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Preliminary Evaluation of the 1980 Larval Year Class Strength of Coastal Maine Herring

by

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INTRODUCTION

Each year the Maine Department of Marine Resources evaluates the relative year class strength of larval herring in coastal waters. From these evaluations, forecasts of the recruitment of 2-year-old herring to the sardine fishery are made. These forecasts are used in the development of management plans for the fishery. This paper presents an evaluation of the relative strength of the 1980 larval year class and forecasts the recruitment to the 1982 fishery.

METHODS

Larval herring are collected from three sectors of the Maine coast: 1) eastern, 2) central and 3) western (Fig. 1). Three areas are utilized in collecting larvae in the central sector (Fig. 2): 1) estuarine during autumn and winter, 2) inshore during spring and 3) coastal during spring. Buoyed and anchored nets are used in the first area and Boothbay depressor trawls are towed in the inshore and coastal areas. Of three such planned sampling systems, two (eastern and central) are presently in full operation, the third (western) is sampled only during the spring (Fig. 2). Spring operations extend from 1966 to the present in the central sector, from 1974 in the eastern sector and from 1975 in the western sector. Autumn and winter operations extend from 1964 to the present in the Sheepscot River estuary of central Maine; but those in Sullivan Harbor of eastern Maine, from 1973-1974 and during 1980.

Sampling designs are described in detail by Graham (1980) and Graham *et al.* (1972). However, the basis for selecting the sampling design for Sullivan Harbor is not available in the literature and results of studies leading to the selection of the design are given in the Appendix. Table 1 summarizes sampling arrangements. Due to rough seas the coastal stations in the eastern and western sectors could not be completed in 1980.

To study relative changes in the well-being of larval herring we applied the following relationship:

$$R_i = (\bar{w}_i - \bar{\bar{w}}) / \sqrt{s^2/Ni}$$

where i is a given sample of larvae from an overnight set of buoyed and anchored nets during the autumn and winter. R_i is the standardized residual of sample i. $\bar{w}$ is the mean dry weight ($\log_{10}$). $\bar{\bar{w}}$ is the mean weight of several samples within the same length class. s^2 is the sum of the variances of all samples over all length classes. N_i is the number of larvae weighed and measured in sample i. The sum of the variances for all length classes was used rather than the sum for each class because Bartlett's test (Zar, 1974) indicated that the variances for the classes were homogeneous ($X^2 = 9.17$, $P_{.05} = 13.85$).

Samples from the buoyed and anchored nets during Oct. - Feb. were returned fresh to the laboratory where they were sorted. On the average 10 larvae from each net were frozen fresh for later age determination. The remaining larvae were preserved in 5% formalin for later measurement. The frozen samples were thawed and the larvae measured, otoliths extracted and read and the numbers of growth increments on one of the saggitta counted, as described by Townsend and Graham (1981). Thawed larvae were from 1 to 2 mm shorter in standard length than those preserved in 5% formalin.

It would not be appropriate to review in detail within this paper the years of data to which the evaluation of the 1980 year class must refer. For this information the reader should consult Graham (1980).

DISTRIBUTION

Summary of Larval Movements

Larval herring hatch in the coastal water just beyond the headlands and either move directly into adjacent estuaries and embayments or along the coast and then inshore at some distance from the area of hatching. Larvae hatch earlier in eastern Maine and, because the alongshore drift is from east to west, appreciable numbers of drifting larvae enter inshore waters as far westward as the Boothbay area. In the 1960's and early 1970's, the shoreward movement either slowed or ceased by early winter. In spring, larvae that did not complete the autumnal migration moved shoreward and by June all larvae were inshore and metamorphosed into small juveniles known as "brit". This pattern of larval movements changed in 1974 when larvae moved inshore in the winter as well as in the autumn. The winter movement was related to an intensification of late spawning, which occurred in 1974-1976, 1978-1980. The timing of larval movement returned briefly to its former pattern during 1977.

Autumn and Winter Sampling 1980

Eastern Maine - Larval catches from Sullivan Harbor in eastern Maine during the autumn and winter of 1980 differed strikingly from those recorded in 1974, the last time we sampled the harbor. In 1974, the largest autumnal movement inshore was well underway by mid-September and a second smaller movement occurred in late autumn (Fig. 3). No larvae were captured during September, 1980; the first catches were in October, about a month later than in 1974. Production in both October and November was very low. However, by December the catch for both years was approximately the same. The absence of larvae from the harbor in September prompted us to make a special cruise in coastal waters of eastern Maine to search for evidence of herring spawning.

Results from the special cruise in October, 1980 showed that herring spawned in eastern Maine. Contours of catch rates are shown in Figure 4 to indicate the abundance and distribution of the larvae. For comparison, contours from a cruise in 1972 are also included in Figure 4. Both cruises occurred approximately one month after hatching began; the latter was one of four cruises during the autumn of 1972 (Graham *et al.*, 1973). Although sampling techniques differed between cruises of 1980 and 1972, some agreement in relative larval abundance and distribution was apparent.

1) Recently hatched larvae (<10 mm S.L.) were clumped in the area off Machias Bay. 2) Few recently hatched larvae occurred west of Frenchman Bay. 3) Larger larvae (10-15 mm S.L.) were more abundant to the westward than those recently hatched. 4) And, the largest larvae (>15 mm S.L.) were relatively abundant in the catches west of Frenchman Bay.

Central Maine - Larval herring catch rates differed considerably from those taken in previous years. For the first time in 13 years there was not an autumn peak in abundance (Fig. 5). Catch rates increased gradually in the Sheepscot River estuary reaching a peak in early December. This peak was twice that of the autumn peak of 1978 (4.39/100 m^3 and slightly lower than that of 1979 (9.56/100 m^3). However, it was much lower than that of the 1977 peak (79.40/100 m^3) and below the average 24.10/100 m^3 obtained over the years since 1966. The low, reached in January, was followed by a truncated peak in February which reached 11.37/100 m^3 the last day of sampling. February peaks were recorded previously for the 1976, 1978 and 1979 year classes but at much lower values of catch rate. Although growth is indicated by the increased length of the February larvae over those of December, data from the section on larval age indicates that they are to a large extent composed of different cohorts of larval herring.

Spring Sampling

Catch rates from the central area of the coast during the spring of 1980 were the lowest recorded in the 16 years of sampling larval herring. Larvae were captured in only 5 of 28 tows at coastal stations for a catch rate of 0.03 per 100 m^3 (Table 2). Six of the 8 inshore stations yielded larvae but the catch rate was still low (.10). With the exception of 1976, spring catch rates have been very low from 1975 to the present.

LARVAL WEIGHTS

Summary of Larval Well Being

In the 1960's, studies of the length-weight relation of larval herring indicated that their seasonal condition in the Boothbay Region of central Maine was relatively good in autumn and spring, but low in winter (Chenoweth, 1970). Studies of the 1976-78 larval year classes were more detailed and suggested that when larvae were not abundant in the Sheepscot River estuary their weight was relatively high, but when they peaked in abundance they suffered a weight loss which paralleled a subsequent decline in catch rates. During 1977 when there were no peaks in catch rate during the winter, as in the 1960's, the relative larval weight fluctuated randomly. Possibly, the parallel decline in catch rate and weight was related to mortality associated with overcrowding which caused starvation and debilitation. The random distribution during the winter of 1977 perhaps indicated the vicissitudes of the environment.

Larval Weights of 1980 Sampling

Data from the estuary disagreed somewhat with the concept that variations in larval weight were a function of larval density. In October, a relatively high larval weight accompanied a low larval abundance, as expected (Fig. 6): When larvae increased in abundance, a drop in weight coincided with the broad plateau in catch rate that gradually developed by December. However, the drop in weight was small and it was followed by an increase in weight which occurred prior to the subsequent low in abundance during January. The unusual low in larval weight in February did coincide with a record high in larval abundance for that month, although the decline in weight preceded somewhat the initial rise in abundance.

Since 1978, there have been exceptions to the concept that departures from the average weight of larvae within the estuarine channel is largely a function of larval density. In the autumn of 1978, two cohorts of larvae may have declined almost to extinction. This coincided with a large relative decrease in larval weight despite an increase in overall abundance caused by the migration of a third cohort into the estuarine channel. In 1979, severe decreases in weight did not accompany the small autumn peak in abundance (Graham and Joule, 1980) and the usual low in weight did not occur at the end of February because there was an early increase in spring larval forage (Townsend, 1981). These departures and those in 1980 in December and January may stem from the new low level of larval density present along the coast since 1978.

