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Factors Affecting the Depth Distribution of Larval Herring (*Clupea harengus* L.) in Coastal Maine Waters

by

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INTRODUCTION

The sardine fishery of coastal Maine harvests mainly two age groups (2 and 3 year old fish) of juvenile herring and thus landings are especially sensitive to fluctuations in recruitment. An unusually severe fluctuation occurred in the early 1960s, when in 1960 the sardine fishermen captured 113,000 MT (metric tons) and in 1961, only 23,000 MT. In an effort to anticipate such fluctuations for the fishing industry, larval herring were sampled along the coast to determine whether indices of larval abundance or their correlatives could be used to forecast sardine harvests.

Results of a series of coastal cruises (1961-66) suggested that the average catch rate of larvae during the spring was a potential index. But, the rocky coast caused sampling difficulties. To avoid the numerous submerged rock ledges, tows were located only within relatively deep water, perhaps causing a bias in the estimates of larval abundance. Graham et al. (1972a) found that the coastal circulation transported the larvae during their shoreward migration in the spring and that the circulation was controlled partially by bottom topography (Graham 1970a). Presumably, the preliminary coastal cruises sampled larvae from only a certain portion of the transporting circulation. To avoid a possible bias in the results of subsequent cruises, the coastal water was stratified for sampling into 10-min. squares of latitude and longitude, beginning in the spring of 1967. The squares were subdivided into quarters and sampling in one quarter was randomly selected within each square. The direction of tow was determined randomly for two tows and their catches averaged. Because the coastal bottom was very rugged, it was necessary to choose 20 m as a uniform maximum sampling depth.

The depth distribution of larval herring was studied during the spring of 1967 to determine the possible effects of this limitation upon the mean catch rates of the daylight cruises during the spring. This paper presents the results of the study and discusses the possible effects of the depth limitation on larval migration and the spring cruise data. It also suggests an explanation for the contradictory results often obtained from various studies of the depth distribution of larval herring.

METHODS

Sampling Design

An experiment was designed to permit sampling during the relatively few days when ship's time and personnel were available. The design was a 2^3 factorial analysis (Graham 1972a) which examined three factors that might affect larval depth distribution: 1) incident light, 2) tidal phase and 3) depth of sampling. Incident light was chosen for study

because light may influence larval depth distribution (Blaxter 1973). Tidal phase was chosen for study because it affects the vertical distribution and migration of larval herring in the Sheepscot River estuary (Graham 1972a). The levels selected for the factors were: dull and bright days, ebb and flood tidal phases, and shallow and deep tows, respectively.

The levels of the three factors were determined in the following manner. Incident light was measured with a deck cell of an irradiance meter having a Wratten No. 2 filter, which adjusted the response of the cell to match that of the human eye. Incident light on the bright day varied from 45,161-64,516 lux (4,200 ftc. to 6,000 ftc.) and on the two dull days from 13,978-20,430 lux (1,300 ftc. to 1,900 ftc.). The bright day was largely cloudless; the dull days were heavily overcast and sometimes accompanied by intermittent rain. The sampling period was from April 14 to May 3; 20 days. Secchi disc readings taken over this same period in previous years suggested a relatively small variation in light extinction with water depth. Depths recorded for the Secchi disc near mid and late April were: 7, 7-3/4 m (1962); 3, 4 m (1963) and 3, 5 m (1965). Tidal phase was judged by the direction of the surface current which paralleled the long axis of the bay. Sampling was delayed until the current was well developed to avoid any possible lingering flow of the opposite tidal phase near the bottom. A subsequent investigation of currents in the vicinity of the sampling station suggested that this was a reasonable procedure (Graham and Morgan 1974). Sampling tows from just below the surface to 20 m were considered shallow and those from 30-50 m, deep.

All tows were made at the same location: the mouth of the Sheepscot River estuary, Sheepscot Bay. Water depth was about 60 m. On April 14, a bright day, two shallow tows and two deep tows were made at 4 knots with a Boothbay Depressor trawl No. 4 during an ebb tide. These four tows were repeated on the subsequent flood tide. On April 24, four similar tows were made during a dull day on an ebb tide and during a flood tide on May 3, a dull day.

