

INVESTIGATING THE VALIDITY OF THE SCALE METHOD
IN DETERMINING THE GROWTH OF TWO SPECIES
OF FISH IN OKLAHOMA AND ITS RELATION
TO TEMPERATURE AND WATER LEVEL

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CHAPTER I

INTRODUCTION

Scientists became interested in the structure of the fish scales in the seventeenth century after the invention of the microscope. The first record relative to the growth of scales is found in the letters of Leeuwenhoek (1686) (cited by Van Oosten, 1929) in which he described the appearance of the scale of an eel. DeReaumur (1718) (cited by Van Oosten, 1929) was the first to propose using scales for age determination of fish. However, the use of scales to determine the age of fish did not become a common practice until the late 19th century, after Hoffbauer (1898) (cited by Van Oosten, 1929) indicated that the age of carp could be determined by the examination of their scales. In this country many authors have used the scale method in age determination but this technique did not become firmly established until Van Oosten (1929) published his work on the lake herring of Lake Huron. For good reviews of the early work see Van Oosten, 1929; Taylor, 1916; and Creaser, 1926. Unfortunately, the scale method was used in subsequent years by many workers for age determination of fish without critical analysis of the method itself. Van Oosten (1941, p. 196-197) wrote:

"Our investigators have woefully neglected to make critical studies of the scale method, although it has been widely used throughout the North American Continent. It is a sad commentary on the attitudes of our investigators that although age determinations of at least sixty fresh-water species have been published in this country and Canada, by more than 80 authors, in more than 150 papers, in only some half dozen

publications did the authors attempt to evaluate critically the scale method as it applied to the species studied by them."

The situation has improved since 1941, but it is unfortunate that most authors still neglect such critical analyses or depend on only one or two criteria for the assumption of the validity of their scale readings. Critical study is still needed for many species and all age and growth studies should include evidence as to the validity of the method applied.

Fishery biologists also have concerned themselves with the annual growth of the fish, neglecting the importance of the rate of growth within the growing season, which may be important in the regulation and the harvest of the fishery. Studies of changes in growth rate within a year can be of great value in predicting the time of the year when the maximum biomass of the population is reached (Beyerle and Cooper, 1966).

Water level is one of the factors that might have a direct effect on the growth of fish; or indirectly, by affecting the abundance of food organisms (Van Oosten, 1944). Stroud (1949) also stated that fluctuation in water level might influence the growth of fish. Biologists became interested in the effect of high and low water levels in relation to fish and fish food, but the relation between water level and the growth of fish has been based mostly on speculation, rather than on empirical data. Authors who attempted to explain the growth rates in relation to meteorological conditions found no information regarding the relationship between growth and environmental factors (Latta, 1963).

The first serious attempt to relate water level to fish growth was that of Keeton (1963). Unfortunately, Keeton concerned himself with

many species of fish on which data were not abundant. He also used the length frequencies in detecting the growth of some species rather than the scale method. In the species for which he collected sufficient numbers of scales, the river carpsucker, he questioned the accuracy of some of his age and growth computations. However he concluded that growth seemed to be unrelated to fluctuations in water level.

The effect of temperature on the growth of fish has been appreciated by biologists for a long time (Belding, 1928). However, the relationship established has been in regard to the growth of fish in waters of different thermal regions (Purkett, 1951; Gunther, 1950) rather than the effect of temperature on the seasonal growth of the fish in a single body of water. The specific growth rate (growth increment per unit of time) of fish in relation to temperature has been demonstrated only in laboratory studies and mostly on salmonoids (Brown, 1946a and 1946b; Grahm, 1949; Sullivan, 1945; and Swift, 1955 and 1961).

The objective of this study was to explore the relationship between the growth rate of two species of fish during the growing season and fluctuations in temperature and water level in an Oklahoma impoundment. In order to accomplish these goals, it was necessary to validate the scale method for aging the fish.

This project is the first age and growth study conducted on the fishes of Keystone Reservoir; it furnishes basic information about the growth of fish in the early years of the reservoir and will allow a comparison with similar data in future studies:

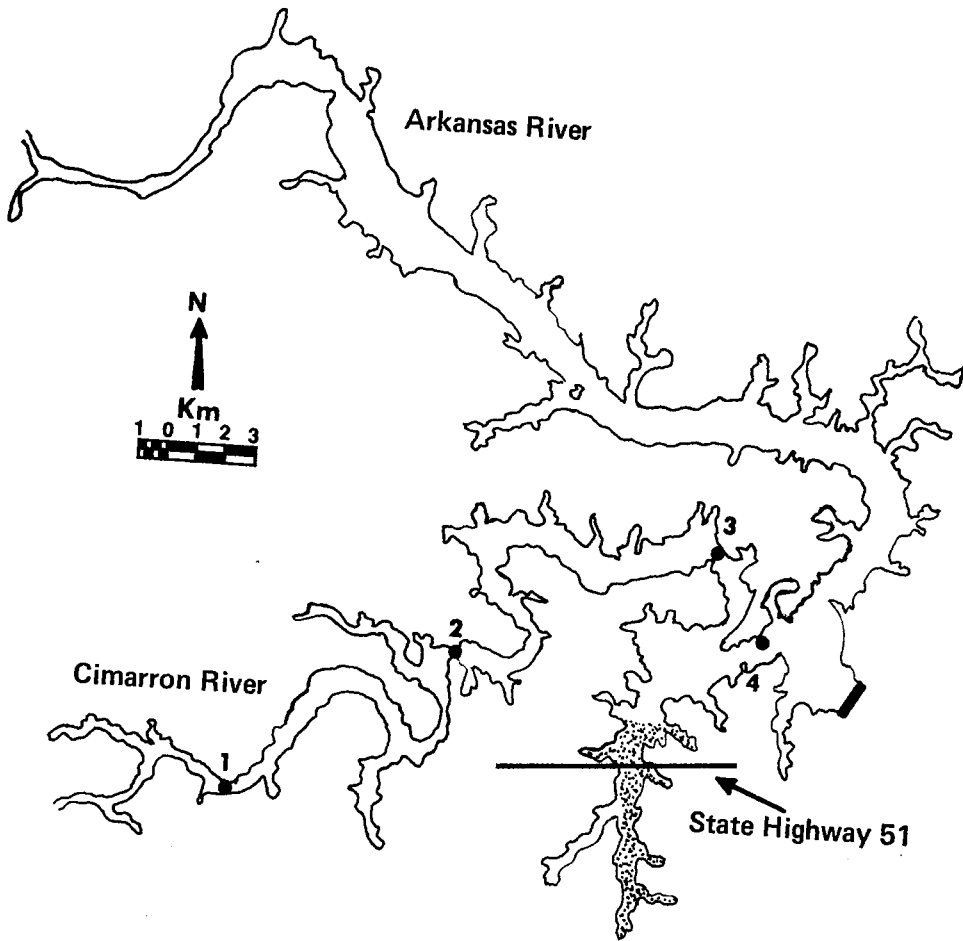
CHAPTER II

KEYSTONE RESERVOIR, THE STUDY AREA

Keystone Lake is a multipurpose reservoir built by the U. S. Corps of Engineers for flood control, hydroelectric power generation, recreation, and navigation purposes. The reservoir was formed by impounding the Cimarron and the Arkansas Rivers at their confluence, approximately 20 km upstream from Tulsa, Oklahoma. The actual filling of the reservoir began in 1964, and reached 726.80 feet msl (221 m) on November 20th of the same year. Normal pool level in the reservoir is 723 feet msl (220 m). The reservoir has a surface area of $106 \times 10^6 \text{ m}^2$, a mean depth of 7.7 m, a maximum depth of 22.9 m and a shoreline of 531 km at normal power pool level. Because of the large size of the reservoir, the sampling area was limited to the Salt Creek Cove of the lake which extends about 4 km south and 2 km north of State Highway 51 (Figure 1). This cove has a surface area of $10 \times 10^6 \text{ m}^2$.

This reservoir was chosen for the study because sampling could be conducted by a team. Graduate students working on various projects involving fish sampling assisted each other in data collection. This team effort also allowed comparison of sampling methods with those used by other students to determine whether the gear used in sampling were selective. Several students were also studying aspects of limnology, community structure and water chemistry of the reservoir and their findings were of value in explaining the results of this study.

Figure 1. Keystone Reservoir, Oklahoma. Dotted area indicates sampling area. Arabic numerals indicate sampling stations of Eley, Carter and Dorris (1968).



Concurrent to these efforts, the Army Corps of Engineers monitored the water level and the U. S. Geological Survey recorded daily air temperatures. Dr. Rex Eley studied the physiochemical limnology during this study and his data are especially useful in interpreting the present data.

CHAPTER III

MATERIALS AND METHODS

Collection of Specimens

During the summer and early autumn of 1966 and 1967, field data (scale samples, length, and weight) were collected for two species of fish, gizzard shad, Dorosoma cepedianum and white crappie, Pomoxis annularis. In 1966, 459 crappie were collected and examined between August 1 and September 30, and 1,524 gizzard shad were collected between July 1 and September 30. In 1967, 1,347 crappie and 2,443 shad were collected and examined between June 1 and September 30.

The gizzard shad were collected, by a crew of two people, using a 230 volt A. C. electric shocker. One man guided the boat while the other was engaged in dipping stunned fish. Because shad move in schools, an attempt was made to sample the entire shoreline of the entire cove to assure obtaining an adequate sample.

Data for each species were divided into samples, each sample included the collections of a half-month period. Average increase in growth for each sample was determined to test the effect of fluctuation in water level and temperature on the growth rate; also, to test consistency in average calculated length and the consistency in abundance or scarcity of year classes.

Two or three collections were made weekly except during the first half of July, 1967. During that period only one shad collection was made due to a breakdown of the electric generator.

Crappie were collected with barrel nets. Eight barrel nets were used in 1966 and 14 nets were used in 1967. These were set at depths of 2 to 7 m. Sampling area is shown in Figure 1.

Electric shocking is not selective for or against gizzard shad of different sizes. Fish which were collected with gill nets, placed in a Latin-square design with mesh size of $3/4$, $1\frac{1}{2}$, 2, $2\frac{1}{2}$, and 3 inches by Neil Carter, more or less concurrently, showed that the size range for gizzard shad was from 4 to 14 inches (101.6 to 355.6 mm) but most individuals were in the 5 to 7 inch (127.0 to 177.8 mm) range (Eley, Carter and Dorris, 1968). In this study the size range of this fish is 44 to 282 mm with an average total length (exclusive of age group 0) of 162.9 mm in 1966 and 151.7 mm in 1967.

Barrel nets seem to be selective against fish less than 100 mm in length. In the present study, the size range of crappie is 104 to 395 mm with an average length of 140.2 mm in 1966 and 153.4 mm in 1967. White crappie data collected with gill nets by Carter had similar ranges of 4 to 7 inches (101.6 to 177.8 mm).

Measurements and Scale Preparation

During collection, captured fish were placed in a tub of water until they could be examined. All fish were released, except for the crappie from which stomach samples were taken in 1967. All measurements were taken on live fish, therefore avoiding difficulties of weight increases following death of the fish (Larimore, 1952). Weight

was recorded to the nearest gram. Total length was recorded to the nearest millimeter.

Between 2 and 15 scales were taken with a pocket knife from the anterior part of the body just under the tip of the pectoral fin and just below the lateral line. Scales were taken from 450 crappie in 1966, 1,338 crappie in 1967, 1,408 shad in 1966 and 1,698 shad in 1967. The right side was used for taking scales in most cases, but if the scales were regenerated in this location, the same area of the left side of the fish was used. To avoid the accidental mixing of scale samples, the knife was rinsed after the scales had been taken from each fish.

Scale Analysis

Impressions of crappie scales were made on clear plastic strips, using a roller press similar to that described by Smith (1954). Impressions of regenerated scales were avoided as much as possible by examining the scales under a magnifying lens before being selected. The scale impressions were then projected by a scale projector at a magnification of 80X.

An unsuccessful attempt was made to make impressions of shad scales in plastic, particularly for scales of young fish. The technique ultimately adapted was that of making temporary wet mounts. Shad scales were placed in watch glasses filled with water and allowed to soak overnight. Two persons were needed for wet mount preparation. One individual prepared the wet mounts by placing the scales between two glass microslides and handed them to the author who projected and read the scales on a scale projector at a magnification of 80X.

In all cases, more than one scale was examined to verify the presence of the same number of annuli on all scales.

The crappie annuli were identified on the antero-lateral portion of the scale. This area was selected because the annuli are clearest here. Moreover, the scale may begin to grow on its antero-lateral edges before it begins growth in any other portion. The distance between the center of the focus and the respective annuli were measured with the same metric ruler, and recorded to the nearest millimeter.

Shad scales do not possess a focus, because the circuli are not circular but crescent shape. Circuli extend between the lateral sides of the scale only in the anterior portion of the scale. The midpoint of the first circulus was selected to function as the focus for the shad scales in this study. Validity of visual location of the midpoint of the first circulus was tested statistically in a sample of 20 scales. Distances between the visually determined focus and the first annulus and distances between the focus and the margin were measured. The same measurements were then made using focal points that were located at the midpoint of the first circulus by actual measurement. A t-test showed no significant difference, at any level, between the measurement made by visual or measured location of the focus (Table 1).

Measurements of shad scales were taken on the anterior portion of the scales, and the distance from the focus to the annuli and to the margin was recorded to the nearest millimeter. A second measurement was taken along the primary transverse groove for the scales collected during the second half of September, 1967, to compare these two methods of measurement.

Table 1. Comparison between the two measurements of shad scales. In method 1 distances from focus to margin or annulus were measured using focal points that were determined visually, while in method 2 the same distances were determined using focal points that were determined by actual measurement.

Fish Number	Distance from focus to first annulus (mm)		Distance from focus (to margin (mm))		
	Method 1	Method 2	Method 1	Method 2	
1	182	182	227	227	
2	166	165	216	217	
3	180	180	220	219	
4	143	142	183	182	
5	246	247	328	329	
6	202	201	247	246	
7	170	169	195	198	
8	165	168	211	213	
9	222	220	253	252	
10	219	213	260	258	
11	160	160	201	201	
12	141	141	181	182	
13	149	149	197	196	
14	140	140	182	182	
15	130	131	169	171	
16	207	207	261	261	
17	160	160	191	190	
18	139	138	177	180	
19	175	176	232	232	
20	131	131	170	171	
\bar{X}	=	171.3	171.0	215.0	215.7
		0.035		0.020	
Significant t = 0.688 at the 50% level and 2.845 at the 99% level					

Body-Scale Relationship

A computer program was used to determine the body-scale relationship, to calculate the intercept (a) value, and to perform an analysis of variance to test whether reduction due to fitting a second-degree polynomial is significantly larger than that attributed to fitting a linear regression. The analysis of variance follows the procedures outlined in Steel and Torrie (1960). These data show that for both gizzard shad and white crappie there is a linear relationship between lengths of the body and the length of the scale. The reduction due to fitting a second degree polynomial to these data is insignificant for the shad collected in 1966, slightly significant for the shad collected in 1967, and highly significant for crappie collected in both 1966 and 1967 (Table 2). Complete analysis of variances are shown in Appendix A.

The length of fish that correspond to different scale length intervals were computed using both linear and polynomial body-length, scale-length relationship (Tables 3 and 4) and the results were plotted in Figures 2,3,4, and 5.

These results indicate that in the 1967 shad collection, curvilinearity exists only for the fish of less than 100 mm in length. Since the smallest fish collected with an annulus was 104 mm long, the body scale length relationship can be considered to be linear for the purpose of calculation. In crappie, curvilinearity also existed in the small fish. However, the intercept (a) value in the curvilinear body scale relationship is so exaggerated that it exceeds the total length of most fish within the range in which differences existed between the length calculated by using a linear equation and those calculated by the

Table 2. Correlation coefficient of body scale relationship. Values of the intercept (a) and the F values for ANOV used to test for linearity and curvilinearity of body-scale relationship.

Species	Body-scale correlation coefficient	Intercept (a) value			F Values	
		Linear	Curvi-linear	Linear	Curvi-linear X^2	due to inclusion
Shad 1966	.8946	60.15	60.45	5721.13	2858.59	.0058
Shad 1967	.9377	35.42	25.62	11785.57	5933.74	10.7620
Crappie 1966	.7463	59.41	103.86	545.64	324.23	46.1060
Crappie 1967	.7255	74.15	126.99	1469.77	821.24	82.3400

Table 3. Length of gizzard shad (mm) that corresponds at the different scale length intervals computed by using linear and polynomial equations.

Scale length (mm)	Length of fish (mm)		Length of scale (mm)	
	1966 data		1967 data	
	Linear equation	Linear equation	Polynomial equation	
0	60.155	35.424	25.625	
25	72.341	49.944	42.587	
50	84.527	64.464	59.221	
75	96.721	78.983	75.526	
100	108.898	93.503	91.504	
125	121.084	108.023	107.153	
150	133.270	122.543	122.474	
175	145.455	137.062	137.467	
200	157.641	151.582	152.131	
225	169.827	166.102	166.468	
250	182.013	180.622	180.477	
275	194.198	195.141	194.156	
300	206.384	209.661	207.508	

Table 4. Length of white crappie (mm) that corresponds to different scale length intervals computed by linear and polynomial equations.

Scale length (mm)	Length of fish (mm) 1966 data		Length of fish (mm) 1967 data	
	Linear equation	Polynomial equation	Linear equation	Polynomial equation
0	59.406	103.860	74.148	126.990
25	70.726	104.644	83.544	125.136
50	82.045	106.777	92.939	124.603
75	93.365	110.261	102.336	125.391
100	104.685	115.092	111.732	127.501
125	116.003	121.274	121.128	130.931
150	127.324	128.804	130.523	135.683
175	138.644	137.684	139.919	141.756
200	149.964	147.823	149.316	149.150
225	161.284	159.492	158.712	157.865
250	172.603	172.418	168.108	167.901
275	183.923	186.695	177.503	179.262
300	195.243	202.322	186.900	191.937

Figure 2. The relation between scale length and body length of gizzard shad collected July 1 to September 30, 1966 from Keystone Reservoir.

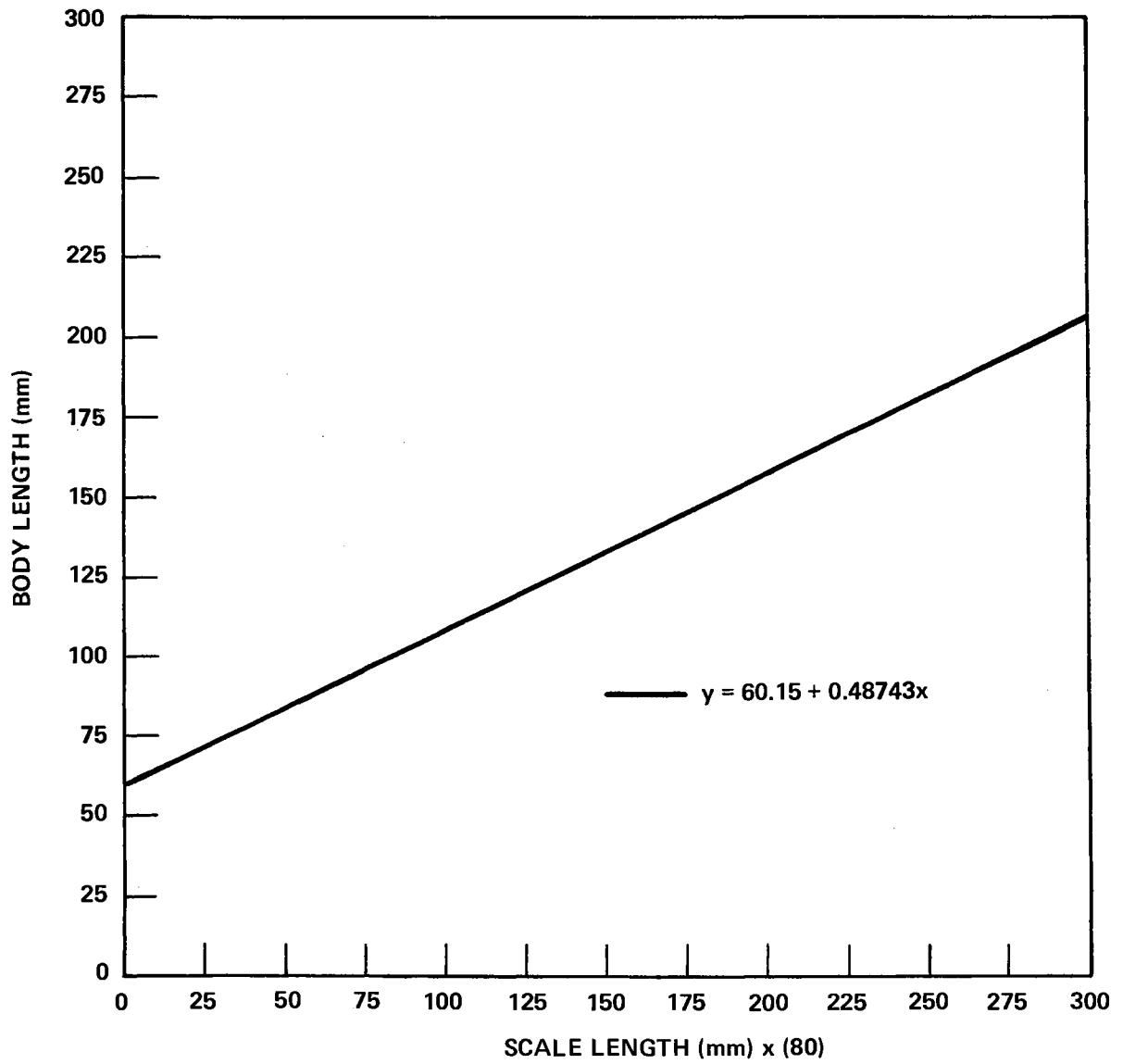


Figure 3. The relation between scale length and body length of gizzard shad collected June 1 to September 30, 1967 from Keystone Reservoir.

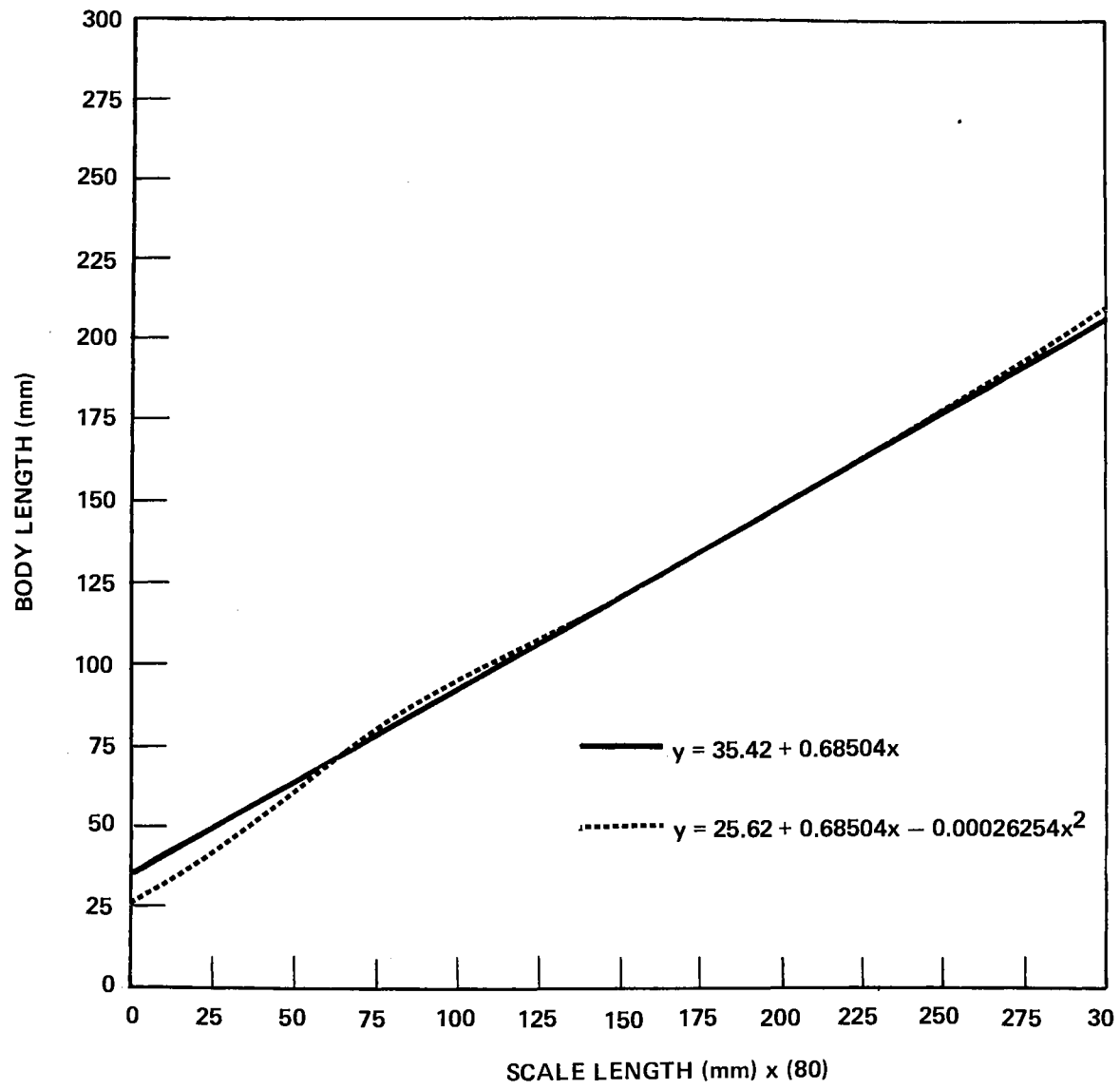


Figure 4. The relation between scale length and body length of white crappie collected August 1 to September 30, 1966 from Keystone Reservoir.

