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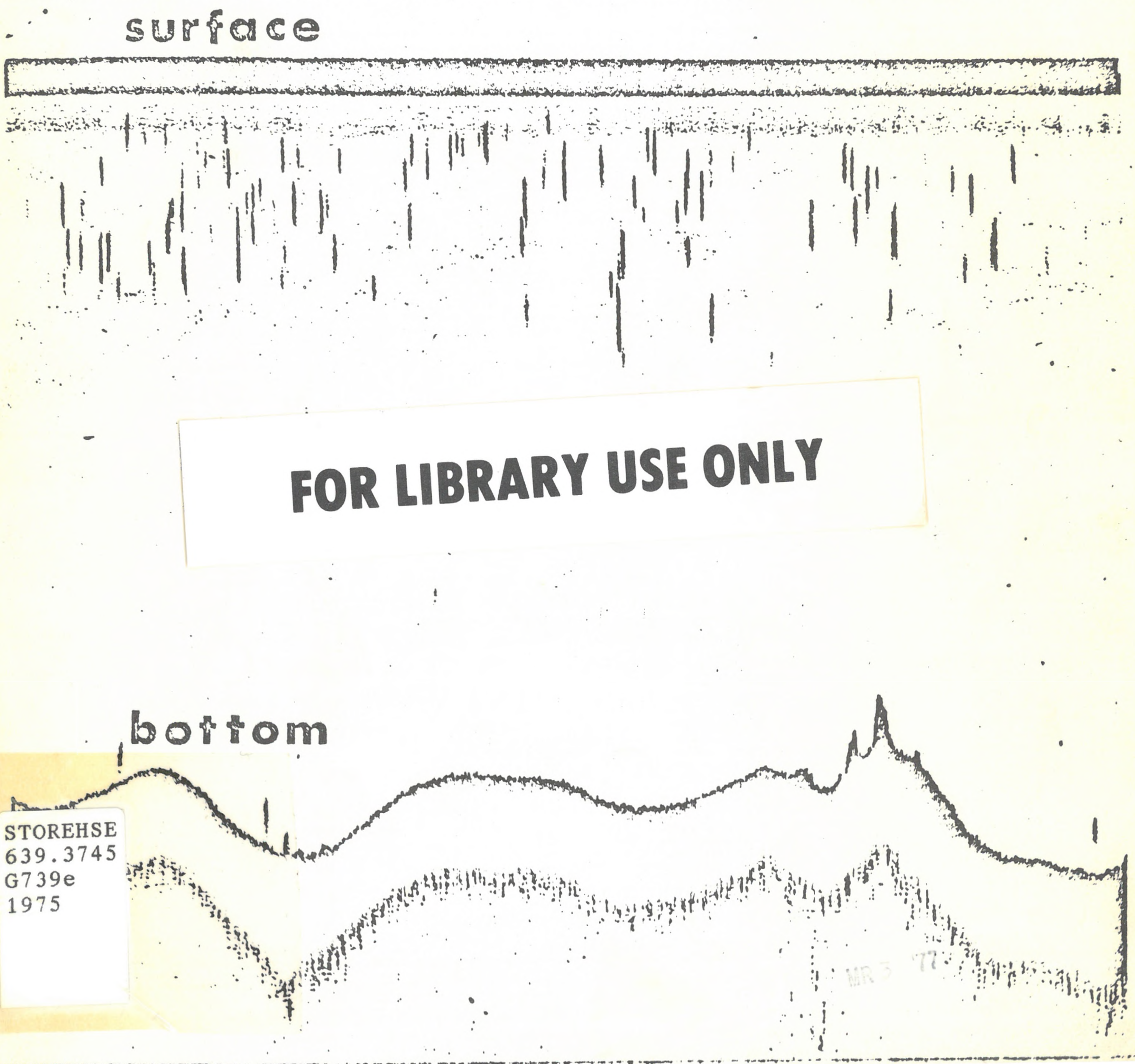

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Cover: Echo sounding traces within an aggregation of larval herring on April 13, 1969 within the channel of the Sheepscot estuary. The average trace is 0.6 m thick and 1.5 m deep (1.8 ft. and 5 ft. respectively). Such aggregations may extend over 2 km (over 1 mile) in length but as shown here may be only 10 m (33 ft.) deep. Catches with a high speed larval fish trawl showed that the concentration of larvae varied from 47.4-69.7 per 100 m^3 (35 cu. ft.) of water strained by the net. The size mode of the larvae was 40.5 mm (S.L.) or about 1-4/5" in total length.

