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Evaluation of the Use of Larval Survey Data to Tune Herring Stock Assessments in the Bay of Fundy/Gulf of Maine

by

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Abstract

Extensive autumn surveys of herring larvae have been undertaken annually in the Bay of Fundy and Gulf of Maine for more than 15 years. Recently (since 1981), an index of larval abundance has been used to "fine-tune" cohort analysis for the 4WX herring stock assessment. In this paper we examine and evaluate the larval abundance index and its use in stock assessment.

SPECIAL SESSION ON BIOLOGICAL SURVEYS

Introduction

Fishery-independent estimates of stock size or abundance are valuable in "tuning" (calibrating) and otherwise validating analytical stock assessments. The possible relationship between larval abundance and stock size has received considerable attention in this regard and various ways of quantifying larval abundance as indices have been derived.

These larval abundance indices are seen as having several potential advantages including:

(i) allowing the maximum possible advance knowledge of recruitment to the fishery;

(ii) evaluating the life-history stage at which year-class strength may be assumed to be determined and

(iii) being the result of relatively inexpensive and efficient field surveys using conventional (plankton) techniques.

Two essentially different and mutually exclusive approaches to the use of larval abundance data have been adopted in the past; to forecast recruitment and to hindcast spawning stock size.

Recruitment forecasting, assumes that at the time of spawning year-class strength has already been determined; alternatively that subsequent mortality factors are constant from year to year. It would be used in assessment as a direct estimate of abundance of the youngest year-class.

"Hindcasting" spawning stock size from larval abundance assumes constant hatching rates from deposited spawn, and, for absolute estimates of spawning stock size, requires an estimate of fecundity to translate egg production (by interpolation and on the assumption of a mortality rate on the surviving larvae) into spawning biomass. More usually a "relative" index is used which assumes, more generally, that the combined effect of mortality and year availability factors are constant from year to year.

Over a number of years a relationship between the relative index and estimated stock size is built up which allows the estimate of terminal fishing rates for the current year, an essential part of sequential population analysis.

In the Bay of Fundy, a larval herring survey has been carried out each year since 1969, and with standardized procedures since 1972. Changes since 1972 have been aimed at improving coverage without affecting continuity of the series. Since 1981 a larval abundance index from this survey has been used to tune cohort analysis for the 4WX herring stock assessment. In this paper we address the development of this larval abundance index, and evaluate its use in assessment.

Bay of Fundy larval survey

Comprehensive surveys of the Bay of Fundy were begun in 1969 and standard surveys of 116-163 stations (Fig. 1) have been undertaken annually, during late October and early November, since 1972 (Table 1). Sawtooth oblique tows (as recommended for ICNAF larval surveys, Anon. 1972), have been made using paired 61-cm bongo nets (.505 mm mesh) equipped with digital flowmeters. Tows were made to a depth of 5 m off bottom. Set and haul rates were 50 and 20 m min^{-1}, respectively, while the vessel was proceeding at 3.5 knots. If initial tow duration was less than 10 min, the gear was payed out again for a second tow as soon as it surfaced. Samples have been stored in 5% buffered formalin and sorted for all herring and herring-like larvae* to a minimum sorting precision of 10%. Larval numbers are expressed volumetrically on the basis of the measured volume filtered by the net and are converted to numbers beneath a square metre based on the mean depth during the occupation of each station.

An abundance index is calculated as the product geometric mean** of the larval density (no. M^{-2}) for all stations sampled in a particular survey. Stations on the grid that could not be surveyed are excluded and samples without larvae are assigned to value of 1 for the calculations, which is subsequently removed for the final result.

Use of the larval index in the 4WX herring assessment

The 4WX herring fishery is large (~ 100,000 t per year), involves several gear types, and is complex in spatial and temporal distribution (Miller and Iles, etc.). Consequently, there is no single, adequate CPUE series to use in assessment at present***. In addition, catch data from this fishery is of very inconsistent quality because of sporadically high levels of misreporting (Stephenson et al. 1985, Mace 1985). As a result, there has been a particular need for an independent index of abundance, for the purpose of assessment and as the basis for demonstrating a need for more adequate monitoring of the catch.

At the same time, there has been a major increase in the understanding of the ecology of herring larvae from these studies. Of greatest significance in this context is that larvae tend to be persistent in their distribution, occupying "retention areas" (Iles and Sinclair 1982) that can be relatively easily covered by a survey grid.

