
May	232	330	179
June[1]	89	89	89
July	277	818	95
August	151	787	64
September	53	132	39
October	286	2005	81
November	403	946	132
December	437	846	227
1973			
January	252	420	154
February	428	1531	179
March	442	1257	162
April	496	918	235
May	314	1532	134
June	176	423	109
July	98	146	59
August	73	101	53
September	48	62	39

[1]One reading in June 1972

Table 3. Seasonal occurrence (% of total samples/season in which species occurred) and abundance (number of specimens/collection) for Lepomis auritus from natural (N) and heated (H) habitats of the James River near Bremo Bluff, Virginia during extreme high and low seasonal river discharges (October 1971 through September 1973).

Season	River Discharge (m^3/sec)	Habitat	% Occurrence	Average Abundance / Collection
Fall				
High	437	N	10	0.1
		H	25	0.5
Low	115	N	100	3.6
		H	100	3.8
Winter				
High	428	N	50	0.5
		H	50	0.8
Low	119	N	60	2.2
		H	100	4.0
Spring				
High	324	N	90	5.1
		H	67	1.3
Low	95	N	80	2.6
		H	100	1.7
Summer				
High	277	N	50	0.5
		H	0	0.0
Low	48	N	100	10.8
		H	100	4.4

Table 4. Mean standard lengths of *Lepomis auritus* (sexes combined in year class O, separated in year classes I - V) from natural (N) and heated (H) habitats in the James River near Bremo Bluff, Virginia, October 1971 - September 1973. Tests for significance are X^2, variation from a 1:1 sex ratio/habitat/year class; T, difference in length between sexes/habitat/year class; and T_t, difference in length between corresponding sexes (between combined sexes in year class O) from each habitat/year class.

Year Class	Habitat	Sex	No.	$\bar{X}$ S.L.	2 S.D.	2 S.E.	X^2	T	T_t
O	N	Total	178	33.56	16.36	1.22	-	-	
									3.43*
	H	Total	109	37.31	20.26	1.94	-	-	
I	N	M	79	66.16	29.56	3.32	5.38*	0.29	3.78*
		F	111	65.49	32.18	3.06			5.41*
	H	M	32	78.67	36.16	6.40	0.62	1.29	
		F	26	84.67	33.90	6.66			
II	N	M	109	97.10	37.24	3.56	0.69	0.18	4.48*
		F	97	97.55	31.92	3.24			1.65
	H	M	26	114.21	23.18	4.54	0.83	2.84*	
		F	33	102.96	34.56	6.02			

Table 4. (Continued)

Year Class	Habitat	Sex	No.	$\bar{X}$ S.L.	2 S.D.	2 S.E.	X^2	T	T_t
III	N	M	46	132.77	32.02	4.72	2.13	2.13*	0.57
		F	33	126.13	18.68	3.24			1.51
	H	M	9	136.00	22.06	7.34	0.60	3.12*	
		F	6	120.08	13.88	5.66			
IV	N	M	45	151.52	20.70	3.08	9.61*	5.07*	0.52
		F	20	137.72	19.10	4.26			1.20
	H	M	20	150.20	13.96	3.12	12.56*	1.10	
		F	3	145.00	23.50	13.58			
V	N	M	10	156.85	10.04	3.18	0.22	0.24	0.25
		F	8	155.68	28.22	10.00			-
	H	M	4	156.00	15.30	7.64	-	-	
		F	0	-	-	-			

*Statistically significant

$X^2_{.95} = 3.84$ $T_{.95}(77) = 1.99$ $T_{t.95}(285) = 1.96$ $T_{t.95}(53) = 2.01$

$T_{.95}(188) = 1.96$ $T_{.95}(13) = 2.16$ $T_{t.95}(109) = 1.99$ $T_{t.95}(37) = 2.03$

$T_{.95}(56) = 2.00$ $T_{.95}(63) = 2.00$ $T_{t.95}(135) = 1.96$ $T_{t.95}(63) = 2.00$

$T_{.95}(204) = 1.96$ $T_{.95}(21) = 2.08$ $T_{t.95}(133) = 1.96$ $T_{t.95}(21) = 2.08$

$T_{.95}(57) = 2.00$ $T_{.95}(16) = 2.12$ $T_{t.95}(128) = 1.96$ $T_{t.95}(12) = 2.18$

Table 5. Seasonal sexual composition of populations of *Lepomis auritus*, year classes O-IV, from natural (N) and heated (H) habitats in the James River, near Bremo Bluff, Virginia, October 1971 - September 1973. Values are expressed as seasonal abundance (no. of each sex), Chi square (X^2, variance from expected 1:1 sex ratio/habitat) and Z test (difference in proportion of males to total population/habitat between natural and heated environments).

