ABSTRACT

James Walton Kornegay. A COMPARISON OF THE SCALE AND OTOLITH METHODS OF AGEING ALEWIFE (*Alosa pseudoharengus*) AND BLUEBACK HERRING (*Alosa aestivalis*). (Under the direction of Charles W. O'Rear, Jr.) Department of Biology, July 1977.

The purposes of this study were to determine levels of agreement between ages obtained from scales and otoliths of alewife and blueback herring; to compare age composition of the sample as determined by both methods; to compare length composition within each scale and otolith age group; to compare fork length/scale radius and fork length/otolith radius relations; and to compare growth curves derived from scale and otolith data.

Levels of agreement between scale and otolith ages were 57.19% (alewife) and 67.96% (blueback herring). Age composition of the alewife sample as determined by both methods was statistically similar; however, differences occurred within the blueback herring sample. Length composition of each scale and otolith age group was determined to be statistically similar except in the age three groups of both species. Fork length/scale radius relations were linear in both species. Fork length/otolith radius relations differed notably. Mean fork lengths of each scale and otolith age group were plotted as growth curves and appear similar in both species. Fork lengths at each previous scale and otolith age were determined by back calculation of annuli measurements of scales and otoliths. Mean back calculated fork lengths were plotted as growth curves. In both species, growth curves derived from back-calculation of scale annuli measurements tend to estimate values higher than growth derived from otolith annuli measurements.

A COMPARISON OF THE SCALE AND OTOLITH METHODS OF AGEING ALEWIFE (*Alosa pseudoharengus*) AND BLUEBACK HERRING (*Alosa aestivalis*)

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by

James Walton Kornegay

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A COMPARISON OF THE SCALE AND OTOLITH METHODS

OF AGEING ALEWIFE (*Alosa pseudoharengus*) AND

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by

James Walton Kornegay

APPROVED BY:

SUPERVISOR OF THESIS ______________________
Dr. C.W. O'Rear, Jr.

CHAIRMAN OF THE DEPARTMENT OF BIOLOGY

____
Dr. J.S. McDaniel

DEAN OF THE GRADUATE SCHOOL

____
Dr. J.G. Boyette

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I am indebted to my patient mother who typed this thesis and to Rose Westbrook, my fiancee, whose support and encouragement have been continual throughout this study.

This thesis is dedicated to the memory of the late Dr. E.T. Humphries, who first nurtured my interest in fisheries biology.

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INTRODUCTION

Age determination of fishes is an essential fishery management tool. From age data, natural population fluctuations and the effects of commercial exploitation can be detected and to a great extent, predicted. In conjunction with length and weight data, fish ages may also provide information on growth, production, and mortality within the population (Ricker, 1971). Regulatory decisions affecting exploitation of fish stocks are based on age compositions. These decisions can have a tremendous impact on the survival of fish populations, and are financially significant to those involved in exploitation.

On the Atlantic coast of North America, many commercially important fish populations are monitored to gain information on age compositions. In North Carolina, populations of the anadromous alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*), among others, are sampled to provide information concerning age and length compositions, growth, and mortality. These two species constitute a substantial proportion of the total commercial landings of finfish in North Carolina each year. Alewife and blueback herring (collectively known as river herring) are sold for human consumption, crab bait, and fertilizer. The 1973 landings for river herring in North Carolina totaled 3,598,404 kg, at an estimated value of $214,000. Records indicate that landings have been as high as 10,781,138 kg in 1887, at an estimated value of $173,000 (Chestnut and Davis, 1975). The monetary value of these species is only a small part of their true value. The river herring occupy an essential ecological niche, serving as primary consumers. They are also available for predation by large sport and commercial species which may be largely dependent on the river herring for nutrition (Bigelow and Schroeder, 1953).

Fish ages are determined by several methods. The most widely used techniques involve examination of the calcareous or hard structures of the fish. These structures include scales, otoliths, opercular bones, vertebrae, and fin rays (Lagler, 1956). Close examination of these structures reveals discernable patterns of calcium deposition in the form of rings, or annuli. Annuli are formed as a result of increased or decreased growth rates of the fish that correspond to seasonal or environmental changes. In most fishes, the annuli are formed on a yearly basis and subsequently are an indicator of true age (Lagler, 1956).

Populations of alewife have been aged using the scale method since the 1920's in the Great Lakes region and on the Atlantic coast (Marcy, 1969). Although the method has been used, documentation of the techniques was not mentioned in the literature. Cating (1953) first described successful methods of ageing American Shad (Alosa sapidissima), which has a scale structure very similar to that of the alewife and blueback herring. He demonstrated that annuli could be consistently located within the proximity of identifiable transverse grooves. Cating's method has since been validated by La Pointe (1958) and Judy (1961).

The techniques of Cating have been applied to several populations of alewife and blueback herring. Rothschild (1963) and Norden (1967) showed that these techniques could be applied to landlocked populations of alewife in Cayuga Lake, New York, and Lake Michigan, respectively.

Marcy (1969) successfully applied Cating's techniques to anadromous populations of river herring in Connecticut.

Little mention has been made in the literature on the use of otoliths to age alewife and blueback herring. Netzel and Stanek (1966) used otoliths to age river herring taken from Georges Bank. Norden (1967) attempted to verify ages determined by scales by reading otoliths from 200 specimens out of a sample of over 2,000 fish. He noted the uniformity in size and appearance of otoliths and stated an agreement between the two methods. In both cases, no mention of validity of otoliths as an indicator of true age was made, and no techniques were described.

A problem has arisen in recent years concerning the scale and otolith methods of ageing river herring. Biologists on the Atlantic coast predominantly use the scale method of age determination. Biologists associated with foreign commercial fishing fleets offshore generally utilize the otolith method. This latter technique is used because advanced trawling, pumping, and handling techniques remove the scales from the river herring before the biologists can take scale samples (Messieh and Tibbo, 1972).

The International Commission on Northwest Atlantic Fisheries (ICNAF) has agreed that each country involved in commercial fishing on the high seas must monitor the age composition of harvested fish. The problem becomes very evident when a comparison is made of data from the United States and foreign countries on age composition of harvested river herring. Disagreements can occur, since each country's biologists assume that their methods are valid and indicate true fish age (Street, 1976).

The objectives of this study are to compare the scale and otolith methods of ageing river herring. Scale ages and otolith ages from a large sample of alewife and blueback herring were compared on an individual basis, to determine levels of agreement between the two methods. Age composition of the sample derived from scale and otolith ages were compared. Length compositions of each scale and otolith age group were compared to detect differences or similarities. The fork length/scale radius and fork length/otolith radius relations were determined, to estimate length compositions at previous ages by back-calculation. Estimates from scale and otolith data were compared. Mean annual growth for each species was also calculated, using scale and otolith data, with subsequent comparisons made.

Description of the Scale and Otolith of River Herring

Scales are most widely used to age river herring because they are easily obtained and present no storage problems. Scales may be visually enlarged and projected by a variety of methods so that several readers may make simultaneous counts of annuli. River herring scales are thin, semi-transparent, and cycloid (Figure 1). The anterior field of the scale contains well defined transverse grooves and annular markings. The first (and innermost) ring formed on the scales is the freshwater zone. This ring is formed when the juvenile river herring first enters the saline ocean environment after hatching (Cating, 1953). The annual year marks on Alosid scales occur outside the freshwater zone and are formed during winter periods of slow growth. Scar-like annuli, known as spawning checks, are visible on scales of mature river herring which have spawned in years prior to collection. These spawning checks are formed due to erosion and absorption of the scales during the migration from the ocean into fresh water prior to spawning. Spawning checks have been validated as year marks because they are formed at the same time as annuli (Cating, 1953;

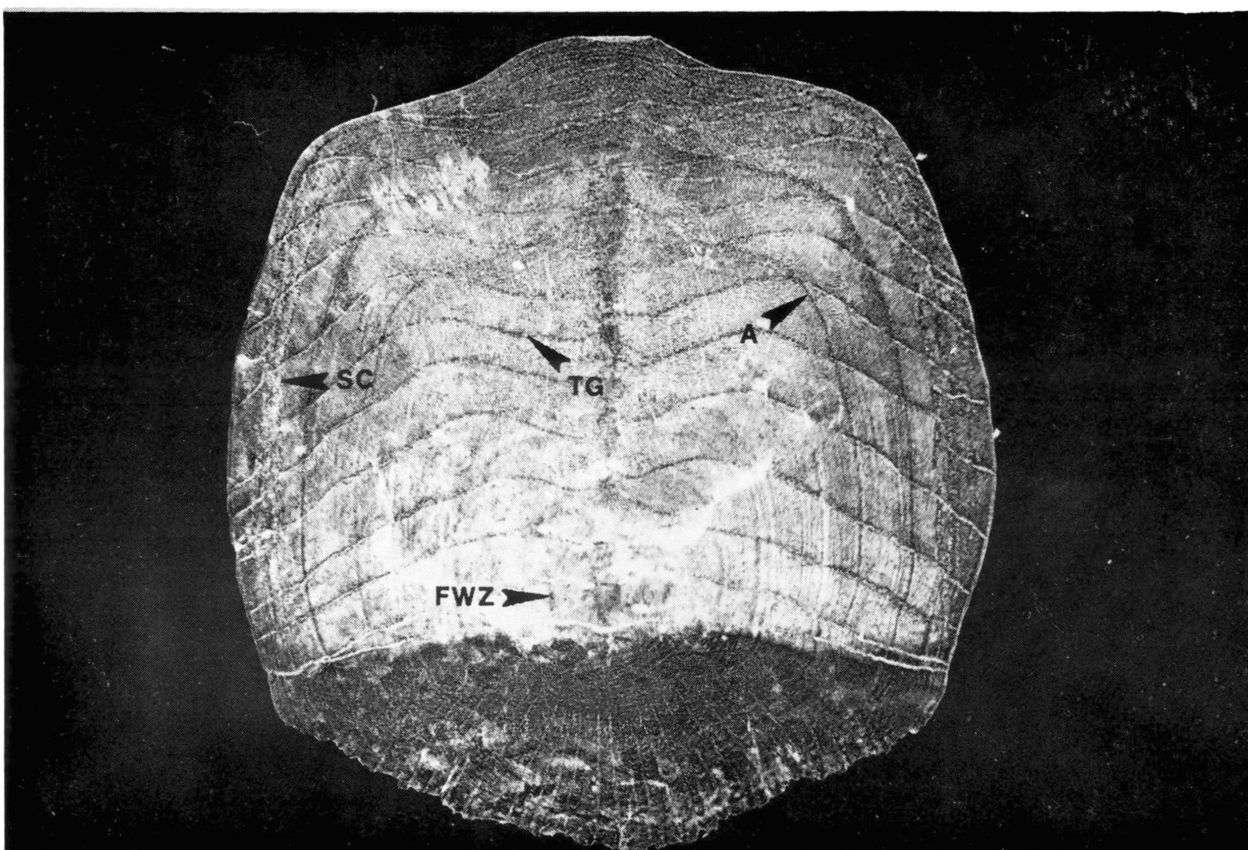
Figure 1. Photograph of river herring scale.

FWZ - freshwater zone

A - annulus

SC - spawning check

TG - transverse groove


SC
TG
A
FWZ

Judy, 1961; Rothschild, 1963; Marcy, 1969). The scales of the alewife have been described in detail by Rothschild (1963) and the scales of blueback herring are not significantly different in appearance from those of the alewife.

The scales of river herring do not firmly adhere to the body of the fish. It is not uncommon to observe river herring in commercial catches completely devoid of scales. River herring undergo rather vigorous spawning behavior which includes scraping of the body against bottom substrates, logs, and other debris. In the process of these activities, many scales are removed from the fish, with no apparent ill effects. This is evidenced by observations of healthy individuals with a high percentage of regenerated scales. Scale loss also occurs due to catch and entrapment methods employed by commercial fishermen. Entire catches of river herring from pound nets and gill nets in North Carolina have been observed to have sustained large percentages of scale loss.

When scales are unavailable, many researchers remove the otoliths from the head of the fish for age determination. There are three types of otoliths in the head of bony fishes. These structures, which are composed of aragonite crystals of calcium carbonate, function in equilibrium maintenance and sound perception. The otoliths are enclosed in the sacculus of the labyrinth, which lies posterior to the brain cavity (Nicol, 1967). The largest of the three otoliths, the sagitta, is used for age determination. The sagitta are oval, with a sharp rostrum protruding from the ventro-anterior margin (Figure 2). The surface distal to the brain is smooth and concave. The proximal surface has a deep furrow running almost the entire length of the sagitta. The margin of the sagitta is usually irregularly indented.