It is with this understanding of larval distribution, and a reasonable time series of larval abundance data that the larval index was proposed (Sinclair et al. 1979) and encorporated into the 1980 4WX assessment (Sinclair and Iles 1981). The relationship between geometric mean larval

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*Includes Clupeidae and Osmeridae

**The geometric mean is used as a conservative measure of central tendancy (Spiegel 1961).

***This problem is being addressed in a study of the purse seine fishery Mace 1985).

abundance (Table 1) and population biomass (mature and 5+ at January 1 following the survey) (Fig. 2) is used to indicate an appropriate terminal F value, based upon the best combination of high correlation coefficient and low intercept (Table 2).

The larval abundance index has been used in four of the last five assessments. It was not used in the 1981 assessment (Sinclair et al. 1982) because of an apparently anomalous sharp decline in the index in that year. No satisfactory explanation of this anomaly has yet been forthcoming and is not expected until, and unless, more detailed analysis of the accumulated data based has been carried out (see below).

Evaluation of survey design

Figure 3 illustrates the two approaches to the use of larval survey data and demonstrates the relative constraints placed on the timing of the surveys as a result of the assumptions involved in forcasting and hindcasting. Surveys used for recruitment forecasting should become more reliable later in the larval stage because of the assumption of year-class determination; surveys used to hindcast spawning stock size are best undertaken early in the larval stage to minimize the effect of larval mortality. In both cases the relative value of the survey decreases at metamorphosis due to changes in fish distribution, gear avoidance etc. Larval surveys for hindcasting are of two kinds. The first is designed to cover the whole spawning area and spawning period by a temporal series of collections in order to integrate larval production during a relatively early stage (usually up to a larval length of 10 mm; e.g. ICES Herring Working Group, Anon. 1985). The second is designed to cover the entire area of larval distribution at a single time, subsequent to the end of hatching, but close enough to the mean time of spawning to minimize the affect of variable mortality after hatching. Both methods assume constant hatching rates from deposited spawn. The first type (temporal series) is potentially, better but is impractical and expensive in large areas.

Discussion of assumptions regarding survey design

The timing and protocol of this particular survey involves a number of assumptions that have to be evaluated both individually and in conjunction with each other:

1) Timing of the survey

This survey is of the second type discussed above, a single coverage subsequent to the end of hatching. It is assumed that the interval between mean hatching and the survey is short, or at least constant from year to year, that larval mortality is equivalent and that availability to the year is constant from one year to the next.

The survey was originally designed to coincide with peak larval abundance based upon an estimated mean peak spawning date of Sept. 1 (Sinclair et al. 1979). The mid-date of surveys for 1972-84 is Nov. 9 but the range in mid-dates spans 33 days. In recent years (since 1978), survey timing has been more consistent; all sampling has occurred between Oct. 26 and Nov. 22.

Accumulated information indicates that spawning on the major SW Nova Scotia grounds takes place over a one-month period with a peak between August 25 and September 10 (Sinclair and Tremblay, 1984). This implies a hatching period extending as late as early October and indicates that the mean survey date is three to four weeks after the last hatching.

The mean length of larvae which gives at least a crude impression of this factor on the reliability of the survey as a comparative index was similar in seven cruises between 1975 and 1983, ranging from 11.2 $\pm$ 2 (mm $\pm$ SD) to 13.9 $\pm$ 2 (Table 3). This is equivalent to about two weeks of larval growth, but surprisingly the mean length was not different between early and late cruises (Fig. 5).

2) Areal extent of survey

The fixed survey pattern implicitly assumes that the entire larval distribution (or at least a constant portion) is sampled, and this seems to be the case. Maps of larval distribution (as in Fig. 6) show consistent patches within the bounds of the survey each year and scattered stations around the periphery (e.g. to Georges Bank in 1984) show an absence of larvae. Indeed, the persistence and integrity of larval distribution within this survey formed the basis of the Iles and Sinclair (1982) larval retention area hypothesis.

3) Availability of larvae to gear

It is assumed that larvae are being sampled equally within and between surveys, including all sizes, from all depths, day and night, etc. The most easily tested aspect of this is the possible avoidance of the net by day.

Table 4 contains a comparison of occurrence and abundance of herring larvae in day, night and twilight sets. No diurnal trend is apparent; the variation is likely the result of the uneven spatial distribution of larvae. Length-frequency distributions from 1978 and 1982 (Fig. 7) indicate that more large larvae are taken in night tows.