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Abstract

This paper estimates the numbers of larval herring and other larval fishes during 1965-68 in a constricted channel of the Sheepscot River estuary of Maine. The basis for the estimates is that the sampling gear (buoyed and anchored nets) was effective, the channel was the center of a persistent larval concentration and the sampling design examined those factors that were significant in the accumulation and concentration of the larvae. The average number of larval herring estimated to occupy the channel during a single over night sampling varied from 0.2 to 9.1 million. The total number of all larval fishes including herring varied from 9.7 to 35.1 million. An estimate of the value of the larval herring in the channel was made by assuming that the peak number within the channel in the spring became juveniles and were canned as sardine herring. Although there are objections to such an assumption these are countered by other factors, especially when the valuation is applied to the channel as a nursery ground. The average number of cases of canned sardines expected from the larval estimates would be 13,000 per year. At current wholesale and retail prices these sardines would be valued at $260,000 and $598,000 respectively.

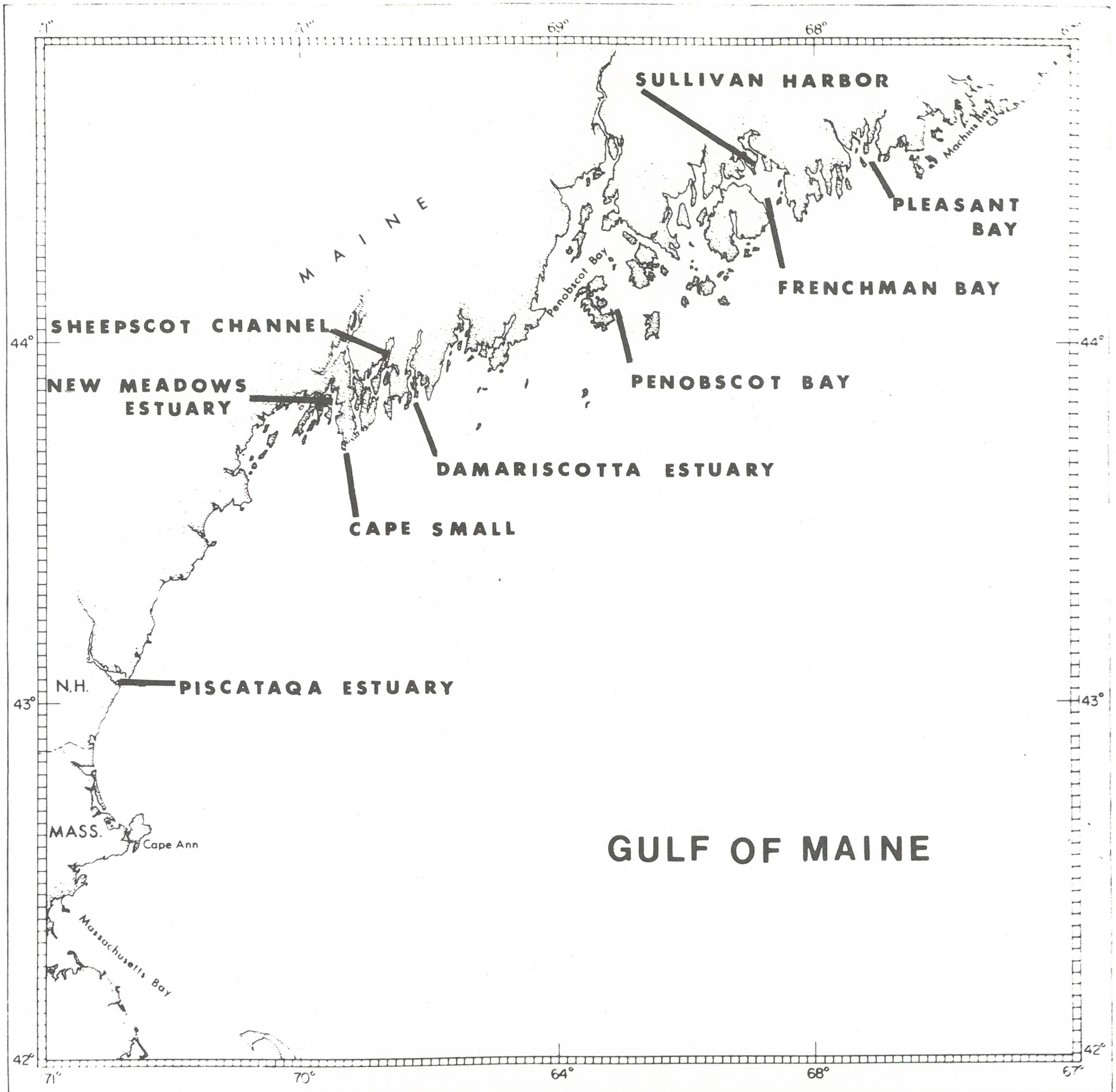
Introduction:

Coastal embayments and estuaries may be referred to as nursery grounds because many species of young fishes and invertebrates inhabit these areas. One such species is the Atlantic herring, *Clupea harengus harengus*, Linnaeus, which commonly inhabits the coastal waters of Maine (Fig. 1). In autumn, larval herring hatch along the coast between the headlands and the 50 fm. isobath and many subsequently enter the bays and estuaries. By early winter this inshore movement ceases, but with the onset of spring, a second movement begins involving the remaining larvae hatched the previous autumn along the coast and probably some which hatched beyond the coastal shelf. By late spring to early summer all of the larvae are inshore where they assume their juvenile form (Graham, Chenoweth, and Davis 1972, Davis and Graham 1970). These juvenile herring, about 5 to 10 cm long, are recruited to the sardine fishery of Maine for the first time the following autumn as one-year-old fish. The next summer, as two-year-old fish about 12 to 20 cm long, they are the major contributors to the fishery.

Often large accumulations of larval fishes occur within the shoreward portions of lower estuaries where the channels become narrow and shallow, thus concentrating the larvae. Concentrations of larval herring have been studied in the Sheepscot and Damariscotta estuaries (Graham, Chenoweth and Davis 1972) and Sullivan Harbor (Graham and Bickford, unpublished), and catches have also been obtained indicating that larval herring may concentrate within the estuaries of the New Meadows and Piscataqua Rivers (Graham and Venno, 1968). To demonstrate the importance of one such concentration we estimated the number of larval herring within a channel of the Sheepscot estuary and approximated their monetary value to the sardine fishery of Maine and to the public.

FIGURE 1

Location of the Sheepscot channel and other estuaries and embayments along the coast of Maine.



SULLIVAN HARBOR
PLEASANT BAY
FRENCHMAN BAY
Machias Bay
MAINE
Penobscot Bay
SHEEPSCOT CHANNEL
NEW MEADOWS ESTUARY
PENOBSCOT BAY
DAMARISCOTTA ESTUARY
CAPE SMALL
N.H.
PISCATAQA ESTUARY
MASS.
Cape Ann
Massachusetts Bay
GULF OF MAINE
44°
43°
42°
71°
70°
69°
68°

To further indicate the value of the channel as a nursery area, we also estimated the total number of other abundant larval fishes.

Basis for the estimates:

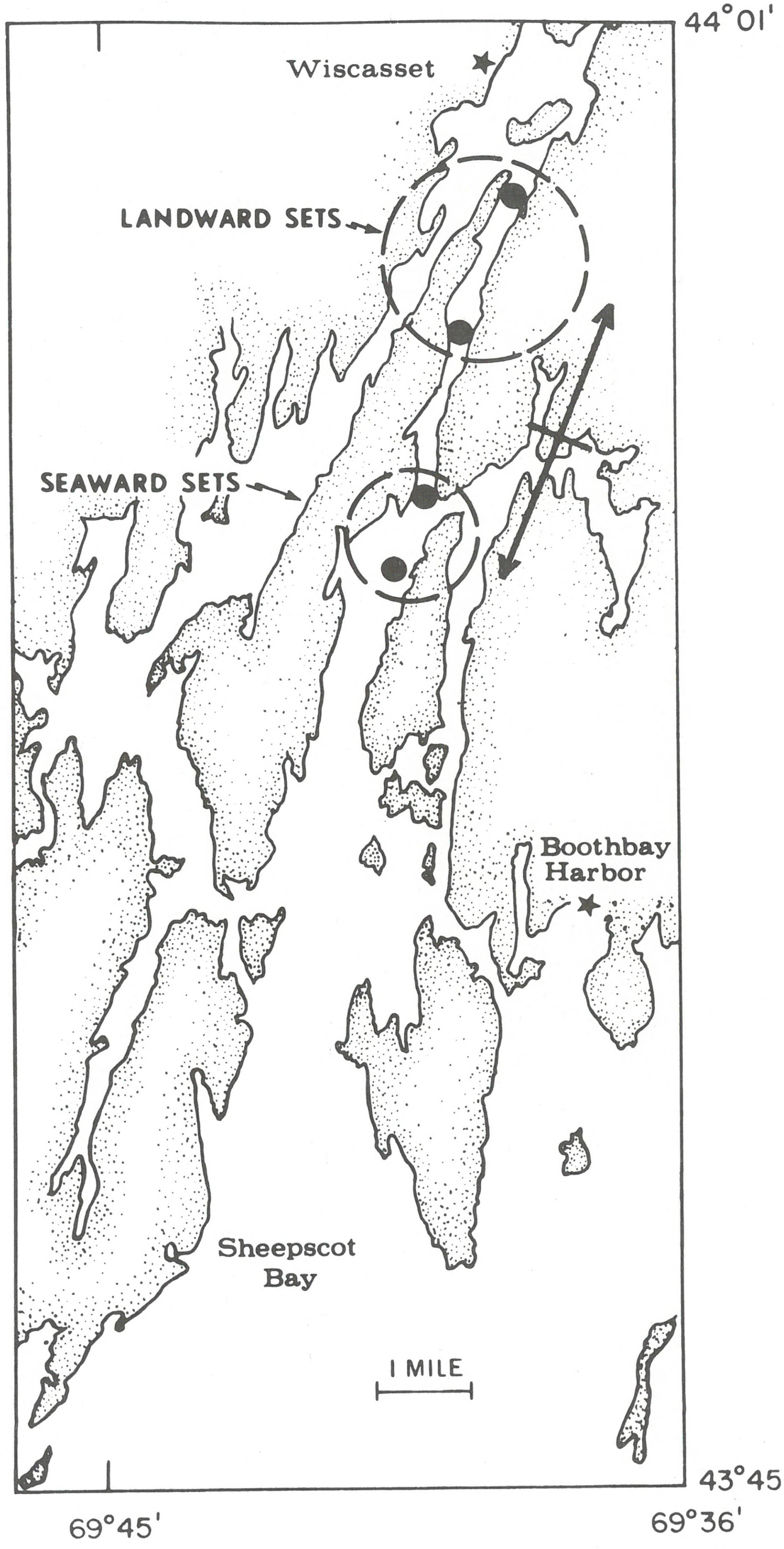
The estimates are based on a study done in the upper channel of the lower Sheepscot estuary during each autumn through spring, beginning in the autumn of 1965 and ending in the spring of 1968. Buoyed and anchored nets were used to capture larvae at night by straining the tidal flows. Four sets of nets were fished at the stations shown in Fig. 2. The sampling area or channel, U-shaped in cross section, was approximately 8 km. long, 1/2 km. wide and 21 m. deep throughout its length, and covered 260 hectares. During a single tidal cycle the nets strained approximately 23,000 of the 55,000,000 m^3 of water present in the channel. Larval catch rates were examined in relation to three factors and their interactions: 1) location, 2) depth, and 3) tidal phase on which the larvae were caught. An example of the analysis of catch rates is detailed by Graham (1972).

Estimates of absolute numbers from catch rates of larvae in a given area require considerable knowledge of the ecology of the larvae and confidence in sampling procedures. In this instance, the estimates were attempted for the following reasons: 1) the buoyed and anchored nets proved to be an effective gear (Graham and Venno, 1968), 2) the confining channel was the center of a persistent concentration of larval herring (Graham et al, 1972), and 3) the factors selected for analysis were those that were significant in the accumulation and retention of the larval concentration within the channel (Graham and Davis, 1971).