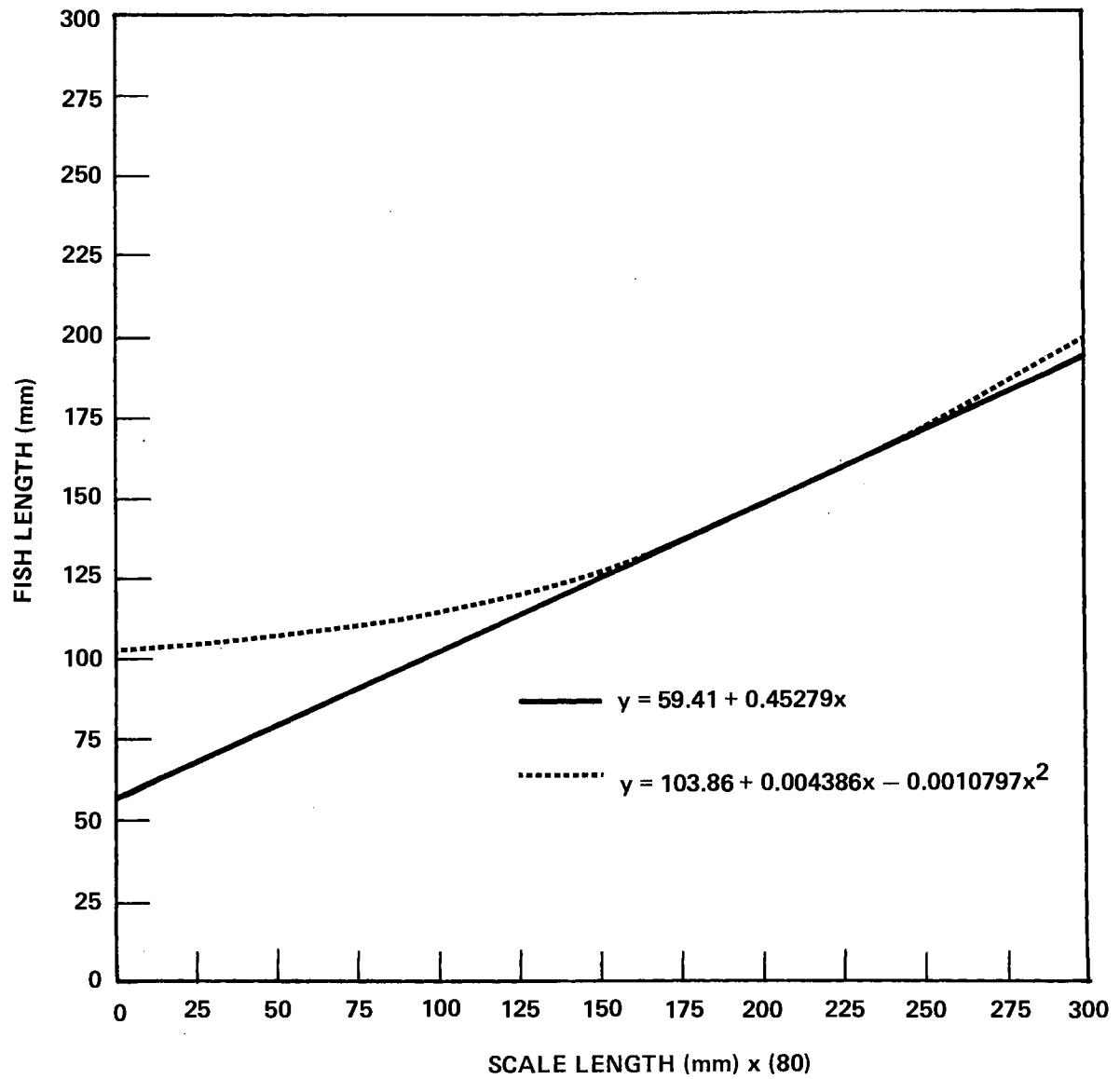
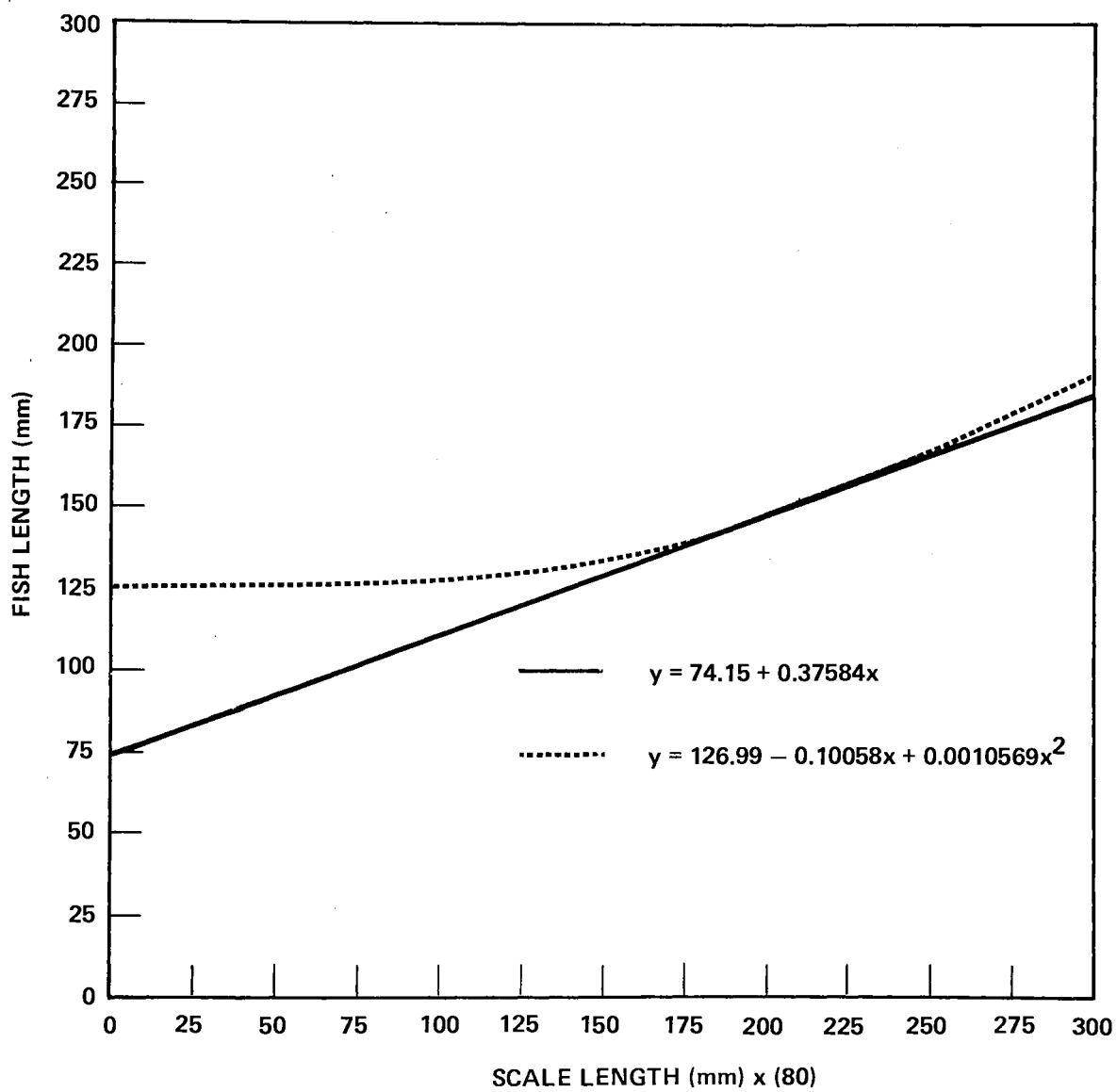


Figure 5. The relation between scale length and body length of white crappie collected June 1 to September 30, 1967 from Keystone Reservoir.



use of polynomial equations. Therefore, the back calculation in this work was computed using the Lee formula:

$$L_n = S_n \left(\frac{L-a}{S} \right) + a$$

L_n = length of fish at annulus n

S_n = distance from the scale focus to annulus n

L = length of fish at capture

S = scale radius

a = intercept value from body-scale relationship
(Table 2)

Monastyrsky (1930) (cited by Lagler, 1961) applied this polynomial (Sheriff) equation to several species of fish and obtained similar results. White crappie scales first occur in the caudal peduncle of fish at size of 16 to 19 mm and form progressively anterior and ventral to the lateral line. The first fully scaled fish observed was 27 mm long (Siefert, 1965).

These exaggerated intercept values might be due to the fact that in most collections small fish are not represented. Weese (1951) found that the intercept value (a) of white bass, Roccus chrysops, increases with size. Similar results were reported for the white crappie by Jehkins (1953). Bowman (1970) also found that the intercept value for the black redhorse, Moxostoma dequesnei (Lesueur) was 37.1 for fish up to 170 mm of standard length and 117.3 for fish larger than 230 mm.

This is also evident in the present study. The intercept value for white crappie was 59.4 for the 1966 collection and 74.1 for the 1967 collection. The 1966 data were mostly of age-group I averaging 140.3 mm and the 1967 data were mostly of age-group II averaging 153.5 mm in total length.

Comparison between scale measurements taken on the anterior portion of the scales and the measurements taken along the primary transverse groove for the shad collected during the second half of September, 1967 indicated that the later measurements gave larger average calculated length at the first annulus than the former measurement, but it gave smaller average calculated total length at the second annulus than the former. However, the measurement taken in the anterior portion of the scale had smaller variance than the measurement taken along the primary transverse groove (Appendix B). This measurement was used in the present study.

The differences in the standard errors were rather small, therefore the two measurements are, indeed, equally practical for the purpose of back calculation.

The common and scientific names of fish used in the text are those approved by the American Fisheries Society.

Statistical analysis followed Snedecor (1956) unless otherwise stated.

CHAPTER IV

DESCRIPTION OF SCALES

White Crappie

The ctenoid scales of white crappie are round in appearance in the posterior and the lateral fields but blunt in the anterior fields (Fig. 6). The clear, unsculptured center of the scale is the focus (F) which represents the original scale plate in the young fish. The focus is surrounded by the more or less concentric structures, the circuli, that represent the crests of the striae of the osseous layer (Wallin, 1957). The circuli are more abundant in the anterior portion of the scale than in the posterior portion. This is due to greater resistance for scale growth in the anterior (imbedded) portion of the scale. Wallin (1957) found that the parts of newly formed regenerated scales of roaches, Rutilus sp., developed striae at the time they encountered resistance. However, the part of the scales that grew free of interference lacked striae over the greater part of the surface. The distance between the circuli (striae) indicates the rate of growth of fish at the time when these circuli were formed. The distance between the circuli are wider following the annulus formation than later (Figs. 7,8,9, and 10) indicating a faster rate of growth during early periods of the growth season.

Circuli are not formed in all portions of the scale at the same time, therefore when the growth is retarded or ceases during winter these circuli do not grow to completion. When rapid growth resumes in the spring a new, complete circulus is formed that cuts over the incomplete circuli. These incomplete and fragmented circuli leave a wide clearance followed, in most cases, by a wide-spaced circuli. These situations are most useful in determining the presence of an annulus (Figs. 7 and 9).

In the autumn the growth of the fish and of the scales ceases, and the calcification of the osseoid zone with the striae occurring in it continues (Wallin, 1957). When the calcification passes these striae, they are left behind as low striae that terminate freely upon the surface of the osseous layer, because the stria do not run exactly parallel with the outer edge of the osseoid zone. Therefore, the stria is not developed simultaneously throughout its entire length but from a single point by a gradual growth around the scale. The first stria is formed when growth is resumed. This stria is then complete. Few more striae are formed close to each other, but with the increase in width of the osseoid zone, the striae are formed at gradually increasing intervals.

The annulus is more defined in the anterior and the antero-lateral ridge areas of the scale, becoming gradually less defined posteriorly. The annulus is obscured by the ctenii in the posterior portion of the scale.

The annuli are easily recognized in the I, II and III age groups. In older fish, the first and the last annuli are not difficult to recognize but the recognition of the annuli between these two is difficult (Fig. 11).

False annuli (FA) (Figs. 13 and 14) resulting from retardation of growth, can be caused by a variety of factors. These were also encountered in the scales of white crappie in this study. The false annulus is mostly restricted to the anterior portion of the scale. The spaces between the circuli following the false annuli are not as wide as they are between the circuli that follow a true annulus. The false annulus is usually present on some scales but it is absent on other scales of the same fish. A true annulus is present in all scales.

The groove-like structures rising from near the focus and interrupting the continuity of the circuli are the radii (R). These radii are similar in appearance to the radii of other sunfishes (see Regier, 1962 and Beckman, 1943). These radii are broad and few in number (8-12) and are restricted to the anterior portion of the scale. Seldom do additional radii form on scales as the fish becomes older. Therefore, the radii of white crappie are mostly of the antero-primary type (Al-Rawi, 1964). A secondary radius (SR) (radius that rises from the region of the second year of growth) is shown in Figure 7. Interrupted radii (IR) (radii that do not reach the margin of the scale) are shown in Figures 7 and 9 but their occurrence is not common. The number of radii has been shown to vary within individuals of the same age (Al-Rawi, 1964). It has been shown also that the number and degree of development of radii is primarily dependent upon the degree to which the movement of a scale is restricted by overlying tissue (Creaser, 1926). Different classifications of the type of radii have been suggested by Wallin (1957) and Al-Rawi (1964).

Ctenii (CT) are present in a relatively small area in the posterior field and they vary in number from one fish to another. They are

almost absent in some scales (Fig. 11) especially in regenerated ones (Fig. 12).

The antero-lateral ridges (AR);(Van Oosten, 1929) are well-defined in some scales (Figs. 6 and 13) but they are less defined in others. However, the postero-lateral ridges are inconspicuous.

Regenerated scales are easily distinguished by the absence of a focus and the cracked surface appearance of their centers that lack circuli. This appearance is due to multiple growth centers in the regenerated scales producing multiple platelets that grow independent of each other. Overlap results in the cracked-surface appearance in the center of the scale. The absence of circuli is due to the absence of resistance for the growth of the scale. When the scale reaches the original size, however, it will encounter resistance from the scale pocket and the surrounding tissue and circuli will form as usual (Wallin, 1957).

The presence of an annulus-like structure between the first annulus and the focus (FC)(Figs.10 and 12) could be easily confused by an inexperienced scale reader with the first annulus. However, it is much less defined than a true annulus. The circuli in this band are less fragmented and do not leave such wide clear areas as it has described above. It is never followed by wide-spaced circuli. This structure could be the result of retarded growth caused by shift in feeding or by high temperatures. False annuli similar to this one have been described from the scales of bluegills (Sprugel, 1954).

Gizzard Shad

The scales of gizzard shad are cycloid and typically clupeoid (Fig. 15). Postero-lateral and antero-lateral ridges are lacking. The posterior portion is devoid of circuli and other features except for the annulus which, in some scales, appears as a dark band (Figs. 16, 17 and 18). The lack of the outer part of the dermal scale pocket (Berry, 1958) might be related to the absence of circuli in the posterior region. Thus this portion of the scale grows without the interference that results in the formation of the circuli (striae).

The radii (Chugunova, 1959) or transverse grooves (Borodin, 1925) extend in the dorso-ventral direction and do not extend from the focus as they do in the ctenoid and other cycloid scales. Two types of transverse grooves are present in the scales of gizzard shad. The first is a complete groove extending between the dorsal and the ventral margins of the scale separating the anterior and the posterior portions (PTG). The second type are those formed later as the scale grows larger (STG). These grooves extend from the lateral margins of the scale and terminate somewhere in the middle without completion. To distinguish between the two types, the first is called the primary transverse groove and the second is called the secondary transverse grooves. These secondary transverse grooves increase in number as the fish gets older and have been used by some workers for age determination of other species of shad. Borodin (1925) aged the American shad, Alosa sapidissima, by counting the number of these grooves and dividing by two to determine the age in years. Other authors disagreed with the accuracy of this method and showed that the annulus is more

valid as an annual mark (LaPointe, 1958, and Judy, 1961). In this study, the number of secondary transverse grooves increases as the fish get larger but they do not correspond with the number of annuli. This is in agreement with Lagler and Applegate (1942) and Berry (1958).

The scales of gizzard shad lack a focus and the circuli (striae) are not concentric but gently curved, becoming more crescent-shaped as the scale grows larger. The circuli in the early growth zone are set more closely to each other than in later growth giving a darker appearance to this inner portion of the scale. Circuli close to the center of the scale intersect the primary transverse groove, while those formed later end at the lateral margins. Circuli formed early in the second year of life in the lateral portions of the scale also intersect the primary transverse groove while those formed in this region later, as well as those formed in the anterior portion of the scale terminate at the margins. This pattern is followed in the third year of life. The first circulus which is formed in the anterior field, never cuts across the paths of the circuli formed in the previous year in the lateral fields. This is in direct contradiction of Bodola (1966).

The annulus (A) is concentric and runs parallel to the scale margin. It can be recognized in the anterior field by its incomplete circuli that sometimes leave a clear area filled with only fragments of circuli (Fig. 15).

In the lateral aspect of the scale the annulus appears as a dark band. The circuli from the old portion of the scale continue to the marginal part of the newly formed basal plate. The circuli bend as they pass from the thick portion of the scale to the thin, newly formed portion thereby forming the annulus. The circuli also frequently

thicken before they bend toward the annulus and some become interrupted. This gives the annulus its sharp definition as a dark band in the lateral regions. This is also true in other clupeid fishes (Chugunova, 1959). In some scales, the annulus appears as a dark band in the posterior portion. This can be used as an aid to distinguish between a false and a true annulus (Fig. 15).

The regenerated scales of gizzard shad possess circuli running in different directions. The presence of these circuli can be related to the thinness of the scale, therefore the slight resistance the regenerated scale might encounter in the course of its growth results in the formation of these circuli.

Figure 6. Scale impression of a 3-year-old white crappie, Pomoxis annularis, taken from Keystone Reservoir, August 15, 1966. Total length, 165 mm. Weight, 52 grams. Scale shows typical structures. Letters are explained in the text. Magnification of photographs is not the same for all scale impressions.

A - annulus
AR - antero-lateral ridge
C - circulus
CT - ctenii
E - edge
F - focus
R - radius

Figure 7. Scale impression of a 2-year-old white crappie, Pomoxis annularis, taken from Keystone Reservoir, June 20, 1967. Total length, 149 mm. Weight, 38 grams. Scale shows typical example of the 1967 data. It also shows how the annulus is followed by wide-spaced circuli, and an example of a secondary and an interrupted radius.

SR - secondary radius
IR - interrupted radius

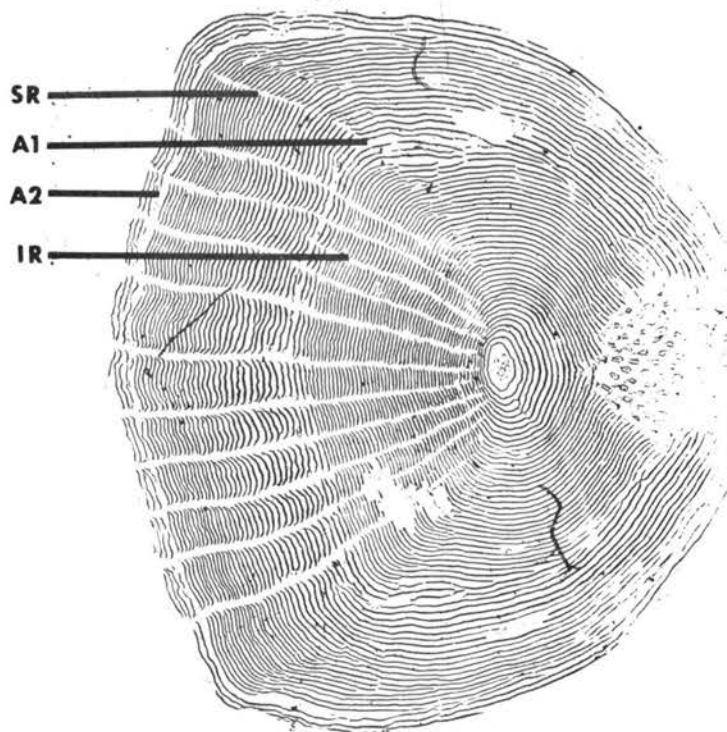
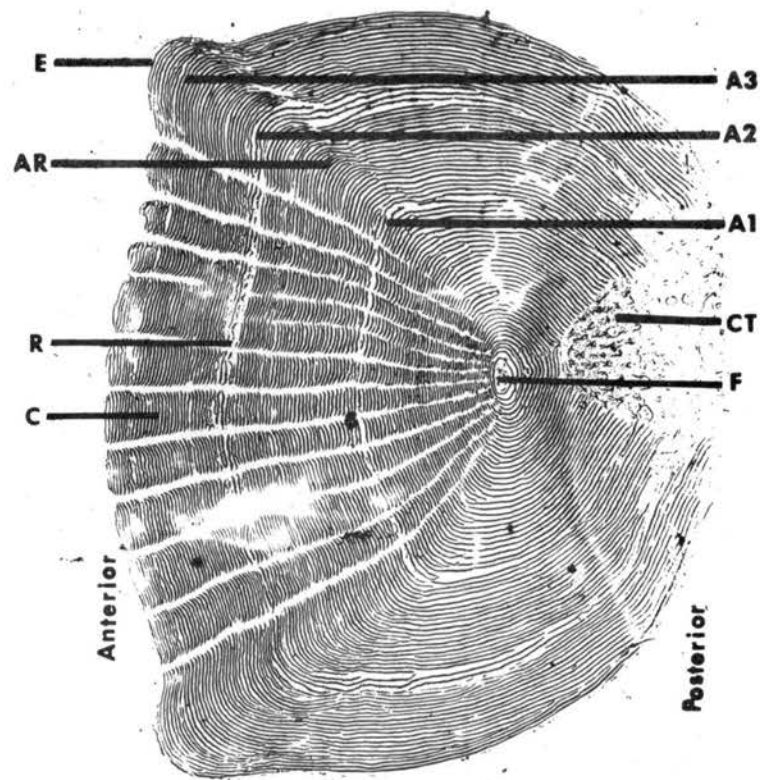


Figure 8. Scale impression of a 1-year-old white crappie, Pomoxis annularis, taken from Keystone Reservoir, September 14, 1966. Total length, 135 mm. Weight, 29 grams. Scale shows annulus-like structure(FC) between focus and first annulus.