4) Station number and density

Station density is higher than in most ichthyoplankton studies. The results of earlier surveys have been examined (O'Boyle and Iles, unpublished data) to show the effect of simulating the reduction of station numbers over the survey area by random removal. There was no dramatic change until the simulated removal of 70-80% of the stations (Fig. 8). It was concluded that the survey design is very robust in terms of estimation larval numbers taken by the gear.

Discussion and Conclusions

A thorough review and analysis of the whole data base is being undertaken and which is designed to evaluate the effect of the factors, listed above, that determine the value and reliability of this survey.

This analysis will; a) attempt to resolve the 1981 anomaly, b) derive correction factors for each of the factors and thus generate a definite relationship, c) suggest modifications to the survey design that optimize future protocols, and d) deal with the important question of the highly variable relationship between the slopes of spawning stock biomass/larval abundance plots that appear to preview their acceptance as reliable indicators in the northeast Atlantic.

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Table 1. 4WX larval herring cruise distribution and abundance indices; from number of larvae per m^2 (to bottom) of all stations sampled (n = 116-150) for each year.

Cruise	Year	# Sets (N)	Mid-date of Survey[b]	# Days	Arithmetic mean	Geometric mean
P109	1972	130	Nov. 23	14	7.24	2.64
P127	1973	132	Nov. 24	8	5.27	2.30
P147	1974	102	Nov. 9	8	37.49	7.60
P160	1975	103	Nov. 10	10	24.56[a]	6.02[a]
P175	1976	124	Nov. 15	15	11.62	4.44
P190	1977	128	Oct. 22	8	4.57	1.83
P207	1978	116	Nov. 8	19	3.51	1.24
P232	1979	115	Nov. 1	9	6.32	2.18
P246	1980	131	Nov. 12	19	19.48	4.61
P263	1981	151	Nov. 16	13	2.59	1.50
P280	1982	157	Nov. 2	14	9.10	3.73
P298[c]	1983	157	Nov. 6	15	11.33	4.29
P315[c]	1984	157	Nov. 9	16	13.48	5.13

[a]Interpolated.

[b]Mid-date = 1st day + $\left(\frac{\text{1st day} - \text{last day} + 1}{2}\right)$

[c]Deletion of 17 low abundance stations and addition of new stations off Nova Scotia in area of concentration.

Table 2. Use of the larval index in the 1984 4WX herring assessment. Intercepts and r of the regression of SPA derived biomass vs larval abundance for a range of terminal F values; A = Nominal Catch Matrix, B = Adjusted (for underreporting) Catch Matrix. From Stephenson et al. 1985.

	Mature Biomass		5+ Biomass	
Terminal F	r	intercept	r	intercept
A) NOMINAL MATRIX				
.15	.766	86677	.814	34421
.20	.845	81008	.860	30303
.225*	.850	79120	.860	28930
.25	.838	77612	.852	27833
.30	.789	75350	.823	26186
.35	.734	73736	.791	25012
B) ADJUSTED MATRIX				
.20	.742	116481	.798	47687
.25	.817	110713	.842	43545
.30*	.841	106870	.851	40780
.35	.825	104130	.839	38809
.40	.790	102078	.818	37334

Table 3. Length (mean and SD) of larval herring from Bay of Fundy 1975-83.

Cruise	Year	Mid-date of survey	Abundance (geometric mean)	Length Mean	Length SD
P160	1975	Nov. 10		12.52	2.03
P175	1976	Nov. 15	4.44	13.55	1.88
P190	1977	Oct. 22	1.83	11.97	2.09
P207	1978	Nov. 8	1.24	13.86	2.01
P263	1981	Nov. 16	1.50	12.73	2.00
P280	1982	Nov. 2	3.73	11.19	1.99
P298	1983	Nov. 6	4.29	12.35	2.21

Table 4. Herring larvae in day, night and twilight sets, Bay of Fundy larval cruise: Number of stations, occurrence of herring (% of stations sampled), and abundance (mean number per station with occurrence).