LARVAL AGE

Summary

Assuming that rings of the larval otolith are laid down with daily periodicity, an age and growth study was undertaken of the 1978 larval year class in the Sheepscot River estuary (Townsend and Graham, 1981). Two cohorts of larvae were detected by aging. One hatched in early October and another in late November. Both were about 4 weeks old when entering the estuary and grew in total length at about 2 mm per week from October to early January and from late February to early March. In the intervening period the larvae grew little, if at all. Two additional cohorts were evident from their length frequency distributions in mid-October, but they apparently suffered considerable mortality and disappeared by late October when sampling of larvae for age determination began. One of the significant results of the study was that it identified a cohort hatched later than usual (late November) supporting the suggestion that late spawning has been intensified along the coast since 1974. Previously, such identifications were obtained by comparisons of larval lenghts.

Sampling Larval Otoliths 1980

Aging larvae of the 1980 year class revealed that initial ring formation in the otolith occurred throughout the period from August 18 to December 13 with 5 larval cohorts generated by the hatching pulses over this extended period. In Sullivan Harbor, (Fig. 1A) one cohort was evident in mid September from samples collected on October 8 and a second in early October from collections on October 21 (Fig. 7). A remnant of the first cohort was apparent on the latter date, but disappeared on November 19 and during December when only a trace of the second was present and some larvae apparently had an initial ring formation in mid October. In the Sheepscot estuarine channel of central Maine, 2 cohorts were apparent in the October samples, one in early September and another in mid September (Fig. 8). A suggestion of a third was indicated in early October. This third cohort was the largest during November sampling. A fourth cohort had an initial ring formation in early November according to December sampling and a fifth, in late November according to January sampling. With time, each cohort progressively diminished but sampling in January indicated that traces of all five cohorts were present and in February at least three remained. Most of the otoliths in February were unreadable and the cohort of larvae forming the peak catch on February 24 was not identified. However, the few otoliths read on that date suggest a spread in time over two or three of the cohorts that formed their first rings from early October to late November.

These data from eastern and central Maine are summarized in Figure 8 where the two cohorts of Sullivan Harbor and the five from the estuary are apparent. The presence of larvae which formed their first ring in August and early September both from the harbor and the estuary suggests that those in the estuary hatched along the east coast and drifted westward, since larvae usually do not hatch that early in central and western Maine. The striking similarity in frequency between the cohorts in early October from the two areas shown in Figure 8 is also evidence of this drift, which has been indicated by samples of larvae from surveys along the coast (Graham M.S.). Comparison of the November cohorts was not possible between the eastern and central areas. The numbers of larvae were few (Fig. 3) in Sullivan Harbor in December and sampling in the harbor during January was not feasible.

EVALUATION AND FORECAST

Summary of Forecasts

Forecasting of the recruitment of 2-year-old herring to the Maine sardine fishery since 1973 is based on reference fisheries. In 1971, a qualitative forecast of recruitment failed. This forecast was based on larval indices of winter mortality and spring abundance. In 1973 the basis was broadened to include all possible distinguishing characteristics of larval distribution and ecology. These characteristics of a given year class were compared with those of previous classes. When matched, the harvest of the one or more previous year classes was used as a forecast. Because the characteristics of a given year class often involved one or more new aspects it was not always possible to provide a range of forecasts. Beginning with the 1975 larval year class, the forecasts also served as a test of a conceptual model of the production of larval herring just prior to their spring metamorphosis into the juvenile form (Graham, 1980). The model was based on two assumptions. 1) The basic determinants of larval year class strength are the level of larval abundance following a density dependent phase of mortality in autumn and a density independent phase of mortality during winter. And, 2) these basic determinants may be modified by late spawning and the nature of the distribution of larvae along the coast after hatching in the autumn. The successes and failures of forecasting 1973-1979 are summarized in Table 3.

Larval Year Class Characteristics 1980

No autumn peak in abundance - Assuming that the level of abundance at the beginning of winter is a basic determinant of year class strength, the absence of an autumn peak should not appreciably reduce the standing crop of spring larvae. In Sullivan Harbor the catch level was about the same by early December for both the 1980 and 1974 year classes despite the absence of an autumn peak (Fig. 3).

December peak in abundance - December catch rates contained three cohorts of larvae indicating initial ring formation in 1) early October, 2) early November and 3) late November. Allowing 5 days for yolk sac absorption at 10°C (Baxter and Hempel, 1966) their average hatching date was 1 October, 3 November and 23 November respectively. The latter two days would be considered late by comparison with data collected in the 1960's and early 1970's (Graham, 1980; M.S.). Late hatching reduces the period of winter mortality, according to the assumptions of the model, and thus increases the spring larval abundance.

February peak in abundance - Unfortunately, the age composition of larvae from February samples could not be ascertained. However, the available information suggests that the peak in abundance did not contain a new cohort of later spawned larvae. Under this circumstance the peak might represent an early reaggregation of larvae following their winter dispersal in January and the usual movement shoreward again in the spring including those few that overwintered in the coastal water beyond the headland.

Record low relative weight in February - If the truncated February peak in larval abundance resulted from an early spring aggregation and movement it is unlikely that its subsequent decline would be related to mortality caused by starvation and debilitation as in the autumn and winter . Presumably, the advent of spring would produce an improvement in their condition as forage became more plentiful. The decline in catch rate, if we continued sampling into the spring, would have stemmed from their unavailability to our gear as they approached their juvenile form.

Record low spring catch rate - If an early spring aggregation and movement did occur, then the timing of our spring cruise (Table 2) might have been too late. Many of the larvae perhaps had already approached metamorphosis and were unavailable to the gear.

Forecast of the 1982 Fishery

The characteristics of the 1980 larval year class were comparable to only two previous year classes, 1974 and 1976. The 1974 year class had a December peak in abundance and produced a harvest of 13,200 metric tons (MT). However, the general level of larval abundance in 1974 was higher than in 1980 and the peak itself substantially larger (18 larvae /100 m^3 in 1974, 8/100 m^3 in 1980 respectively). The 1976 year class had both a December and February peak and yielded a harvest of 12,500 MT. But, there were two differences between the 1980 and 1976 year classes. 1) The general level of larval abundance was higher for the 1976 year class, and 2) the February peak declined to a low by the end of February. However, the effect of this peak would be to reduce the period of winter mortality despite its different origin within the 1976 and 1980 year classes. Therefore, we have chosen the harvest of the 1976 year class as a reference fishery and suggest that the harvest of 2-year-old herring in the 1982 sardine fishery will be close to 12,500 MT. If the 1980 truncated peak in larvae abundance was composed of a cohort not identified by the otolith study (Fig. 8), then the harvest may exceed 12,500 MT. Some of the otoliths from February sampling will be examined again. Possibly, some otoliths showing faint rings may be read with recently available equipment. Also, the results of the spotter plane observations on young juvenile (brit) herring of the 1980 year class will be compared to our larval results to gain more information on year class strength. Depending on the outcome of these observations the forecast may be revised in the near future.

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Table 1. Methods of sampling larval herring along coastal Maine during 1980-1981. Two tows were taken at each coastal station, their location (and direction) within a quartile of each 10' square of latitude and longitude shown in Figure 2 was determined randomly. All tows were stepped oblique with equal effort at each step. All sets of buoyed and anchored nets were overnight.

Abbreviations: (A-B) buoyed and anchored nets, (BB No. 5) Boothbay Depressor trawl No. 5, (A) autumn, (W) winter, (S) spring, (M) middepth, and (B) bottom.

Coastal Sector	Sector Area	Sampling Season	Gear Type	No.	Samples Depth m.	Duration	Water Strained m^3	Collection Velocity cm/sec.
Eastern	Sullivan Hbr.	A-W	B-A	20	0-10-12 15-B	12 hrs.+	15,076 ($\bar{x}$)	101 max.
	Inshore	S	BB No.5	7	0-M-B	30 mins.	5,371	206
Central	Sheepscot Estuary	A-W	B-A	24	0-10-15-B	12 hrs.+	25,984 ($\bar{x}$)	98 max.
	Inshore	S	BB No.5	8	0-M-B	30 mins.	5,371	206
	Coastal	S	BB No.5	30	0-10-20	7½ mins.	1,343	206
Western	Inshore	S	BB No.5	6	0-M-B	30 mins.	5,371	206

Table 2. Spring larval catch rates, indices of larval abundance for coastal and inshore areas and estimates of relative abundance (combined). Catch rates have not been adjusted for length of tow as in Graham (1980).

