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A preliminary report on the age and growth of larval herring (Clupea harengus) from daily growth increments in otoliths

by

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Abstract

Larval herring were collected along the western Gulf of Maine during October, 1976, for otoliths analysis. A significant correlation was found between larval length and otolith growth increments. The regression indicated that otolith ring formation was initiated at a larval length of about 7 mm, the size of herring larvae at the time of yolk sac resorption. The data were consistent with the assumption that each otolith growth increment represents one day, and after adjustment for the period from hatching to yolk sac resorption, a regression between larval length and age was made to represent a growth curve. The growth rate (0.34 mm/day) based on the slope of the regression line was comparable to estimates made by conventional methods from other studies. Using this new larval otolith aging technique, it may be possible to calculate very accurate growth curves for a comparison of the effect of environment on larval growth among different spawning areas and seasons; and by a careful comparison of larval otolith morphometrics it may be possible to distinguish between separate spawning populations in the Gulf of Maine region.

Introduction

Techniques for accurately aging larval fish have become increasingly important to fisheries research. Previously, age estimates have been made primarily based on length frequencies and these estimates have been used for growth calculations. Larval growth rates are essential for estimating larval survival and comparing the effects of varying environmental conditions. Therefore, the accuracy of growth estimates and all further estimates of larval population parameters depend upon the accuracy of aging techniques.

Only recently have otoliths been used in the aging of larval fish. Daily growth rings in adult fishes were first observed by Pannella (1971). He used daily ring counts to confirm annual growth ring aging. Brothers, Mathews and Lasker (1976) successfully applied the findings of Pannella to the aging of larvae of various fishes. Strusaker and Uchiyama (1976) made further use of daily growth rings in calculating the age and growth of the nehu, Stolephorus purpureus, held in captivity. They found that back calculations from daily otolith growth increments to length of fish could be done

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very accurately. Taubert and Coble (1977), working with freshwater Centrachids, postulated that daily rings on otoliths resulted from a 24-hour light-dark cycle that entrained an internal, diurnal clock.

Estimates of growth of western North Atlantic herring larvae, Clupea harengus, have been made by Sameoto (1972), Boyar et al. (1973), and Lough (1976) following length-frequency modes through time. Further refinement of these estimates could be made by accurate otolith aging of larvae.

It is also possible that races or subpopulations of larvae may be separated by a careful analysis of their otoliths. Einarsson (1951) found that races of adult herring in the North Sea could be distinguished by the appearance of their otoliths. Adults originating from stocks spawned in different seasons were found to vary in the composition of their otolith nuclei. Postuma and Zijlstra (1958) found that the time of spawning and the size of the otolith nucleus in those fish spawned during the same season of the year were related. Fish hatched early in the slow growth period of the year would be expected to have a larger hyaline nucleus than those hatched later in the period. Parrish and Sharman (1958) found that different races of herring differ in measurement ratios of various parts of the otoliths as well as nuclear character and the texture of the bone. To date, larval fish have not been utilized in racial studies. Comparison of the otoliths from larvae of Georges Bank, the western Gulf of Maine and Nantucket Shoals may further substantiate the discreteness of spawning populations in these areas (Figure 1). Specific objectives of this study are to:

1. Determine an accurate age of herring larvae by documenting the occurrence of daily growth rings in their otoliths.

2. Determine when daily otoliths growth ring formation begins during larval development.

3. Relate head and standard length measurements to various dimensions of the otolith, i.e. the radius of daily growth rings, the total radius of the otolith and the size of the otolith nucleus. Determine how these dimensions are related to larval growth.

4. Attempt to separate races of spawning populations of herring by interregional comparisons of larval otolith morphometrics from the western Gulf of Maine, Georges Bank, and Nantucket Shoals.

5. Calculate growth curves based on larval length versus age (based on otolith rings) for the first six months of larval life. Compare larval growth curves among the different spawning areas.

Methods

Larval herring were collected at selected stations in the western Gulf of Maine, Georges Bank and Nantucket Shoals during the Fall 1976 ICNAF[1] Larval Herring Survey (Table 1, Figures 2 and 3). Most of the sampling effort this past season was concentrated in the Georges Bank area. Stations were selected on each survey where a high density of larvae were encountered.

Sampling of larvae was made using a 61-cm bongo net with mesh sizes of 0.333 and 0.505 mm. Standard ICNAF tows were made to a depth of 100 meters or to within five meters of the bottom. Immediately after the nets were brought aboard, larvae were sorted from the plankton sample and frozen.

In the laboratory, 30 to 50 larvae per station were measured for standard length (snout to end of caudal peduncle) and head length (snout to sagittae in normal position) to the nearest 0.01 mm. Measurements also included eye height, head height, maximum skull width, maxillary length and pectoral angle. These additional measurements are being used to evaluate larval condition in relation to prey selection (see Ehrlich et al. 1976).

Otoliths from both sides of the head were removed when possible and mounted in Canada balsam or a synthetic mounting medium. The otoliths were whole mounted and no difficulty was found in reading the bones intact.