Figure 9. Scale impression of a 2-year-old white crappie, Pomoxis annularis, taken from Keystone Reservoir, September 12, 1967. Total length, 153 mm. Weight, 41 grams. Scale shows several interrupted radii.

FA - false annulus

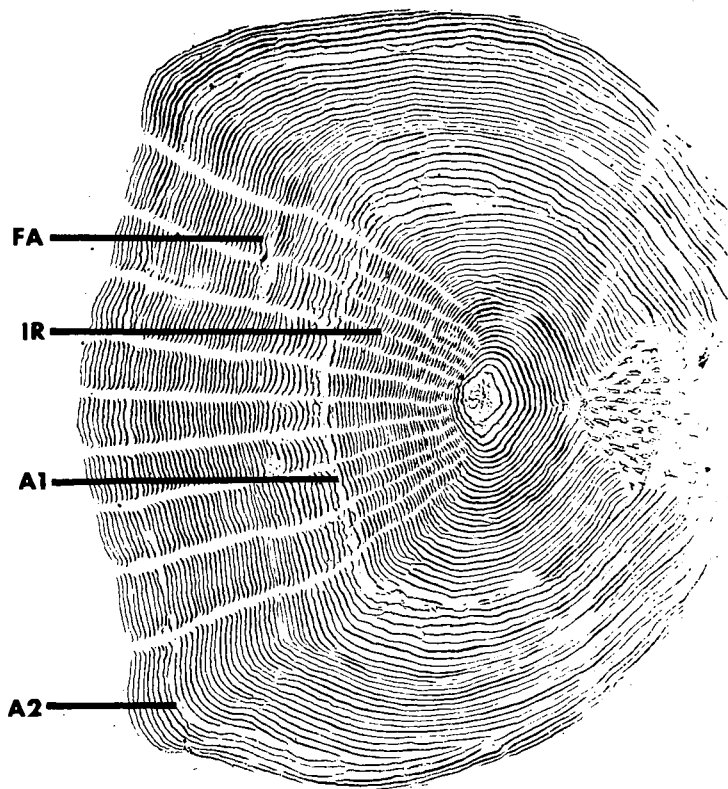
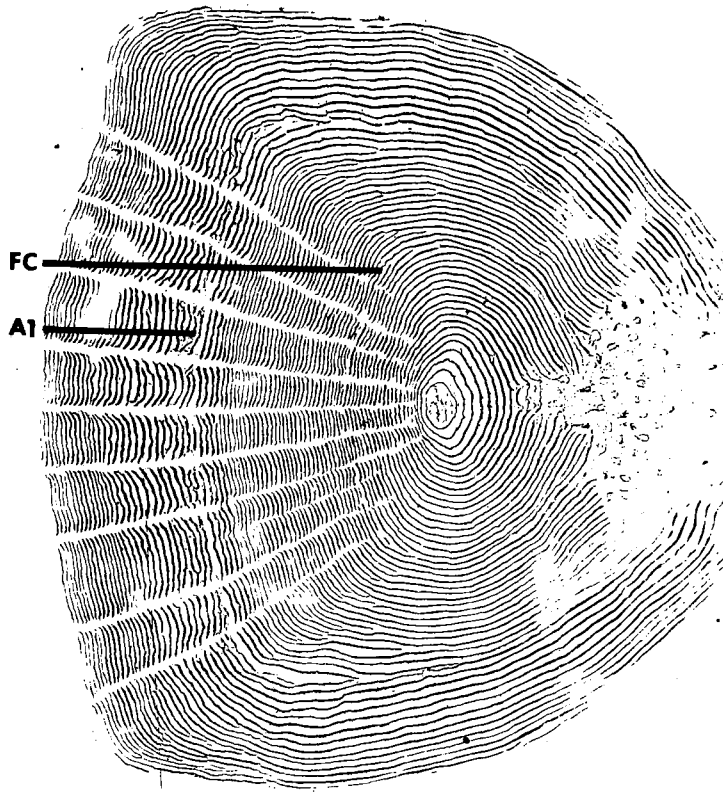




Figure 10. Scale impression of a 1-year-old white crappie, Pomoxis annularis, taken from Keystone Reservoir September 8, 1966. Total length, 130 mm. Weight, 25 grams. An example of the majority of fish scales collected in 1966.

Figure 11. Scale impression of a white crappie, Pomoxis annularis, taken from Keystone Reservoir, June 20, 1967. Total length, 246 mm. Weight, 229 grams. Scale shows that in old scales first and last annulus are recognizable but annuli in between are obscured.

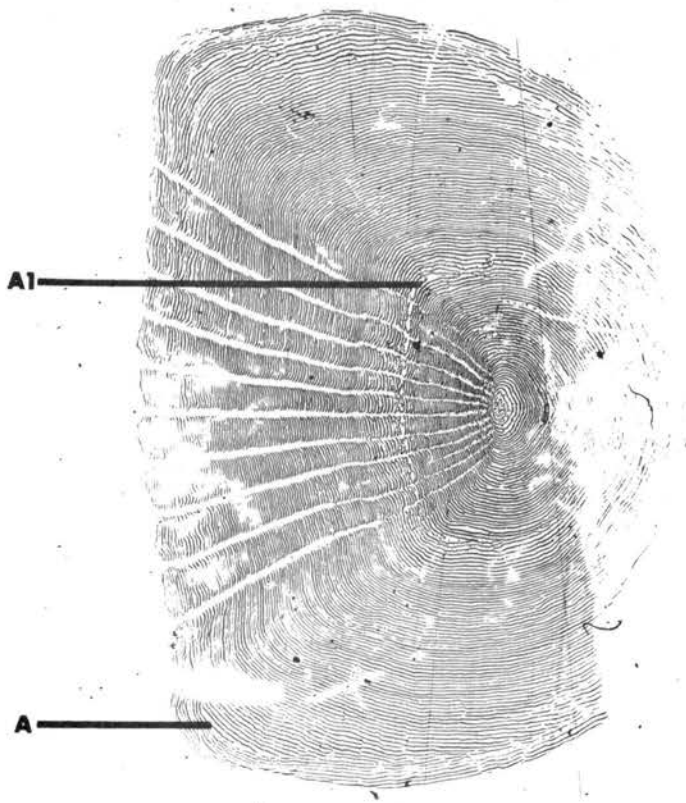
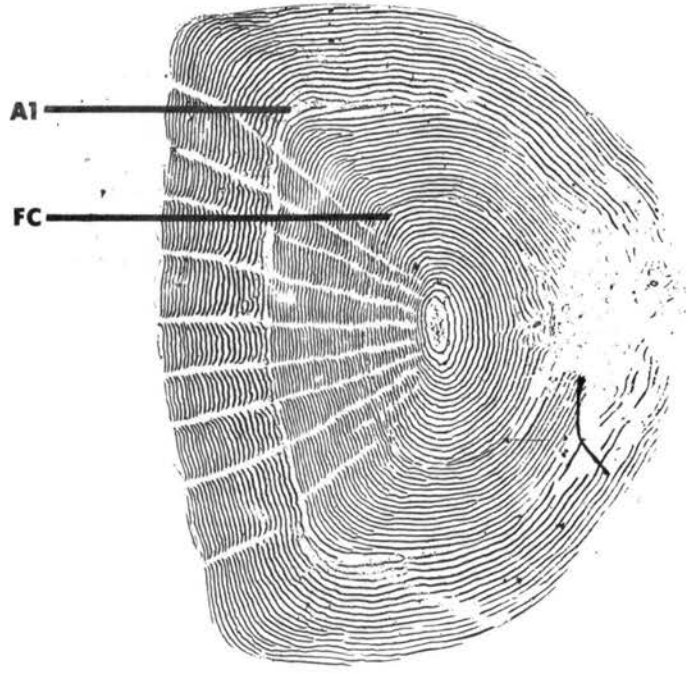


Figure 12. Impression of a regenerated scale of a white crappie, Pomoxis annularis taken from Keystone Reservoir August 13, 1966. Total length, 117 mm. Weight, 16 grams.

Figure 13. Scale impression of 1-year-old white crappie, Pomoxis annularis, taken from Keystone Reservoir, August 15, 1966. Scale shows fast growth late in the season leaving an impression of a false annulus between the first annulus and the margin of the scale.



Figure 14. Scale impression of a 1-year-old white crappie, Pomoxis annularis, taken from Keystone Reservoir, August 12, 1966. Total length, 142 mm. Weight, 38 grams. The scale shows false annulus.

Figure 15. Scale of a 2-year-old gizzard shad, Dorosoma cepedianum, taken from Keystone Reservoir, July 22, 1967. Total length, 160 mm. No weight was recorded. Scale shows typical structures. Magnification of photographs is not the same for all scales.

PTG - Primary transverse groove
STG - Secondary transverse groove

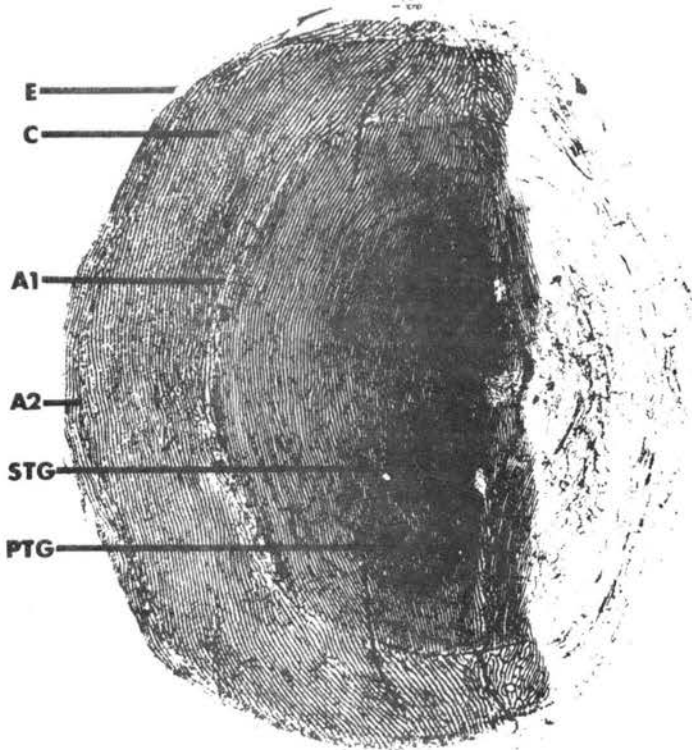
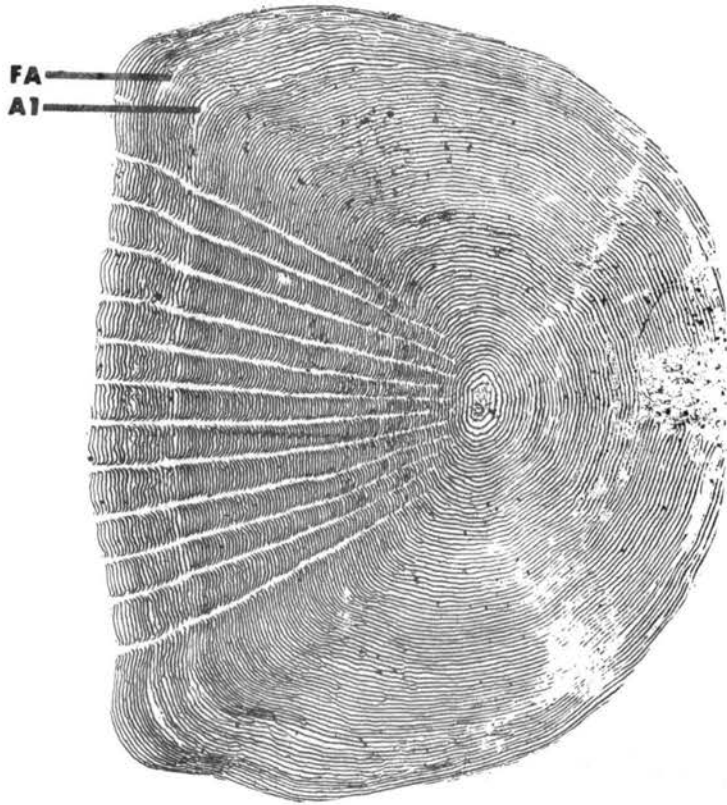


Figure 16. Scale of a 2-year-old gizzard shad, Dorosoma cepedianum, taken from Keystone Reservoir, July 22, 1967. Total length, 128 mm. No weight was recorded. Scale shows two annuli. This explains the overlapping of the I and II age groups in the 1967 collection.

Figure 17. Scale of a 1-year-old gizzard shad, Dorosoma cepedianum, taken from Keystone Reservoir, June 30, 1967. Total length, 133 mm. Weight, 24 grams. Scale shows false annulus.

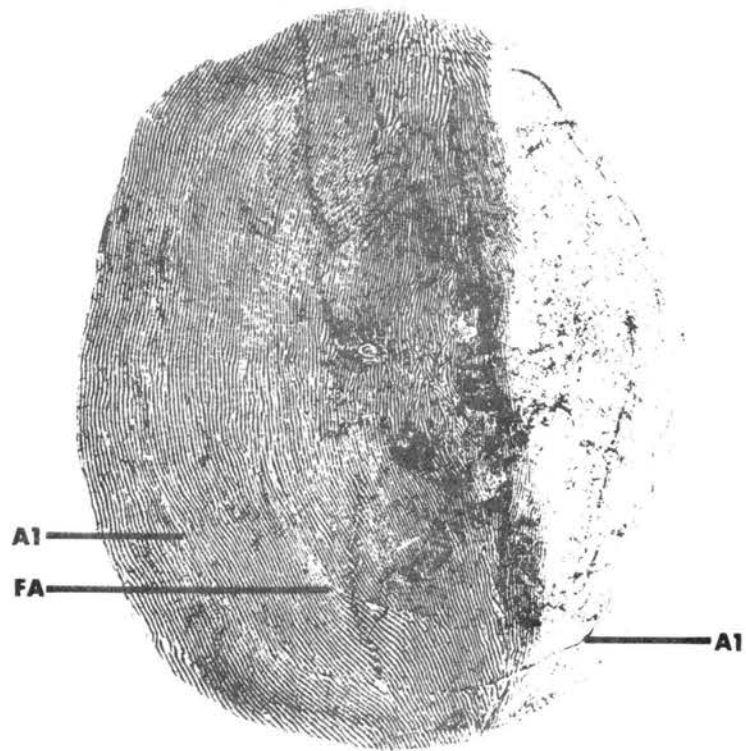
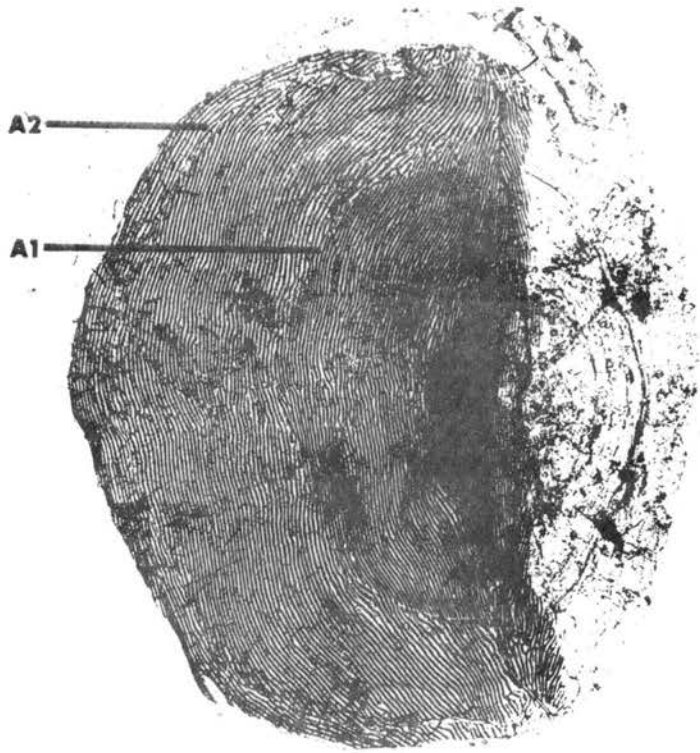
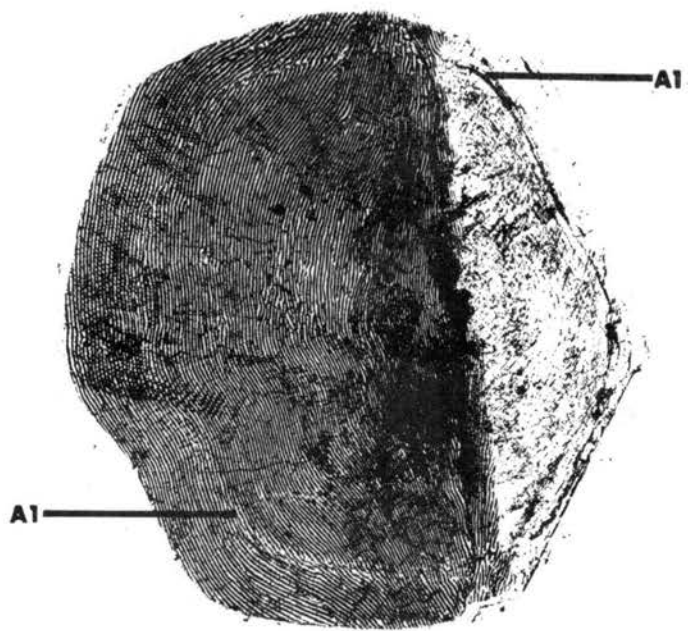


Figure 18. Scale of a 1-year old gizzard shad, Dorosoma cepedianum, taken from Keystone Reservoir, June 30, 1967. Total length, 130 mm. Weight, 20 grams. Scale shows an example of a well defined annulus in a small fish scale.

Figure 19. Regenerated scale of a gizzard shad, Dorosoma cepedianum, taken from Keystone Reservoir, September 23, 1967. Total length, 163 mm. Weight, 45 grams.



CHAPTER V

CALCULATED GROWTH DATA

Definition of Terms

The fish in this study were assigned to age groups. Fish that showed no annulus on their scales were designated as age group 0. Those with one annulus on their scales were designated as age group I, those with two annuli were designated as age group II and so on.

Years of life are designated by Arabic numerals; first year of life refers to the life of the fish from the time it was hatched to the time growth ceased in that particular year. Second year of life is the period between the formation of the first and second annulus respectively. Year class refers to the year in which the fish were hatched. A fish captured in 1967 with one annulus belongs to the 1966 year-class and a fish captured in 1967 with two annuli belongs to the 1965 year-class and so on.

In comparing growth data from two years, or two sampling periods, the growth in the early year, or period, refers to the year or the period listed in the left of the column titled "Years involved in Comparison." The growth in the later year or period refers to the year or period listed to the right of the column. For example, if the years to be compared are 1964 and 1965, the early year is 1964 and the later year is 1965.

The term "no scales" used in the legend of the length-frequency histograms (Figs. 22,23,24 and 25) refers to fish from which no scales were taken and to the fish with scales which were not readable.

Annual increment refers to the amount of growth that the fish completed during a full growing season. That is, between the time the fish was first hatched and the formation of the first annulus, or during the time between the formation of two adjacent true annuli. Marginal growth refers to the growth of fish between the formation of the last annulus and the capture of the fish.

Growth of White Crappie

Average total length of each annulus and at capture was determined for each half-month period. This included four samples in 1966 (Table 5) and eight samples in 1967 (Table 6).

Average total length at each annulus for the entire 1966 sample, and for the entire 1967 sample (Table 9) showed that the largest length increment was attained during the first year of life. The 1964 year-class (the year the lake was first filled with water) showed the best growth. Fish showed a better rate of growth during 1966 than they showed in 1967.

The decrease in the rate of growth with aging of the reservoir is a typical phenomenon. Data from new impoundments (impounded three years or less) in Oklahoma show higher rates of growth in new rather than in older reservoirs (Jenkins, 1953). The present data were collected during the first three years of impoundment. Therefore, it is useful to compare the present rates of growth with data collected from reservoirs that were 3 years old or less when the data were collected,

Table 5. Average calculated total length (mm) of white crappie collected from Keystone Reservoir, Oklahoma, 1966. Data are grouped in half-month periods.

Age group	Date	Number of fish	Mean calculated total lengths at annulus				Average length at capture	1966 growth increment
			1	2	3	4		
I	8/1-15	229	111.5				136.4	24.9
	8/16-31	86	110.7				139.3	28.6
	9/1-15	43	110.5				140.2	29.7
	9/16-30	65	113.4				144.7	31.4
	Mean		111.5				138.7	27.2
II	8/1-15	1	136.0	167.0			193.0	26.0
	8/16-31	4	123.5	160.3			179.2	18.9
	9/1-15	1	104.0	143.0			157.0	14.0
	Mean		122.3	158.5			177.7	19.2
III	8/1-15	1	97.0	132.0	158.0		165.0	7.0
	8/16-31	1	93.0	138.0	167.0		188.0	21.0
	Mean		95.0	135.0	162.5		176.5	14.0
IV	8/1-15	2	110.0	156.3	205.0	246.5	266.5	
	8/16-31	1	102.0	154.0	263.0	263.0	274.0	
	Mean		107.3	155.7	252.0	252.0	269.0	17.0

Table 6. Average calculated total length (mm) of white crappie collected from Keystone Reservoir, Oklahoma, 1967. Data are grouped in half-month periods.

Age group	Date	Number of fish	Mean calculated total length at annulus				Average length at capture	1966 growth increment
			1	2	3	4		
I	6/1-15	1	135.0				162.0	27.0
	6/16-30	1	126.0				148.0	22.0
	7/1-15	8	111.1				133.2	22.1
	7/16-31	21	107.6				126.5	18.9
	8/1-15	10	112.6				138.0	25.4
	8/16-31	5	107.2				132.6	25.4
	9/1-15	2	123.0				162.5	39.5
	9/16-30	2	113.5				161.0	47.5
	Mean		110.9				136.4	25.5
II	6/1-15	188	112.0	145.6			151.4	5.8
	6/16-30	120	113.4	145.1			150.2	5.1
	7/1-15	119	111.1	144.5			154.5	10.0
	7/16-31	390	109.5	142.5			153.8	11.3
	8/1-15	222	108.2	141.7			153.4	11.7
	8/16-31	99	112.7	144.9			156.7	11.8
	9/1-15	95	108.2	142.6			154.3	11.7
	9/16-30	31	120.8	153.3			168.1	14.8
	Mean		110.6	143.7			153.7	10.0

Table 6. (Continued)

Age group	Date	Number of fish	Mean calculated total length at annulus				Average length at capture	1966 growth increment
			1	2	3	4		
III	6/1-15	3	101.0	130.3	153.7		166.0	12.3
	7/1-15	3	129.3	178.3	204.0		214.7	10.0
	7/16-31	2	109.5	141.0	164.5		170.0	5.5
	8/1-15	1	129.0	185.0	223.0		229.0	6.0
	8/16-31	1	144.0	187.0	242.0		250.0	8.0
	Mean		118.3	158.0	186.7		196.1	9.4
IV	6/1-15	1	123.0	170.0	202.0	221.0	234.0	13.0

i.e., Canton Reservoir (Buck and Cross, 1952) Fort Gibson and Tenkiller Reservoirs (Hall and Jenkins, 1953) and Wister Reservoir (Latta, 1951) (Appendix C). These data indicate that the rate of growth in Keystone Reservoir is lower than the average rate of growth in other newly impounded reservoirs in Oklahoma. Age-group I showed better rates of growth than fish from Canton and Wister Reservoirs. Crappie in the Keystone Reservoir showed the poorest rate of growth during the second year of life. Most of these fish were from the 1965 year-class (the first to hatch in the lake). This year-class was dominant in both the 1966 and the 1967 collections. The slow growth in the second year of life may be attributed to crowding or to unfavorable chemical conditions of the water during the summer of 1966 (Eley, Carter, and Dorris, 1968) when these age-group II fish were in their second year of life. However, crappie showed a better rate of growth between the time of annulus formation and the time of their capture in 1966, when these unfavorable water conditions existed, than the rate of growth for the same period in 1967. In 1966, the marginal growth was 27.2, 19.2, 14.0, and 17.0 mm for the I, II, III, and IV age-groups, respectively, compared to 25.5, 10.7, 9.4, and 13.0 for the corresponding age-groups in 1967 (Table 9). This suggests that crowding which may have resulted from a very successful 1965 year-class is likely to be the cause of the poor rate of growth during the second year of life and the decrease in the rate of growth during the 1967 growing season.

