GROWTH STUDIES OF LABORATORY AND WILD POPULATION SAMPLES OF SMALLMOUTH BASS, *MICROPTERUS DOLOMIEUI* LACÉPÈDE, WITH APPLICATIONS TO MASS MARKING OF FISHES

GROWTH STUDIES OF LABORATORY AND WILD POPULATION SAMPLES OF SMALLMOUTH BASS, MICROPTERUS DOLOMIEUI LACÉPÈDE, WITH APPLICATIONS TO MASS MARKING OF FISHES

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science

By

FRANK W. PEEK, B. S.
State University of New York
College at Fredonia, 1963

1965
The University of Arkansas

This thesis is approved
for recommendation to the
Graduate Council

Major Professor:

Kirk Strawn

Thesis Committee:

Carl E. Hoffman

Douglas James

Albert M Davis

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF FIGURES

LIST OF PLATES

INTRODUCTION

Fish marking is a valuable tool of the fisheries biologist. The fresh-water-fisheries biologist uses marking methods in the evaluation of statewide stocking programs, costing many thousands of dollars. The numerous marking methods which have been tried to date have been summerized by Jensen (1962) and Roundsefell and Kask (1945). Basically these methods fall into two categories: (i) attaching some kind of tag to the fish, or (ii) mutilation of the fish. More recently other marking methods such as dying fish (Ward and Verhoeven 1963) and the use of radioactive markers (Pendleton 1956) have been tried. The two major limitations of these marking methods are: (i) they all in some way harm the fish being marked, and (ii) few provide a mark lasting the life of the fish. A method of marking fish permanently without injury would therefore be of great value to the fisheries biologist.

Fry *et al*. (1960) have placed a time mark on the scales of various fishes by injecting them with lead versenate. The lead is deposited in the scale a few days after injection, thus permanently marking the fish. The major drawback of this marking method has been the toxicity of the lead.

The major objective of the present study was to find a method of placing a permanent and harmless mark on the scales of fishes. The study was based on the assumption that: (i) prolonged exposure to low temperature, starvation, or darkness would cause the production of an annulus on the scales of fish, and that (ii) a laboratory-raised fish with scales having an abnormal distance between their focus and first annulus could be distinguished from wild fish.

Wallin (1957) in his comprehensive study of the growth, structure, and development of scales demonstrated that annuli could be produced on scales of the roach by a combination of cold temperature and starvation. He found that when the growth of the fish and consequently the growth of the scale ceases, calcification in the scale continued until the entire scale was calcified. The circuli (concentric ridges on the surface of a scale) became progressively closer together as the scale growth slowed and some of the circuli terminated freely upon the lateral margins of the scale. When the temperature of the water in which the fish had been living was raised, the fish were given food, and allowed to grow for several weeks, scale growth was resumed. The first circulus was complete since its curvature was determined by the outline of the calcified scale. With increasing scale growth the circuli were formed at increasing intervals. Thus all the components of the annulus were formed: (i) a zone of crowded circuli, (ii) circuli which terminate blindly (cutover), and (iii) a complete enclosing circuli. Bennett (1962) noted that any natural or artificial phenomenon which will stop the feeding and growth of a fish for about 14 days or longer will be followed, once growth is resumed, by the appearance of an annulus on the margins of the scales.

The present study uses the smallmouth bass, Micropterus dolomieui Lacépède, as the experimental animal and provides the basic information necessary for the field testing of a "scale method" of mass-marking fish. Because there is an intimate relationship between the growth of a fishes body and the annulus patterns on its scales, any attempt to mark a fish by altering its scales must begin with an understanding of the growth of that fish. Therefore, this study was also concerned with growth.

The study was conducted in three phases:

1. An investigation of growth and temperature choice of laboratory-raised smallmouth bass. These fish were then used as the subjects of

"scale-marking" experiments.

2. An investigation concerning growth of wild smallmouth-bass populations from samples taken throughout Arkansas.
3. "Scale marking" smallmouth bass in the laboratory using low temperature, darkness, and starvation to induce artificial annulus formation.

METHODS AND MATERIALS

The Collection and Care of Bass Eggs

The smallmouth bass eggs, used as the source of laboratory bass for experiments carried out during 1963, were obtained by Dr. Kirk Strawn in early May 1963 at the Arkansas Game and Fish Commission Hatchery at Centerton, Arkansas. The eggs were transported to the laboratory in styro-foam containers and then transferred to wide mouth gallon jars. The eggs were hatched in the laboratory at a constant temperature of 22° C.

The smallmouth bass eggs, used in the laboratory experiments performed during 1964 were collected on May 16, 1964 at the Centerton hatchery. During the week preceding the collection of these eggs over 50 breeding-sized smallmouth bass, collected from Crooked Creek in Boone County, Arkansas, were turned loose in the bass pond at the hatchery. These Crooked Creek bass were placed in the same pond with the brood bass already at the hatchery. The fish used in this study could have any of three possible genetic backgrounds: (i) they could be pure Centerton Hatchery fish, (ii) they could be hybrids between hatchery bass and Crooked Creek bass, or (iii) they could be pure Crooked Creek fish. It is believed that the fish used in this experiment are pure Crooked Creek stock because at the time the Crooked Creek breeding stock was placed in the hatchery pond the Centerton breeding stock had apparently finished spawning.

Approximately 350 eggs were collected using a large cooking baster to suck them up from between the rocks and pebbles of the nest; the nest was covered by about two feet of water. The eggs were placed in fresh-pond water in styro-foam containers for transportation back to the laboratory at the University of Arkansas. The temperature of the pond water was 21° C. During the transfer to the laboratory the temperature of the water in the containers rose only 0.5° C.

At the laboratory, about 90 eggs were placed in each of four 1-gallon wide-mouth jars. The jars were completely submerged in aged tapwater, which was kept at a constant temperature of 23° C.

Laboratory-Growth-Rate and Temperature-Choice Studies

Transfer of fish for the growth-rate study

By the evening of May 16, 1964, virtually all of the eggs had hatched. By the evening of the 17th the fry had reached the dark-eyed stage. On May 21st, 35 fry, which were free swimming and averaged 9.8 mm in length, were transferred to each of nine temperature controlled tanks. The water temperature of the tanks had been previously adjusted to 31, 30, 29, 28, 27, 26, 23, 20, and 17° C, respectively. All transfers were completed within 20 minutes.

Description of tanks and temperature control systems

The tanks were constructed of plywood and coated with polyester resin to make them water proof. The inside measurements of the tanks were 22.6 in. long by 16.5 in. wide by 14 in. deep and they held approximately 15 gallons of water. Each tank was supplied with a 12 in. by 23 in. plastic bottom filter beneath approximately 2 in. of washed sand. One air stone and a bowl filter containing glass wool and bone carbon were used in each tank to clean, aerate, and promote the circulation of the water. All tanks were lighted 24 hours a day by fluorescent lights.

The temperature in each tank was controlled by a thermoregulator, sensitive to temperature changes of 0.01° C, which was connected to a transistorized relay unit that operated a 150-watt aquarium heater submerged in the tank.

The water temperature of each tank was recorded three times daily at approximately 8:00 AM, 3:00 PM, and 11:00 PM using thermometers calibrated to 0.1° C. The temperature, except in one instance, never varied more than 0.6° C from the original constant setting. On June 11 the 35 fish being raised at a constant 20° C were all killed when the control relay stuck, thereby raising the temperature in the tank to 37° C.

Feeding and care of the bass

Within an hour after all the transfers were made the fish were fed brine shrimp. Thereafter, they were fed brine shrimp three times a day. On May 27th the brine shrimp diet was supplemented with daphnia. By the 2nd of June all fish except those at 17° C had grown enough to eat mosquito wigglers, which they began receiving. The feeding of daphnia and brine shrimp was discontinued in these tanks and a constant supply of wigglers was kept in each tank to insure maximum growth of the fish. After June 10, the fish were fed three times a day on a diet of chopped earth worms supplemented once a day with mosquito wigglers.

Every other day the bottoms of all the tanks were siphoned to remove the accumulated detritus and a gallon of fresh tap water was added. Once a week bowl filters were cleaned and the activated charcoal and glass wool in them was replaced.

Rocks were placed in the tanks to provide shelter for the fish with the hope that this would reduce the stress on them and increase the amount of energy available for growth.

Recording bass growth

Beginning with the transfer of fry on May 21 a random sample of ten fish from each of the nine tanks was measured, generally at intervals of three days. After each fish of a sample was measured it was returned to its tank.

Fish-measuring devices were designed and constructed to permit accurate measuring while at the same time avoiding injury to the fish. Each fish-measuring device consisted of a foot-long piece of transparent tygon tubing with a funnel attached to one end. In all there were six measurers each with a different diameter tube grading in size from a 1 in. tube to a 3/8 in. tube. Fish were measured with these devices in the following manner: (i) a measurer was selected having a tube diameter slightly larger than the body depth of the fish to be measured, (ii) the fish was captured with the funnel which then directed it into the transparent tube, (iii) the fish, clearly visible inside the tube, was measured to the nearest millimeter using dividers and a plastic rule. At no time during the measuring process did the fish leave water (the tube was kept full of water) nor was the fish ever handled. Hundreds of measurements were made with no apparent injury to any of the fish except one. This fish was killed when it was placed in an undersized measuring tube. In all cases the measurement made was that of fork length (Troutman 1957).

On August 10th the comparative-growth-rate study of the nine lots of bass raised at constant temperatures was terminated (Figure 1). The fish were either preserved in 10% formalin solution or used as subjects for various other experiments.

<u>The temperature choice experiment</u>

On September 1, 1964, 17 bass which had been raised at 28° C were placed in a temperature choice tank (Figure 1). The inside measurements of this tank were 89 in. long by 26 in. wide by 14 in. deep. The tank, which was constructed of plywood and coated with polyester resin, was divided into eight compartments formed by seven plexiglass partitions. Each plexiglass partition had two 1¼ in. diameter holes in it near the bottom. These holes were well below the water line so that fish could pass freely from compartment to compartment. The outer wall of the sides and back of the tank extended 14 in. above the maximum water-line and supported a roof of plywood. The sides and roof completely enclosed the tank except for a 14 in. by 93 in. opening in the front. This opening faced an identical tank 32 in. away. Two eight foot 75 watt cool-white fluorescent bulbs extending the entire length of the tank provided constant uniform lighting in all compartments. Cooling coils, built into one end of the tank, chilled the water in the compartment at that end. The flow of freon-cooling fluid through these coils was controlled by an electro-magnetic valve which was operated by a thermoregulator-relay system identical to those described above. The compartment at the opposite end of the tank was heated by two 150-watt aquarium heaters controlled by a separate thermoregulator-relay system. By heating one end compartment of the tank and cooling the other a temperature gradient was established in the tank. Three temperature-gradient ranges were used: (i) from 31 to 17° C, (ii) from 35 to 21° C, and (iii) from 38 to 27° C.

At the close of the experiment all fish were confined, at approximately 24° C, to the last three compartments of the tank. The social hierarchy was then partially worked out by removal experiments. The fish excluding all other fish from its compartment was removed and measured. The fish replacing it was then removed and measured. This cycle was repeated until six fish had been removed and measured.

Age and Growth of Wild Bass

Collection of wild bass

Samples of wild populations of smallmouth bass were collected from 52 locations throughout its range in Arkansas during the years 1962, 1963, and 1964, and from one location in Missouri during 1962. Four collecting methods were used: (i) electro-fishing, (ii) seining, (iii) hook and line fishing, and (iv) chemical poisoning (two samples with rotenone and one with phenol). Electro-fishing equipment and the details concerning its operation have been described by Castro (1963).

Each collection is represented by a three number code to facilitate computer processing of the data. The first code number indicates the river basin in which the collection was taken. Basin 1 is the Arkansas River Basin, basin 2 is the White River Basin, and basin 3 is the Ouachita-Little River Basin. The second number of the code indicates the specific stream from which the collection was taken. The third code number indicates location on a stream. Throughout this paper collections will generally be referred to by identification code number only. All collection locations are listed in Table 1.

Freshly collected wild specimens were placed in 10% formalin solution as a temporary preservative. Later the specimens were washed with water and transferred to 35% isopropyl alcohol which was used as the permanent preservative. Large fish were cut on the left side of the abdomen, before being placed in formalin, to insure maximum penetration of the preservative.

Collecting and reading scale samples

Approximately 20 scales were removed from an area just touching the tip of the extended pectoral fin and about five scales below the lateral line of each specimen. This method of scale sampling was closely adhered to in an attempt to obtain uniform and comparable scale samples. Each scale sample was placed in a 2¼ in. by 3½ in. coin envelope. The fishes number, the collection from which it came, and its standard length were recorded on the envelope. All fish sampled were measured to the nearest millimeter using the fisheries-research method given by Hubbs and Lagler (1947).