Each tow was a stepped oblique haul; deep tows had steps at 50, 40 and 30 m and shallow tows, at 20, 10 and 1.5 m below the surface. Previously calibrated, the amount of towing wire deployed indicated the depth reached by the trawl. Towing trials with Boothbay Depressor trawls indicated that they were stable underway (Graham and Vaughn 1966) and calibrations showed that the ratio of towing wire deployed to the depth of the trawl was 3.1:1. Upon completion of the deep tow, the trawl was winched to the surface at approximately 1 kn. Considering the large size of larval herring in the spring and their ability to avoid the trawl (Graham et al. 1972), it is unlikely that the larvae would be captured in the upper water during this slow retrieval. There were no closing devices adaptable to the trawl at the time this study was done (1967). Each tow was timed to last 7-1/2 min. with 2 min. at each step. The short 7-1/2 min. tow was chosen because each series of 4 tows could be completed in one hour. A longer period might have allowed a group of larvae to be transported out of the sampling area by the tidal flow. A series of current measurements made later in the vicinity of the towing location determined that currents sometimes exceeded 50 cm/sec. (Graham and Morgan 1974). A group of larvae could therefore be transported approximately 1.8 km in an hour. All tows were made in the direction of the current flow. The trawl strained water efficiently (Graham 1972b) and when calibrated over a known distance during 7-1/2 min., strained 1343 m^3 through the 1.45 m^2 mouth opening and 3 mm mesh openings of the liner which was tied off at its end.

Mesh opening

The 3 mm mesh opening of the liner was larger than the standard mesh size (2 mm) used on spring cruises and larvae less than 37 mm S.L., with an average body depth of 3 mm, could be expected to pass through the liner. However, earlier studies suggested that larvae with a body depth less than a given mesh opening are retained by the trawl liners.

In one study a Gulf III (Gehringer and Aron 1968) and a Boothbay Depressor trawl No. 1 were towed at each of 21 stations along the Maine coast. The open mesh diameter of the Gulf III was .366 mm and that of the trawl was 4 mm. One gear was towed to a given station and the other away from it. Tows at 4 knots were timed for 30 min. with 10-min. steps at 20, 10 m and the surface. The Gulf III captured larvae of two modal lengths, one at 12 mm and the other at 18 mm. The trawl captured larvae only at the larger modal length (Fig. 1). The largest larva captured was 33 mm, which would have an average body depth of 2.5 mm. The capture of larvae of this size and smaller demonstrates that the trawl will retain larvae even though their body depths are less than the mesh opening of the trawl.

In another study, we compared larvae captured by a trawl liner with a 4 mm mesh opening to those captured by a trawl liner with a 2 mm mesh opening. Two boats, each with a trawl, towed simultaneously towards each other through a narrow channel (1/2 km) of the Sheepscot River estuary. The boats passed each other sampling undisturbed and disturbed water about equally. Tows lasted 10 min. and towing velocities were 206 cm/sec. (4 km) for the smaller BB#1 trawl with the 4 mm mesh and 232 cm/sec. (4.5 km) for the larger BB#2 trawl with a 2 mm mesh. Mouth openings of the trawls were 1 m^2 and 4.2 m^2, respectively. Effort (m^3) was determined from calibrated flow meters mounted on each trawl. Two larval samples were obtained from horizontal tows near the surface and two at mid-depth (10 m) for each trawl. The size range and average catch rates were similar (Fig. 1). The peak percentages occurred at 33 mm length for the 2 mm mesh opening and at 34 mm, for the 4 mm opening. Apparently, ~~that~~ the retention of larvae with less body depth than the liner mesh openings is caused by the peristaltic action of the trawl nets (Graham 1972b). During the depth experiments it was assumed that gear selectivity was constant during all tows and that changes in the size composition of the populations sampled were not so large as to invalidate the measures of larval abundance.

RESULTS

Catch and Larval Lengths

The 16 tows captured 1,028 larval herring with individual catches varying from 11 - 208 (Table 1). The larvae had an overall size mode of 33 mm and a range of 24 - 42 mm (Fig. 2). Larvae from the three different sampling dates exhibited different length frequency distributions; those obtained on April 14 had a size mode at 34 - 35 mm; on April 24 -33 mm and May 3 - 37 mm.