Year Class		O				I			
Habitat		N		H		N		H	
Sex		M	F	M	F	M	F	M	F
Fall	no.	31	52	16	28	29	34	20	14
	X^2	5.31*		3.27		0.39		1.06	
	Z	0.13				-1.20			
Winter	no.	5	10	10	14	2	1	3	5
	X^2	1.66		0.66				-	
	Z	-0.53				-			
Spring	no.	6	5	1	1	9	20	3	3
	X^2	0.09		-		4.17*		-	
	Z	-				-0.95			
Summer	no.	6	3	5	2	39	56	6	4
	X^2	-		-		3.04		0.40	
	Z	-0.22				-1.31			

*Statistically significant

$X^2_{.95} = 3.84$

$Z_{.95} > 1.96$ or < -1.96

Table 5. (Continued)

Year Class		II							III						
Habitat		N				H			N				H		
Sex		M		F		M		F	M		F		M		F
Fall	no.	15		23		8		12	2		1		2		2
	X^2		1.68				0.80			-				-	
	Z				-0.07							-			
Winter	no.	2		1		4		1	5		0		1		0
	X^2		-				-			-				-	
	Z				-							-			
Spring	no.	48		28		5		9	25		20		2		3
	X^2		5.26*				1.14			0.55				-	
	Z				2.00*							0.68			
Summer	no.	44		45		9		11	14		12		4		1
	X^2		0.01				0.20			0.15				-	
	Z				0.67							-1.08			

*Statistically significant

$X^2_{.95} = 3.84$

$Z_{.95} > 1.96$ or < -1.96

Table 5. (Continued).

Year Class		IV						
Habitat			N				H	
Sex		M		F		M		F
Fall	no.	5		2		2		0
	X^2		-				-	
	Z				-			
Winter	no.	2		0		2		1
	X^2		-				-	
	Z				-			
Spring	no.	15		13		6		2
	X^2		0.14				-	
	Z				-1.05			
Summer	no.	23		5		10		0
	X^2		11.57*				10.00*	
	Z				-1.38			

*Statistically significant

$X^2_{.95} = 3.84$

$Z_{.95} > 1.96$ or < -1.96

Table 6 . Two-factor analysis of variance tests (year class and season) for standard length measurements of *Lepomis auritus*, year classes 0-IV, from natural and heated water in the James River near Bremo Bluff, Virginia, October 1971 - September 1973.

Natural

Source	df	SS	MS	F
A (year class)	4	329887.2	82471.8	476.96*
B (season)	3	5661.5	1887.2	10.91*
AB	12	4163.4	346.9	2.01*
error	708	122421.9	172.9	
Total	727	462134.0		

*Statistically significant

$F_{.95}(4, 708) = 2.37$

$F_{.95}(3, 708) = 2.60$

$F_{.95}(12, 708) = 1.75$

Heated[1]

Source	df	SS	MS	F
A (year class)	3	186607.1	62202.4	428.67*
B (season)	3	3951.9	1317.3	9.08*
AB	9	3237.9	359.8	2.48*
error	234	33954.3	145.1	
Total	249	227751.2		

*Statistically significant

$F_{.95}(3, 234) = 2.60$

$F_{.95}(9, 234) = 1.88$

[1]Year class III omitted as no specimens were collected during winter season

Table 7. Two-factor analysis of variance tests (habitat and season) for standard length measurements of *Lepomis auritus*, year classes O - IV, from natural and heated water in the James River near Bremo Bluff, Virginia, October 1971 - September 1973.

Year Class O

Source	df	SS	MS	F
A (habitat)	1	386.5	386.5	5.08*
B (season)	3	19.2	6.4	0.08
AB	3	589.7	196.6	2.58
error	279	21216.1	76.0	
Total	286	22211.5		

*Statistically significant

$F_{.95}(1,279) = 3.84$

$F_{.95}(3,279) = 2.60$

Year Class I

Source	df	SS	MS	F
A (habitat)	1	1307.6	1307.6	5.66*
B (season)	3	9472.5	3157.5	13.67*
AB	3	945.9	315.3	1.36
error	248	57281.2	230.9	
Total	255	69007.2		

*Statistically significant

$F_{.95}(1,248) = 3.84$

$F_{.95}(3,248) = 2.60$

Table 7. (Continued)

Year Class II

Source	df	SS	MS	F
A (habitat	1	696.1	696.1	3.24
B (season)	3	6369.1	2123.0	9.88*
AB	3	187.7	62.6	0.29
error	257	55237.5	214.9	
Total	264	62490.4		

*Statistically significant

$F_{.95}(1,257) = 3.84$

$F_{.95}(3,257) = 2.60$

Year Class III[1]

Source	df	SS	MS	F
A (habitat)	1	0.7	0.7	.004
B (season)	2	479.7	239.8	1.33
AB	2	6.1	3.0	.02
error	83	14962.7	180.3	
Total	88	15449.2		

*Statistically significant

$F_{.95}(1,83) = 3.97$

$F_{.95}(2,83) = 3.12$

[1] Winter season omitted as no specimens were collected

Table 7. (Continued)