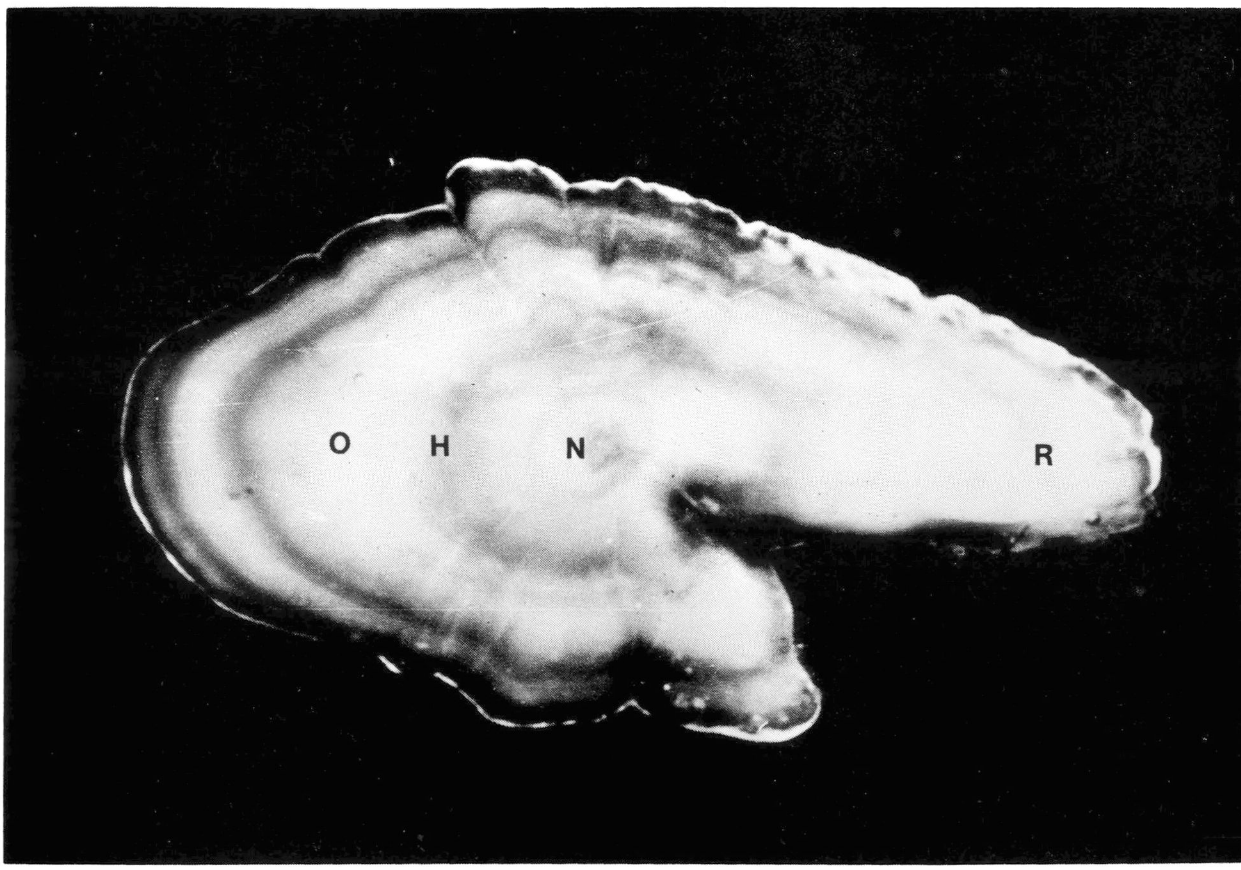
Figure 2. Photograph of river herring otolith.

O - opaque zone

H - hyaline zone

N - nucleus

R - rostrum


O
H
N
R

The average sagitta of an adult river herring measures approximately 4 mm from the anterior margin to the posterior margin, and approximately 2 mm from the dorsal margin to the ventral margin.

Annuli appear as light and dark bands when viewed through a dissecting microscope, using a black background and reflected light. The light or opaque bands correspond with summer growth, and the dark or hyaline bands correspond with reduced winter growth (Williams and Bedford, 1973). The nucleus of the river herring otolith is opaque, which agrees with the findings of Watson (1964) in his study of the otoliths of sea herring (*Clupea harengus harengus*). His results confirm that the otolith of a spring-hatched fish should begin with the opaque growth of summer.

The use of otoliths for age determination is not as convenient as the use of scales. If large samples are desired, the process of dissecting each individual presents a time problem. Otoliths of many species may also present a storage problem. Some otoliths must be stored in glycerol or alcohol solutions to prevent degradation of the annuli (Williams and Bedford, 1973). Otoliths of many species (including river herring) do not provide a method of assessing spawning history. Unlike scales, there are no detectable differences between spawning checks and annuli.

MATERIALS AND METHODS

Sample Sites and Collection Methods

From March 1 until May 15, 1976, adult alewife and blueback herring were collected from the Albemarle Sound region of North Carolina. Approximately 95 percent of the total commercial landings of river herring in North Carolina are taken from the Albemarle Sound and tributaries, particularly the Chowan River (Pate, 1973). River herring were obtained from catches of commercial fishermen. Most fishermen gladly donated fish; however, some chose to charge a nominal fee. Figure 3 gives sample site locations throughout the Albemarle Sound area and gear employed by the fishermen. Methods of catch were varied among fishermen; therefore, the influence of gear selectivity on sizes of adults obtained for this study was considered insignificant.

From June until October 1976, monthly samples of spring-hatched river herring were obtained from personnel at the North Carolina Division of Marine Fisheries. First growth characteristics of scales and otoliths were observed from these samples. Throughout the entire sampling period, a total of 491 alewife and 563 blueback herring (adults and juveniles) were collected.

Data Collection

Specimens were either examined immediately or frozen and examined several days after collection. As a matter of convention, fork lengths were measured to the nearest millimeter. Each fish was sexed by examination of the gonads and was assigned an identification number to facilitate individual comparisons of scales and otoliths.

Figure 3. Study area.

Sample Site	Gear Used
1 Alligator River	Pound Nets
2 Scuppernong River	Pound Nets, Gill Nets
3 First Colony Farms Canals	Gill Nets
4 Albemarle Sound	Gill Nets, Seine (Juveniles)
5 Meherrin River	Pound Nets, Haul Seine


5
4
2
3
1

Approximately 20 scales were taken from each fish by prying the scales from the body with a pocket knife. The scales were removed from the area directly under the dorsal fin and above the lateral line as suggested by Rothschild (1963) and Marcy (1969). Scales were stored in small coin envelopes. Fish identification number, sex, collection date, and sample site were recorded on the envelopes.

Otoliths were obtained by dissection of the head region. A cut was made through the dorsal portion of the head, approximately 5 mm behind the eye. The cut was made to a distance of half the depth of the head region. This procedure bisected the brain cavity. The exposed brain tissue was then evacuated from the posterior portion of the cavity with forceps. By grasping the semicircular canal structures with the forceps, the entire labyrinth, including the otoliths, could be removed from the posterior base of the cavity. After removal, otoliths were rubbed between the fingers to remove excess tissue, and stored dry in 4 ml glass vials. Each vial was labeled with the appropriate fish identification number.

Six to ten scales were examined from each fish. The scales were placed between two microscope slides, and were then inserted into a Xerox microfiche reader similar to those used in libraries. This microfiche reader provided a magnification of 42 X. Annuli, spawning checks, and the scale edge were counted to determine age. The assumption was made that each fish had completed a full year's growth at the time of capture, thus justifying the edge as a yearmark (Pate, 1973). Agreement of age among at least three scales had to be found before a definite decision on age was made. If matched scales were not found, the specimen was considered as "age undeterminable" and was deleted from the sample. Many specimens were deleted as a result of the presence of false annuli or regenerated scales which rendered the scales unreadable (Figures 4 and 5). One representative scale from each aged individual was chosen for annuli measurements. Distances from the midpoint of the first transverse groove or baseline were measured anteriolaterally to each annulus and spawning check directly from the microfiche reader by using a clear plastic scale partitioned in millimeters. The values obtained were divided by a factor of 42 to obtain actual annuli distances.

Otolith ages were determined by examination with a dissecting microscope under low power (20 X). The otoliths were placed in a depression microscope slide containing distilled water, which cleared the annular features and reduced the glare effects from the white otoliths. The depression slide was then placed on a black background. Reflected white light provided the best image for age determination. The dark, winter formed hyaline bands were counted as annuli on the distal, posterior portion of the otoliths. This portion of the otolith provided the best contrast between annuli. Annuli on the anterior portion were seen to merge in the vicinity of the rostrum, and thus were unusable for age determination. As in the case of scales, the otolith edge was counted as a year mark. Distances from the otolith nucleus to each annulus were measured, using a calibrated ocular micrometer mounted in the microscope and then converted to actual distances in millimeters.

Disagreement in ages between right and left otoliths was so rare that it was considered insignificant. Disagreements occurred in several seven and eight year old fish and were caused by interpretational differences of overlapped annuli on the otolith margin. The otolith margin presented

Figure 4. Photograph of river herring scale with false annuli.

FA - false annuli

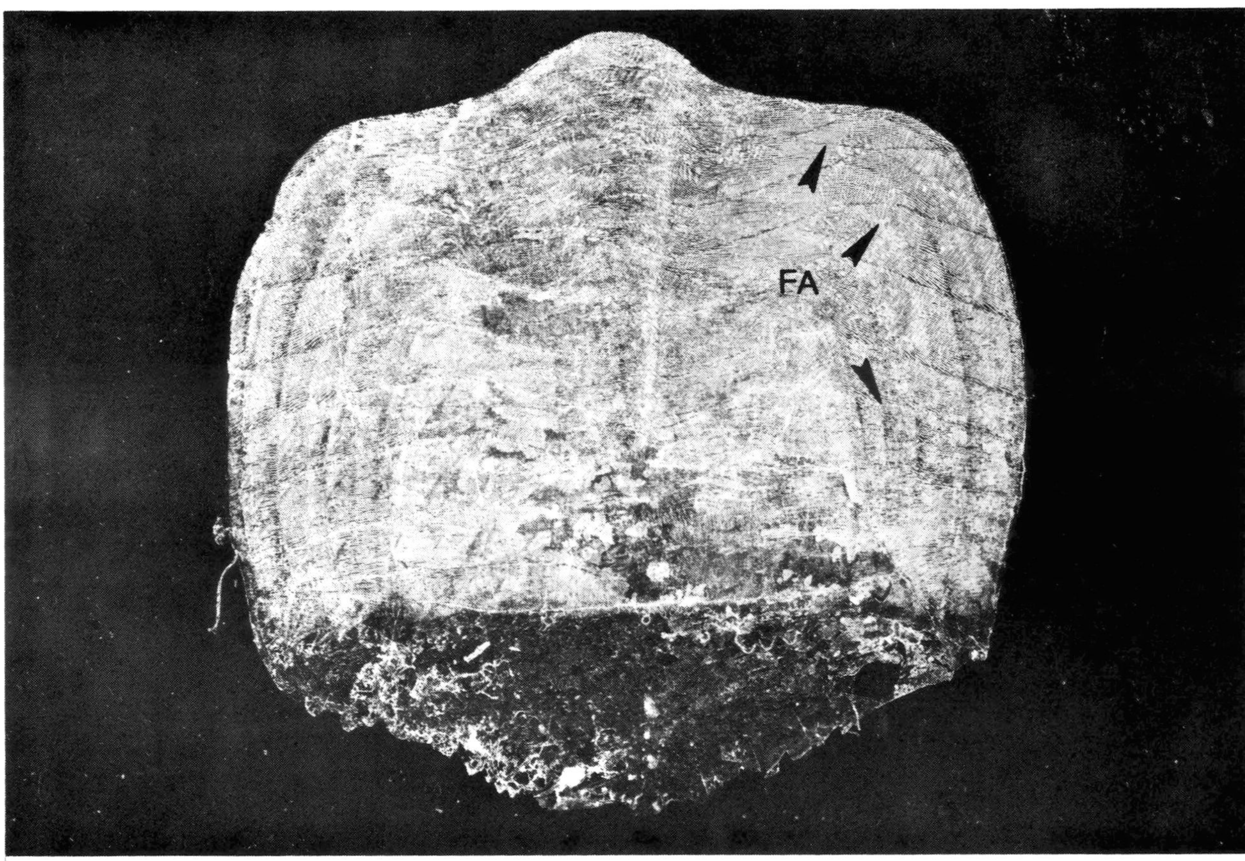
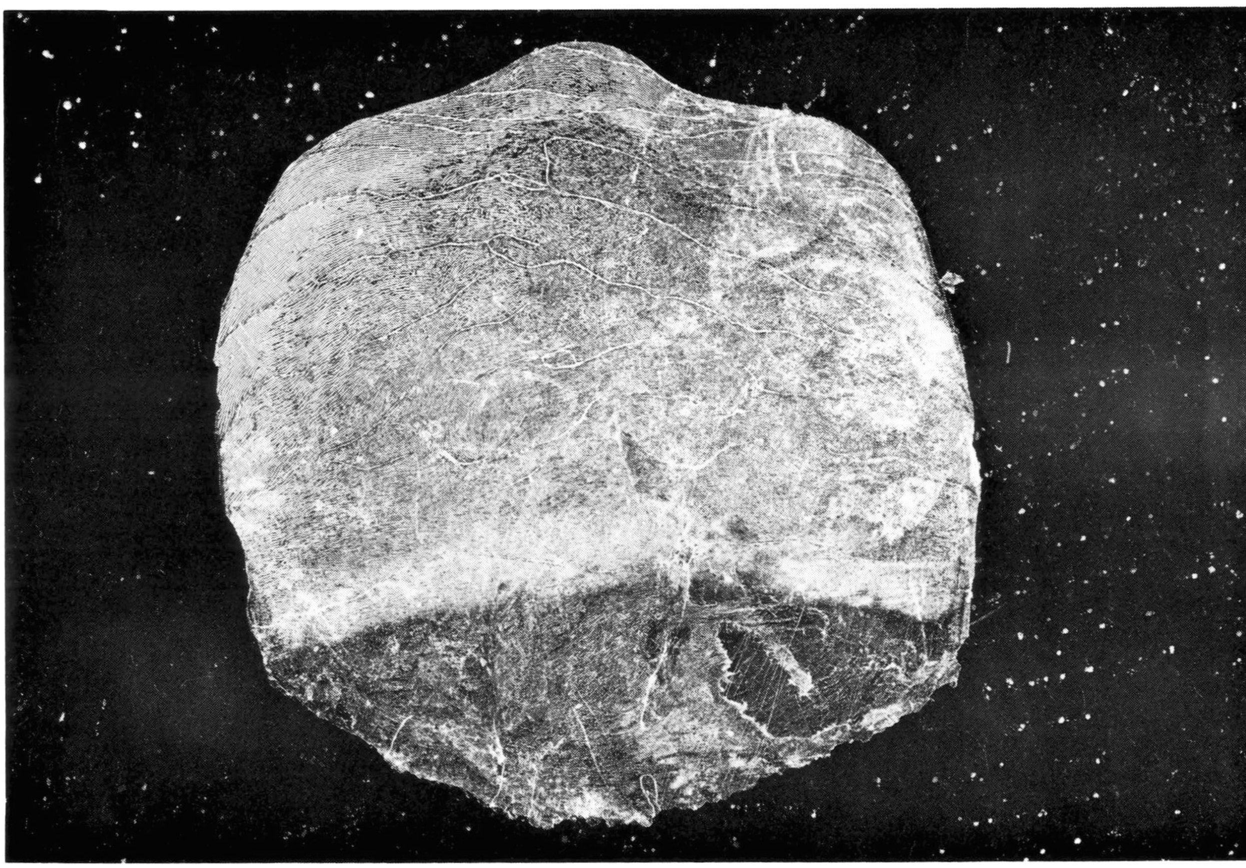

FA

Figure 5. Photograph of regenerated river herring scale.



problems of age determination in many individuals because it is severely and irregularly indented, causing the outer annuli to be obscure (Figure 6). Otoliths of this type were considered as "age undeterminable" and were deleted from the sample. Table 1 summarizes the number of specimens in which scales and otoliths were read or deleted.

