Validation of the Scale Method for Estimating Age and Growth of Bluegills[1, 2]

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ABSTRACT

Bluegill age and growth data were obtained from 24 small farm ponds near Ithaca, New York. Criteria for annulus recognition were developed from scales of known-age bluegills which consisted of original stock in the ponds. Twelve separate criteria permitted recognition of annuli in nearly all samples.

The 24 body-scale relationships estimated in the present study were compared with 18 relationships determined by 10 other authors after units of measurement had been standardized. Body-scale relationships were found to be approximately rectilinear for the key-scale area used in this study except for bluegills below 1.5 inches. The hypothesis that differences between intercepts (*i.e.*, correction factors) were due only to chance variation was tested and rejected. From a practical standpoint, however, inaccuracies resulting from use of an average intercept were found to be negligible.

Bluegills occasionally fail to form annuli near the focus or at the margin. Validity of annulus determination and back-calculation were examined by comparing back-calculated lengths with observed lengths in previous years for each of 24 populations. Poor agreement was found in segments of four populations, and acceptable agreement otherwise.

The scale method, as applied in this study, was generally valid for age and growth determinations of bluegills.

INTRODUCTION

Numerous studies have been made of bluegill (*Lepomis macrochirus*) age and growth based on the scale method. Criteria for annulus recognition have been stated by Bennett, Thompson, and Parr (1940) and Sprugel (1954). Time of annulus formation has been reported by Beckman (1943), Morgan (1951), and others. The manner in which the form of the body-scale relationship is influenced by location of the key scale has been described by Proffitt.[4] Proffitt (*op. cit.*), Whitney and Carlander (1956), and DiCostanzo (1957) have described the bivariate distribution underlying the body-scale relationship.

The present study emphasizes three aspects of the scale method as applied to bluegills:

1. Criteria for annulus recognition;
2. Estimates of body-scale relationships;
3. Accuracy of age determinations and back-calculated lengths.

MATERIALS AND METHODS

Bluegill populations in 24 farm ponds near Ithaca, New York, were studied during 1950 to 1959. The ponds were man-made, they varied from 0.2 to 1.3 acres surface area, their maximum depths ranged from 5 to 9 feet, and they had diverse chemical and physical characteristics. The ponds and populations are described in detail by Regier.[5, 6]

All ponds but one were stocked with fingerling bluegills at rates of approximately 100, 500, or 1,000 per acre. In one pond the original bluegill stock consisted of adults. Bluegills were stocked only once in each pond, and during the period 1950 through 1955. Fingerling largemouth bass (*Micropterus salmoides*) were stocked once in each pond at approximately 100 per acre.

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[1] Based on an M.S. thesis submitted at Cornell University in 1959.

[2] Contribution of Federal Aid to Fish and Wildlife Restoration Project F-17-R, New York.

[3] Present address: Lake Erie Fisheries Research Station, Department of Lands and Forests, Wheatley, Ontario.

[4] Proffitt, M. A. (1950) Comparative morphometry and growth of scales in the bluegill, *Lepomis m. macrochirus* Rafinesque, with special reference to related body growth. Ph.D. thesis, University of Michigan, Ann Arbor, Mich. 96 pp.

[5] Regier, H. A. (1959) An evaluation of the scale method for age and growth determination of bluegills in New York farm ponds. M.S. thesis, Cornell Univ., Ithaca, N.Y. 140 pp.

[6] Regier, H. A. (1961) Some aspects of the ecology and management of warm-water fish in New York farm ponds. Ph.D. thesis, Cornell Univ., Ithaca, N.Y. 420 pp.

Most ponds were inventoried each year after stocking using bag seines 50 to 150 feet long with ¼- to ¾-inch mesh (bar measure), and 10-foot minnow seines with ⅛-inch mesh. In view of the large size of the seines and the small size of the ponds, sampling is believed to have been relatively unselective for bluegills over 3.0 inches total length. Snyder[7] found good agreement between the size compositions of samples of bluegills seined from 10 ponds near Ithaca and the actual populations recovered by draining the ponds.

Most of the scales used in this study were collected during 1958. Populations in 6 ponds were inventoried by seining following almost complete drainage of the ponds, in 6 other ponds by seining after partial drainage, and in the remaining 12 ponds by seining only. Each population was stratified by 0.1-inch intervals of total length; lengths and weights were measured and scale samples removed from one or more bluegill per stratum. Length tallies were made of approximately random samples of each population. In nine ponds with large populations the lengths of several hundred bluegills over 2.0 inches long were measured. Most of the bluegills in smaller populations were measured. Samples of bluegills under 2.0 inches long were preserved for subsequent measurement in the laboratory. Numbers measured and sampled were much lower before 1958, and usually totaled between 20 and 40 bluegills.

Scale samples were taken near the tip of the pectoral fin when pressed to the body; *i.e.*, the "V" position shown in Figure 1. Approximately 10 scales were removed per fish. Bluegills less than 2.0 inches long were measured and placed entire into separate scale envelopes; scales were subsequently removed in the laboratory under a binocular microscope.

Impressions of uncleaned scales were made on cellulose acetate strips. Usually seven or more impressions of scales without large regenerated portions were made, and several scales with such "scars" were included when available. Efforts were made to be non-selective concerning scales chosen for mounting and examination.

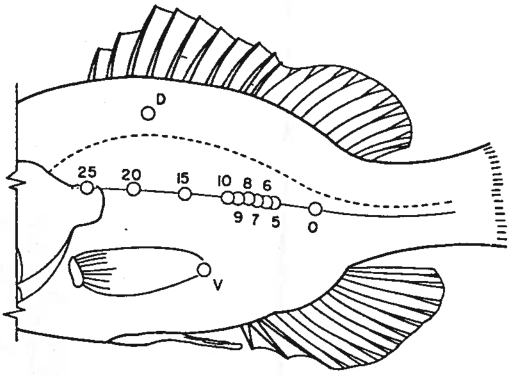

FIGURE 1.—Key scales and key areas. Circles designate key scales used by Proffitt (*op. cit.*); redrawn from Proffitt's figure.

