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Age and Growth of the Blueback Herring Alosa aestivalis (Mitchill)

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Age and Growth of the Blueback Herring

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ABSTRACT

The ages and rates of growth were determined for 317 blue-back herring (Alosa aestivalis) collected from the Rappahannock River in 1965 and 1966. The ages determined from scales, ranged from 4 to 9 years (males), and from 4 to 11 years (females). Immature fish 2 and 3 years old were not available for age determination. During the first year of life, males grew 38% of the length attained at 9 years, and females grew 36% of their length at 11 years. The greatest growth in weight occurred during the 4th year of life, males having gained 59 g and females gained 62 g. Differential rate of growth in length occurs between the sexes, with females exceeding males ar all ages. In all years after the second, females weighed more than males. Growth rates for males and females were computed using a proportional formula with a correction term of 37.96 mm (the length intercept of the body-scale regression).

Blueback herring become sexually mature at 4 years, although predominant age groups in the spawning run are 5- and 6-year-old fish. Females produced from 60,000 to 200,000 eggs, with an average of 120,000. There is a shift in the sex ratio during the spawning run, with males outnumbering females during the beginning of the run, females predominating during the middle of the run, and males often becoming dominant again at the end.

AGE AND GROWTH OF THE BLUEBACK HERRING

INTRODUCTION

The purpose of the present study is to determine the age and rate of growth of the blueback herring, *Alosa aestivalis* (Mitchill, 1814), by interpreting marks on the scales. Cockerell (1910, 1913) described blueback herring scales, but he did not attempt to determine age from the scales. Rings on blueback scales which resemble annuli on alewife (*Alosa pseudoharengus*) scales suggested that the age of the blueback might be determined using the scale method. Rothschild (1963) used alewife scales for age determination, and validated the annulus. Judy (1961) took scales from the closely related American shad (*Alosa sapidissima*) and validated the annuli.

Although the biology of the blueback has been described (Bigelow and Welsh, 1925; Bigelow and Schroeder, 1953; Hildebrand, 1963; Mansueti and Hardy, 1967), only generalities have been reported on the rate of growth, age at sexual maturity, and age structure of the commercial catch. Maximum age and the number of times adults return to spawn was also unknown.

The blueback herring is caught commercially with its close relative the alewife, as these species make spawning migrations up rivers flowing into the western North Atlantic. A systematic sampling of the spawning migrations of blueback herring, alewives, American shad, and hickory shad (*Alosa mediocris*) was undertaken in 1964 at the Virginia Institute of Marine Science (VIMS), Gloucester Point, Virginia. Scale samples and data on sex, length, weight, and gonad condition were collected weekly. Data reported herein are taken from a portion of that study.

REVIEW OF THE BIOLOGY AND LIFE HISTORY

The blueback herring is also known as glut herring, summer herring, black-belly, saw-belly, kyack, alewife, cat-thrasher, May herring and river herring (Goode, 1879; Smith, 1907; Hildebrand, 1963). In Canada the species is known as mulhaden or Alose d'été (Leim and Scott, 1966). The blueback is often confused with the alewife.

The dorsal surface of the blueback is bluish in life, while that of the alewife is grayish green (hence the name "grayback" sometimes applied to the alewife). The sides and the belly are silvery as in all members of the genus. The diameter of the eye of adult bluebacks is equal to or smaller than the snout length, whereas the eye of the alewife is slightly larger than the snout length. The peritoneum of the alewife is white or pinkish gray. Although a black peritoneum is characteristic of the blueback, rare variations may cause difficulty in positive identification. Goode and Bean (1879) stated that the fins are lower (shorter) in bluebacks. Although the alewife is deeper-bodied as a juvenile, this character is less distinct in mature individuals.

Pectoral fin rays vary from 14 to 16, dorsal rays from 15 to 20, anal rays from 16 to 21, and ventral rays are 9. The number of scutes (keeled belly scales) ranges from 31 to 36, with 18 to 21 anterior to the ventral fins. The number of vertebrae ranges from 47 to 53 (Mansueti and Hardy, 1967). Gill rakers are variable and increase with age from 28 to 36 (at approx. 40 mm SL) and from 42 to 50 (at approx. 140 mm SL) (Mansueti and Hardy, 1967). Reed (1964) determined nine races of blueback, using meristic data obtained from collections from Canada to Florida.

Maximum total length of the blueback is reported to be about 15 inches (380 mm TL) (Bigelow and Schroeder, 1936), but fish taken from Chesapeake Bay rarely attain a length of 13 inches (330 mm TL). Unless noted otherwise, all lengths here reported are fork lengths (FL). Standard length is designated as SL, and folded tip total length as TL.

In January and February, adult bluebacks are occasionally taken by trawlers south of the Virginia Capes as the fish move toward the mouth of Chesapeake Bay. Early arrivals first appear in pound net catches in the southern-most rivers, the James and York, late in March. The run reaches the Rappahannock and Potomac Rivers by the 1st and 2nd weeks of April, respectively.

Blueback herring do not spawn until the water temperature is from 21 to 24 C (Bigelow and Welsh, 1925). Collins (1952) found that bluebacks and alewives preferred warm streams when presented with a choice between streams of different water temperatures.

On the spawning run into fresh water, males precede the majority of females by about two weeks. Vincent (1960) suggested that blue-backs and alewives may hybridize, because spawning beds and spawning periods overlap. Spawning grounds in the Rappahannock River are from 30 to 95 nautical miles (55 to 174 km) above the river's entrance into Chesapeake Bay. In the Potomac River, spawning occurs as far as 100 nautical miles (183 km) above the mouth.

I observed paired fish on the spawning grounds to be relatively stationary over the bottom, facing upstream. Occasionally a pair would make a slow circle, the head of one to the tail of the other. Often they swam slowly into the current, advancing side-by-side or one slightly ahead of the other. After advancing upstream, they fell back in circling fashion, then remained immobile for several seconds. Sudden shadows produced by cloud cover initiated rapid darting movements. A gust of wind which rippled the surface of the stream also brought on fright reactions.

Kuntz and Radcliffe (1917) and Mansueti and Hardy (1967) described the embryology and larval stages of the blueback. Incubation at 22 C requires 50 hours (Bigelow and Welsh, 1925). Length at hatching is approximately 3.5 mm TL. The yolk sac is absorbed in 4 days, at which time the fry have grown to about 5.0 mm TL. Scales first appear at a length somewhat over 25 mm TL, forming in the posterior portion of the body and along the belly. Larvae transform to juveniles at about 38 mm TL (Mansueti and Hardy, 1967) and attain a length of 30 to 50 mm TL when a month old (Bigelow and Welsh, 1925). Juveniles 55 to 80 mm slowly migrate downstream. Size of juveniles (more than age or season) appears to be the criterion for entry into the Bay. Juveniles are present in the rivers and Bay throughout the fall, but largest fish are always collected near or in the Bay. A few juveniles of 70 to 90 mm may be taken in rivers up to 15 nautical miles (28 km) from their entry into Chesapeake Bay during January, February, and March, but by April this size is found only in the Bay. Bluebacks 110 to 200 mm are rarely observed in the Bay, but some fish may remain throughout the second summer (Hildebrand and Schroeder, 1928).

After passing the Virginia Capes, the young disappear in the Atlantic for 3 to 4 years and return only as mature adults. The species is infrequently taken at sea, and its distribution is unknown. Hildebrand (1963) suggested that bluebacks winter near the bottom. Netzel and Stanek (1966) reported large bottom trawl catches of blueback herring and alewives on Georges Bank (41°29'N, 68°34'W) in July 1964. However, exploratory bottom trawling by VIMS on the Continental Shelf between Cape Hatteras, North Carolina and Cape May, New Jersey took adult bluebacks at only one station, and juveniles at only six stations of the 54 stations occupied during the winter of 1966. No bluebacks were taken in this area during spring, summer, or fall sampling (Jackson Davis, personal communication).

Blueback herring occur from northern Florida (Jordan and Evermann, 1896) north to the Canadian maritime provinces of Nova Scotia (Cockerell, 1910; Leim and Scott, 1966) and Cape Breton (Bigelow and Schroeder, 1953). Livingston (1953) however, felt the alewife had been falsely identified as the blueback in all Canadian reports. Nevertheless, bluebacks are common as far north as Maine and Massachusetts, and constitute a major fishery in Chesapeake Bay.

Adult bluebacks 200 to 280 mm are captured in the Bay and in rivers from March to June. Few adults are landed after the first week in June, although the fishery is prolonged on the eastern side of Chesapeake Bay where the catch is predominantly spent (spawned) fish.

Predatory fish probably take their toll during the blueback's early life; however, the down-stream migration seems to be well timed to avoid predators. The weakfish (Cynoscion regalis) has been reported feeding heavily on blueback herring juveniles (Welsh and Breder, 1924). Since almost nothing is known of the blueback's life at sea, one can only speculate on oceanic predators. I saw a snapping turtle (Chelydra serpentina) feeding on a dead adult in Diascund Creek, but could not determine if it was a predator or a scavenger.

The commercial fishery for blueback herring concentrates on the spawning migration of adults. In Tidewater Virginia bluebacks and alewives are marketed together as river herring, but local fishermen can distinguish between the two. The principal gear used in the Chesapeake Bay region is the pound net, although bluebacks are also caught with weirs, fyke, and gill nets, haul seines, purse seines, and dipnets. The average annual catch of river herring in the Bay and its tributaries from 1960 to 1965 was 26,000,000 lbs., valued (ex-vessel) at $447,000 (U. S. Bureau of Commercial Fisheries, 1960-1965).

Wilson (1917) and Alperin (1965) reported that bluebacks are parasitized by Lernaeenicus radiatus, a parasitic copepod. Wilson (1932) found Lernaeenicus affixus on bluebacks. Sumner, Osburn and

Cole (1913) reported *Echinorhynchus acus* and Hoffman (1967) reported *Pomphorynchus bulbocolli* as the acanthocephalan parasites of the blueback. Hahn (1918) listed *Chloromyxum clupeidae* and Sindermann (1966) listed *Kudoa clupeidae* as myxosporidians occurring on the blueback. Sumner *et al*. (1913) reported the blueback was a host for the nematode *Heterakis foveolata*. The cestode *Trypanorhyncha* sp. is listed as a parasite of the genus (Hoffman, 1967). I found three immature nematodes in preserved ovaries of bluebacks collected on 9 May 1967 from the Chickahominy River. These specimens have not yet been identified, nor has the extent of parasitism been determined.

DETERMINATION OF AGE AND RATE OF GROWTH USING SCALES

One method for determining the age of fishes is interpreting the layers or rings on the hard parts of the fish. These rings reflect periodic changes in metabolism and growth rate. Apparently the first to state that the rings on scales and bones of fish correspond to periods of retarded and accelerated growth and that the age of the fish could be determined from these rings was van Leeuwenhoek in 1684 (Nikolsky, 1963).

If age is to be interpreted from growth rings, they must satisfy three criteria (Hile, 1941). A regular increase in fish length should coincide with each succeeding growth ring. There should be a close agreement between calculated length of a fish at any annulus and the actual length of the fish of the corresponding age group at the time of capture. The modes in the length-frequency distribution of the sample should coincide with the mean calculated lengths of age groups based on scale reading. Van Oosten (1929) stated that scales should grow in proportion to growth and remain constant in number throughout the life of the fish. In addition, the annulus must be formed at approximately the same time each year. The annulus of blueback herring is validated at the conclusion of this section.

Collection of Material

If races of blueback herring exist as Reed (1964) has indicated, and if bluebacks return to streams of their origin to spawn, it is reasonable to expect that differences in growth and form would arise and be characteristic of each race. Bluebacks from the Rappahannock River (Fig. 1) were selected for age-growth analysis because this river has no major branches, hence there was little chance that more than one sub-population was sampled.

Specimens were removed from a 50 lb. random sample of river herring obtained weekly from pound nets. Fork length, weight, sex, and sexual condition were recorded for each of 100 bluebacks from each sample. The fish were measured to the nearest millimeter. Weight was recorded to the nearest gram using a spring balance (diet type) or a "Direct Reading Balance" (Pennsylvania Scale Company).

In order to determine the body area with the most uniformly shaped scales, scales were removed from the following locations on the left side of the fish: (1) just above the midline anterior to the insertion of the dorsal fin, (2) just above and behind the pectoral fin, (3) from the midline posterior to the dorsal fin, and (4) below the midline above the anal fin. Scales from the region above the midline anterior to the insertion of the dorsal fin were the most uniform.