It is interesting to note the occurrence of an unexplained phenomenon of crystalline otoliths. Of the alewife sample, 3.6% had a single crystalline otolith, and 3.7% of the blueback herring sample had the same. Only one specimen from the entire combined sample had paired crystalline otoliths. These otoliths are partially transparent and crystalline in appearance, with no annular marks present (Figure 7). Watson (1964) noted a similar occurrence in the otoliths of sea herring, noting that 6% of his entire sample had a single crystalline otolith. He also stated that observations of paired crystalline otoliths were extremely rare and occurred only twice in every 2,000 specimens.

<u>Verification of Reading Techniques</u>

Scale reading accuracy was checked by personnel of the North Carolina Division of Marine Fisheries. A sample of 50 alewife and 50 blueback herring scales was read independently for age, to determine levels of agreement between the two readings.

Otolith reading accuracy was checked by personnel of the National Marine Fisheries Service at Woods Hole, Massachusetts. A sample of 50 alewife and 50 blueback herring otoliths was sent to these persons for an independent reading.

Figure 6. Photograph of indented otolith margin.

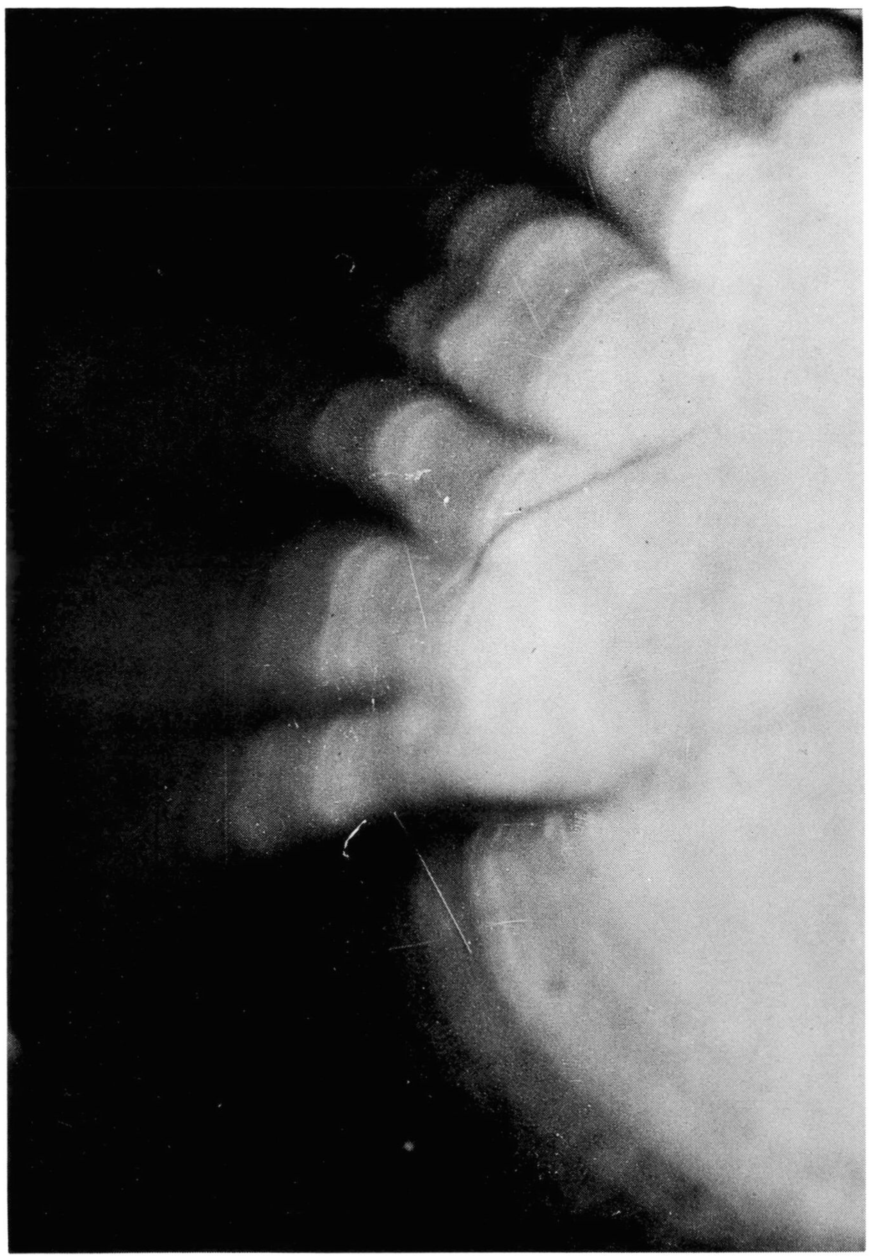


Table 1. Summary of the number of specimens in which scales and otoliths were read or deleted.

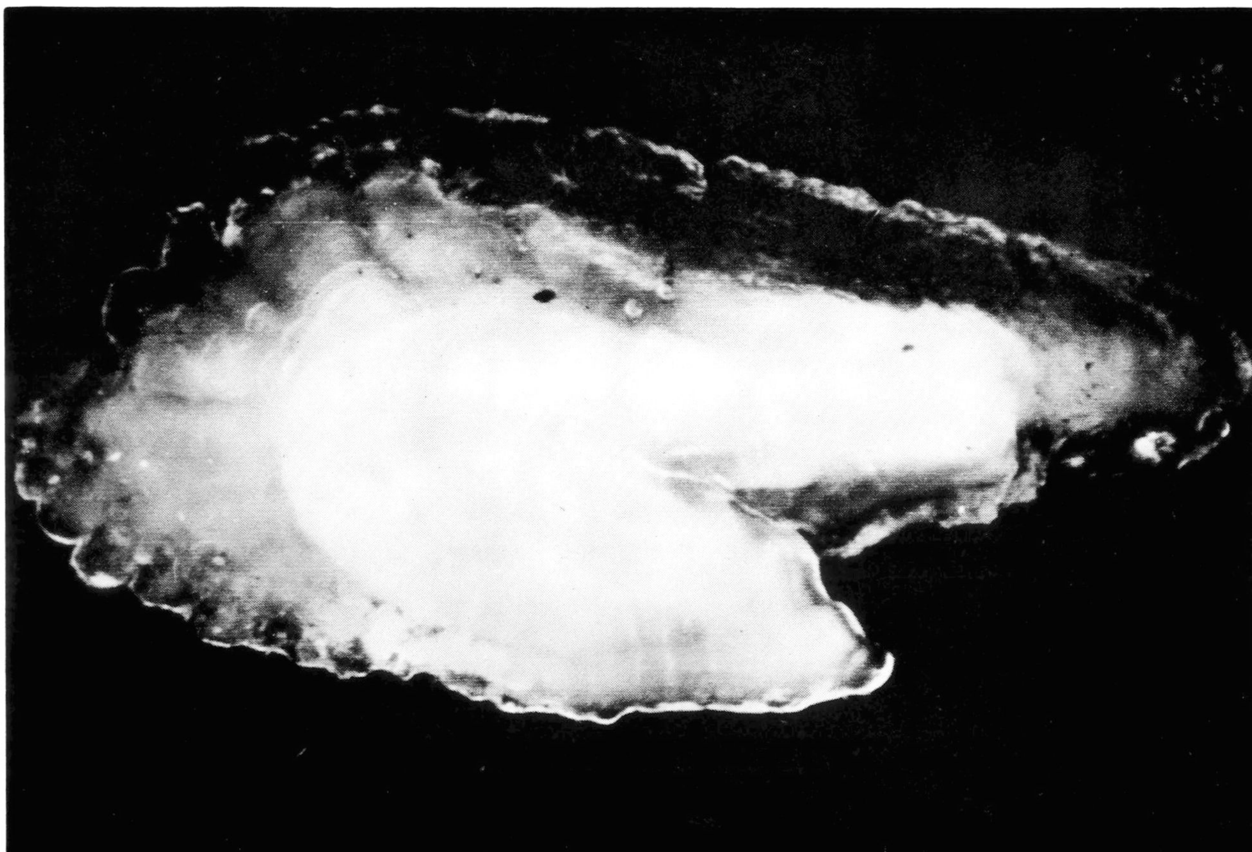
Alewife

Number of Specimens	
18	Juveniles (not used for ageing purposes)
111	Otoliths unreadable
98	Scales unreadable
264	Scales and otoliths readable
Total 491	

Blueback Herring

Number of Specimens	
46	Juveniles (not used for ageing purposes)
71	Otoliths unreadable
66	Scales unreadable
380	Scales and otoliths readable
Total 563	

Figure 7. Photograph of crystalline otolith.



Data Analysis

Fish identification numbers, fork lengths, ages, and annuli measurements were recorded directly on Fortran coding sheets. Raw data was then recorded on computer cards for analysis. Analysis of data was accomplished by the use of the Statistical Analysis System (SAS 76, 1976) and the Statistical Package for the Social Sciences (SPSS, 1976).

RESULTS AND DISCUSSION

Scale and Otolith Reading Accuracy

Independent age readings of scales yielded an agreement level of 73.9% for alewife and 87.5% for blueback herring. Variations occurred in older specimens and were due to differences in interpretation of spawning checks.

Independent readings of otoliths produced an agreement level of 82% for both species. Variation was again seen in older specimens and was due to differences in interpretation of closely spaced outer annuli.

Among researchers using strictly the scale method to age Alosids, agreement is nearly always seen to decrease in fish older than five years. Disagreements are generally caused by different interpretations of spawning checks. During formation of spawning checks, substantial erosion of the scale occurs. This erosion may destroy the previous years' spawning checks on the dorsal and ventral portion of the scale which narrows the reader's choice of locations to count the annuli. The general practice is to closely scrutinize the anterior and posterior postions of the scale in an attempt to detect vestigial traces of previous spawning checks which may be obscured by erosion. Disagreements occur due to differences in opinion as to whether the vestigial traces were previous spawning checks.

Another source of disagreement between Alosid scale readers occurs in the designation of the first annulus. The first annulus on scales of river herring collected for this study were seen to be very faint and in some cases, not visible. The possibility exists that juvenile river herring spend their entire first year after hatching in the estuarine areas of North Carolina. In these areas, decreases in water temperature during winter months may not be as pronounced as they would experience in waters of the North Atlantic Ocean, where these fish would normally reside after recruitment to the adult population. Residence of juvenile river herring in the less environmentally severe estuaries may explain the faintly formed first annulus.

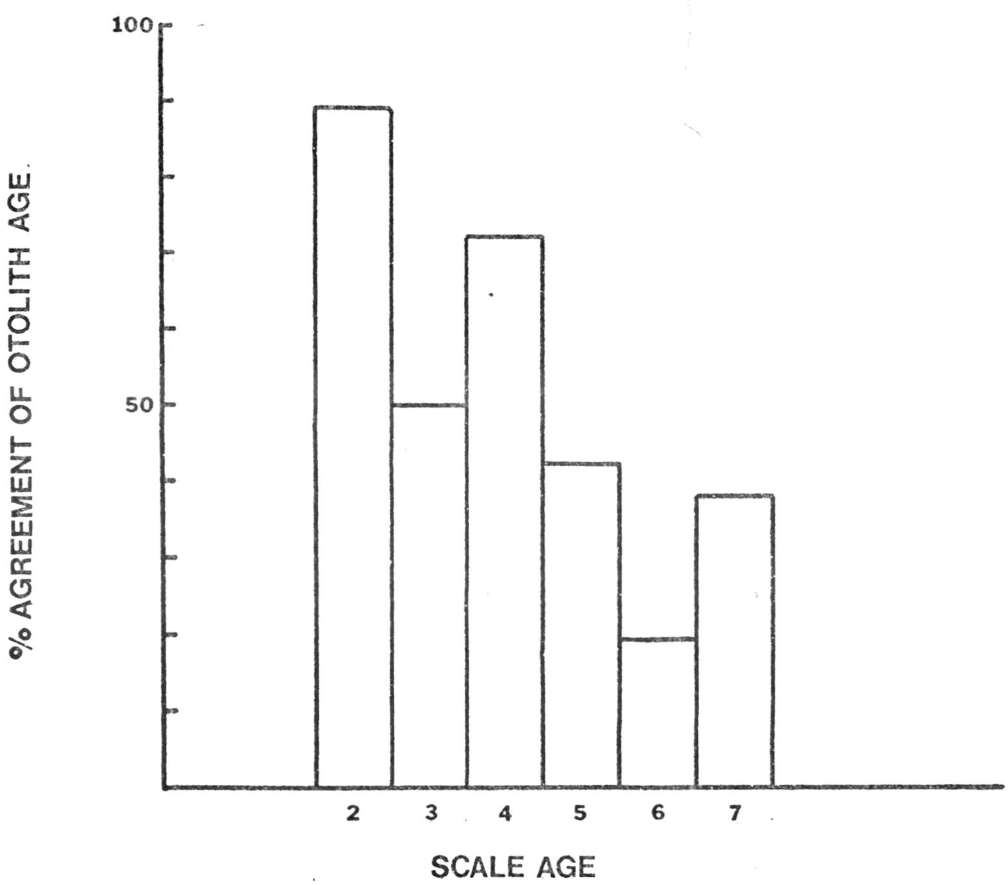
The second annulus on scales of both species was seen to be very distinct. The unusual clarity of the second annulus may prompt some scale readers to mistake this as the first annulus. This would result in an immediate underestimation of age of one year. Marcy (1969) also observed the same phenomenon of an obscure first annulus and distinct second annulus on scales of river herring from Connecticut waters.

The same type of variation in age interpretation among otolith readers has been illustrated by Blacker (1974), in cod (Gadus sp.). He sent otolith samples to researchers in several countries and compiled results of the exchanges. Several sources of variation occurred in this investigation, including location of central annuli, position on the otolith where annuli were counted, and interpretation of spawning checks. Disagreements of age were seen in all age groups and were especially high in older age groups.