The anterior radii of five scales without large scars were measured for estimating the body-scale relationship. The mean of the five measurements was then used to estimate the body-scale relationship by least squares regression.

One of the more regular scales was selected for back-calculation. Scale measurements were made along a line from the center of the focus anteriorad to a point on the last circulus in the interradial space nearest the middle of the anterior field. Scale measurements were marked on manila strips, and back-calculation done with a "fish-size calculator" (Schuck, 1949).

RESULTS

Scale characteristics

Photographs of bluegill scales with a description of their characteristics have been published by Potter (1923), Schoffman (1938), Bennett *et al.* (1940), Beckman (1943), Burress,[8] Lagler (1952), and Sprugel (1954).

The scales of known-age bluegills often show more distortions in their basic pattern of concentric circuli than can be explained as year marks. Superfluous marks have been designated by different terms by different

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[7] Snyder, E. P. (1956) Evaluation of seine sampling as a means of describing composition and size of fish populations in ten New York farm ponds. M.S. thesis, Cornell Univ., Ithaca, N.Y. 74 pp.

[8] Burress, R. M. (1949) The growth rates of bluegills and largemouth bass in fertilized and unfertilized ponds in Central Missouri. M.A. thesis, Univ. of Missouri, Columbia, Mo. 79 pp.

authors. Here the term "annulus" is used to designate a true year mark, and superfluous marks are termed "accessory checks." "Checks" as a general term includes annuli and accessory checks.

Bluegill age and growth studies using scales have been reported from Rhode Island (Saila and Horton, 1957), Alabama (Swingle and Smith, 1940), Texas (Brown[9]) and other areas. Thus this species usually forms annuli throughout its range. Accessory checks are also frequently formed.

Criteria by which annuli on bluegill scales may be identified have been stated by a number of authors, but no simple combination of criteria seems wholly dependable (Sprugel, 1954). A list of 12 criteria that may be applied to bluegill scales follows. All citations in this section are from papers on bluegills except those of Hile (1931), Lagler (1952), and Van Oosten (1957). Where citations are not given, statements are based on the present study.

1.—The well-known criteria that apply to many species of fish generally apply to bluegills. Generalized descriptions of annuli are given by Lagler (1952), Van Oosten (1957), and others.

2.—Scales bearing accessory checks often present a "confused appearance" which alerts the investigator (Hile, 1931).

3.—A check with a zone of relatively widely spaced circuli proximal to the focus, and closely spaced circuli distally, is usually an accessory check (Sprugel, 1954). These features are usually clearest in an anterolateral angle of the scale.

4.—Lack of extensive anastomosis of circuli with the check, and limited extension of the check across the posterolateral field frequently characterize accessory checks (Sprugel, 1954). In annuli, circuli proximal to the check are usually discontinuous, distal circuli continuous; in accessory checks the reverse is sometimes true, or some circuli may be continuous through the check.

5.—Loss of a scale may produce an accessory check on adjacent scales (Van Oosten. 1957), although such checks can usually be distinguished from annuli (Proffitt, *op. cit.*). In correlating location of accessory checks with regenerated portions in adjacent scales, it should be noted that the scars on such scales are usually smaller than the size of the scale lost, except perhaps on a starving bluegill (Creaser, 1926).

6.—A given annulus is usually equally well defined on all scales of an individual bluegill, but an accessory check may not be (Proffitt, *op. cit.*; Sprugel, 1954).

7.—Accessory checks are sometimes more conspicuous than annuli on the anterior field of the scale (Ricker, 1942a).

8.—Particularly dark bands on a scale should be treated with suspicion (Burress, *op. cit.*; Sprugel, 1954). Erosion pits on the nonsculpured under-surface sometimes obscure scale ridges (Carlander, 1956). These considerations apply to images of scales but not to images of scale impressions.

9.—Consider a questionable check to be an annulus provisionally. If the individual's growth history as estimated from scale proportions does not approximate the growth pattern of its provisional year class, then the check stands suspect (Ricker, 1942a; Burress, *op. cit.*; Sprugel, 1954). Use of the growth pattern as a criterion presupposes that the bluegill population has been discrete during the period under investigation.

10.—Recognition of the first annulus is sometimes difficult if the annulus is less than 0.25 millimeter from the the focus. Cutting-over (*i.e.*, a complete circulus encompassing one or more incomplete circuli) may be confined to a single circulus, may be present on some scales and absent on others of the same fish, or may be absent entirely. Where cutting-over is absent, the annulus may be marked only by small segments of a circulus in the anterior field, or only by a relatively wide space between circuli. Finally, no noticeable mark may show in some bluegills that were quite small in spring at age I (Ricker, 1942a; Burress, *op. cit.*; Proffitt, *op. cit.*).

11.—Scale abnormalties are apparently more common in bluegills growing at unusually rapid or slow rates than those growing at

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[9] Brown, R. S. (1960) An investigation to determine the adequacy of the scale method in revealing the age of the bluegill sunfish, *Lepomis macrochirus* (Raf.) from Lake Austin, Texas. M.S. thesis, Cornell Univ., Ithaca, N.Y. 87 pp.

average rates (Bennett, 1948; Burress, *op. cit.*).

12.—The only clear indications of recent annuli in a large, slowly growing bluegill may be in an anterolateral corner of the scales. Larger bluegills in starving populations may not form annuli, or portions of scales on which annuli were formed may be resorbed.

Figures 2 to 5 are based on photographs of bluegill scales chosen to illustrate some of the 12 criteria listed above.

Occurrence and causes of accessory checks

Several authors have paid particular attention to identification, occurrence, and causes of accessory checks. Bennett *et al.* (1940), Bennett (1948), Ricker (1942a, b) and Burress (*op. cit.*) all found a high incidence of accessory checks with rapidly growing bluegills of young populations in artificial impoundments.

It has been postulated that incidence of accessory checks in new impoundments may be caused by marked fluctuations in availability of food organisms. However, Sprugel (1954) and Carlander and Sprugel (1955) found no consistent relationship between environmental conditions, sexual development, or rate of growth, and the formation of accessory checks with bluegills from a new lake.