However, the lake seems to have been a more suitable habitat for white crappie than that which existed in the river before the impoundment, because the first year-class that hatched in the reservoir (1965 year-class) was very successful and the rate of growth is better than

that reported by Linton (1961) from the Cimarron River before the reservoir was impounded (Appendix C).

The growth rate and growth increments for the present study, plus similar data from the Cimarron River and other Oklahoma reservoirs are presented in Appendix C and shown in Figure 20.

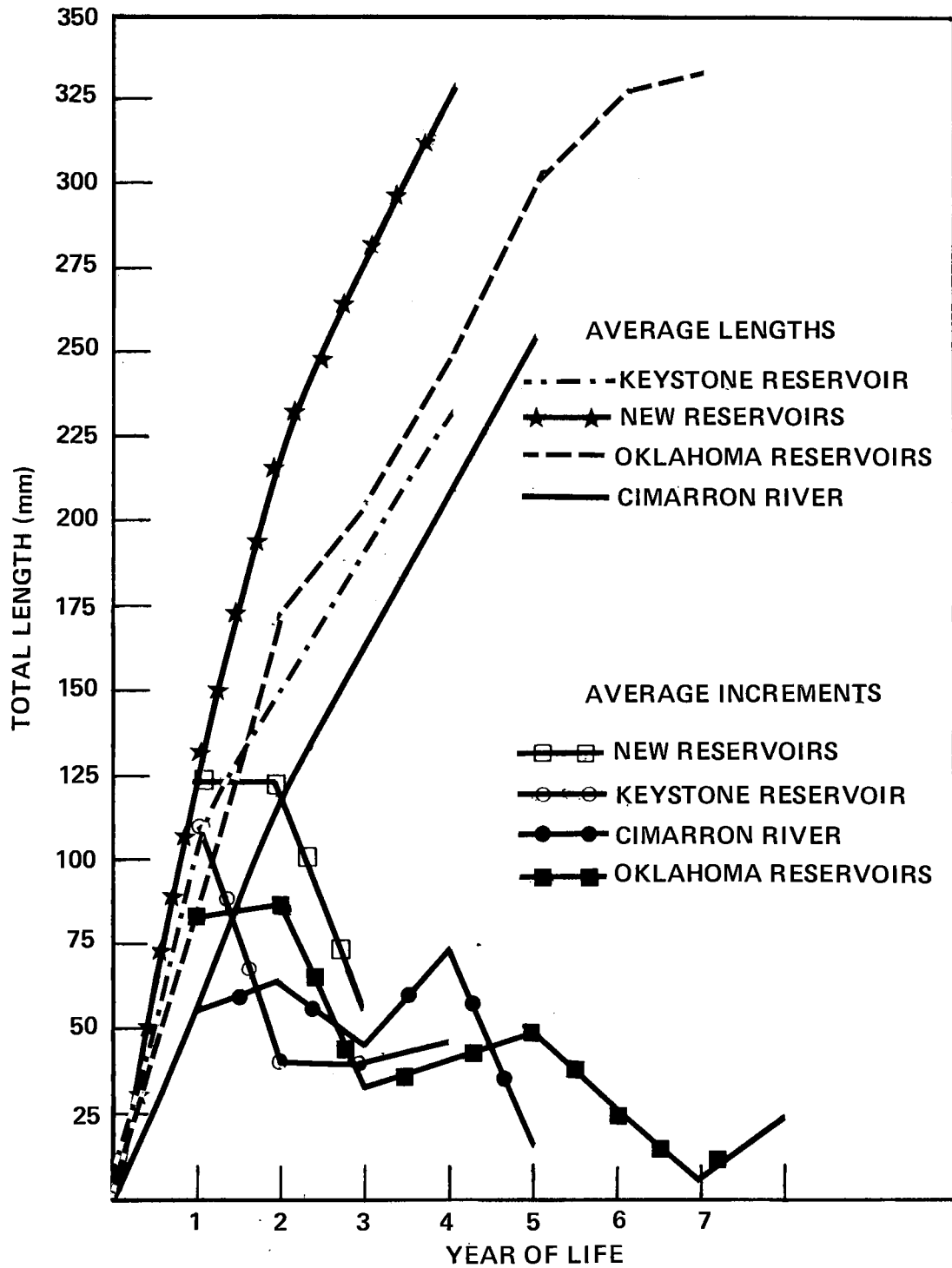
The 1966 year-class is poorly represented in the collections, but the selectivity of the collecting gear cannot be the reason for its failure to be represented in the collections, since the average size of this year-class is similar to that of the 1965 year-class.

Patriache (1953) stated that the stability of water level during the spawning season is an important factor in the success of reproduction of fish spawning in shallow water and that there is a possibility that a whole year class may be eliminated by a rapid drop in the water level. The water level in Keystone Reservoir was fairly stable during April, May, June, and July, 1966.

There was a decided increase in the catch of white crappie in mid-July and the first half of August. The catch decreased sharply during the second half of August and the entire month of September. This was evident in both 1966 and 1967. Echmeyer, Stroud and Jones (1944) also reported an increase in the take of white crappie in mid-July that continued through October. They attributed this to inshore movements but they were unable to explain the reason for it.

This inshore movement is probably coincident with stratification of the lake and therefore fish move to more mixed and well-oxygenated water. Eley, Carter and Dorris (1968) reported that in July, 1966, the water mass below six meters was anoxic and contained 18 mg/l free carbon dioxide, and water samples from the hypolimnion had a strong

Figure 20. Growth and growth increment curves of white crappie collected from Keystone Reservoir, Oklahoma, 1966 and 1967, and from the Cimarron River and other Oklahoma Reservoirs.



oder of hydrogen sulfide.

Growth of Gizzard Shad

Average total length of each annulus and at capture were determined for fish collected during each half-month period. This included six samples in 1966 (Table 7) and eight samples in 1967 (Table 8).

Average total length at each annulus and at capture for the entire 1966 and 1967 collections (Table 10) showed evidence of the reverse of Lee's phenomenon of apparent change of growth in both the 1966 and the 1967 collections. The older fish tend to have greater calculated lengths than do the younger fish at the same annulus. This may be because the fast growing fish reach the "threshold size of survival" (Lagler and Applegate, 1942) sooner than the slower growing fish and therefore escape predation. This phenomenon was reported for other species where the females tend to grow faster and live longer than the males (Ricker, 1958).

Bodola (1966) found that female gizzard shad age II and older, taken from western Lake Erie, are larger than males of the same age groups, but become less numerous in age-groups IV to VI. Since the oldest gizzard shad in the present study were age-group III, it is more likely that selective predation on small size fish is the reason for the reverse of Lee's phenomenon in the present study.

The largest increments in length were made during the first year of life, similar to the growth of white crappie. The growth rate of gizzard shad showed a gradual decline with the aging of the reservoir (Tables 13,17).

Table 7. Average calculated total length of gizzard shad collected from Keystone Reservoir, Oklahoma, 1966. Data are grouped in half-month periods.

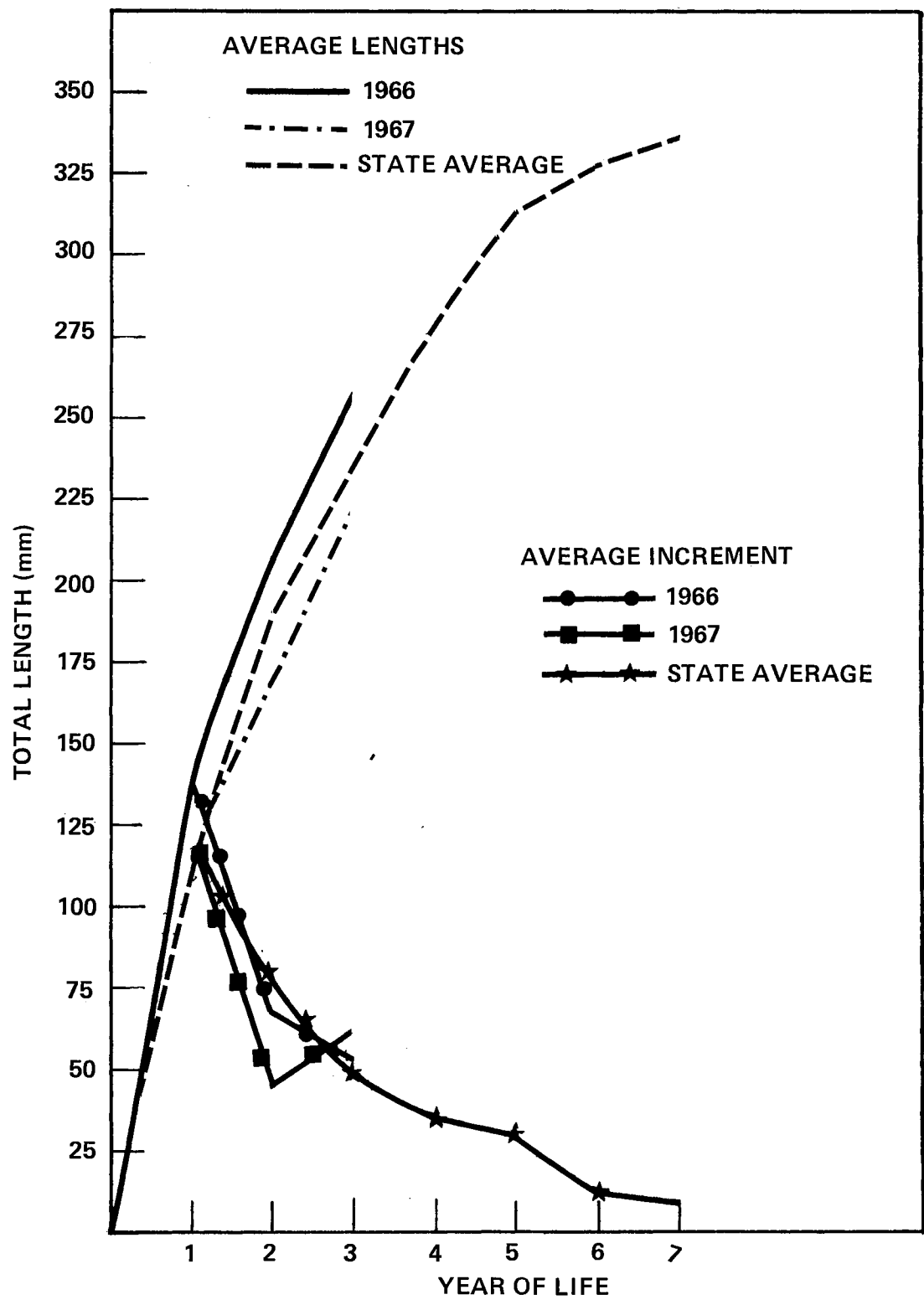
Age group	Date	Number of fish	Mean calculated total length at annulus			Average length at capture	1966 growth increment
			1	2	3		
0	7/1-15	4				137.7	
	7/16-31	30				63.3	63.3
	8/1-15	6				84.2	84.2
	8/16-31	22				91.7	91.7
	9/16-30	7				92.6	92.6
	Mean					80.0	80.0
I	7/1-15	159	132.0			151.7	19.7
	7/16-31	348	140.9			164.2	23.3
	8/1-15	222	138.6			164.3	25.7
	8/16-31	213	143.0			170.6	27.6
	9/1-15	186	139.0			164.3	25.3
	9/16-30	196	148.3			175.9	27.6
	Mean		140.6			165.5	24.9
II	7/1-15	2	135.5	164.5		173.0	8.5
	7/16-31	11	135.2	178.3		199.6	21.3
	8/1-15	12	142.8	221.5		243.9	22.4
	8/16-31	5	154.0	233.8		257.4	23.6
	9/1-15	2	134.0	198.0		215.5	17.5
	9/16-30	3	146.3	247.7		256.7	9.0
	Mean		141.4	207.3		227.3	20.0
III	9/1-15	1	155.0	219.0	261.0	272.0	11.0

Table 8. Average calculated total length of gizzard shad collected from Keystone Reservoir, Oklahoma, 1967. Data are grouped in half-month periods.

Age group	Date	Number of fish	Mean calculated total length at annulus			Average length at capture	1966 growth increment
			1	2	3		
0	8/1-15	15				69.0	69.0
	9/1-15	12				83.1	83.1
	9/16-30	3				90.0	90.0
	Mean					76.7	
I	6/1-15	217	131.2			166.2	35.0
	6/16-30	121	124.6			158.2	33.6
	7/1-15	83	114.0			145.6	31.6
	7/16-31	213	109.1			138.1	29.0
	8/1-15	225	113.9			144.2	30.3
	8/16-31	232	121.3			158.5	37.2
	9/1-15	197	110.5			140.4	29.9
	9/16-30	155	125.2			162.9	37.7
Mean		118.7			151.6	32.9	
II	6/1-15	24	127.8	177.8		189.1	11.3
	6/16-30	21	126.6	167.7		175.2	7.5
	7/1-15	6	123.5	168.0		180.2	12.2
	7/16-31	26	115.6	154.2		162.9	8.7
	8/1-15	15	120.1	166.3		180.7	14.4
	8/16-31	20	120.9	165.7		179.5	13.8
	9/1-15	14	122.6	160.0		175.2	15.2
	9/16-30	14	123.1	167.1		180.1	13.0
Mean		122.4	165.7		180.1	14.4	
III	6/16-30	1	128.0	165.0	218.0	224.0	6.0
	7/16-31	1	126.0	201.0	233.0	238.0	5.0
	Mean		127.0	183.0	225.0	232.0	7.0

The gizzard shad in Keystone Reservoir showed better rates of growth than the state average in 1966. The 1967 data showed poorer growth, except for age group I, than the state average (Linton, 1961) Fig. 21).

Figure 21. Growth and growth increment curves of gizzard shad collected from Keystone Reservoir, Oklahoma, 1966 1967 and from the State of Oklahoma.



CHAPTER VI

VALIDITY OF THE SCALE METHOD

The criteria used to test the validity of the scale method of aging fish follows procedures suggested by Van Oosten (1929), and Hile (1941) the criterion mention by Al-Rawi (1964) and an additional criterion established in this study.

Correlation Between Age and Size

The regularity of the increase in the number of annuli should be accompanied by a similar increase in the size of the fish. This condition proves that the occurrence of annuli on the scales is not haphazard, but that annuli are added systematically as growth proceeds. Tables 5,6,7,8,9, and 10 show that such an increase is evident in all groups collected in 1966 and 1967 for both gizzard shad and white crappie.

Also, fish assigned to the same age group have similar lengths, although the size ranges overlap to some extent (Tables 5,6,7, and 9) except for a few instances where the number of fish in the sample is small. The 1967 shad collection (Table 8) showed some deviation from this criterion. This is due to the fact that two distinct populations with different rates of growth were sampled. This situation will be discussed in detail later.

Table 9. Average calculated total lengths (mm) and length increments of white crappie collected from Keystone Reservoir, Oklahoma, 1966 and 1967.

Year	Year class	Age group	Number of fish	Calculated total length at annulus				Average total length at capture	Marginal growth
				1	2	3	4		
1966	1965	I	423	111.5				138.7	27.2
	1964	II	6	122.3	158.5			177.7	19.2
	1963	III	2	95.0	135.0	162.5		176.5	14.0
	1962	IV	3	107.3	155.7	210.7	252.0	269.0	17.0
		Mean		111.5	153.5	191.4	252.0		
Average annual increment				111.5	42.0	37.9	60.6		
1967	1966	I	50	110.9				136.4	25.5
	1965	II	1,264	110.6	143.7			153.7	10.0
	1964	III	10	118.3	158.0	186.5		196.1	9.4
	1963	IV	1	123.0	170.0	202.0	221.0	234.0	13.0
		Mean		110.7	143.8	187.9	221.0		
Average annual increment				110.7	33.1	44.1	33.1		

Table 10. Average calculated total length (mm) and length increments of gizzard shad collected from Keystone Reservoir, Oklahoma, 1966 and 1967.

Data collected	Year class	Age group	Number of fish	Calculated total length at annulus			Average total length at capture
				1	2	3	
1966	1965	I	1,324	140.6			165.5
	1964	II	35	141.4	207.3		227.3
	1963	III	1	155.0	219.0	261.0	272.0
	Mean			140.6	207.6	261.0	
Average annual increment				140.6	67.0	53.4	
1967	1966	I	1,443	118.7			151.7
	1965	II	140	122.4	165.7		180.1
	1964	III	2	127.0	183.0	225.5	232.0
	Mean			119.0	165.9	225.5	
Average annual increment				119.0	46.9	59.6	

Age-groups can often be estimated, at least for the younger age-groups from length frequency distributions. Therefore, average lengths determined from scale reading and the average lengths established from length frequencies should agree. The modes for the combined length frequencies of white crappie and gizzard shad collected in 1966 and 1967 are shown in Figures 22,23,24 and 25. The average lengths at capture, as suggested by these modes, are shown in Table 11. These lengths are very close to those indicated for the age-groups 0, I and II of gizzard shad and age-groups I and II of white crappie in both 1966 and 1967.

Limits were established from the length-frequency histograms (Figs. 22,23,24, and 25) for each age group by visual inspection (Table 12). These results show that the limits calculated for age-groups I and II of the 1966 and 1967 white crappie, age-groups 0, I, and II of the 1966 shad, and age-groups 0 and I of the 1967 shad agree well with limits determined visually, but age-group II in the 1967 shad collection do not. Very few fish of age-group II in the 1967 shad collection fit the limits of the length-frequency histogram as most of the age-group came from a population having a disproportionate number of small fish. Age-group III of gizzard shad and age-groups III and IV of white crappie are represented by very few specimen. Therefore, it is difficult to establish interval limits of their total lengths from the length-frequency histograms.

Figure 22. Combined length-frequency histogram of white crappie, collected from Keystone Reservoir, Oklahoma, 1966 with age groups as determined by scales.

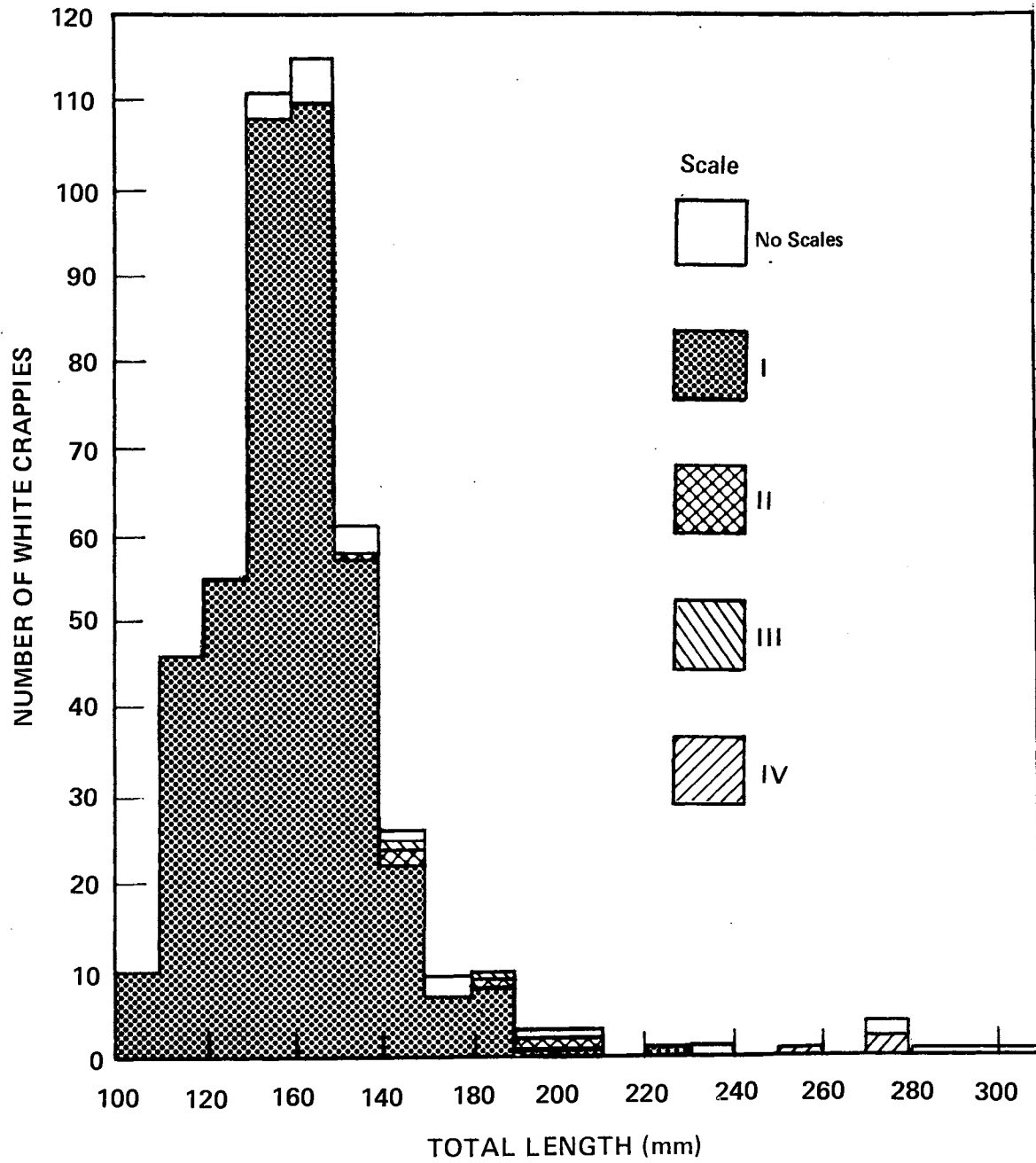


Figure 23. Combined length-frequency histogram of white crappie, collected from Keystone Reservoir, Oklahoma, 1967, with age-groups as determined by scales.