Counts of growth rings were made using a compound microscope with magnifications of 400 to 500 X. Counts were repeated until a minimum acceptable range of 5% variability was reached. In the future, each otolith will be photographed so that all final measurements can be made from the enlarged prints.

In order to determine the precise age when ring deposition first begins in larval herring otoliths, an attempt was made to rear herring larvae from eggs in the laboratory. Eggs were collected from the Jeffreys Ledge area in October, 1976, and reared for two months at the Narragansett Laboratory. The eggs and larvae were maintained at 10°C, under natural light conditions, and fed raw plankton collected from Narragansett Bay. A weekly sample of larvae was taken from the rearing vessels, frozen, and the otoliths from a few larvae have been analyzed as described above.

Basic statistical techniques of linear regression and analysis of variance were used to analyze the available data. When the remainder of the samples have been processed, various types of growth curves may be generated. The Laird-Gompertz growth curve for larval fish (Zweifel and Lasker, 1976) seems very promising for this kind of data.

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[1]International Commission for the Northwest Atlantic Fisheries.

Results and Discussion

Otoliths from only a few of the lab-reared herring larvae were examined and it was observed that otolith growth was stunted to a large degree. The growth increments were extremely faint and difficult to read so that no useful lab data is available yet. This abnormality in otolith growth may have occurred as a result of low feeding levels and/or low calcium levels in the rearing water (Irie et al., 1967). Variations in photoperiod and temperature, that normally occurs in the natural environment, may serve to increase the size of the otolith growth increments, aiding their resolution (Taubert and Coble, 1977). The age at which the initiation of otolith growth increments begins, based on lab-reared larvae, may be gained through future work if the larvae are reared for a short period of approximately five days after yolk sac absorption, carefully monitoring food supply and calcium levels. It appears that otolith ring deposition only can be documented if larval growth is fairly normal.

Only larvae collected along the western Gulf of Maine, R/V Annandale cruise, 1-18 October 1976, have been processed and their otolith data partially analyzed to date from the various larval herring surveys listed in Table 1. Four stations were sampled for herring larvae on this cruise (Figure 3) and otoliths from 120 specimens examined. Photographs clearly showing otolith rings from two herring larvae are provided in Figure 4. A summary of the statistics for all otolith growth increments by 1 mm standard length (SL) class intervals is given in Table 2. No recently hatched larvae (<10 mm SL) were collected on this cruise. The average number of otolith growth increments is generally greater than the respective size class. Also, the range of increments is fairly wide for each size class. The standard deviation within a size class appears to increase as the larvae increase in size, but many of the size classes have too few observations to make a definitive statement. This wide variability is to be expected as many herring spawning beds occur along the western Gulf of Maine, each differing in their hatching times, with the larvae intermixing along the coast as the currents transport them in a southwesterly direction. Each larval group probably has its own specific growth curve depending upon temperature, food availability, etc.

A regression analysis of larval standard length versus otolith growth increments for individual stations and combined station data is given in Table 3 and Figure 5. A high degree of correlation ($r = 0.7$) and significant regression was calculated for all station data except for station 3 which had too few observations ($n = 7$) to be meaningful in this case. An analysis of covariance made on the composite station data indicated a significant difference among the individual slopes ($F = 6.357$, 115 & 112 df., <1% level). However, if the analysis of covariance is made on only the data within the 10-20 mm length range, thereby excluding size classes with few observations, then the slopes of the lines were found to not be significantly different. The bulk of the data lies within the 10-20 mm length range so that the validity of the composite regression shown in Figure 5 seems substantiated.

A regression analysis of head length versus otolith growth increments was made in the same manner as for standard length and is given in Table 4. Head length was measured as it was believed that it might provide a more stable dimension for basing larval growth. The regressions calculated were all significant and all correlation coefficients (r) were >0.7.

The composite regression of standard length versus increments yields a Y-intercept of -15.64. This point corresponds to the time when the eggs were spawned assuming each increment corresponds to one day. Herring eggs hatch in approximately 10-12 days from the time spawn (Cooper et al., 1975; Blaxter and Hempel, 1966). The X-intercept (7.40 mm) of the composite regression is the projected length of the larvae when ring deposition begins. This length of 7.40 mm corresponds closely with information on the lengths of herring larvae when the yolk sac is resorbed. Less than 10% of the recently hatched herring larvae with a modal length of 7 mm collected on Georges Bank and Jeffreys Ledge, 11-15 October 1974, still had yolk sacs (Lough, unpublished data). Blaxter and Holliday (1963) reported yolk sac resorption for North Sea herring larvae at a length range of 8-12 mm. Brothers et al. (1976) found that the first daily otolith growth rings in Engraulix mordax was formed after the yolk sac was absorbed and in Leuresthes tenuis after hatch. They state that the exact timing of the initiation of daily otolith rings varies between species and must be independently determined. From the data analyzed to date for larval herring, it seems reasonable to assume that daily ring deposition begins when yolk resorption is completed. Blaxter and Hempel (1966), reported that larval herring yolk sac resorption occurs five days from hatching at 10°C. Therefore, referring to Figure 5, western Gulf of Maine herring larvae at the X-intercept length of 7.40 mm were five days old from hatching when otolith ring deposition was initiated.