Levels of Agreement Between Scale and Otolith Ages

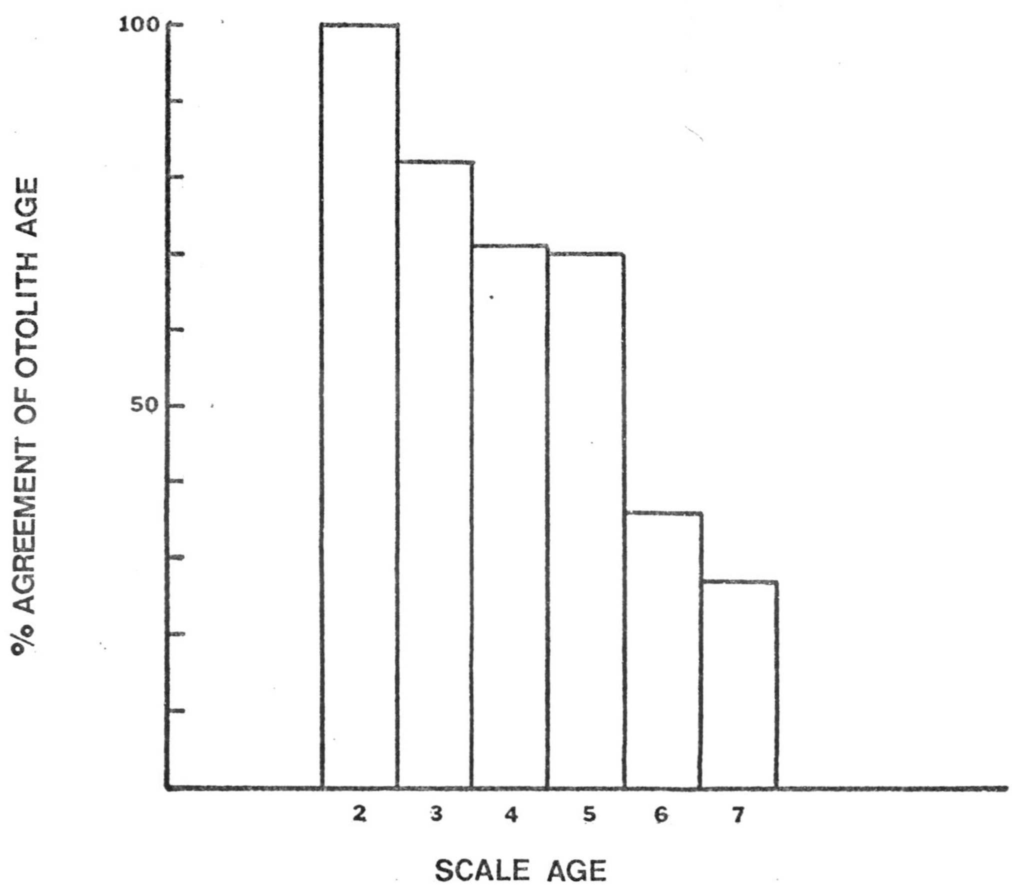
Levels of agreement between the two ageing methods were established by comparing scale age and otolith age of each individual. For both alewife and blueback herring, agreement of ages was highest among the younger individuals, and was seen to decrease with an increase in age. Figures 8 and 9 graphically summarize levels of agreement between the two methods for each species. Appendix Tables 1 and 2 present tabulated data of agreement and variation of otolith ages from scales for each species.

Figure 8. Levels of agreement between scale ages and otolith ages of alewife.



100
50
% AGREEMENT OF OTOLITH AGE
2
3
4
5
6
7
SCALE AGE

Figure 9. Levels of agreement between scale ages and otolith ages of blueback herring.


100
50
% AGREEMENT OF OTOLITH AGE
2
3
4
5
6
7
SCALE AGE

The overall agreement level between scale and otolith ages of alewife was 57.19%. Otolith age varied ± two years from scale age in only 12 individuals. The otolith age in 101 individuals varied ± one year from scale age. The remaining 151 otolith ages agreed with scale ages. An agreement level of 67.96% between the two methods was obtained for blueback herring. Otolith age varied ± three years in only two cases, ± two years in 19 cases, and ± one year in 102 cases. The remaining 257 otolith agreed with scale ages.

From these results, it is evident that variation of age interpretation can occur between persons using scales only or otoliths only. If variations can occur within ageing methods, it is apparent that variations of age agreement can easily occur between ageing methods.

Ages obtained from scales and otoliths of the same fish should agree. Growth of scales and otoliths occurs simultaneously with growth of the fish. As growth of the fish slows during winter months, growth of scales and otoliths also slows, which forms growth checks (annuli) on both structures. Hence, an equal number of annuli should be present on scales and otoliths obtained from the same fish. Variation of scale and otolith ages must therefore be due to the subjective nature of interpretation of annuli.

To summarize, scale and otolith ages of river herring tend to agree the majority of the time but can vary quite easily ± one year. A variance of otolith age from scale age of ± two years seldomly occurred, and variations of ± three years were rare. Most of the variance of otolith age from scale age is probably due to the subjective nature of interpretation of annuli on both scales and otoliths.

Age Composition of the Sample

The age composition of the adult portion of the sample was determined by calculating the percentage of the sample (in which both scales and otoliths were readable) represented by each age group. A comparison of percent composition by scale and otolith age groups was made for each species (Figures 10 and 11).

Chi square tests indicate no statistical difference between age composition of the alewife sample as determined by both methods ($p<.05$). In the blueback herring sample, however, there is significant variation within the two, three, four, and five year otolith age groups. Variation of the otolith age two group was probably caused by individuals in which scale age was determined to be three, but otolith age was seen to be two. Variation of the otolith age four group was similarly caused by individuals in which scale age was determined to be five, but otolith age was seen to be four.

Length Composition of Age Groups

For both species, length frequency data for each scale and otolith age group were tabulated and compared, to detect inconsistencies. Length composition within each age group, as determined by scales and otoliths, was plotted as frequency polygons, using 5 mm class intervals. These frequency polygons by age are presented in Figures 12 and 13. Chi square tests were used to determine statistical similarities between the length frequencies derived from scale and otolith data. Results of these tests are presented in Appendix Table 3. In both species, length frequencies were not seen to be statistically different except in age three fish.

Figure 10. Age composition of the alewife sample from scale age and otolith age.

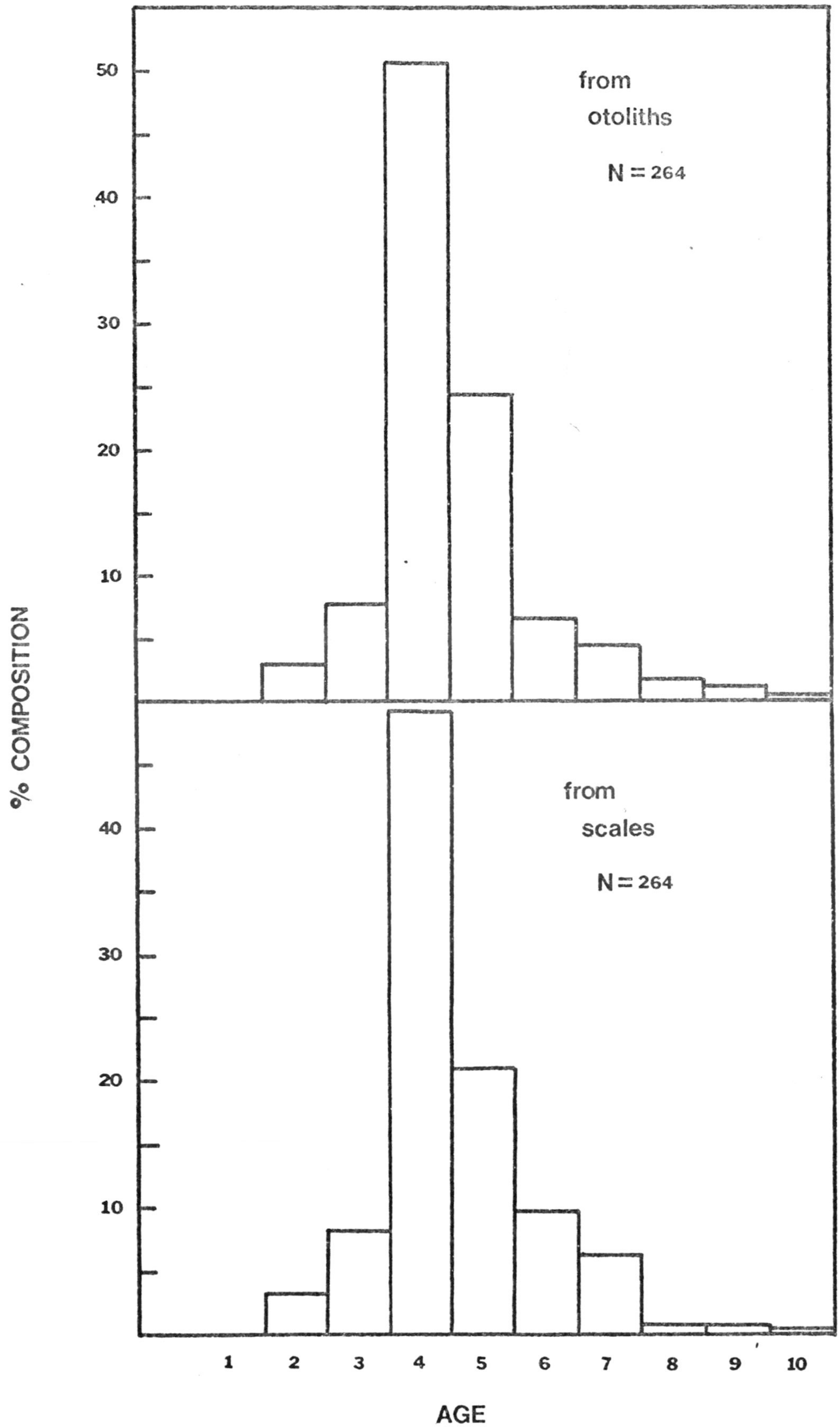
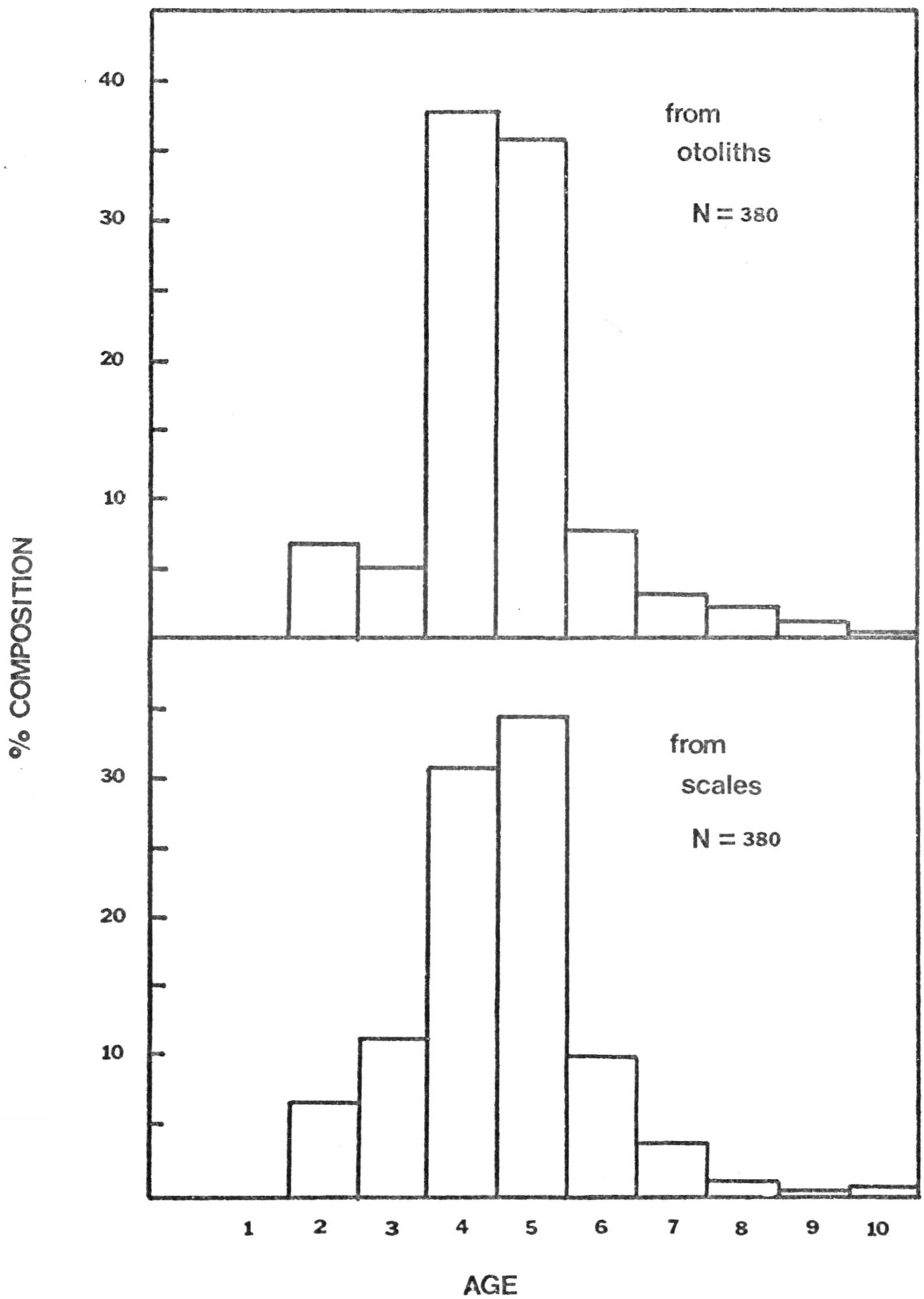

50
40
30
20
10
from
otoliths
N = 264
40
30
20
10
from
scales
N = 264
% COMPOSITION
1
2
3
4
5
6
7
8
9
10
AGE

Figure 11. Age composition of the blueback herring sample from scale age and otolith age.



% COMPOSITION
40
30
20
10
from
otoliths
N = 380
30
20
10
from
scales
N = 380
1
2
3
4
5
6
7
8
9
10
AGE

Figure 12. Length composition of age groups, alewife.