"Perfect false annuli" have occurred or been induced in bluegills in the laboratory by von Limbach (Bennett, 1948) and Proffitt (*op. cit.*). Proffitt found that no accessory checks indistinguishable from annuli were formed by normal handling, such as removal from aquaria for gross examination.

No quantitative analysis of incidence of accessory checks was made in the present study. The most pronounced accessory checks occurred in original stock or in bluegills growing rapidly after previous stunting. But some very rapidly growing fish had no accessory checks at all, at least on some scales. Whatever the causes, spawning seems not to have been clearly related to the formation of accessory checks.

Missing or unrecognizable annuli

First annuli may be absent or unrecognizable. Bluegills spawn intermittently during the summer. Young-of-year from a late summer spawning may grow little during autumn and winter, especially if very numerous. According to Proffitt (*op. cit.*) scales with anterior radii less than about 0.25 millimeter long may not form typical annuli. This scale size corresponds to a bluegill length of about 1.0 to 1.5 inches depending upon which of the conventional key-scale areas is used. Thus annuli may be difficult to recognize if formed when bluegills are less than 1.5 inches long.

Proffitt found that first annuli in "D" scales (Figure 1) were sometimes atypical, indistinct, or missing in bluegills in Michigan. Similarly, Burress (*op. cit.*) found annuli indistinct or absent near the "15 to 20" areas. In the present study, some apparent anomalies in back-calculated lengths were ascribed to missing first annuli.

Several authors have stated that older bluegills may not form annuli until late in summer. There is clear evidence in the present study that marginal annuli were not formed at all by some older bluegills of original stock in some ponds heavily populated with bluegills. There was no evidence that bluegills hatched in ponds missed marginal annuli.

In autumn 1958 some of the originally stocked bluegills in 4 of the 22 ponds in which such bluegills were present were found to be lacking one or two annuli at the scale margins. In three of the four populations, the correct age of these bluegills could have been inferred from a study of growth pattern since some of the bluegills of similar size had the correct number of annuli. However, in the fourth pond the only evidence that annuli may have been missed was extensive resorption on the lateral margins of the scales.

Valid back-calculation with scales requires that no resorption has occurred in that part of the scale measured unless exactly compensatory growth of the scale has occurred before the next annulus is formed. It is also necessary to assume that no annulus has been resorbed. Very little resorption was noted on the anterior margins of the scales used in the present study, even when the bluegills had failed to form two annuli.