The scales were read on a conventional scale reader. Approximately 15 scales from each sample were placed between two glass microscope slides along with a drop of water. The slides were placed in the reader and the number of annuli were determined using the criteria for distinguishing annuli given by Lagler (1952). Measurements were then taken from the focus of the scale, along the primary radius of the scale, to each annulus and to the outer margin of the scale. All measurements of focus to annulus distances made were recorded in fractional form. When a scale is placed on the scale reader its image is magnified and then projected onto a ground glass screen. On the screen the magnified image of the scale can be measured using a rule. The numerator of the fraction is the measurement in millimeters of the magnified scale image and is taken directly from the screen, for example, 51 mm. The denominator of the fraction is always 57, the magnification of the scale reader. The focus to annulus distance of the unmagnified scale is, in this case, $\frac{51 \text{ mm}}{57}$ or dividing the fraction out it is about 0.89 mm.

Placing Artificial Annuli on Laboratory-Raised Bass

The use of temperature to place annuli on the scales of bass

On May 6, 1963, ten fry which had just hatched from eggs obtained at the Centerton Hatchery were transferred to temperature-controlled tanks similar to those used in the laboratory-growth-rate study. The fish were kept at a constant temperature of 28° C until July 23. From July 23rd to September 25th the fish were kept at room temperature which averaged about 25° C. Throughout the summer and fall of 1963 the fish were fed twice daily on chopped earthworms. On September 25th the fish were placed in a large chilling tank which was constructed of plywood and insulated with polyester foam. The inside measurements of the tank were 42 in. long by 26 in. wide by 15 in. deep. The tank was equipped with two 12 in. by 23 in. under sand aquarium filters to clean the water. Two 20-watt fluorescent lamps, suspended approximately 8 in. above the water provided a constant light source for the tank. Four air stones were placed in the tank to eliminate temperature gradients and to aerate the water.

The water temperature in the tank was controlled by a thermoregulator-relay system as described in the laboratory-growth-rate study. Low temperatures were obtained by circulating freon through copper cooling coils built into the walls of the tank. The temperature relay was connected to an electromagnetic valve thereby controlling the flow of refrigerating fluid through the coils in the tank.

The water temperature in the tank was lowered a degree a day until 10° C was reached. The fish were kept at 10° C for three weeks. The temperature was then raised a degree a day until 28° C was reached. The fish were grown at this temperature for three weeks and then preserved. Scale samples were taken from each fish.

On August 11, 1964, 20 of the smallest fish from the lots of bass raised at 26, 27, 30, and 31° C (Figure 1) were placed in a chilling tank, which was identical to the one described above. Beginning on September 25th the temperature of the water was lowered approximately a degree and a half a day till a temperature of 10° C was reached on October 5th. While at 10° C the bass fed little even though they were offered chopped worm and had mosquito wigglers available in the tank at all times.

Disease was a problem in keeping bass alive at low temperatures. On December 1st the fish developed a severe unidentified fungal infection. The infection was finally cured and thereafter kept under control by dissolving terramycin in the water. About 1 tablespoon of Pfizer Co. Egg formula containing 25.0 g terramycin per pound was used per 30 gallons of water, every two days.

Beginning on December 15th the temperature of the water was raised about a degree a day until 28° C was reached. The fish were kept at 28° C, a temperature at which they fed and grew, till they were preserved on February 3, 1964. Scale samples were taken from each preserved fish.

<u>The use of darkness and starvation to place annuli on the scales of bass</u>

On August 11, 1964, fifteen fish which had been raised at 30° C (Figure 1) were placed at 29° C in one of the 15-gallon tanks which had been used in the laboratory-growth-rate study described above. This tank was covered with a black rubberized cloth which excluded all light except the minute amount transmitted through the glass of the thermometer kept in the tank. The fish were kept in darkness except for the 15 to 20 minutes a day required to feed them. After one month of being in darkness the rubberized cover was removed, the fish were grown in light for 3 weeks, and then preserved and scale samples were taken.

On November 19th, 1964, upon termination of the temperature choice experiment, seven of the fish which appeared to be in good condition were transferred to seven, 2.5-gallon fish bowls. The water in each bowl was allowed to vary with room temperature and consequently ranged between 23 and 26° C.

The fish were starved for a period of 17 days. At the end of this period the fish were fed on chopped worm and small fish for 20 days and then preserved. Scale samples were then taken from each fish.

Statistical and Graphical Methods

Statistical methods were employed to accomplish the following tasks:

1. To compare bass growth among basins, streams, and locations in streams.
2. To fit the scale and body-length measurements for all bass to ten linear and curvilinear models (Table 2). Models were fitted for all bass grouped first by locations, then by streams, and finally by basins.
3. To test each of the above equations to determine which ones best expressed the data and to determine what level of grouping was valid.
4. To apply confidence intervals to the fitted equations.

The majority of the statistical calculations used in this study were done by computer, therefore all data was first punched on I.B.M. cards. An I.B.M. 7040 computer was programmed to carry out all variance analysis comparing means of scale measurements, all calculation of estimated mean squares, all curve fitting and testing, and all setting of confidence intervals.

The Duncans new multiple-range test for unequal samples (Kramer, 1956) was utilized to make comparisons among means of scale measurements for the first years of life for bass populations having identical body-scale relationships. This method permits quick comparisons between any two locations. The studentized ranges (Duncan factors) were taken from Steel and Torrie (1960). For comparisons among bass populations having different body-scale relationships, means of back-calculated lengths were used.

The model for the normal distribution curves used to compare the focus to first-annulus distances of wild and laboratory-raised bass was taken from Steel and Torrie (1960). The population size of the laboratory reared bass was adjusted to correspond to that of the wild bass. A planimeter was used to estimate the areas contained under the curves.

Data from the laboratory-growth-rate study was presented on a response surface diagram. The assumption was made that the lengths of the 35 fish at each temperature were normally distributed. A growth law $Y=A\ (1-e^{-Kt})$ was used where: Y = fish length in millimeters, t = time in days, A = estimated ultimate fish length in millimeters, e = the base of the Naperian system of logarithms, and K = a constant. Contour lines of equal growth were plotted from points obtained by programming the computer to calculate t from the above growth equation for each temperature as Y was set equal to 5 mm, 10 mm, 15 mm, ... 120 mm.

Confidence intervals were calculated for the estimates of ultimate length for each temperature (Steel and Torrie, 1960).

All probability levels given in this paper are the odds that the observed differences are due to chance. The term significance is used to indicate the 5% level of probability unless otherwise stated. The sample size, range, mean, variance, standard deviation, and standard error of all samples were used to draw conclusions presented in this paper.

RESULTS

Laboratory-Growth-Rate and Temperature-Choice Studies

Growth rates of bass at nine constant temperatures

The average lengths of bass raised at the constant temperatures of 28 and 29° C were greater than the average lengths of bass raised at both higher and lower temperatures. Minimum growth occured at a constant temperature of 17° C. Based on growth during the entire 82 days of the experiment, bass grown at 29° C had a mean rate of growth per day of 1.10 millimeters while bass raised at 17° C and 31° C had mean rates of growth per day of 0.42 millimeter and 0.96 millimeter, respectively (Table 3). The rate of growth for bass at all temperatures decreased with time.

Temperature choice in bass

Removal experiments demonstrated that the six largest fish were the dominant fish in the tank. The degree of dominance was directly related to size of the fish. The largest fish dominated all other fish in the tank, the next largest fish dominated all fish smaller than itself and so on.

When the temperature range in the tank was 31.0 to 17.0° C the two most dominant fish chose a temperature of approximately 31.0° C. The greatest concentration of bass was found at an average temperature of 26.0° C (Table 4). One fish, the smallest (89 mm), died in the 17° C compartment during this period. When the temperature range was changed to 35.0 to 21.0° C the largest, most dominant fish remained at a temperature of approximately 31.0° C. The greatest concentration of bass was found at an average temperature of 27.0° C. One fish, the smallest (91 mm), died in the 21.0° C compartment during this period. When the temperature was changed to 38.0 to 27.0° C the dominant fish again chose a temperature of approximately 31.0° C. The greatest concentration of bass was found at an average temperature of 29.0° C. One fish, the smallest (98 mm), died in the 27° C compartment during this period. During the entire temperature choice experiment no fish was ever found at a temperature higher than 32.8° C nor at a temperature lower than 17° C, the lowest temperature available to the bass.

Age and Growth of Wild Bass

All of the 1453 wild smallmouth bass used in this study were grouped into 25 mm intervals of standard length and tabulated on a length frequency diagram. The fish showed a steady progression in length at increasing ages (Table 5). As age increased there was a progressive decrease in rate of growth. On the basis of the number of annuli on their scales none of the smallmouth bass were more than nine years old. Ninety per cent of the bass were under four years of age. Only 139 individuals were four years of age and older. The two year olds were the largest age group, making up 30% of the total sample. After the second year of life, the mortality rate was generally over 50% per year. Between the second and third year the mortality rate was 56%, between the third and fourth year 65%, between the fourth and fifth year 44%, between the fifth and sixth year 54%, between the sixth and seventh year 67%, between the seventh and eigth year 0%, based on small sample size (Table 5), and between the eigth and ninth year 83%.

Scale-length body-length relationships

The relationship between the growth in body length and the growth of the scale was found to vary significantly among bass from the various basins, streams, and locations. Numerous equations were needed to adequately express the body growth scale growth relationship for all bass used in this study. All of these equations with three exceptions, caused by small sample size, fitted one of two general equation types.

Type	General Equation
1	$L = B_1 + B_2S$
2	$L = B_1 + B_2S + B_3S^2$

Where: L = the standard length of the fish, B_1 = the Y intercept, B_2 and B_3 are constants derived from the data, and S is the scale measurement in millimeters from focus to annulus times 57. The mathematical relationship between the growth in body length and growth in scale length for all fish sampled from basin 1 is expressed by the equation,

$$L = 25.01 + 1.21\ S - .006\ S^2.$$

In basin 2 the relationship between growth in body length and growth in scale was found to vary significantly among streams and in the case of stream 2-1 and stream 2-9 to vary significantly among locations. Many equations were necessary to describe this relationship for fish sampled from basin 2 (Table 6).

In basin 3 the relationship between body length and scale length was found to vary significantly among the samples taken from various streams. A separate equation for each stream was necessary to describe this relationship for the fish sampled from basin 3 (Table 7).

For samples of fewer than five fish the length-scale relationship takes the form $L = B_1$ indicating that there were too few fish to establish a trend. This results in the Y intercept B_1 being equal to $\frac{\Sigma L}{N}$ with variation in scale length S having no effect on fish length L.

The body-length scale-length relationship for samples of more than five fish but less than thirty fish was best expressed by a general equation of the first type. Samples of thirty or more fish generally displayed a curvilinear body-length scale-length relationship represented by a general equation of the second type.

Confidence intervals were calculated assuming large sample sizes for each body-scale relationship. All showed essentially the same pattern as those plotted for basin 1 and stream 2-10 (Figure 2). The intervals remained essentially constant for all scale sizes plotted, indicating the variance of individuals about the mean was uniform.

It is interesting to note that in comparing fish of equal size from basin 1 and Calf Creek (which is typical of basin 2) the basin 1 fish have larger scales than the fish from basin 2 (Figure 2). It might be expected that if two equal-length fish have different sized scales the fish having the larger scales would also have fewer scales. Hoyt (1965) found that fish from basin 1 did indeed have fewer scales than fish from basin 2.

Comparative growth rates of wild bass

For the first three years of growth the analysis of variance test of the nested samples of bass from basins, streams, and locations on streams from which multiple collections were taken (Table 8) shows significant differences in growth only among locations on streams. These differences among locations are significant at the 1% level of probability. There were no significant differences in growth among the various streams within basins nor among the three basins.

The analysis of variance results for the fourth, fifth, sixth, seventh, and eighth year growth rates were placed in the appendix. Comparisons of growth rates for fish over three years of age were of doubtful value due to the paucity of fish at these ages.

The estimated mean square percents for basins, streams, locations, and residuals for each of the first three years of growth (Table 8) showed that the variation in the growth rates of individual bass from the same locations (the residual term) was responsible for the greatest portion of the differences in growth rates detected, 47%, 48%, and 63%, respectively. The differences in the growth rates of individual fish from the same location increases with increasing age being least the first year and greatest the third year.

A significant portion of the growth rate differences detected was shown to be due to the effect of locations upon the growth rates of fish (Table 8). The amount of differences in growth rate attributable to this source decreases with increasing age of the fish.

Comparisons of growth rates of bass from basin 1, based on scale measurements

The Duncans new multiple range test, using Kramer's (1956) modification for unequal samples, showed which locations differed with respect to growth rate as indicated by scale measurements and which locations were the same for each of the first three years of growth (Tables 9, 10, and 11). The rank order of means for locations remains essentially the same for the first three years of growth. During the third growing season the bass growth rates were essentially the same for all locations tested. Locations such as Spavinaw Creek (1-4-2) showed consistently slow growth while locations such as the Fourche La Fave (1-13-1) showed continued relatively high growth rate.