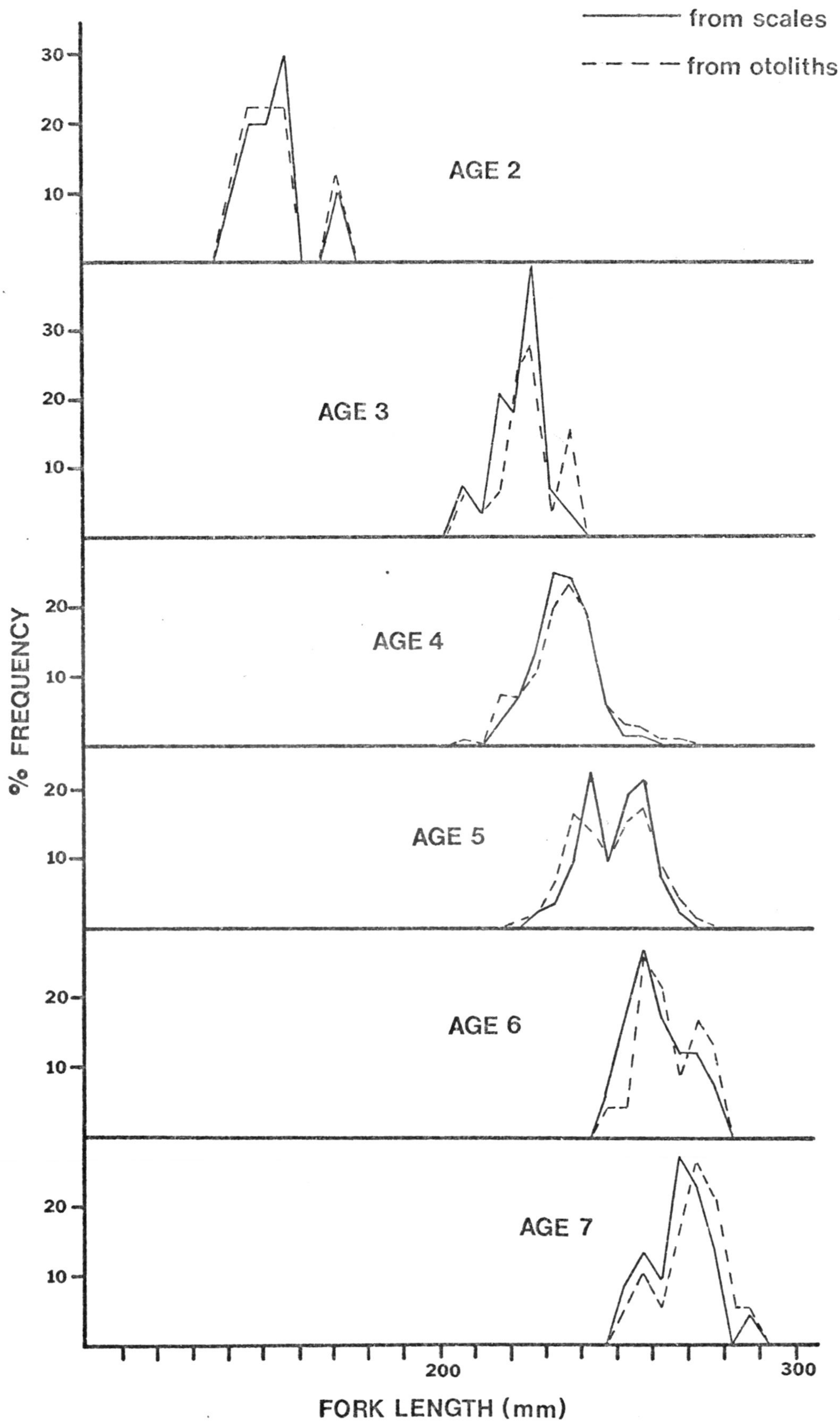
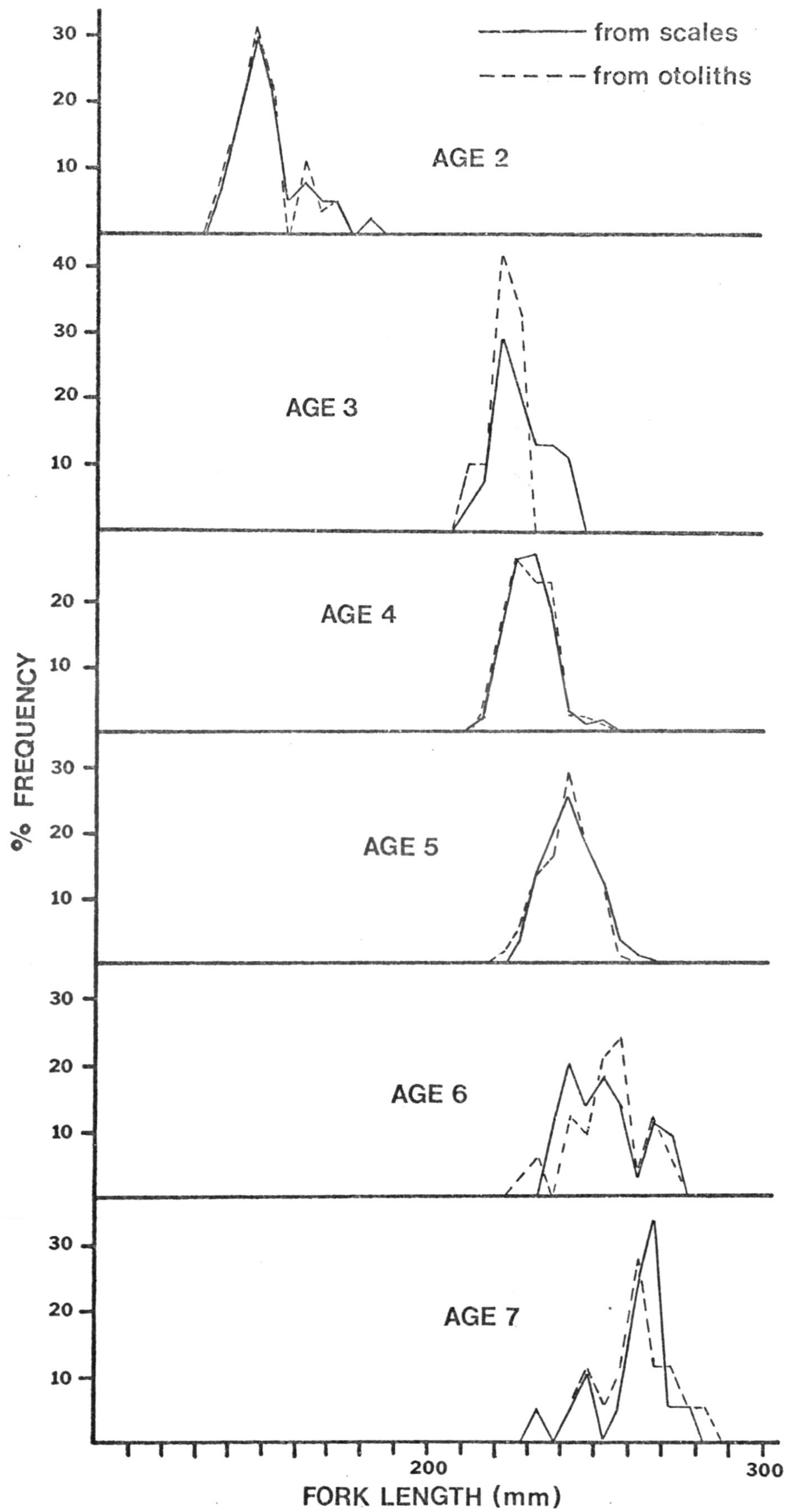

from scales
from otoliths
AGE 2
AGE 3
AGE 4
AGE 5
AGE 6
AGE 7
% FREQUENCY
30
20
10
200
300
FORK LENGTH (mm)

Figure 13. Length composition of age groups, blueback herring.


from scales
from otoliths
AGE 2
AGE 3
AGE 4
AGE 5
AGE 6
AGE 7
% FREQUENCY
10
20
30
40
200
300
FORK LENGTH (mm)

Most of the frequencies plotted from both scale and otolith data are at least bimodal. This may indicate the presence of different groups of fish in which growth rates may be different within the same age groups.

Fork Length/Scale Radius and Fork Length/Otolith Radius Relations

Growth history of both species was determined by establishing the relation between fork length and scale radius, and fork length and otolith radius. Since other studies have indicated that male and female river herring exhibit different growth rates, each species was separated by sex. Fork length/scale radius regressions and fork length/otolith radius regressions were calculated for each sex within the species.

The relation of scale radius and fork length was linear in both species. Regressions of these relations are presented in Figures 14 and 15. The regression slope for both sexes of each species was determined to be significantly different ($p<.05$); therefore, a combined sex regression was not calculated for either species. Scatter diagrams of fork length/scale radius data are presented in Appendix Figures 1 and 2.

The relation between otolith radius and fork length appeared curvilinear. By using log transformation of both otolith radius and fork length, a linear pattern was seen. Regression of the transformed data yielded a higher coefficient of determination than the raw data. Regressions of the transformed data are presented in Figures 16 and 17. Scatter diagrams of the transformed data are presented in Appendix Figures 3 and 4.

From these regressions, it is apparent that growth of scales and growth of otoliths occur at different rates. This fact is apparent upon visual inspection of scales and otoliths. Annuli on otoliths are seen to

Figure 14. Fork length/scale radius regression, alewife.

Male:

$$FL = 50.29 + 32.45\ RD^{**}$$

$$R = .9301^{**}$$

$$R^2 = .8650$$

$$N = 149$$

Female:

$$FL = 14.61 + 38.60\ RD^{**}$$

$$R = .9759^{**}$$

$$R^2 = .9524$$

$$N = 136$$

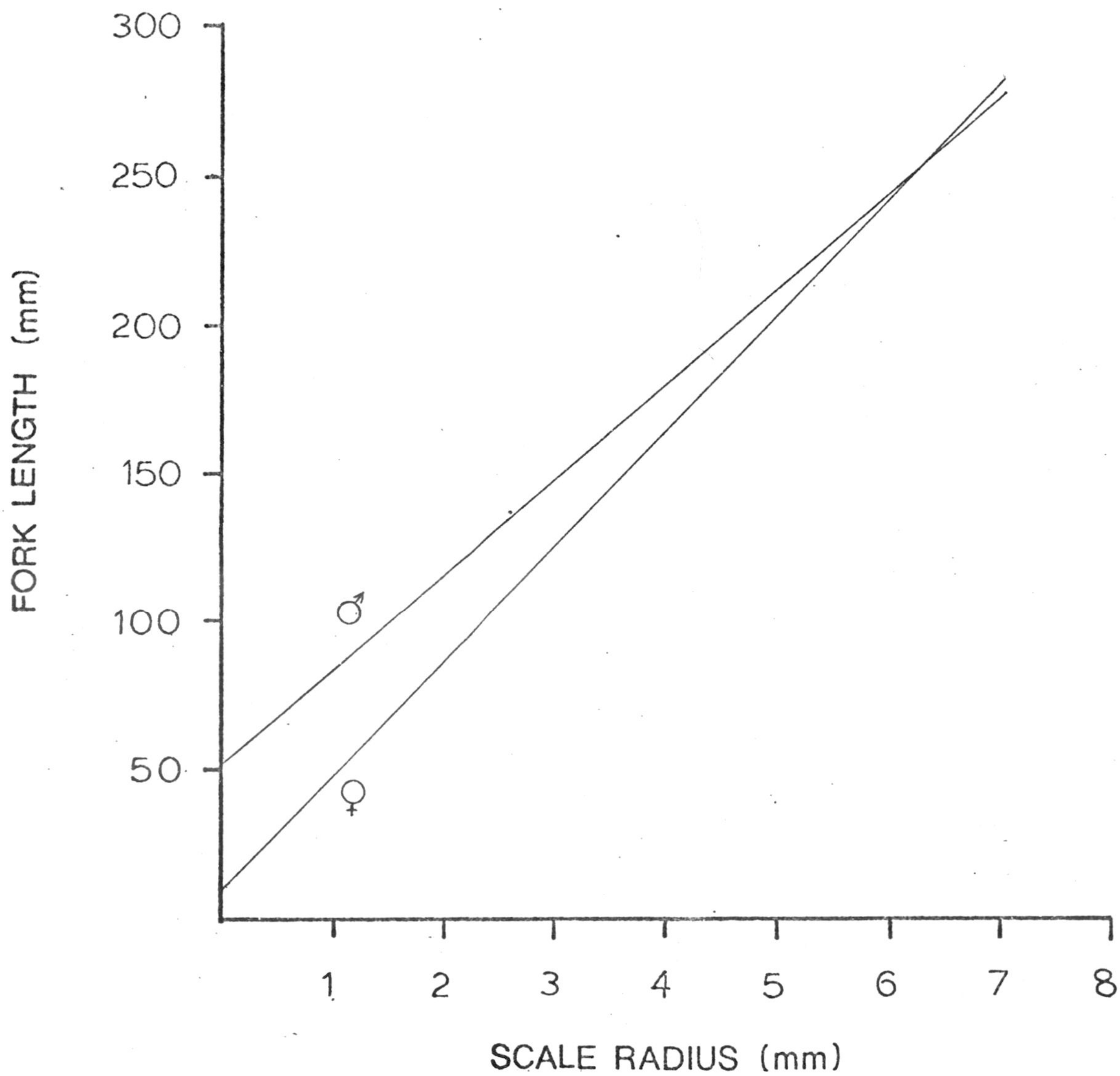

300
250
200
150
100
50
FORK LENGTH (mm)
♂
♀
1
2
3
4
5
6
7
8
SCALE RADIUS (mm)

Figure 15. Fork length/scale radius regression, blueback herring.