Scales were taken from 25 bluebacks from each sample in 1965 and from 50 bluebacks in 1966. About 50 scales were removed from each fish and stored in numbered envelopes. If a fish had no scales in the optimum area on the left, they were taken from the right side or from less desirable areas. Some specimens were without scales,

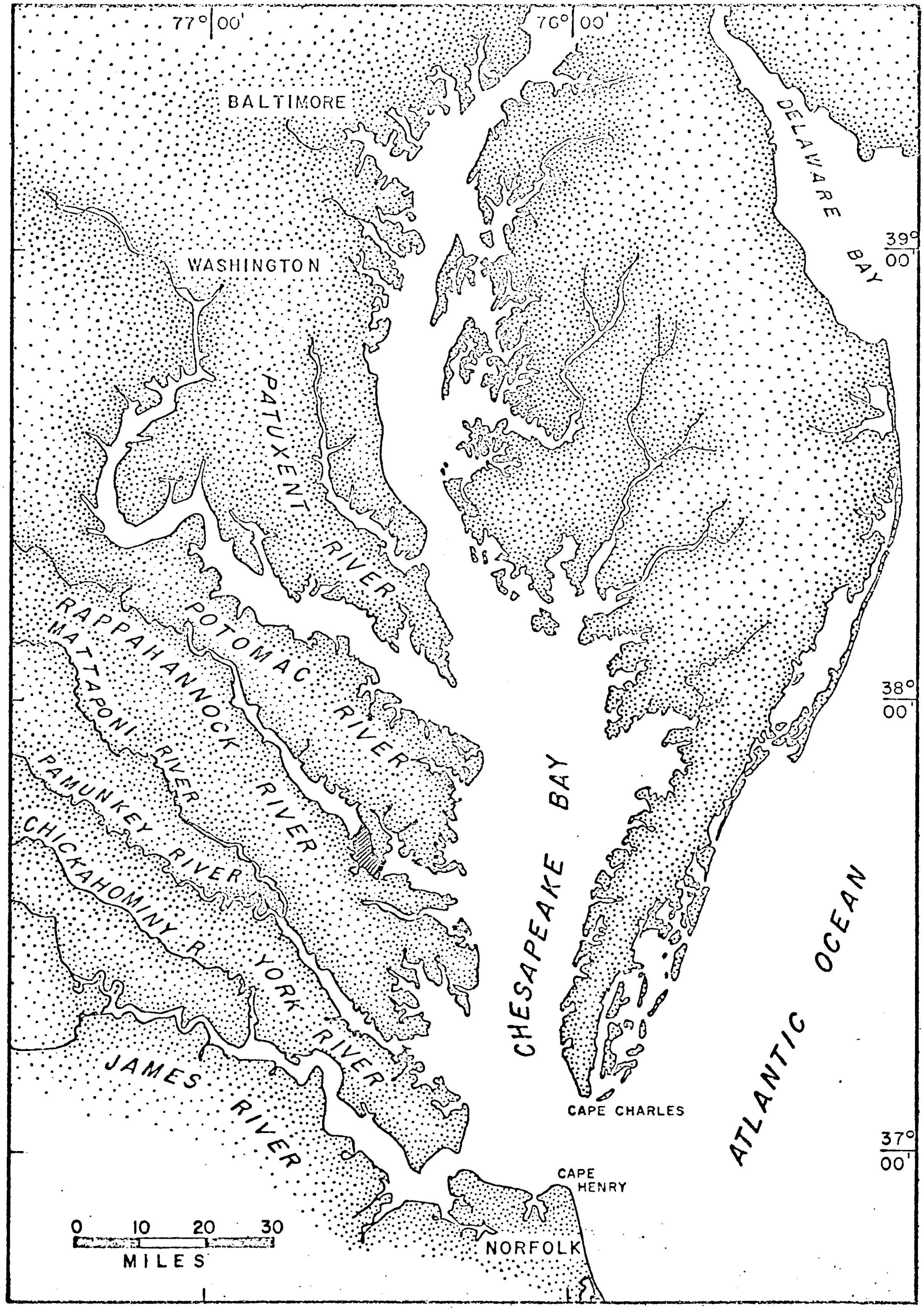


FIG. 1. Sampling area in the Rappahannock River (shaded portion).

and were discarded.

Impressions of the five cleaned scales from each fish were made in cellulose acetate sheets measuring 3 x 5 x 0.025 inch by a modification of the technique of Greenbank and O'Donnell (1950). This technique has been shown to be an accurate method of preserving the characteristic markings of scales by Butler and Smith (1953). Scales were soaked in fresh water for several hours and cleaned of adhering integument and mucus by rubbing between the thumb and forefinger. Cleaned scales were held in place on the sheets by "Time Tape" (Professional Tape Company, Inc.). Generally scales from 9 to 10 fish were placed on a single sheet. A legend was added at the time the scales were mounted, indicating collection number, date, and specimen numbers. If wet scales taped to the sheets were not allowed to dry at least 24 hours before being pressed, moisture trapped under the tape damaged the impression. Cover sheets of cellulose acetate were added above and below the sheet to be pressed, and impressions were made on a Carver Laboratory Press, Model B, maintained at 175 F (80 C) and 24,000 psi for 2.5 min. The Time Tape with adhering scales was removed and discarded. The sheet with impressions was cleaned with "Windex" or ethyl alcohol and a soft cloth.

Scale impressions were examined at 40X on an "Eberbach Projector", similar to the scale projector described by Van Oosten, Deason and Jobes (1934). Dr. Jackson Davis and I read the plastic impressions of the scales. Initial agreement between our independent readings averaged 80%. We re-examined all scales for which we had different interpretations of age, and an agreement was usually reached without consulting our previous determinations. Thirty of the 347 scales could not be read and were not included in growth determinations. I made a second reading to check the age determinations, and to mark the positions of the focus, annuli and spawning checks on strips of paper.

The distances to each annulus were entered as data in AGEGROW, a computer program written by Voigtlander and Roochvarg (1967). AGEGROW computed mean length at capture, gain in length since the last annulus, and mean length for each annulus by back-calculation using the modified proportion formula given by Fraser (1916):

$$L' = C + \frac{S'}{S} (L - C)$$

where L' is fork length at each annulus, S' is the scale radius from focus to annulus, S is scale radius from focus to margin at time of capture, L is fork length at time of capture, and C is the correction term (37.96) found by extrapolation of the regression of scale radius on fork length. All computations were done separately by sex and sample number, then the samples were combined.

Scale Characteristics

Blueback scales are thin, cycloid, easily removed structures arranged in an imbricate fashion. Scales from most parts of the body are subquadrate, though scales from the pectoral and anal fin regions are irregular. The anterior two-thirds to three-fourths of the scale is sculptured and imbedded in the dermis. The exposed posterior portion is covered with a thin layer of epidermis and lacks the markings characteristic of the anterior field (Fig. 2). Transverse grooves and ridges run from the dorso-lateral edge to the ventro-lateral edge.

Transverse ridges (striae) are fine crenulations in the hyalodentine of the imbedded anterior portion of the scale (Fig. 2). Striae are roughly parallel to the anterior edge, often discontinuous, and generally interrupted by annuli and spawning marks.

Transverse grooves are distinct grooves in the anterior field of the scale. They are few in number, variably spaced, and run parallel to the transverse ridges. Many grooves cross the scale as unbroken lines, while others are interrupted in the antero-posterior axis. Transverse grooves curve most near the anterior margin and are straight lines posteriorly. The number of transverse grooves is to some extent related to age, as will be demonstrated below.

The baseline is the first transverse groove on or just anterior to the zone separating the posterior and anterior portions of the scale (Cating, 1953). For scale measurement, I chose a point midway on the baseline as a focus (Fig. 3), after the technique used by Judy (1961) on American shad scales.

Annular marks on the blueback scale consist of zones of growth, annuli, and spawning checks. Growth zones appear as broad areas separated by narrow dark rings. The zones cannot be traced into the posterior field. The annulus is a disruption of the transverse ridges

FIG. 2. Scale of a blueback herring 6 years old. The anterior field (AF) consists of transverse grooves (TG), transverse ridges (TR), and annuli (A). The posterior field (PF) lacks these marks. The baseline (BL) separates anterior from posterior field. Transverse groove counts begin with the first groove above the baseline.

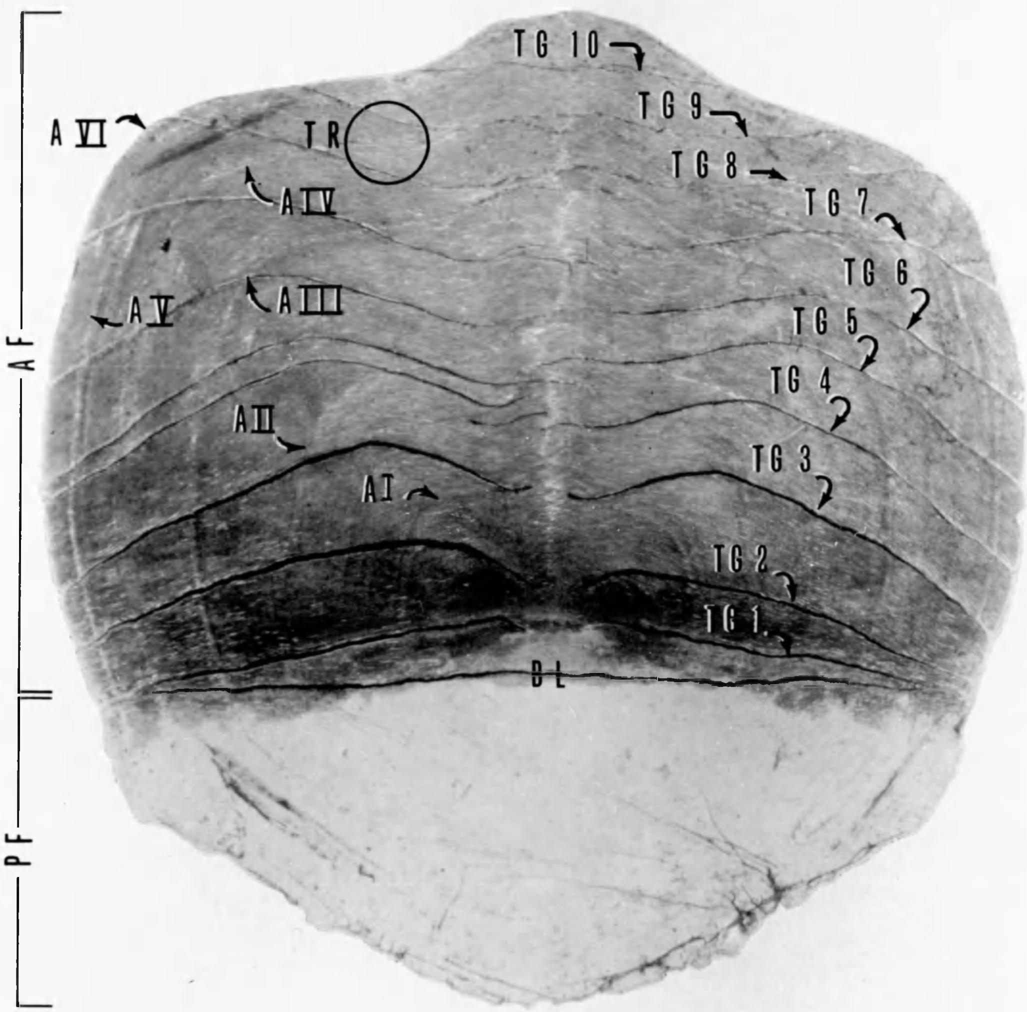
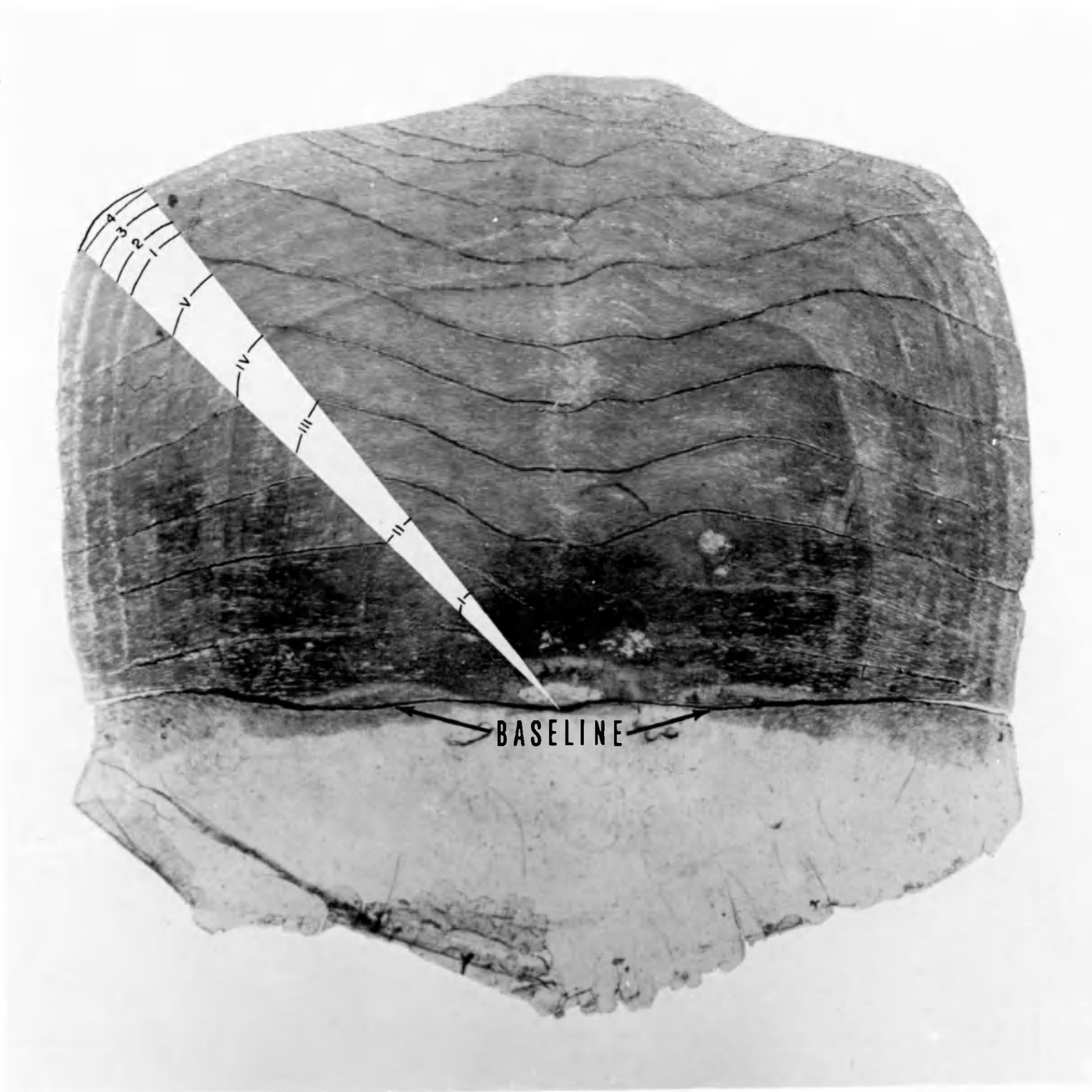

TG 10
TG 9
TG 8
TG 7
TG 6
TG 5
TG 4
TG 3
TG 2
TG 1.
DL
A VI
TR
A IV
A V
A III
A II
A I
AF
PF

FIG. 3. A blueback herring scale showing the method of measuring the scale radius. This scale shows 5 annuli and 4 spawning checks. The length at capture of this female was 280 mm FL.