Year Class	Sampling Period	Number of Larvae Coastal	Inshore	Combined	Catch per 100 m^3 Coastal	Inshore	Combined
(I) Central sampling system							
1965	9-22 Mar. 1966	603	68	671	0.63	0.20	0.83
1966	28 Mar.-6 Apr. 1967	284	136	420	0.49	0.60	1.09
1967	3-12 Apr. 1968	120	193	313	0.22	0.68	0.90
1968	15-22 Apr. 1969	160	208	368	0.31	0.73	1.04
1969	7-13 Apr. 1970	94	77	171	0.20	0.43	.63
1970	30 Mar.-12 Apr. 1971	90	258	348	0.20	0.85	1.10
1971	30 Mar.-12 Apr. 1972	33	482	515	0.04	1.16	1.20
1972	16-22 Apr. 1973	328	130	458	0.84	0.30	1.14
1973	11-26 Apr. 1974	120	171	291	0.32	0.40	0.72
1974	10-16 Apr. 1975	17	362	379	0.04	0.84	0.88
1975	7-13 Apr. 1976	77	110	187	0.20	0.25	0.45
1976	11-19 Apr. 1977	107	1169	1176	0.28	2.72	3.00
1977	29 Mar.-10 Apr. 1978	33	159	192	0.08	0.37	0.45
1978	11-16 Apr. 1979	14	44	58	0.08	0.29	0.37
1979	31 Mar.-7 Apr. 1980	28	169	197	0.07	0.39	0.46
1980	10-16 Apr. 1981	12	55	67	0.03	0.10	0.13

Table 3. In recent years the Maine Department of Marine Resources (DMR) attempted to forecast the catch of 2-year-old herring in the sardine fishery of coastal Maine. This table indicates their successes and failures.

Fishery	Year Class	Reference Fishery	Forecast M.T.	Comment	Fishery Catch M.T.	Source
1975	1973	1969-1971	2,800-6,700	Closer to 2,800.	8,400	Special Report DMR Project 1086
1976	1974	1969	6,700	Forecast should be minimal, should exceed 1975.	13,2,00	Special Report DMR Project 1086
1977	1975	1976	13,200	Should approach 1976. "Stocks may be attempting comeback."	10,600	Special Report DMR Project 1355
1978	1976	1973	>8,100	Will be exceeded.	13,500	Maine Commercial Fisheries August 1977
1980	1978	1973-1977	8,400-10,600	Some additional strength possible.	9,000	DMR Res. Ref. Doc. 79/19
1981	1979	1978	>9,000	Above that of 1980.	>9,000[1]	DMR Res. Ref. Doc.
1982	1980	1976	12,500[1]	Some additional strength possible.		This Manuscript

[1]Preliminary estimate

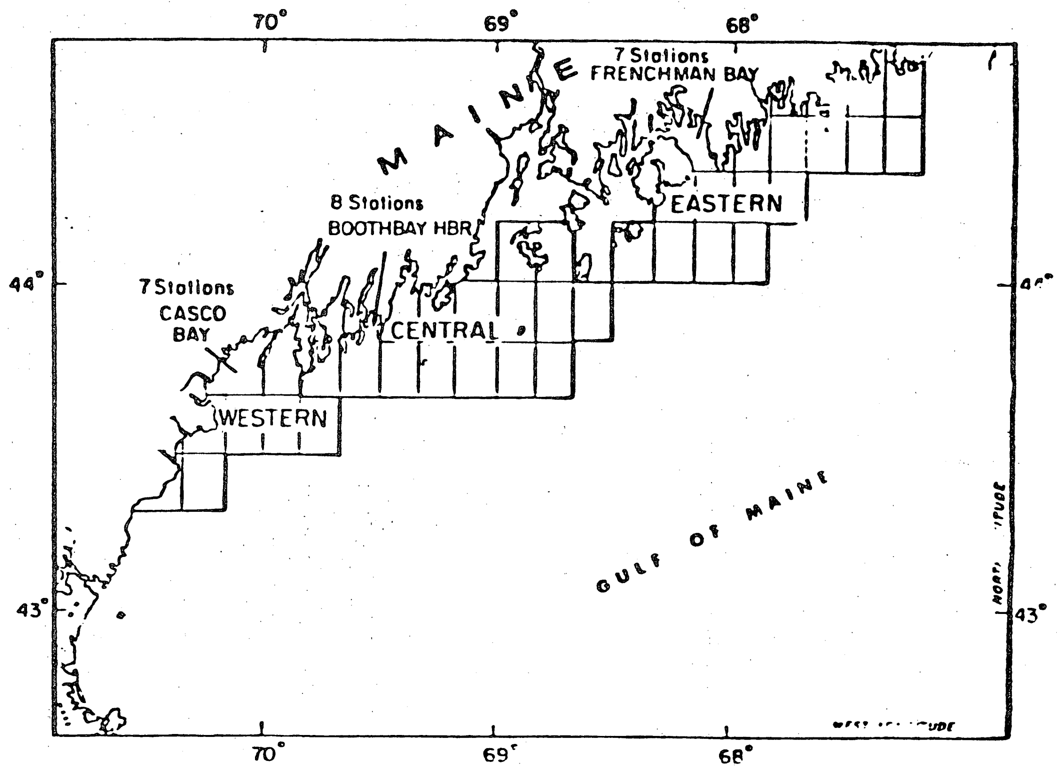

Fig. 1. Station positions for sampling larval herring along coastal Maine during the autumn, 1972.

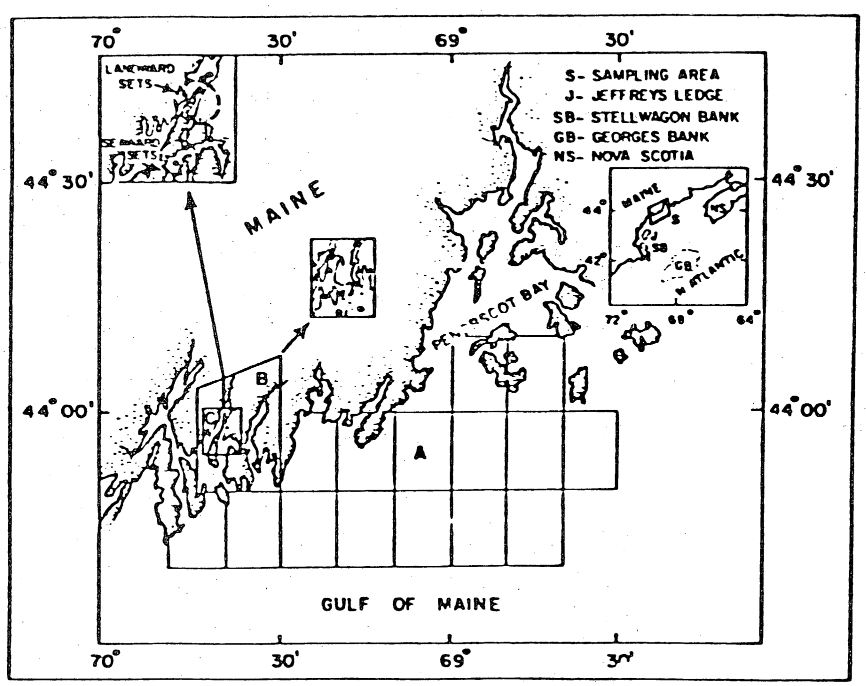

Fig. 2. Location of monitoring stations, 1964-1978. A - coastal along shore with towed gear in spring. B - inshore (Boothbay area), with towed gear in spring. C - estuarine (Sheepscot River), with buoyed and anchored nets in autumn and winter.

