

Preliminary Analysis of the use of Bay of Fundy  
Larval Survey Data in 4WX Herring Assessments

by

M. Sinclair<sup>1</sup>, J. Black<sup>2</sup>, T.D. Iles<sup>2</sup> and W. Stobo<sup>1</sup>  
<sup>1</sup>Marine Fish Division  
Bedford Institute of Oceanography  
Dartmouth, Nova Scotia

<sup>2</sup> Marine Fish Division  
Biological Station  
St. Andrews, New Brunswick

### Introduction

A standard survey (116 stations) for Bay of Fundy herring larvae was defined in autumn 1972 (Fig. 1). At a minimum, an autumn and a spring cruise have been maintained each year since that time (Table 1). A standard larval sampling methodology, except for one major change beginning in the November 1975 cruise, has been used for all cruises. Prior to November 1975 only the upper 100 meters of the water column was sampled at deep stations. Since then the whole water column has been sampled. Oblique tows were made at 3.5 knots using paired 60 cm bongo-type ichthyoplankton frame with either paired 0.505  $\mu$  mesh nets, or 0.505 and 0.333  $\mu$  mesh nets (Table 1). During each tow the nets were deployed at approximately 50 m/min and retrieved at 10 m/min. Tow duration at each station was between 10 to 25 minutes. In order to ensure a minimum towing time of 10 minutes at all stations, in shallow waters two sequential tows were necessary without bringing the bongos on board between tows. Sampling was carried out on a 24 hour basis.

Since the major part of the herring stock in S.W. Nova Scotia spawn in late summer and early autumn, the autumn larval survey potentially provides an independent estimate of 4WX spawning stock size. The exact proportion of the 4WX stock that is not autumn-spawning is unknown, but it is probably less than 10%. The major spawning area is indicated on Figure 1. Second, if the year-class strength is defined during the first several months of the planktonic life stage the spring cruise may be a useful predictor of recruitment success. The aim of this paper is to look at these two aspects with special reference to the 4WX herring assessment. The life history aspects (growth, distribution etc.) of the larval survey data are not considered here.

### Back-calculation

The larval abundances ( $\#/m^2$ ) were expanded to a standard area which surrounds each station (Fig. 2). These areas were delineated by drawing a straight line between adjacent stations and then constructing

a perimeter around the station by joining lines that are orthogonal to the mid point of the lines between stations. Stations not occupied during a cruise were subjectively assigned mean abundances from surrounding stations (Table 1). The inshore boundary was the five fathom depth contour. The average area represented by each station in the standard survey is 174 km<sup>2</sup>. From the 1973 autumn survey the larval abundance estimated within the standard grid was found to represent 91% of the total by considering ICNAF stations (Fig. 2). Thus the larval abundance estimates from the standard grid were adjusted upwards accordingly.

The combined % length frequencies of several autumn and a single spring survey are shown in Figure 3. There is some evidence for discontinuous spawning on a short time scale (days). The larval length-frequencies of October and November 1973 appear to have modes at respectively 11 and 16 mm, and 17 and 23 mm. The shift in the modes suggests growth of ~ 2 mm/day. The modal distribution and the growth estimate suggest two spawning runs separated by approximately 10 days. On a longer time scale (weeks) there is no evidence of discontinuous spawning. The Scotts Bay spring spawning larvae (location on Fig. 1) for example are not evident in the distributions (Fig. 3). Because of the normal distributions in numbers at length (on the longer time scale) and the approximately normal distribution in spawning intensity (as shown by the daily drift gillnet catches of spawning fish 1977, (Fig. 4) a simple back calculation method not involving length composition of the larval population was thought appropriate as a first approximation. This was necessary in any case since lengths have not been measured for the cruises subsequent to cruise EEP 145.

The method assumes that the whole stock spawned instantaneously at the day of peak spawning and that all the larvae are the same age (aged to the mid-date of the cruise). It follows that all eggs hatch instantaneously at peak date of hatching. This method, which is graphically shown in Fig. 5, needs less information on larval distributions than do the more detailed methods of Sette and Ahlstrom (1948) (the expanded area and day method) and Saville (1956) (the normal curve approximation method.). However, additional information such as spawning time and hatching time is necessary, and the method is inherently less precise.