4
3
2
1
V
IV
III
II
I
BASELINE

and appears as a dark ring due to diffraction. Annuli are more clearly defined on the lateral margins near the baseline, where they may be visible entering the posterior field. Annuli follow the general contour of the scale margin and can usually be traced completely around the anterior field - and sometimes the posterior field as well. However, annuli are not always clearly defined anteriorly, so scales were measured along an antero-lateral axis (Fig. 3). Presumably annuli are formed when growth slows and calcification proceeds to the margin. Normally only one annulus is laid down each year. False annuli (also called accessory rings) may be formed during the year probably in response to injury, disease or other abnormal stress. A false annulus can rarely be followed completely around the anterior field, cannot be detected in the posterior field, and is often manifested as a break in the striae accompanied by a regenerated portion of the scale (Fig. 4).

Spawning checks are formed by erosion or absorption of the scale margin during the spawning migration. These marks are scar-like in the lateral field, and similar to annuli in the anterior field. Like true annuli, spawning checks also extend into the posterior field, but usually cannot be seen encircling this area. Because of their scar-like appearance, spawning checks are easily identified (Fig. 3). Annuli are formed during the spawning migration (April to June), consequently in mature fish the spawning check is the annulus. Cating (1953), Judy (1961) and Rothschild (1963) counted the spawning checks as annuli in determining age of American shad and alewives.

FIG. 4. A blueback herring scale showing a false annulus and regeneration of part of the scale. Closely spaced transverse grooves are common on regenerated scales.

The scale edge was counted as a year, and an arbitrary birthdate of 1 January was assigned. Thus a blueback spawning for the first time at 5 years of age has four annuli plus the growth to the margin, and is designated as Age Group V. A "repeater" is a fish with one or more spawning checks. For example, a 7-year-old repeater which spawned for the first time at 5 years would have 4 annuli, 2 spawning checks, plus growth to the margin.

The absence of spawning checks on a few fish as old as seven years suggests that spawning is not invariably indicated by a spawning check.

Relationship of Body Length to Scale Radius

The relationship between body length and scale radius was determined from 146 adults and 64 juveniles taken from the Rappahannock River. Of the five scales normally mounted for adults, one scale was chosen as characteristic. Miller (1946) and Everhart (1950) used the antero-lateral radius in back-calculating body lengths, and Judy (1961) used this radius in age determinations. This axis is the greatest distance along a line from the focus to the ventral corner of the scale where the lateral and anterior edges meet (Fig. 3). Differences between antero-lateral radius and anterior radius were non-significant (*F*-test) when fork length was used as the independent variable. Since annuli and spawning checks are clearest in the antero-lateral zone, this axis was used for measuring blueback scales. A regression of the means of scale radii in 5 mm intervals versus means of the corresponding fish lengths was computed by the method of Whitney and Carlander (1956). A straight line appears to best fit the data (Fig. 5). The equation

$$L = 37.96842 + 0.77639(S)$$

was computed by the least squares method, where L is fork length in millimeters and S is scale radius (X40) in millimeters. The correlation coefficient was 0.98897, indicating a very close relationship between body length and scale radius. However, bluebacks between 100 and 200 mm are rarely taken in Chesapeake Bay, and none in this size range were available to supplement the data in Fig. 5. When fish in this size range become available for study, the equation above may have to be altered.

Ageing by Transverse Grooves

Borodin (1924, 1925) determined the age of American shad by counting transverse grooves and dividing by two. Unfortunately, he did not present criteria for including or rejecting incomplete transverse grooves. Barney (1924, 1925) used American shad otoliths to confirm Borodin's results. However, Greeley (1937) disagreed with Borodin's technique, and Judy (1961) got erroneous results using Borodin's method on marked American shad. Cating (1953) counted transverse grooves to locate the first three annuli of American shad.

I used Borodin's method of counting transverse grooves and dividing by 2 to get age, but obtained inconclusive results because incomplete transverse grooves were common on the anterior-most margin. However, the number of grooves crossing the first and second annuli

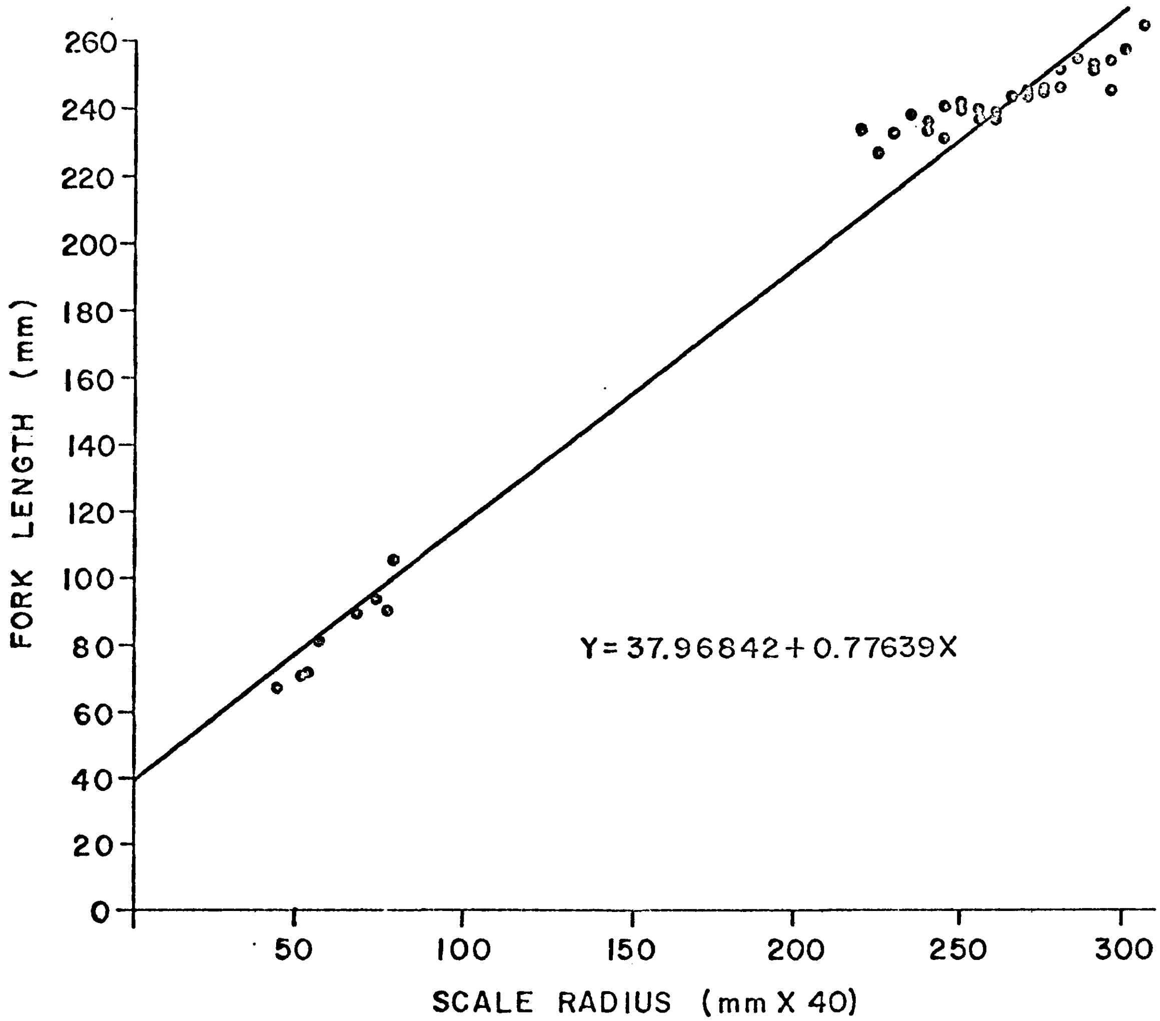


FIG. 5. Regression of fork length on scale radius. The dots represent 5 mm intervals of scale radii and the corresponding mean fork lengths.

appeared relatively constant and the number of transverse grooves increased with the size of the scale. These observations suggested a correlation between the number of transverse grooves and age.

The number of transverse grooves crossing the first through fourth annuli was recorded for scales from four places on the body. In most cases, when scales from one body location were compared with scales from another, there was no change in the number of transverse grooves crossing an annulus, and at most the deviation was ± 1. All counts fell within the range presented in Table 1.

There was considerable variability in scale shape from body region to body region, and incomplete grooves in the irregular scales from near the pectoral and anal fin regions may have caused errors in enumeration. Nevertheless, the results derived from reading scales from the several body locations serve to substantiate the hypothesis that the number of transverse grooves crossing the 1st through 4th annuli is fairly constant, regardless of scale location.

Application of Cating's (1953) method to blueback scales indicated a correlation between age and number of transverse grooves. Scales from 147 fish were examined. Independent readings by two investigators showed the annuli could be readily determined. The number of transverse grooves crossing the first through fourth annuli were recorded. Counting began with the first transverse groove above the baseline. Grooves which branched were counted as one. Fig. 2 illustrates the procedure of numbering the transverse grooves. The number of transverse grooves crossing the first annulus ranged from

TABLE 1. Frequency distribution of transverse groove counts in each annulus

Number of transverse grooves	Distribution of 147 counts in --							
	First annulus		Second annulus		Third annulus		Fourth annulus	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
1	1	0.6						
2	53	36.0						
3	89	60.5	1	0.6				
4	4	2.7	44	29.9	1	0.6		
5			89	60.5	6	4.0		
6			12	8.2	43	29.2	1	0.6
7			1	0.6	68	46.2	4	2.7
8					27	18.4	46	31.2
9					2	1.4	69	47.0
10							21	14.3
11							6	4.0

one to four (Table 1), but was characteristically two or three. The number entering the growth zone enclosed by the second annulus ranged from three to seven, but was usually four or five. The number of transverse grooves crossing the third annulus was generally six or seven while the number crossing the fourth annulus was usually eight or nine. Grooves are commonly incomplete beyond the fourth annulus, and counts beyond that point were not included. This is not a weakness of the method, however, since annuli and spawning marks are easily recognized beginning with the third annulus. No scales from young-of-the-year bluebacks had more than three transverse grooves, and the counts were comparable with the number of grooves in the first annulus of adults.

Since annuli, especially the second, are occasionally difficult to determine, the number of transverse grooves is useful as an index for differentiation of true and false annuli.

Length-Frequency

Young-of-the-year fish collected in late summer and fall at the mouths of tributaries entering Chesapeake Bay are typically from 65 to 75 mm long. Bluebacks tend to school by size. In a collection of several hundred juveniles, lengths may deviate from the mean by only $\pm$ 3 mm. A few young-of-the-year fish spend the winter in the rivers, attaining a mean length of 76 mm by February. Fish of this size are found in the Rappahannock River as far as 40 nautical miles (74 km) from the Bay, but by April are no longer taken in the river.

Curiously, 11 bluebacks measuring 82 to 111 mm ($\bar{x}$ = 100 mm) were caught on 1 May 1968 in the Potomac River approximately 83 nautical miles (152 km) from the Bay. These fish are without a doubt 1 year old, but are of a length seldom taken in Chesapeake Bay.

Juvenile bluebacks were collected in the Rappahannock River by otter trawl from January to March 1968. Several samples were also taken at sea from 7 to 9 March 1968 (Table 2). Samples collected from Chesapeake Bay in 1913 by Hildebrand and Schroeder (1928) showed a mean fork length of 78 mm, slightly larger than the mean fork length of Rappahannock River bluebacks (76 mm) taken during the same period in 1968 (1 to 15 March). Samples from rivers rarely have mean lengths greater than 76 mm, thus these results are typical. The mean fork length of juvenile bluebacks taken in the North Atlantic during this period was 82 mm, larger than both the Chesapeake Bay and Rappahannock River samples.

Two-year-old bluebacks were quite scarce in my collections, though some were taken at sea by the R/V Albatross IV in March 1968. However, whether these fish came from the Rappahanock River or not is unknown. As mentioned earlier, little is known about the first 3 years spent at sea. Bluebacks are seldom captured in trawls until migrating to the spawning grounds as adults. Thus it is important to note that Hildebrand and Schroeder (1928) reported bluebacks taken in Chesapeake Bay in the size range of 120 to 180 mm FL. Hildebrand (1963) discussed the importance of the length-frequencies, stating, "If the six largest examples, which may be about three years

TABLE 2. Length-frequency of juvenile bluebacks of age group I, Rappahannock River and North Atlantic 1968

Fork length (mm)	Rappahannock River January 16-31	Rappahannock River February 01-15	Rappahannock River March 01-15	North Atlantic March 01-15
50-54	-	-	-	-
55-59	-	2	-	-
60-64	-	5	-	3
65-69	24	11	5	2
70-74	119	84	35	4
75-79	121	128	57	10
80-84	45	59	35	15
85-89	7	12	3	2
90-94	-	2	1	7
95-99	1	-	-	4
100-104	-	-	-	1
105-109	-	-	-	1
110-114	-	-	-	-
Total	317	303	136	49
Mean	74.9	76.2	76.4	82.4
$S_{\bar{x}}t_{.05}$	± 0.4	± 0.6	± 0.8	± 2.9

old, are excluded, the range for the fish that apparently are two years old is 140-184 mm [TL]." Converted to fork length, this size range is 123 to 161 mm. The mean of 145 mm is very close to the grand average back-calculated fork length for two year old males (142 mm) and females (144 mm) (Tables 3 and 4). Bean (1887) reported two collections of bluebacks which I believe were 1½ years old. One sample, taken 28 November 1885, had 46 specimens with a size range of 112 to 133 mm FL. A second sample had 13 specimens 112 to 122 mm FL, taken on 10 December 1885.

Figs. 6 and 7 illustrate the length-frequency, mean length and confidence intervals ($\bar{x} \pm S_{\bar{x}} t_{.05}$) of each age group (males and females, respectively). Length intervals of 2 mm were used because larger intervals obscure the individual modes. The confidence intervals about each mean length for each age group are significantly different in all cases for males, and in all cases except for the 9-year-old females. For a species which shows very little growth in the older age groups, overlap of confidence intervals is often more extensive than found in the blueback. Non-overlapping confidence intervals of younger fish indicate that in future sampling by age groups, at least 95% of the sample means will fall within the appropriate confidence intervals. This provides an easy method for separating the sampled catch into age groups.

Growth Determinations

Rate of growth was determined by two methods (Tables 3 and 4).