Assuming each otolith growth increment represents one day, and adding five days to each increment observation to allow for the time from hatching to yolk sac absorption when the first increment begins, a plot of larval age versus standard length is shown in Figure 6. Although there is some indication that the growth curve is curvilinear in nature, a linear regression line was calculated to represent the general slope of the growth curve for western Gulf of Maine larvae. The form of the growth equation is

$$Y = ax + b$$

where Y = standard length of larvae in mm, x = age of larvae based on otolith growth increments, a = 0.344 (slope), b = 7.404 (Y-intercept). The computed regression was highly significant with a correlation coefficient (r) of 0.857 between the two variables. Thus far, insufficient data has been compiled to permit the use of the Laird-Gompertz growth model (Zweifel and Lasker, 1976). It is hoped that in the future, the data can be used in such a model as it incorporates vital parameters such as temperature.

Larval herring growth based on length versus age for the composite data for western Gulf of Maine was estimated from the slope of the regression line as 0.34 mm/day. This growth rate is somewhat higher but comparable with other values reported in the literature. Ehrlich et al. (1976) reported lab-reared growth of Firth of Clyde herring larvae to be 0.22 mm/day during 91 days from hatching. Sameoto's (1972) larval herring growth values were approximately the same (~0.2 mm/day) during the first 2½ months of growth in the fall in St. Margaret's Bay, N.S.. Boyar et al. (1973) estimated larval herring growth in the Georges Bank-Gulf of Maine area from September through June to average 0.17 mm/day with a range of 0.14-0.25 mm/day. Lough's (1976) winter growth estimates of Georges Bank herring larvae ranged from about 0.15-0.20 mm/day. The overall larval growth curve based on length may be divided into two phases, an initial exponential growth phase during the fall followed by a logarithmic growth phase during the winter when food organisms may be sparse. Future studies of the kind reported in this paper should provide a more definitive growth curve to examine the effect of the environment on larval survival and subsequent recruitment.

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Table 1. Schedule of cruises and areas where special hauls were made for larval herring used in otolith analysis.

Country	Vessel	Date	Area
USA	Annandale	1-18 Oct. 1976	Gulf of Maine
Poland	Wieczno	13 Oct.-4 Nov. 1976	Georges Bank
FRG	Anton Dohrn	14-30 Nov. 1976	Georges Bank-Nantucket Shoals
USA	Researcher	26 Nov.-13 Dec. 1976	Georges Bank-Nantucket Shoals
USA	Mt. Mitchell	7-25 Feb. 1977	Georges Bank-Nantucket Shoals
FRG	Anton Dohrn	15-21 Mar. 1977	Nantucket Shoals

Table 2. Summary of statistics for otolith increments by 1 mm standard length (SL) class intervals. Summary represents composite data for herring larvae collected on all four stations along the western Gulf of Maine, 1-18 October 1976, Annandale.

Class Interval (SL, mm)	Number of observations	Average no. otolith increments	Standard deviation	Range
11	4	14.75	2.06	12-17
12	5	12.60	1.34	11-14
13	12	12.75	2.70	6-17
14	15	15.87	3.93	10-24
15	19	16.95	1.75	13-20
16	23	19.26	3.49	15-29
17	12	20.25	3.46	13-24
18	8	22.75	3.62	20-29
19	8	25.50	5.81	16-32
20	1	32.0	-	-
21	3	32.33	5.69	26-37
22	1	3.00	-	-
23	4	37.50	4.20	33-42
24	1	52.0	-	-
25	1	45.0	-	-

Table 3. Summary of statistics for individual station and composite regressions of standard length (SL) versus otolith growth increments on herring larvae collected along the western Gulf of Maine, 1-18 October 1976.

Station	Parameter	Number of observations	Mean	Standard deviation	Y = ax+b a	Y = ax+b b	Standard error	R	R^2	F-value
1	X (SL)	36	15.52	2.67	1.516	-4.209	3.487	.765	.585	47.84**
	Y (Increments)	36	19.47	5.33						
2	X	39	14.34	1.67	1.924	-11.608	2.512	.792	.628	62.40**
	Y	39	15.97	4.06						
3	X	7	17.53	2.48	2.589	-24.235	10.686	.550	.303	2.17 n.s.
	Y	7	21.14	11.68						
4	X	38	17.47	3.12	2.830	-26.468	4.255	.903	.815	159.03**
Composite regression										
1-4	X	120	15.87	2.84	2.217	-15.638	4.306	.827	.685	255.98**
	Y	120	19.54	7.60						

F* = .05 significance level.
F** = .01 significance level.
n.s. = not significant.

Table 4. Summary of statistics for individual station and composite regressions of head length (HL) versus otolith growth increments on herring larvae collected along the western Gulf of Maine, 1-18 October 1976.