Burress (*op. cit.*) found scale resorption in

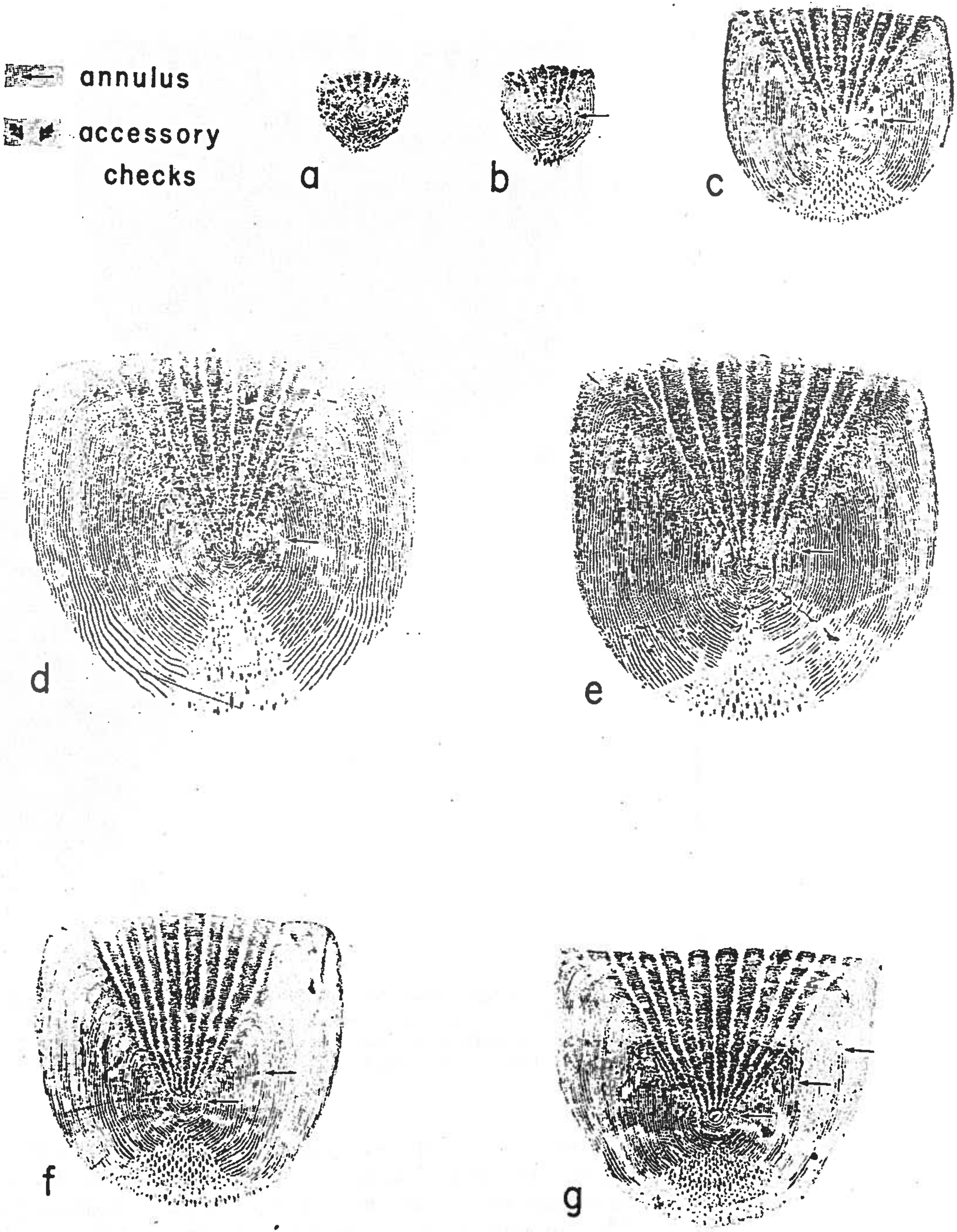


FIGURE 2.—Bluegill scale photographs. (a) Typical scale from young-of-year bluegill. (Age O+ years, total length 1.4 in., collected Oct. 11, 1958). (b) Scale from stunted yearling; annulus I poorly defined. (I+, 1.7 in., Aug. 12, 1958.) (c) Accessory check present at I+ but very indistinct. (I+, 3.1 in., 0.01 lb., Oct. 24, 1958.) (d and e) Scales of two bluegills from the same population. Pronounced accessory check at I+ in (d), only slight check in comparable position in (e). In (d) some circuli are continuous through the accessory check. (d: I+, 4.5 in., 0.10 lb., Sept. 3, 1958. e: I+, 4.6 in., 0.09 lb., Sept. 3, 1958.) (f) First annulus near the focus. (II+, 4.2 in., 0.04 lb., Oct. 30, 1958.) (g) Scale from slowly growing bluegill. Note annulus I and accessory check at III+. (III+, 4.6 in., 0.06 lb., Oct. 11, 1958.)

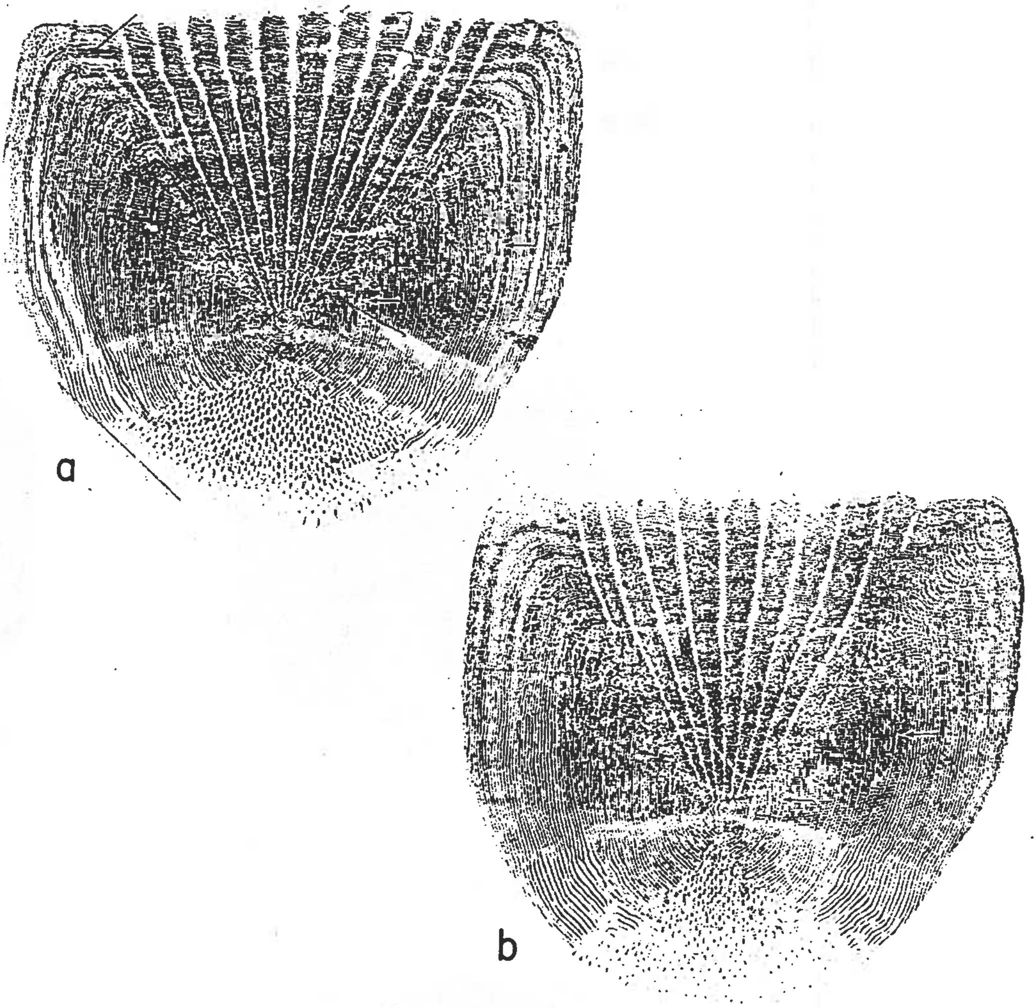
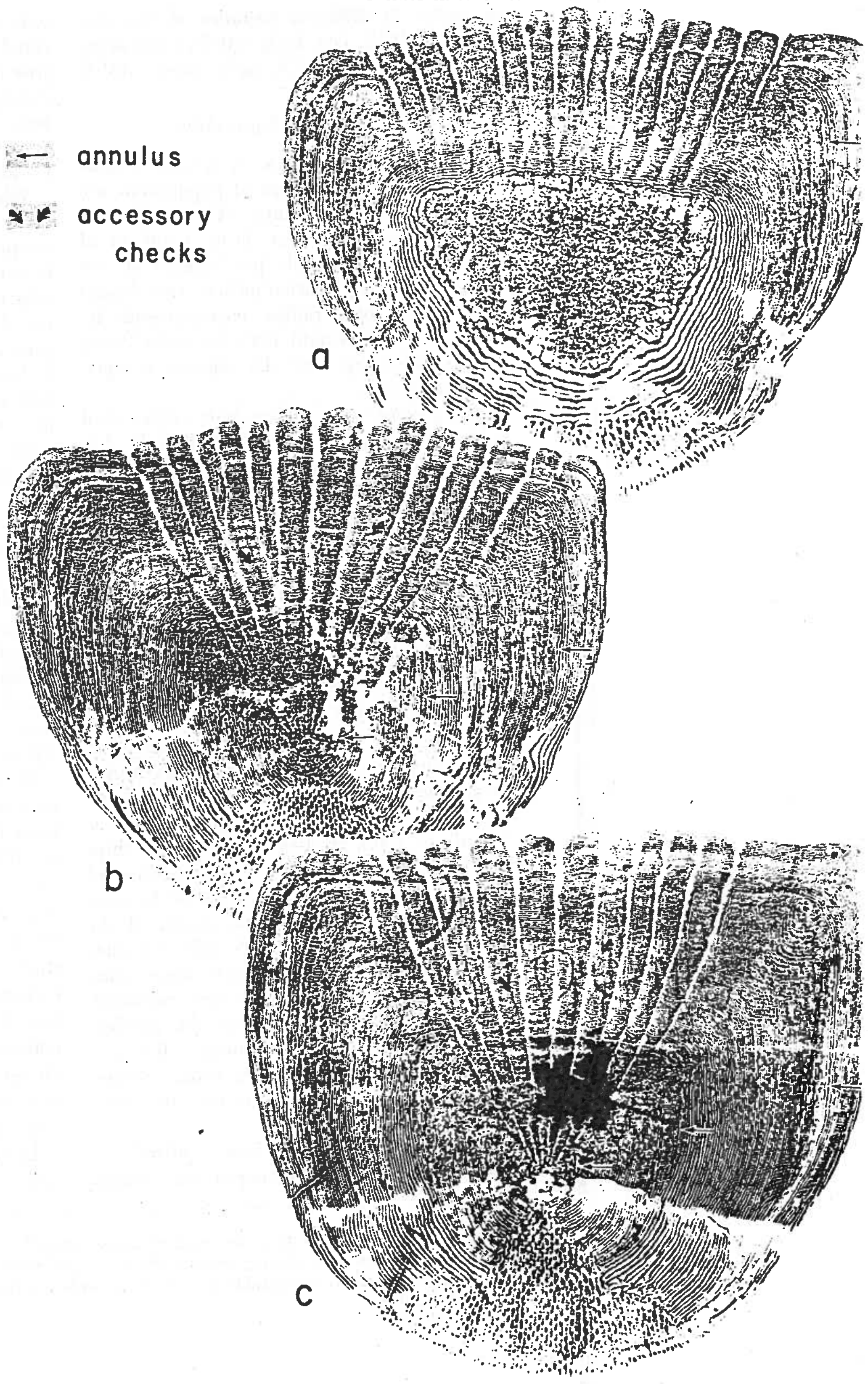