Cruise		Day	Night	Twilight	Total
P207	# stations sampled	48	63	3	114
(1978)	% with herring	73	78	100	76
	# herring/station	41	30	4	33
P232	# stations sampled	46	65	4	115
(1979)	% with herring	83	83	75	83
	# herring/station	18	21	206	26
P246	# stations sampled	53	62	16	131
(1980)	% with herring	77	85	75	81
	# herring/station	60	114	19	93
P280	# stations sampled	80	107	8	195
(1982)	% with herring	90	96	88	93
	# herring/station	70	46	45	56

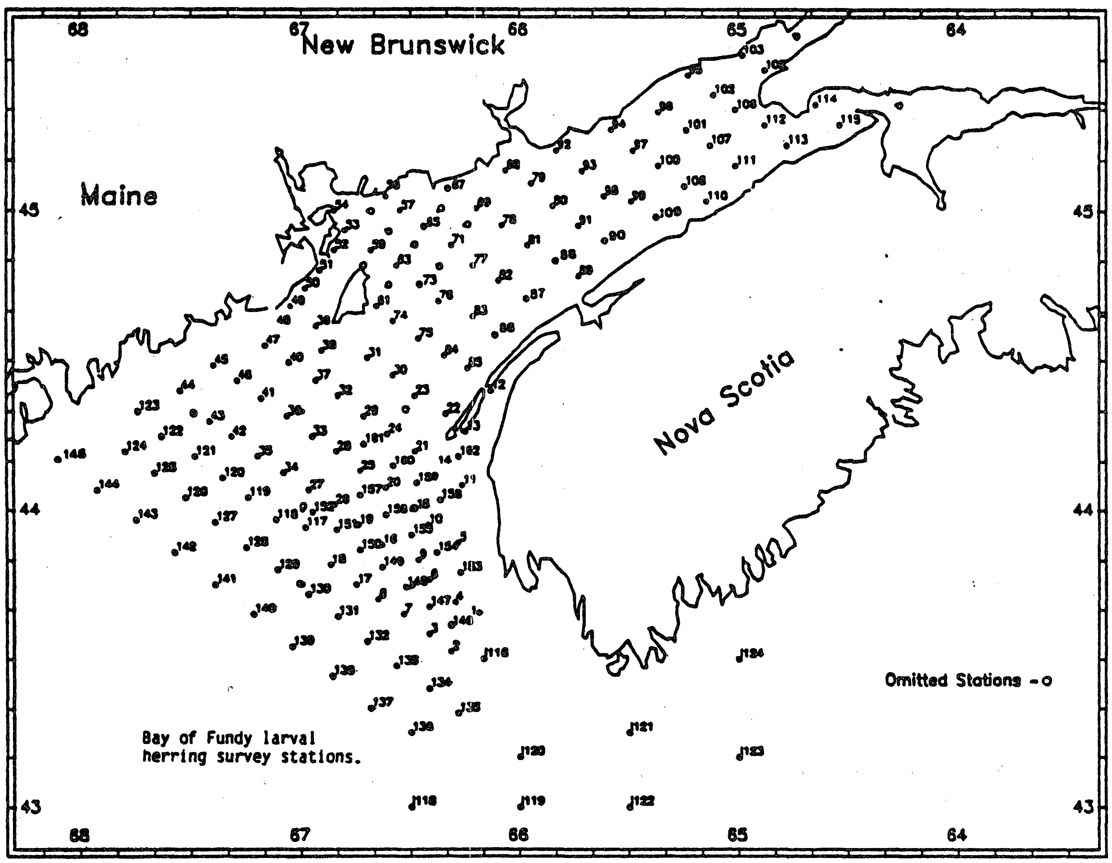

Fig. 1. Standard survey points, Bay of Fundy larval herring cruise; 1972-85.