Year Class IV

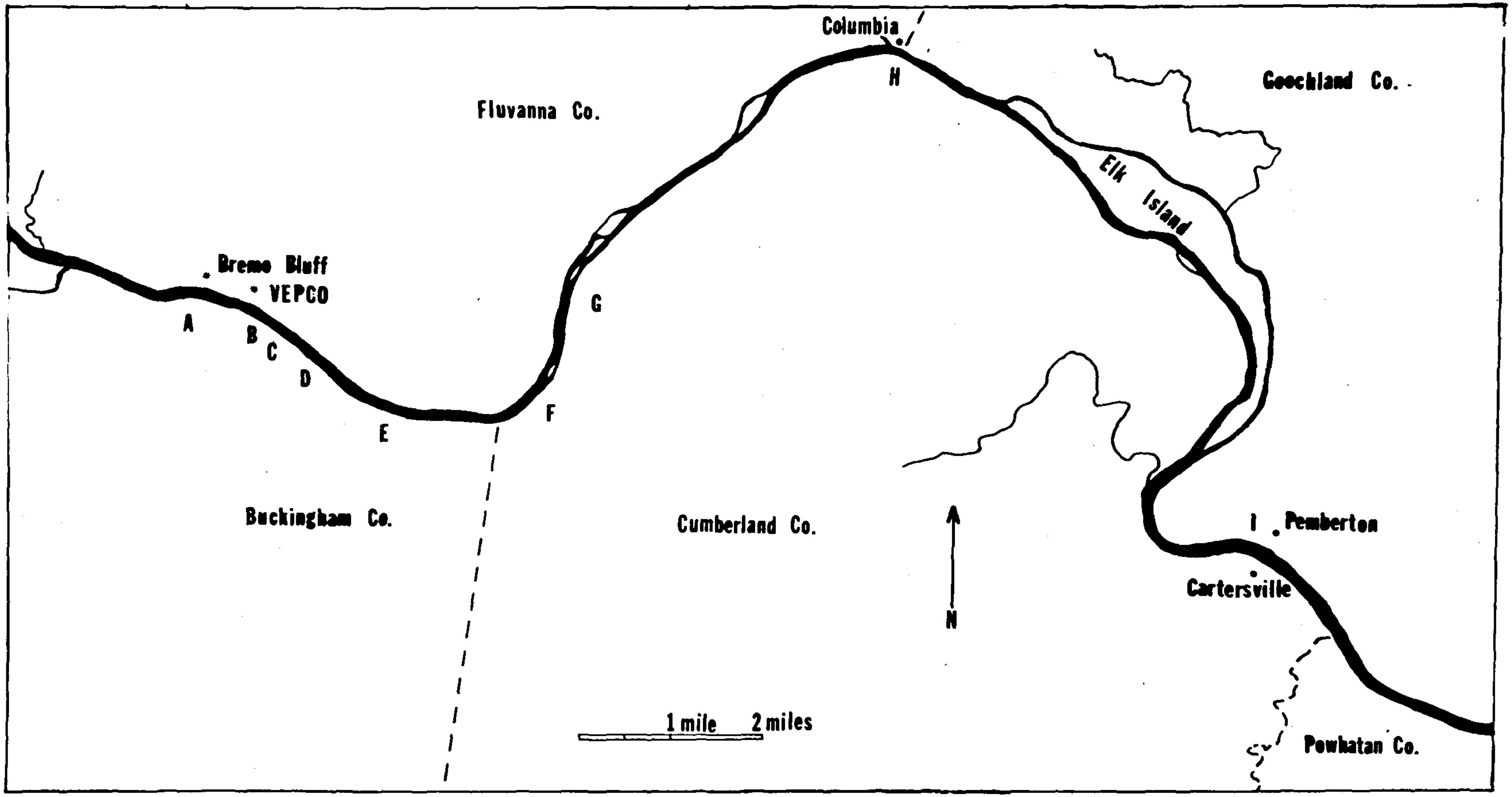
Source	df	SS	MS	F
A (habitat)	1	23.3	23.3	0.20
B (season)	3	973.0	324.3	2.82*
AB	3	210.3	70.1	0.60
error	82	9443.1	115.2	
Total	89	10649.7		

*Statistically significant

$F_{.95}(1, 82) = 3.97$

$F_{.95}(3, 82) = 2.73$

Figure 1. The James River, Virginia study area. Capital letters denote collecting transects. 1 mile equals 1.6 km.


Columbia
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Cumberland Co.
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Powhatan Co.

Figure 2. Lepomis auritus, year class II female 75 mm S. L., from James River near Bremo Bluff, Virginia.