FIGURE 3.—Scales from two bluegills of same year class and same population. Both fish grew rapidly; the scale of one (a) shows several accessory checks, scale of other (b) shows none. Study of the growth pattern here useful to corroborate identification of annulus II in 5.8-inch bluegill. (a. II+, 5.8 in., 0.15 lb., Aug. 29, 1958. b. II+, 6.2 in., 0.17 lb., Aug. 27, 1958.)

starving bluegills. However, judging from his figures, the lateral margins were resorbed more extensively than the anterior margin. Thus an anterior radius seems best for back-calculation, and difficulties arise only with severely starved bluegills.

Time of annulus formation

Given sufficient food and space for the bluegill population, time of annulus formation apparently varies approximately with the latitude. Dates of bluegill annulus formation are available from Illinois (Bennett *et al.*, 1940), Indiana (Ricker, 1942a), Michigan (Beckman, 1943), Ohio (Roach and Evans, 1947), Missouri (Burress, *op. cit.*), Iowa (Sprugel, 1954), Ohio (Morgan, 1951), and from the present study in New York. The present author proposes the following generalization for approximate dates of bluegill annulus


annulus
accessory checks
a
b
c

formation in different latitudes of the area covered: 38°N, late April; 40°N, early May; 42°N, late May; 44°N, early June; 46°N, late June.

Body-scale relationships

Body-scale relationships for at least 11 bluegill populations or groups of populations are described in the literature. Almost all relationships were based on large numbers of bluegills with one scale per bluegill chosen either from a key location or key area. Means of anterior scale radius measurements by intervals of fish length (or vice versa) were usually computed, and the regression equations calculated.

The present study differs from others cited below in sampling design. Relatively few bluegills (usually between 50 and 75) were used per population studied, but the samples were representative of almost all 0.1-inch total length classes for which bluegills were present in the populations. Means of five scales per fish from the "V" key area were used in estimating the body-scale relationships for individual populations This method yielded sufficiently accurate relationships for practical purposes except in 7 of the 24 populations. In the seven excepted populations almost all the data were from two age groups of large fish, and no method of random sampling would ensure accurate estimates in such situations.

Proffitt (*op. cit.*) showed that various "classical" types of body-scale relationships could be derived from a single population of bluegills, depending on the key-scale location used. Further, he found that length of the intercept on the body length axis indicates approximately the bluegill's size when squamation of the particular key area occurred. The intercept should therefore be smallest using scales from near the mid-side line caudally, and largest with scales taken anterior to the "D" area (Figure 1), or near the pectoral fins.

Body-scale relationships from Proffitt's key scales (Figure 1) were all curvilinear, though only slightly so in most cases. A straight line fitted to such data might underestimate the true intercept if data from either older or younger fish were given greater weight or were more abundantly represented. Some "unusual" intercepts likely have been obtained in this manner (Table 1).

When total lengths and mean scale radii were plotted for individual populations of the present study, it was apparent from inspection that data from originally stocked bluegills usually did not fit straight lines estimating body-scale relationships of succeeding generations in the ponds. Deviations occurred in both directions; *i.e.*, scale data from original bluegills fell above the regression line in some populations and below the line in others. All data from original bluegills were therefore disregarded in estimating the body-scale relationships (but back-calculation of original stock according to these body-scale relationships proved valid, see below). Data from bluegills less than 1.5 inches long were also deleted since the body-scale relationships of these smaller fish were found to be quite curvilinear (see also Proffitt, *op. cit.*).

Table 1 lists linear body-scale relationships found in or estimated from data in the literature. Also included are the 24 relationships estimated in the present study.