The mean, standard error and confidence intervals (95%) were calculated from the catch rates after their transformation to common logarithms. The anti-logarithms of the mean and confidence intervals

FIGURE 2

Locations (circled) of buoyed and anchored nets in the Sheepscot estuary of Maine (after Graham and Davis, 1971). Arrows show average tidal excursions; downstream at the surface during ebb tide, upstream at 15 meters during flood tide. Distance between arrows is approximately 6 km.


44°01'
Wiscasset
LANDWARD SETS
SEAWARD SETS
Boothbay
Harbor
Sheepscot
Bay
1 MILE
43°45'
69°45'
69°36'

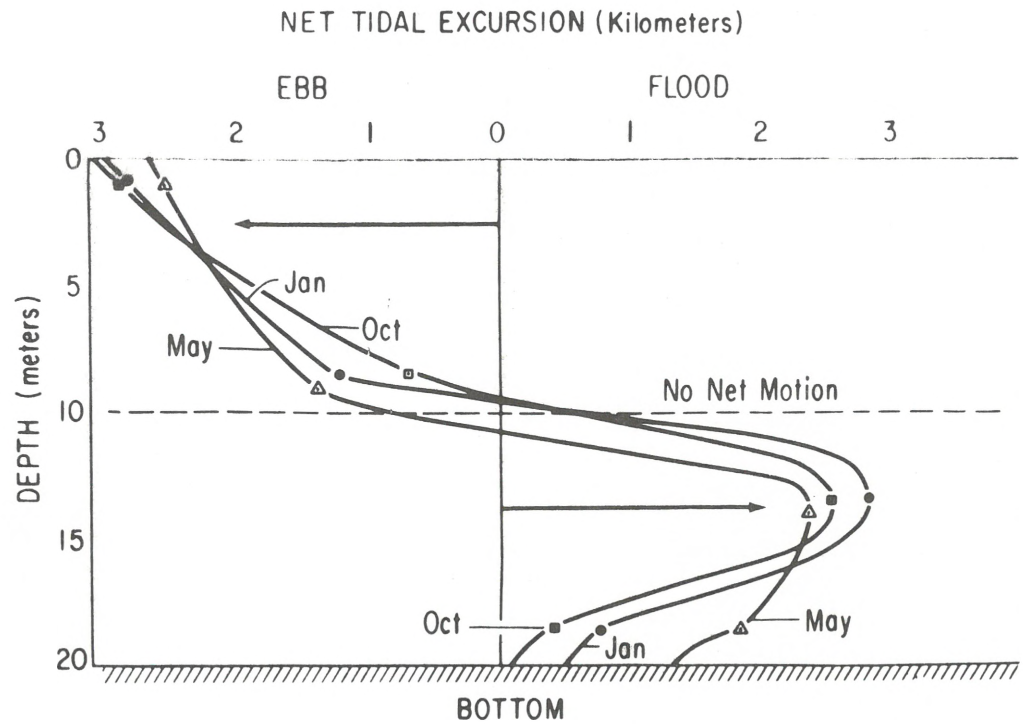
in number per cubic meter were multiplied times the volume of water in the channel in cubic meters to estimate the number of larvae in the channel. For example, an average of 500,000 larvae were estimated to occupy the channel on the night of October 26, 1967. But, the true average lay between certain limits determined by the chance variation within our samples. Calculation of the confidence intervals indicated only a 5% probability that when sampling the same population one would obtain an average that was either less than 400,000 or more than 600,000. When the intervals of the population estimate for one night did not overlap those of another night we concluded that the difference between the averages from the two nights was significant, statistically,

Retention of Larval Herring:

Larval herring are retained in the shoreward portion of the lower Sheepscot estuary by tidal flows. An hypothesis of the manner in which they are retained is given by Graham (1972). In the channel, the same amount of water moves landward on the flood tide as on the ebb tide at about mid-depth, a level of no net motion (Figure 3). Below mid-depth, more water moves upstream on the flood than downstream on the ebb tide. Above mid-depth, more water moves downstream on the ebb than upstream on the flood tide. This system of net tidal currents is destroyed upstream near the town of Wiscasset (Figure 2) where the water shoals and is thoroughly mixed. It was hypothesized that larvae entered the channel by remaining below mid-depth where they were transported landward by the net tidal current. When reaching the upper part of the channel and approaching the area where the system of tidal currents breaks down, the larvae ascended above mid-depth. The larvae were then transported downstream by the net tidal currents only to sink below mid-depth and return landward on the upstream current.