Male:

$$FL = 75.74 + 28.11\ RD^{**}$$

$$R = .9196^{**}$$

$$R^2 = .8457$$

$$N = 238$$

Female:

$$FL = 29.84 + 36.28\ RD^{**}$$

$$R = .9864^{**}$$

$$R^2 = .9730$$

$$N = 220$$

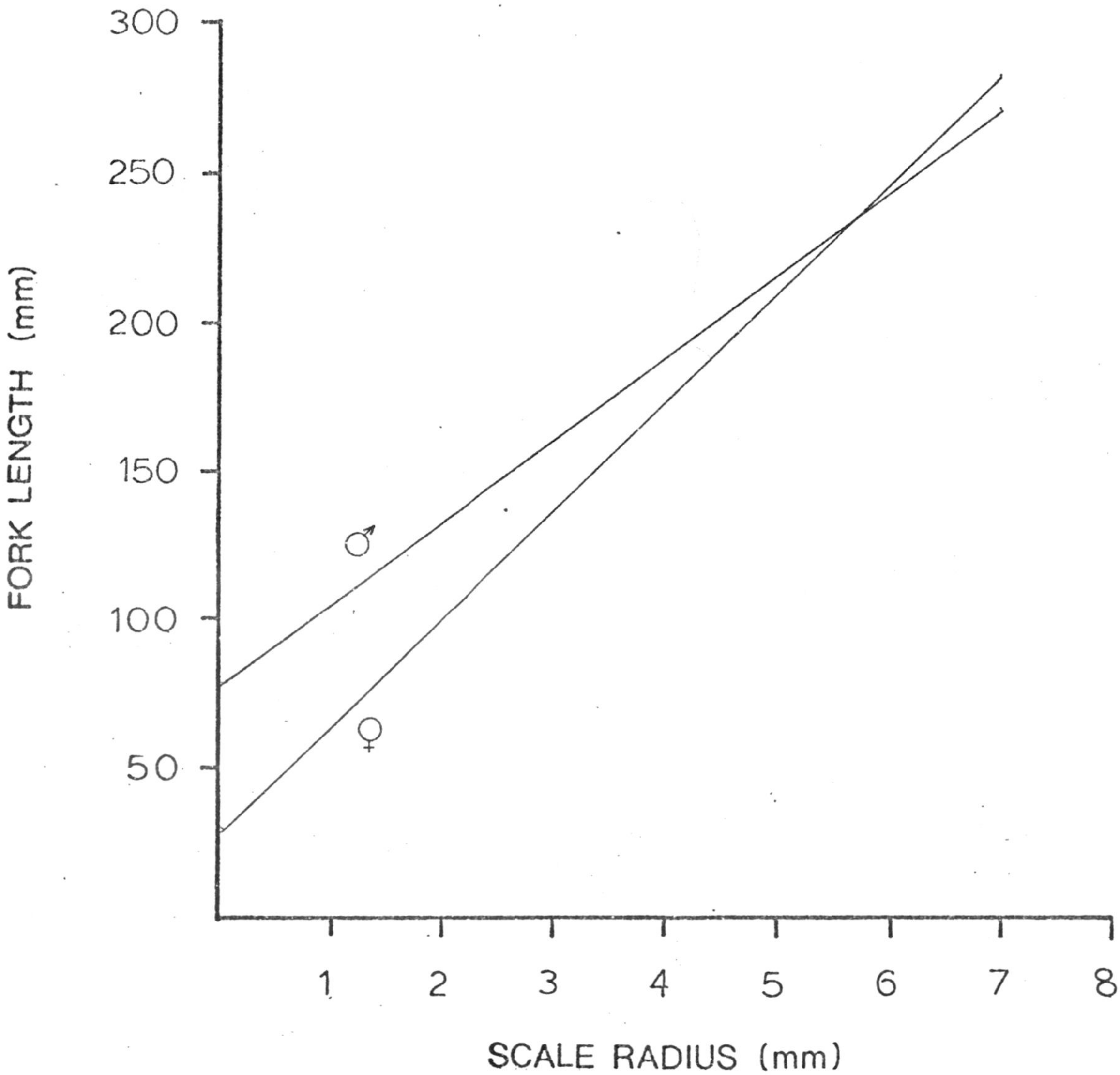

300
250
200
150
100
50
FORK LENGTH (mm)
♂
♀
1
2
3
4
5
6
7
8
SCALE RADIUS (mm)

Figure 16. Log fork length/log otolith radius regression, alewife.

Male:

$$\text{Log FL} = 2.15 + 1.20 \text{ Log RD}^{**}$$

$$R = .7572^{**}$$

$$R^2 = .5733$$

$$N = 175$$

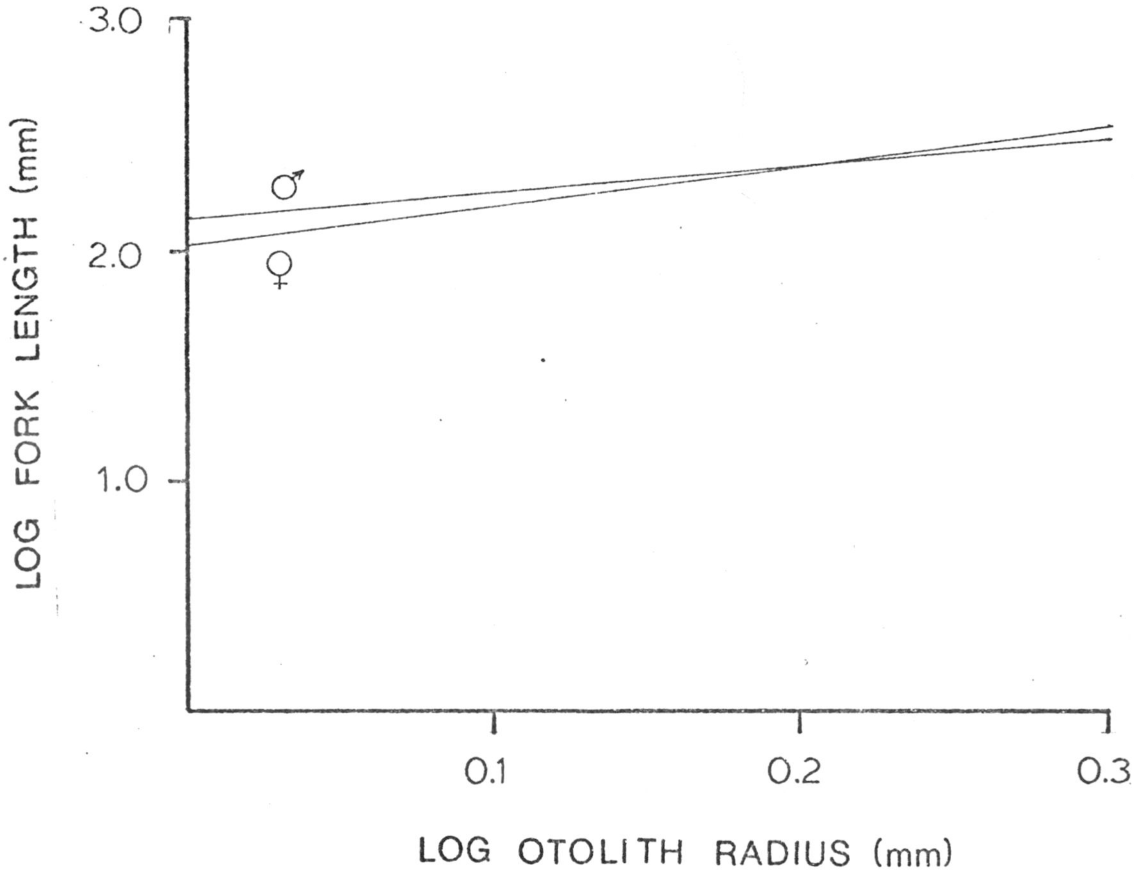
Female:

$$\text{Log FL} = 2.04 + 1.72 \text{ Log RD}^{**}$$

$$R = .9510^{**}$$

$$R^2 = .9044$$

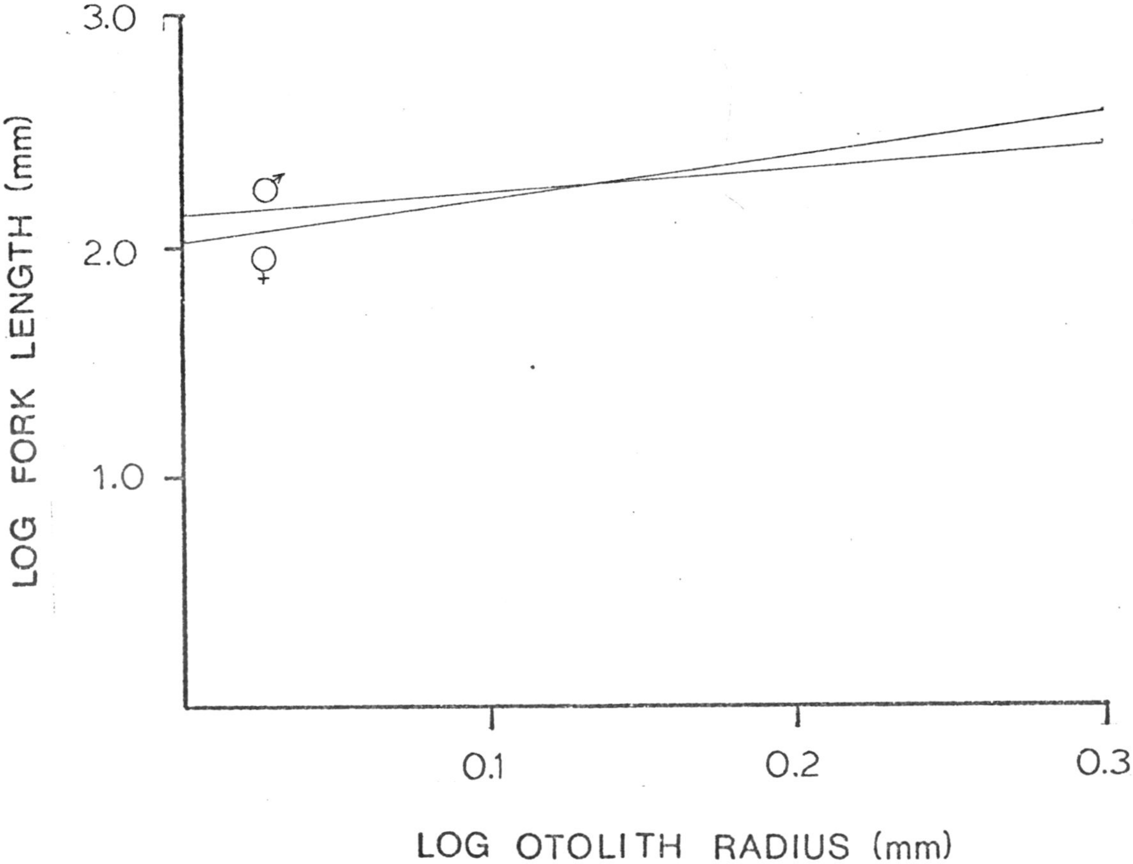
$$N = 163$$



3.0
2.0
1.0
LOG FORK LENGTH (mm)
♂
♀
0.1
0.2
0.3
LOG OTOLITH RADIUS (mm)

Figure 17. Log fork length/log otolith radius regression, blueback herring.

Male:	Log FL	= 2.14 + 1.06 Log RD**
	R .	= .5387*
	R^2	= .2902
	N	= 225
Female:	Log FL	= 2.02 + 1.70 Log RD**
	R	= .9861**
	R^2	= .9725
	N	= 221



3.0
2.0
1.0
LOG FORK LENGTH (mm)
♂
♀
0.1
0.2
0.3
LOG OTOLITH RADIUS (mm)

be more compacted after the third annulus than on scales. From the results of the log transformation of otolith data, it is evident that growth of otoliths slows with an increase in age, at or near a logarithmic rate. Distances between annuli on scales are also seen to decrease after the third annulus; however, the decrease is not as pronounced as in otoliths.

Growth

Average yearly growth rates were calculated for both species of river herring from raw scale and otolith data and from back-calculated growth history derived from annuli measurements.

Growth curves from the raw data were obtained by calculating the mean length of individuals within each age group. A comparison of growth curves obtained from scale and otolith data for each species is presented in Figures 18 and 19. Growth curves calculated from the raw scale and otolith data appear similar.

Growth history was obtained from annuli measurements of scales and otoliths. Using the regression equations from the fork length/scale radius and fork length/otolith radius relations, these annuli measurements were converted to fork lengths at previous ages. Confidence intervals for regression slopes and predicted values appear in Appendix Table 4. Mean values and standard errors are reported in Appendix Table 5. Growth curves obtained from back-calculations are presented in Figures 18 and 19. These curves vary from each other to a greater extent than curves derived from the raw sample data; however, all remain similar. This difference is probably due to the variability in position of the annuli on the scales and otoliths. A difficulty encountered in obtaining accurate scale annuli

Figure 18. Growth of alewife derived from raw data and back calculated data.