Station	Parameter	Number of observations	Mean	Standard deviation	Y = ax+b a	Y = ax+b b	Standard error	R	R^2	F-value
1	X(HL)	30	2.06	.46	8.276	2.249	3.492	.739	.546	33.67**
	Y(Increments)	30	19.27	5.09						
2	X	38	1.81	.30	10.627	-3.088	2.578	.776	.602	54.53**
	Y	38	16.11	4.03						
3	X	7	1.92	.33	26.101	-28.972	8.571	.743	.551	6.15*
	Y	7	21.14	11.68						
4	X	38	2.00	.55	15.676	-8.346	4.567	.887	.787	133.26**
	Y	38	22.97	9.77						
Composite regression										
1-4	X	113	1.94	.45	13.494	-6.668	4.786	.785	.616	178.05**
	Y	113	19.57	7.69						

F* = .05 significance level.
F** = .01 significance level.

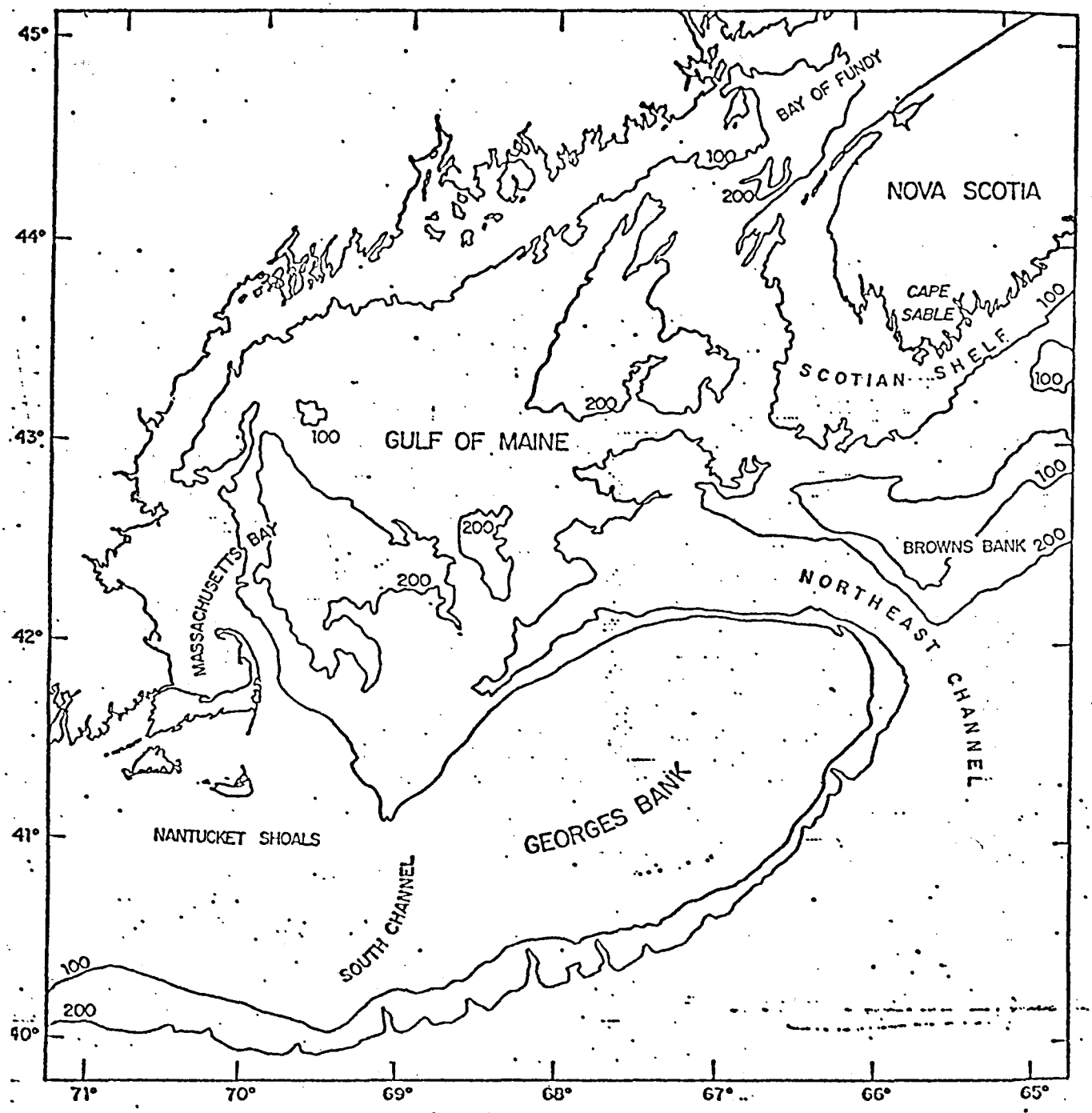


Fig. 1. The Gulf of Maine. (Depths are in meters).