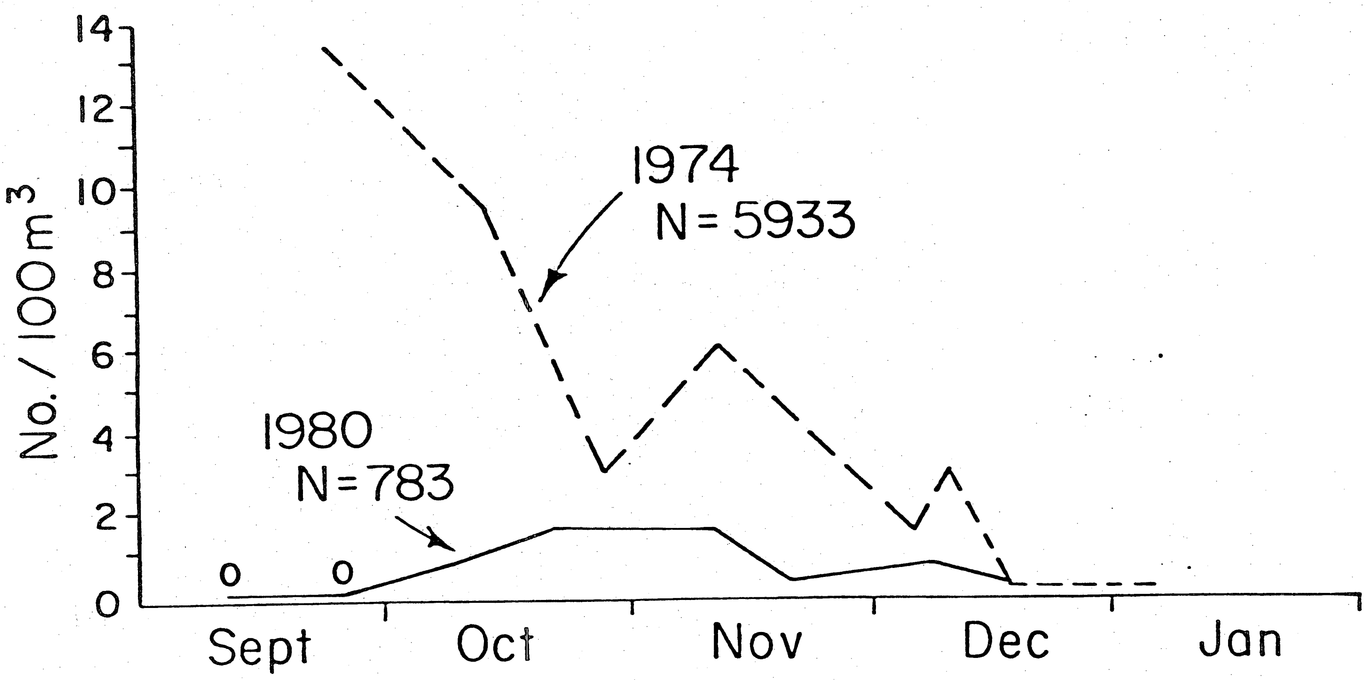

Fig. 3. Catch rates of larval herring from Sullivan Harbor of eastern Maine in 1974 and 1980.

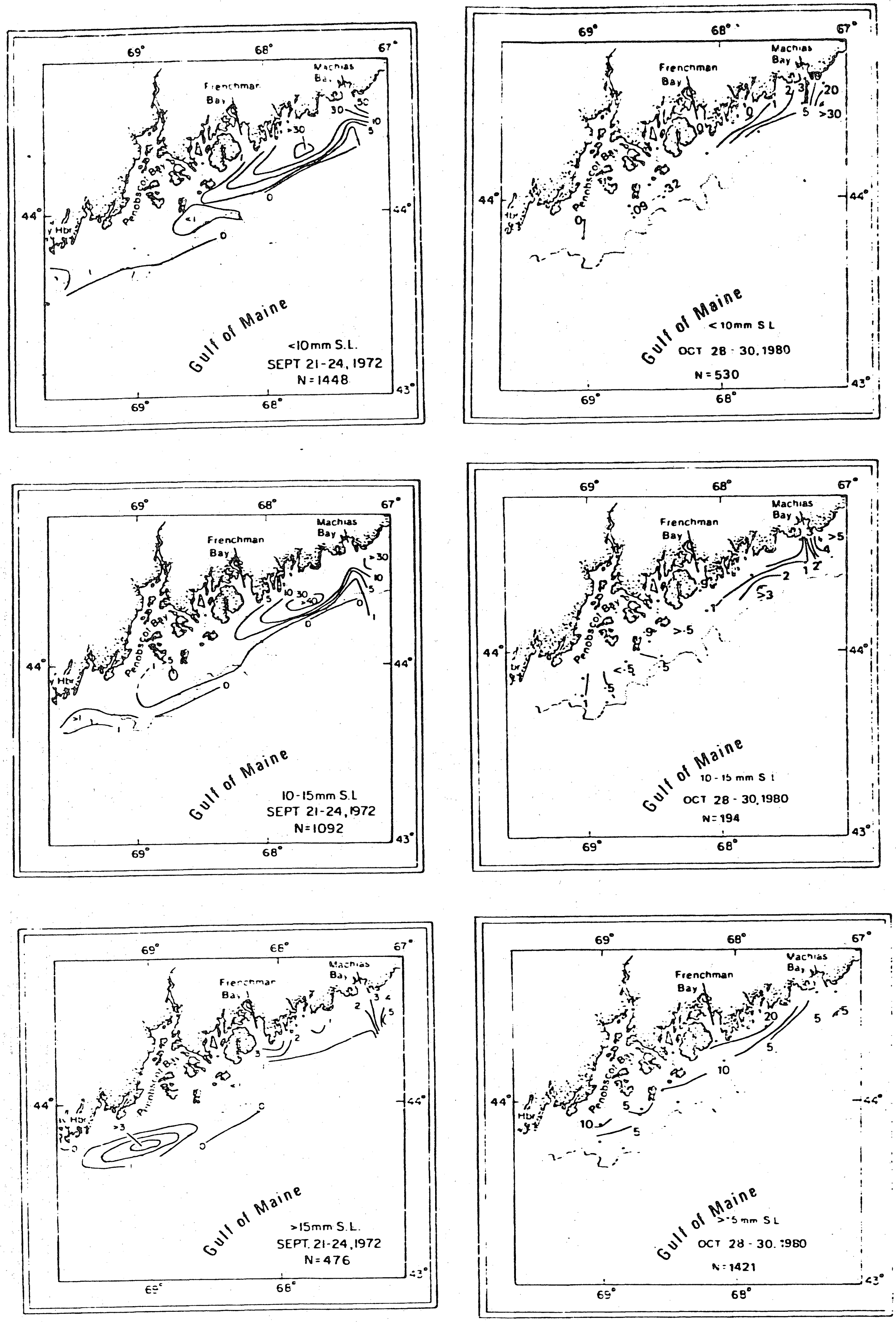

Fig. 4. Comparison of contours of larval catch rates in 1972 (No. under m^2 sea surface) and 1980 (No. per 100 m^3).