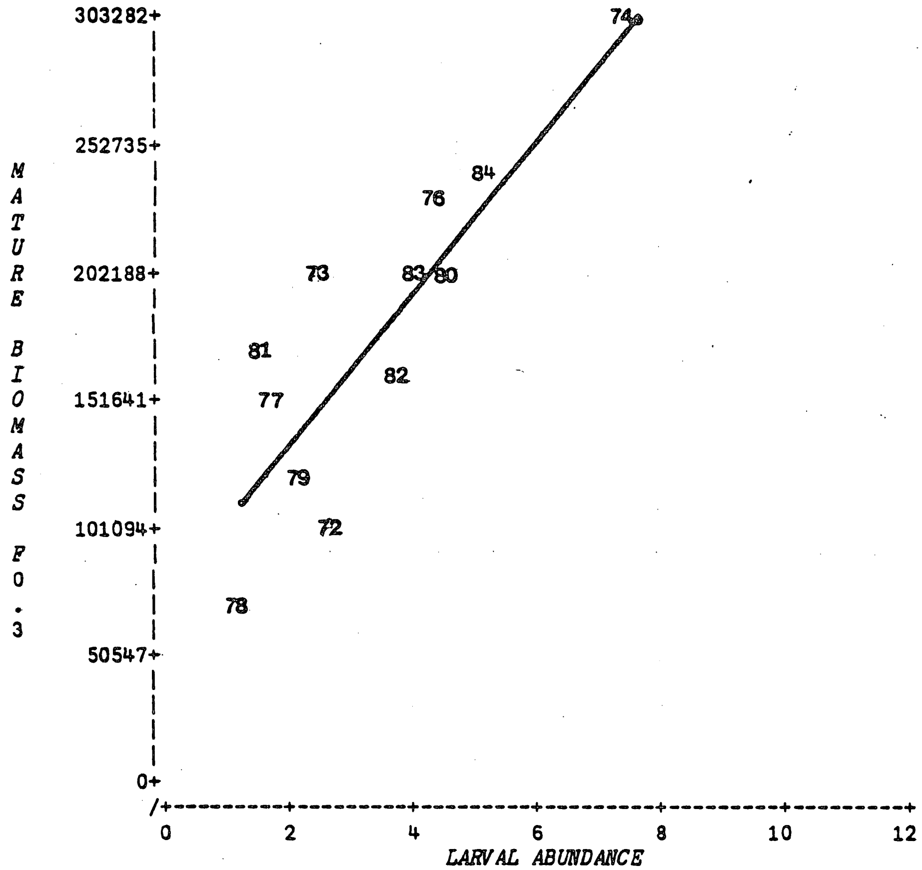

Fig. 2. 4WX herring "nominal" SPA estimated mature biomass v.s. larval abundance; 1972-84. (From Stephenson et al. 1985).

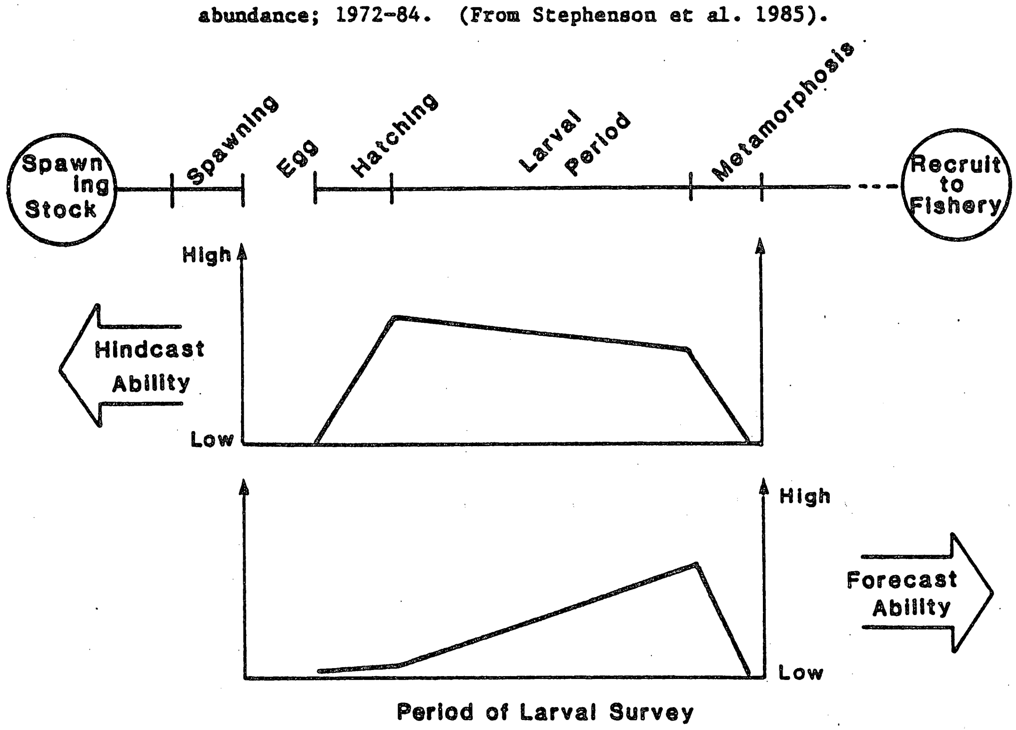

Fig. 3. Schematic representation of the affect of larval survey timing on the relative ability to hindcast spawning stock size and to forecast recruitment to the fishery.