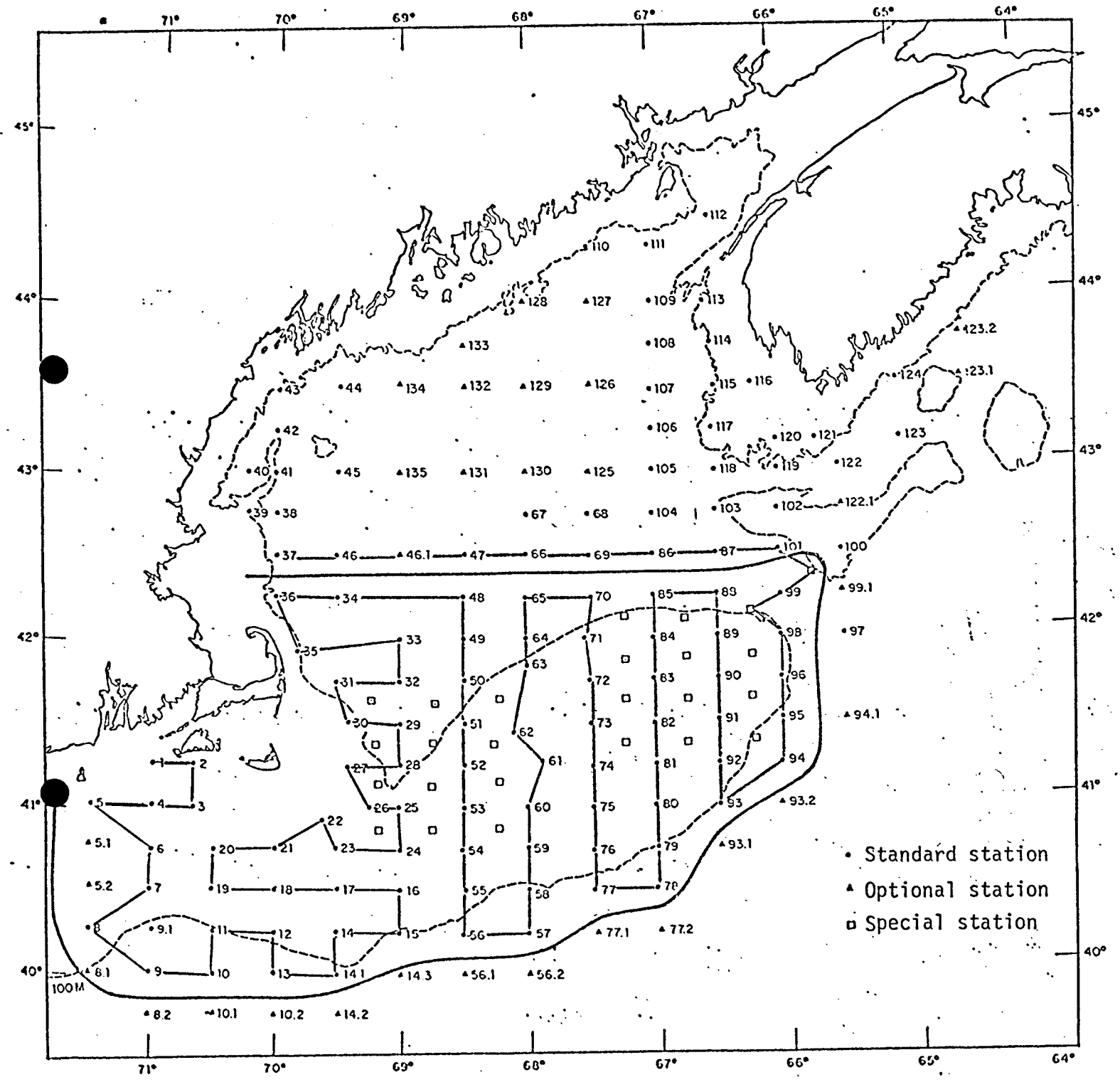


Fig. 2. ICNAF Larval Herring survey standard stations and cruise track.