The sharp decline in the frequency of larvae 40 mm and larger on May 3 probably reflected larval avoidance of the gear and their unavailability. Comparison of night versus day trawl samples by Graham et al. (1972) suggested that larval avoidance began at 37 mm length and was appreciable at 40 mm length. They also found that this size larvae assumed a juvenile form and schooled in the shallow waters of coves and bays, usually about late April.

Statistical Analysis

The interaction of daylight and depth was significant at the 5% level of probability, accounting for approximately 36% of the total variability (Table 1). The catch rates of larvae were greater than average for deep tows on bright days and for shallow tows on dull days. Plots of the residual errors were examined to determine whether uncontrolled factors influenced the results. Trends were not evident in a frequency plot of the residuals, nor in their comparison with sampling order. The possible influence of larval lengths on the results in Table 1 was examined by a stepwise regression with mean larval length, light, tide, depth, all possible first order interactions, and the light-tide-depth interaction as the independent variables and the common logarithms of the larval catches as the dependent variable. Neither length nor any of the length interaction terms produced significant ($P = 0.05$) reductions in the residual sums of squares. Evidently, larval length had not confounded the experimental results.

DISCUSSION

Observations on the vertical distribution of larval herring are often contradictory. Seliverstov (1974) and Lough (1975) reviewed past literature regarding such disagreements. Their reviews revealed that when making night - day comparisons of larval catches as evidence of diurnal migration, some researchers reported large catches by night and others, large catches by day. Regarding larval size, relatively larger larvae were reported to be more abundant either near the surface or near the bottom during the day. In other instances, relatively larger larvae were more abundant near the surface at night.

Recent research further revealed the considerable variability exhibited by the vertical distribution of larval herring. Sjoblom and Parmanne (1978) found that larval herring of the Gulf of Finland were in relatively deep water by day and closer to the surface at night during early summer, but these positions were reversed later in the summer. They could not explain this reversal by either the amount of light present or the size of the larvae although vertical migration was more pronounced for relatively large larvae. The vertical distribution of the larvae was associated neither with water temperature, the vertical temperature gradient, wind velocity nor with the vertical distribution of zooplankton. Grainger (1980) observed that larval herring (7 - 12 mm in length) in Galway Bay, Ireland exhibited a daytime abundance at or near the surface and a decrease in abundance with depth. No significant variation in larval length occurred with water depth. Factors affecting light intensity in the water were not associated with the mean depth of the larvae. Dubravin et al. (1976) recorded the vertical distribution of larval herring in the North sea. They found that larvae 6 - 12 mm long were most abundant under the continuity layer. Larvae 13 - 21 mm long performed two vertical migrations daily returning to the discontinuity layer after sunset and after sunrise. Potter and Lough (1980) studied the vertical distribution of larvae on Nantucket Shoals, Northwest Atlantic, sampling the same body of larvae before and after a drift of 7 km over 10 days. On the first day of sampling, larvae were most abundant in the surface layer during both night and day. On the second day of sampling, larvae were distributed uniformly throughout the water column during both night and day. Larvae ranged in length from 5 - 30 mm and their average length increased gradually with depth. Lough (1975) suggested that perhaps generalizations concerning the vertical distribution of larval herring cannot be made for various water bodies because larval behavior differs with changes in environmental conditions. He also suggested that larval reactions to light may vary with developmental stage as indicated by the research of Siliverstov (1974).

A laboratory study by Wales (1975) suggests that larval herring reactions to light are very complex. His experiments showed that the response of blinded larvae to light could be divided into both phototaxis and extraretinally evoked kinesis. The response of sighted larvae could not be similarly separated. Assuming their response in the water colums may be either phototaxic, extraretinal or both, it will be difficult to determine cause - effect relations within larval data from field studies.