Most authors reporting bluegill body-scale relationships used different combinations of body length (standard, fork, or total; inches or millimeters) and scale magnification (27×, 42×, 50×, etc.). In order to compare body-scale relationships it is necessary that standard units be chosen. The units used in this study are total length in inches and unmagnified scale radius in millimeters. If it is desired that both units be inches, then all the tabulated relationships may be modified by multiplying each b, where $Y = a + bX$, by 25.4. If it is desired that both units be millimeters, then each a and b may be multiplied by 25.4.

Length conversion factors were used in order to reduce all body-scale relationships to

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FIGURE 4.—Three scales from key area on same bluegill. Upper scale with regenerate center; middle scale with two accessory checks; lower scale with one accessory check. Curved arrows indicate locations on scales approximately comparable to location of accessory checks in middle scale. (III+, 7.4 in., 0.30 lb., Oct. 21, 1958.)

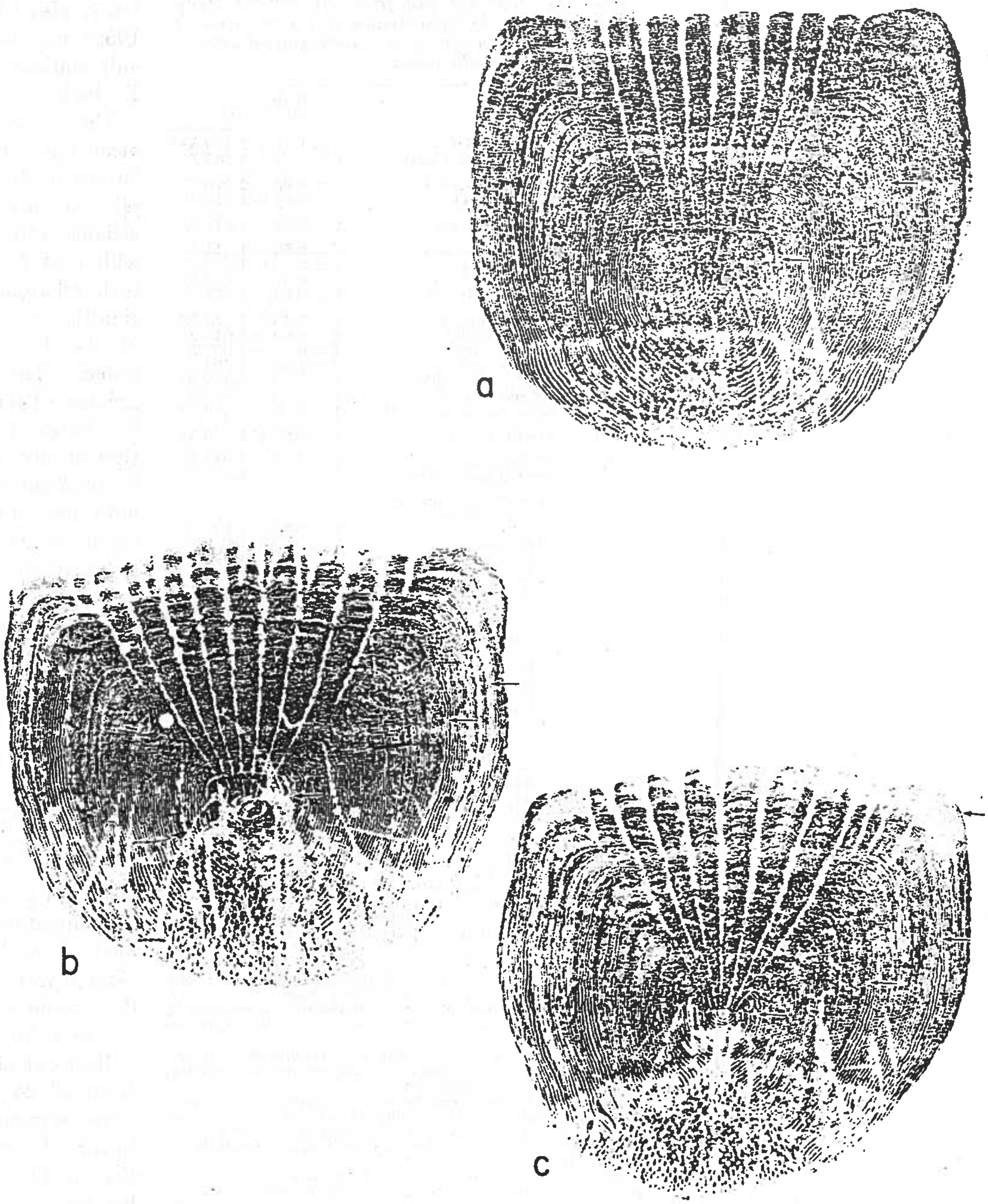

FIGURE 5.—Bluegill scale photographs. (a) Scale from bluegill of original stock in pond; annuli III and IV missing. Note evidence of resorption. (IV+, 6.8 in., 0.21 lb., Nov. 5, 1958.) (b and c) Scales from two bluegills of original stock in same population. Note growth pattern. Annuli IV and V missing in scale (b); annulus V missing in scale (c). Note evidence of resorption. (b. V+, 6.9 in., 0.20 lb., Sept. 22, 1958. c. V+, 6.7 in., 0.25 lb., Sept. 22, 1958.)

a standard. When such conversion factors were not included in the published studies, estimates presented by Carlander (1953) were used. Where axes were changed, it was assumed that perfect correlation existed between the variables. Some of the relationships listed in Table 1 are therefore somewhat inaccurate, but at least they are comparable.