Growth summary based on the back-calculated lengths of all bass collected

The average calculated standard lengths in millimeters as used in fisheries research (Hubbs and Lagler,

1947) for each year of life are presented for bass from each location investigated (Table 12). Bass growth at location 2-1-8 (Bull Shoals Reservoir) the only lake sampled for this study was much greater than the growth rate obtained in any streams. Bass from stream 1-4 (Spavinaw Creek) a cold stream, showed relatively slow growth, smallmouth from stream 2-9 (The Buffalo River) a warm stream showed relatively fast growth. A high growth rate was also obtained for bass from location 2-9-2 (A headwater location) the bass population here had been drastically thinned two years before. Bass in many streams, where multiple collections were made such as 1-2 (Little Sugar Creek), 1-9 (Lee Creek), 2-1 (The White River), and 2-9 (The Buffalo River) showed a gradient in growth rate from slow at headwater locations to increasingly faster at locations progressively further downstream (Table 12).

Production of Artificial Annuli in Bass

Ten fish having scales with large focus to artificial annulus distances were produced by exposing them to low temperature in the laboratory during 1963. The average focus to annulus distance was $\frac{53.6\ \text{mm}}{57}$ (Plate 1a) the range was from $\frac{46}{57}$ to $\frac{65\ \text{mm}}{57}$.

Twenty fish having scales with a small focus to artificial annulus distances were produced by exposure to low temperature in 1964. The average focus to annulus distance was $\frac{23.0\text{ mm}}{57}$ (Plate 1b) the range was from $\frac{19}{57}$ to $\frac{28\text{ mm}}{57}$.

The twelve fish grown to large size in 1964 (Figure 1) had scales with focus to outer edge distances ranging from $\frac{56}{57}$ to $\frac{77\text{ mm}}{57}$ with an average of $\frac{63.0\text{ mm}}{57}$.

None of the fifteen fish kept in darkness to induce artificial annulus formation, produced annuli on their scales. The scales showed no unusual marks of any kind.

All of the eight fish used as subjects of the starvation experiment showed distinct artificial annuli on their scales (Plate 1c).

DISCUSSION

Laboratory-Growth-Rate and Temperature-Choice Studies

Growth rates of bass at nine constant temperatures

The rate of growth of smallmouth bass was found to be greatly affected by the temperature of the water in which they lived. Variation in growth rate with temperature results from the effect temperature has upon the amount of food digested by the fish and the amount of energy required for maintenance. Though maintenance requirements were low at 17° C the food intake of the bass also was low, providing little energy for growth. The maximum amount of energy available for growth occurred at 28 - 29° C. Above 29° C maintenance requirements undoubtedly increased faster than food intake resulting in decreased growth (Figure 3).

The restrictions imposed by laboratory conditions should be considered when interpreting growth rate results. Because of low food intake at lower temperatures the fish living at 17, 20, and 23° C probably received a maximum or near maximum diet. At higher temperatures (30 and 31° C) feeding three times a day on worms may not have provided the maximum diet. Effects such as crowding and metabolic poisoning could also have biased the results by favoring growth at lower temperatures where the fish were smaller.

Estimates of maximum potential length (Table 13) based upon the growth trends established during the experiment, indicate that if conditions had remained constant, the bass would soon have attained their maximum size. Factors such as decrease in appetite and progressive crowding with attendant increased metabolic poisoning tend to substantiate the prediction that growth would be limited to a rather small ultimate length.

The type of diet a bass receives appears to be correlated with its growth rate (Figure 4). The bass grew faster on diets of mosquito wigglers and brine shrimp than they did on a diet of chopped earth worms. The faster growth rate attained with mosquito wigglers and brine shrimp was, at least partially, attributed to the fact that wigglers could be kept in the tanks constantly and the shrimps remained alive in the tanks over an hour after feeding. The chopped worms were available only during feeding time. The bass were observed to be more attracted to the very motile wigglers and brine shrimp than to the slowly moving pieces of chopped earth worm. At times the bass were reluctant to accept the latter. When mosquito wigglers and earth worms were offered to the bass simultaneously the bass invariably chose mosquito wigglers. No increase in length was detected during the period when the bass's diet was changed from mosquito wigglers to earth worms (Figure 4). This change-over undoubtedly corresponds to the change-over from insects to fish with consequent slowing of growth reported for wild smallmouth bass (Hubbs and Bailey, 1938).

An optimum growth temperature between 28 and 29° C (Figure 3), as found in the laboratory, appears high for a fish which has been characterized as an inhabitant of cool streams (Beeman, 1924). In his investigation of wild smallmouth bass in Illinois Durham (1955) found that they grew better in warmer water. Data on growth rates of wild populations of first year smallmouth bass indicated that they grew faster downstream, where the water is presumably warmer, than they did upstream. Purkett (1958) found that smallmouth bass in Missouri streams also grew faster downstream than upstream.

Temperature choice in bass

The 17 bass used in the temperature choice experiment were raised at a constant temperature of 28° C (Figure 1) and then transferred to a temperature choice tank. Fergusion (1958) working with many species including smallmouth bass found that this level of acclimation has very little influence upon the range of preferred temperature.

Laboratory studies of temperature choice by fish have some limitations which must be considered when interpreting results. Space limitation in the laboratory is one of the most important deviations from natural conditions. Limited space necessitates using unnaturally compressed thermal gradients. Because the tanks used in this study were compartmentalized the temperature gradient was composed of eight distinct temperatures. The difference in temperature between two adjacent compartments at times was as great as 4.8° C. Space limitations resulted in fish experiencing more interference from physical boundaries and having more contact with each other than would occur in a stream. Fish behavior under crowded conditions must be taken into account, particularly territorial behavior and social hierarchy. In the present experiment a definite social hierarchy was established with the larger fish being dominant and occupying defended territories.

The estimation of the preferred temperature was greatly complicated by territoriality. One estimate of the temperature preferred by bass fingerlings would be 31° C, the temperature chosen by the largest, most dominant fish (Table 4). This temperature is above the optimum temperature for growth established for laboratory fish (Figure 3). No fish was observed above 32.8° C and only rarely did a fish venture into 32° C water

(Table 4). Inability to withstand high temperatures was not the reason the bass failed to choose temperatures above 32.3° C. Smallmouth bass have been kept in our laboratory for six days at a temperature of 35° C.

Another estimate of preferred temperature would be 27.8° C, the average of the three temperatures at which the majority of bass remained under the three temperature setups (Table 4). Fergusion (1958) testing smallmouth bass in vertical temperature gradient for periods of less than 24 hours reported that they preferred a temperature of 28° C. These temperatures are close to the optimum-growth temperature as determined in the laboratory-growth experiment and would indicate that bass fingerlings tend to choose the temperature at which their growth is maximum. Field observations made during July 1964 in a headwater pool of the Middle Fork of the White River (stream 2-2) indicate that wild smallmouth bass fingerlings also choose warm temperatures. They were found to stay in the shallow water at the periphery of the pool where the water temperature was consistently above 26° C and in places rose to 35° C. The larger bass usually remained in the deep water at the center of the pool where the water temperature averaged around 22° C. These observations are supported by Fergusion (1958) who found that the temperatures chosen by smallmouth bass fingerlings were consistently higher than the temperatures chosen by adults.

Age and Growth of Wild Bass

Validity of the scale method for Arkansas bass

The validity of the scale method for back-calculating the growth of Missouri smallmouth bass was demonstrated by Patriarche and Lowry (1953), and by Purkett (1958). Jenkins (1956) found the scale method was applicable to Oklahoma smallmouth bass.

The fish used in this study show a steady progression in length (at capture), for successive ages (Table 5). This substantiates the belief that the annuli laid down by the smallmouth bass in Arkansas are true year marks and indicates that the scale method is valid for aging the fish used in the present study. The range in length of fish within each age group is attributed to differences in growth of individual fish and to differences in the time of year at which the fish were caught.

Many investigators working with various species of fish have found that false annuli occur, particularly during the first year of growth. Sprugel (1953) reported that during some years as many as 90% of the bluegills taken from a new lake possessed scales with false first annuli. This false annulus was attributed to the temporary cessation in growth resulting from the scarcity or absence of an appropriate-size range food. No false first annuli were found on the scales of the smallmouth used in this study. The first check on the bass's scale was a true rather than a false first annulus. This is indicated by the following:

1. The age-length relationship for the bass used in this study (Table 5) agrees with the age-length relationship found for known age smallmouth bass (Lowry, 1954).
2. Scales from 24 young of the year bass collected from six locations during the months of November, December, January, February, and April show no checks.
3. None of the fish used in the laboratory growth rate study produced artificial annuli, even though growth was temporarily stopped (Figure 4) when the diet of these fish was changed from small to large-sized food.

Age composition of wild bass populations and collecting bias

The great majority (90%) of the 1459 bass collected were less than four years old. After the second year of life the mortality rate of the smallmouth in the area of Arkansas investigated was generally over 50%. Bennett (1962) gives the total mortality for smallmouth in Michigan as 58% per year (22% fishing mortality plus 36% natural mortality). He gives the life span of smallmouth bass in Central and Southern United States as being 9 to 12 years. In this study no bass over nine years old were taken.

Some age-group inbalance was undoubtedly introduced by collecting methods. Hook and line collecting, for example, is not as effective on older fish as is electro-seining (Table 14).

Scale-length body-length relationships

Because of the differential in the rate of growth in length of a fishes body and the rate of growth of a fishes scale, a relationship must be established between the two in order to predict one from the other. Early workers were unaware of the differences in growth rate between the fishes body and its scales. A direct proportion method (Table 2) was therefore considered adequate for the calculation of body length from scale length (Van Oosten, 1929). With the realization that a fishes body and its scales grow at different rates came many attempts to mathematically express the relationships between scale growth and body growth (Table 2). For the majority of bass used in this study the general equation best expressing the body-scale relationship was either

$$L = B_1 + B_2S \quad \text{or} \quad L = B_1 + B_2S + B_3S^2.$$

These equations correspond to those used by Lee and Sherriff (Table 2). Differences in the body-scale relationship seem to be related to differences in growth rate. In basin 1, where growth rates were fairly consistent, one equation expressed this relationship for all bass samples. In contrast, each bass population in streams 2-1 and 2-9 had a different body-scale relationship. These streams contained very fast growing fish as well as a very slow growing fish.

The degree of the equation satisfying the body-scale relationship for bass from a specific location was generally related to the size of the collection at that location. Body-scale relationships for locations where small collections were made were satisfied by a linear equation. The body-scale relationship for locations where large collections were made was best satisfied by a quadratic equation.

The Y intercept or B_1 values for every equation used were averaged. This average value, an approximation of the size of the average fish at the time of scale formation in the region of the pectoral fin, was 29.93 mm. Everhart (1949), using microtechniques, found that the average length of some New York State smallmouth bass having newly formed scales in the pectoral region was approximately 30.0 mm. This very close agreement suggests that the average size at which a smallmouth bass acquires scales in the pectoral region is characteristic of the species.

Eight of the wild bass used in this study were found to have small scales in the pectoral region. The standard lengths of these bass were 40, 37, 39, 41, 43, 33, 36, and 37 millimeters. These fish were undoubtedly smaller when the scales first formed because microtechniques were not needed to see the scales.

No indication of the accuracy of the scale method of fish-length back-calculation was found in the literature. However, confidence intervals calculated for the body scale relationships used in this study (Figure 2) indicate that a certain amount of error is inherent in this method. A substantial range of fish lengths can be expected from one scale measurement.

Comparative growth rates of wild bass

No significant differences in growth rates were found among either bass collected from the three basins or among bass taken from different streams within each basin. Smallmouth bass growth did vary significantly among locations on the same stream (Table 8). Apparently the specific habitat is the important factor in determining the growth rate of a bass, not the stream or basin in which its habitat is located. Purkett (1958) found that the growth of smallmouth bass often varied more between different locations on the same stream than between different streams.

In many streams such as the White River (2-1) and the Buffalo River (2-9) where multiple collections were made a gradient in the growth rates of bass was found from slow at the headwaters to fast at the mouths of streams (Table 12). This gradient in the growth rate can be attributed to many physical and biological factors working in conjunction. Mean water temperature during the growing season is probably one of the important physical factors. Very little temperature information was available for the streams studied, though it is probable that the lower mean temperatures occurred at the headwaters where the streams are fed from springs and higher temperatures would occur downstream where the streams are less shaded. For one stream, the Buffalo River (2-9), a few temperatures were available. On July 31, 1963, a river temperature of 27° C was recorded at Ponca, Arkansas, 122 miles upstream from the mouth. On August 2, 1963, the water temperature at the mouth was recorded as being 32° C (U. S. Army Corps of Engineers, 1964). In his ecological study of smallmouth bass in Illinois Durham (1955) found faster growth in situations having higher mean water temperatures. This trend is supported by data obtained in the laboratory phase of the present study. As the wild fish grew older their growth apparently was less affected by temperatures and they grew as well upstream as downstream (Table 11).