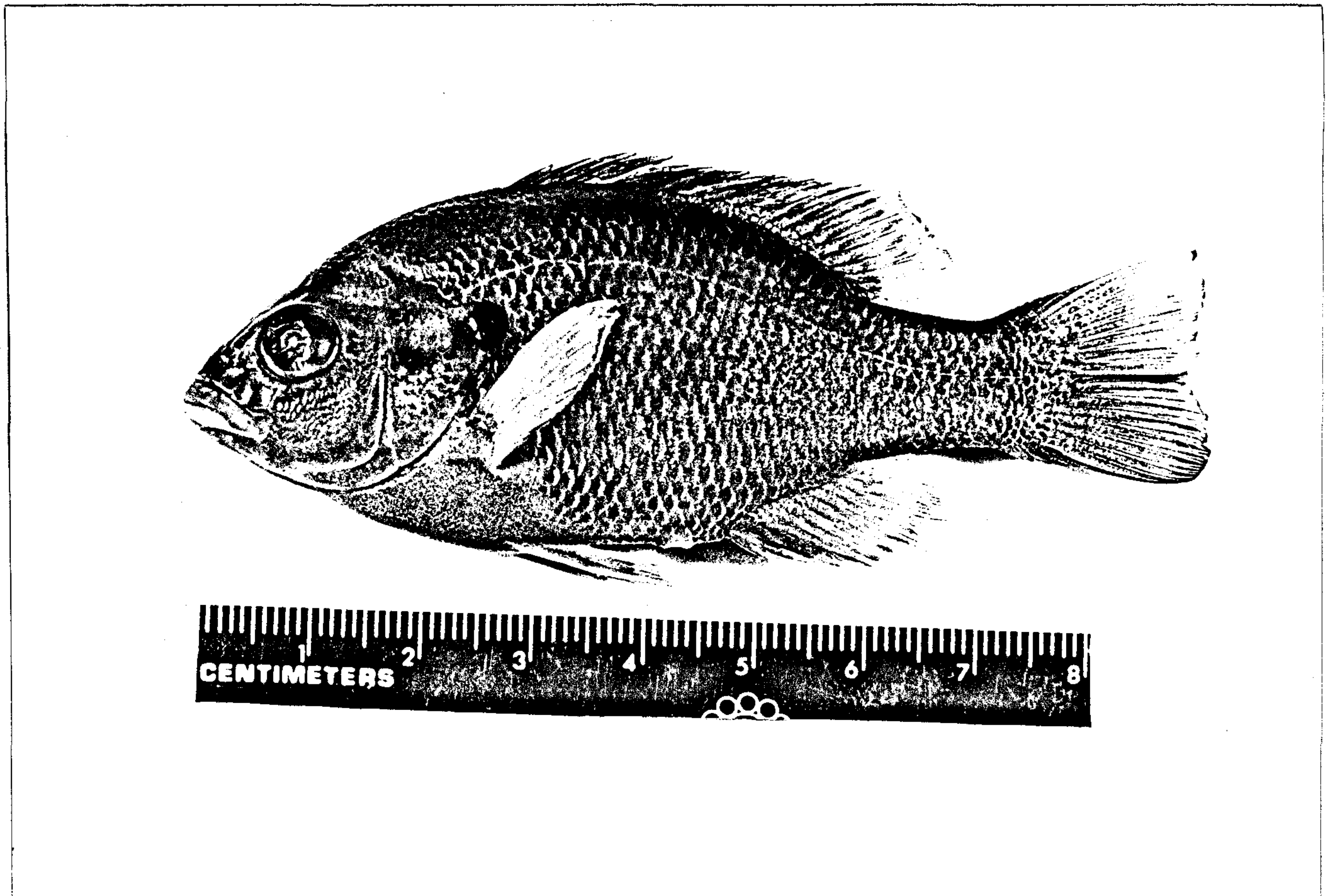
CENTIMETERS

Figure 3. Scales from the pectoral region of two *Lepomis auritus* collected from the James River (August 1972) near Bremo Bluff, Virginia.

A. Female, year class I, 55 mm S. L.

Actual scale size, 2.2 mm.

B. Male, year class III, 150 mm S. L.

Actual scale size, 6.0 mm.

Arrows indicate annuli.