TABLE 3. Calculated fork length at end of each year of life of male blueback herring from the Rappahannock River, 1965-1966

Age group	No. of fish	Mean length at capture (mm)	Gain since last annulus (mm)	Calculated fork length at each year of life (mm) 1	2	3	4	5	6	7	8
I	none	--	--								
II	none	--	--								
III	none	--	--								
IV	24	225	28	101	152	198					
V	47	234	15	96	141	184	220				
VI	64	240	8	94	140	185	218	232			
VII	27	245	5	94	140	186	220	232	240		
VIII	6	256	4	96	146	188	222	240	246	250	
IX	1	261	5	93	146	200	220	237	244	250	256
Total	169										
Grand ave. calculated length				96	142	187	218	232	241	250	256
$S_{\bar{x}} t_{.05}$				± 1.0	± 1.6	± 1.8	± 1.2	± 1.2	± 1.8	± 3.2	---
Average increment of length				96	46	45	31	14	8	9	6
Grand ave. increment of length				96	46	45	33	14	8	4	6
Percent of growth per year				38.0	18.4	17.6	13.2	5.6	3.0	1.7	2.2
Sum of grand ave. increments				96	142	187	220	234	242	246	252

TABLE 4. Calculated fork length at end of each year of life of female blueback herring from the Rappahannock River, 1965-1966

Age group	No. of fish	Mean length at capture (mm)	Gain since last annulus (mm)	Calculated fork length at each year of life (mm)									
					2	3	4	5	6	7	8	9	10
I	none	--	--										
II	none	--	--										
III	none	--	--										
IV	14	233	32	101	154	202							
V	38	244	18	97	142	189	226						
VI	50	251	10	98	144	192	226	242					
VII	33	257	7	97	144	188	221	240	250				
VIII	7	266	6	96	139	191	228	245	254	260			
IX	4	269	7	92	149	192	222	239	249	256	262		
X	1	271	4	88	136	180	217	238	254	258	262	267	
XI	1	275	6	100	162	203	222	240	253	258	261	266	270
Total	148												
Grand ave. calculated length				98	144	191	224	241	250	259	262	266	270
$S_{\bar{x}}t_{.05}$				±1.2	±1.8	±2.0	±1.5	±1.4	±2.2	±3.7	±7.0	±8.9	---
Average increment of length				98	46	47	33	17	9	8	3	4	4
Grand ave. increment of length				98	46	47	34	17	10	6	5	4	4
Percent of growth per year				35.8	17.2	17.2	12.6	6.2	3.6	2.4	1.8	1.6	1.2
Sum of grand ave. increments				98	144	191	226	242	252	259	264	268	272

FIG. 6. Length-frequency distributions of male bluebacks from the Rappahannock River, 1965-1966. Length-frequencies of each age group are within the length-frequency of all bluebacks taken ($N = 465$). The boxes above represent mean lengths, $S_{\bar{x}}t_{.05}$, and range for each age group.

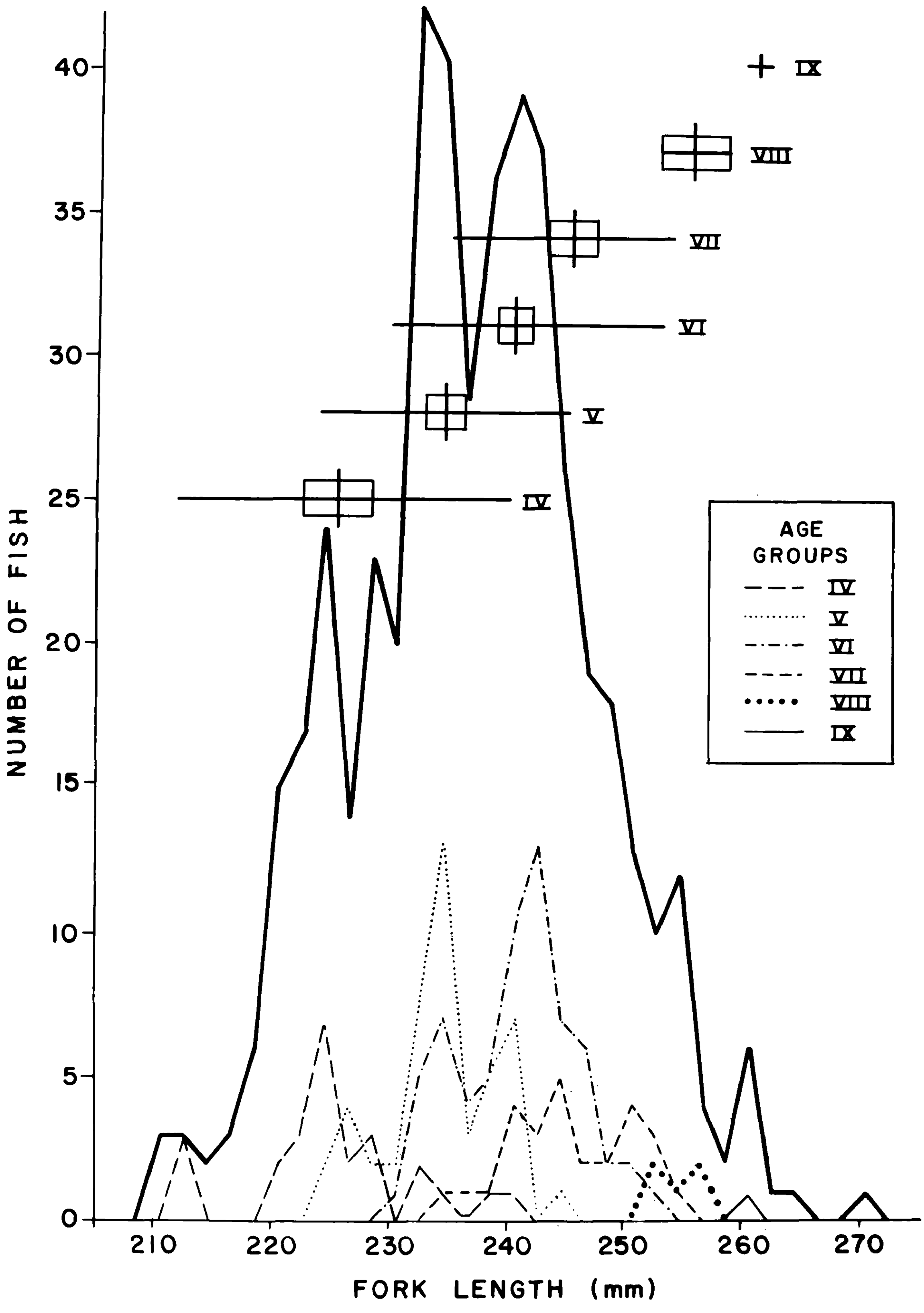
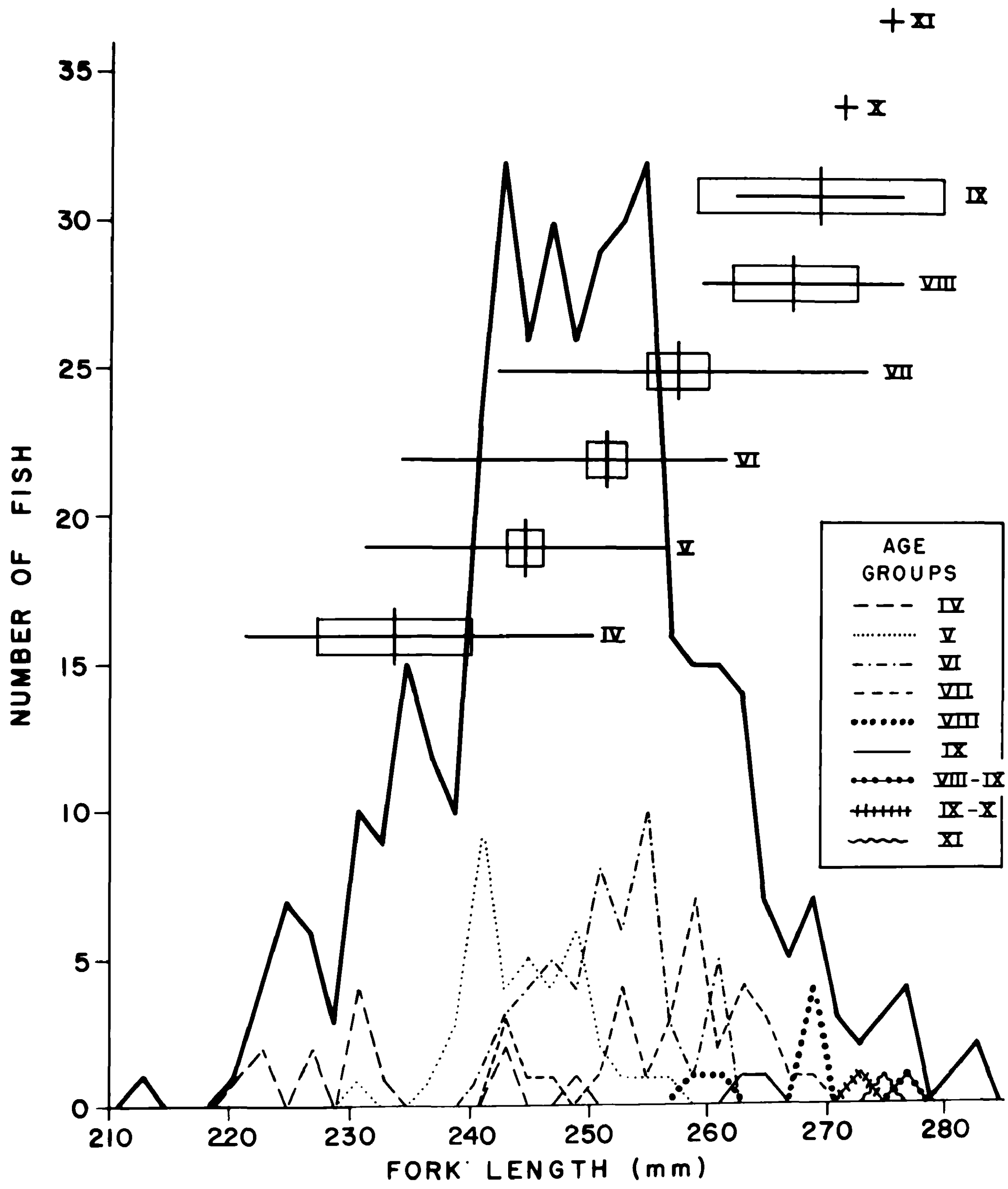

NUMBER OF FISH
FORK LENGTH (mm)
0
5
10
15
20
25
30
35
40
210
220
230
240
250
260
270
IV
V
VI
VII
VIII
IX
AGE GROUPS
IV
V
VI
VII
VIII
IX

FIG. 7. Length-frequency distribution of female bluebacks from the Rappahannock River, 1965-1966. Length-frequencies of age groups are within the length-frequency of all bluebacks taken (N = 400). The boxes above represent mean lengths, $S_{\bar{x}}t_{.05}$, and range for each group.



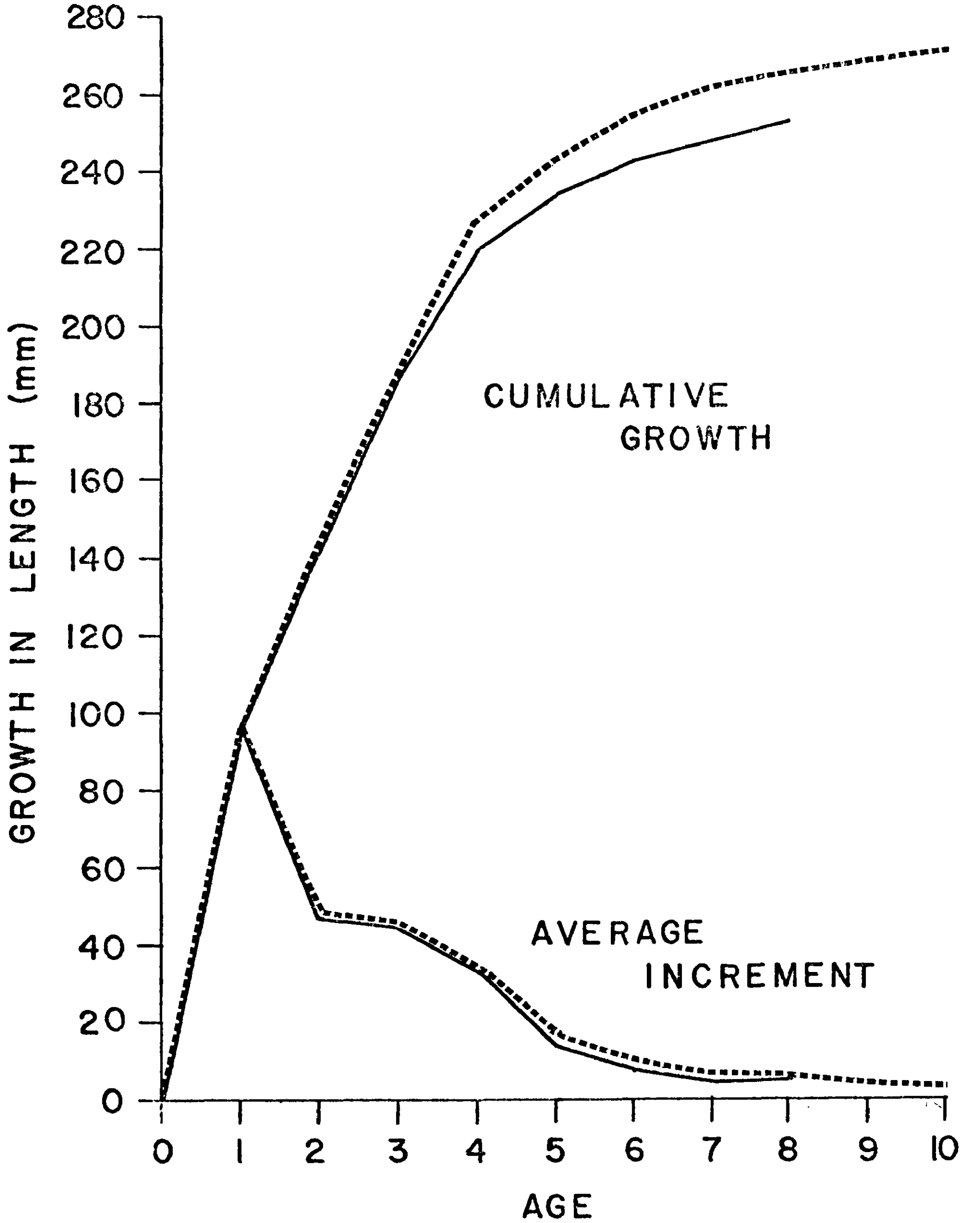
NUMBER OF FISH
FORK LENGTH (mm)
AGE GROUPS
IV
V
VI
VII
VIII
IX
VIII-IX
IX-X
XI
X

The first method involved computing a grand average calculated length by summing all back-calculated lengths for a particular age, and dividing by the number of fish. The second method employed the grand average increment of length. The methods gave similar results. The summations of average increments were used in the preparation of Fig. 8. Females grew at a faster rate than males, a common characteristic of migrating fishes (Nikolsky, 1963). The grand average increment of length plotted against age (Fig. 8) shows that the length increment during the 3rd year was approximately the same as the increment for the 2nd year. Thus, after leaving the Chesapeake Bay nursery areas, juveniles apparently grow in length at a slower but more nearly constant rate in the Atlantic Ocean.