FIGURE 3

Vertical profiles of mean tidal flows for the four sets of buoyed nets in the Sheepscot estuary (after Graham and Davis, 1971). Relation of tidal excursions to the channel is shown in Figure 2.


NET TIDAL EXCURSION (Kilometers)
EBB
FLOOD
3
2
1
0
1
2
3
0
5
10
15
20
DEPTH (meters)
Jan
Oct
May
No Net Motion
Oct
Jan
May
BOTTOM

Numbers of Larval Herring:

During the years (1965-68) of sampling the average number of larval herring on a given night varied from 0.2 to 9.1 million within the channel (Table 1). They were most numerous in the autumn and spring and least numerous in the winter. The confidence intervals of the number of larvae in the channel varied considerably in the autumn when the larvae first entered the channel and then concentrated there. The addition of larvae slowed or ceased by mid-December and the mortality of the larvae reduced their numbers to a final low in January or February. The intervals obtained at that time do not overlap those obtained during their autumn peak suggesting differences between abundances of the two seasons that were statistically significant. Similarly the intervals do not overlap for the low numbers in winter and the peak numbers in April, after the movement of other larval herring into the channel. The intervals determined from spring experiments overlap suggesting no statistical differences in larval numbers during that season, but the decrease in average numbers of larvae in late April and early May is likely caused by their metamorphosis into juvenile form (Graham, et al, 1972). After metamorphosis they are no longer available to the buoyed and anchored nets in the channel.

Numbers of All Larval Fishes:

Other larval fishes are commonly present in the channel during the spring. Those most abundant are known as the rock eel, *Pholis gunnellus* (Linnaeus), the sculpins, *Cottidae*, and the sea snails, *Liparis* sp. These larvae dominate larval populations in the Boothbay Region where they are primarily located within the shoreward portions of the lower estuaries (Chenoweth, 1973) and reach their peak numbers in March. When their numbers were combined with those of herring, an average 35.1

TABLE 1

Numbers of larval herring captured in the nets and the numbers estimated to occupy the channel.

Date Mo.-Day-Year	Numbers in the nets	Millions in the Channel Average	Confidence Intervals
10-26-67	541	0.5	0.4-0.6
11- 1-65	1456	2.6	1.1-6.0
11- 8-67	3829	4.6	2.3-9.3
11-15-66	592	0.7	0.6-0.8
11-20-67	1610	1.8	0.3-10.9
11-21-66	2856	3.8	1.8-7.7
12- 6-66	1649	2.5	0.9-6.6
12- 7-67	352	0.4	0.3-0.7
12- 9-65	912	1.2	0.6-2.7
12-18-67	462	0.8	0.2-2.9
12-21-66	1045	1.9	0.9-4.1
1-10-67	718	1.4	0.8-2.6
1-18-68	197	0.4	0.1-1.0
1-20-66	252	0.2	0.1-0.6
2- 7-68	223	0.5	0.2-1.5
2- 8-67	437	0.5	0.2-1.3
2-28-68	237	0.4	0.2-1.0
3-14-68	862	1.4	0.5-2.8
3-20-67	716	1.0	0.6-1.7
3-26-66	1991	2.3	0.9-6.0
3-28-68	869	2.1	1.2-3.7
4-15-68	3426	5.4	1.8-15.1
4-26-67	4520	8.4	2.2-30.9
4-27-66	2145	9.1	6.2-13.3

TABLE 1 (Cont.)

Date Mo.-Day-Year	Numbers in the nets	Millions in the Channel Average	 Confidence Intervals
4-28-66	4862	4.9	2.3-9.2
5- 4-67	3887	8.4	4.7-15.0
5- 9-67	2234	4.6	2.0-10.3

million larvae were estimated to occupy the channel on the night of March 20, 1967, and this estimate could be expected to vary from 16.9 to 72.9 million (Table 2). The lowest estimate (1969) was obtained with an average 9.7 million larval fishes present with a possible variation of 5.3 to 18.4 million.