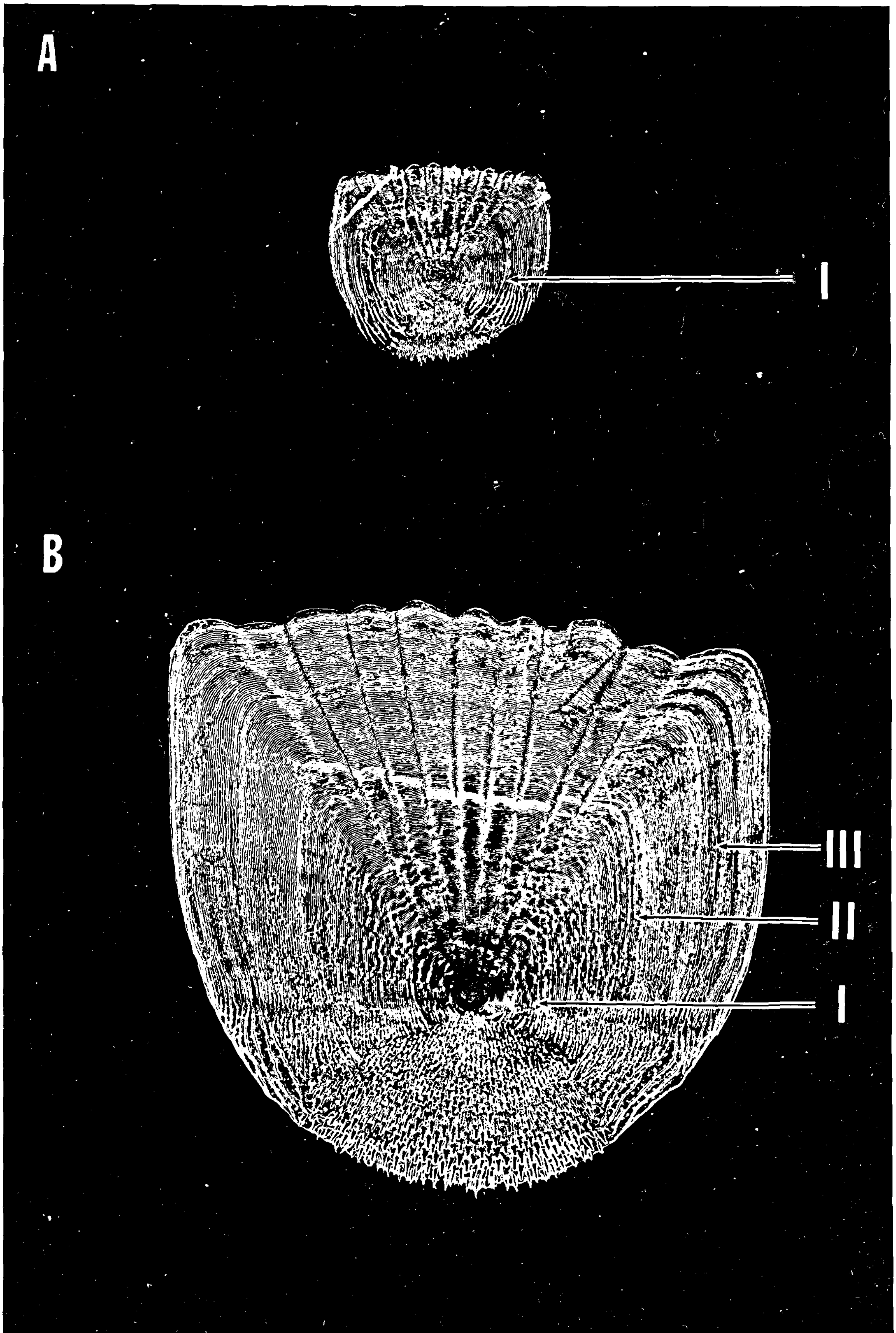
A
I
B
III
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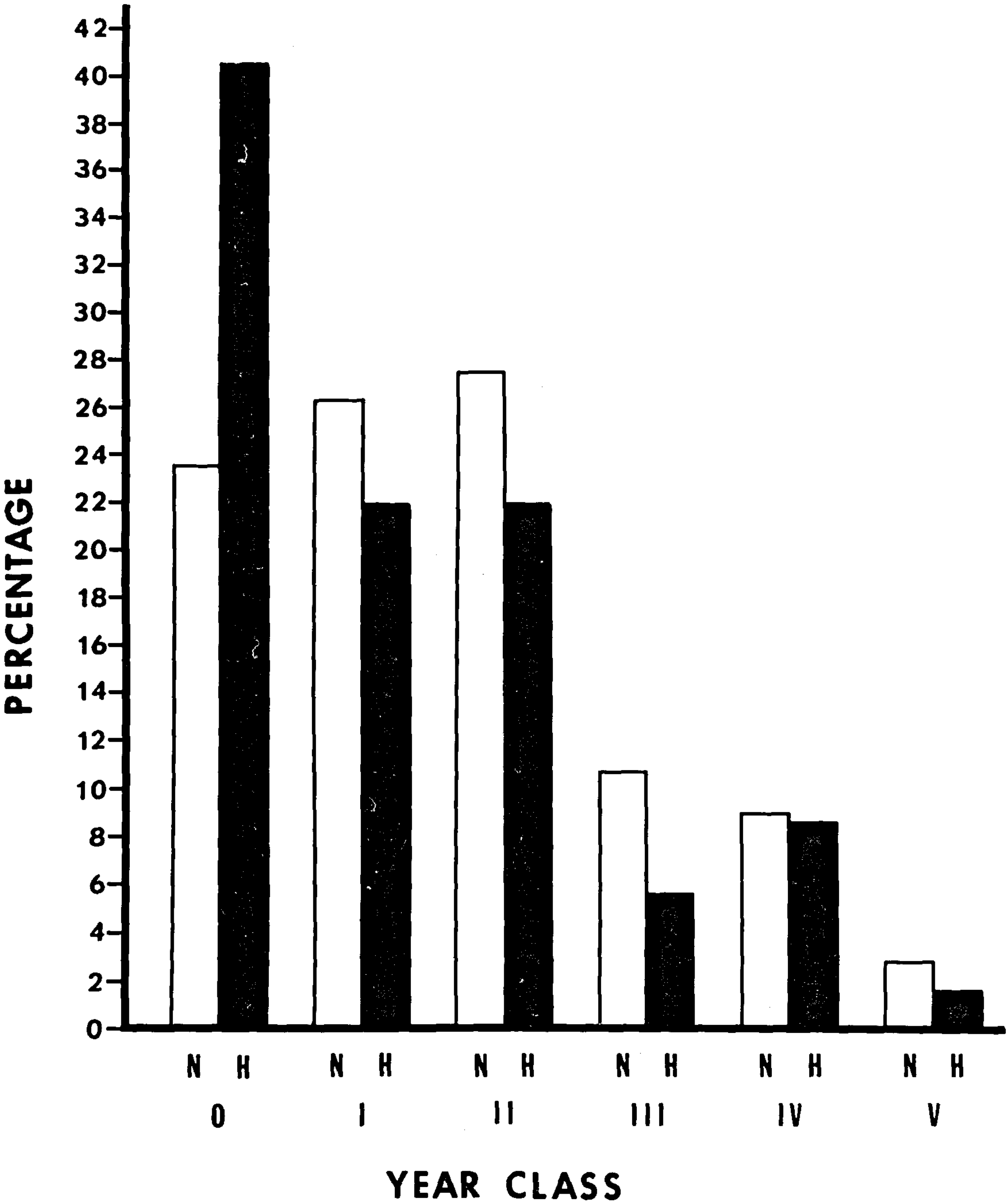
Figure 4. Total (seasons combined) composition of sample populations of *Lepomis auritus* from natural (N; white bar) and heated (H; black bar) water temperature habitats in the James River near Bremo Bluff, Virginia (October 1971 - September 1973). Composition expressed as percentages of the sample populations which each year class comprised.