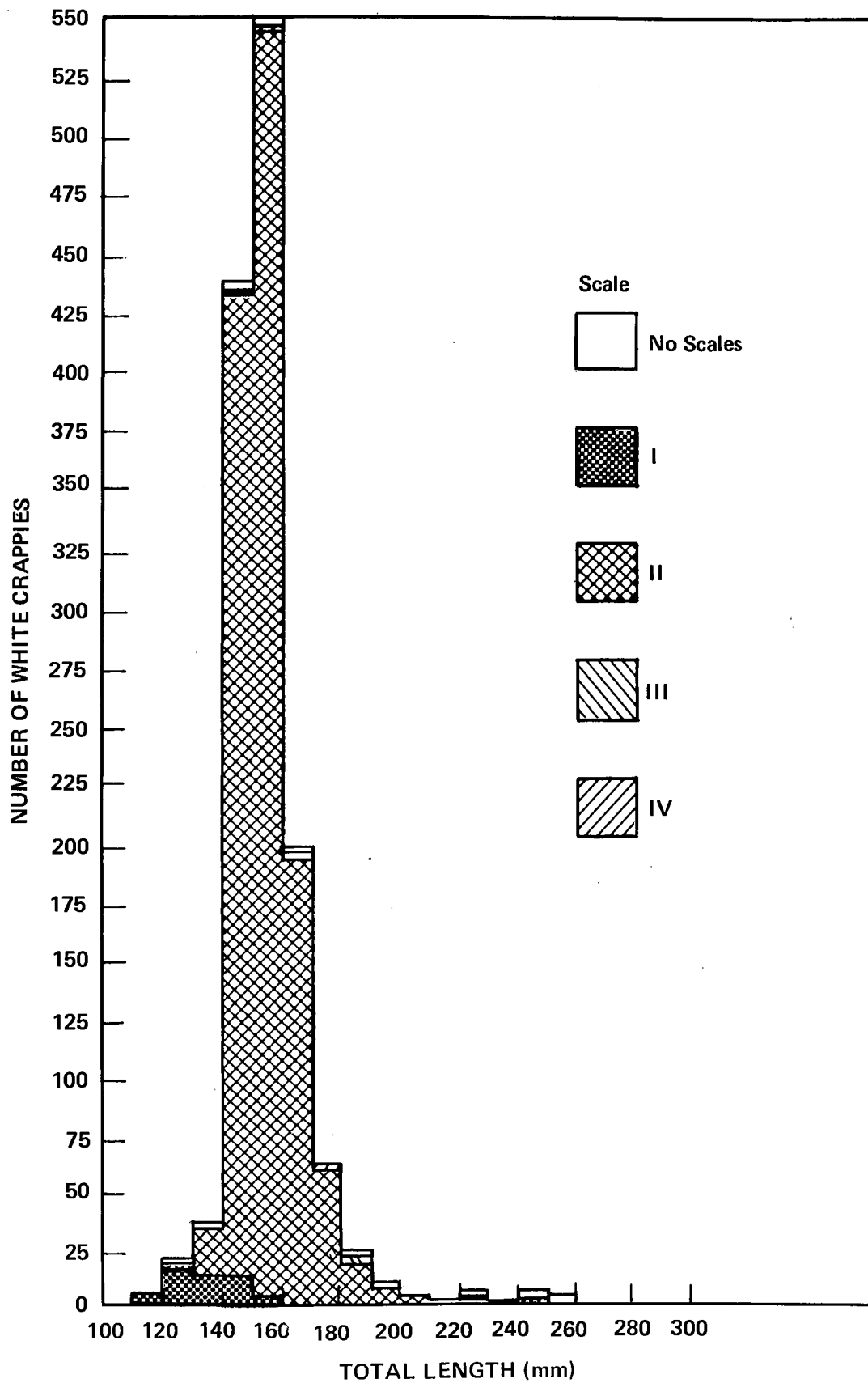


Figure 24. Combined length-frequency histogram of gizzard shad, collected from Keystone Reservoir, Oklahoma, 1966 with age-groups as determined by scales.

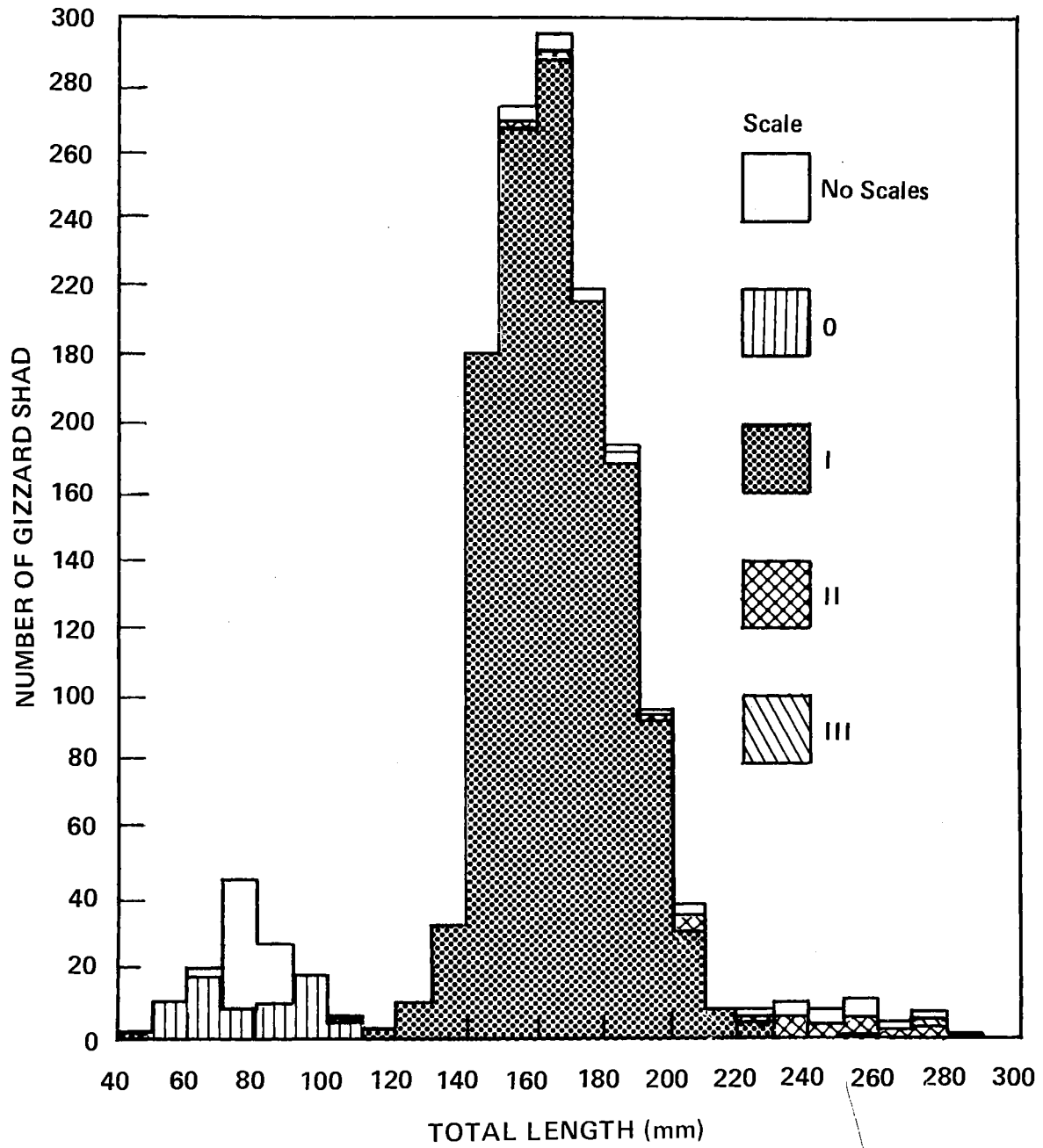


Figure 25. Combined length-frequency histogram of gizzard shad, collected from Keystone Reservoir, Oklahoma, 1967 with age-groups as determined by scales.

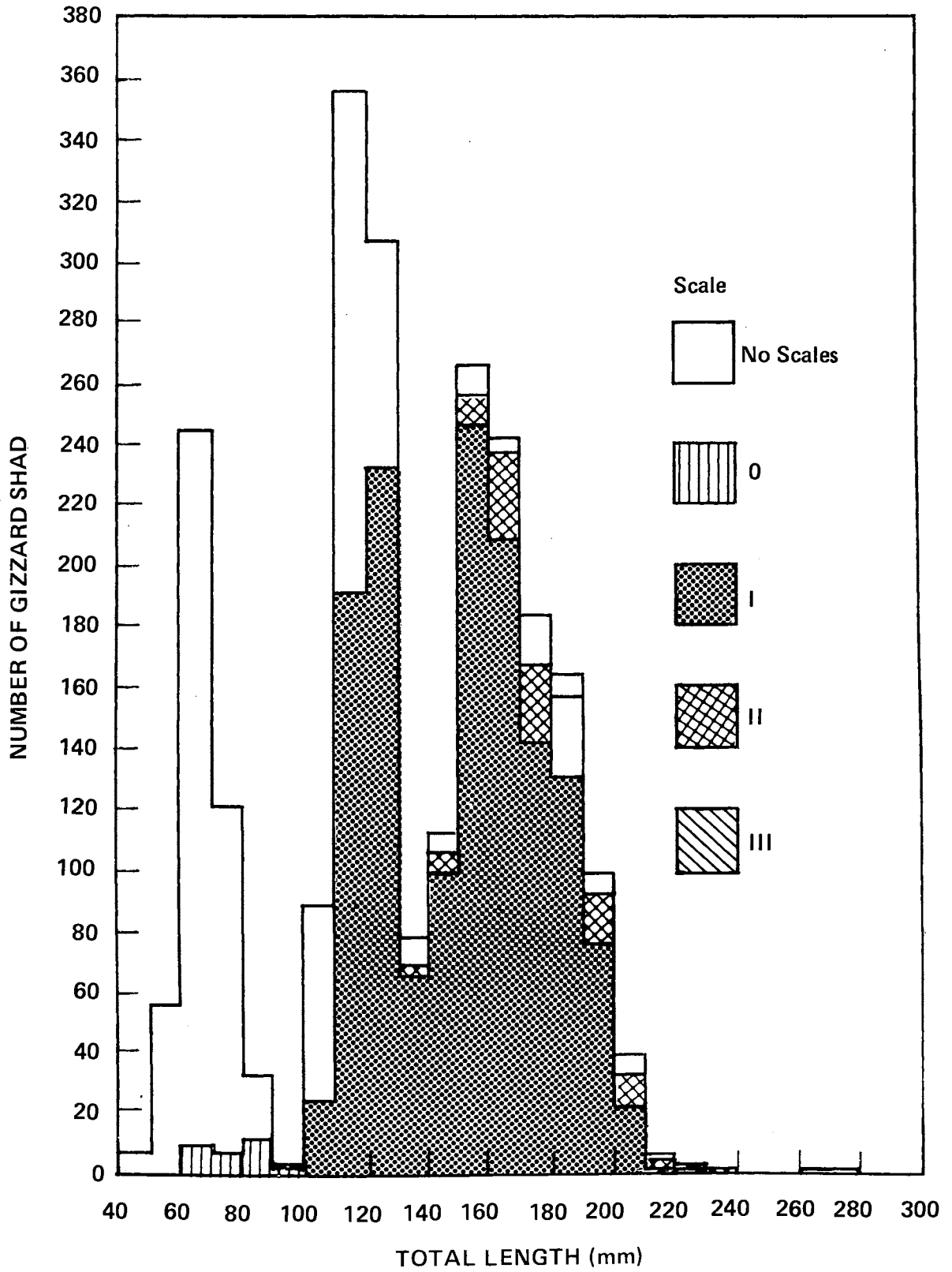


Table 11. Average total length (mm) at capture of different age groups, as estimated from the length frequency histograms and the total lengths calculated from the scale readings, of gizzard shad and white crappie collected from Keystone Reservoir, Oklahoma, 1966 and 1967.

Fish and year of capture	Age group	Average total length estimated from length- frequency histograms	Average calculated total length at capture
Gizzard shad 1966	0	75	80.0
	I	165	165.5
	II	230	227.3
Gizzard shad 1967	0	70	76.6
	I	150	151.0
	II	180	180.1
White crappie 1966	I	140	138.7
	II	180	177.7
White crappie 1967	I	135	136.4
	II	155	153.7

Table 12. Age class composition and the number and percentages of fish in each age group. Limits for each were established from the length frequency histograms of white crappie and gizzard shad collected from Keystone Reservoir, Oklahoma, 1966 and 1967.

Fish and year of capture	Age group	Limits as determined from length frequencies (mm)	Number of fish based on scale reading	Number of fish within the limits in each age group	Fish within the limits (%)
White crappie 1966	I	100 - 169	423	405	95.7
	II	170 - 219	6	3	50.0
	Total		429	408	95.1
White crappie 1967	I	100 - 139	50	34	68.0
	II	140 - 200	1,264	1,239	98.0
	Total		1,314	1,273	96.9
Gizzard shad 1966	0	40 - 109	65	65	100.0
	I	110 - 219	1,324	1,317	99.5
	II	220 - 279	35	21	60.0
	Total		1,424	1,403	98.5
Gizzard shad 1967	0	40 - 94	30	29	96.7
	I	95 - 209	1,443	1,440	99.8
	II	210 - 200	140	6	4.2
Total		1,585	1,475	92.9	

Agreements Among Calculated Growth Histories

Lengths at the end of various years of life calculated from scale measurements should agree well with the corresponding empirical lengths of younger age-groups whose ages were determined by the examination of scales. Total lengths at capture (Tables 9 and 10) for age-group I fish are between the average calculated lengths at annulus 1 and 2; the lengths at capture for age-group II fish are between the average calculated lengths at annulus 2 and 3, etc., for both species in both the 1966 and 1967 collections.

There should also be agreement between calculated data on length of fish collected in different years and in different samples. Tables 9 and 10 show that there is a good agreement between the calculated length of crappie of the same age collected in 1966 and those collected in 1967 except where few specimens were collected. Some of the disagreements might be due to the fact that the average rate of growth varies from one year to another. Therefore, comparison between mean calculated lengths of different samples is more meaningful. The average lengths of white crappie calculated from scale examination are very consistent in age-group I in 1966 and age-group II in 1967 where sufficient numbers of fish are present (Tables 5 and 6).

Table 10 indicates that there are noticeable differences between the average calculated lengths of shad in the 1966 and the 1967 collections. However, it has been stated that two different populations may exist within the 1967 collection which resulted in such a discrepancy. The lower mean total lengths calculated for 1967 shad might be partially due to decrease in rate of growth with the aging of the reservoir. Jenkins

(1953) showed that the average rate of growth of white crappie in new reservoirs (3 years old or less) is higher than their rate of growth in older reservoirs. Data in this study also shows a gradual decrease in the rate of growth of both crappie and gizzard shad (Tables 13,14,15,16, and 17). In general, the growth data for different age groups of the same year's collections are quite similar, with some exceptions in the 1967 shad collection (Tables 5,6,7, and 8).

More important, however, there should also be good agreement of growth histories of the different age-groups of the same year-class. This is well illustrated for white crappie (Table 18) except for the 1963 year-class where lengths of age-groups II and IV were calculated from the scales of only three specimens.

Since it has been pointed out that the 1966 and 1967 shad collections are not comparable, the validity of the age determination for shad can best be tested by comparing the data from the various half-monthly samples. The fairly consistent (less than 5.47 percent of the average calculated total length for all samples combined) average calculated lengths for each age-group in all the 1966 samples where sample size is adequate (Table 7), suggests that the scale readings for the 1966 data are generally valid. Discrepancies have been shown in the 1967 shad collection (Table 8) and the probable reason for the discrepancies has been suggested. However, when the two populations were partially separated, the average calculated lengths for the half-monthly samples of both populations were found to be fairly consistent (Table 19), which suggests that the 1967 scale readings are also valid.

There should be good agreement among different year-classes as to the goodness or poorness of growth in certain calendar years. To

Table 13. Annual increments of growth in length (mm) of white crappie and gizzard shad collected from Keystone Reservoir, Oklahoma, 1966 and 1967.

Fish and year of capture	Year of life	Increment of growth in calendar year				
		1962	1963	1964	1965	1966
White crappie 1966	4				44.3	
	3			55.0	27.5-	
	2		48.4	40.0-	36.2-	
	1	107.3	05.0-	122.3+	111.5-	
White crappie 1967	4					19.0-
	3				32.0	28.5-
	2			47.0	39.7-	33.1-
	1		123.0	118.3-	110.6-	110.9+
Shad 1966	3				42.0	
	2			64.0	65.9+	
	1		155.0	141.4-	140.6-	
Shad 1967	3					42.5
	2				56.0	43.3-
	1			127.0	122.4-	118.7-

Table 14. Annual mean increments of growth (mm) of white crappie collected from Keystone Reservoir, Oklahoma, 1966 and 1967.

Year of life	Increment of growth in calendar year				
	1962	1963	1964	1965	1966
4				44.3	19.0
3			55.0	29.7	28.5
2		48.8	43.5	38.0	38.1
1	107.3	109.0	120.3	111.0	110.9

Table 15. Annual mean increments of growth (mm) of gizzard shad collected from Keystone Reservoir, Oklahoma, 1966 and 1967.

Year of life	Increment of growth in calendar year			
	1963	1964	1965	1966
3			42.0	42.5
2		64.0	61.0	43.3
1	155.0	134.2	131.5	118.7

Table 16. Hile index for white crappie collected from Keystone Reservoir, Oklahoma, 1966 and 1967.

Years involved in comparison	Growth in early year (mm)	Growth in later year (mm)	Average	Change in growth (mm)	Change in growth %	Year	% of deviation from	
							1962 level	1962-66 average
1962 and 63	107.3	109.0	108.15	+ 1.7	+ 1.99	1962	0.00	+ 7.97
1963 and 64	157.8	163.8	160.80	+ 6.0	+ 3.73	1963	+ 0.99	+ 8.96
1964 and 65	218.8	178.7	198.75	-40.1	-20.18	1964	+ 2.70	+10.67
1965 and 66	223.0	196.5	209.75	-26.5	-12.63	1965	-15.46	- 7.49
						1966	-28.09	-20.12
Total							-39.86	
Average							- 7.97	

Table 17. Hile index for gizzard shad collected from Keystone Reservoir, Oklahoma, 1966 and 1967.

Years involved in comparison	Growth in earlier year (mm)	Growth in later year (mm)	Average	Change in growth (mm)	Change in growth %	Year	% deviation	
							1963 level	1962-63 average
1963 and 64	155.0	134.2	144.6	-20.8	-14.38	1963	0.00	+13.95
1964 and 65	198.2	192.5	195.3	- 5.7	- 2.92	1964	-14.38	- 0.43
1965 and 66	234.5	234.5	219.5	-15.0	- 6.83	1965	-17.30	- 3.35
						1966	-24.13	-10.18
Total							-55.81	
Average							-13.95	

Table 18. Average calculated total lengths (mm) of white crappie of certain year-classes collected from Keystone Reservoir, Oklahoma, 1966 and 1967.

Year class	Age group	Number of fish	Average calculated total length at annulus			
			1	2	3	4
1966	I	50	110.9			
1965	I	423	111.5			
	II	1264	110.6	143.7		
1964	II	6	122.3	158.5		
	III	10	118.3	158.0	186.5	
1963	III	2	95.0	135.0	162.5	
	IV	1	123.0	170.0	202.0	221.0

Table 19. Average total length (mm) of the two populations of gizzard shad in the 1967 collection. Small-sized population includes fish 134 mm or less in total length. Large-sized population includes fish with 135 mm or more in total length.

Date	Small-sized population			Large-sized population		
	Number of fish	Total length at 1st annulus	Total length at capture	Number of fish	Total length at 1st annulus	Total length at capture
6/1-15	30	106.1	121.6	197	133.7	170.7
6/16-30	19	100.8	126.1	102	129.0	164.2
7/1-15	31	98.9	120.0	52	122.3	161.0
7/16-31	111	99.7	122.4	102	119.0	155.3
8/1-15	108	97.5	120.4	117	127.6	166.2
8/16-31	47	95.7	117.5	175	126.4	166.7
9/1-15	112	98.5	120.6	85	124.7	163.4
9/16-30	38	98.2	121.7	117	133.9	176.2
Total	496	98.8	121.1	947	128.1	166.6

illustrate this point, the technique used by Hile (1941) was used, and the results demonstrated that in a particular calendar year the growth increments tended to increase or decrease consistently in comparison with corresponding increments of the preceding year (Table 13).

Persistence, Abundance, or Scarcity of Certain Year-Classes

The mortality rate of gizzard shad is very high and the number of fish of a particular year-class that survive from one year to the next is rather low. Therefore, it will be impossible to use the data for testing the abundance or scarcity of a year-class of shad over a period of years. Thus, a comparison was made for the abundance of various year-classes in the samples taken in 1966 and in the samples taken in 1967. The results (Table 20) shows that the age-group I shad (the 1965 year-class in the 1966 collection and the 1966 year-class in the 1967 collection) is the most abundant year-class collected.

The 1965 year-class of white crappie was the first to hatch in the reservoir and became the dominant year-class in both the 1966 and the 1967 collections (Table 21). This year-class was also the dominant year-class in all the samples collected in 1966 and 1967.

Length at Capture During Growing Season

Al-Rawi (1964) used another line of evidence for testing the validity of the scale method. There must be a gradual increase in the average length at capture for a particular age-group with the progress of the growing season. In general increases in the average lengths at capture of a particular age-group are evident in the 1966 and the 1967 crappie data (Figs. 26 and 27) and in the 1966 shad data (Fig. 28) as

Table 20. Age class composition (in percentages) of gizzard shad collected from Keystone Reservoir, Oklahoma, by half-month periods, 1966 and 1967.

Year	Year class	Age group	Date of collection								Total
			6/1-6/15	6/16-6/30	7/1-7/15	7/16-7/31	8/1-8/15	8/16-8/31	9/1-9/15	9/16-9/30	
1966	1965	I			98.7	97.0	94.9	97.7	98.4	98.5	97.5
	1964	II			1.3	3.0	5.1	2.3	1.1	1.5	2.4
	1963	III							0.5		0.1
	Total number				161	359	234	218	189	199	1360
1967	1966	I	90.0	84.6	93.3	88.8	93.7	92.1	93.4	91.7	91.0
	1965	II	10.0	14.7	6.7	10.8	6.3	7.9	6.6	8.3	8.9
	1964	III		0.7		0.4					0.1
	Total number		241	143	89	240	240	252	211	169	1585

Table 21. Age class composition (in percentages) of white crappie collected from Keystone Reservoir, by half-month periods, 1966 and 1967.

Year	Year class	Age group	Date of collection								Total
			6/1-6/15	6/16-6/30	7/1-7/15	7/16-7/31	8/1-8/15	8/16-8/31	9/1-9/15	9/16-9/30	
1966	1965	I					98.3	93.5	97.7	100.0	97.5
	1964	II					0.4	4.3	2.3		1.4
	1963	III					0.4	1.1			0.5
	1962	IV					0.9	1.1			0.6
		Total number					233	92	44	65	434
1967	1966	I	0.5	0.8	6.2	5.1	4.3	4.8	2.1	6.1	3.8
	1965	II	97.5	99.2	91.5	94.4	95.3	94.3	97.9	93.9	95.4
	1964	III	1.5		2.3	0.5	0.4	0.9			0.7
	1963	IV	0.5								
		Total number		193	121	130	413	233	105	97	33

Figure 26. Length-frequency histograms of white crappie, collected from Keystone Reservoir, Oklahoma, 1966.