Marginal erosion of the scale during spawning can cause underestimation of the true length by back-calculation. LaPointe (1958) found extensive erosion on scales of American shad which had previously spawned, and used only non-repeaters for his growth determinations.

To test the extent of marginal erosion in the blueback herring, fork lengths of 89 male and 72 female virgin spawners were back-calculated. The results were compared statistically with back-calculated lengths of 80 male and 76 female repeaters. Although the calculated lengths at each year of life were greater for virgin spawners in every case except one, the differences were not significant when tested with the <u>t</u>-test (Snedecor, 1956). There was no evidence that pooling data obtained from first year spawners

FIG. 8. Cumulative growth in length for each year of life and grand average increments of length for blueback herring, Rappahannock River, 1965-1966. Solid line represents growth for males, and the dotted line represents females.


GROWTH IN LENGTH (mm)
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
CUMULATIVE GROWTH
AVERAGE INCREMENT
0
1
2
3
4
5
6
7
8
9
10
AGE

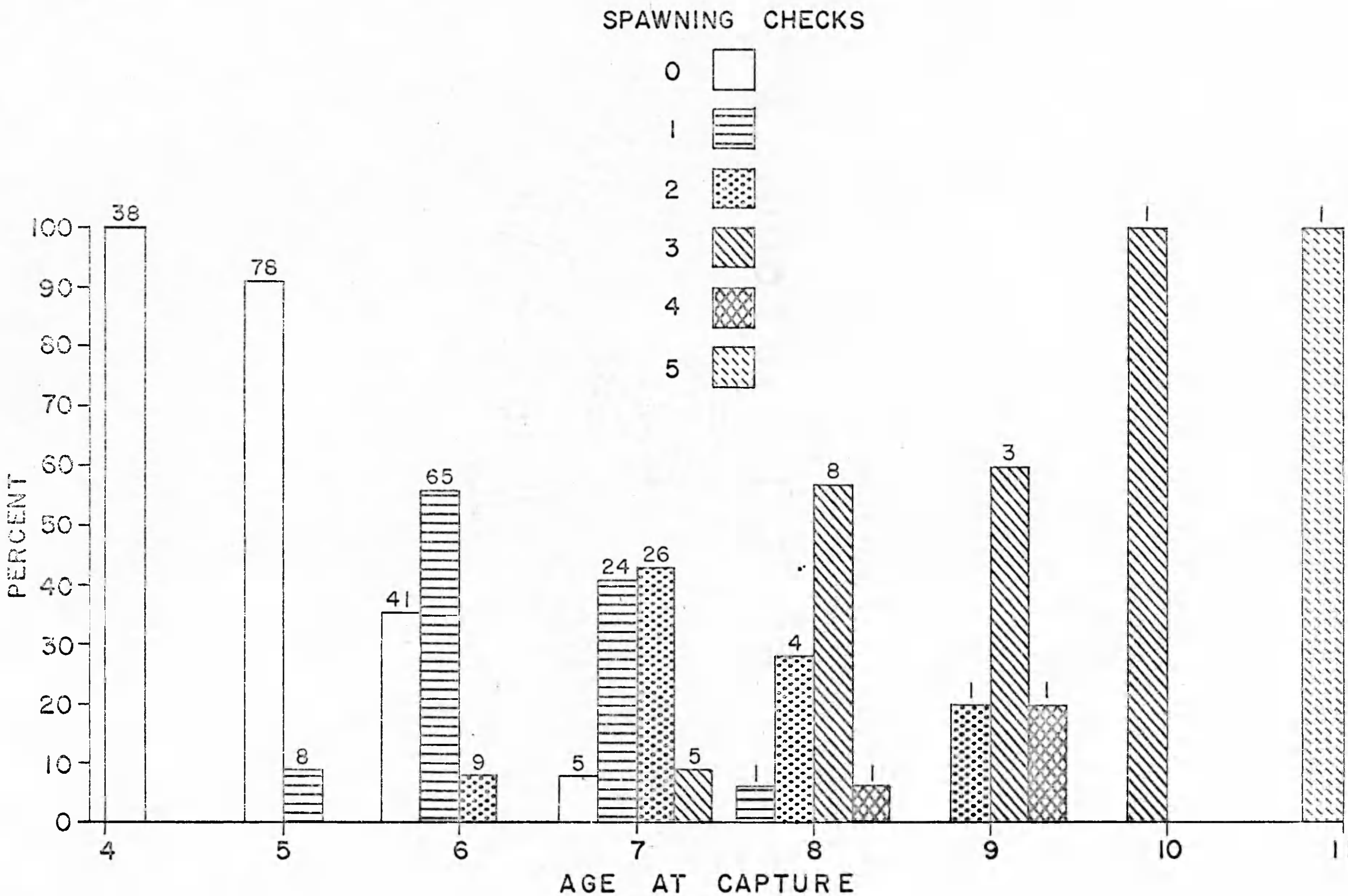
and repeaters would result in inaccurate length determinations. Some bluebacks may spawn without forming a spawning mark, but this possibility was not explored in the present study.

Fig. 9 shows the percent of first year spawners and 1st to 5th year repeaters in each age group. Virgins were still found at seven years. One female had five spawning checks.

Validation of the Annulus

Bluebacks are unavailable throughout most of the year, and the exact time of annulus formation is not known. An annulus is not visible on the margins of scales taken from adults in the spawning migration. Juvenile and adult bluebacks appear to form an annulus at the same time of the year, as shown by comparing the computed lengths at age IV, using virgin spawners 5 and 6 years old and repeat spawners who spawned first at 4 years. The spawning mark of the repeaters is thus compared with the annulus of the immature fish having the same age. Rothschild (1963) found juvenile and adult alewives laying down annuli at the same time of the year (June to July). Cating (1953) and Judy (1961) determined that annuli of adult and juvenile American shad are formed at the same time. Theoretically, the mean observed lengths should be the same as the calculated lengths if annulus formation does indeed occur during the time of the spawning run each year. Tables 3 and 4 show mean length at capture to be nearly identical to the calculated lengths for each age group. The greatest difference was in the 4-year old fish

FIG. 9. Percent virgin spawners and repeaters in each age group, sexes combined, Rappahannock River blueback herring, 1965-1966. Numbers at the top of each bar indicate the number of fish in that category.


SPAWNING CHECKS
0
1
2
3
4
5
PERCENT
100
90
80
70
60
50
40
30
20
10
0
38
78
8
41
65
9
5
24
26
5
1
4
8
1
1
3
1
1
1
4
5
6
7
8
9
10
11
AGE AT CAPTURE

(4 mm for males, 7 mm for females). Modes in the length-frequency distribution of the samples coincide with the modes of the age groups (Figs. 6 and 7). Overlap in the length frequency distribution of adjacent age groups may indicate inclusion of a few incorrect age determinations. In general, the distribution can be termed normal for age groups characterized by small annual increments after sexual maturity. As is apparent in Tables 3 and 4, there is a regular increase in fish length with each succeeding annulus. Thus, all of Hile's (1941) criteria for validating the annulus are met, and the markings on the scales of blueback herring are true annuli. Annuli have been validated on the scales of alewives (Rothschild, 1963) and American shad (LaPointe, 1958; Judy, 1961). The similarity between blueback scales and scales from these two species suggested early in the study that the rings on blueback scales were indeed true annuli.

SEX RATIO

Males predominated in samples taken early during the spawning season (Fig. 10). The area sampled in the Rappahannock River encompassed about 5 nautical miles (9.2 km), located 15 nautical miles up-river from the mouth and well below the spawning areas. The percentage of males in samples taken from the Rappahannock River ranged from 62 to 100 for the first 2 weeks of April (1965 to 1968). By the end of April the sex ratio had decreased to approximately 50:50. By the second week of May, females usually predominated (about 60% of the samples). The late season increase in the percentage of males is attributed to down-stream migrating males which have remained on the spawning grounds longer than females. At Diascund Creek spawning grounds, males outnumbered females 63 to 18 (3.5:1) on 6 May 1968, about 1 to 2 days after the peak of spawning activity. The sex ratio of bluebacks taken there late in the season (16 May 1967) was 148 to 7 (21:1) in favor of males. Since males do remain on the spawning beds longer than females, it follows that when males leave the creeks, they would predominate in catches. From Fig. 10 one might suspect that the sex ratio averages 50:50 when the entire run is considered. I examined the 1967 catch records of the fisherman from whom we obtained our weekly samples. His records showed peak catches of blueback herring in the last two weeks of April. By applying the sex ratio determined from my samples, I estimated

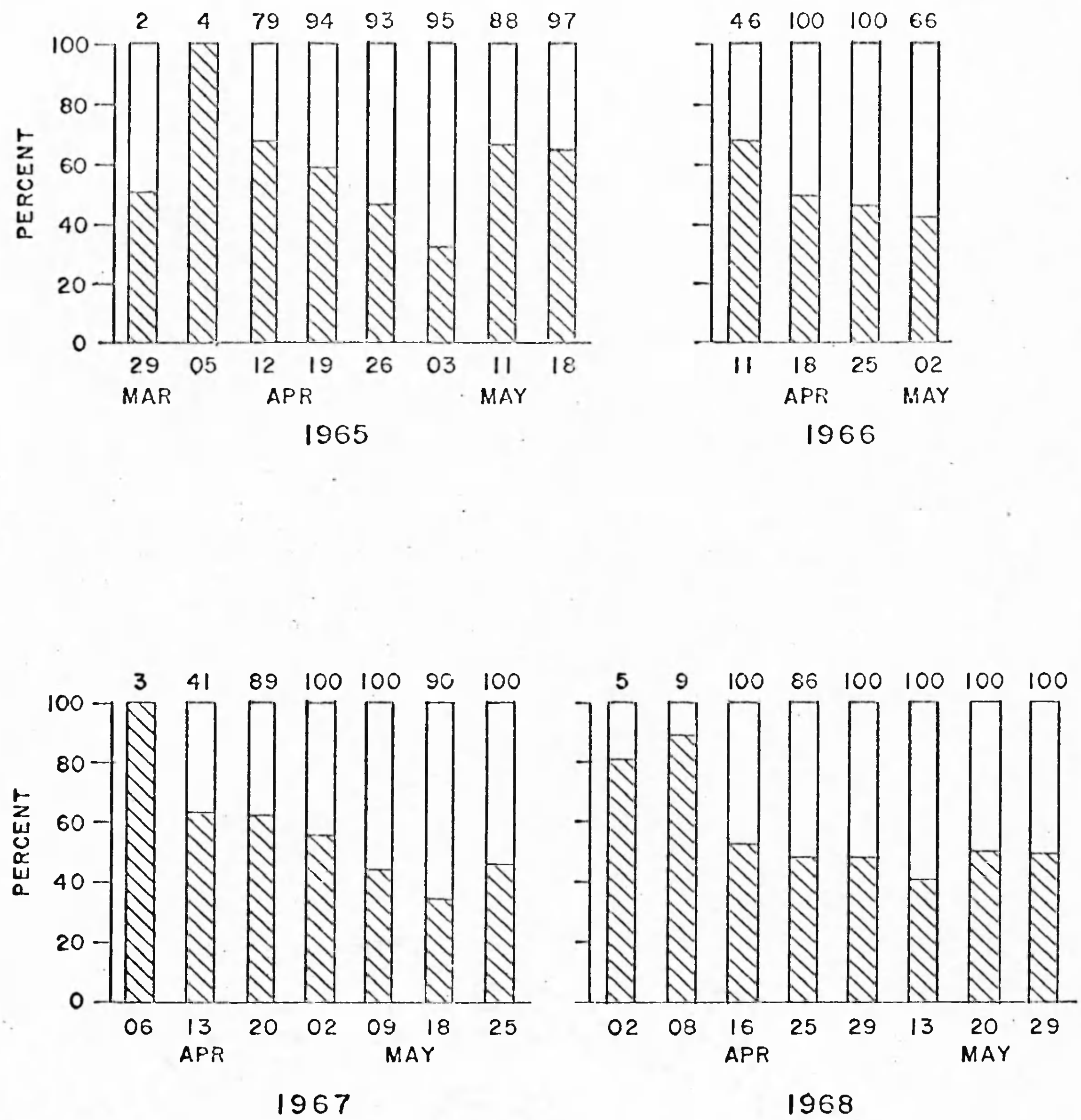


FIG. 10. Sex ratio of blueback herring in the Rappahannock River, 1965 to 1968. Solid bars represent males, hollow bars represent females. Numbers at the top of each bar indicate sample size.

the number of bluebacks of each sex in the catches. The estimated sum of males was compared against the sum of females for the entire run. Males were found to outnumber females 62:38. When this sex ratio was tested using Chi-square, males were found significantly more abundant than females. However, the percentage of each sex from the weekly samples used in age determinations did not deviate significantly from a 50:50 ratio when data for the whole year were tested by Chi-square. The samples did not indicate the true sex ratio because the peak of the run occured when the sex ratio was roughly 60:40 in favor of males, and sampling effort was disproportionate to the size of the catches.

Fig. 11 shows the percent of the catch in each age group by sex. Males are predominant in the 4th through 6th age groups. Also noteworthy is that 5- and 6-year-old fish make up 60% to 65% of the samples in both sexes. Males dominated age groups V and VI (Table 5), and 63% of the 4-year-old fish were males. Seven-year-old fish were predominately females (55%), and older age groups were also dominated by females.