PERCENTAGE
42
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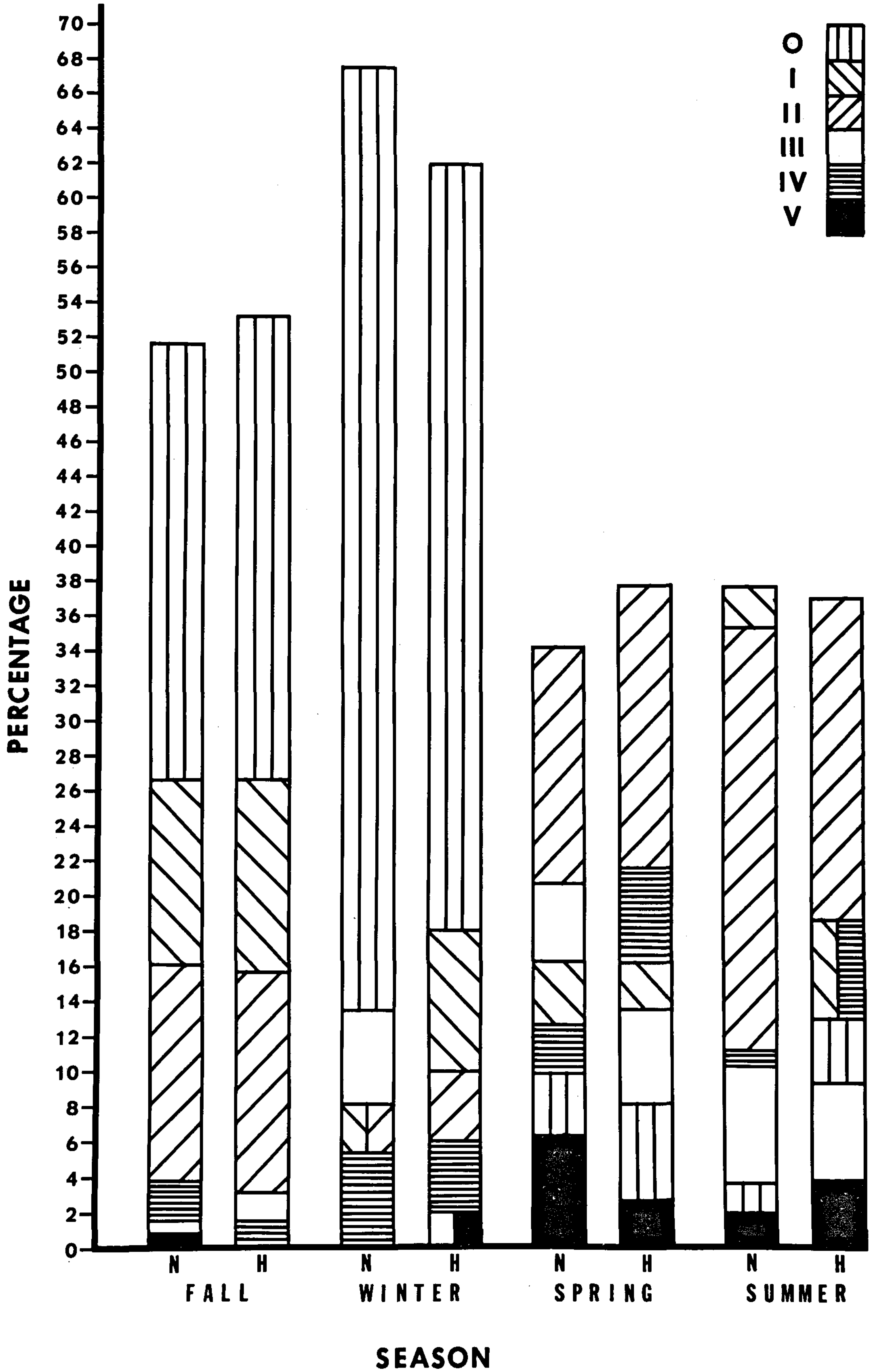
16
14
12
10
8
6
4
2
0
N H
0
N H
I
N H
II
N H
III
N H
IV
N H
V
YEAR CLASS

Figure 5. Seasonal composition of sample populations of *Lepomis auritus* from natural (N) and heated (H) water temperature habitats in the James River near Bremo Bluff, Virginia (October 1971 - September 1973). Percent of the total seasonal population that each year class represents is indicated by the top line of the appropriate symbol for that year class.