Two physical factors which apparently did not significantly influence the rate of bass growth were soil type and minor growing-season differences. When collection locations were plotted upon a soil map of Arkansas no correlation between fast growth and any particular soil type was evident. The absence of significant growth differences among bass collected from the three basins (Table 8) suggests that the average 10-20 day difference in the length of growing season between basin 1 and basin 3 did not significantly affect the length attained by bass during one growing season. The growing season difference between the northernmost collection on Shoal Creek in Barry County, Missouri, and the southernmost collection on the Cossatot near Gillham, Arkansas, was approximately 30 days (USDA, 1941).

The only biological factor which seemed to be positively correlated with good growth was abundance of minnows. An abundance of minnows was noted at the time of collection in many locations where high bass growth rates were later found.

Comparisons of growth rates as indicated by scale measurements and back-calculated lengths

In comparing the growth rates of bass from the 54 locations investigated, two methods were used. One method was to directly compare (using an appropriate test) growth rates as indicated by the fishes scales. This method was found to be accurate only when comparing the growth rates of bass from populations having the same body-scale relationships as was the case in basin 1 (Tables 9, 10, and 11). This method of comparing growth rates avoids the error involved in length back-calculation.

The other method of comparing growth rates is to compare back-calculated fish lengths (Table 12). This method was found to give an indication of the relative growth rates of bass irrespective of varying body-scale relationships, however the error of length back-calculation is always involved in such comparisons. Thus, when working with bass populations known to possess identical body-scale relationships growth comparisons based upon scale measurements would be preferable.

Mass Marking Bass with Artificial Annuli

Marking bass using low temperature

In 1963 smallmouth bass were grown in the laboratory to sizes larger than attained by first year wild bass in most habitats. The scales of these fish with few exceptions were larger from focus to outer margin than were the scales of wild smallmouth bass. These large-sized fish were kept in 10° C water long enough for their growth and consequently the growth of their scales to be arrested. When growth was resumed an annulus was formed on each scale. The annuli thus formed differed greatly in size from the annuli of the usual wild fish (Figure 5 and Plates 1a and d). As shown by this figure, the scales of laboratory raised bass are distinguishable from the scales of Spavinaw Creek (stream 1-4) bass on the basis of the first-annulus size. There is only a 5% chance (the shaded area of the graph) that a laboratory raised fish would be mistaken for a Spavinaw Creek specimen on the basis of its scales. The 5% chance for error could be reduced or eliminated by grading the marked fish and using only the larger ones. This demonstrates that "scale marking" fish is feasible.

The three largest bass raised in laboratory in 1964 were 143, 140, and 136 millimeters in length. The focus to outer margin distances on the scales of these fish were $\frac{75}{57}$, $\frac{70}{57}$, and $\frac{67}{57}$ millimeters, respectively, as compared to $\frac{65}{57}$, the focus to annulus distance of the largest marked fish represented in Figure 5. It is believed that if these fish were stocked in the fall with the fish in Spavinaw Creek (Figure 5), for example, they would be "scale marked" by the natural low water temperatures of winter. The reasons for expecting this are:

1. If an abnormally large fish was stocked it would continue to grow at the same rate as the fish already in the stream, thus maintaining the size differential between it and the fish

native to the stream.

2. That the following spring it would form its first annulus along with the stream fish.
3. That the distance from the focus to this annulus would be significantly larger on the stocked fish than on the stream fish thereby providing a character by which the former could be distinguished from the latter.

In 1964 a lot of small bass was "scale marked" using cold temperature to induce artificial annulus formation (Plate Ib). Placing small artificial annuli on fish results in a saving of food and time but for marking purposes has one possible disadvantage. A small annulus like check could occur naturally on the scales of any wild fish, thus making it indistinguishable from a fish "scale marked" with a small artificial annulus. Bennett (1962) cites injury and starvation as factors which can cause the production of an annulus like check on the scales of wild fish.

Marking bass using darkness and starvation

Experiments were conducted to determine the possibility of using factors other than temperature to induce artificial annulus formation, thereby "scale marking" fish more inexpensively.

Rasquin and Rosenbloom (1954) reported that the fish *Astanax mexicanus* (Filippi) developed a condition of "stress" and grew very slowly when kept in total darkness. It was hypothesized that living in total darkness would slow the growth of smallmouth bass enough to induce annulus formation. However, being kept in complete darkness except at feeding time did not result in the formation of an artificial annulus on bass. The scales of these bass showed no evidence of greatly decreased growth as a result of lack of light.

Another lot of bass (Figure 1) kept between 25 and 29° C was starved for 17 days and then grown for 20 more days in an attempt to induce artificial annulus formation. The fish which survived this experiment had definate annuli (Plate 1c). This indicates that a severe shortage of food would cause the formation of a food check on the scales of wild bass. The use of starvation to "scale mark" fish, however, is of doubtful value unless less severe starvation than used in this study would effectively cause an artificial annulus to form. All of the fish surviving this experiment had defective swim bladders and possessed no hydrostatic control. They remained on the bottom unless actively swimming.

Practicality of scale marking bass with artificial annuli

In a four year study of smallmouth bass raised in rearing ponds in Ohio Langlois (1935) found that bass could be raised to large size in one growing season. Bass, which were raised in ponds containing few fish, and were permitted to range and eat freely together of an abundant food supply (ground carp), showed a normal-length-frequency distribution with a very high mode (165 mm of length). Fish of this size would possess a first-year scale length much larger than any bass examined in this study.

First year bass raised to large size in hatchery ponds could be "scale marked" in any of the following three ways:

1. By placing them in chilling tanks at 10° C for two to three weeks to induce annuli to form on their scales.
2. By allowing them to winter over in the pond thereby acquiring an annulus (scale mark).
3. By directly stocking them in a stream on the assumption that the annulus formed in spring of the following year would be significantly

larger than that formed on the scales of the smallmouth bass native to that stream.

SUMMARY

During the summer of 1964, smallmouth bass, Micropterus dolomieui Lacépède, raised from hatchery eggs, were grown in the laboratory at nine constant temperatures. The young bass grew best at constant temperatures of 28-29° C; poorer growth was noted at both higher and lower temperatures.

During the fall of 1964, 17 bass were kept in a temperature choice tank which had a horizontal temperature gradient. Three temperature range setups were used during the experiment. The temperature preferendum of smallmouth bass fingerlings was somewhere between 31 and 26° C.

The growth of wild bass was studied from 1453 fish collected in Arkansas and 6 fish from Missouri. The scale method for calculating growth rates was found to be valid for Arkansas bass. Body-growth scale-growth relationships were determined for all bass and used to calculate a summary of their growth. Analysis of variance tests of the growth-rate differences detected showed

that the specific habitat of the bass was the important factor in determining its growth rate, rather than the stream or basin where that habitat was located.

A large focus to annulus distance was placed on the scales of bass raised in the laboratory by growing them to large size, placing them in 10° C water for three weeks, and finally, growing them at 28° C for three more weeks. The focus to annulus to distances on scales taken from laboratory raised fish were shown to differ significantly from focus to annulus distances on the scales of bass from selected wild populations. Fish with abnormally large focus to first annulus distances on their scales are thus marked for life.

ACKNOWLEDGEMENTS

This study was made possible through the financial aid of the Arkansas Game and Fish Commission and the Sports Fishing Institute. I also wish to express my gratitude to the University of Arkansas for providing materials and space needed to complete this study.

I wish to gratefully acknowledge Dr. Kirk Strawn for his assistance in organizing, planning, and carrying out all aspects of this study. Sincere thnaks are given to Mr. Harold Alexander, Mr. Andrew Hulsey, Mr. Robert Jenkins, Mr. Tom Duncan, and Mr. Al Houser for their help during this study. Thanks are also extended to Dr. A. M. Davis and Dr. James Dunn for their help on statistical procedures, Dr. Carl Hoffman and Dr. Douglas James for their constructive criticism in reading this manuscript, and to Robert Hoyt, Charles Wallace, Ronald Hodson, and William Neill, Jr., who made up our collecting crew during 1964. The assistance of State Game Wardens during collection trips is greatly appreciated.

Special thanks are given to my wife, Joan, for her critical reading and typing of the manuscript.

LITERATURE CITED

Beeman, Henry W. 1924. Habits and propagation of small-mouthed black bass. Trans. Am. Fisheries Soc., 54:92-107.

Bennett, G. W. 1962. Management of artificial lakes and ponds. Reinhold Pub. Corp., New York, 210 p.

Carlander, Kenneth D. 1945. Age, growth, sexual maturity, and populations of the yellow pike-perch, Stizostedion vitreum vitreum (Mitchill), with reference to the commercial fisheries, Lake of the Woods Minnesota. Trans. Am. Fisheries Soc., 73:90-107.

Castro, Gilbert A. 1963. "Meristic variations of wild and laboratory-raised smallmouth bass, Micropterus dolomieui Lacépède." Unpublished M. S. Thesis, Univ. of Arkansas Graduate School, 1963, 69 p.

Durham, Leonard. 1955. Ecological factors affecting the growth of smallmouth bass and long ear sun-fish in Jordon Creek, Illinois. Ill. Acad. Sci. Trans., 47:25-34.

Everhart, H. W. 1949. Body length of smallmouth bass at scale formation. Copeia, 1949:110-115.

Fergusion, R. G. 1958. The preferred temperature of fish and their midsummer distribution in temperate lakes and streams. Jour. Fish. Res. Bd. Canada, 15:607-624.

Fry, F. E. J., D. Cucin, J. C. Kennedy, and A. Papson. 1960. The use of lead versenate to place a time mark on fish scales. Trans. Am. Fisheries Soc., 89:149-153.

Hoyt, Robert D. 1965. "Meristic variation of smallmouth bass in Arkansas." Unpublished M. S. Thesis, Univ. of Arkansas Graduate School, 1965. 45 p.

Hubbs, Carl L. and Reeve M. Bailey. 1938. The small-mouthed bass. Cranbrook Inst. Sci. Bull., no. 10, Jan. 1938, 92 p.

_______, and Karl F. Lagler. 1947. Fishes of the Great Lakes region. Bloomfield Hills, Mich. Cranbrook Press, 146 p.

Jenkins, Robert M. 1956. The fishery resources of the Little River system, McCurtain County, Oklahoma. Okla. Fish. Res. Lab. Rept., no. 55, 82 p.

Jensen, Albert. 1962. Marking and tagging fishes. U. S. Fishery and Wildl. Serv., Fishery Leaflet, no. 534, 8 p.

Kramer, Clyde Y. 1956. Extension of multiple range tests to group means with unequal number of replications. Biometrics, 12:307-310.

Lagler, Karl F. 1952. Freshwater fishery biology. Dubuque, Iowa, Wm. C. Brown Co., 421 p.

Langlois, T. H. 1935. A study of the smallmouth bass Micropterus dolomieui (Lacepede) in rearing ponds in Ohio. Ohio Biol. Surv., 6 (4):Bull. 33, 191-221.

Lowry, E. 1954. How big is a smallmouth bass. Missouri Conservationist, 15:4-6.

Patriarche, M. H. and E. M. Lowry. 1953. Age and rate of growth of five species of fish in Black River, Missouri. Univ. Mo. Studies, 26(2):85-109.

Pendleton, Robert C. 1956. Labeling animals with radioisotopes. Ecology, 37:686-689.

Purkett, Charles A. 1958. Growth rates of Missouri stream fishes. Dingell-Johnson Project, Fish Game Div. Rept., 0-J Ser., no. 1, 46 p.

Rasquin P. and L. Rosenbloom, 1954. Endrocrine imbalance and tissue hyperplasia in teleosts maintained in darkness. Bull. Am. Mus. Nat. Hist., 104:359-426.

Rousenfell, George and John Kask. 1945. How to mark fish. Trans. Am. Fisheries Soc., 73:320-363.

Sprugel, J. 1953. Growth of bluegills in a new lake with particular reference to false annuli. Trans. Am. Fisheries Soc., 83:58-75.

Steel, R. G. and J. H. Torrie. 1960. Principles and procedure of statistics. New York, McGraw-Hill, 481 p.

Troutman, M. B. 1957. The fishes of Ohio. Baltimore, Ohio State Univ. Press, 683 p.

U. S. Army Corps of Engineers. 1964. White River Basin comprehensive study. Missouri and Arkansas. Interim Report on the Buffalo River Basin, U. S. Army Engineer District Little Rock Corps of Engineers, Little Rock, Arkansas. Vol. 2, 401 p.

U. S. Department of Agriculture. 1941. Climate and man. Washington, D. C., U. S. Government Printing Office, 1248 p.

Van Oosten, John. 1929. Life history of the lake herring, Leucichthys artedi (Le Sueur) of Lake Huron revealed by its scales with a critique of the scale method. Bull. U. S. Bur. Fish., 44:265-428.

Wallin, Olle. 1957. Growth structure and development of scales. Rept. Inst. Freshwater Res. Drottningholm, 38:385-406.

Ward, F. J. and L. A. Verhoeven. 1963. Two biological stains as markers for sockeye salmon fry. Trans. Am. Fisheries Soc., 92:379-383.