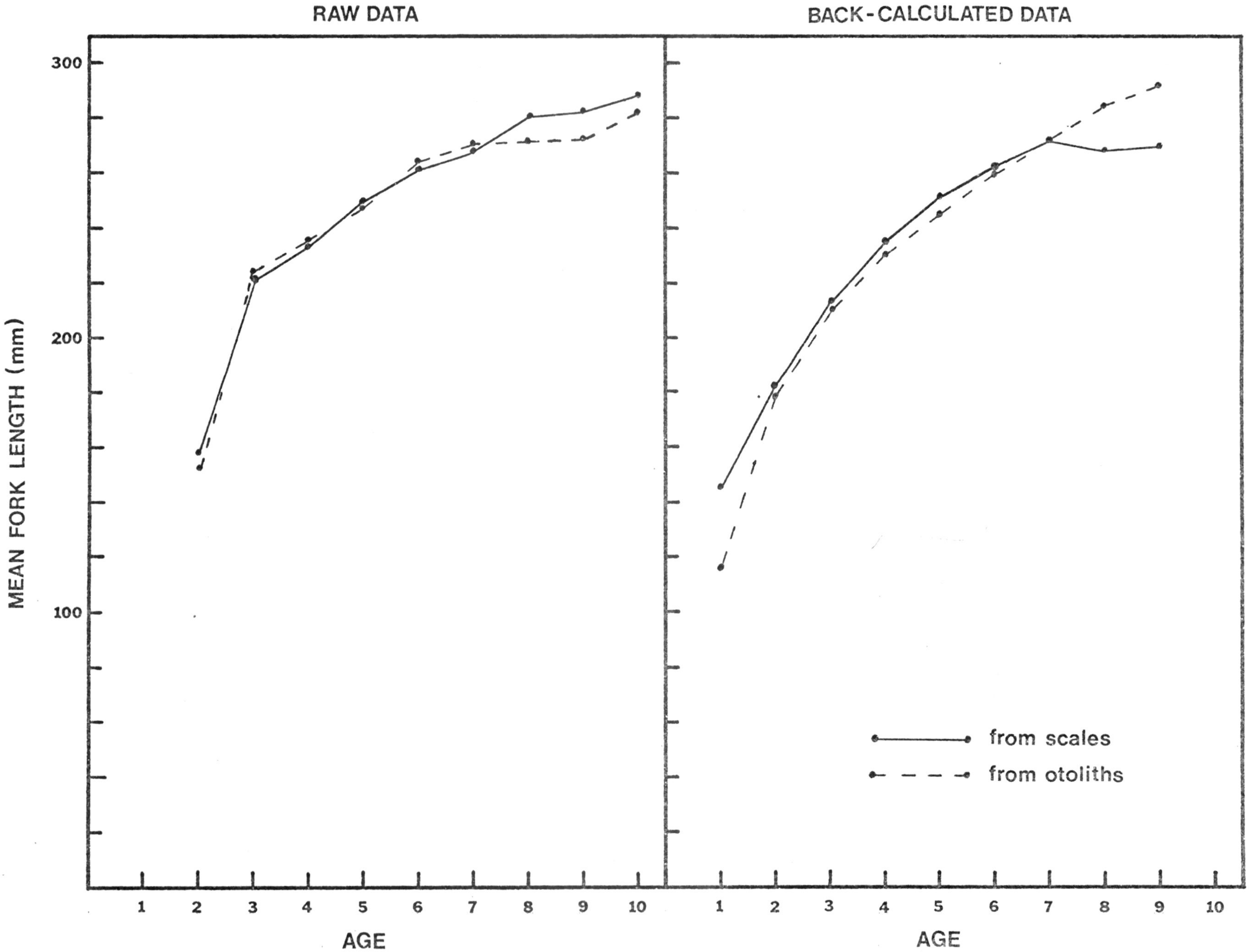
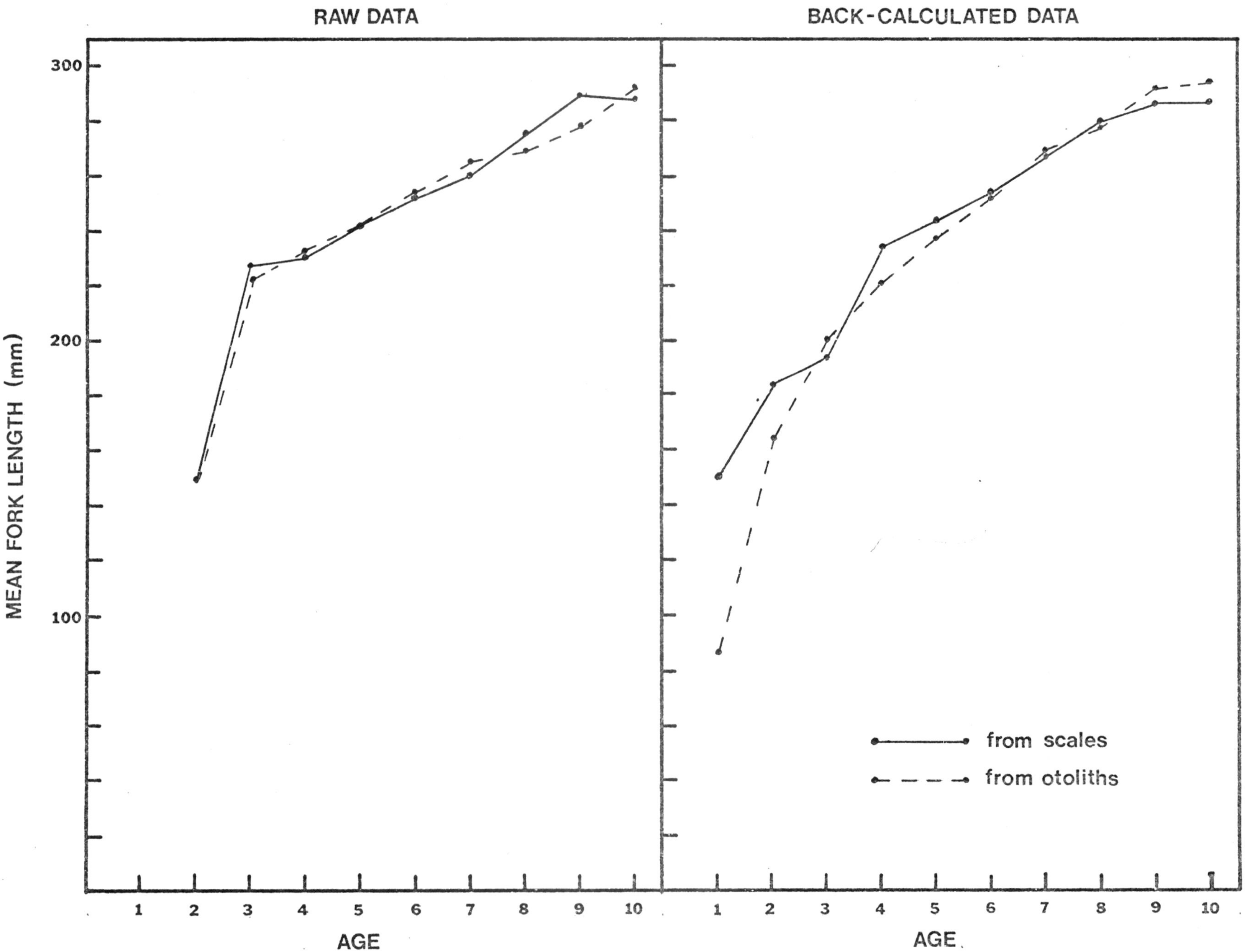

RAW DATA
BACK-CALCULATED DATA
MEAN FORK LENGTH (mm)
300
200
100
1
2
3
4
5
6
7
8
9
10
AGE
from scales
from otoliths

Figure 19. Growth of blueback herring derived from raw data and back-calculated data.


RAW DATA
BACK-CALCULATED DATA
MEAN FORK LENGTH (mm)
300
200
100
1
2
3
4
5
6
7
8
9
10
AGE
from scales
from otoliths

measurements was in locating a representative or "key" scale. Scales of river herring are highly variable in size and radius, making measurement of annuli a difficult task. Otoliths are much more uniform in size, but the annuli are more compacted than on scales, which also hinders measurement.

In the case of both alewife and blueback herring, growth curves derived from back-calculations of scale annuli measurements tend to give higher growth rate estimates than from growth curves derived from otolith annuli measurements, especially in younger age groups ($<$three years). Differences also appear in older age groups ($>$seven years), and are probably caused by small sample sizes within these groups.

Generally, growth curves derived from scale and otolith annuli back-calculations tend toward similarity, with greatest differences in young and old age groups. These curves also conform to growth curves derived from the raw sample data.

SUMMARY AND CONCLUSIONS

1. Independent readings of scales yielded an agreement level of 73.9% for alewife and 87.5% for blueback herring. Variations were due to differences in interpretation of spawning checks.

2. Independent readings of otoliths yielded an agreement level of 82% for both alewife and blueback herring. Variations were due to differences in interpretation of closely spaced outer annuli.

3. The overall agreement level between scale and otolith ages of alewife was 57.19%. An agreement level between the two methods of 67.96% was obtained for blueback herring. Variations of scale and otolith ages were due to the subjective nature of human interpretation of annuli.

4. Very little difference was seen in the age composition of the sample as determined from scale and otolith ages of both species.

5. Length composition of each scale and otolith age group was determined to be statistically similar except in the age three groups of both species. This difference was caused by the wide range of lengths attained by river herring during their third year of growth.

6. The fork length/scale radius relation was seen to be linear in both species. The fork length/otolith radius relation differed notably. Log transformation of fork lengths and otolith radii yielded a linear relation, indicating a slowing of otolith growth at or near a logarithmic rate with an increase in age.

7. Mean fork lengths of each scale and otolith age group were plotted as growth curves and appear similar in both species.

8. Annuli measurements taken from scales and otoliths were back calculated to determine fork lengths at previous ages. Mean fork lengths at each previous scale and otolith age were plotted as growth curves. In both species, growth curves derived from back-calculation of scale annuli measurements tend to estimate values higher than from growth derived from otolith annuli measurements.

SUMMARY OF THE USE OF SCALES AND OTOLITHS TO AGE RIVER HERRING

The use of scales is the most convenient method of ageing river herring. Scales can be quickly removed without mutilation of the fish and are easily stored in small envelopes. Although collection of scales is time efficient, interpretation of annuli can be a tedious task. True annuli are often obscured due to the presence of false annuli, transverse grooves, scale erosion during spawning, and the presence of epidermal tissue which reduces scale transparency.

The use of otoliths to age river herring offers less convenience than scales because dissection of the head is necessary to obtain otoliths. If sampling of commercial catches of river herring is involved, it may be necessary to purchase specimens in order to obtain otoliths, as most commercial fishermen are not likely to allow mutilation of their catch. Otoliths are usually stored in glass vials and require mounting for microscope observation. Interpretation of annuli on otoliths is generally not as difficult as those on scales. River herring otoliths are more uniform in size than scales, have fewer false annuli, and less variability in annuli position. Unlike scales, otoliths do not offer a method of assessment of spawning history. There are no detectable differences between true annuli and spawning checks on these otoliths.

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APPENDIX

Appendix Table 1. Tabulated data of variation of otolith ages from scale ages for alewife.

Scale Age

Otolith Age Variation	2	3	4	5	6	7	8	9	10
-2					1	2	1		
					4%	13%			
-1			8	26	12	6			
			6%	47%	46%	38%			
Agree	8	11	94	23	5	6	1	2	1
	89%	50%	72%	42%	19%	38%			
+1		11	28	4	5	1			
		50%	21%	7%	19%	5%			
+2	1		1	2	3	1			
	11%		1%	4%	12%	5%			

N = 264

Appendix Table 2. Tabulated data of variation of otolith ages from scale ages for blueback herring.

Otolith Age Variation	Scale Age 2	3	4	5	6	7	8	9	10
-3						1			
						7%			
-2					4	1			1
					10%	7%			
-1		1	10	27	13	5		1	2
		2%	8%	21%	33%	33%			
Agree	28	35	84	90	14	4	2		
	100%	81%	71%	70%	36%	27%			
+1			23	10	6	3	1		
			19%	8%	15%	20%			
+2		7	1	1	2	1	1		
		16%	2%	.5%	5%	7%			
+3				1					
				.5%					

N = 380

Appendix Table 3. Chi square tests for differences of length frequencies from scale and otolith data.

Alewife

Age	x^2	DF	Critical x^2
2	1.333	6	12.592
3	13.154*	6	12.592
4	14.575	8	15.507
5	13.748	9	16.919
6	11.320	6	12.592
7	5.333	5	11.070

Blueback Herring

Age	x^2	DF	Critical x^2
2	8.733	9	16.919
3	20.835*	6	12.592
4	11.207	8	15.507
5	8.480	7	14.067
6	11.266	7	14.067
7	7.238	8	15,507

Appendix Table 4. Confidence intervals (95%) for regression slopes and predicted values. RD = radius; FL = estimated fork length.

Alewife

Fork Length/Scale Radius Regressions

CI for Regression Slopes

Male: CI = 32.45 ± 2.07

Female: CI = 36.60 ± 1.47

CI for Predicted Values

Male			Female		
RD	FL	CI	RD	FL	CI
1.00	82.74	± 1.26	1.00	53.21	± 2.07
2.00	115.19	± 1.26	2.00	91.81	± 2.07
3.00	147.64	± 1.26	3.00	130.41	± 2.06
4.00	180.09	± 1.26	4.00	169.01	± 2.06
5.00	212.54	± 1.25	5.00	207.61	± 2.06
6.00	244.99	± 1.25	6.00	246.21	± 2.06
7.00	277.44	± 1.25	7.00	284.81	± 2.06

Log Fork Length/Log Otolith Radius Regressions

CI for Regression Slopes

Male: CI = 1.20 ± .154

Female: CI = 1.72 ± .087

Appendix Table 4. (cont'd)

CI for Predicted Values

Male LRD	Male LFL	Male CI	Female LRD	Female LFL	Female CI
.05	2.21	± .01	.05	2.13	± .01
.10	2.27	± .009	.10	2.21	± .008
.15	2.33	± .009	.15	2.29	± .008
.20	2.39	± .009	.20	2.38	± .007
.25	2.45	± .009	.25	2.47	± .008
.30	2.51	± .01	.30	2.56	± .008

Blueback Herring

Fork Length/Scale Radius Regressions

CI for Regression Slopes

Male: CI = 28.11 ± 1.537

Female: CI = 36.28 ± .804

CI for Predicted Values

Male RD	Male FL	Male CI	Female RD	Female FL	Female CI
1.00	103.85	± 1.40	1.00	66.12	± 1.73
2.00	131.96	± 1.40	2.00	102.40	± 1.73
3.00	160.07	± 1.39	3.00	138.68	± 1.72
4.00	188.18	± 1.39	4.00	174.96	± 1.72
5.00	216.29	± 1.39	5.00	211.24	± 1.72
6.00	244.40	± 1.39	6.00	247.52	± 1.72
7.00	272.51	± 1.39	7.00	283.80	± 1.72

Appendix Table 4. (cont'd)

Log Fork Length/Log Otolith Radius Regressions

CI for Regression Slopes

Male: CI = 1.06 ± .219

Female: CI = 1.70 ± .037

CI for Predicted Values

Male			Female		
LRD	LFL	CI	LRD	LFL	CI
.05	2.15	± .03	.05	2.19	± .03
.10	2.25	± .02	.10	2.25	± .02
.15	2.30	± .01	.15	2.30	± .01
.20	2.35	± .01	.20	2.35	± .01
.25	2.41	± .02	.25	2.41	± .01
.30	2.46	± .03	.30	2.46	± .03

Appendix Table 5. Summary of growth tabulations from raw data and back-calculated data.