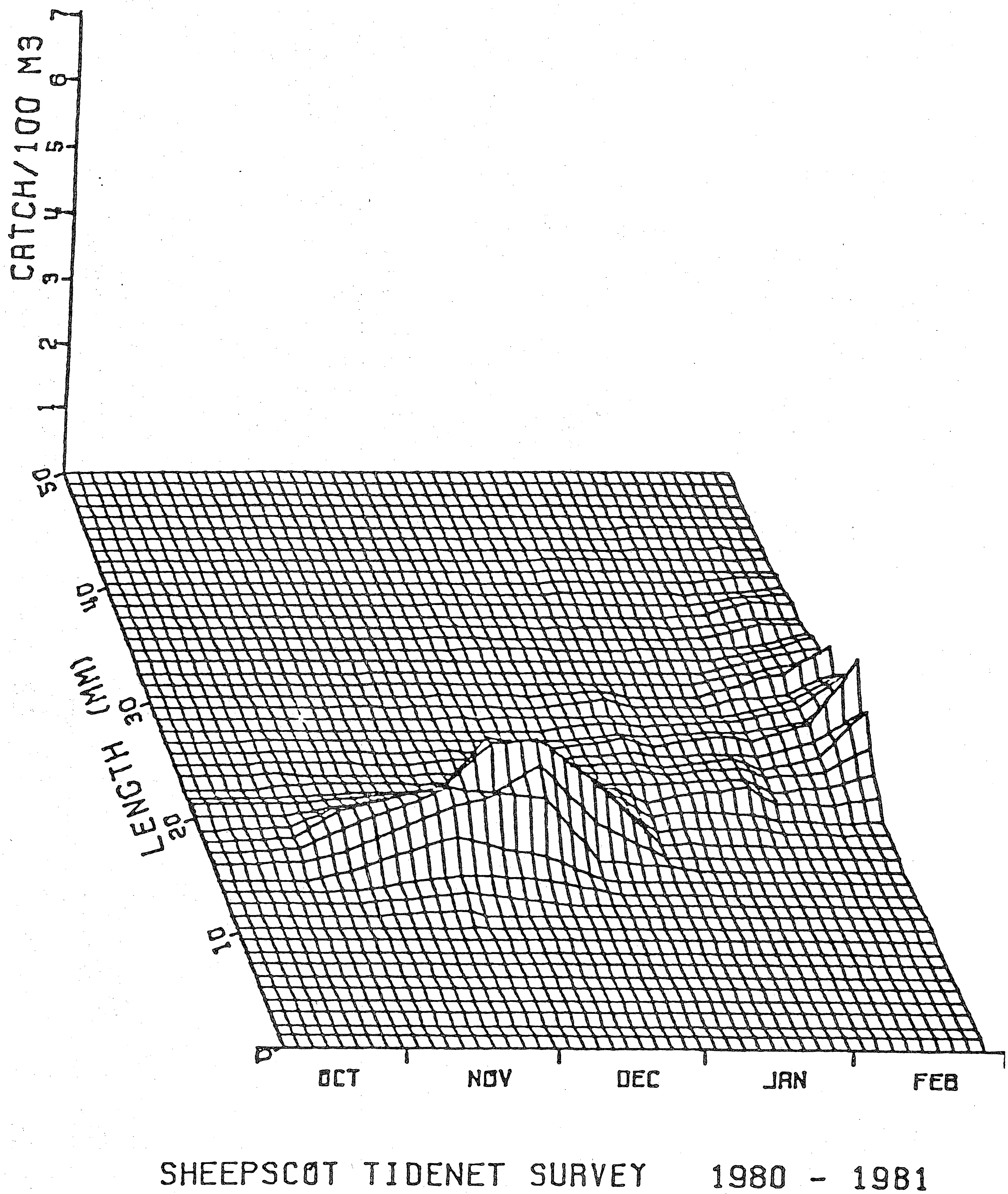

Fig. 5. Numbers of larvae per 100 m^3 at intervals of 1 mm larval length (S.L.) captured in the Sheepscot River estuary of Maine.

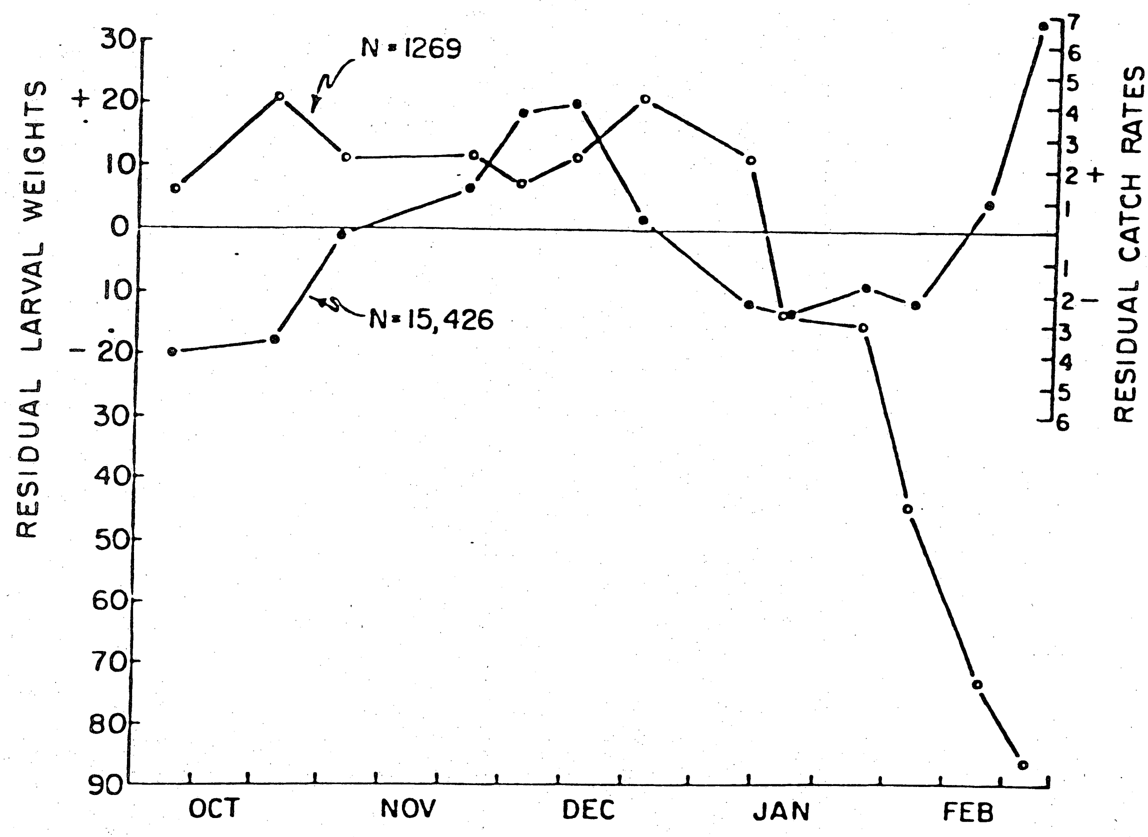

Fig. 6. Departures of larval weights and catch rates during 1980-81.

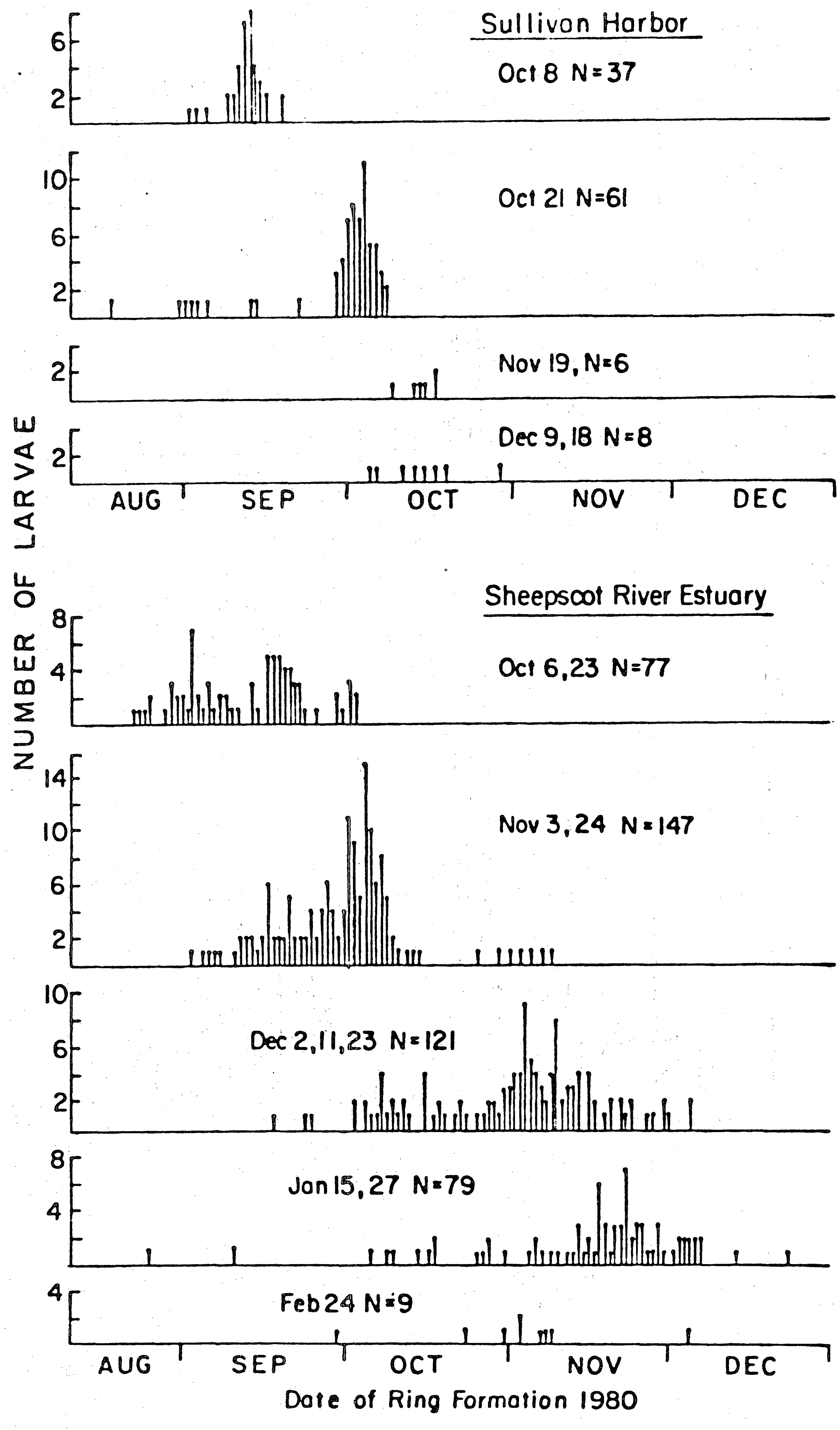

Fig. 7. Dates of initial ring formation in the otoliths of larval herring from eastern (top) and central (bottom) Maine during sampling in the autumn and winter of 1980-81.