Mean peak date of spawning (September 1) was initially estimated by discussion with an experienced drift gillnet port sampler and from the 1978 daily catch data from the purchase slips. The actual peak date for each year is in the process of being estimated from two independent sources, the drift - gillnet purchase slips and the maturity stage data from the detailed biological samples. The assumption of a constant peak date of spawning introduces an additional source of error. Cushing (1970) indicates that for North Sea herring that the date of peak spawning varies by  $\pm 7$  days. A difference of this degree would introduce approximately  $\pm 25\%$  error due to misestimated larval mortality. The hatching time was estimated from a temperature relationship derived by Laevasta and Hela (1970):

$$\text{Hatching time} = 4 + 44.7e^{-0.167 t}$$

The relationship was derived specifically for Atlantic herring based principally on data collected by Y. Jean, St. Andrews Laboratory (where  $t$  is temperature). Bottom temperature at Lurchers was assumed to be representative of all spawning sites in the area. The mean September temperature at the bottom was estimated from surface temperature at St. Andrews (1952 to 1969) using the following regression:

$$\text{Bottom } t \text{ (Lurcher's)} = 0.125 + 1.06 \text{ Surface } t \text{ (St. Andrews)} \\ (R=0.76)$$

Both the assumption of the general representivity of Lurcher's bottom temperature and the in situ mean temperature will be measured in 1979.

A daily larval mortality of 0.04 was applied for the appropriate number of days (estimated peak date of hatching to mid-date of cruise). This value was calculated from the decrease in population from October to November 1974, and perhaps fortuitously, it is identical to the mean value observed for Georges Bank herring larval mortality (1st three months), Lough (1978). Egg mortality both by predation and physiological causes are not known with any certainty for any herring stock. From direct observation Caddy and Iles (1973) estimated a daily mortality of 7% on egg beds. Lough et al. (1979) used a conservative total egg-mortality correction factor of 10% for the whole incubation period. In this paper the higher mortality level (7% per day) is used. This is a major assumption based on fragmentary information. For example changing daily mortality from 7% to 2% reduces the egg production estimate by ~50%.

Potential production of eggs from VPA estimated population abundance were made. The minimum population size shown in Sinclair et al. (1979) was used (traditional "stock" and adjusted effort combination). The mature portion of the population was estimated using maturity ogives derived from the detailed biological samples taken in August from the purse-seine catch. Since the maturity at age for females has remained relatively stable for the years 1972 to 1976, as well as for individual year-classes (Fig. 6), a single ogive, that for 1976 was used:

Age	2	3	4	5	6	7	8	9	10	11+
%mature	0	33	89	100	100	100	100	100	100	100

There appears to be no recent trend in maturity at age for females in spite of order of magnitude fluctuations in the year-class sizes. There is evidence of some density dependence in age at maturity for males (Fig. 6) but it is not clear-cut. Using weight at age during July for the mature portion of the female population potential egg production was estimated using the fecundity-weight relationship given by Messieh (1976) for S.W. Nova Scotia

$$\log F = -3.07 + 1.37 \log W$$

where F = #s of eggs  
W = weight in kg

Since Messieh used only pre-spawning fish sampled in July and August the July weight at age used in this analysis is appropriate. This equation assumes that the fecundity weight relationship is constant, which will be investigated starting in 1979 reproductive season.