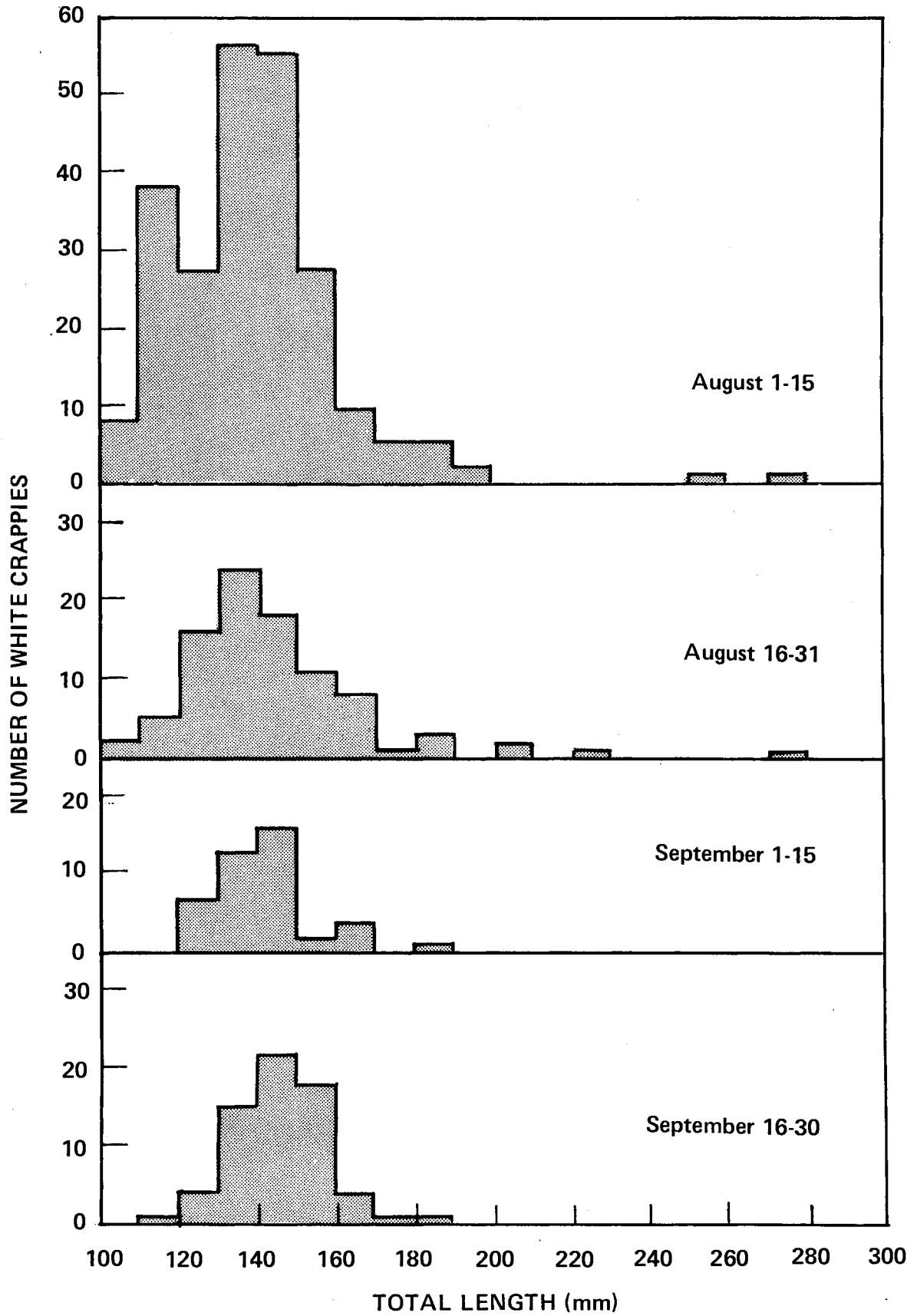


Figure 27. Length-frequency histograms of white crappie, collected from Keystone Reservoir, Oklahoma, 1967.

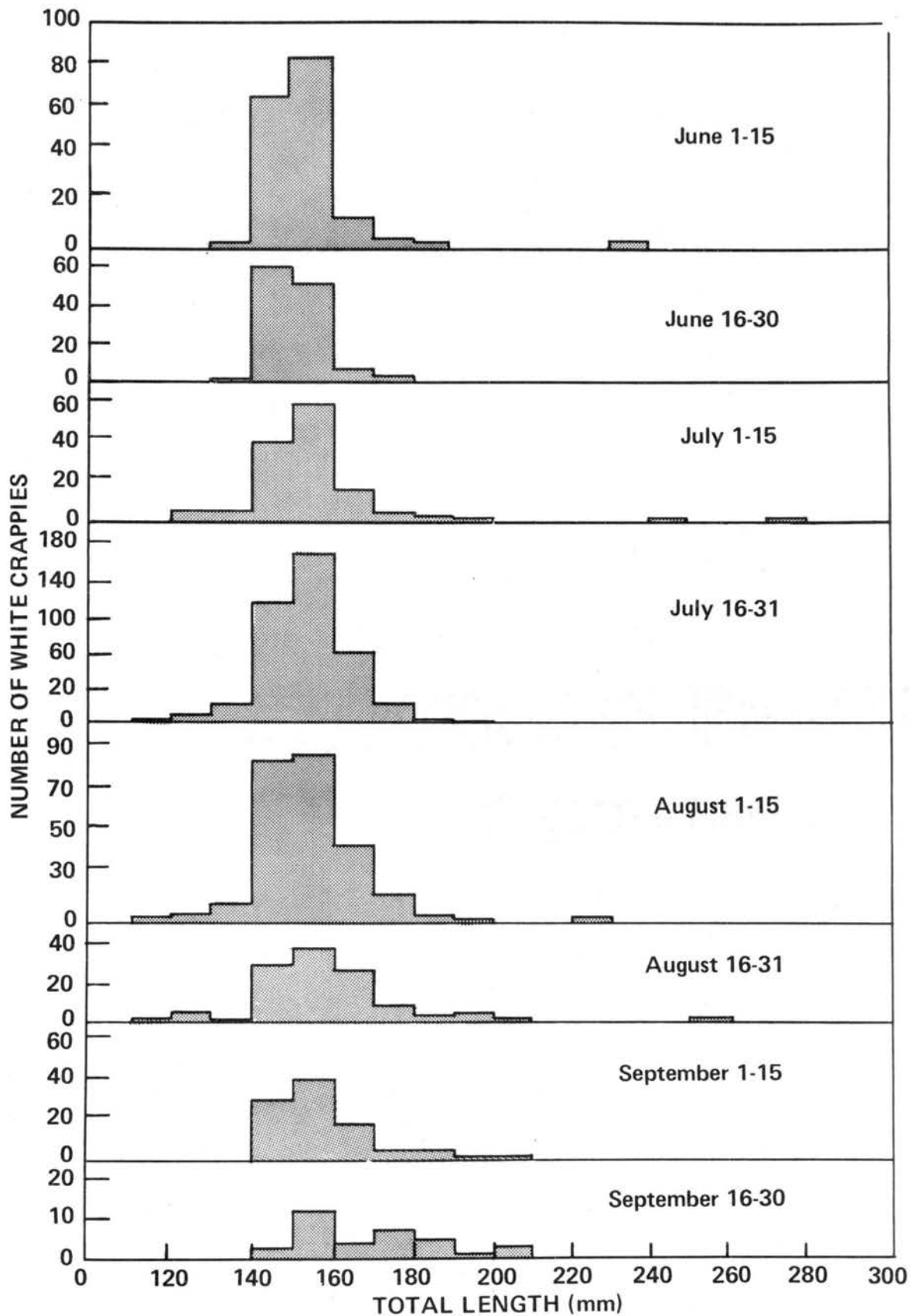
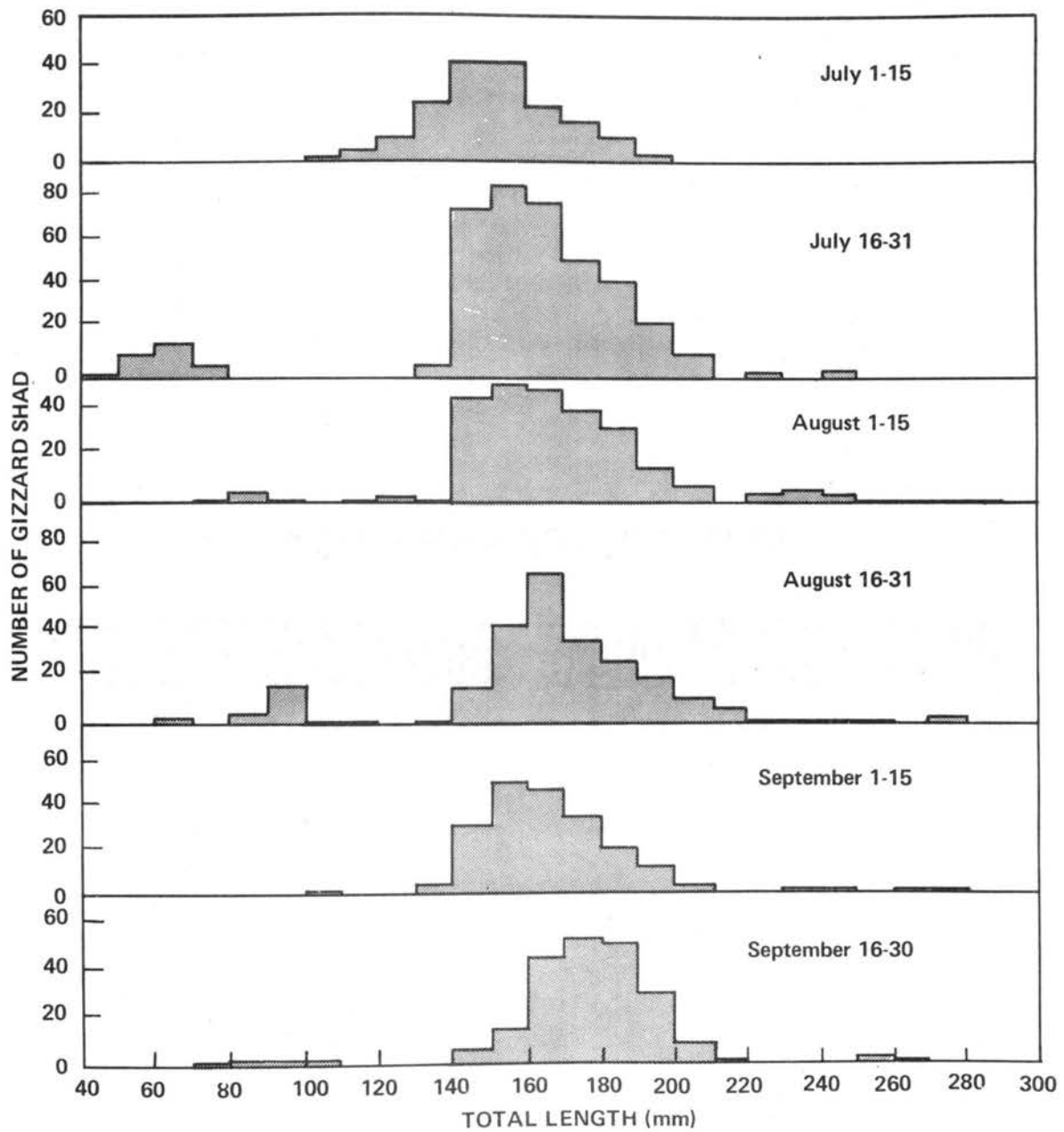


Figure 28. Length-frequency histograms of gizzard shad, collected from Keystone Reservoir, Oklahoma, 1966.

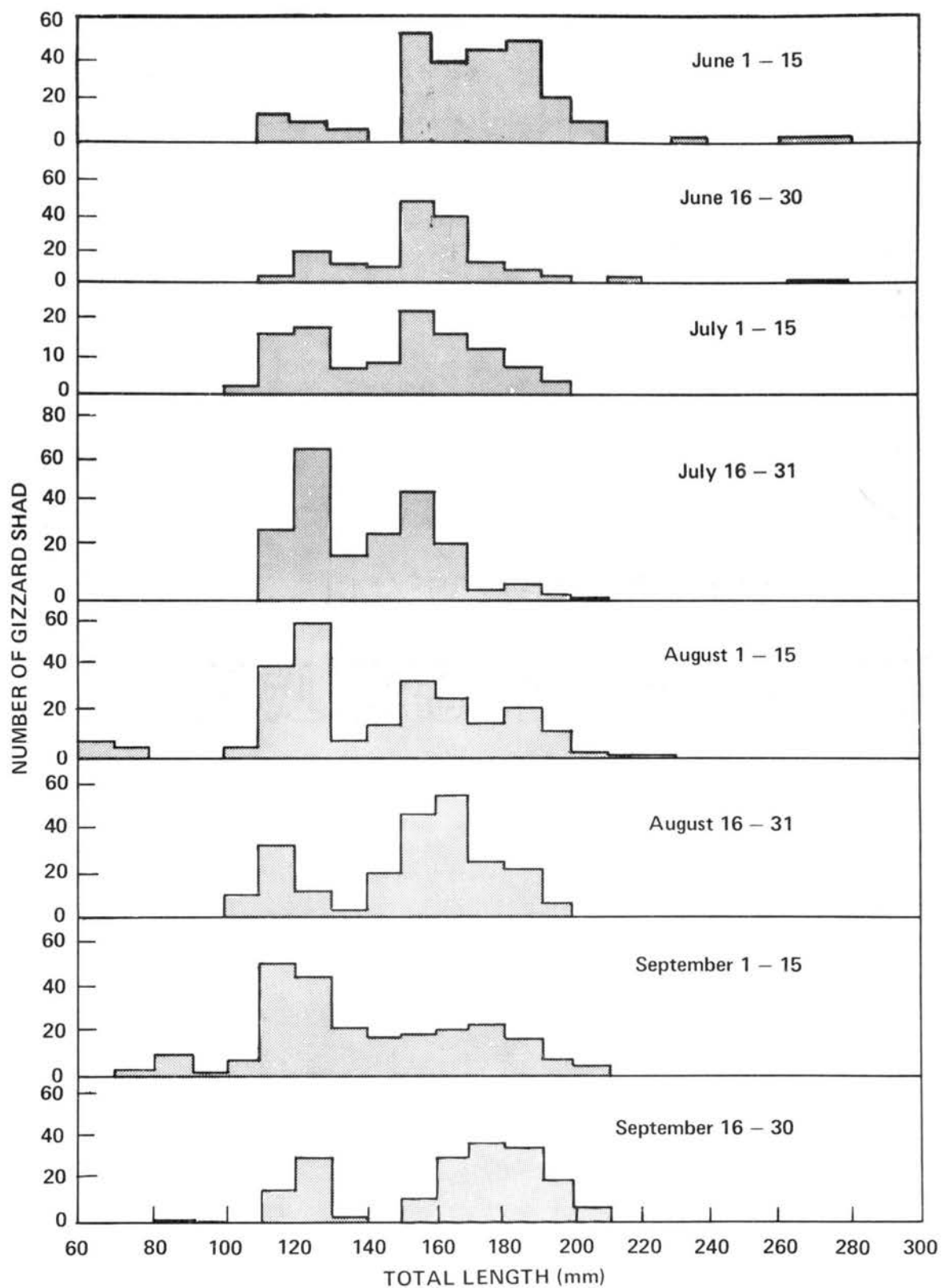


well as in the 1967 shad data, when the two populations are examined separately (Fig. 29). This is also well illustrated in Tables 5 and 7 for the 1966 crappie and shad data except for the groups which are represented by very small numbers of fish. It must be noted that four shad that were collected in 1966 during the first half of July and assigned to age-group 0 are actually one year old but they had not formed an annulus yet. It is also evident to some extent, in the 1967 crappie data (Table 6), and for the 0 age-group of the 1967 shad data (Table 8). The fact that the remainder of the 1967 shad data did not conform with this criterion, is another line of evidence to illustrate two discrete populations of shad were collected during 1967.

It has been shown that the annulus is formed during a certain definite period of the year (Fraser, 1916; Clark, 1925; Hansen, 1936 and 1951; Bucholz, 1957; Hall, Jenkins, and Finnell, 1954). The above can best be illustrated by calculating the growth increments between the last annulus and the edge of scales by half-month intervals (Tables 5, 6, 7, and 8). The marginal growth for the 1966 and the 1967 crappie and the 1966 shad as well as age-group 0 of the 1967 data, increased with the progress of the season as would be expected, except for the 1967 shad, excluding age-group 0, because two populations may exist, and the poorly represented age groups.

In addition to the above established criteria, another criterion was established in this study. Since the growth, in most species, is continued through the autumn months and even during winter, we can assume that in any particular year-class the average calculated growth increment for the last annum should exceed, or at least equal, the growth between the last annulus and the margin (marginal increment) in

Figure 29. Length-frequency histograms of gizzard shad, collected from Keystone Reservoir, Oklahoma, 1967.



the previous year. For example, Table 22 shows that the average size of the age-group I shad in 1967 was 118.7 mm which is greater than the average total length of the 0 age-group in 1966 (80.0 mm) and also greater than the maximum length that age-group 0 attained during the last part of September of 1966 (92.6 mm). The 1963 year-class of white crappie is an exception. Here the mean calculated increment for the last annulus was smaller than the maximum marginal growth increment attained in the preceeding year. However, it is still greater than the average marginal increment of that year, although the 1963 year-class was represented by only two fish (age group II) in the 1966 data and by 3 fish (age group IV) in the 1967 collection.

Table 22. Marginal and annual increment (mm) for different year classes of white crappie and gizzard shad collected from Keystone Reservoir, Oklahoma, 1966 and 1967.¹

Species	Year	Compared age groups		Marginal increments in previous year		Mean increment for the last annum	Increment after Sept. 30	% Increment after Sept. 30
		1966	1967	maximum	mean			
Shad	1966	0	I	92.6	80.0	125.2	45.2	36.1
	1965	I	II	27.6	24.9	43.0	18.1	42.1
	1964	II	III	23.6	20.0	42.5	22.5	52.1
Crappie	1965	I	II	31.4	27.2	33.1	5.9	17.8
	1964	II	III	19.2	26.0	28.5	2.5	8.8
	1963	III	IV	21.0	14.0	19.0	5.0	26.3

¹Marginal growth is that between the last annulus and the margin. Annual growth is that between the focus and the first annulus or between two adjacent annuli.

CHAPTER VII

THE 1967 SHAD COLLECTION

A significant number of small shad scales collected during 1967 had one clear, well-defined annulus (Figs. 16 and 18). These scales were taken from fish much smaller than those collected in 1966, and most of those collected in 1967. Furthermore, the scale method was not completely valid for calculating growth of 1967 shad as discussed earlier. These observations, together with an inspection of the length frequency histograms (Figures 25 and 29) suggested that two populations might be represented in the shad collection in 1967.

These two populations apparently overlap in the 130-140 mm range (Figure 25). The assumption was made that shad belonging to the small-sized population had a total length of 134 mm while those belonging to the large-sized population were longer than this. The average total lengths at the first annulus and at capture were calculated (Table 19) for both groups. These data clearly show that the average total length of fish in each population at the first annulus are very similar regardless of the date of capture. However, the average total length at annulus I for the small fish is greatly different from that of the other population. The small-sized population has an average total length of 98.1 mm at the first annulus while the large-sized population has an average total length of 128.1 mm. Total length at capture can not be used to test if the differences in the mean total lengths

between the two populations are significant, because an upper limit of 134 mm was imposed on the small-sized population. Therefore, comparison was made between the two populations on the basis of the total length they attained at the end of the first growing season as computed from their scales. Carlander (1950) suggested that lengths at time of last annulus might be more valid for comparative purposes in fish studies than lengths at capture. A t-test was conducted to learn if the average total length at first annulus of the small-sized population was different from the average total length at first annulus of the large-sized population. The t-test indicated that the two populations were significantly different from each other ($t = 2.648$) at the 95 percent confidence level.

There are two explanations as to the source of these two populations. The first is related to a fish kill on 22 July, 1966 (Eley, Carter and Dorris, 1968) and the author's personal observations. It could be assumed that a second shad hatch took place after July, since it is reported that shad have a prolonged spawning season (Miller, 1960). Therefore a large proportion of shad possibly came from the hatch that might have occurred after July.

Gunther (1938) stated that spawning of shad takes place in fresh water from late winter (mid-March) through most of the summer (at least to August 20). Miller (1960) stated that the bulk of the population that inhabit the warm to temperate waters of the United States (28° to 41° N. latitude) spawns during April, May, and June at temperatures between about 50° and 70° F. (Sampling area in this study is between 36° and 37° N. latitude.) In Iowa, the species is reported to spawn in late April or early May (Harland and Speaker, 1956). In Florida,

spawning was first observed in March in 1954 and 1955 and the peak of spawning occurred around the end of March and the beginning of April of both years, and conditions substantiated that spawning may possibly have occurred in February (Berry, 1958). However, the onset of spawning seems to vary with local weather. Swingle (1949) reported that in experimental ponds at Auburn, Alabama, gizzard shad hatched at the end of April in 1941 but first appeared in the middle of March in 1942; in 1941 the last brood hatched on August 20, but in 1942, hatching continued only into July. Bodola (1966) stated that gizzard shad in Western Lake Erie spawn from early June to mid-July. He also thinks that temperature is the important factor in the onset and progress of spawning. He reported that gizzard shad appeared in the net at temperatures of 59 F and were common at about 67 F; and, when temperature dropped to about 65 and 65.5 F in mid-June the numbers of shad also dropped. Warner (1941) also reported 15.0-15.5 (59-60 F) as the normal water temperature for initial spawning of gizzard shad in Ohio, and the spawning period normally extends over about two weeks and one ripe female was taken in the latter part of July. Cramer and Marzolf (1970) reported that gizzard shad larvae first appeared on May 22, in samples they collected with tow nets from Tuttle Creek Reservoir, Kansas. They also reported that the surface water temperature, at that date, was 16.5 C (61.5 F). In Keystone Reservoir an average surface water temperature of 14.5 C was recorded for April in 1966 (Dr. Rex Eley, unpublished data).

The variations in the average calculated total lengths in the 1965 data suggest a prolonged spawning period (Lagler and Applegate, 1942). The spawning period would have to be protracted for the present

hypothesis to hold. Young of the year fish were observed in the samples taken during the second half of July in 1966 and in the first half of August in 1967 and averaged 63.7 mm and 69.0 mm in total length respectively. This fact, plus the fact that the April water temperature in Keystone Reservoir correspond with those temperatures reported as the optimum temperature for initial spawning, suggest an early spring spawning of this species in Keystone Reservoir. The gradual increase in the average total length of age-group 0 in 1966 and 1967 without interruption also suggests that spawning took place only early in the season. But since no gizzard shad less than 44 mm in total length were taken with the sampling gear (electric shocker) in this study, a second hatch after July 22 is still possible. These fish would have escaped collection due to their small size. But the depression of the average total lengths of both age-group I and age-group II during the same periods when the small-sized shad are most abundant, and the presence of this small-sized group in small proportions in the samples collected during June and the second half of September, but not during July and August, favors a second hypothesis.

The second hypothesis is that the Cimarron arm and the Arkansas arm of Keystone Reservoir support two different populations of shad. The absence of small fish in the 1966 collection may be due to the great distance of the Arkansas arm from the sampling area (Fig. 1). Therefore, the 1966 collection would have to come from local stock.

Only small numbers of shad belonging to the small-sized population were collected in June and in late September. They were most abundant in collections made between mid-July and mid-August. This suggests that this small-sized population is not local, but had

migrated to the Salt Creek Cove area from another locality. This assumption is supported by the fact that during the period from July 22 to July 27, large numbers of shad were seen by the author moving into Salt Creek Cove in the portion south of State Highway 51. They were so dense they could have been scooped with dip nets. The fish were seen to about a meter below the water surface and were generally small in size. At that time, it was thought that they were either feeding on plankton that might be more abundant near the surface or were seeking more oxygenated water. Gizzard shads are known to be migratory. These fish are primarily marine and enter brackish water for spawning (Miller, 1960). The gizzard shad are landlocked, completing their whole life cycle in inland waters (Miller, 1960). Spawning migration up the Mississippi River was reported (Gowanloch, 1933) but no exact date was given. Swanson (1932) reported upstream migration of gizzard shad in the Minnesota rivers and streams during midwinter months. Miller (1960) stated that in the Chesapeake Bay region there is a fall "run" in September and October, and that a corresponding spring "run" has been recorded in North Carolina. In Keystone, Reservoir, Eley, Carter and Dorris (1968) reported that gizzard shad were more numerous in the upper stations during the fall, but were in large numbers at station four during winter and were most abundant at the lower stations during the summer (Fig. 1).

This explanation is also supported by data based on 21 shad specimens collected from the Arkansas River before the reservoir was constructed (Linton, 1961). The data indicate that the average size of these fish was smaller than the average size of gizzard shad collected in other Oklahoma waters. The differences are more pronounced in the

smaller age groups (Table 23). Interestingly, the average total length at the first annulus (97 mm) is similar to that calculated from the small-sized groups in the present study (98.1 mm). Hubbs and Whitlock (1928) found that young gizzard shad collected from the Arkansas River seem to be abnormal and differed greatly from those collected from the Poteau River. The abnormality of the Arkansas River specimens appear to be related to the excessive siltiness of the water in which they were living (Hubbs and Whitlock, 1928). These differences become less conspicuous in larger fish. The assumption that the Cimarron and the Arkansas Rivers have two races of shad and that the small race is of an Arkansas River origin is reasonably valid.

Table 23. Average total length (mm) of gizzard shad collected from the Arkansas River compared to the average total lengths of shad collected elsewhere in Oklahoma (Linton, 1961). Original data were recorded by inches and were transferred to mm by the author using conversion tables in Carlander (1950a).