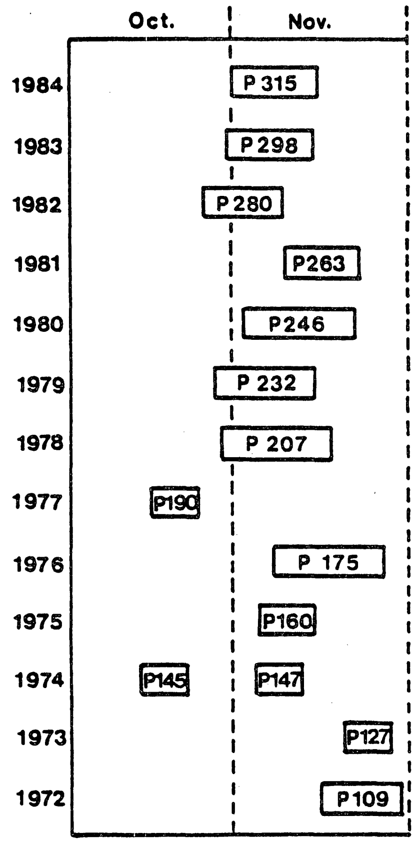

Fig. 4. Temporal distribution of Bay of Fundy autumn larval herring cruises; 1972-84.

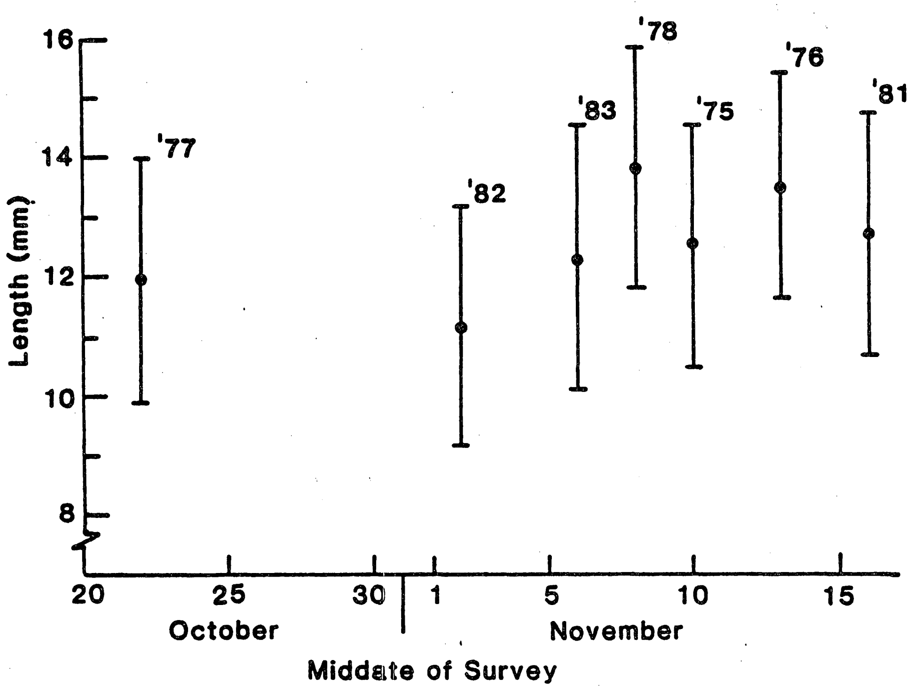

Fig. 5. Mean and variance (SD) of larval herring length vs mid date of the Bay of Fundy survey, 1975-83.