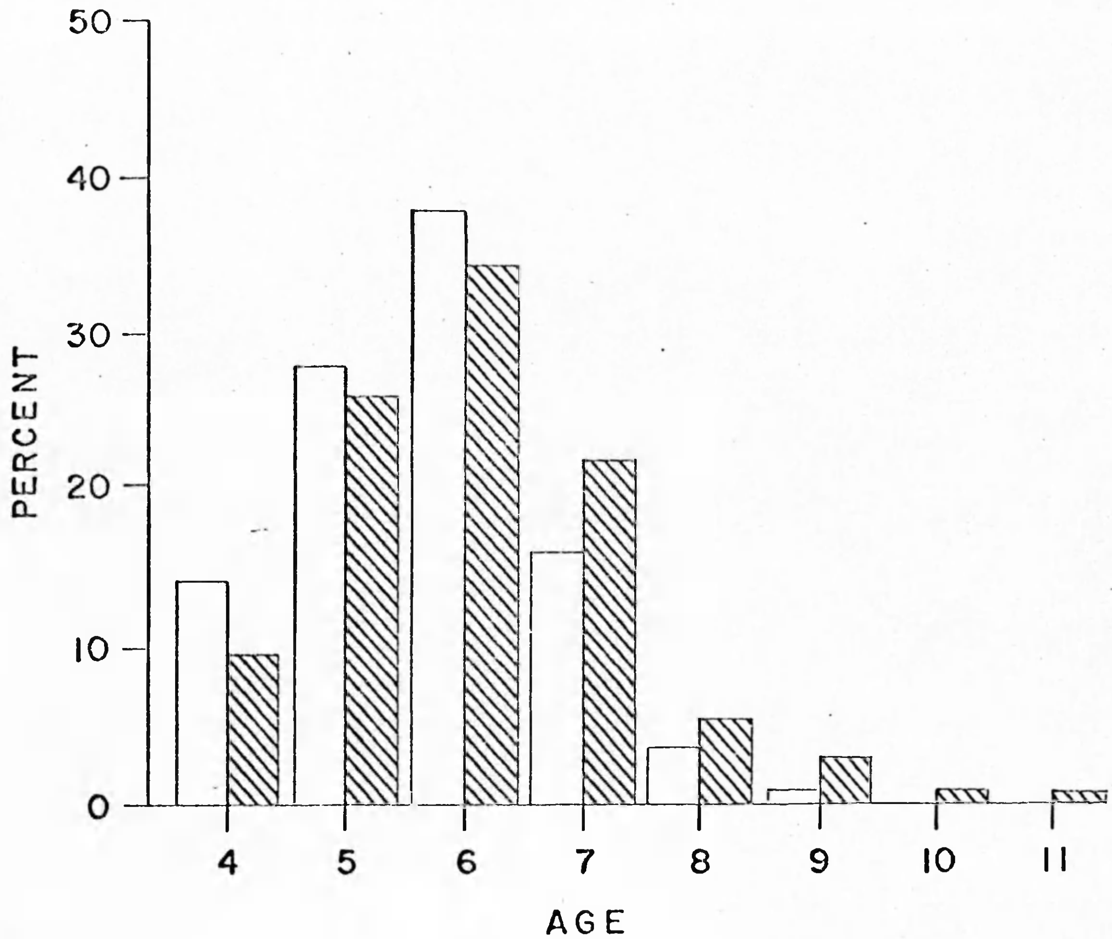


FIG. 11. Percent of the catch of blueback herring from the Rappahannock River in each age group (sexes separate), 1965-1966. Open histograms represent males, solid histograms represent females.

TABLE 5. Sex ratio (percent) by age groups

Age group	Males		Females		Total
	Number	Percent	Number	Percent	
I	--	--	--	--	--
II	--	--	--	--	--
III	--	--	--	--	--
IV	24	63.2	14	36.8	38
V	47	55.2	38	44.7	85
VI	64	56.1	50	43.8	114
VII	27	45.0	33	55.0	60
VIII	6	46.2	7	53.8	13
IX	1	20.0	4	80.0	5
X	--	--	1	100.0	1
XI	--	--	1	100.0	1
Total	169		148		317

LENGTH-WEIGHT RELATIONSHIP

The relationship between length and weight was determined for male and female blueback herring separately and combined. The equation

$$W = cL^n$$

was used in the following form:

$$\log W = \log c + n(\log L)$$

where L is fork length in millimeters, W is weight in grams, and c and n are constants computed by the following equations:

$$\log c = \frac{\Sigma\log W \cdot \Sigma(\log L)^2 - \Sigma\log L \cdot (\Sigma\log L \cdot \log W)}{N \cdot \Sigma(\log L)^2 - (\Sigma\log L)^2}$$

$$n = \frac{\Sigma\log W - N \cdot \log c}{\Sigma\log L}$$

where N is the sample size (Rounsefell and Everhart, 1953). The equation for males and females combined,

$$\log W = -5.5003 + 3.2724(\log L)$$

is illustrated in Fig. 12. The regressions of length and weight for males and females are:

$$\text{males:}\quad \log W = -5.2591 + 3.1707(\log L)$$

$$\text{females:}\quad \log W = -5.6413 + 3.3314(\log L).$$

Growth in Weight

The calculated growth in weight of Rappahannock River bluebacks (Table 6) was determined by applying the length-weight equations (sexes separate) to the calculated lengths (sum of grand average

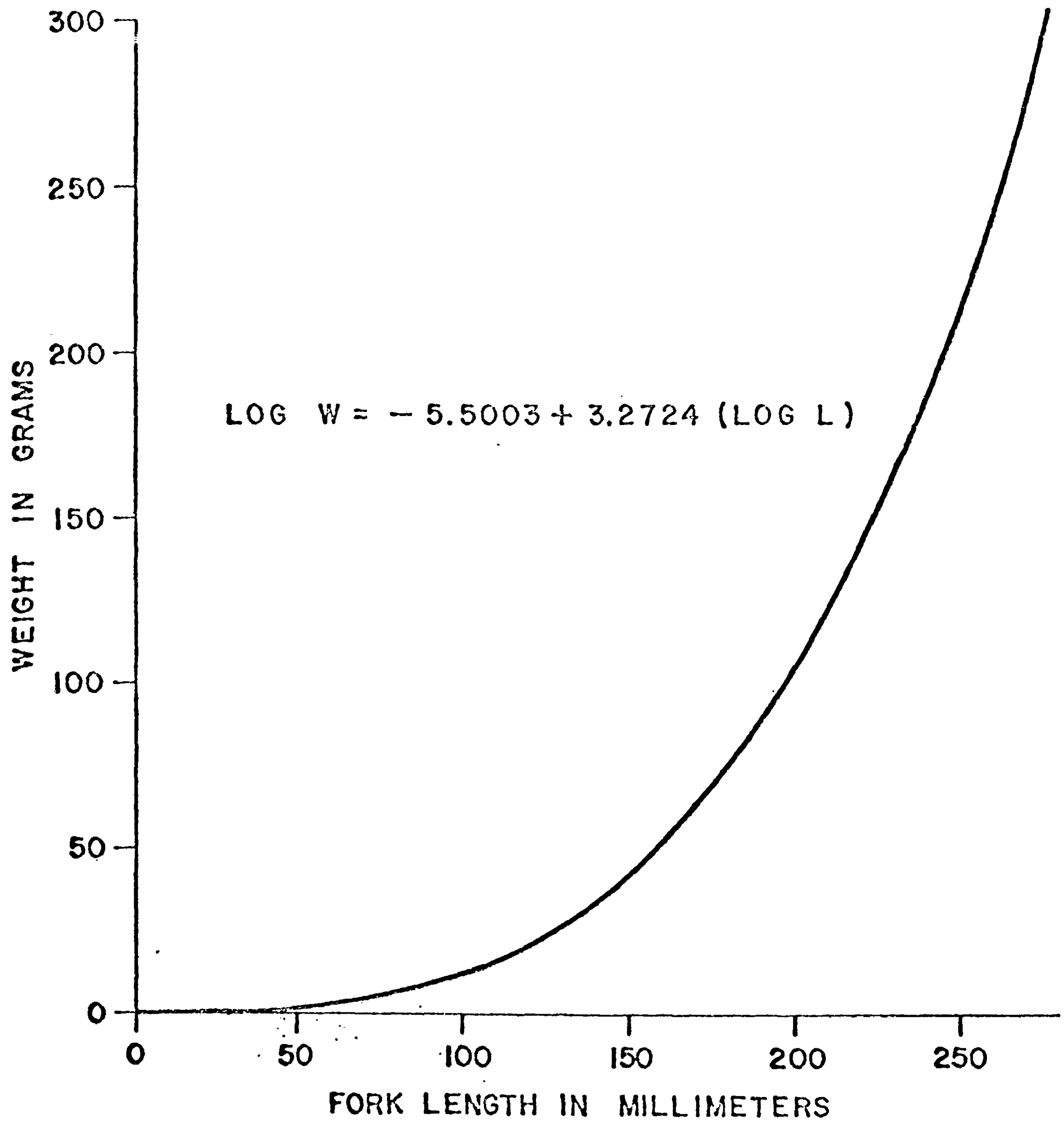


FIG. 12. Length-weight relation for male and female blueback herring from the Rappahannock River, 1965-1966.

TABLE 6. Calculated growth in weight of blueback herring from the Rappahannock River, 1965-1966

Year of life	Males			Females		
	mean length (mm)	calculated weight (g)	increment (g)	mean length (mm)	calculated weight (g)	increment (g)
1	96	10	10	98	10	10
2	142	38	28	144	36	26
3	187	87	49	191	93	57
4	220	146	59	226	154	62
5	234	180	34	242	202	48
6	242	200	20	252	229	27
7	246	208	8	259	252	23
8	252	226	18	264	269	17
9				268	282	13
10				272	295	13

increments) at the end of each year. The increased growth rate of females was reflected in the higher weight increments. In samples taken during the spawning migration, gonadal development and condition influences weight considerably, so two fish of one sex and of equal length may have a weight difference of more than 100 g.

Both sexes had their greatest growth in weight in their 4th year of life (59 g for males and 62 g for females). Many bluebacks become sexually mature at 4 years, so much of this increased growth is probably directed toward buildup of gonadal products. Often associated with sexual maturity are secondary sexual characteristics, one of which is a differential rate of growth between the sexes (Nikolsky, 1963). After age 2 females gain weight faster than males (Fig. 8).

FECUNDITY

Scales and ovaries were removed from 32 gravid blueback herring collected in the Chickahominy River on 9 May 1967. Length and weight were recorded before the ovaries were removed. Females of different sizes were selected with the aim of sampling different age groups. Ovaries were stored for several months in 15% formalin solution.

The ovaries were dried of excess moisture on paper towels then weighed to 0.01 g on an electric "Sartørius" scale. A subsample of eggs was removed from 2 or 3 different sections of the ovary and weighed. The subsample was then placed in a bowl of water and the ovarian tissue was teased apart with forceps. The formalin-hardened eggs were yellowish-white, and could be moved about easily. Free eggs were removed from the bowl with a pipette. The pipette was held horizontally in front of a light background and the ripe and unripe eggs were counted. Up to 200 eggs were counted in each pipette-full.

Total number of eggs per female was determined by direct proportion as follows:

$$\text{total eggs} = \frac{\text{weight ovary} \cdot (\text{number eggs in subsample})}{\text{weight of subsample}} .$$

Average number of eggs per female was 120,000 (Table 7), but the range was from 60,000 (for a 238 mm fish) to 204,000 eggs (for a 263 mm fish).

Number of eggs per female and age are not closely correlated.

TABLE 7. Mean number of eggs and ratio of ovary weight to total body weight of 32 gravid blueback herring caught in the Chickahominy River, 1967

Age group	No. of specimens	Mean fork length (mm)	Mean no. eggs per female (thousands)	Mean weight body (g)	Mean weight ovary (g)	Percent of total weight
IV	1	228	84	164	22.76	13.8
V	12	240	94	179	28.66	16.0
VI	5	252	147	233	40.46	17.3
VII	3	260	127	266	41.64	15.6
VIII	4	264	120	258	43.64	16.9
IX	3	268	157	254	39.86	15.6
X	3	277	140	270	28.82	10.6
XI	1	280	162	321	63.63	19.8
Total	32					
Grand Average		254	120,000	225	35.56	15.8

The gonads were taken from gravid females, which had not yet spawned, so apparently there is considerable variability in number of eggs produced in each age group. The data are insufficient for a statistical comparison of egg numbers with spawning checks.

CONVERSIONS OF STANDARD, FORK, AND TWO TOTAL LENGTHS

The purpose of this section is to make available to others a rapid means for converting one length of the blueback herring into another. There are 11 length measurements of fish in use by biologists today. Ricker and Merriman (1945) and Hile (1948) have documented 8 variations of standard length and 2 variations of total length. Fork length, also called median length, apparently has no variations.