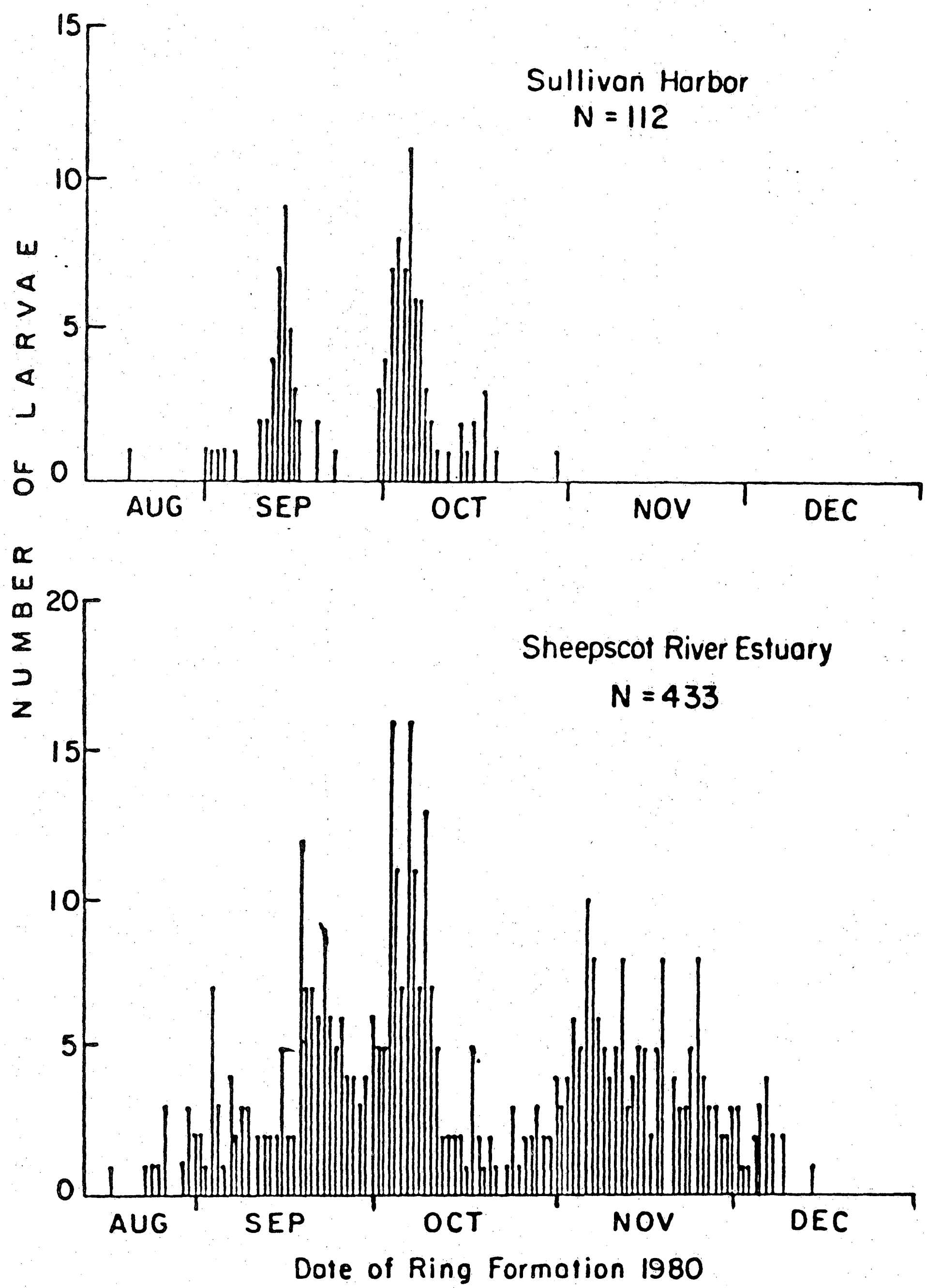

Fig. 8. Summary of Data from Figure 7.

APPENDIX

SULLIVAN HARBOR

Exploratory Sampling

During 1969, excellent catches of one year old herring in eastern Maine prompted an exploration for larval herring in the inshore waters of the area. We towed Boothbay Depressor trawls in the locations shown in Figure 1A. Larvae were present in all of the locations sampled and catch rates were comparable to those obtained in the Boothbay area (Graham *et al.*, 1972). A single overnight sampling of tidal nets was made in Sullivan Harbor on 17 December. The four strings of nets captured 26 larvae for a catch rate of .87/100 m^3 which was similar to that made with a trawl (.89/100 m^3) one day later. Experimental sets of tidal nets in the harbor during 22 Oct., 1970 captured larvae in Sullivan Harbor but sets made on 8 December and 6 January did not. The absence of the larvae was attributed in part to a poor sampling design. We decided to sample the harbor intensely rather than the other areas which were either too difficult to navigate, too exposed for tidal net operations, or too deep with complex circulations.

Sampling Area

Sullivan Harbor is an embayment within the eastern coast of Maine (Fig. 1A). A constriction formed by an island, a point of land and rock ledges divides the harbor approximately into northern and southern halves. The southern half opens into Frenchman Bay, which in turn opens into the Gulf of Maine. The northern half or harbor constricts into a tidal falls eventually bifurcating into broad extensive shallows. Only small streams enter these shallows, about 5 km north of a highway bridge and Sullivan Harbor is relatively salty (31/32°/oo).

A subtidal channel traverses the northern harbor. Between the constricting ledges the bottom is scoured to 20 m and gradually shallows northward to 12 m. Throughout most of its length the channel is moderately uniform in width and smooth subtidal mud flats intrude on the channel with gentle monotonous slopes. The subtidal channel broadens in the southern harbor, which is divided longitudinally by an island and ledges. A narrow channel connects the two halves which deepen as they open onto the bay.

Current Measurements

Tidal currents were recorded with an Ekman-Merz current meter during the summer of 1975 at the three stations shown in Figure 1A. The current velocities and directions for each of these stations are shown in Figure 2A. For each depth, a rosette of vectors are drawn representing the velocity and direction of currents at approximately hourly intervals over a semidiurnal tidal cycle. Each vector is numbered in hours according to the stage of tide at the town of Sullivan located near the head of the harbor. For example, a dotted line bearing the number 2 indicates this current existed two hours after high water at the town of Sullivan; a solid line, two hours after low water.

The subtidal channel and flats are important features of the harbor controlling the flow of tidal waters. At station 1 in the southern harbor, most of the flow is directed southerly near the surface. Its direction changes gradually with depth until near the bottom at 20 m the flow is largely northerly. Generally, water moves in alignment with the subtidal channel below 5 m while at the surface it spreads over the southern harbor. At station 2 in the northern harbor, water flows primarily in a southerly direction as it spreads over the flats. However, there is an anomalous flow during ebb tide (....3, Fig. 2A). This anomaly is related to the constriction between the northern and southern harbors. As water pours rapidly down the tidal falls (Fig. 1A) on the ebb tide, the channel directs its flow southeastward, filling first the eastern subtidal flat as its escapement is retarded by the constriction between the harbors. With the filling of the eastern flat, there is an abrupt flow to the northwest filling the western flat.