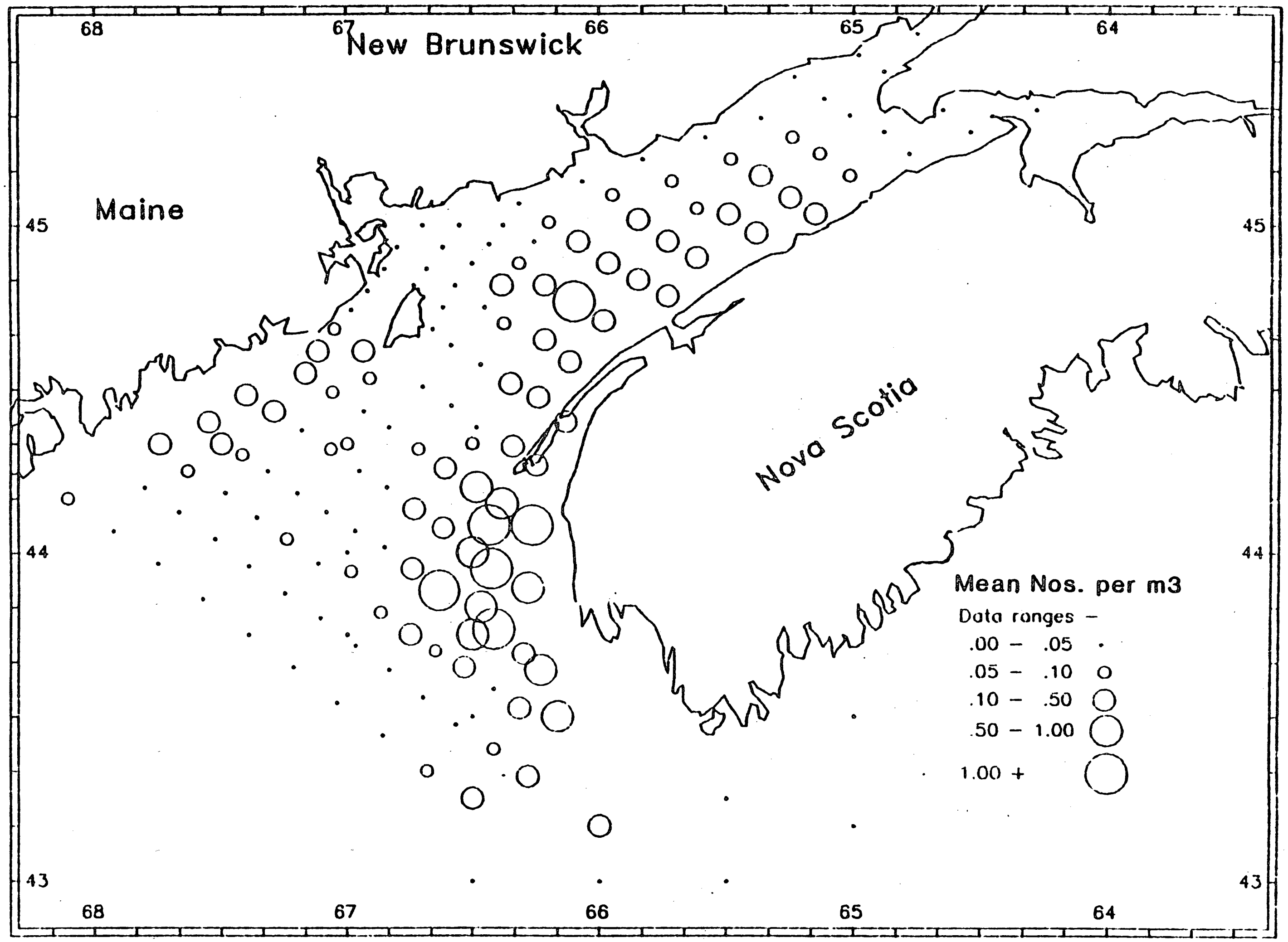

Fig. 6. Spatial distribution of herring larval abundance, Bay of Fundy, 1974-82.