Discussion:

Numerous proposals for the use of the coastal resources of the state of Maine have been made recently. Those proposals of large scope concern the establishment of ports for large ocean tankers and facilities ashore for refineries, the enlargement or establishment of atomic plants, and dredging and dumping operations for clearing waterways. Scientists for the Maine Department of Marine Resources, the University of Maine at Orono, and from the Ira C. Darling Center at Walpole, Maine are studying the possible effects of thermal pollution from an atomic plant on larval fishes in a series of channels (Montsweag Bay) adjacent to the Sheepscot channel discussed in this paper.

A monetary evaluation of biological resources in a given locality is usually attempted to assist those designated in determining the multiple uses of our coastal environments. Such an evaluation is possible in the Sheepscot estuary because we have estimates of the number of larval herring in the channel and the herring is a commercial species with a market value. By assuming that all larvae from the peak spring estimates survive we can postulate their value if canned later as two-year-old sardines. There are objections to such an assumption, but these are countered by other factors that make the valuation reasonable. Our assumption would result in an overestimate of the actual number of larvae recruited to the fishery as sardines because: 1) as larvae some

TABLE 2

Total numbers of larval fishes captured in the nets and the numbers estimated to occupy the channel.

Date Mo.-Day-Year	Numbers in the nets	Millions in the channel Average	Confidence Intervals
3-20-67	21,049	35.1	16.9-72.9
3-20-69	3,495	9.7	5.3-18.4
3-28-68	8,677	17.6	8.7-35.0
4-15-68	7,373	10.0	2.8-35.1

herring would die after the estimate of their numbers in the channel was made, 2) as juveniles others would die before they were recruited to the fishery, and 3) as two-year-old sardines not all of the surviving larvae would be captured by the fishery. However, the spring estimates of the number of larvae in the channel are used thus avoiding autumn estimates when larval mortality is high (Graham, 1973). The spring mortality is considered to be comparatively low (Graham, et al, 1972). During April and May the number of larvae in the channel is underestimated because those that metamorphose at that time are not available to our gear. Although not all juveniles are harvested as two-year-old sardines, some are captured as yearlings and those that escape the fishery are later subjected to other fisheries as adults.

A valuation of the larvae as sardine herring is given in Table 3. On the average, a can of sardines holds six juvenile herring and a case holds 100 cans. For the three years 1967-69, the average number of cases expected from the larval estimates would be 13,000. At 1974 wholesale and retail prices (Wheeland and Thompson, 1975) these would be valued at $263,000 and $556,000 respectively. The lowest number of cases expected from the larval herring would be 3,000 at $61,000 wholesale and $128,000 retail. The highest number of cases expected was 25,000 at $506,000 wholesale and $1,070,000 retail. Essentially the average value of the larvae from the small Sheepscot channel was approximately 2% of the wholesale value of all sardines captured in Maine waters.

The valuation of larval herring is only a partial valuation of the biological resources of the Sheepscot channel since it does not include the other larval fishes not sought eventually by commercial fisheries. Further, the estimates of the numbers of larval herring were made during

TABLE 3

Valuation of the estimated numbers of larval herring in the Sheepscot channel assuming all survive to become 2-year-old sardines. Conversion factors: 6 fish per can, 100 cans per case, wholesale price (1974) $20.24 per case, retail (1974) $42.78 per case.

Larvae Spring Captured	Sardines Year Harvested	Cases of Sardines (1,000's) Average	Limits	Wholesale ($1,000's) Average	Limits	Retail ($1,000's) Average	Limits
1966	1967	15	10-22	304	202-445	642	428-941
1967	1968	14	8-25	283	162-506	599	342-1070
1968	1969	9	3-25	182	61-506	385	128-1070
Three Year Average		13		263		556	

years of small herring populations and relatively poor fisheries (Anthony, 1972). Ten years prior to these estimates, the two-year-old sardine catch in Maine waters was three times greater. If conservation measures could return the herring population to its former level, then perhaps the value of the channel as a nursery area would be greatly increased.

Finally, the valuations given here are only point estimates in time because the herring is a renewable resource. Proper care not to destroy the tidal system retaining the larvae or to subject their vulnerable accumulations to toxic materials will permit to us an accrual of their annual value over the long geologic life of the estuarine channel.

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