In many field studies of the vertical distribution of larval herring, scientists have collected larvae from what was assumed to be a single population and have simultaneously conducted extensive environmental monitoring. The relationships between larval behavior and the environmental factors have been examined by multiple regression techniques (Grainger 1980). Saila (1964) suggested that such exploratory data gathering be used for the preliminary screening of environmental variables, but that further studies should use factorial designs. It is likely that factorial experiments would be a productive technique for examining larval responses to environmental factors. Field studies which monitor larval behavior and environmental factors without the assurance of sampling from wide ranges and diverse combinations of environmental conditions might expend considerable effort and not discern which factors and interactions affect larval behavior.

Although the results cannot be considered conclusive, the Sheepscot Bay experiment was an unusual larval herring study because the sampling design required relatively little effort and yet examined a wide range of some environmental factors and their interactions (Table 1). But, it did not indicate how larval herring would respond to intermediate light intensities in the bay. The response could be either continuous or discontinuous. A continuous response to changes in light intensity would suggest that a complex array of circumstances would be needed to move the larvae to those depths which would transport them shoreward each spring. A discontinuous threshold response at extreme conditions, however, would permit the larvae to adapt to the "best depths" during intermediate conditions. The nature of this behavioral response might be responsible for some of the apparent contradictions in the literature concerning the influence of light on the depth distribution of larval herring.

The results of the Sheepscot Bay experiment suggest that the estimates of larval abundance derived from the spring coastal cruise results were biased by the selection of 20 m as a maximum daytime sampling depth. The significant light/depth interaction indicates that shallow samples taken on a dull spring day would overestimate the true average density at a station and conversely, shallow samples taken on a bright day would underestimate the true average density. Despite this problem the same survey design was continued. It was assumed that natural variations in light intensity (Graham 1970b) during the course of a cruise would tend to mitigate any systematic effects on the mean larval catch rates. To extend the depth range of sampling would require that certain coastal areas be excluded from the cruise tracks because of their highly irregular bottom topography. The magnitude of systematic errors created by sampling from only selected portions of the circulation which transports the larvae was considered to be greater than that caused by sampling to only 20 m depth.

The results of the Sheepscot Bay experiment suggested that further investigation into the effects of light and larval migration on the vertical distribution of herring larvae in Sheepscot Bay was needed. Hydrographic and current studies were completed in the bay during the summer of 1973 and the current study was repeated in 1974 (Graham and Morgan 1974). Exploratory nighttime sets of buoyed and anchored nets were made at the center of the bay, daytime trawl tows were made at the sides of the bay, and experimental designs were formulated. Unfortunately, the low levels and increased variability of larval herring abundance beginning in the early 1970's (Graham 1980) prevented a successful completion of the project.

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LITERATURE CITED

Blaxter, J.H.S. 1973. Monitoring the vertical movements and light responses of herring and plaice larvae. J. Mar. Biol. Ass. U.K. 53: 635-647.

Dubravin, V.F., B.I. Dubravin and E.M. Karaoseva. 1976. Results of studies of horizontal and vertical distribution of larval herring from the North Sea. Atlant NIRO No. 63, In Ocean. Res. Atlant. Ocean, Kaliningrad USSR: 123-131.

Gehringer, J.W. and W. Aron. 1968. Field techniques. In D.J. Tranter (editor), Reviews on zooplankton methods, p. 87 - 104. UNESCO Managr. Oceanogr. Methodol. 2 (Part 1).

Graham, J.J. 1980. Production of larval herring, Clupea harengus along coastal Maine (1964-1978) and its relation to recruitment mechanisms of the sardine fishery. Northw. Atlant. Fish. Org. SCR Doc. 80/1/123: 28 p.

_____. 1972a. Retention of larval herring within the Sheepscot estuary of Maine. Fish. Bull., U.S. 70(2): 299-305.

_____. 1972b. Filtration efficiencies of Boothbay Depressor nets. Fish. Bull, U.S. 70: 518-520.

_____. 1970a. Coastal currents of the western Gulf of Maine. Int. Comm. Northw. Atlant. Res. Bull. 7: 19-31.

_____. 1970b. Temperature, salintiy and transparency observations, coastal Gulf of Maine, 1962 - 65. U.S. Fish. Wildl. Serv., Data Rep. 42: 43 p.

Graham, J.J. and D. Morgan. 1976. Preliminary study of residual currents in Sheepscot Bay. The Maine Biologist, 8(1): 9.