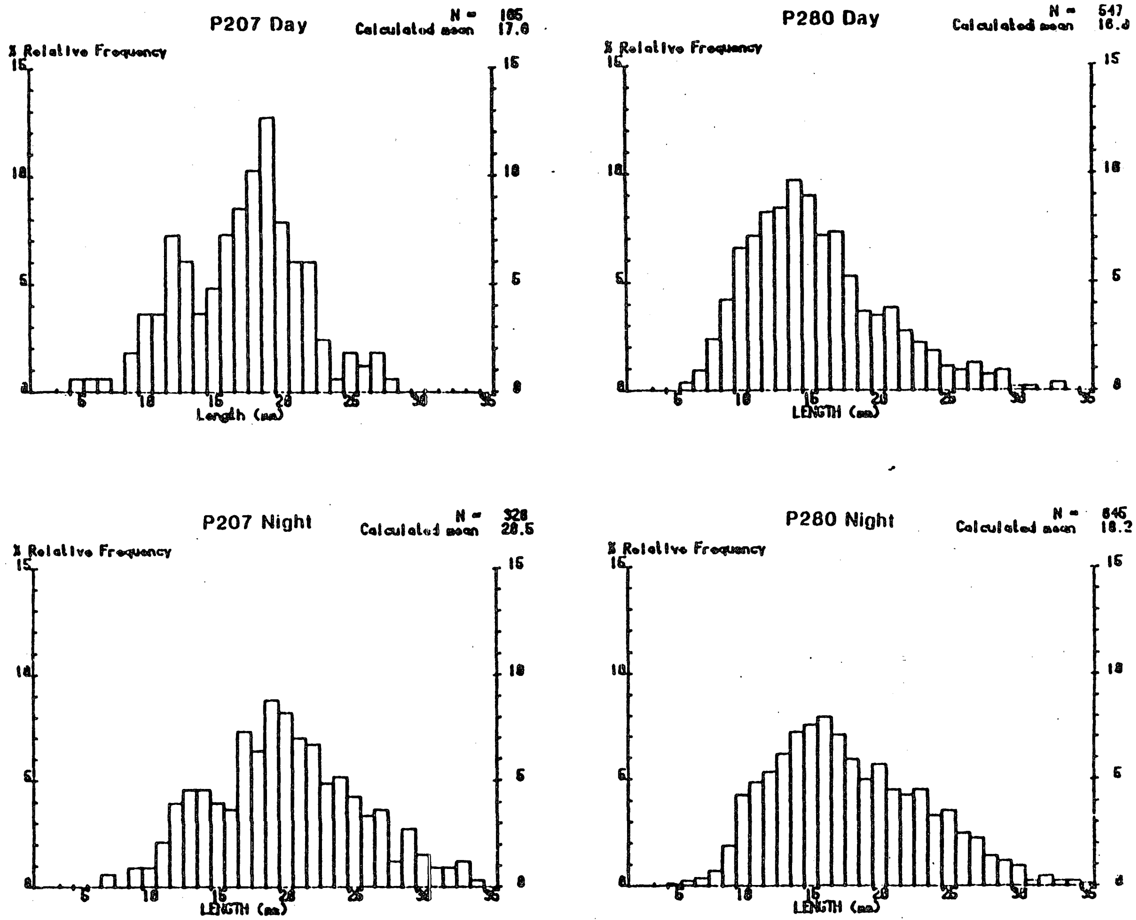

Fig. 7. Length frequency of herring larvae from day and night tows, 1978 (P207) and 1982 (P280).

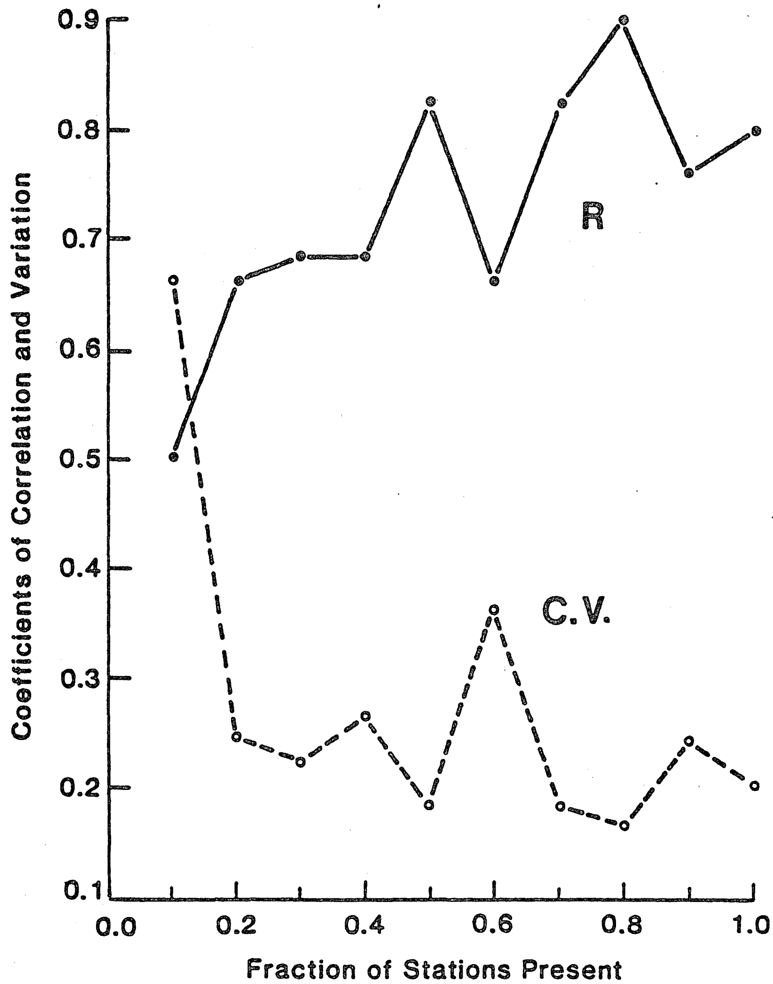

Fig. 8. Effect of station density on coefficient of variation of VPA/larval estimate ratio and correlation coefficient for Bay of Fundy data set (R. N. O'Boyle and T. D. Iles, unpublished data).