Alewife - Raw Data

Scale Age

	2	3	4	5	6	7	8	9	10
$\overline{FL}$	159.7	223.3	235.6	250.6	262.0	268.2	281.5	283.5	288
N	10	28	159	84	41	22	2	2	1
S.E.	5.98	1.33	0.59	1.05	1.28	1.76	1.49	2.49	0

Otolith Age

	2	3	4	5	6	7	8	9	10
$\overline{FL}$	153.8	224.4	236.5	249.2	264.0	270.9	272.8	273.5	282.5
N	8	25	166	86	23	19	5	2	2
S.E.	3.31	1.85	0.75	1.16	2.21	2.16	4.12	7.49	5.50

Alewife - Back-calculated Data

Scale Age

	1	2	3	4	5	6	7	8	9
$\overline{FL}$	146.1	182.0	214.7	236.4	251.8	263.5	272.1	268.8	270.3
N	271	271	262	239	126	60	27	5	3
S.E.	0.66	0.67	0.67	0.66	0.92	1.54	2.69	8.77	12.99

Otolith Age

	1	2	3	4	5	6	7	8	9
$\overline{FL}$	117.4	180.1	211.4	231.3	247.5	260.6	273.6	285.4	292.3
N	322	322	314	289	131	48	27	8	3
S.E.	1.17	1.21	1.09	1.09	1.98	4.47	6.48	12.81	14.77

Appendix Table 5. (cont'd)

Blueback Herring - Raw Data

Scale Age

	2	3	4	5	6	7	8	9	10
$\overline{FL}$	150.3	228.5	231.9	243.3	253.4	261.6	277.8	290.0	289.0
N	37	45	138	148	44	19	6	1	2
S.E.	2.14	1.19	0.60	0.61	1.62	2.69	4.36	0	1.99

Otolith Age

	2	3	4	5	6	7	8	9	10
$\overline{FL}$	150.4	224.4	232.1	242.2	255.7	266.1	270.3	279.8	293.0
N	31	18	166	148	33	18	12	6	1
S.E.	2.11	1.31	0.55	0.61	1.83	3.33	2.71	5.72	0

Blueback Herring - Back-calculated Data

Scale Age

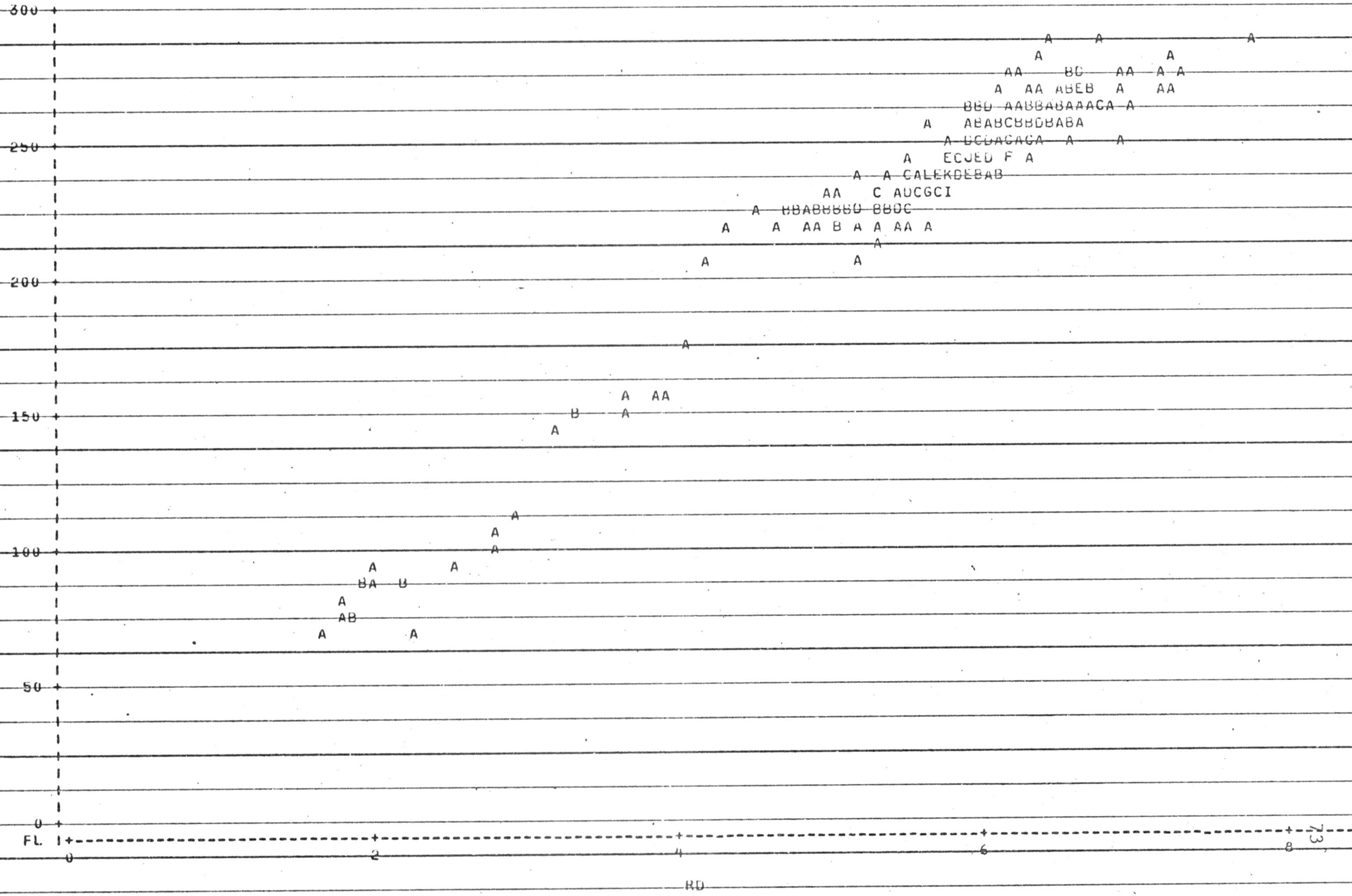
	1	2	3	4	5	6	7	8	9	10
$\overline{FL}$	151.1	184.8	215.6	234.4	245.8	255.1	266.3	280.0	287.0	287.0
N	418	417	395	342	211	72	28	10	4	3
S.E.	0.78	0.83	0.70	0.63	0.79	1.55	2.26	4.88	8.78	7.51

Otolith Age

	1	2	3	4	5	6	7	8	9	10
$\overline{FL}$	87.4	165.3	201.7	222.4	238.9	253.5	268.1	279.9	291.1	295.5
N	403	403	401	356	210	66	35	18	8	2
S.E.	1.02	1.03	0.91	0.93	1.42	2.81	4.54	7.90	13.49	16.50

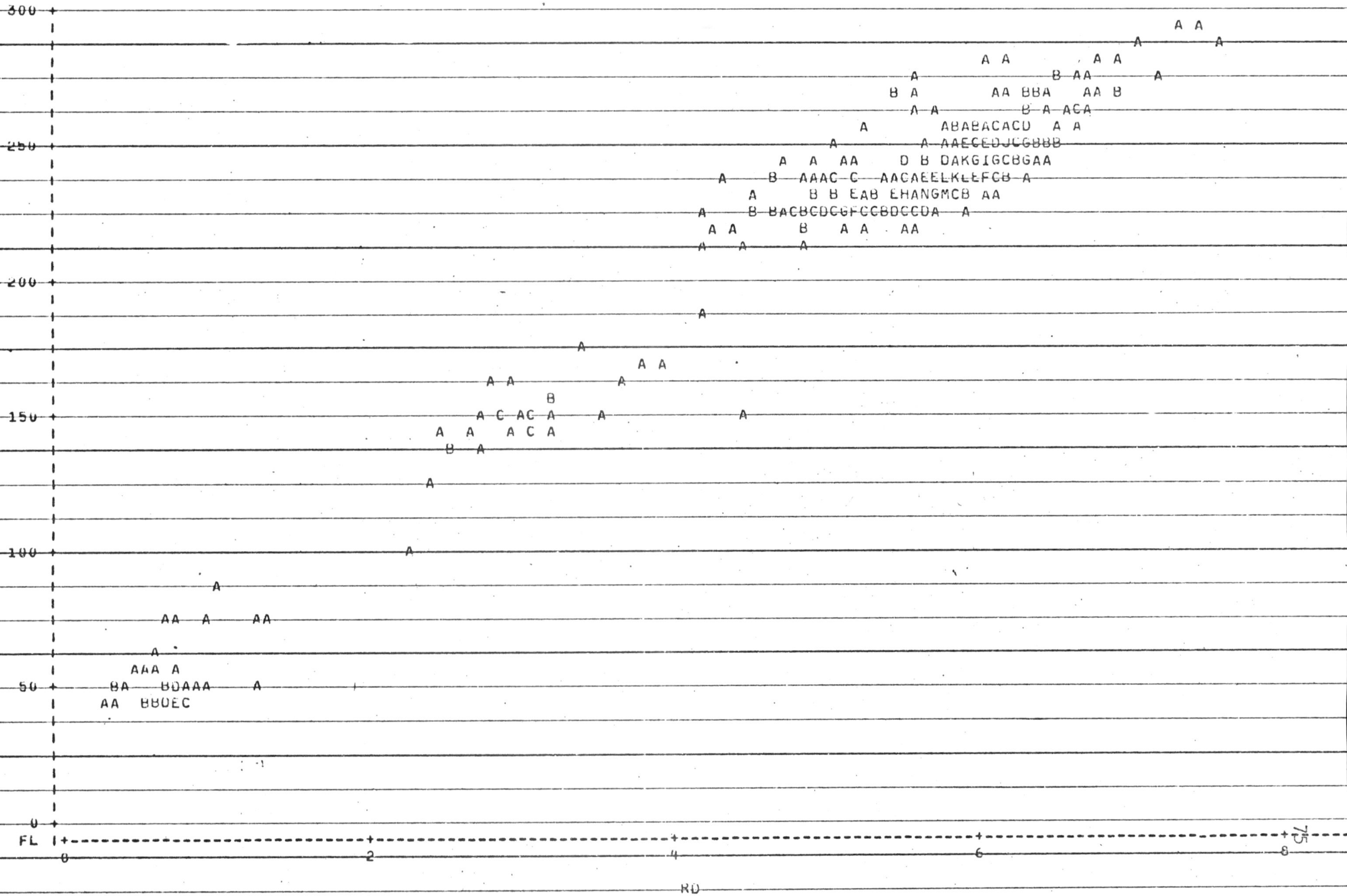
Appendix Figure 1. Scatter diagram of fork length/scale radius data, alewife.

PLOT OF RD*FL   LEGEND: A = 1 OBS , B = 2 OBS , ETC



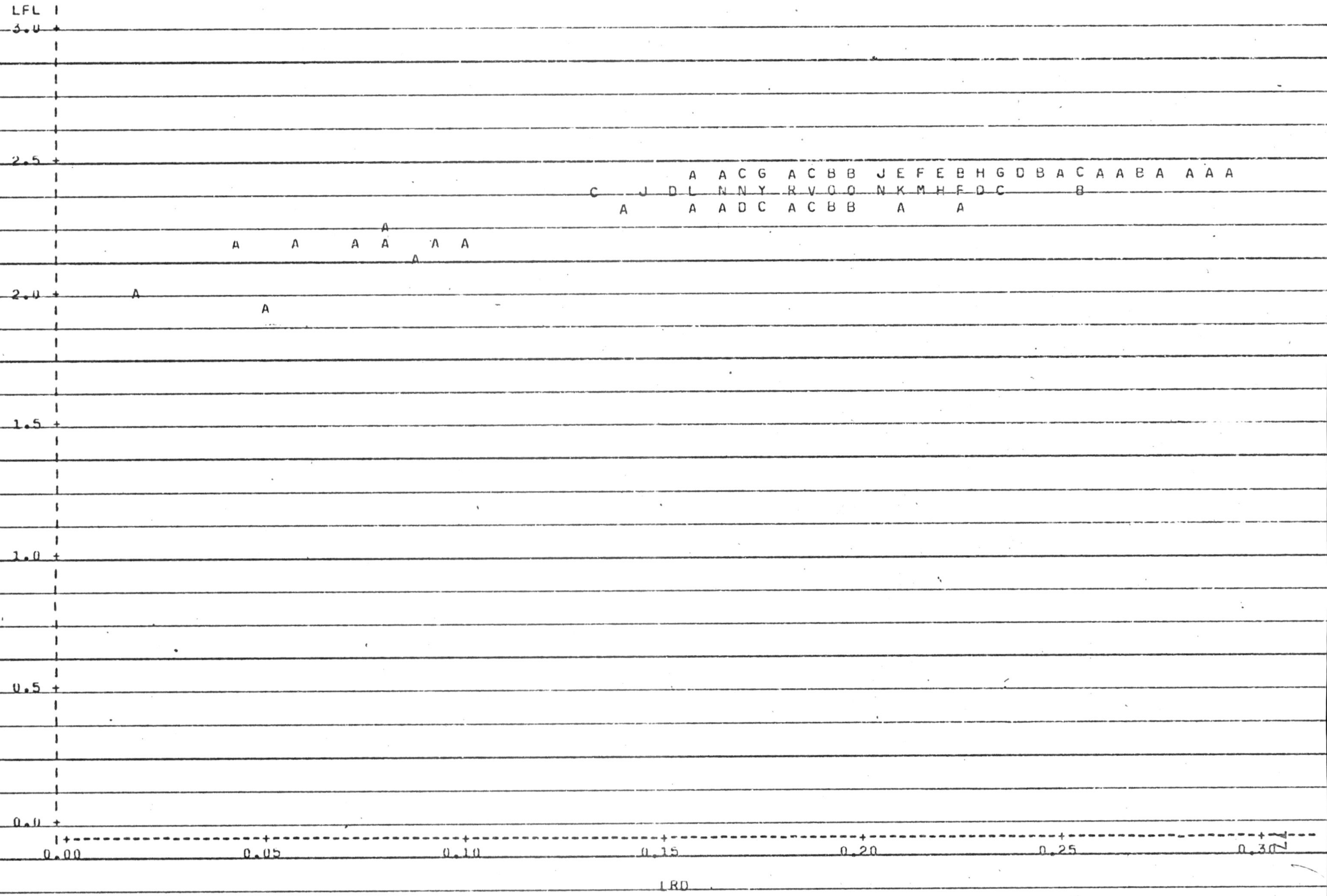
Appendix Figure 2. Scatter diagram of fork length/scale radius data, blueback herring.

PLOT OF RD*FL   LEGEND: A = 1 OBS, B = 2 OBS, ETC



Appendix Figure 3. Scatter diagram of log fork length/log otolith radius data, alewife.

PLOT OF LRD*LFL LEGEND: A = 1 OBS , B = 2 OBS , ETC



Appendix Figure 4. Scatter diagram of log fork length/log otolith radius data, blueback herring.

PLOT OF LRD*LFL   LEGEND: A = 1 OBS , B = 2 OBS , ETC.