Table 1. Smallmouth Bass Collection Locations

ARKANSAS RIVER DRAINAGE

Sample Number	Number of Fish		County	Reference	Township Range Section	Collection date
1-1-1	5	Shoal Creek	*Barry	4 mi. E. of Rocky Comfort	T23N-R28W-Sec. 19	30/06/62
1-2-1	13	Little Sugar Creek	Benton	1.5 mi. NW. of Bella Vista	T21N-R31W-Sec. 35	06/10/62
1-2-2	87	Little Sugar Creek	Benton	3 mi. N. of Bella Vista	T21N-R31W-Sec. 23 & 26	24/07/62
1-3-1	6	Butler Creek	Benton	1/2 mi. N. of Sulphur Springs	T21N-R33W-Sec. 15	29/09/64
1-4-1	34	Spavinaw Creek	Benton	2 mi. S. of Gravette	T20N-R33W-Sec. 24	13/07/62
1-4-2	35	Spavinaw Creek	Benton	6 mi. W. of Decatur	T19N-R34W-Sec. 1	18/07/62
1-5-1	3	Illinois River	Washington	Upstream from Moffitt	T14N-R31W-Sec. 4	06/10/64
1-5-2	3	Illinois River	Washington	At Hgwy. 62 bridge	T15N-R31W-Sec. 8	11/07/62
1-6-1	10	Muddy Fork of Illinois River	Washington	6 mi. N. of Prairie Grove	T16N-R32W-Sec. 14 & 23	07/08/62
1-7-1	5	Clear Creek	Washington	At Savoy	T17N-R31W-Sec. 31 & T17N-R32W-Sec. 36	22/08/62
1-8-1	31	Barren Fork of Illinois River	Washington	At Hgwy. 45 bridge	T14N-R33W-Sec. 22 & 23	19/09/64
1-9-1	14	Lee Creek	Crawford	3.5 mi. NE. Lee Creek	T12N-R31W-Sec. 20	17/07/62
1-9-2	9	Lee Creek	Crawford	Below mouth of Fall Creek	T12N-R31W-Sec. 20	07/05/64
1-10-1	40	Fall Creek	Crawford	3.5 mi. NE. Lee Creek	T12N-R31W-Sec. 17	06/08/62
1-11-1	37	Mulberry River	Johnson	1 mi. down from mouth of Little Mulberry River	T12N-R25W-Sec. 30	13/09/64
1-12-1	34	Illinois Bayou	Pope	2 mi. N. of Scottsville	T10N-R19W-Sec. 28,29 & 32	21/08/64
1-13-1	11	South Fork of Fourche La Fave	Perry	6.5 mi. SE. of Nimrod Dam	T 3N-N19W-Sec. 7, 17, & 18	11 & 25/10/64

* This collection is from Barry County, Missouri. All other collections are from Arkansas.

WHITE RIVER DRAINAGE

Sample Number	Number of Fish		County	Reference	Township Range Section	Collection date
2-1-1	30	White River	Madison	At St. Paul Cemetary	T14N-R26W-Sec. 33	11/08/62 & 9/29/62
2-1-2	5	White River	Madison	1.5 mi. W. of St. Paul	T13N-R26W-Sec. 5 & 6	21/01/64
2-1-3	7	White River	Madison	At Patrick	T14N-R27W-Sec. 31	04/08/62
2-1-4	12	White River	Madison	Downstream from Patrick	T14N-R27W-Sec. 30 & 31	13/06/62
2-1-5	7	White River	Madison	Above ford at Thompson	T15N-R28W-Sec. 34	05/08/62
2-1-6	3	White River	Washington	2 mi. N. of Durham	T15N-R28W-Sec. 18	07/06/63
2-1-7	9	White River	Benton	At Lost Bridge	T20N-R27W-Sec. 19	23/07/63
2-1-8	6	Bull Shoals	Marion	Hgwy. 125 access area	T21N-R17W-Sec. 2	18/11/64
2-2-1	20	Middle Fork of White River	Washington	1 mi. W. of Sulphur City	T15N-R29W-Sec. 16	06/06/63

Table 1. (Continued) Smallmouth Bass Collection Locations

WHITE RIVER DRAINAGE (cont.)

Sample Number	Number of Fish		County	Reference	Township Range Section	Collection date
2-3-1	12	West Fork of White River	Washington	1 mi. S. of West Fork	T14N-R30W-Sec. 4 & 9	01/12/62
2-3-2	3	West Fork of White River	Washington	E. of Fayetteville Airport	T15N-R30W-Sec. 3,4, & 9	03/07/62
2-4-1	3	Richland Creek	Washington	1 mi. N. of Tuttle	T16N-R28W-Sec. 20	28/06/62
2-5-1	12	Brush Creek	Washington	Below Hgwy. 45 bridge	T17N-R28W-Sec. 22	09/11/63
2-6-1	9	Henderson Creek	Madison	At Aurora	T15N-R26W-Sec. 1	19/07/63
2-7-1	22	War Eagle Creek	Madison	At Aurora	T15N-R23W-Sec. 2	17/07/63
2-7-2	5	War Eagle Creek	Madison	At ford 2.5 mi. E. of Huntsville	T16N-R26W-Sec. 1	11/07/63
2-7-3	5	War Eagle Creek	Madison	Above Hgwy. 68 bridge	T17N-R25W-Sec. 19 ,30, & T17N-R26W-Sec. 25	11/06/63
2-7-4	12	War Eagle Creek	Benton	At War Eagle Mills	T18N-R28W-Sec. 19	29/08/62
2-7-5	9	War Eagle Creek	Washington	8 mi. N. of Goshen	T19N-R28W-Sec. 34	07/03/64
2-8-1	5	Kings River	Madison	At Marble below hgwy. 68	T17N-R24W-Sec. 18	23/08/62
2-9-1	63	Buffalo River	Newton	At Ponca	T16N-R22W-Sec. 30	25/07/62
2-9-2	24	Buffalo River	Newton	At Ponca	T16N-R22W-Sec. 30	03/01/64
2-9-3	21	Buffalo River	Searcy	Below mouth of Calf Creek	T15N-R17W-Sec. 3 & T16N-R17W-Sec. 34	02/02/64
2-9-4	90	Buffalo River	Searcy	At Gilbert	T16N-R16W-Sec. 31	29/08/62
2-9-5	97	Buffalo River	Marion	Above mouth of Rush Creek	T17N-R15W-Sec. 11	28/09/62
2-9-6	50	Buffalo River	Marion	Above its mouth	T18N-R14W-Sec. 35 & 36	27/08/64
2-10-1	167	Calf Creek	Searcy	4 mi. SW. of Gilbert	T15N-R17W-Sec. 3 & 10	22 & 28/08/62
2-11-1	59	Devils Fork of Little Red River	Cleburne	3 mi. N. of Brownsville	T12N-R10W-Sec. 33 & 34	22/08/62
2-12-1	16	Matt Creek	Fulton	7 mi. SW. of Mammoth Springs	T20N-R 6W-Sec. 11 & 12	26/08/64
2-13-1	9	South Fork of Spring River	Fulton	3 mi. N. of Salem	T20N-R 8W-Sec. 10 & 11	25/08/64

OUACHITA AND LITTLE RIVER DRAINAGE

Sample Number	Number of Fish		County	Reference	Township Range Section	Collection date
3-1-1	8	Ouachita River	Polk	4 mi. NE. of Mena	T2S-R30W-Sec. 2	15/08/62
3-2-1	2	Glazypeau Creek	Garland	At Mt. Pine	T2S-R20W-Sec. 8	13/07/63
3-3-1	9	Mill Creek	Montgomery	2 mi. NW. of Caddo Gap	T4S-R25W-Sec. 11	13/07/63
3-4-1	35	Little Missouri River	Pike	3 mi. E. of Athens	T5S-R27W-Sec. 16 & 17	20/08/64
3-5-1	53	Mt. Fork of Little River	Polk	4 mi. NW. of Hatfield	T3S-R32W-Sec. 8	14/08/62
3-6-1	29	Cossatot River	Sevier	4.5 mi. SE. of Gillham	T7S-R30W-Sec. 18 & 19	19/08/64
3-7-1	73	Saline River	Howard	7 mi. NW. of Dierks	T6S-R29W-Sec. 33	20/08/64

Table 2. Body-Scale Relationships Used in Other Studies (Lagler, 1952) and Body-Scale Relationships Tested in this Study

Body-Scale Relationships Tested in this Study

$$L = B_1+S$$

$$L = B_1+B_2S$$

$$L = B_1+B_2S+B_3S^2$$

$$L = B_1+B_2S+B_3S^2+B_4S^3$$

$$L = B_1+B_2S+B_3S^2+B_4S^3+B_5S^4$$

$$L = B_1+B_2S+B_3S^2+B_4S^3+B_5S^4+B_6S^5$$

$$L = B_1+B_2S+B_3S^2+B_4S^3+B_5S^4+B_6S^5+B_7S^6$$

$$L = B_1+B_2S+B_3S^2+B_4S^3+B_5S^4+B_6S^5+B_7S^6+B_8S^7$$

$$L = B_1+B_2S+B_3S^2+B_4S^3+B_5S^4+B_6S^5+B_7S^6+B_8S^7+B_9S^8$$

$$L = B_1+B_2S+B_3S^2+B_4S^3+B_5S^4+B_6S^5+B_7S^6+B_8S^7+B_9S^8+ B_{10}S^9$$

L = Body Length

S = Scale Length

B_1 = The Y Intercept

B_2 - B_{10} = Constants

Table 2. (Continued) Body Scale Relationships Used in Other Studies (Lagler, 1952) and Body-Scale Relationships Tested in this Study

Summary of Body-Scale Relationships

Used in the Past

---

1. <u>Direct Proportion Method</u>

$$\frac{\text{Length of scale included in annulus of year X}}{\text{Total length of scale}} = \frac{\text{Length of fish at end of year X}}{\text{Length of fish at time of capture}}$$

2. <u>Dahl-Lea Method</u>

   $L = cS$

3. <u>Lee Method</u>

   $L = a + cS$

4. <u>Sherriff Method</u>

   $L = a + bS + cS^2$

5. <u>Carlander Third-Degree Polynomial Method</u>

   $L = a + bS + cS^2 + dS^3$

L = Body Length

S = Scale Length

a = The Y Intercept (the length of the fish at time of scale formation in pectoral region)

b, c, and d = constants

Table 3. Accumulative Mean Rate of Increase in Length in Millimeters at Nine Constant Temperatures

Date	No. of Days Used in Calculation	Accumulative Mean Rate of Increase in Length Per Day (mm)								
		17°	20°	23°	26°	27°	28°	29°	30°	31°
5/29/64	9	1.44	1.77	1.98	2.09	2.06	2.14	2.15	2.08	2.07
6/10/64	20	0.92	1.23	1.53	1.65	1.69	1.80	1.83	1.78	1.70
6/21/64	31	0.74	died	1.23	1.41	1.42	1.55	1.51	1.51	1.41
7/2/64	42	0.64		1.05	1.15	1.28	1.34	1.35	1.33	1.18
7/10/64	50	0.62		0.94	1.04	1.20	1.26	1.23	1.20	1.17
7/19/64	59	0.55		0.93	0.99	1.11	1.17	1.19	1.16	1.12
7/30/64	70	0.49		0.79	0.88	1.01	1.08	1.10	1.04	1.02
8/11/64	82	0.42		0.73	0.86	0.99	1.04	1.10	1.00	0.96

Table 4. Temperature Choice of 17 Smallmouth Bass in Three Different Temperature Range Setups

* Mainly the two Largest Fish

** The Largest Fish

September 1, Through September 30, 1964
Temperature range from 31.4 to 17.0°C

Compartment No.	1	2	3	4	5	6	7	8
Average Temperatures	31.11	28.81	27.14	25.42	23.81	22.35	20.49	17.0
Total fish observed per compartment	60	68	131	143	44	30	7	18
Ave. No of fish observed per Compt. per day	2*	2.27	4.37	4.77	1.47	1.0	0.23	0.60

October 2, 1964 to October 13, 1964
Temperature range from 35.0 to 20.8°C

Compartment No.	1	2	3	4	5	6	7	8
Average Temperatures	35.0	31.85	29.58	27.69	26.38	25.18	24.21	21.27
Total fish observed per compartment	0	2	10	84	77	9	14	11
Ave. no. of fish observed per compt. per day	0	0.17**	0.83**	6.63	6.42	0.75	1.17	.92

Table 4. (Continued) Temperature Choice of 17 Smallmouth Bass in Three Different Temperature Range Setups

* Mainly the two Largest Fish

** The Largest Fish

October 14, 1964 to October 25, 1964
Temperature range from 38.0 to 26.8°C

Compartment No.	1	2	3	4	5	6	7	8
Average Temperatures	37.75	35.51	33.01	31.23	30.40	29.47	28.93	27.83
Total fish observed per compartment	0	0	0	11	24	67	62	18
Ave. No. of fish observed per compt. per day	0	0	0	1.00**	2.18	6.09	5.63	1.63

Table 5. Length-Frequency Distribution of 1453 Arkansas Smallmouth Bass According to Age Groups and 25 millimeter Intervals of Standard Length at Capture