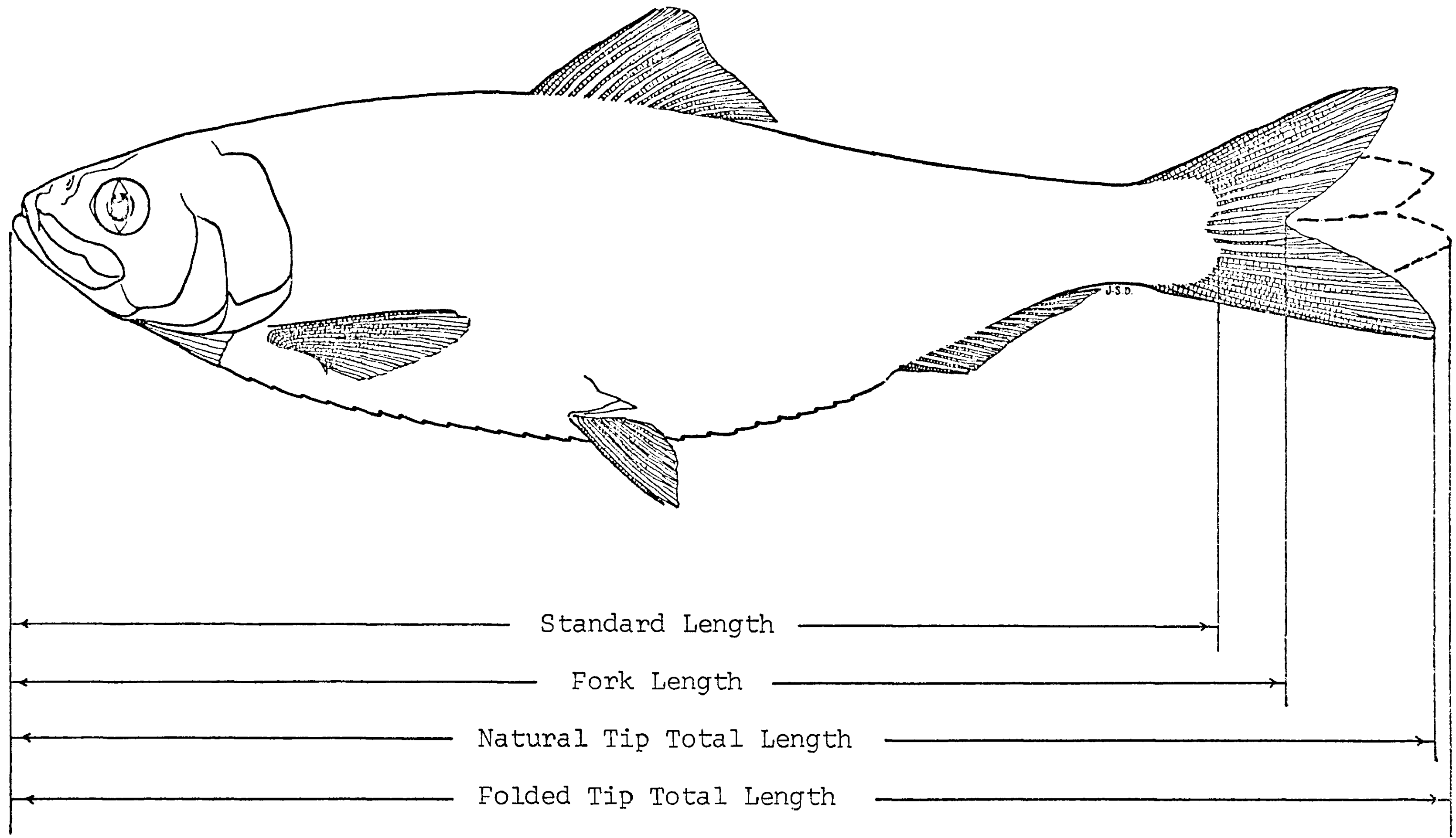
The criteria governing the use of any measurment should be convenience and uniformity. Any length measurement is adequate for all regular purposes if it can be clearly defined. With respect to the eight variations of standard length listed by Ricker and Merriman (1945), it is apparent that the differences are more in definition than in dimension (Hile, 1948). In his work on the Atlantic herring (*Clupea harengus*), Scattergood (1952) used standard length defined as the length from the mouth to the end of the silvery area of the caudal peduncle, with the scales removed. Since the blueback also has the characteristic silvery mark on the caudal peduncle, Scattergood's technique was adopted in this study. Although Royce (1942) reported total length to be a better indicator of weight, Carlander and Smith (1945) found all length measurements to be accurate for predicting weight. In the present study, total length was found to be more time consuming than fork length. I prefer fork length because the numerals of the meter stick are more accurately and more easily read. Fork length may be taken by one person when necessary, as only one hand is needed to hold the fish on the measuring board, and the other hand may be used for recording. Because both hands are needed for measuring folded tip total length, another person is required to record notes, or the data sheet will soon become soiled.

In measuring blueback herring, two people worked together, one recording notes, the other measuring. The following measurements were taken to the nearest millimeter: standard length, fork length, natural tip total length, and folded tip total length.

Fork length is defined as the distance from the tip of the mouth, jaws closed, to the posterior end of the middle rays of the caudal fin (Fig. 13). The lower jaw is slightly anterior to the upper jaw in bluebacks, therefore the length measurements were taken from the tip of the lower jaw. Natural tip total length is the distance from the tip of the lower jaw to the longest lobe of the caudal fin lying in a "natural" position. Folded tip total length is the length from the tip of the lower jaw to the longest lobe of the caudal fin when the lobes are squeezed together. Standard length is defined as the length from the tip of the lower jaw to the posterior end of the silvery colored portion of the caudal peduncle.

Data on the collections (date, area sampled, and size range of the fish) are listed in Table A of the Appendix. The majority of the fish came from Chesapeake Bay (510 specimens). The smallest fish was 46 mm SL, and the largest was 265 mm SL (281 mm FL). Average lengths

FIG. 13. Measurements taken from blueback herring. (Drawing from Joseph and Davis, 1965).


J.S.D.
Standard Length
Fork Length
Natural Tip Total Length
Folded Tip Total Length

at 10 mm intervals were calculated for each of the four lengths for statistical purposes (Table 8).

Table 9 shows the regression equations and the correlation coefficients between each of the various lengths. Standard length was compared with fork length, with natural tip total length, and with folded tip total length. Fork length was compared with standard length and with folded tip total length. Folded tip total length was compared with standard length and with fork length. Since natural tip total length is so little used, I have compared it only with standard length. These regression equations are shown graphically in Fig. 14. In order to test the validity of the equations, the mean standard lengths at 10 millimeter intervals (obtained from Table 8) were used to compare the calculated and empirical values for each of the other lengths. For each comparison, a correlation coefficient was determined (Table 10). Using standard length as the independent variable, the correlation coefficient was 0.9999 for fork length, 0.9996 for natural tip total length, and 0.9997 for folded tip total length. Since these values indicate near perfect correlation, we can use the equations with confidence.

As growth continues throughout life, the proportional rate of growth of the caudal fin decreases. This is a common characteristic of fish (Beckman, 1948). Since the ratios of the various lengths divided by standard length decrease with increasing length in the blueback herring (Tables 11, 12 and 13), the growth of the tail decreases with respect to the growth of the body as one would expect.

TABLE 8. Average lengths of blueback herring by 10 mm class intervals

STANDARD-LENGTH INTERVALS	NUMBER OF SPECIMENS	MEAN STANDARD LENGTH	MEAN FORK LENGTH	MEAN TOTAL LENGTH NATURAL TIP	MEAN TOTAL LENGTH FOLDED TIP
MM		MM	MM	MM	MM
30- 39	0	---	---	---	---
40- 49	5	47.4	50.8	63.6	65.4
50- 59	21	54.4	58.8	65.0	67.0
60- 69	18	66.2	71.2	79.1	80.5
70- 79	62	73.7	79.2	88.0	89.7
80- 89	11	82.8	88.9	97.7	100.0
90- 99	8	92.4	98.4	108.6	110.5
100-109	1	100.0	108.0	121.0	123.0
110-119	0	---	---	---	---
120-129	0	---	---	---	---
130-139	2	136.0	145.5	163.5	166.0
140-149	5	147.4	158.6	177.4	180.6
150-159	11	154.1	164.5	185.2	187.6
160-169	10	164.5	174.7	194.9	198.1
170-179	2	175.0	185.5	210.0	211.5
180-189	1	185.0	197.0	221.0	224.0
190-199	10	195.0	209.8	237.3	239.8
200-209	29	204.7	217.8	246.6	249.9
210-219	54	215.3	229.2	257.7	261.9
220-229	169	224.9	238.4	268.0	272.6
230-239	132	233.9	247.5	278.2	282.7
240-249	75	243.9	258.1	294.5	295.2
250-259	33	252.9	266.7	300.2	302.3
260-269	5	262.4	277.0	308.6	317.0
270-279	0	---	---	---	---
280-289	0	---	---	---	---

TABLE 9. Regression equations and correlation coefficients for various lengths of the blueback herring

Independent Variate (X)	Dependent Variate (Y)	Regression Equations	Correlation Coefficient
Standard Length	Fork Length	$Y = 1.9384 + 1.0510X$	0.9991
Standard Length	Natural Tip Total Length	$Y = 0.5177 + 1.1921X$	0.9869
Standard Length	Folded Tip Total Length	$Y = 1.7628 + 1.2025X$	0.9975
Fork Length	Standard Length	$Y = -1.4770 + 0.9497X$	0.9991
Fork Length	Folded Tip Total Length	$Y = -0.3397 + 1.1436X$	0.9979
Natural Tip Total Length	Standard Length	$Y = 4.6596 + 0.8171X$	0.9869
Folded Tip Total Length	Standard Length	$Y = -0.4740 + 0.8274X$	0.9975
Folded Tip Total Length	Fork Length	$Y = 1.1562 + 0.8708X$	0.9979

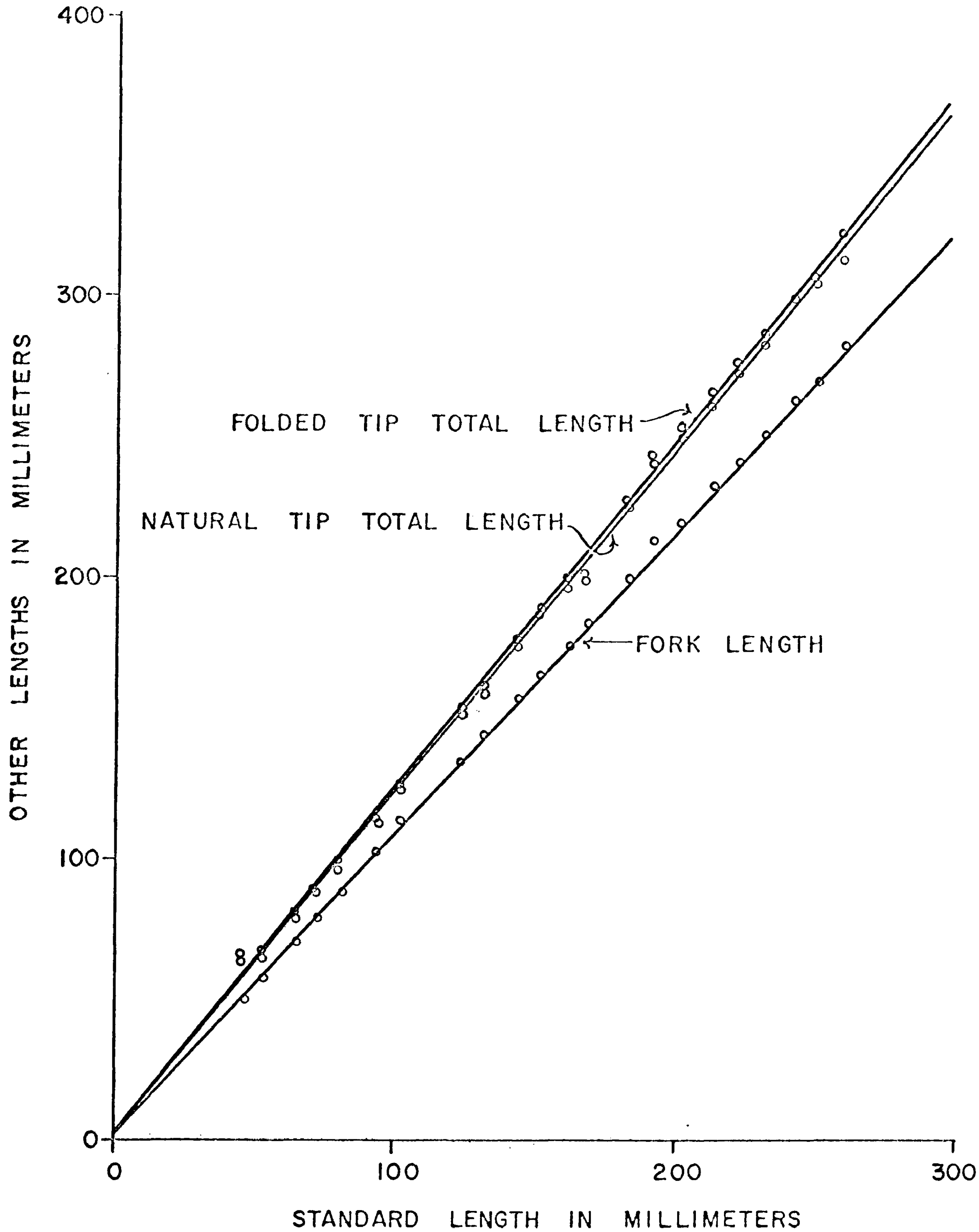


FIG. 14. The relationship of various length measurements to standard length.