TABLE 1.—*Standard body-scale relationships derived from the literature and from the present study. Data grouped by approximate key scale area.* Y *is total length in inches,* X *is unmagnified anterior scale radius in millimeters.*

Key scale area[1]	Study	Body-scale relationship
D	Proffitt (*op. cit.*)	$Y = 1.11 + 2.380\,X$[2,3]
	Bennett *et al.* (1940)	$Y = 0.93 + 1.885\,X$[2,3]
25	Proffitt (*op. cit.*)	$Y = 0.69 + 2.170\,X$[2]
	Lane (1954)	$Y = 0.82 + 1.815\,X$
20	Proffitt (*op. cit.*)	$Y = 0.59 + 1.911\,X$[2]
15	Proffitt (*op. cit.*)	$Y = 0.59 + 1.811\,X$[2]
	Ricker (1942a)	$Y = 0.89 + 1.994\,X$[5]
	Ricker (1942a)	$Y = 0.89 + 1.773\,X$[5]
	Mayhew (1956)	$Y = 0.64 + 1.577\,X$
10–5	Proffitt (*op. cit.*)	$Y = 0.43 + 1.845\,X$[2]
	Lewis (1950)	$Y = 0.65 + 1.617\,X$
	Sprugel (1953)	$Y = 0.42 + 1.863\,X$
	Jenkins (1955)	$Y = 1.45 + 1.584\,X$[6]
	DiCostanzo (1957)	$Y = 1.53 + 1.337\,X$[7]
	DiCostanzo (1957)	$Y = 1.15 + 1.450\,X$[7]
	Saila and Horton (1957)	$Y = 0.99 + 1.670\,X$[6]
0	Proffitt (*op. cit.*)	$Y = 0.28 + 2.520\,X$[2]
V	Proffitt (*op. cit.*)	$Y = 0.67 + 1.911\,X$[2]
	Present study, mean	$Y = 0.58 + 1.894\,X$
V	Present study, individual populations	
	Alfred	$Y = 0.70 + 1.841\,X$
	Arnot K-2	$Y = 0.79 + 1.789\,X$
	Arnot K-3	$Y = 0.60 + 1.889\,X$
	Arnot K-5	$Y = 0.84 + 1.772\,X$
	Barrett CC	$Y = 0.39 + 2.004\,X$
	Barrett Rw	$Y = 0.56 + 1.912\,X$
	Brown	$Y = 0.76 + 1.792\,X$
	Catherwood	$Y = 0.72 + 1.697\,X$
	Cotton-Hanlon	$Y = 0.66 + 1.867\,X$
	Foster	$Y = 0.75 + 1.749\,X$
	Hayes	$Y = 0.82 + 1.905\,X$
	Hoffman	$Y = 0.63 + 1.912\,X$
	Lange	$Y = 0.68 + 1.825\,X$
	Moore	$Y = 0.80 + 1.715\,X$
	Silliman	$Y = 0.64 + 1.794\,X$
	Warren II	$Y = 0.62 + 1.954\,X$
	Agronomy A	$Y = 1.56 + 1.525\,X$[8]
	Arnot K-1	$Y = 2.56 + 1.409\,X$[8]
	Baldwin	$Y = 1.00 + 1.612\,X$[8]
	Beattie	$Y = 0.69 + 1.777\,X$[8]
	Hatchery H	$Y = 0.77 + 1.920\,X$[8]
	S. Teeter	$Y = 0.23 + 2.043\,X$[8]
	Warren I	$Y = 0.27 + 2.089\,X$[8]

[1] See Figure 1 for location of key scale areas.

[2] Estimated from figures published by other authors.

[3] Quite curvilinear, concave upwards for $Y > 3$; equation fairly accurate for $2.5 < Y < 6.5$.

[4] Quite curvilinear, concave downwards for $Y > 3$; equation fairly accurate for $Y < 7$. Bluegills over 7 inches long judged by present author to be original stock.

[5] The intercept 0.89 chosen by Ricker for convenience in back-calculation; *i.e.*, 20 mm fork length and accurate within 5 mm.

[6] Large intercept possibly due to curvilinearity and unequal distribution of data with respect to X (Jenkins, Saila, personal communications).

[7] Same basic data used for both equations. First equation based on regression using individual data, second equation based on means of total lengths by intervals of scale radius. Difference due to curvilinearity according to DiCostanzo.

[8] Body-scale relationships based on few data, or data poorly distributed over the usual range of total lengths.

The last seven relationships in Table 1 indicate the variability in intercepts and slopes that occurs when body-scale relationships are based on few data poorly distributed over the usual range of bluegill lengths.

If the body-scale relationship is linear over the total range of back-calculation, then the Frazer method (Rounsefell and Everhart, 1953; also called the Lee method by Lagler, 1952) may be used for back-calculating. The only statistic necessary is the intercept on the Y (body length) axis.

The author wished to determine whether a mean intercept could be used for all 24 populations in the present study. This would simplify calculations, and probably result in more reliable estimates of back-calculated length with data from populations for which body-scale relationships were not very reliable. The significance of differences between intercepts of the 17 more reliable relationships was tested. The F-test indicated significantly greater differences than would be expected by chance ($F_{16,966} = 12.15$). The practical significance of these differences was examined by back-calculating one set of data using the most aberrant of the 17 intercepts and the mean intercept. The greatest discrepancy between results was about 0.2 inches, which was considered negligible. The mean intercept was therefore used in back-calculating with data from all 24 populations.

Accuracy of aging and back-calculation

The test of the validity of assumptions on which back-calculation is based, the accuracy of aging, and the accuracy of back-calculation is in each case the degree to which back-calculated lengths agreed with lengths of bluegills sampled during inventories in preceding years. If good agreement exists, then annulus determinations as well as the assumptions and methods of back-calculation may all be considered valid. A series of compensating errors that would result in good agreement is hardly conceivable.