Length at Capture in Millimeters	Age Group 0	1	2	3	4	5	6	7	8	9	10	Total fish in size group
0-25												
25-50	41											41
50-75	170											170
75-100	86	16										102
100-125	17	151	9									177
125-150	9	168	78	3								258
150-175		28	197	33								258
175-200			127	87	12	2						231
200-225			26	48	20	13	1					108
225-250				18	24	6	3					53
250-275				2	11	7	3	1				24
275-300					1	7	7	2	1			18
300-325			2			4	3	1	2			12
325-350							1	1	1	1		4
350-375								1	1			2
375-400									1			1
Total fish in age group	323	363	439	191	68	39	18	6	6	1		1453

Table 6. Body-Length Scale-Length Relationships for Smallmouth Bass from Various Streams and Locations in Basin 2

Stream	Location	Equation
2-1	2-1-1	$L = 20.69 + 1.49S - .002S^2$
	2-1-2	$L = 18.87 + 1.22S$
	2-1-3	$L = 27.73 + 1.20S$
	2-1-4	$L = 48.47 + 0.91S$
	2-1-5	$L = 37.07 + 1.04S$
	2-1-6	$L = 191.66$*
	2-1-7	$L = 59.45 + 0.58S$
	2-1-8	$L = 47.27 + 0.89S$
2-2		$L = 34.34 + 1.00S$
2-3		$L = 28,44 + 1.05S$
2-4		$L = 200.39$*
2-5		$L = 38.57 + 0.98S$
2-6		$L = 23.36 + 1.09S$
2-7		$L = 19.60 + 1.30S - .0012S^2$
2-8		$L = 31.88 + 1.04S$
2-9	2-9-1	$L = 36.92 + 1.03S$
	2-9-2	$L = 11.54 + 1.54S - .0018S^2$
	2-9-3	$L = 23.23 + 1.22S - .0007S^2$
	2-9-4	$L = 29.23 + 1.04S - .00009S^2$
	2-9-5	$L = 25.02 + 1.16S - .0007S^2$
	2-9-6	$L = 18.55 + 1.36S - .0016S^2$
2-10		$L = 17.28 + 1.53S - .0018S^2$
2-11		$L = 34.04 + 1.03S$
2-12		$L = 43.64 + 0.96S$
2-13		$L = 55.98 + 0.79S$

*Special case where $B_1 = \frac{\Sigma L}{N}$ resulting from a small sample size

Table 7. Body Length-Scale Length Relationships for Smallmouth Bass from Various Streams in Basin 3

Streams	Equations
3-1	$L = 17.24 + 1.03S$
3-2	$L = 123.5$*
3-3	$L = 30.79 + 0.94S$
3-4	$L = 30.49 + 1.02S$
3-5	$L = 11.67 + 1.62S - .004S$
3-6	$L = 30.36 + 1.07S$
3-7	$L = 40.90 + 0.97S$

*Special case where $B_1 = \frac{\Sigma L}{N}$ resulting from a small sample size

Table 8. Analysis of Variance and Mean Square Percents for Growth Rate Differences Among Smallmouth Bass from Basins, Streams, and Locations within Streams for the First Three Years of Growth

** 1% Level of Probability

First Year Growth for all Fish One Year and Older

	S.S.	M.S.	Df	F	Est.M.S.%
Basins	2317.815	1158.906	2	.914	2.31%
Streams	37999.234	1266.641	30	1.018	7.66
Locations	26131.250	1244.345	21	15.650**	42.65
Residuals	86742.780	79.507	1091		47.38

Second Year Growth for all Fish Two Years and Older

	S.S.	M.S.	Df	F	Est.M.S.%
Basins	2976.546	1488.273	2	2.806	1.49%
Streams	15908.281	530.276	30	.537	15.59
Locations	20744.094	987.813	21	9.380**	34.88
Residuals	75714.890	105.305	719		48.04

Third Year Growth for all Fish Three Years and Older

	S.S.	M.S.	Df	F	Est.M.S.%
Basins	344.652	172.326	2	.526	0.93%
Streams	8518.218	327.624	26	.559	9.72
Locations	8203.957	585.997	14	4.242**	26.00
Residuals	40057.543	138.129	290		63.35

Table 9. Duncans New Multiple Range Test of the Differences in First Year Growth as Indicated by Scale Size Among Bass from all Locations in Basin 1.

Location Number	Mean Scale Measurement (mm×57)	Significance
1- 5-1	77.5	
1-13-1	52.5	
1- 9-2	51.6	
1-12-1	50.5	
1- 8-1	49.1	
1- 6-1	47.8	
1-11-1	46.9	
1- 7-1	46.3	
1- 5-2	43.0	
1-10-1	36.7	
1- 2-2	36.0	
1- 3-1	35.5	
1- 4-1	34.8	
1- 2-1	34.7	
1- 9-1	32.2	
1- 4-2	32.0	
1- 1-1	31.4	

Table 10. Duncans New Multiple Range Test of the Differences in Second Year Growth as Indicated by Scale Size Among Bass from all Locations in Basin 1

Location Number	Mean Scale Measurement (mm×57)	Significance			
		1	2	3	4
1- 7-1	69.2	x			
1-13-1	60.6	x	x		
1- 6-1	59.7	x	x		
1- 9-2	49.1		x	x	
1-10-1	48.9		x	x	x
1-11-1	47.6		x	x	x
1-12-1	46.3		x	x	x
1- 8-1	44.6		x	x	x
1- 3-1	44.3		x	x	x
1- 4-1	41.7			x	x
1- 2-2	40.4			x	x
1- 4-2	39.3			x	x
1- 5-2	38.0			x	x
1- 1-1	38.0			x	x
1- 2-1	36.8			x	x
1- 9-1	30.2				x
1- 5-1	25.0				x

Table 11. Duncans New Multiple Range Test of the Differences in Third Year Growth as Indicated by Scale Size Among Bass from all Locations in Basin 1 from which Three Year Old Fish were Collected

Location Number	Mean Scale Measurement (mm×57)	Significance
1- 1-1	51.0	
1- 2-2	47.5	
1- 5-1	44.0	
1-10-1	42.0	
1- 4-1	41.6	
1- 9-1	38.0	
1-11-1	33.0	
1- 6-1	32.1	
1- 4-2	32.1	
1- 8-1	31.3	
1- 2-1	30.5	
1- 3-1	27.0	
1- 7-1	24.7	

Table 12. Growth Summary of Smallmouth Bass from 32 Arkansas Streams and One Missouri Stream

Average Calculated Standard Length at end of Year (mm)

Location	1	2	3	4	5	6	7	8	Total No.
Basin 1									
1-1-1	57.0	119.3	190.4	255.6					5
1-2-1	60.0	121.4	177.7	222.5	268.8	320.3	371.8	414.6	10
1-2-2	60.8	124.9	193.8	258.8	319.9	375.0			71
1-3-1	60.4	127.2	180.5	237.2	292.2				6
1-4-1	59.9	124.9	189.9	244.9	295.5	345.1	392.3	439.6	34
1-4-2	57.6	120.9	178.6	232.8	283.0	331.7	382.6	421.3	32
1-5-1	82.7	134.2							2
1-5-2	65.9	128.2							3
1-6-1	69.2	145.0	202.8						8
1-7-1	68.2	148.2							5
1-8-1	70.0	137.2	194.2	255.0					31
1-9-1	58.0	114.1	176.4						12
1-9-2	71.5	141.5							9
1-10-1	61.4	131.2	196.4	261.7	308.5				28
1-11-1	68.6	137.7	196.1	259.2					37
1-12-1	70.5	138.1	197.6	265.5					29
1-13-1	71.7	148.0	199.4						10

Underlined figures: less than 9 fish

Table 12. (Continued) Growth Summary of Smallmouth Bass from 32 Arkansas Streams and One Missouri Stream

Average Calculated Standard Length at end of Year (mm)

Location	1	2	3	4	5	6	7	8	Total No.
Basin 2									
2-1-1	48.4	96.8	140.9	187.4	234.9				25
2-1-2	69.2	142.9							5
2-1-3	68.2	140.9	191.4						6
2-1-4	85.3	184.3	284.5						12
2-1-5	64.1	151.1							6
2-1-6									3
2-1-7	93.8	182.8							9
2-1-8	104.7	258.4							5
2-2-1	86.5	170.6	241.5						20
2-3-1	62.7	127.6	188.6						3
2-3-2	68.9	133.5	190.3	254.9	309.6				6
2-4-1									3
2-5-1	74.7	153.6	236.3	330.4	422.9	520.2			11
2-6-1	70.4	141.6	197.7	251.6					9
2-7-1	76.6	157.7	230.3	304.2	375.1	460.9			22
2-7-2	76.8	155.6	195.6						4
2-7-3	83.7	168.6	256.3						5
2-7-4	74.8	160.6							6
2-7-5	72.9	151.4	237.1	311.9					9

Underlined Figures: less than 9 fish

Table 12. (Continued) Growth Summary of Smallmouth Bass from 32 Arkansas Streams and One Missouri Stream

Average Calculated Standard Length at End of Year - (mm)

Location	1	2	3	4	5	6	7	8	Total No.
(Basin 2 (continued)									
2-8-1	63.6	146.4	220.9						4
2-9-1	61.1	134.8	186.7	239.8	331.0				53
2-9-2	85.2	169.7	252.8	330.9					21
2-9-3	79.3	156.3	224.9	295.7	375.1	463.0	547.2	619.03	14
2-9-4	84.2	167.1	234.8	305.6	381.6				59
2-9-5	81.1	169.0	245.7	323.2	396.6	453.0	503.0	552.0	54
2-9-6	90.0	172.3	244.1	311.7	369.5	431.5			31
2-10-1	72.7	159.9	239.1	311.1	396.1				143
2-11-1	72.8	155.7	227.3						52
2-12-1	81.0	165.1	241.5						12
2-13-1	87.1	182.3							9
Basin 3									
3-1-1	49.2	104.3	154.3	212.7	237.7				6
3-2-1									2
3-3-1	81.5	163.0	243.0						9
3-4-1	72.1	145.5	211.4	274.0					29
3-5-1	66.3	141.4	209.6	259.3					46
3-6-1	83.9	164.1	234.9	294.2					28
3-7-1	84.1	168.7	234.2						72

Underlined figures: less than 9 fish

Table 13. Estimates of Ultimate Lengths with Confidence Intervals for Bass Grown in the Laboratory at Eight Constant Temperatures (Estimates of Ultimate Lengths and Confidence Intervals are Based on Means of Ten-Fish Samples)

Constant Temperature degrees centigrade	Estimate of A (Ultimate Length) Millimeters	Confidence Bounds on A Millimeters
17	54.4	50.7 ≤ A ≤ 58.1
23	70.0	66.0 ≤ A ≤ 74.0
26	79.9	74.2 ≤ A ≤ 85.5
27	117.6	108.2 ≤ A ≤ 127.0
28	117.4	108.1 ≤ A ≤ 126.4
29	114.6	104.8 ≤ A ≤ 124.3
30	117.9	108.2 ≤ A ≤ 127.3
31	111.4	102.5 ≤ A ≤ 121.0

Table 14. Comparison of Ages of Smallmouth Bass
Taken by Five Collecting Techniques

Age Group

	0	1	2	3	4	5	6	7	8	9	Total Fish
Conventional Sein			40%	40%	20%						5
Rotenone	59%	13%	21%	3%	2%	0.4%	0.7%	0.4%	0.4%		276
Phenol		40%	60%								5
Electro-Shocking	14%	26%	30%	14%	7%	6%	2%	0.6%	0.5%	0.1%	617
Conventional Hook & Line & Bait Seining	14%	30%	35%	15%	5%	0.7%	0.3%				556
											1459

Figure 1. Fish Utilization Chart

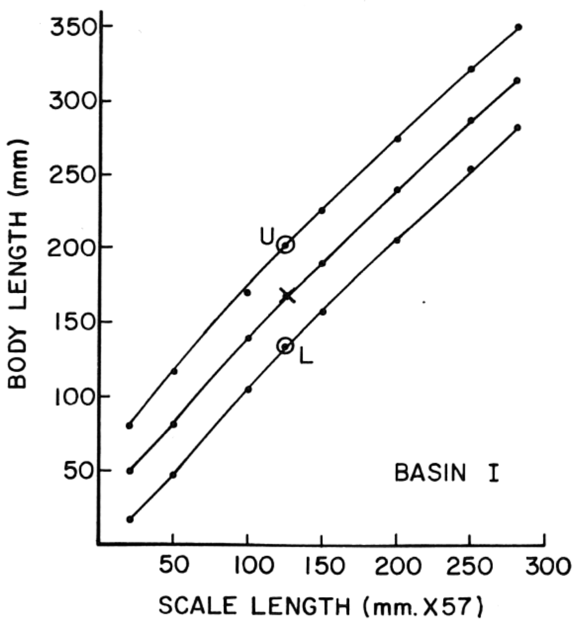
Each lot of bass is identified by the constant temperature at which it was raised. Each lot originally contained 35 fish.