Graham, J.J. and G.B. Vaughn. 1966. A new depressor design. Limn. Oceanogr. 11: 130-135.

Graham, J.J., S.B. Chenoweth and C.W. Davis. 1972. Abundance, distribution, movements and lengths of larval herring along the western coast of the Gulf of Maine. Fish. Bull., U.S. 70: 307-321.

Grainger, R.J.R. 1980. The distribution and abundance of early herring (Clupea harengus L.) larvae in Galway Bay in relation to oceanographic conditions. Proc. R. Ir. Acad. Sect., B, 80(3): 60 p.

Lough, R. G. 1975. A preliminary report of the vertical distribution of herring larvae on Georges Bank. Int. Comm. Northw. Atlant. Res. Doc. 75/50: 9 p.

Potter, D.C. and R.G. Lough. 1980. Vertical distribution of herring larvae (Clupea harengus L.) on Nantucket Shoals. November 1977, collected by MOCNESS aboard Anton Dorn 77 - 30. Northw. Atlant. Fish. Org. SCR Doc. 80/1x/133: 35 p.

Saila, S.B. 1964. An elementary approach to studying interactions. In: Marshall, Nelson (ed.), Experimental Marine Ecology. Univ. Rhode Island Occasional Publ. 2: 95-101.

Seliverstov, A.S. 1974. Vertical migration of larvae of the Atlanto-Scandian herring (Clupea harengus L.). In: Blaxter, J.H.S. (ed.), The early life history of fish: 253-262. Heidelberg.

Sjoblom, V. and R. Parmanne. 1978. The vertical distribution of Baltic herring larvae (Clupea harengus L.) in the Gulf of Finland. Fin. Fish. Res. 2: 5-18.

Wales, W. 1975. Extraretinal control of vertical migration in fish larvae. Nature. Lond. 253: (5486) 2-43.

Table 1. Sampling design, number of larvae captured per tow and analysis of variance for three factors: (A) Daylight, (B) Tidal Phase and (C) Tow Depth. **Statistically significant; P.05 = 5.32, P.01 = 11.26.

		Shallow		Deep	
	Replicates	1	2	1	2
Dull Day	Ebb	208	197	49	11
	Flood	51	72	21	21
Bright Day	Ebb	13	51	109	51
	Flood	40	64	35	35

Analysis of Variance

Factor	Sums of Squares	Degrees of Freedom	Mean Square	F-ratio
(A) Daylight	.0151	1	.0151	.26
(B) Tidal Phase	.0908	1	.0908	1.53
(A) (B)	.0708	1	.0708	1.20
(C) Tow Depth	.0320	1	.3020	5.20
(A) (C)	.7245	1	.7245	12.24**
(B) (C)	.0050	1	.0050	.08
(A) (B) (C)	.3036	1	.3036	5.13
Within	.4733	8	.0592	
Total	1.9851			