Back-calculation was done with scale data from all 24 populations. The resulting data were summarized in the form of growth history diagrams as in Figure 6. The vertical lines in Figure 6 represent ranges in observed lengths (continuous lines) and back-calculated lengths (dashed lines) for separate year classes. Dotted vertical lines are estimates based on very few data. Time of annulus formation is arbitrarily set in May. Diagonal lines join mid-points of the ranges of observed and back-calculated lengths. Continuous diagonal lines indicate satisfactory agreement, dot-

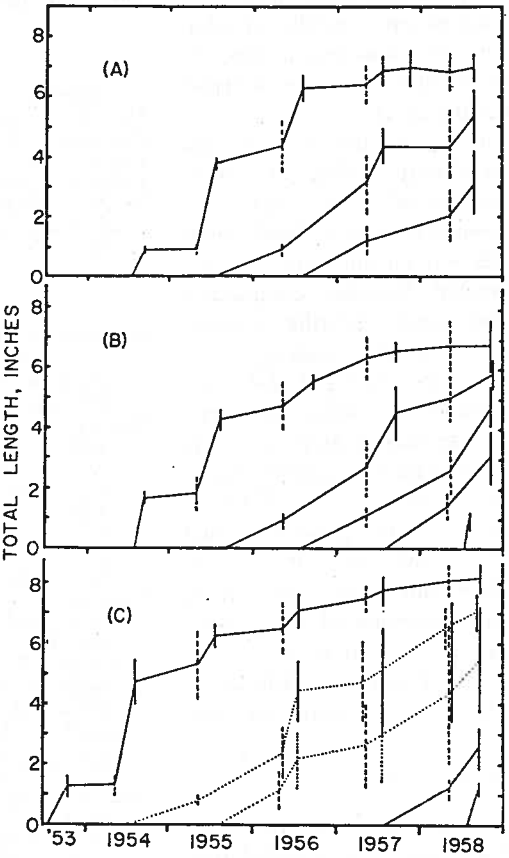

FIGURE 6.—Growth history diagrams for bluegill populations in three ponds. Symbols are explained in text. Data from Barrett CC pond (A), Catherwood pond (B), and Arnot K-2 pond (C).

ted diagonal lines indicate results in which the author has relatively little confidence.

The conventions and implications of Figure 6 may be clarified by referring to some numerical data from which part of it was constructed. As an example, consider the uppermost "curve" of Figure 6-A. Table 2 contains the data from which this curve was constructed. The length data are from two sources; annual inventories, and back-calculation from 1958 data. Measurements made in annual inventories are summarized by continuous vertical lines. Data from back-calculation using scales collected in autumn 1958 are summarized by dashed vertical lines. The data were summarized in this manner to permit a visual evaluation of the accuracy of back-calculation.

TABLE 2.—*Growth history of original-stock bluegills in Barrett CC pond*

[These data are summarized graphically in the uppermost "curve" of Figure 6-A]

Date	Total lengths (inches)			
	How obtained	Minimum	Mean	Maximum
September 1954	Measured	0.8	1.0	1.1
May 1955	Back-calculated	0.8	1.0	1.1
July 1955	Measured	3.5	3.8	4.0
May 1956	Back-calculated	3.3	4.2	5.2
August 1956	Measured	5.9	6.3	6.7
May 1957	Back-calculated	5.7	6.4	7.0
July 1957	Measured	6.3	6.8	7.3
November 1957	Measured	6.3	7.0	7.6
May 1958	Back-calculated	6.1	6.8	7.4
September 1958	Measured	6.5	7.0	7.5

Back-calculation and inventory data for a given year class are not directly comparable since they relate to different times during the growing season. Little direct information on seasonal growth is available from the present study, but Bennett *et al.* (1940), Burress (*op. cit.*), Carlander and Sprugel (1955), Jenkins (1955), and DiCostanzo (1957) show that bluegills usually complete most of their seasonal growth by midsummer. If this holds for populations of the present study, then back-calculated lengths should generally approximate the observed lengths during midsummer of the previous year more closely than those of the current year.

Validation of back-calculation is relatively straightforward with fish of known age since such analysis need not take into account uncertainties in age determination. The known-age bluegills in this study were those recognizable as original stock. Scale-length data from original bluegills were not used for the estimation of body-scale relationships, but were assumed to be rectilinear with an intercept equal to that of the mean of succeeding generations in the 24 populations. Figure 6 illustrates the agreement between back-calculated lengths and observed lengths found with all originally stocked bluegills. This agreement seems sufficiently good to conclude that back-calculation was valid for these bluegills.

Figure 6 shows three degrees of difficulty encountered in the analysis of the scale method's validity with non-original bluegills in the 24 populations. Figure 6-A illustrates the case of a population in which length-frequency distributions of the three year classes present did not overlap at the time of the final inventory, August 1958. The scales were not difficult to read. There is good agreement between back-calculated lengths and lengths of bluegills sampled during previous inventories. Of the 24 sets of scale data, 11 were analyzed with as little difficulty as this set.

Data summarized in Figure 6-B differed from those in 6-A chiefly in that the length-frequency distributions of some consecutive year classes overlapped at time of final inventory. Scale reading was on the whole not difficult, and agreement between comparable back-calculated and sample lengths is good. Nine sets of data fell into this category.

Some of the data shown in Figure 6-C were confusing. The confusion stemmed partly from overlapping year classes at final inventory, with some first annuli probably being missed by smaller members of the 1954 year class. There is also a strong possibility that bluegills from the 1954 and 1955 year classes from another pond entered the Arnot K-2 pond after 1955. Segments of 4 out of the 24 sets of population data fell in this "confusing" category, and Figure 6-C illustrates the case where the author's confusion was greatest.

DISCUSSION

It may not be possible under certain conditions to age some bluegills in a population correctly from scale data alone. However, in nearly all cases the nature of a check or the absence of an annulus can be inferred from scale and length data alone, provided sufficient scales are available from a sample representative of all size classes in the population.

Annulus determinations, both their number and position on the scale, were probably accurate in nearly all scales read in this study. Success was in part due to the following: 1. The literature includes a number of papers discussing the scale method as applied to bluegills. 2. Proposed criteria could be tested on scales of known-age bluegills from 22 populations. 3. Plastic impressions of scales rather than the scales themselves are examined.

Serious uncertainties concerning the reliability of back-calculated lengths existed with segments of data from 4 of the 24 populations. Notwithstanding these uncertainties, the author concludes that the assumptions and methods of back-calculation were generally valid for the bluegill populations studied.

ACKNOWLEDGMENTS

I gratefully acknowledge advice and criticism from Drs. A. W. Eipper and D. S. Robson of Cornell University. Dr. K. D. Carlander of Iowa State University made valuable suggestions. I have made rather free use of the unpublished Ph.D. thesis of Dr. M. A. Proffitt, now at Indiana State College. Mr. D. M. Payne of Cornell University made the photographs of the scales.

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