About an hour later a balance is achieved between the volumes of the two flats and the flow turns southerly. Below the edge of the subtidal channel the water is restricted in its movements with primarily a landward flow. At the entrance to the subtidal flat, station 3, there is a nozzle effect at the surface creating some very strong currents on the ebb tide. This effect is less pronounced on the flood tide near the bottom, presumably because of the abrupt shallowing at the entrance to the flat.

The currents of the harbor with its constrictions and tidal falls are relatively complex and the three current meter stations are not adequate to provide a complete description of the circulation. However, the results are sufficient to indicate a strong residual flow northward along the subtidal channel below its edge (Fig. 1A) that suggests an opportunity for larval retention within the harbor.

Intensified Sampling - In 1973-1974 we intensified our overnight sampling with buoyed and anchored tidal nets in Sullivan Harbor. On 23 October, 1973 we fished two lines of tidal nets along the subtidal channel of the northern harbor and two, in line, near the mouth of the southern harbor. Those in the southern harbor strained little water and the nets were relocated on November 12, one at the constriction between the harbors and the other at the end of the subtidal channel in the southern harbor (Fig. 1A). The nets captured 2,360 larvae during 7 overnight samplings between late October and late March (Fig. 3A). The catch was high in October, declined to a winter low in February and increased slightly in March. This progression was comparable to that of larvae from the Sheepscot River estuary in central Maine, except that the progression occurred earlier in the harbor because larvae hatch sooner in the coastal water of eastern Maine.

Length frequencies were plotted in Figure 3A for those overnight sets which captured a reasonable number of larvae. In one instance, catches from two overnight sets were combined 6-11 December; in another, 26 November, the tidal phases were fished separately. The results indicated that larger larvae were located below the edge of the subtidal channel. There appeared to be little difference in larval size between the two tidal phases.

During 1974, tidal nets were set within the northern harbor (Fig. 3A). Four nets were attached to each buoyed and anchored line placed at seaward (Stations 1 and 2) and landward (Stations 3 and 4) ends of the northern harbor. Two of the nets fished above the edge of the subtidal channel (0 and 3 m) and two below the edge (10 m and bottom). Two additional lines bearing two nets each were positioned laterally to the channel at the entrances to the eastern and western subtidal flats (Stations 5 and 6). One net fished at the surface and the other near the bottom (3-4 m). Seven overnight sets were made between 23 September 1974 and 5 January 1975.

The relative distribution of larval herring differed among sampling locations and depths and usually such differences were associated with larval lengths. On 23 September, the deeper nets captured more larvae per unit effort than the shallow nets at all locations. This difference involved larvae longer than 13 mm S.L. and was greatest at the seaward location. On 14 October, a new but small group of larvae entered the harbor, although the overall catch rate declined (Fig. 3A). At the landward end of the subtidal channel most of the larvae were still below the channel edge. This distribution was very evident through October, but the catch was reduced at the seaward location and almost extinguished over the flats. On 11 November, a new group of larvae entered the northern harbor raising the overall catch rate. A tendency to occupy the deeper water was evident only at the seaward end of the channel on 19 December. On 5 January, no larvae were captured over the flats and the numbers of larvae were drastically reduced at the two channel locations with a few larvae below the channel edge.

Catch rates of larval herring were higher in the Sheepscot River estuary than in Sullivan Harbor during the autumn and winter, 1974. As in 1973, the autumnal peak in abundance was later in the estuary, but a record high peak occurred in December. This second peak was of small larvae which hatched later, during November rather than September or October (Graham 1980). Perhaps the small rise in catch rate within the harbor on 10 December was also related to late spawning. During December, some recently hatched larvae (<10 mm S.L.) were present in the nets.

The distribution of larval herring within Sullivan Harbor suggests that at times the larvae are concentrated below the edge of the subtidal channel where they are likely to be retained by the landward residual tidal flow. Perhaps this opportunity for retention might also explain why larvae may disappear from the flats but not from the channel locations. Larvae may enter the harbor and circulate throughout the upper waters, eventually accumulating in the location of the subtidal channel. But, to follow the movements of the larvae in the harbor would require more sampling effort than utilized in the present (1974) sampling design. More overnight sets, an additional line of nets at the entrances to the subtidal flats and sampling of individual tidal phases would be needed. Nevertheless, it is likely that as in the Boothbay area of central Maine, larval herring move throughout the inshore waters as far shoreward as the tidal flows maintain a circulation conducive to their transport and retention. Their versatility regarding transport and retention is suggested by their presence in Somes Sound, a fjord, and Gouldsboro Bay, whose entrance is considerably barred by a series of submerged and exposed ledges of rock across its mouth. Presumably, the feature that may terminate the landward spread of larvae in the harbor, through destruction of the harbor circulation, is the same as that performing the same function in the Sheepscot River estuary, a tidal falls.

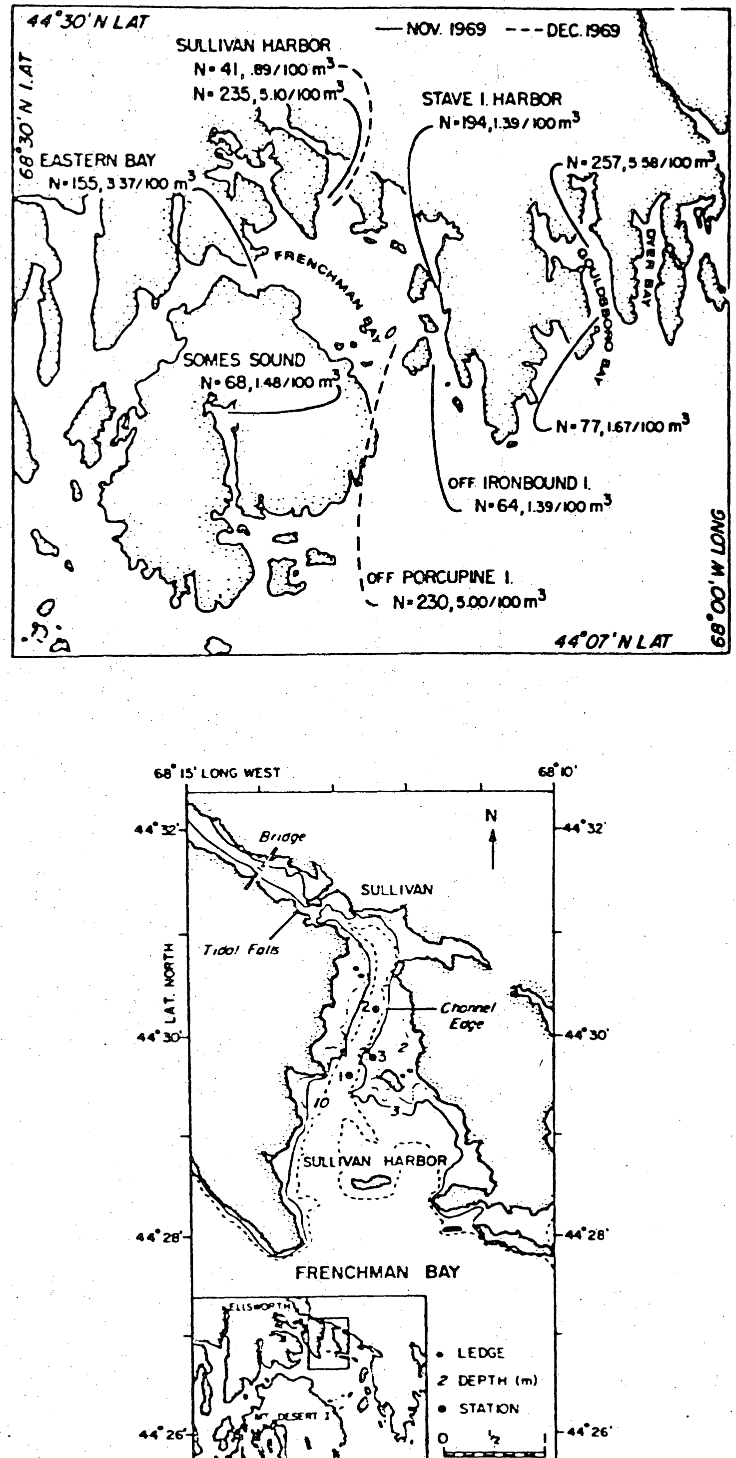

Fig. 1A. (Top Panel) Results of exploratory tows in some inshore waters of eastern Maine. (Bottom Panel) Sullivan Harbor located at the head of Frenchman Bay in eastern Maine. Locations of current meter stations are shown.