	No. of fish	Average calculated total length at annulus						
		1	2	3	4	5	6	7
Arkansas River	23	97	175	221	264	302	325	238
Okla. State Average	1,082	117	193	241	282	315	238	338

If two different populations are represented in the shad population sampled during 1967, the problems of using scale validation criteria on

these fish can be resolved. The main points of the conflict were as follows. The calculated total lengths at the first annulus did not agree with observed lengths. There was no gradual increase in total length and in length increment with the progress of summer. The depression of the average total lengths at first annulus and at capture in some samples could be explained by the inclusion of large number of the small-sized population in those samples (Tables 8 and 19).

However, other problems remain. For examples, the average total lengths at capture and length increments should not be expected to increase with the progress of summer, even after the two populations were separated using the technique in this paper. That is because the separation is not complete. Members of the small-sized population that reached 135 mm in total length were included in the large-sized population as there was no way to identify fish to a population in the range of overlap. This can be illustrated by a simple mathematical example (Table 24). Assume a constant rate of growth of 5 mm per 0.5 month period and that the two populations contributed equal numbers of individuals to the two populations sampled, and that the annulus is formed the first of May.

Table 24 shows that the average total length in the mixed population dropped below the average total length of the large-sized group collected before the small-sized race entered the samples.

Data in Tables 8 and 19 show a trend similar to those illustrated in Table 24 which indicates that the interpretation of the discrepancies in the 1967 data is valid.

Another factor that can obscure the gradual increase in average total length and length increment with the progress of summer is that

Table 24. Theoretical total mean length (mm) at capture of the small-sized and large-sized population with a constant rate of growth to illustrate what happens to the gradual increase in total length, length increments and the half-month increments when the small-sized population reaches an average total length of 126 mm as suggested by actual data in Table 19 and contributes to the large-sized population.

Date	Expected total length of small-sized population	large-sized population	Lengths overlapping ¹ population	Assumed 1967 increment	Assumed $\frac{1}{2}$ month increment
5/1-15	105	130			
5/16-31	110	135		5	5
6/1-15	115	140		10	5
6/16-30	120	145		15	5
7/1-15	125	150	137.5	7.5	0
7/16-31	130	155	144.5	14.5	0
8/1-15	135	160	147.5	17.5	2.5
8/16-31	140	165	152.5	22.5	5
9/1-15	145	170	157.5	27.5	5
9/16-30	150	175	162.5	32.5	5

¹Mean total length when small-sized fish contribute to the population.

the fish from the small-sized population that could enter the large-sized population early in the summer are the fast growing fish and that the majority of these small fish entering the large-sized group in the samples collected in mid-summer. The result there will be a drop in the average total lengths and length increments of the samples collected during the mid-summer periods.

To show that the fish that might belong to the small-sized population that entered the large-sized groups are faster growing fish than the average small-sized population, but smaller than the average size of the large-sized groups, the variance and standar error of the average total lengths of the small-sized populations were calculated (9.572 and 3.09 respectively) and a confidence limit for the total length at the first annulus was established at the 95 percent confidence limit (92.1 - 106.7 mm). When the few individual fish within this limit were removed from the large-sized groups to the small-sized groups, the average total lengths, both at capture and at first annulus, increased for all groups (Table 19 and 25).

Table 25. Average total length (mm) of age group I of the two shad populations after fish within the limit interval of the small-sized group, at first annulus, moved from the large-sized group to the small-sized group.

Date	<u>Small-sized population</u>			Number of fish moved	<u>Large sized-population</u>		
	Number of fish	<u>Total length at first annulus capture</u>			Number of fish	<u>Total length at first annulus capture</u>	
6/1-15	34	106.1	126.1	4	193	134.9	171.2
7/16-30	21	101.8	128.0	2	100	129.5	164.6
7/1-15	35	99.1	122.8	4	48	124.1	162.6
7/16-31	116	99.8	123.5	5	97	119.9	155.7
8/1-15	114	97.9	121.9	6	111	128.9	167.2
8/16-31	56	97.2	123.7	9	166	127.6	167.7
9/1-15	119	99.0	121.9	7	78	126.4	165.5
9/16-30	40	98.5	122.9	2	115	134.5	176.8
Total	535				908		
Average		99.2	123.0			129.3	167.4

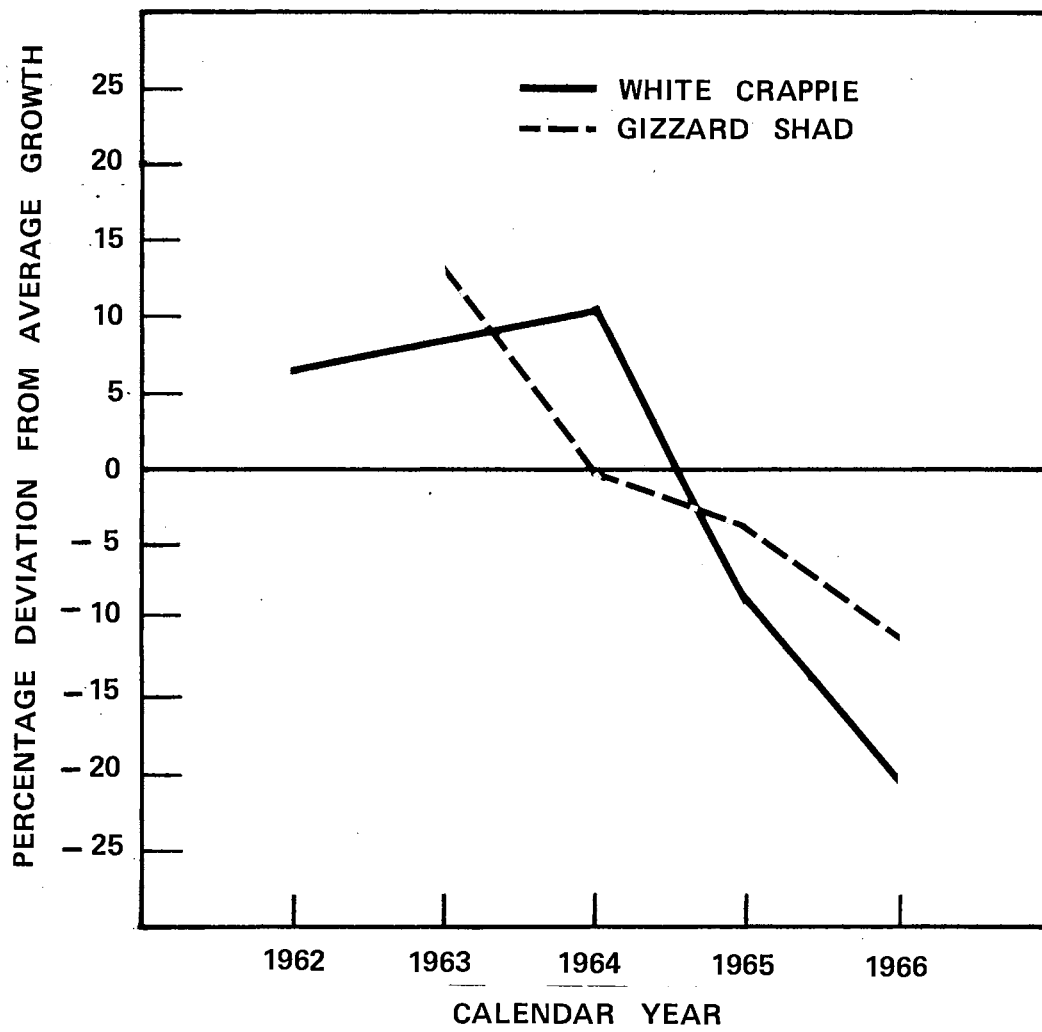
CHAPTER VIII

THE EFFECT OF WATER LEVEL ON GROWTH

These data were collected during the second and third year after the reservoir was filled, and this was the first age and growth study to be conducted on any species of fish in Keystone Lake. Therefore, the effect of water level on the rates of annual growth of fish cannot be determined from the present study because of the lack of a backlog of data. However, a Hile index (Table 17) indicated that the rate of growth of gizzard shad in 1965 was slower than that of 1963. Since gizzard shad (except newly hatched) feed mainly on phytoplankton and algae (Tiffany, 1920; Kutkuhn, 1958; and Cramer and Marzolf, 1970), the decrease in growth might be related to lower productivity in the reservoir compared to that of the rivers. Eley (1970) found that net productivity/biomass ratios decreased from 1.18 at station 1 to 0.97 at station 4 (Fig. 1), but gave no explanation for the decline. Thut (1969) stated that due to the high rates of primary production, the concentrations of CO₂ and available nitrogen are much reduced as the water flows downstream. Consequently, the standing crop of algae is much greater at the head of the stream than at the foot.

The Hile index for white crappie (Table 15 and Fig. 30) indicated that growth was best in 1964, the first year the reservoir was filled. The growth decreased in 1965 and 1966. Good rate of growth of white crappie in newly impounded reservoirs was also reported by Jenkins (1953). This

Figure 30. Annual percentage deviation of the growth of white crappie and gizzard shad collected from Keystone Reservoir, Oklahoma, during 1966 and 1967.



good rate of growth can be attributed to increase of food supply from terrestrial organisms washed into the lake during the filling process. Once the population increased and these additional food supplies were utilized, the rate of growth starts to decline. Good rate of growth in new waters were also reported for bluegills, Lepomis macrochirus, redear sunfish, Lepomis microlophus, green sunfish, Lepomis cyanellus, warmouth, Chaenobryttus gulosus, longear sunfish, Lepomis megalotis, (Jenkins, Elkin, and Finnell, 1955), and channel catfish, Ictalurus punctatus (Finnell and Jenkins, 1954).

On a period-to-period basis, the fluctuation in water level during the period of collection in 1966 was very small (Table 26 and Fig. 31). The average rate of growth of gizzard shad for both age-groups 0 and I decreased while the water level increased. The number of periods (3) for which growth could be calculated for age-group 0 shad was insufficient to permit calculation of the correlation coefficient relating growth to water level. The growth of age-group I gizzard shad was negatively related to water level with a correlation coefficient of .524, which is not significantly different from zero at the 95 percent confidence level. Although the correlation between water level and growth of gizzard shad was negative in 1966, the situation in 1967 was more complex. The only group that could be used to establish this relationship were 0-group. These fish followed a trend of decreasing growth similar to that in 1966 regardless of increase or decrease in water level. Therefore, these data do not show convincingly that the rate of growth of gizzard shad is related to fluctuation of water level. Keeton (1963) also found a significant negative correlation coefficient

Table 26. Average water level (feet above msl) and water temperature of Keystone Reservoir, Oklahoma and the average increments of white crappie and gizzard shad collected in 1966 and 1967.

Period	1966					1967		
	Water level	Temperature C°	Growth			Water level	Temperature C°	Growth Age II crappie
			Age I crappie	Age 0 shad	Age I shad			
April		14.2				15.8		
May		18.7				19.9	5.8	
June 1-15	723.31	25.4			720.69	23.9		
June 16-30	722.99		24.9		725.81	27.0	0.0	
July 1-15	722.92	29.0			727.13	25.1	4.9	
July 16-31	722.32				726.48	24.9	1.3	
August 1-15	722.62	30.0		20.9	724.24	24.4	0.4	
August 16-31	722.72		2.7	7.5	723.31	25.9	0.1	
Sept. 1-15	722.89	24.3	1.1		723.98	21.9	0.0	
Sept. 16-30	723.10	22.4	1.7	0.9	723.39	22.4	3.1	


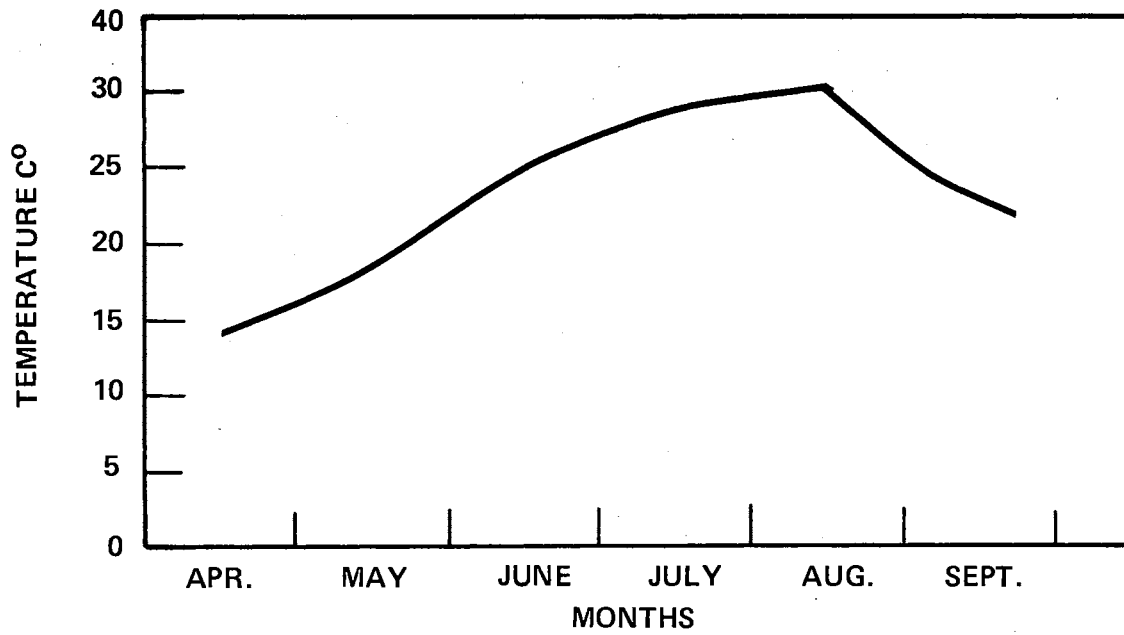
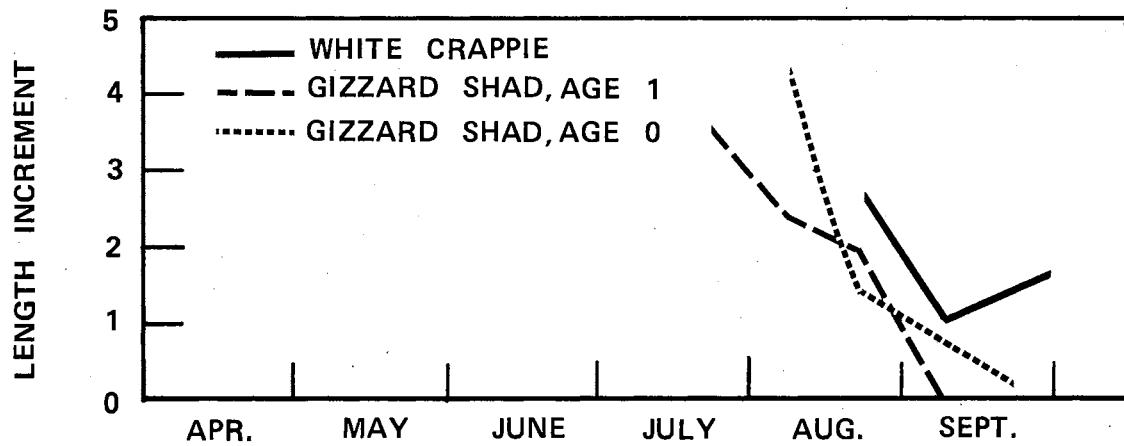
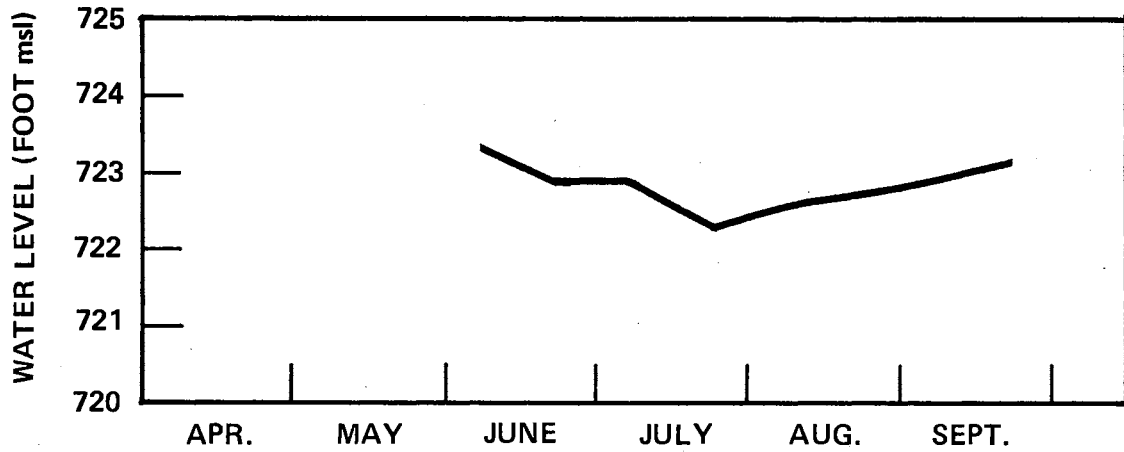


Figure 31. Average length increments of white crappie and gizzard shad collected from Keystone Reservoir, Oklahoma, during 1966 and average water levels and water temperatures. Each length increment unit represents 1 mm for age I shad and white crappie and 5 mm each for age 0 shad.

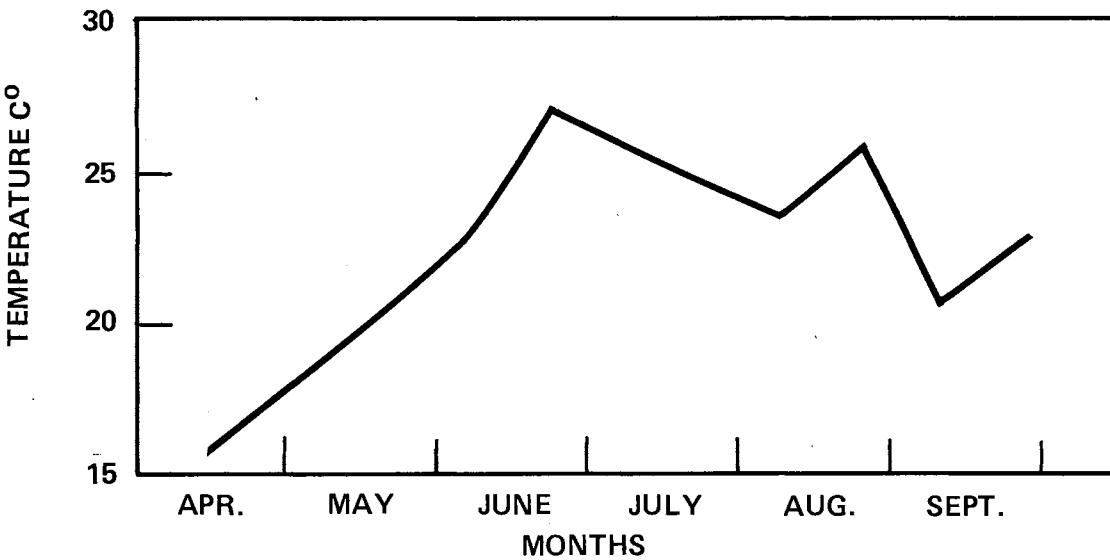
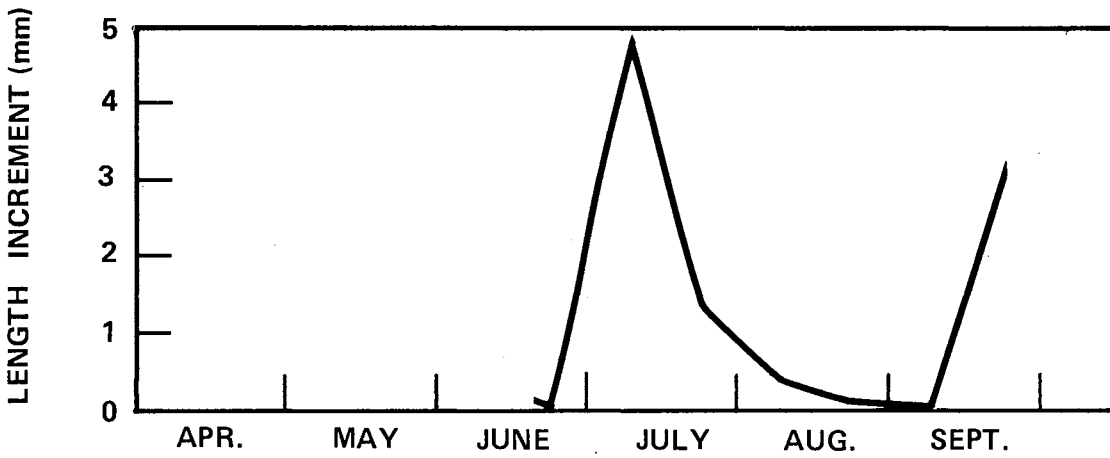
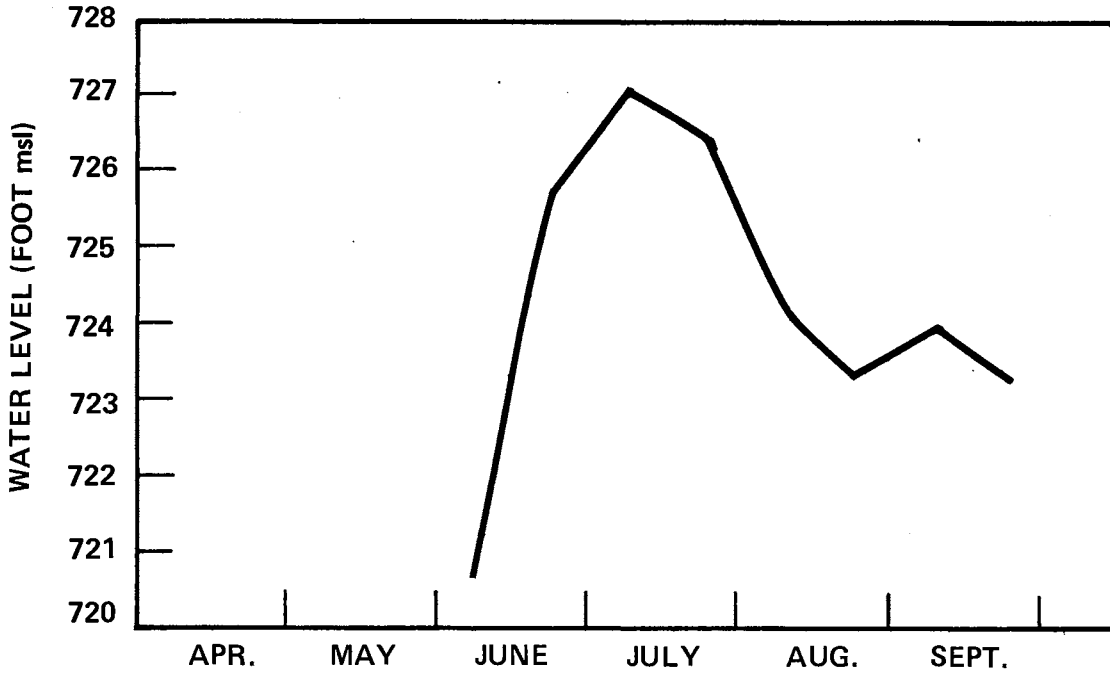


between water level and age-group I river carpsucker in the Des Moines River.

The growth of age-group I crappie in 1966 during the first half of September was less than during the second half of August, but during the second half of September, growth was high. These changes in the rate of growth were apparently independent of the fluctuation of water level, which was increasing steadily during that period. A departure from regular seasonal growth is also apparent from the 1967 data (Fig. 32) where crappie (age-group II) failed to grow during the second half of June. The water level was rising during that period from 720.69 to 725.81 ft msl. During the first half of July, the water level rose even higher, to 727.13 ft msl and the crappie showed the fastest rate of growth observed. These observations indicate that water level fluctuations and the growth of white crappie are not related. To confirm this conclusion statistically, a coefficient of correlation between the rate of growth and water level was calculated which turned out to be extremely low (.025).