Constant Temperature ($^{\circ}C$)

Date	17,20,& 23	26	27	28	29	30	31
May 21	35 fish	35 fish	35 fish	35 fish	35 fish	35 fish	35 fish
June 11	all fish at 20° died						
June 25		15 fish preserved	15 fish preserved	15 fish preserved	15 fish preserved	15 fish preserved	15 fish preserved
Aug. 10	all fish preserved	5 fish preserved 10 smallest fish	8 fish preserved 4 smallest fish	3 fish preserved 17 fish <u>temp.choice exp.</u> ↓ 7 fish <u>Starvation Exp.</u>	6 fish preserved 12 fish Grown to large size at 28°C	15 fish used in <u>darkness exp.</u> 4 smallest fish	14 fish preserved 2 smallest fish

Used in <u>Small annulus production exp.</u>

Figure 2. Confidence Belts (Based Upon Large Sample Size) About the Body-Length Scale-Length Relationship for Bass from Basin 1 and Calf Creek. (X) is the point ($\bar{X}$ $\bar{Y}$), (U) is the upper confidence bound, and (L) is the lower confidence bound.


350
300
250
200
150
100
50
BODY LENGTH (mm)
U
L
BASIN I
50
100
150
200
250
300
SCALE LENGTH (mm. X57)

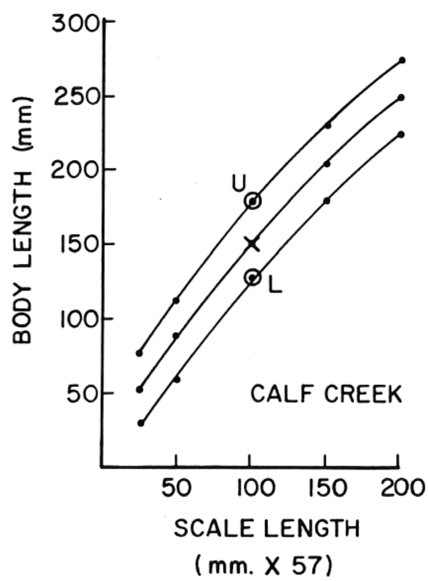
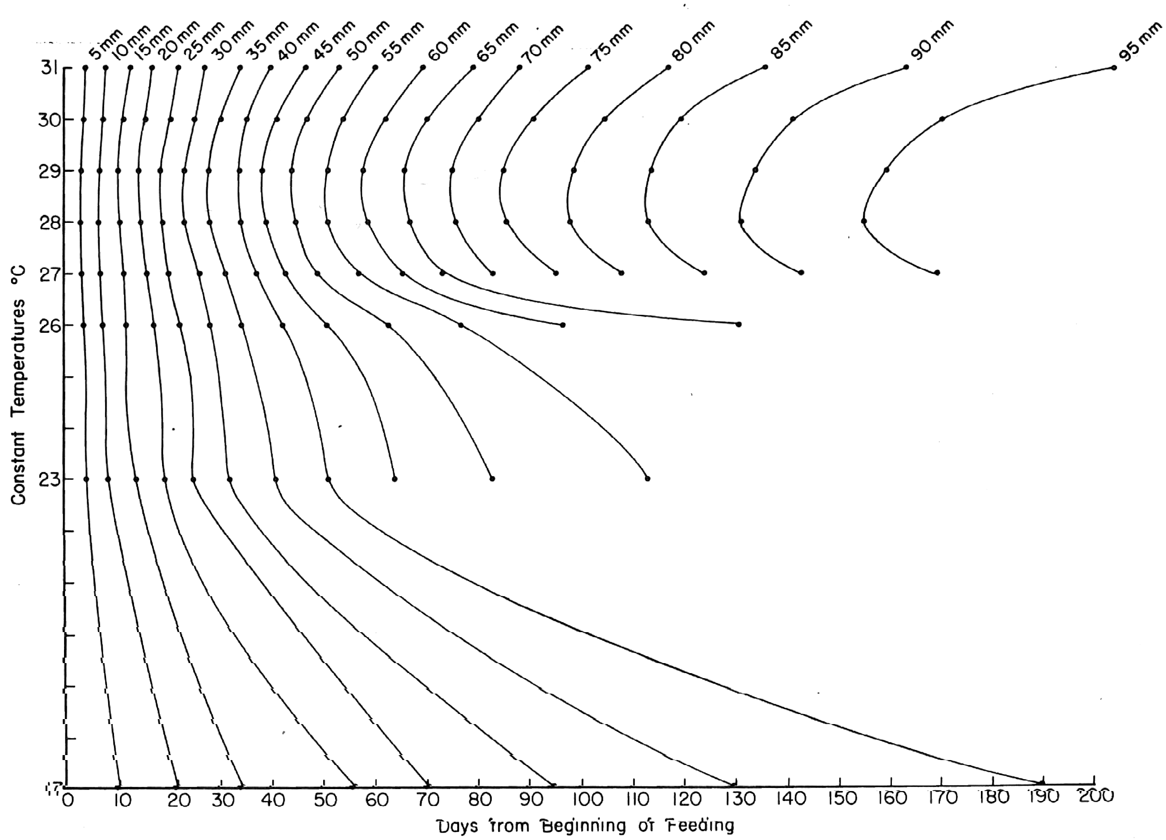

300
250
200
150
100
50
BODY LENGTH (mm)
U
L
CALF CREEK
50
100
150
200
SCALE LENGTH
(mm. X 57)

Figure 3. Response Surface Diagram of Growth of Smallmouth Bass Fingerlings at Eight Constant Temperatures. Contour lines represent gain in length over 9.65 mm (the average length at zero days, the beginning of feeding). All bass were hatched and maintained at 23.0° C prior to the start of feeding.



5 mm
10 mm
15 mm
20 mm
25 mm
30 mm
35 mm
40 mm
45 mm
50 mm
55 mm
60 mm
65 mm
70 mm
75 mm
80 mm
85 mm
90 mm
95 mm
Constant Temperatures °C
31
30
29
28
27
26
23
17
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
Days from Beginning of Feeding

Figure 4. The Effect of Diet and Water Temperatures upon the Growth Rates of Laboratory-Raised Smallmouth Bass. The diets indicated were as follows: (1) brine shrimp; (2) mosquito larva supplemented by daphnia; (3) period of diet change; (4) earth worms supplemented by varying quantities of mosquito larva (17° and 20° bass received only brine shrimp and mosquito larva. The diet 23° bass received was changed to earth worm on July 6th.

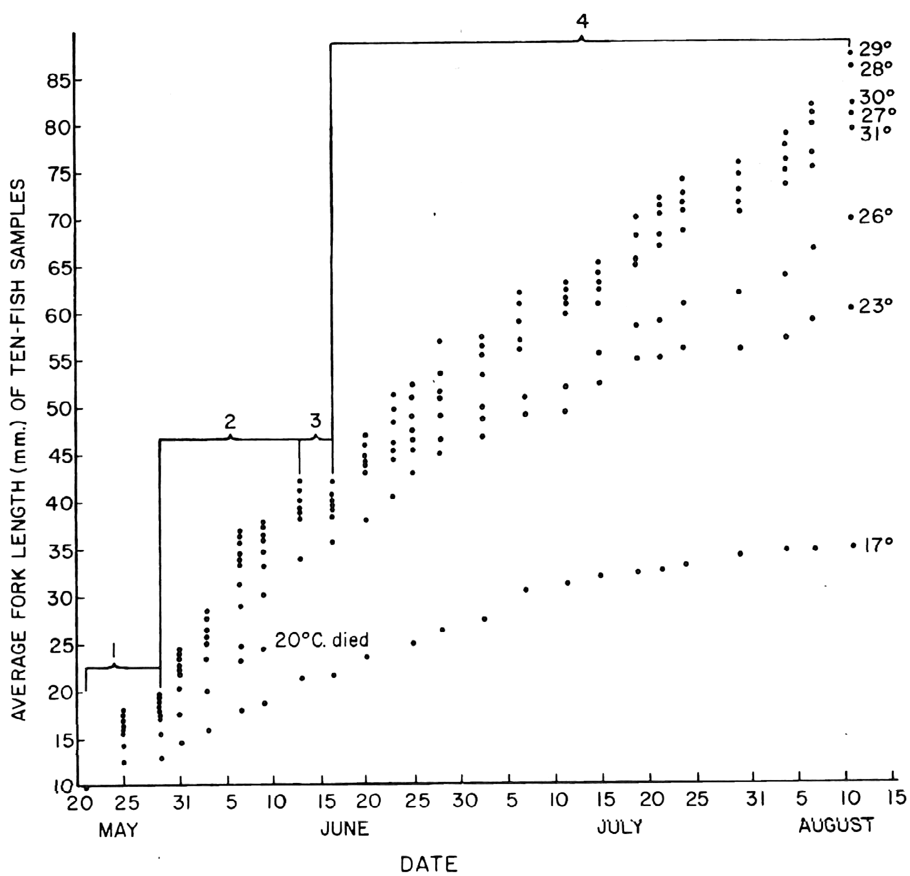
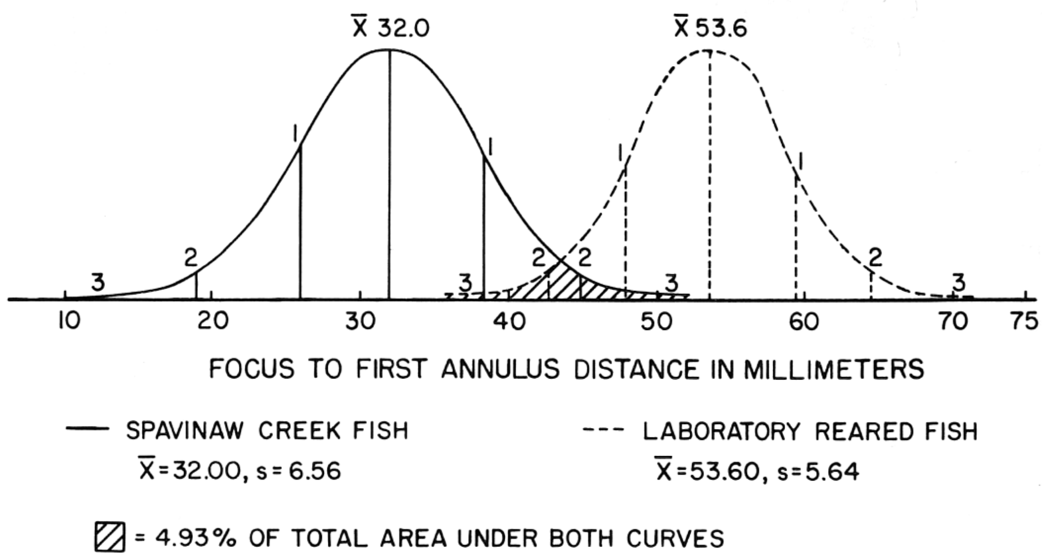

AVERAGE FORK LENGTH (mm.) OF TEN-FISH SAMPLES
DATE
MAY
JUNE
JULY
AUGUST
20°C. died
29°
28°
30°
27°
31°
26°
23°
17°
1
2
3
4

Figure 5. Normal Distribution of the Measurements in millimeters from the Focus to the First Annulus of Scales from Spavinaw Creek (1-4-2) and "Scale Marked" Laboratory-Raised Smallmouth Bass



X̄ 32.0
X̄ 53.6
1
1
1
1
2
2
2
2
2
3
3
3
3
10
20
30
40
50
60
70
75
FOCUS TO FIRST ANNULUS DISTANCE IN MILLIMETERS
SPAVINAW CREEK FISH
X̄=32.00, s=6.56
--- LABORATORY REARED FISH
X̄=53.60, s=5.64
= 4.93% OF TOTAL AREA UNDER BOTH CURVES

Plate 1a

Photograph of a typical scale taken from a smallmouth bass "scale marked" (using low temperature) with a large focus to first annulus distance.

(Magnified 26 times)

Plate 1b

Photograph of a typical scale taken from a smallmouth bass "scale marked" (using low temperature) with a small focus to first annulus distance
(Magnified 26 times)

Plate 1c

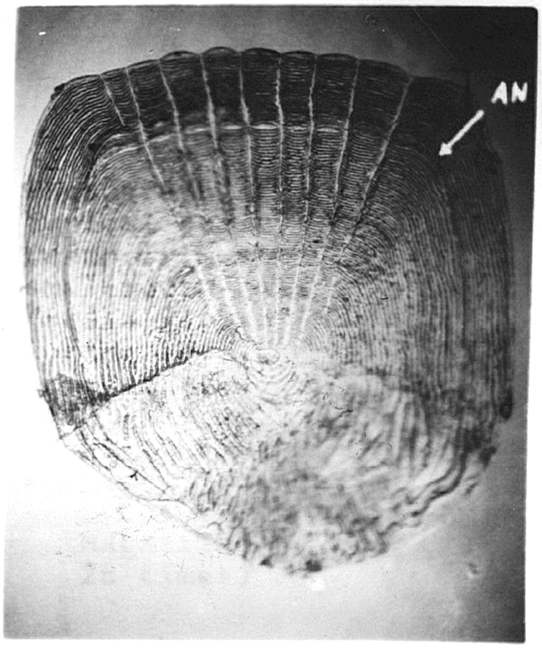
Photograph of a typical scale taken from a smallmouth bass which had been "scale marked" by being starved for two weeks.