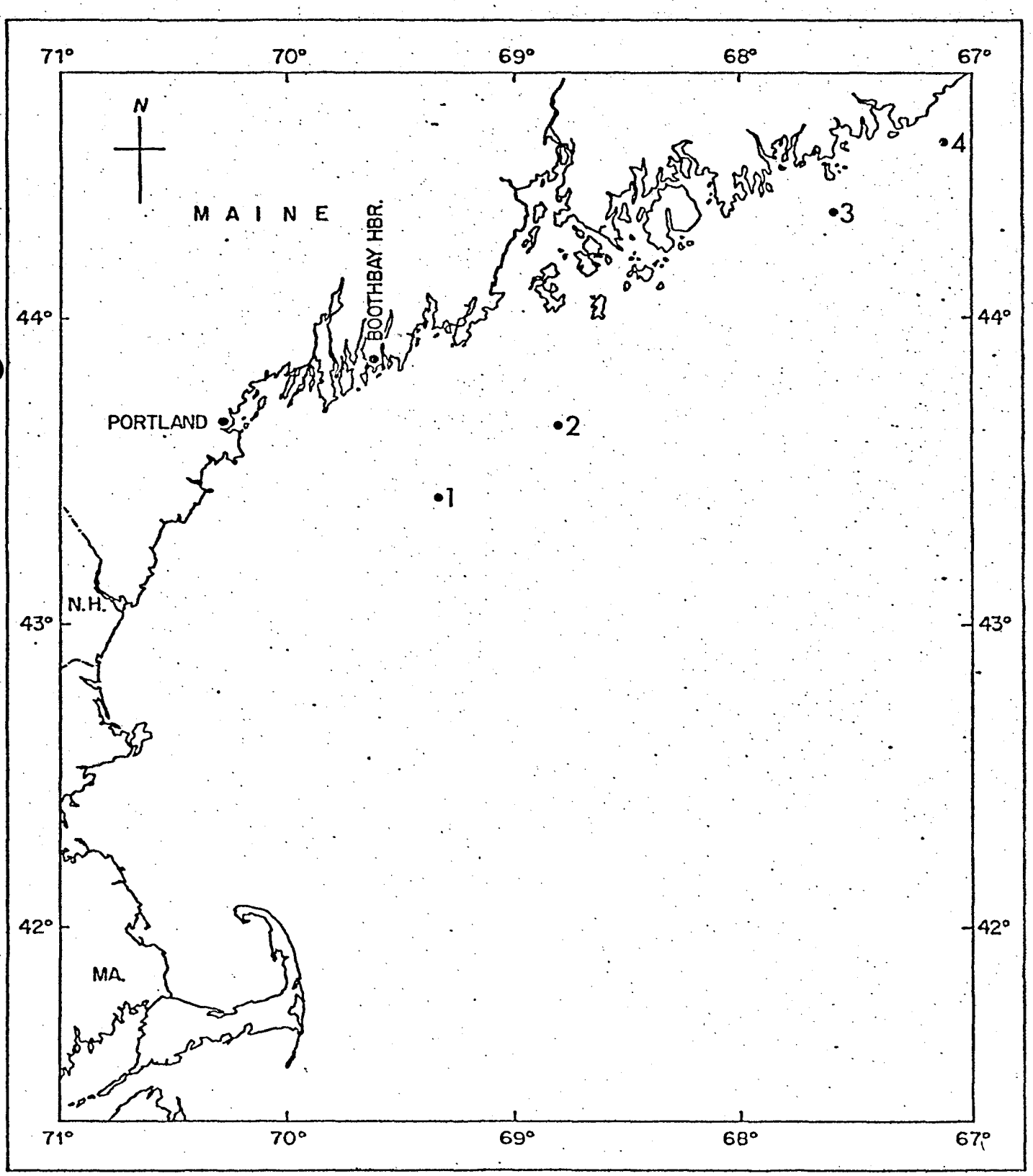
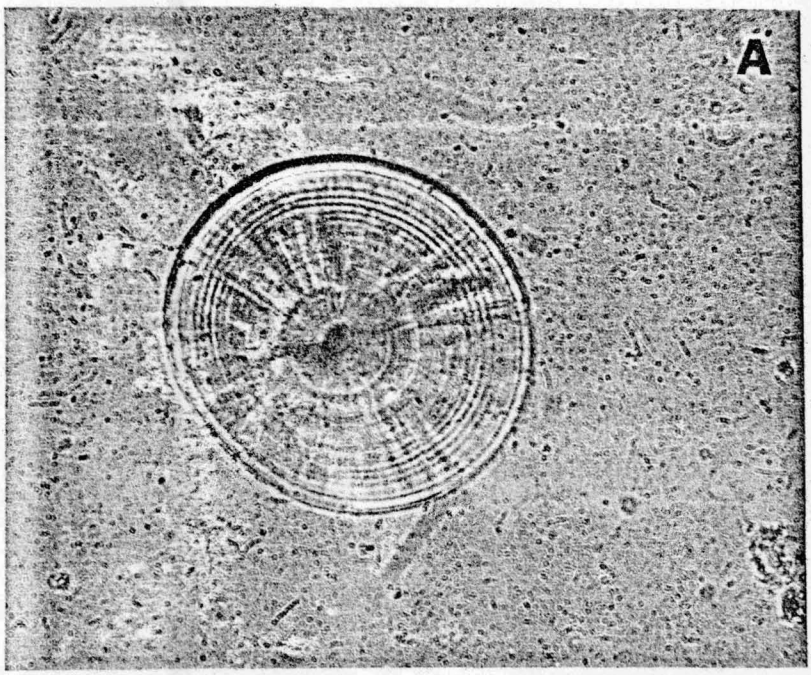


Fig. 3. Station locations along the western Gulf of Maine where herring larvae were collected for otolith analysis, 1-18 October 1976. Annandale.