Although no consistent correlation was observed between the fluctuation in water level and the growth, water level may have a profound effect on fish and fish food. The standing crop of plankton is likely to be reduced during high water levels. Galtsoff (1924) stated that the plankton of the river is subject to great fluctuation, depending on the stage of the water. He reported that during the rise of the water, the plankton is replaced almost entirely by detritus and silt. Similar findings were reported by Starrett and Patrick (1952) from the Des Moines River. They concluded that the fluctuations of water level are not favorable to plankton production. This water level effect is

Figure 32. Average length increments of white crappie collected from Keystone Reservoir, Oklahoma, during 1967 and average water levels and water temperatures.



not restricted to rivers but it is evident in lakes as well. Galtsoff (1924) reported an increase of plankton, especially in the copepods and cladocera populations, in newly formed lakes (Lake Keokuk and Lake Pepin on the Mississippi River and that such increase in plankton production occurs only at low stages of water and disappears during the rise of the river. This led Galtsoff to conclude that from a biological point of view the difference between the river and the lake exists only at a low stage and can disappear at every sudden rise of water. Reinard (1941) also found that the plankton in the Mississippi River decreased when water levels increased.

Studies regarding the effect of water levels on the benthic community of a lake are lacking. However, this has been studied in the stream habitat. Tarzwell (1938) concluded that floods were found to be the outstanding limiting factors in southwestern streams. He also stated that floods not only roil and grind the bottom materials and widen the stream bed, destroy pools and cover, but they also sweep away rich organic materials essential for an abundant bottom fauna and deposit light-colored inorganic silt which is almost barren of life. Tarzwell also reported that streams that were not subject to severe floods for some years are much richer than the streams having frequent floods. Logan (1963) reported that high flows during the spring in Bridger Creek, Montana, reduced the number of bottom organisms and increased the number taken in drift; low stream flow during the fall and winter was accompanied by an abundance of bottom organisms. Starrett (1948) also reported that the microflora of the Des Moines River was scoured during high water periods. Denham (1938) found that, in the White River, Indiana, Hexagenia sp. naids were

washed from their burrows during abrupt rises in the level of water. Jones (1951) stated that floods drastically reduced invertebrate population of the River Towy in Wales.

An increase in water level may also have a positive effect on the abundance of food. Rehder (1959) reported that in the Des Moines River, condition factors of carp were highest in midsummer at time of high water level when earthworms and terrestrial insects comprised most of the food during floods. Stroud (1948) stated that long term cycle of water level fluctuation is beneficial to the sport fish population as a whole because of a periodic increase in the food supply.

Turbidity associated with high water levels is another factor that can influence the growth of fishes. Bailey and Harrison (1948) found that in periods of low, relatively clear water, forage fish were eaten by channel catfish in sharply increased numbers.

Keeton (1959) found that in Oklahoma the growth of channel catfish and largemouth bass in clear ponds were better than in muddy ponds. He stated that predaceous, sight feeding fish had greater visual range in clear water and were much more efficient predators than fish in turbid water. Finnell and Jenkins (1954) reported that in Oklahoma growth of channel catfish in clear water is better than in turbid waters. The same was reported for bluegill sunfish, Lepomis macrochirus, redear sunfish, Lepomis microlophus, green sunfish, Lepomis cyanellus, warmouth, Chaenobryttus gulosus, longear sunfish, Lepomis megalotis, and orange spot sunfish, Lepomis humilis, by (Jenkins, Elkin and Finnell (1955) and for white crappie and black crappie, Pomoxis nigromaculatus, by Hall, Jenkins, and Finnell (1954). Jenkins and Elkin (1957) reported that there were no clear-cut

differences in rate of growth of white bass, Roccus chrysops, under clear and turbid water conditions. Hubbs and Whitlock (1928) concluded that the slow growth rate of young gizzard shad in the Arkansas River may be related to the excessive siltiness of the water in which they were living.

In case of a great reduction in water level, crowding is another factor believed to influence the growth of fish. Keeton (1963) believes that during periods of low water the forage fish populations would be concentrated and more vulnerable for capture by predatory fish. Therefore, growth of predaceous fish would be greater during low-water periods than during high-water periods when forage fish are less concentrated. Herke (1959) compared the growth of largemouth bass crowded in a canal with those fish from an adjacent lake. He found that the condition of bass from the canal were significantly better than those from the lake. He also stated that the most logical explanation for this phenomenon is increased feeding by the bass under crowded conditions. But he reported no detectable differences in the length-weight relationships of redear sunfish and bluegill from the same two habitats. Harrison (1957) thought that channel catfish growth in the Des Moines River was better during 1956 when water levels were low. On the other hand, he reported an increase in growth following an extensive fish kill. Ambrose (1970) found that decrease in the annual growth of channel catfish in Lake Carl Blackwell, Oklahoma, coincided with decreasing water level.

Crowded living space during low water levels may also affect forage fish as well as predatory fish. The growth of Hesperoleucus venustus (cyprinidae) in California streams decreased when streams

dry out and fish become crowded in pools. Beckman (1941) found that growth of rock bass, Ambloplites rupestris, in Standard Lake (now called Booth Lake) was slow, but after the population was reduced by poisoning, Beckman reported an increased growth rate, too great to be accounted for by normal growth fluctuation. Beckman (1943) also reported that the reduction in population size resulted in an increase in length and weight and in the mean coefficient of conditions of fish of all ages. Schmulbach (1959) attributed poor growth of walleye in the Des Moines River in 1958 to low water levels and a high population. Chevy (1933) found that in Cambodia cessation of growth of freshwater fish takes place at the season of low water. On the other hand, he found that at this time that the marine fish off the mouths of the Mekong and the Bassae Rivers benefit from better feeding at this time. Chevey also found that fish in the flooded forest grow much faster than those inhabiting the middle of Grand Lake, stating that the vegetable diet supplied by the submerged forest in times of flood was the case for the surprising rapid growth of fish in the flooded forest portion of the lake.

Brown (1946a) stated that there was an optimum degree of crowding for rapid growth of brown trout, and that overcrowding led to low appetite and inefficiency of utilization of food, while undercrowded trout ate and grew erratically. She also believed that crowding might influence the stability of "social-size hierarchies" which seems to influence rate of growth, stating that the specific growth rate of an individual depends on its size relative to that of the others in the group. She found that the specific growth rates for fish in the most crowded tank were consistently lower than those for fish in the same

position in the size order, but with more living space. While the few fish with a large amount of living space generally grew at lower rates than the corresponding more crowded fish. Van Oosten (1944) emphasized the importance of living space for individual fish in order to grow, citing the example that a goldfish in a bowl or in an aquarium is not expected to grow to 3 pounds as they usually do in a natural habitat.

CHAPTER IX

EFFECT OF TEMPERATURE ON GROWTH

The growth of age-group I gizzard shad collected in 1966 showed a gradual decline in increment per period with the progress of summer. During that period water temperature was increasing. No growth occurred during the month of September, although the water temperature had dropped considerably. However, a comparison of the marginal growth attained by age-group I shad in 1966 with annual increment attained by age-group II fish during the 1966 growth season, indicated that age-group 0, I, and II gizzard shad added 36.1, 42.1, and 52.9 percent of their respective annual increments after September 30.

Age-group I crappie showed a decrease in growth during the first part of September as compared with that of the second half, but showed an increase in growth during the second half of September. Such increase during the second part of September was also evident in the 1967 collection (Table 26) and is probably not accidental. Comparison between the marginal increment attained by the different age groups in 1966 and the annual increment attained in 1966 confirmed that there was a substantial amount of growth after September 30.

The 1967 crappie (age-group II) in general showed a declining rate of growth throughout the summer as might be expected, but a cessation in growth during the second part of June which is unexpected. This cessation coincided with the highest average water temperature recorded

during the summer. The growth increased during the second half of September (Table 26). Table 26 shows that the relatively good growth in the spring was associated with moderate temperatures, while the slow growth during the summer was associated with temperatures above 24 C. High temperature was associated with cessation in growth during the second half of June. Growth was resumed in July when the temperature dropped again. After September 30, the growth again was associated with moderate temperature, but crappie also did not grow during the second part of September, as was the case with the shad in 1966.

From the above information, we can draw a general trend for the growth of gizzard shad and white crappie in Keystone Reservoir. Good growth in spring, associated with moderate temperatures, is followed by a slow growth during summer months associated with temperatures above 24 C. Slow growth continues during the first half of September and then increases during the second half of September or October. There is no reason to believe that high temperatures per se are the cause of slow growth during August as fish generally grow slower in late summer than in early summer. The slow growth during June and the spurt of growth during autumn lead one to believe that in Keystone Reservoir slow growth may be associated with abnormally high temperatures (above 24 C) while good growth is associated with moderate temperatures.

Slow growth during warm temperatures has been reported by several authors. Al-Rawi (1964) found that in the Des Moines River, river carpsuckers, Carpiodes carpio, collected during the month of August, had false annuli on their scales, indicating slow growth. Keeton (1963) also found that during 1961, age-group I and II river

carpsuckers in the Des Moines River showed no increase in length increments during the second half of July. Keeton also reported that growth increments of age II river carpsuckers declined during August to October, but showed a slight increase during the second half of August. Schmulbach (1959) reported that most of the growth of adult walleyes, Stizostedion v. vitreum in the Des Moines River occurs in the late spring and early fall. Stroud (1949) stated that little or no growth occurred in mid-summer in the Norris Reservoir walleyes in Tennessee, but late summer growth was again rapid.

Pentelow (1939) showed that in brown trout, Salmo trutta, there was a period of slow growth during the winter and during the summer and that growth of trout was at its maximum at temperatures between 10 and 15 C. Swift (1961) found a regular annual growth rate cycle in wild and hatchery yearling brown trout; the fish have a high growth rate in the spring and autumn and a low growth rate during the summer and winter of each year. Swift concluded that the water temperature is the main external environmental factor influencing the growth rate, and that maximum growth rate in brown trout is achieved at 12 C. Wingfield (1940) noticed that the growth of brown trout increases from 3.2 C to 15.4 C but it dropped at higher temperatures. Benson (1954) also found that brook trout, Salvelinus fontinalis, in the Pigeon River, Michigan, were in best condition and had the greatest volume of food in their stomachs when the stream temperatures were 12.8 to 17.2 C. Ball and Jones (1960) reported formation of narrow (winter) rings in 30 to 40 percent of the scales of brown trout in Llyn Tegid (Bala Lake), Wales, England, during September, but about three quarters of those trout which formed narrow rings in September resume rapid scale

growth in September and early October.

Increase in growth after mid-summer has been reported for channel catfish in the Tenkiller Reservoir (Jenkins, 1957). Similar trends seem to exist in the data of other workers, but have been overlooked by the use of the moving averages technique. Beyerle and Cooper (1960) found that the specific growth rate in weight of brown trout in Spruce Creek, Pennsylvania, declined from a high of 5 to 6 percent of their body weight per day in early June to negative values in November and December. However, close examination of Table 4 and Figure 3 of Beyerle and Cooper indicate that there was a decline in the growth through August, but growth had increased again in September and dropped gradually during the winter. In Lakes Rensjön, Sweden, good growth of brown trout was correlated with the water temperatures during June and July (Runnström, 1957), but the growth of fish during 1953 was remarkably poor when the temperature was unusually high in June and slightly above normal in July.

From the above discussion, it is clear that the slow growth during the summer months may be associated with high temperatures. In some fish an increase in the growth occurs when the temperature drops to the optimal level in autumn.

The slow growth or the cessation of growth associated with high temperature can be explained by a consideration of the nitrogen metabolism of fish. The endogenous nitrogen excretion (ENE) is the amount of nitrogen excreted when a fish is fed a nonprotein diet. ENE represents the amount of body protein utilized for energy, and this protein must be replaced before growth can occur. Savitz (1969) found that bluegills, Lepomis macrochirus, were not able to adapt

to high temperatures. The rate of ENE per unit of weight increased with an increase in temperature as well as an increase in body weight. The relationship between the ENE and both temperature and body weight was linear over a temperature range of 7.2 to 32.2 C. For a fish to grow at high temperatures, it must consume more. If food becomes scarce at this time, slower growth becomes likely.

Pentelow (1939) found that consumption of natural food and growth rates of young brown trout increased with rising temperatures up to 60 F (15.6 C) then fell off as the temperature increased. Pentelow also reported that the food required for maintaining constant body weight was higher when the water temperature was warmer, and that starved fish lost more weight at higher temperatures than at lower temperatures. Pentelow also stated that between 40 and 50 F (4.4 to 10 C) the amount of growth made is roughly directly proportional to the amount of food eaten, but above 50 F (10 C) no such simple relation exists. Swift (1955) found greater activity of the brown trout and of the thyroid during midsummer and suggested that maintenance demands relatively high at that season.

Brown (1946a) also found that the maintenance requirements of brown trout of equal weight increased with an increase in temperature. Baldwin (1957) found that in brook trout, utilization of food for growth declined with an increase in temperature.

Sullivan (1954) found that spontaneous activity of brook trout increased with temperature, decreased, and then rose again at temperatures above the preferred temperature. Brown (1946b) also found that the specific growth rates of brown trout was high between 7 and 9 C and between 16 and 19 C, and were low above, between, and below these

temperatures. Brown believes that the existence of these two growth rate maxima are due to the differential effect of temperature on the amount of food eaten and the activity of the fish. The food eaten is maximal between 10 and 19 C, and the activity of the fish is maximal between 10 and 12 C. The efficiency of utilization of the food was low when temperature was low and also when the activity was high.

High temperatures might also affect the rate of food consumption. Allen (1940) found that high temperatures result in slow growth of Atlantic Salmon, Salmo salar, and a decrease in the rate of feeding. He also stated that the rate of feeding is not due to any shortage of food. Therefore, he concluded that the change in the feeding behavior of the fish must be due to either some external factor affecting the feeding behavior of the fish or the internal changes within the fish itself. Bailey and Harrison (1948) found temperatures between 50 and 94 F (10 - 34.4 C) do not seem to inhibit feeding of channel catfish in the Des Moines River, Iowa. Pentelow (1939) found that the appetite of fully fed brown trout increased as the temperature rose to 60 F (15.5 C) but generally declined at temperatures higher than this. Benson (1954) found that brook trout in the Pigeon River, Michigan, had the greatest volume of food in their stomachs when stream temperatures were 55 to 66 F (12.8 to 18.8 C).

CHAPTER X

SUMMARY AND CONCLUSIONS

1. Data collected from Keystone Reservoir, Oklahoma included scale samples, length and weight of two species of fish; 459 white crappie were collected between August 1 and September 30, and 1,524 gizzard shad were collected between July 1 and September 30, 1966. In 1967, 1,347 crappie and 2,443 shad were collected and examined between June 1 and September 30.

2. All gizzard shad were collected with a 230 volt A. C. electric shocker. Crappie were collected using barrel nets. Two or three collections were made weekly. The electric shocker was not selective for or against gizzard shad of different sizes. Barrel nets were selective against white crappie smaller than 104 mm in total length.

3. Total length was measured to the nearest millimeter and weight was recorded to the nearest gram. Between two and 15 scales were taken from the anterior part of the body just under the tip of the pectoral fin and just below the lateral line on the right side of the fish. If the scales were regenerated in this location, the same area of the left side of the fish was used.

4. Impressions of crappie scales were made on clear plastic strips. Shad scales were placed in watch glasses filled with water and soaked overnight before temporary wet mounts were made. All scales were projected and read on a scale projector at a magnification of 80X.

In all cases, two or more were examined to verify the presence of the same number of annuli on all scales. The crappie scales were identified by use of the antero-lateral portion of the scale. Measurements of shad scales were taken on the anterior portion of the scales.

5. Validity of visual location of the scale midpoint of the first circulus of gizzard shad was tested statistically in a sample of 20 scales. A t-test showed no significant difference, at any level, between the measurements made by visual or measured location of the focus.

6. A computer program was used to determine the body-scale relationship, to calculate the intercept value (a), to perform analysis of variance for linear and curvilinear body-scale relationship, and for back calculating the length of the fish at the end of different years of life. Results indicated that for both gizzard shad and crappie, there is a linear relationship between lengths of the body and the length of the scale. A curvilinear body-scale relationship was established for shad collected in 1967 and crappie taken in 1966 and 1967. Curvilinearity seems to be due to the absence of small-sized fish in the case of the sample of crappie. The intercept (a) in the curvilinear body scale relationship was so exaggerated that it exceeded the total lengths of most fish within the range in which differences existed between the length calculated by using a linear equation and those calculated by the use of polynomial equations. Therefore, a linear body scale relationship was assumed and the Lee formula was used for back calculation.

7. Scale measurements taken along the primary transverse groove had larger variance than the measurements taken in the anterior portion

of the scale. However, the differences were very small. Therefore, both measurements are practical for the purpose of back calculation.

8. The annulus of white crappie is distinguished by the incomplete and fragmented circuli that leave a wide clearance. This is followed, in most cases, by wide-spaced circuli. The annulus is more defined in the anterior and the antero-lateral ridge areas of the scale, becoming gradually less defined posteriorly. The annuli are easily recognized in the I, II, and III age-groups. In older fish, the first and the last annuli are not difficult to recognize but the recognition of the annuli between these two is difficult.

9. False annuli are mostly restricted to the anterior portion of the scale. The spaces between the circuli following the false annuli are not as wide as they are between the circuli that follow a true annulus. An annulus-like structure between the first annulus and the focus, which can be confused with the first annulus was present. However, this is much less defined than a true annulus.

10. Scales of gizzard shad lack a focus and are devoid of circuli and other features in the posterior portion of the scale except for the annulus which, in some scales, appears as a dark band. The annulus can be recognized in the anterior field by its incomplete circuli and, also occasionally by a clear area filled with only fragments of circuli. In the lateral fields of the scale the annulus appears as a dark band.

The number of the secondary transverse grooves increased in numbers as the fish became larger but they did not correspond with the number of annuli. The regenerated scales of gizzard shad possess circuli running in different directions.

11. Growth of white crappie was best during the first year of life. The 1964 year-class showed the best growth. The growth rate decreased with the aging of the reservoir. Growth of white crappie in Keystone Reservoir is poorer than in other, newly impounded reservoirs in Oklahoma. The 1965 year-class (the first to hatch in the reservoir) was the dominant year-class. The lake seems to be more suitable as a habitat for white crappie than that which existed in the river before the impoundment.

12. Gizzard shad made the largest length increments during the first year of life. The growth of gizzard shad also showed a gradual decline with the aging of the reservoir. Gizzard shad in Keystone Reservoir showed a better rate of growth than the state average in 1966. The 1967 data showed poorer growth than the state average, except for age-group I. Gizzard shad showed evidence of the reverse of Lee's phenomenon due to selective predation on small size fish.

The scale readings conformed with all the criteria used for the validation of the scale readings except for shad collected in 1967.

13. An additional criterion for the validation of the scale method was established; in any particular year-class, the average calculated growth increment for the last annum should exceed, or at least equal, the marginal increment in the previous year.

14. The discrepancies in the 1967 shad collection were postulated to be due to the presence of two populations, each with a different rate of growth. The two populations apparently overlap in the 130-140 mm range. Two explanations as to the source of these two populations are possible. Either a second shad hatch took place after a fish kill during July, 1966, or the Cimarron arm and the Arkansas arm

of Keystone Reservoir support two different populations of shad. Some evidence seems to favor the second hypothesis. The Arkansas River is the source of the small-sized population.

15. Fluctuation in water level during the sampling period was small except during the second half of June and the first half of July, 1967. A negative correlation coefficient (.524) was found between the water level and the growth of age-group I gizzard shad collected in 1966, which is not significantly different from zero. Water level was not correlated significantly to the growth of white crappie. A correlation coefficient of .025 was found between water level and the growth of age-group II white crappie collected in 1967.

16. Temperature seems to be more related to growth than water level. Temperature above 24 C apparently had an adverse effect on the growth of both species. Age-group II crappies did not grow when water temperature reached 27 C.

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APPENDIX A

Table 27. Analysis of variance for relationship between total length and scale length for gizzard shad, collected from Keystone Reservoir, 1966.

Source of variation	Degrees of freedom	Sum square	Mean square	F
Total	1,429	1,149,900	804.67	
Linear regression	1	920,190	920,190.00	5,721.15
Residual	1,428	229,680	160.84	
Curvilinear regression	2	920,190	460,100.00	2,858.59
Curvilinearity	1	000	000	0.005
Residual	1,427	229,680	160.95	

Notice that although the difference between linear and curvilinear regressions is zero, the computer gave a small F value for curvilinearity. That is because the computer carried the decimal point in its memory further than it had printed.

Table 28. Analysis of variance for relationship between total length and scale length for gizzard shad, collected from Keystone Reservoir, 1967.

Source of variation	Degrees of freedom	Sum square	Mean square	F
Total	1,618	1,298,000	802.20	
Linear regression	1	1,141,400	1,141,400	11,785.57
Residual	1,617	156,600	96.84	
Curvilinear regression	2	1,142,400	571,200	5,933.74
Curvilinearity	1	1,000	1,000	10.76
Residual	1,616	155,560	96.26	

Table 29. Analysis of variance for relationship between total length and scale length for white crappie, collected from Keystone Reservoir, 1966.

Source of variation	Degrees of freedom	Sum square	Mean square	F
Total	435	178,320	409.92	
Linear regression	1	99,318	99,318.00	545.64
Residual	434	78,997	182.02	
Curvilinear regression	2	106,920	534.60	324.23
Curvilinearity	1	7,602	7,602	46.11
Residual	433	71,395	164.88	

Table 30. Analysis of variance for relationship between total length and scale length for white crappie, collected from Keystone Reservoir, 1967.

Source of variation	Degrees of freedom	Sum square	Mean square	F
Total	1,324	210,700	159.14	
Linear regression	1	110,890	11,089.00	469.77
Residual	1,323	99,815	75.45	
Curvilinear regression	2	116,740	58,371.00	821.24
Curvilinearity	1	5,850	5,850	82.34
Residual	1,322	93,963	71.08	

APPENDIX B

Table 31. Comparison between scale measurements taken in the anterior portion of the scales and scale measurements taken along the primary transverse groove of gizzard shad, collected from Keystone Reservoir, September 16 to 30, 1967.

Location of measurement	Year	Number of fish	Average length at annulus	
			1	2
Anterior portion	1965	16	123.6	167.1
	1966	154	125.5	
Average			124.5	167.1
Variance	1965		140.0	269.4
	1966		386.5	
Standard error	1965		11.8	16.4
	1966		19.7	
Standard error of the mean	1965		3.0	4.1
	1966		1.6	
Along the primary transverse groove	1965	16	128.7	164.9
	1966	154	128.2	
Average			128.4	164.9
Variance	1965		168.1	298.9
	1966		419.7	
Standard error	1965		13.0	17.3
	1966		20.5	
Standard error of the mean	1965		3.2	4.3
	1966		1.7	

APPENDIX C

Table 32. Comparison of growth of white crappie in Keystone Reservoir, with similar data from the Cimarron River and other Oklahoma reservoirs.¹

Authority	Locality	Average total length (mm) at annulus							
Buck and Cross (1952)	Canton Reservoir	104	198	264					
Hall and Jenkins (1953)	Fort Gibson Reservoir	160	236	287					
Hall and Jenkins (1953)	Tenkiller Reservoir	127	279	315					
Latta (1951)	Wister Reservoir	104	201	269	330				
Mean		124	228	284	330				
Hall, Jenkins and Finnell (1954)	State of Oklahoma Reservoirs	84	175	208	251	302	328	335	358
Linton (1961)	Cimarron River	56	122	168	241	257			
Present Study	Keystone Reservoir	111	149	190	236				
Mean Increments	Mean for the four Reservoirs	124	124	56	46				
	State of Oklahoma Reservoirs	84	89	33	43	51	26	7	23
	Cimarron River	56	62	46	73	16			
	Keystone Reservoir	111	38	41	46				

¹All original data, except those of the present study were recorded by inches and were converted to millimeters using conversion tables in Carlander (1950a).

VITA

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