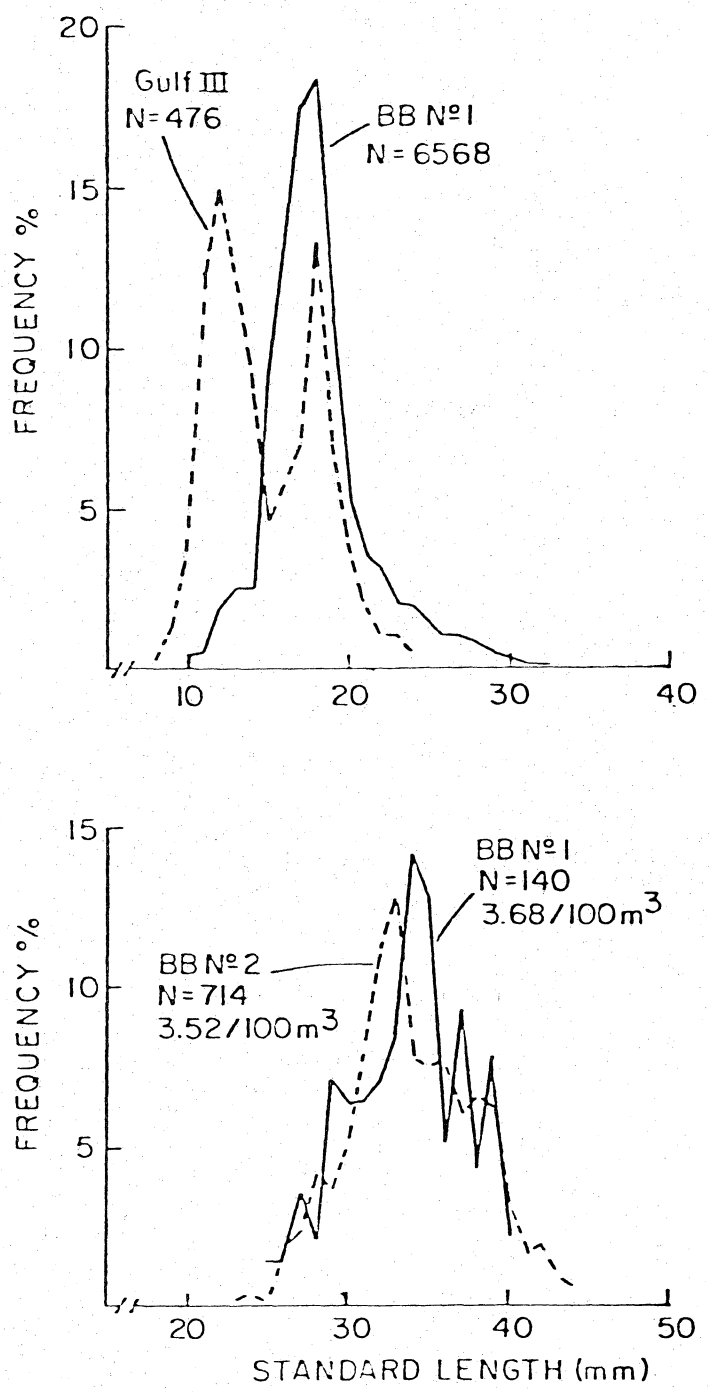

Figure 1. (Upper panel) Lengths of larval herring captured in a Gulf III sampler (Gehringer and Aron 1968) with a mesh size of .366 mm and a Boothbay Depressor trawl No. 1 with a mesh opening of 4 mm (Lower panel). Lengths of larval herring and average catch rate from 4 tows with Boothbay Depressor trawls Nos. 1 and 2, mesh openings 4 mm and 2 mm respectively.

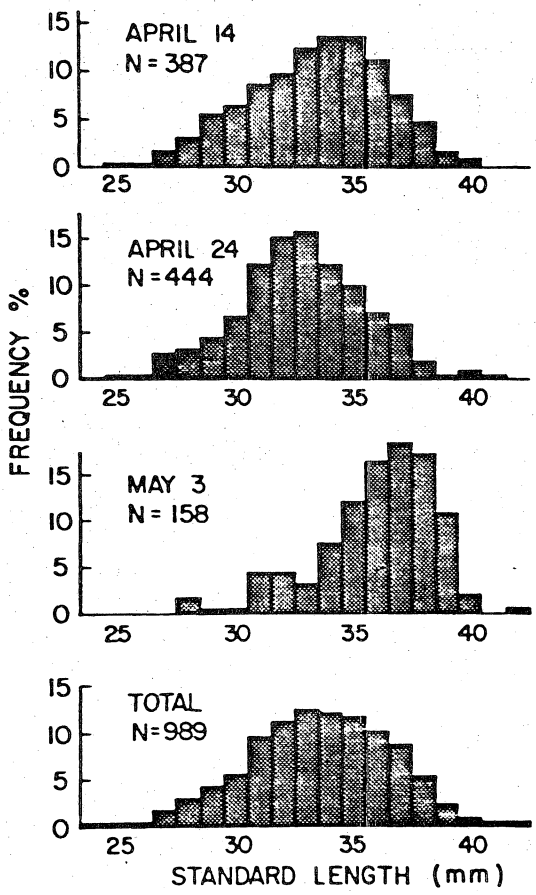

Figure 2. Length frequencies of larval herring captured with a Boothbay Depressor trawl No. 4 (3 mm mesh) on 3 different sampling dates during the spring of 1967 in Sheepscot Bay, Maine.