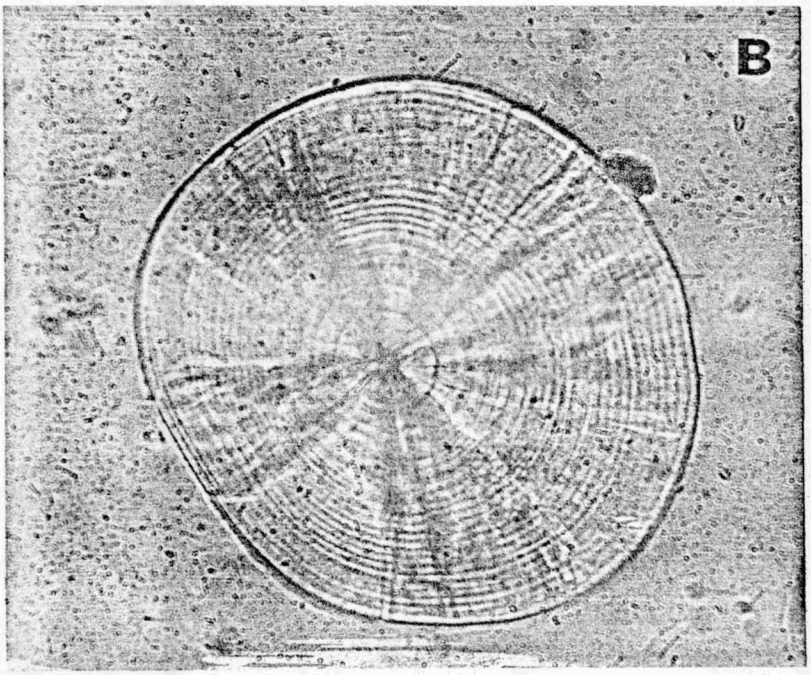


Fig. 4. Daily growth rings in larval herring otoliths collected from the western Gulf of Maine, October, 1976. A. 24 rings, larva standard length 18.26 mm, 400X. B. 31 rings, larva standard length 19.25 mm, 400X.