TABLE 10. Length relationships of blueback herring calculated from averages of grouped data and from the regression equations

MEAN STANDARD LENGTH	MEAN FORK LENGTH		MEAN TOTAL LENGTH (NATURAL TIP)		MEAN TOTAL LENGTH (FOLDED TIP)	
	EMPIRICAL	FROM REGRESSION EQUATION $Y=1.9384+1.0510X$	EMPIRICAL	FROM REGRESSION EQUATION $Y=0.5177+1.1921X$	EMPIRICAL	FROM REGRESSION EQUATION $Y=1.7628+1.2025X$
MM	MM	MM	MM	MM	MM	MM
47.4	50.8	51.8	63.6	57.0	65.4	58.8
54.4	58.8	59.1	65.0	65.4	67.0	67.2
66.2	71.2	71.5	79.1	79.4	80.5	81.3
73.7	79.2	79.4	88.0	88.3	89.7	90.4
82.8	88.9	89.0	97.7	99.2	100.0	101.4
92.4	98.4	99.0	108.6	110.6	110.5	112.8
100.0	108.0	107.0	121.0	119.7	123.0	122.0
136.0	145.5	144.9	163.5	162.6	166.0	165.3
147.4	158.6	156.9	177.4	176.2	180.6	179.0
154.1	164.5	163.9	185.2	184.2	187.6	187.1
164.5	174.7	174.8	194.9	196.6	198.1	199.6
175.0	185.5	185.9	210.0	209.1	211.5	212.2
185.0	197.0	196.4	221.0	221.1	224.0	224.2
195.0	209.8	206.9	237.3	233.0	239.8	236.3
204.7	217.8	217.0	246.6	244.5	249.9	247.9
215.3	229.2	228.2	257.7	257.2	261.9	260.7
224.9	238.4	238.3	268.0	268.7	272.6	272.2
233.9	247.5	247.8	278.2	279.4	282.7	283.0
243.9	258.1	258.3	294.5	291.3	295.2	295.1
252.9	266.7	267.7	300.2	302.0	302.3	305.8
262.4	277.0	277.7	308.6	313.3	317.0	317.3
	CORR. COEFF. =	0.9999	CORR. COEFF. =	0.9996	CORR. COEFF. =	0.9997

TABLE 11. Standard length-fork length ratios of blueback herring, as calculated from a regression equation

STANDARD LENGTH	FROM REGRESSION EQUATION (Y=1.9384+1.0510X)	
	FORK LENGTH	FORK LENGTH / STANDARD LENGTH
MM	MM	
50.0	54.5	1.090
60.0	65.0	1.083
70.0	75.5	1.079
80.0	86.0	1.075
90.0	96.5	1.073
100.0	107.0	1.070
110.0	117.5	1.069
120.0	128.1	1.067
130.0	138.6	1.066
140.0	149.1	1.065
150.0	159.6	1.064
160.0	170.1	1.063
170.0	180.6	1.062
180.0	191.1	1.062
190.0	201.6	1.061
200.0	212.1	1.061
210.0	222.6	1.060
220.0	233.2	1.060
230.0	243.7	1.059
240.0	254.2	1.059
250.0	264.7	1.059
260.0	275.2	1.058
270.0	285.7	1.058
280.0	296.2	1.058

TABLE 12. Standard length-total length (natural tip) ratios of blueback herring, as calculated from a regression equation

STANDARD LENGTH	FROM REGRESSION EQUATION (Y=0.5177+1.1921X)	
	TOTAL LENGTH	TOTAL LENGTH / STANDARD LENGTH
MM	MM	
50.0	60.1	1.202
60.0	72.0	1.201
70.0	84.0	1.199
80.0	95.9	1.199
90.0	107.8	1.198
100.0	119.7	1.197
110.0	131.6	1.197
120.0	143.6	1.196
130.0	155.5	1.196
140.0	167.4	1.196
150.0	179.3	1.196
160.0	191.3	1.195
170.0	203.2	1.195
180.0	215.1	1.195
190.0	227.0	1.195
200.0	238.9	1.195
210.0	250.9	1.195
220.0	262.8	1.194
230.0	274.7	1.194
240.0	286.6	1.194
250.0	298.5	1.194
260.0	310.5	1.194
270.0	322.4	1.194
280.0	334.3	1.194

TABLE 13. Standard length-total length (folded tip) ratios of blueback herring, as calculated from a regression equation

STANDARD LENGTH	FROM REGRESSION EQUATION (Y=1.7628+1.2025X)	
	TOTAL LENGTH	TOTAL LENGTH / STANDARD LENGTH
MM	MM	
50.0	61.9	1.238
60.0	73.9	1.232
70.0	85.9	1.228
80.0	98.0	1.225
90.0	110.0	1.222
100.0	122.0	1.220
110.0	134.0	1.219
120.0	146.1	1.217
130.0	158.1	1.216
140.0	170.1	1.215
150.0	182.1	1.214
160.0	194.2	1.214
170.0	206.2	1.213
180.0	218.2	1.212
190.0	230.2	1.212
200.0	242.3	1.211
210.0	254.3	1.211
220.0	266.3	1.211
230.0	278.3	1.210
240.0	290.4	1.210
250.0	302.4	1.210
260.0	314.4	1.209
270.0	326.4	1.209
280.0	338.5	1.209

For convenience in converting the various lengths of blueback herring, Tables 14, 15 and 16 are presented.

TABLE 14. Conversion of standard length of blueback herring to fork length, total length (natural tip), and total length (folded tip), in millimeters and inches

STANDARD LENGTH		FORK LENGTH		TOTAL LENGTH (NATURAL TIP)		TOTAL LENGTH (FOLDED TIP)	
MM	INCHES	MM	INCHES	MM	INCHES	MM	INCHES
20.00	0.79	22.96	0.90	24.36	0.96	25.81	1.02
30.00	1.18	33.47	1.32	36.28	1.43	37.84	1.49
40.00	1.57	43.98	1.73	48.20	1.90	49.86	1.96
50.00	1.97	54.49	2.15	60.12	2.37	61.89	2.44
60.00	2.36	65.00	2.56	72.04	2.84	73.91	2.91
70.00	2.76	75.51	2.97	83.96	3.31	85.94	3.38
80.00	3.15	86.02	3.39	95.89	3.78	97.96	3.86
90.00	3.54	96.53	3.80	107.81	4.24	109.99	4.33
100.00	3.94	107.04	4.21	119.73	4.71	122.01	4.80
110.00	4.33	117.55	4.63	131.65	5.18	134.04	5.28
120.00	4.72	128.06	5.04	143.57	5.65	146.06	5.75
130.00	5.12	138.57	5.46	155.49	6.12	158.09	6.22
140.00	5.51	149.08	5.87	167.41	6.59	170.11	6.70
150.00	5.91	159.59	6.28	179.33	7.06	182.14	7.17
160.00	6.30	170.10	6.70	191.25	7.53	194.16	7.64
170.00	6.69	180.61	7.11	203.17	8.00	206.19	8.12
180.00	7.09	191.12	7.52	215.10	8.47	218.21	8.59
190.00	7.48	201.63	7.94	227.02	8.94	230.24	9.06
200.00	7.87	212.14	8.35	238.94	9.41	242.26	9.54
210.00	8.27	222.65	8.77	250.86	9.88	254.29	10.01
220.00	8.66	233.16	9.18	262.78	10.35	266.31	10.48
230.00	9.06	243.67	9.59	274.70	10.81	278.34	10.96
240.00	9.45	254.18	10.01	286.62	11.28	290.36	11.43
250.00	9.84	264.69	10.42	298.54	11.75	302.39	11.90
260.00	10.24	275.20	10.83	310.46	12.22	314.41	12.38
270.00	10.63	285.71	11.25	322.38	12.69	326.44	12.85
280.00	11.02	296.22	11.66	334.31	13.16	338.46	13.33
290.00	11.42	306.73	12.08	346.23	13.63	350.49	13.80
300.00	11.81	317.24	12.49	358.15	14.10	362.51	14.27

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TABLE 15. Conversion of total length (folded tip) of blueback herring to standard length and fork length, in millimeters and inches

TOTAL LENGTH (FOLDED TIP)		STANDARD LENGTH		FORK LENGTH	
MM	INCHES	MM	INCHES	MM	INCHES
20.00	0.79	16.07	0.63	18.57	0.73
30.00	1.18	24.35	0.96	27.28	1.07
40.00	1.57	32.62	1.28	35.99	1.42
50.00	1.97	40.90	1.61	44.70	1.76
60.00	2.36	49.17	1.94	53.40	2.10
70.00	2.76	57.44	2.26	62.11	2.45
80.00	3.15	65.72	2.59	70.82	2.79
90.00	3.54	73.99	2.91	79.53	3.13
100.00	3.94	82.27	3.24	88.24	3.47
110.00	4.33	90.54	3.56	96.94	3.82
120.00	4.72	98.81	3.89	105.65	4.16
130.00	5.12	107.09	4.22	114.36	4.50
140.00	5.51	115.36	4.54	123.07	4.85
150.00	5.91	123.64	4.87	131.78	5.19
160.00	6.30	131.91	5.19	140.48	5.53
170.00	6.69	140.18	5.52	149.19	5.87
180.00	7.09	148.46	5.84	157.90	6.22
190.00	7.48	156.73	6.17	166.61	6.56
200.00	7.87	165.01	6.50	175.32	6.90
210.00	8.27	173.28	6.82	184.02	7.25
220.00	8.66	181.55	7.15	192.73	7.59
230.00	9.06	189.83	7.47	201.44	7.93
240.00	9.45	198.10	7.80	210.15	8.27
250.00	9.84	206.38	8.13	218.86	8.62
260.00	10.24	214.65	8.45	227.56	8.96
270.00	10.63	222.92	8.78	236.27	9.30
280.00	11.02	231.20	9.10	244.98	9.64
290.00	11.42	239.47	9.43	253.69	9.99
300.00	11.81	247.75	9.75	262.40	10.33
310.00	12.20	256.02	10.08	271.10	10.67
320.00	12.60	264.29	10.41	279.81	11.02
330.00	12.99	272.57	10.73	288.52	11.36
340.00	13.39	280.84	11.06	297.23	11.70
350.00	13.78	289.12	11.38	305.94	12.04
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TABLE 16. Conversion of fork length of blueback herring to standard length and total length (folded tip) in millimeters and inches

FORK LENGTH		STANDARD LENGTH		TOTAL LENGTH (FOLDED TIP)	
MM	INCHES	MM	INCHES	MM	INCHES
20.00	0.79	17.52	0.69	22.53	0.89
30.00	1.18	27.01	1.06	33.97	1.34
40.00	1.57	36.51	1.44	45.40	1.79
50.00	1.97	46.01	1.81	56.84	2.24
60.00	2.36	55.50	2.19	68.28	2.69
70.00	2.76	65.00	2.56	79.71	3.14
80.00	3.15	74.50	2.93	91.15	3.59
90.00	3.54	84.00	3.31	102.58	4.04
100.00	3.94	93.49	3.68	114.02	4.49
110.00	4.33	102.99	4.05	125.46	4.94
120.00	4.72	112.49	4.43	136.89	5.39
130.00	5.12	121.98	4.80	148.33	5.84
140.00	5.51	131.48	5.18	159.76	6.29
150.00	5.91	140.98	5.55	171.20	6.74
160.00	6.30	150.47	5.92	182.64	7.19
170.00	6.69	159.97	6.30	194.07	7.64
180.00	7.09	169.47	6.67	205.51	8.09
190.00	7.48	178.97	7.05	216.94	8.54
200.00	7.87	188.46	7.42	228.38	8.99
210.00	8.27	197.96	7.79	239.82	9.44
220.00	8.66	207.46	8.17	251.25	9.89
230.00	9.06	216.95	8.54	262.69	10.34
240.00	9.45	226.45	8.92	274.12	10.79
250.00	9.84	235.95	9.29	285.56	11.24
260.00	10.24	245.44	9.66	297.00	11.69
270.00	10.63	254.94	10.04	308.43	12.14
280.00	11.02	264.44	10.41	319.87	12.59
290.00	11.42	273.94	10.78	331.30	13.04
300.00	11.81	283.43	11.16	342.74	13.49
					K. L. BEAL

SUMMARY

1. During the months from March to June, 1965 and 1966, blueback herring were collected from the Rappahannock River, Virginia. Scales from 317 fish were examined for age determinations.

2. The relationship between body length and scale radius appears to be linear, and is represented by the following equation:

$$L = 37.96842 + 0.77639(S)$$

where L is fork length in millimeters, and S is scale radius (X40) in millimeters.

3. Transverse groove counts were helpful in determining the existence of indistinct annuli on scales of fish up to the 4th annulus. Transverse grooves also aided in identification of false annuli.

4. Annuli were validated. Spawning checks and annuli coincide for the same year, and spawning checks were counted as annuli.

5. Length-frequency determinations using 2 mm intervals gave a polymodal distribution with each mode corresponding with a year class. It was necessary to deal with the sexes separately, because females have a greater growth rate than males.

6. Mean calculated fork lengths for the 1st through 8th years was 96 mm, 142 mm, 187 mm, 220 mm, 234 mm, 242 mm, 246 mm, and 252 mm for males. Mean calculated fork lengths for the 1st through 10th years was 98 mm, 144 mm, 191 mm, 226 mm, 242 mm, 252 mm, 259 mm,

264 mm, 268 mm, and 272 mm for females.

7. After young-of-the-year juveniles leave the nursery areas in the rivers, they disappear for at least 3 to 4 years in the Atlantic Ocean. Maturity is usually attained at 4 years, but many individuals do not spawn until 5 or 6 years of age. Some older fish whose scales indicate they are virgin spawners may have spawned without laying down a spawning check.

8. The commercial fishery is concentrated on adults in the spawning run. The catch in the Rappahannock River in 1965 and 1966 consisted of about 12% age group IV, 27% age group V, 36% age group VI, and 19% age group VII. Older age groups accounted for less than 7% of the catch.

9. Males are more abundant than females in age groups IV, V, and VI. Females predominate in all older age groups.

10. The percentage of males and females present in the Rappahannock River changes during the spawning run. Males are more abundant during the first 2 weeks of April, but by the end of the month the sex ratio is usually about 50:50. In early May females predominate, and by the end of the month, males may once again outnumber females. In 1967, the peak of the run occurred when the males predominated (April 15 to 30), giving a sex ratio of 62:38 for the entire run. Whether this ratio is characteristic of the species is not known.

11. The length-weight relationship for males and females combined was

$$\log W = -5.5003 + 3.2724(\log L)$$

where W is weight in grams, and L is fork length in millimeters. There is only slight sexual difference in the length-weight relationship.

12. Ovarian egg counts of 32 blueback herring gave an average of approximately 120,000 eggs per female. The range was from 60,000 to 204,000.

13. Fork length, natural tip total length, and folded tip total length were very closely correlated with standard length (correlation coefficients between 0.9996 and 0.9999). Equations for converting from one length to another were computed.

APPENDIX

TABLE A. Fish collections used for length conversions

Date Collected	Area of Sample	No. Fish	Size Range in Standard Length (mm)
22 Jan 65	Rappahannock R.	70	061-095
29 Nov 66	James River	10	046-053
20 Feb 67	Chesapeake Bay	10	071-078
02 Mar 67	Rappahannock R.	19	052-063
09 Jun 67	Chesapeake Bay	200	190-258
13 Jun 67	Chesapeake Bay	300	202-265
13 Dec 67	NW Atlantic 38°8'N, 75°50'W	11	143-168
17 Jan 68	Rappahannock R.	4	080-088
23 Jan 68	NW Atlantic 38°8'N, 74°35'W	12	153-210
07 Mar 68	NW Atlantic 40°33'N, 71°50'W	7	080-098
09 Mar 68	NW Atlantic 38°21'N, 74°32'W	4	091-134
09 Mar 68	NW Atlantic 38°6'N, 74°50'W	12	137-199
09 Mar 68	NW Atlantic 37°32'N, 75°6'W	5	081-196
Total		664	

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