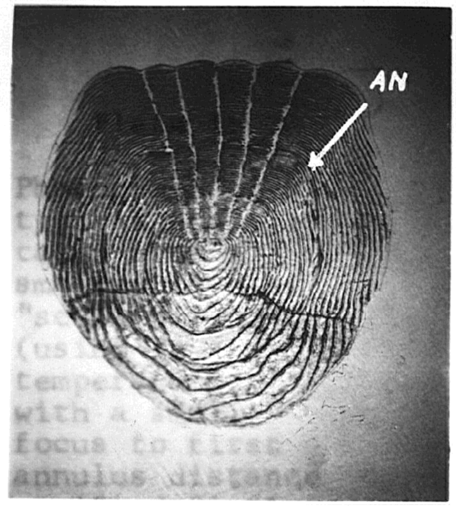
(Magnified 26 times)

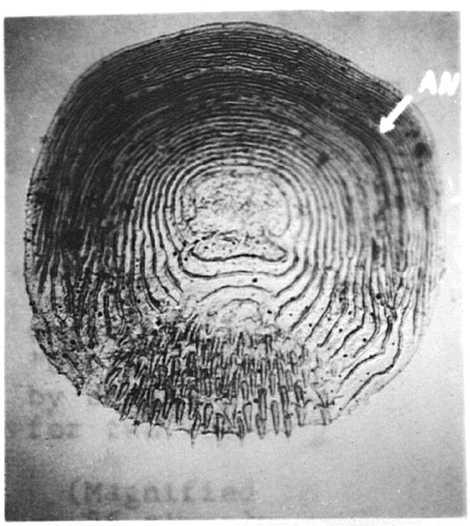
Plate 1d

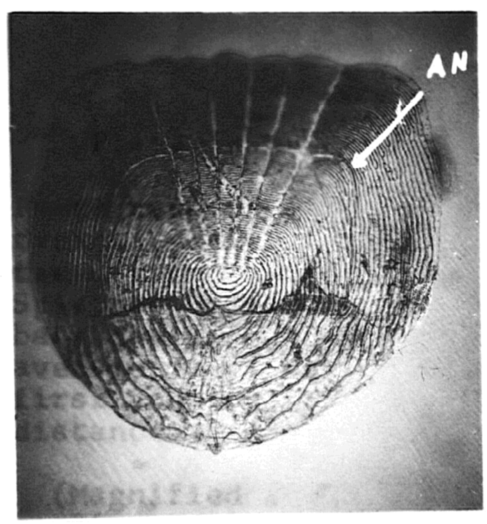
Photograph of a typical scale taken from a wild Spavinaw Creek bass having an average focus to first annulus distance.

(Magnified 26 times)


AN


AN


AN


AN

APPENDIX

Appendix A. Analysis of Variance and Mean Square Percents for Growth Rate Differences Among Smallmouth Bass from Basins, Streams, and Locations on Streams for Years Four through Eight

* 5% Level of Probability

** 1% Level of Probability

Fourth Year Growth for all Fish Four Years and Older

	S.S.	M.S.	Df	F	Est.M.S.%
Basins	2340.619	1170.309	2	5.516*	11.99%
Streams	3394.312	212.144	16	.437	9.05
Locations	4368.875	485.430	9	5.090**	29.60
Residual	11537.496	95.351	121		49.35

Fifth Year Growth for all Fish Five Years and Older

	S.S.	M.S.	Df	F	Est.M.S.%
Basins	3867.886	1933.943	2	10.399**	41.53%
Streams	1487.744	185.968	8	.818	.94
Locations	1363.715	227.285	6	1.702	6.29
Residual	7743.640	133.511	58		51.26

Sixth Year Growth for all Fish Six Years and Older

	S.S.	M.S.	Df	F	Est.M.S.%
Basins	2125.226	2125.226	1	9.992	52.362%
Streams	638.036	212.678	3	1.298	11.337
Locations	655.161	163.790	4	2.472	10.074
Residual	1523.575	66.242	23		26.226

Seventh Year Growth for all Fish Seven Years and Older

	S.S.	M.S.	Df	F	Est.M.S.%
Basins	360.577	360.577	1	23.076	34.672%
Streams	15.625	15.625	1	.085	20.750
Locations	366.508	183.254	2	2.965	19.438
Residual	494.366	61.795	8		25.137

Eighth Year Growth for all Fish Eight Years and Older

	S.S.	M.S.	Df	F	Est.M.S.%
Basins	988.128	988.128	1	197.432*	87.257%
Streams	0.050	0.050	1	0.118	5.381
Locations	84.750	42.375	2	9.970	6.306
Residual	8.499	4.250	2		1.054

Appendix B. Points for Plotting Body-Length Scale-Length Relationships with their Respective Confidence Belts for all Bass Used in this Study. Confidence Belts were Calculated Assuming Large Sample Size.

Scale Meas. (millimeters)		Mean Fish Length (millimeters)		Lower Conf. Bound	Upper Conf. Bound
Basin 1					
$\bar{X}$	128	$\bar{Y}$	169.5	134.8	204.2
	50		83.9	49.0	118.8
	100		139.7	104.9	174.4
	150		192.3	157.5	227.0
	200		241.7	206.9	276.5
	250		288.0	252.8	323.2
White River at St. Paul (2-1-1)					
$\bar{X}$	98	$\bar{Y}$	137.5	102.7	172.2
	50		90.0	67.5	112.2
	100		148.7	126.5	170.8
	150		196.9	174.6	219.3
	200		234.8	209.4	260.2
White River at Patrick, 1962 (2-1-3)					
$\bar{X}$	77	$\bar{Y}$	122.9	100.9	144.9
	50		87.8	62.9	112.7
	100		147.8	123.3	172.4
	130		183.9	155.8	211.9
White River at Patrick, 1963 (2-1-4)					
$\bar{X}$	109	$\bar{Y}$	148.7	118.4	178.9
	50		94.4	61.1	127.8
	100		140.4	110.1	170.7
	145		181.1	150.4	213.7
White River at Thompson (2-1-5)					
$\bar{X}$	65	$\bar{Y}$	104.7	68.9	140.4
	50		89.1	52.2	125.9
	100		141.1	100.0	182.1
	110		151.5	107.3	195.7
White River at Durham (2-1-6)					
$\bar{X}$	157	$\bar{Y}$	191.6	173.0	210.2
	135		179.8	157.1	202.5
	150		187.9	168.8	206.9
	170		198.6	178.5	218.8

Appendix B. (Continued)

White River at Lost Bridge (2-1-7)

	Scale Meas. (millimeters)		Mean Fish Length (millimeters)	Lower Conf. Bound	Upper Conf. Bound
$\bar{X}$	129	$\bar{Y}$	157.3	136.1	178.4
	110		146.3	123.5	169.0
	120		152.1	130.5	173.6
	130		157.9	136.7	179.0
	140		163.7	141.5	184.7

Bull Shoals Reservoir (2-1-8)

$\bar{X}$	154	$\bar{Y}$	185.0	165.5	204.5
	100		136.7	116.8	156.6
	150		181.4	161.9	200.9
	200		226.1	206.3	245.9
	250		270.8	250.1	291.6
	300		315.6	293.3	337.8

Middle Fork White (2-2)

$\bar{X}$	110	$\bar{Y}$	175.7	155.9	195.5
	70		126.5	105.5	147.5
	100		164.6	144.8	184.3
	150		212.9	192.5	233.3

West Fork White (2-3)

$\bar{X}$	91	$\bar{Y}$	124.4	110.4	138.5
	50		81.2	66.8	95.5
	100		133.9	119.9	148.0
	150		186.7	171.9	201.4

Brush Creek (2-4)

$\bar{X}$	154	$\bar{Y}$	189.6	157.1	222.1
	100		136.6	103.5	168.9
	200		234.7	201.8	267.7
	300		332.8	295.9	369.8

Henderson Creek (2-5)

$\bar{X}$	129	$\bar{Y}$	165.0	45.9	284.2
	100		133.2	6.4	259.9
	120		155.1	35.2	275.1
	140		177.1	56.9	297.3
	160		199.1	71.7	326.5

Appendix B. (Continued)

War Eagle Creek (2-7)

Scale Meas. (millimeters)		Mean Fish Length (millimeters)		Lower Conf. Bound	Upper Conf. Bound
$\bar{X}$	115	$\bar{Y}$	153.1	115.7	190.5
	50		81.6	43.5	119.7
	150		187.2	149.7	224.8
	250		268.0	225.0	311.1

KingsRiver (2-8)

$\bar{X}$	118	$\bar{Y}$	155.1	120.2	190.0
	50		84.1	44.3	123.9
	100		136.3	101.1	171.6
	150		188.6	152.6	224.6

Buffalo Ponca, 1962 (2-9-1)

$\bar{X}$	109	$\bar{Y}$	158.3	137.2	179.3
	50		84.2	62.9	105.5
	100		147.8	126.8	168.8
	150		202.3	181.2	223.4
	200		247.7	225.6	269.7

Buffalo Ponca, 1964 (2-9-2)

$\bar{X}$	117	$\bar{Y}$	158.5	135.2	181.8
	50		88.8	64.6	113.1
	100		140.8	117.4	164.2
	150		192.8	169.3	216.3
	185		229.1	204.9	253.4

Buffalo Calf Creek (2-9-3)

$\bar{X}$	164	$\bar{Y}$	203.9	180.3	227.5
	50		82.5	58.3	106.7
	150		190.0	166.5	213.5
	250		282.8	259.0	306.6

Buffalo at Gilbert (2-9-4)

$\bar{X}$	113	$\bar{Y}$	146.7	123.3	107.2
	50		81.5	58.0	105.1
	150		184.4	161.9	208.9
	250		291.3	266.2	316.4

Appendix B. (Continued)

Buffalo at Rush (2-9-5)

Scale Meas. (millimeters)		Mean Fish Length (millimeters)		Lower Conf. Bound	Upper Conf. Bound
$\bar{X}$	80	$\bar{Y}$	113.8	93.8	113.9
	100		134.1	114.6	154.8
	200		231.0	210.8	251.3
	300		313.9	292.8	335.0

Buffalo at Mouth (2-9-6)

$\bar{X}$	117	$\bar{Y}$	154.0	132.0	176.1
	50		82.1	60.0	104.2
	100		137.2	115.2	159.3
	150		183.0	161.8	205.9
	200		222.0	199.8	244.2

Calf Creek (2-10)

$\bar{X}$	100	$\bar{Y}$	152.2	128.4	176.0
	50		89.4	65.5	113.3
	100		152.2	128.4	176.0
	150		206.7	181.9	229.6
	200		250.0	225.5	274.4

Devils Fork (2-11)

$\bar{X}$	105	$\bar{Y}$	147.9	132.1	163.6
	40		66.6	50.2	83.0
	50		81.2	65.3	97.2
	100		142.8	127.0	158.5
	150		185.0	169.1	200.9

Matt Creek (2-12)

$\bar{X}$	112	$\bar{Y}$	151.4	132.6	170.3
	65		106.2	86.2	126.2
	100		139.9	120.9	158.9
	150		188.0	168.4	207.7

South Fork Spring River (2-13)

$\bar{X}$	106	$\bar{Y}$	139.8	111.2	168.4
	70		111.3	79.7	142.9
	100		135.1	106.3	163.8
	140		166.7	135.6	197.9

Appendix B. (Continued)

Ouachita River (3-1)

	Scale Meas. (millimeters)		Mean Fish Length (millimeters)	Lower Conf. Bound	Upper Conf. Bound
$\bar{X}$	111	$\bar{Y}$	132.2	55.5	208.8
	50		69.0	13.2	151.2
	100		120.8	43.9	197.6
	150		172.6	93.7	251.5

Mill Creek (3-3)

	Scale Meas. (millimeters)		Mean Fish Length (millimeters)	Lower Conf. Bound	Upper Conf. Bound
$\bar{X}$	150	$\bar{Y}$	172.9	144.6	201.1
	100		125.5	96.0	155.0
	150		172.9	144.6	201.1
	200		220.2	190.9	249.6

Little Missouri River (3-4)

	Scale Meas. (millimeters)		Mean Fish Length (millimeters)	Lower Conf. Bound	Upper Conf. Bound
$\bar{X}$	107	$\bar{Y}$	140.0	125.2	154.9
	50		81.7	66.5	96.8
	100		132.9	118.0	147.7
	150		184.1	169.1	199.1

Mountain Fork of Little River (3-5)

	Scale Meas. (millimeters)		Mean Fish Length (millimeters)	Lower Conf. Bound	Upper Conf. Bound
$\bar{X}$	48	$\bar{Y}$	82.7	62.7	102.7
	30		57.7	37.7	77.6
	40		71.8	51.8	91.8
	50		85.4	65.4	105.4
	60		98.3	78.4	118.3