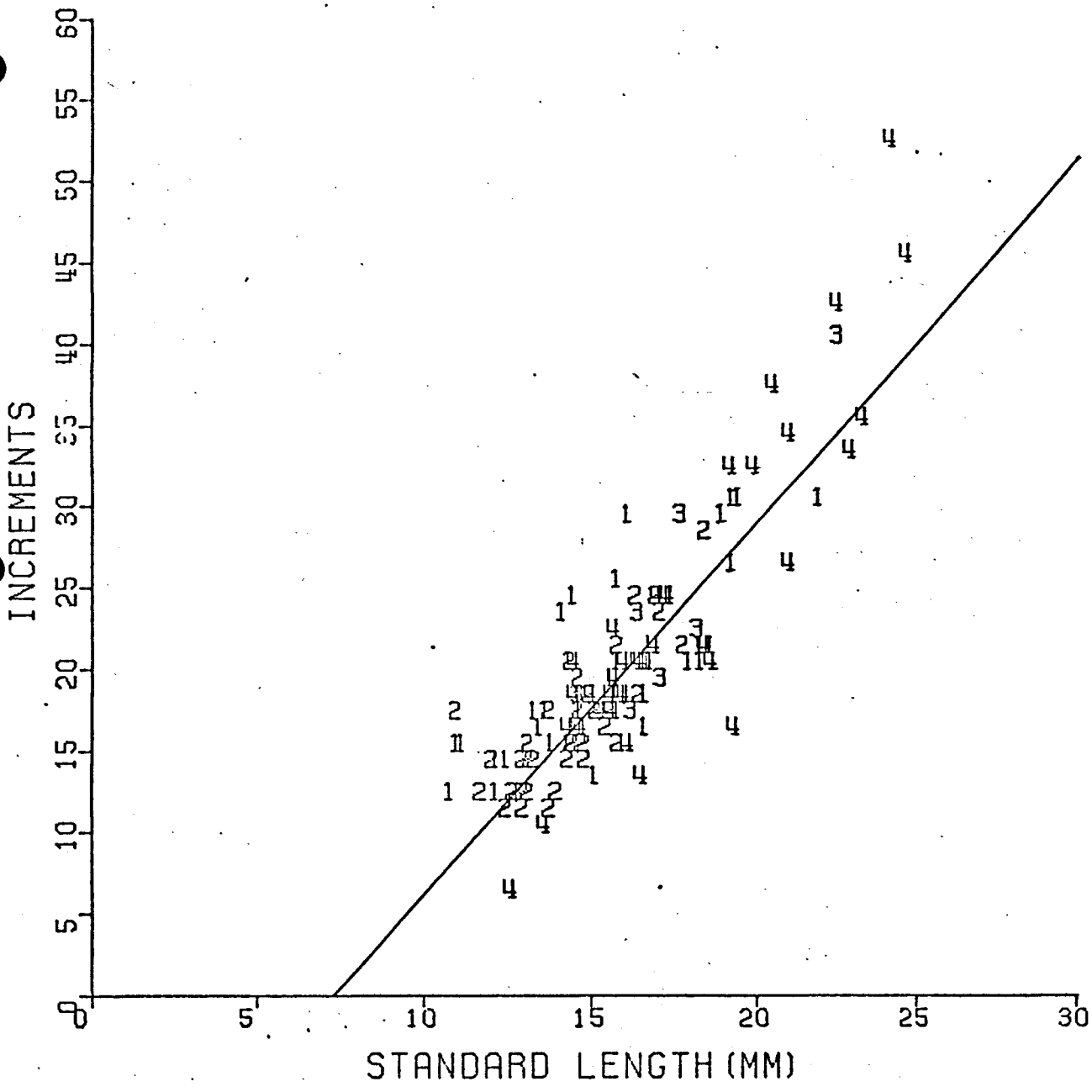


Figure 5. Daily growth increments versus standard length of herring larvae collected along the western Gulf of Maine, 1-18 October 1976. Observation values 1-4 represent individual station data (see Figure 3 for station locations).

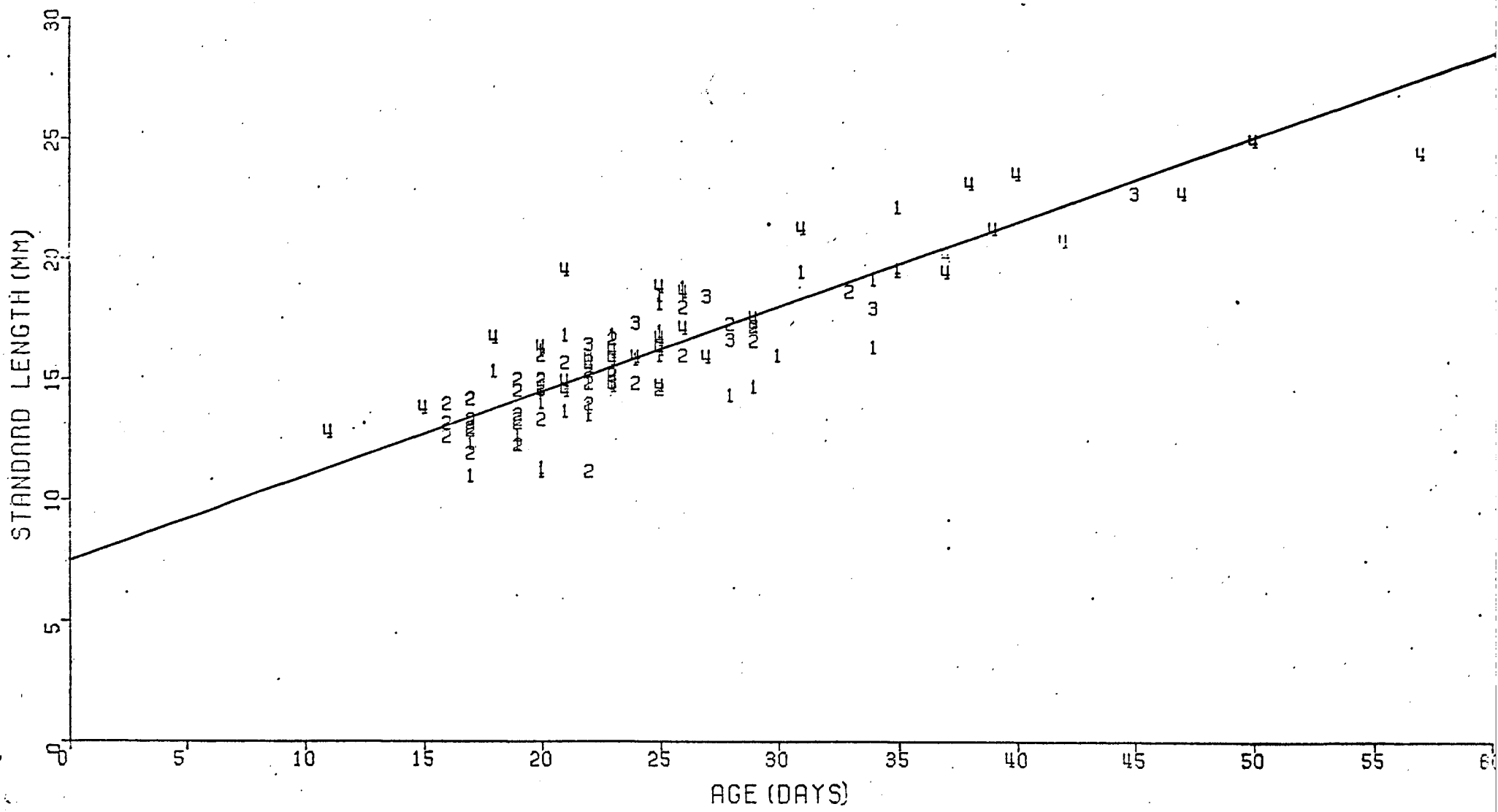


Figure 6. Standard length versus age of herring larvae collected along the western Gulf of Maine, 1-18 October 1974. Observation values 1-4 represent individual station data. See text for details.