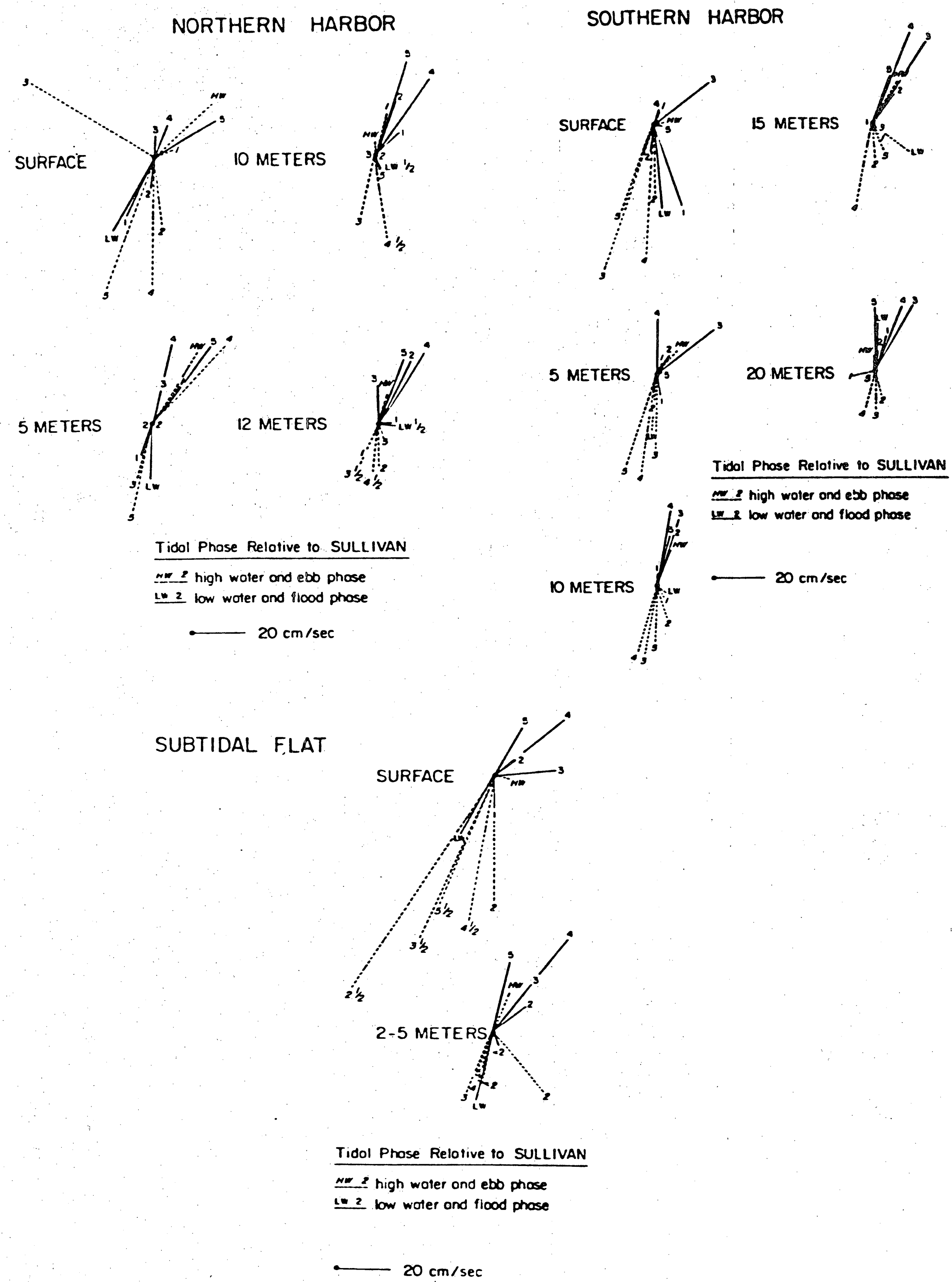

Fig. 2A. Rosettes of current vectors obtained from Sullivan Harbor in August, 1974.

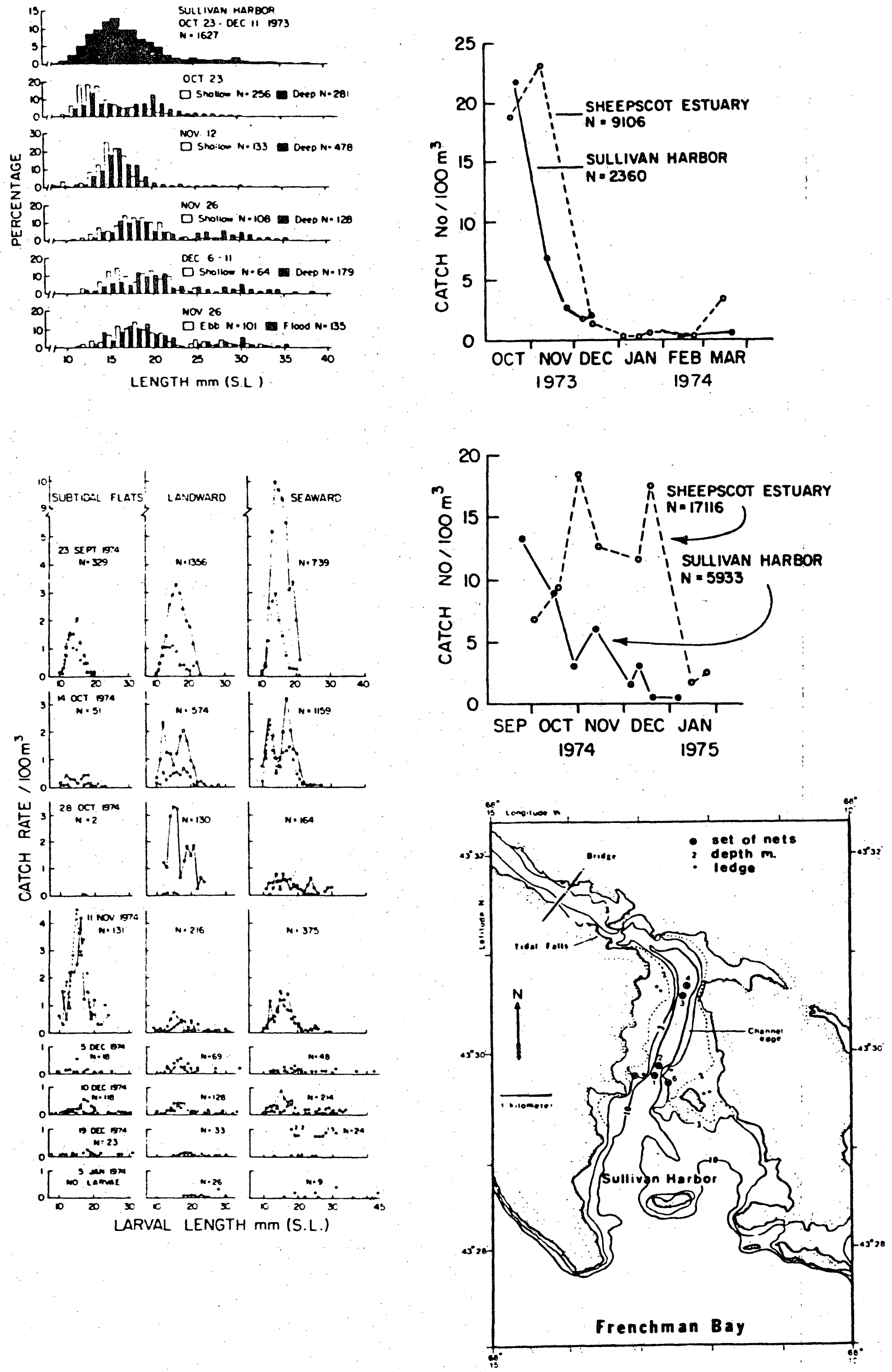

Fig. 3A. Intensified sampling in Sullivan Harbor, eastern Maine. Length frequencies of larval herring: upper left - 1973-74, lower left - 1974-75. (Solid line, deep; dashed line, shallow). Catch rates from the estuary and harbor: upper right - 1973-74, lower right - 1974-75. Locations of sampling stations in Sullivan Harbor, 1974 and 1980.