70
68
66
64
62
60
58
56
54
52
50
48
46
44
42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
PERCENTAGE
O
I
II
III
IV
V
N
H
FALL
N
H
WINTER
N
H
SPRING
N
H
SUMMER
SEASON

Figure 6. A comparison of the standard lengths of male and female Lepomis auritus, year classes I - V (sexes combined in year class O), from ambient temperature habitats in the James River, near Bremo Bluff, Virginia (October 1971 - September 1973). Range indicated by the vertical line; mean, by horizontal line; two standard errors of the mean, by black bar; and two standard deviations by the black bar plus the white bars.

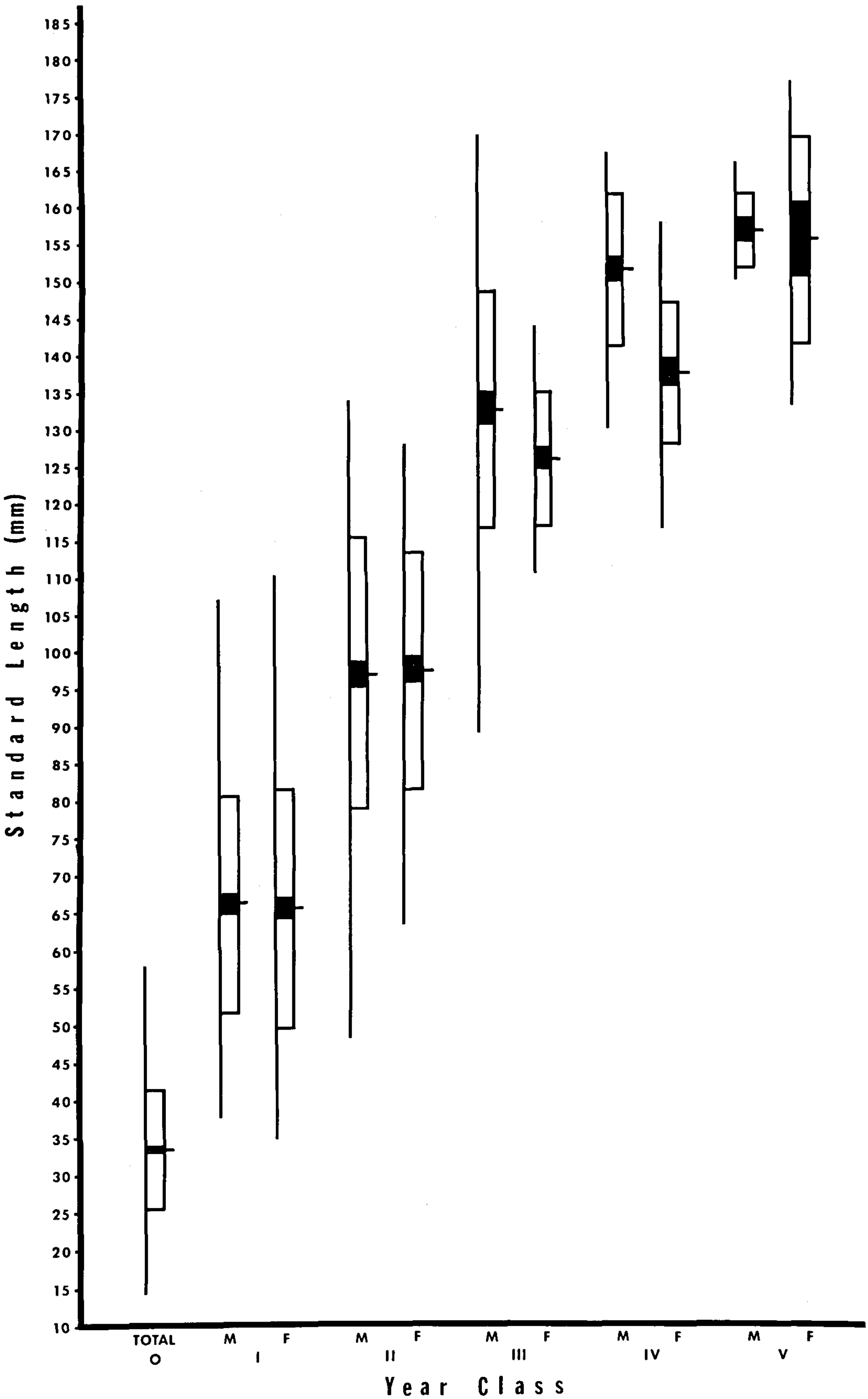
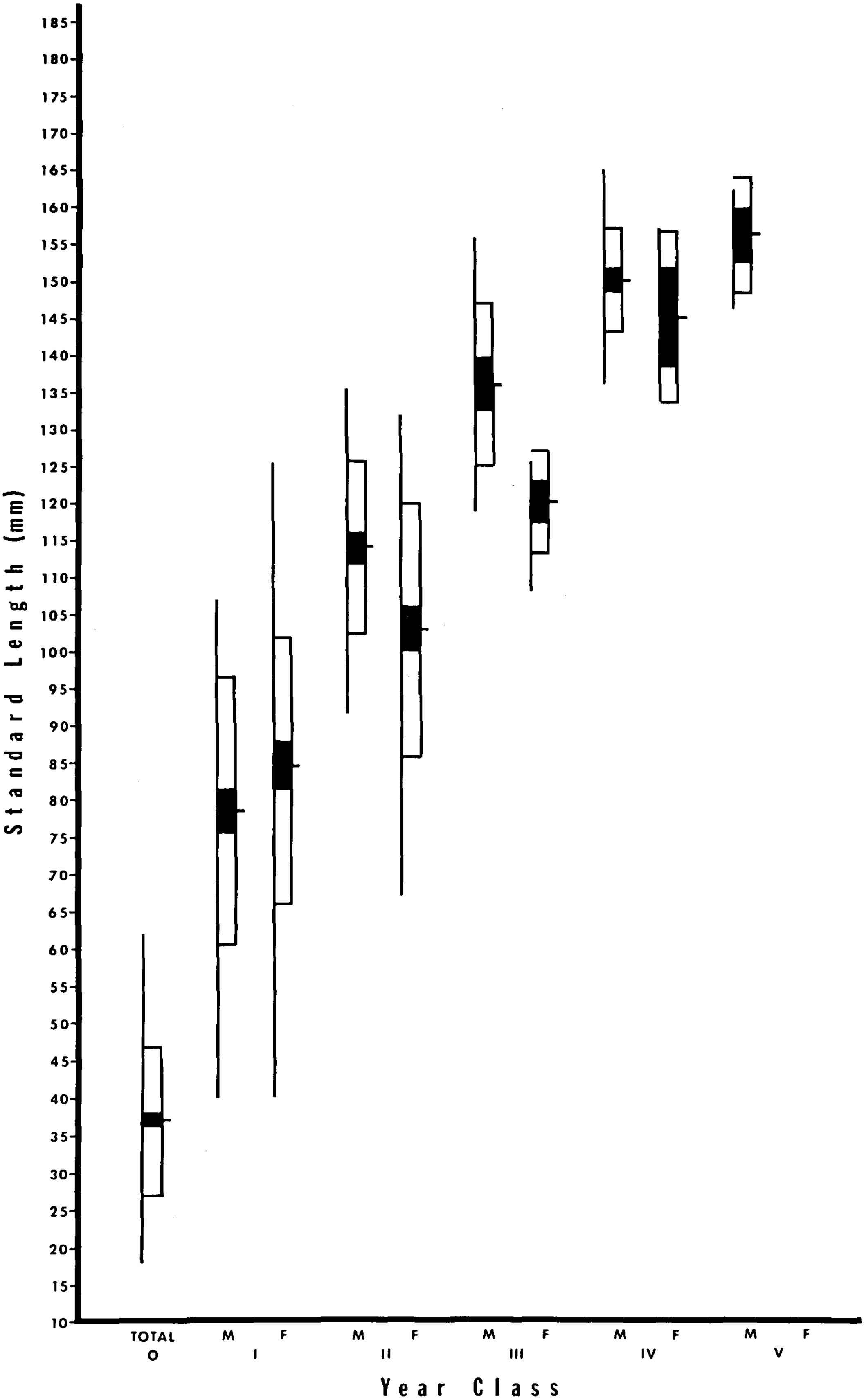

Standard Length (mm)
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
TOTAL
O
M F
I
M F
II
M F
III
M F
IV
M F
V
Year Class

Figure 7. A comparison of the standard lengths of male and female Lepomis auritus, year classes I - V (sexes combined in year class O), from heated temperature habitats in the James River, near Bremo Bluff, Virginia (October 1971 - September 1973). Range indicated by the vertical line; mean, by the horizontal line; two standard errors of the mean, by black bar; and two standard deviations by the black bar plus the white bars at ends.


Standard Length (mm)
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
TOTAL
O
M
F
I
M
F
II
M
F
III
M
F
IV
M
F
V
Year Class

Vita

John Rawls Saecker was born December 19, 1948 in Suffolk, Virginia. There he attended public schools and was graduated from Suffolk High School in June 1967. He then attended the University of Richmond, graduating in June 1972 witn a Bachelor of Arts degree in Biology. In the Fall of 1972 he enrolled in the University of Richmond School of Graduate Studies. During his tenure as a graduate student he worked as a laboratory assistant in the Biology Department and as a part-time graduate assistant at the Virginia Institute for Scientific Research. He is a member of Beta Beta Beta Honorary Biological Society. Requirements for the Master of Science degree from the University of Richmond were completed in August, 1975.