The two estimates of egg production, for the years 1972 to 1976, from cohort analysis spawning stock and from larval data, are shown in Table 2. The cohort analysis egg production is consistently an order of magnitude larger than that estimated from larval abundance. In the larval derived estimate, egg production has been maximized by using high egg bed mortality. The cohort analysis derived estimate of potential eggs is minimized by taking the lowest estimate of population size. The discrepancy can be explained in two not mutually exclusive ways. The total distributional range of the larvae derived from the spawning stock may not have been surveyed. Under-surveying in the offshore direction is unlikely judging from surveys covering a broader area (Sameoto, 1972; Tibbo *et al.* 1958). The nearshore abundances may however be underestimated since the Prince is limited to a minimum depth and minimum distance from shore, and high abundances are found at many of the near shore stations. Studies on larval distribution in the St. Lawrence Estuary (H. Powles, pers. comm.) indicate that although yolk-sac larvae may be extremely abundant over egg beds near shore (depths <5 fm), later stage larvae are rarer near shore than off shore. Also, when catches are integrated over the water column, shallow stations usually have lower catches (no/m<sup>2</sup>) than deep stations. Thus, this source of error may not be extremely important. Nevertheless the possible under estimation of larval abundance in shallow near shore water will be checked concurrent with the next autumn survey. Avoidance of the sampling gear by larvae is an additional bias that has not been accounted for in this analysis. Some studies based on day-night catch rate differences (e.g. Bridger 1956, Isaacs 1966) show much higher catches at night, probably due to avoidance. In contrast Lough *et al.* (1979) indicated no significant day-night differences in herring larval catches, but show no data. If day-night differences tend to increase with larval size, a serious source of bias to mortality estimates may be introduced.

If the larval abundances mortalities and egg production estimates are of the right order of magnitude the catch being incorporated into the 4WX "stock" (for management purposes) comprises fish from more than the S.W. Nova Scotia spawning stock. The constancy in the ratios of the estimates of egg production over the five years (C.V. = 27%)<sup>1</sup> is reassuringly low in comparison to the much more sophisticated international herring larval survey on Georges Bank (C.V. for same ratio = 267%, Lough *et al.* 1979). The low normalized variance of the

1. Coefficient of variation (C.V.) is the standard deviation/meanx100

Bay of Fundy larval survey "back calculated eggs" to VPA potential ratio suggests that the higher station density in this survey produce significantly better estimates of larval population abundance than the Georges Bank survey with a lower station density.

Given the number of assumptions incorporated into the back calculation, and the variance associated with these assumptions, it is the order of magnitude comparisons, rather than the year to year changes, that one can have confidence in. It is surprising then that there is a suggestive relationship between autumn larval abundance and potential eggs estimated from cohort analysis mature stock (Fig. 7). The relationship becomes worse when back calculation adjustments are made. This worsening of the relationship may be due to errors in the assumptions (e.g. constant peak date of spawning, constant daily larval mortality from year to year etc.). With adequate information concerning the assumptions the autumn survey should provide improved estimates of spawning stock size.

### Recruitment prediction

Total larval abundance was estimated from the spring surveys using the same areal expansion method described above. The unadjusted larval population abundances indicate a possible positive relationship with cohort analysis age 2 population size (Fig. 8, bottom). The lowest year-class at age 2 (1974) is associated with the 1975 spring survey of minimum recorded larval abundance. When the larval estimates are adjusted to a fixed day (March 15) the tenuous relationship is lost. This again may be due to incorrect assumptions (e.g. constant larval age at March 15). The 1976 year-class at age 2 is reported to be very large. The inclusion of the results of the spring 1977 survey will indicate if the survey on larvae at this age is a predictive indicator of year-class strength (the full range of recruitment being covered).

### Discussion

Lough (1978) concludes that, for Georges Bank herring, autumn larval abundance is well correlated with spawning stock size (from VPA calculations) and that overwintering larval mortality defines subsequent year-class strength. This conclusion was supported by Graham and Davis (1971) for estuarine larval herring populations in the Gulf of Maine. Therefore spring larval surveys should be the earliest indicators of subsequent recruitment to the fishery. The preliminary data in this paper do not contradict such arguments but are certainly not conclusive in any statistical sense. Attempts to refine the larval abundance estimates by adjusting to standard ages, and the back calculations, diminish the relationships with subsequent recruitment, and spawning stock egg production, respectively. This may be due to lack of accuracy in the assumptions applied.

The back-calculation "exercise" indicates that the supportive information necessary for back-calculation from the autumn larval survey is not being adequately collected. The following information is needed:

1. Date of peak spawning
  - (a) maturity stage analysis
  - (b) drift gillnet daily catch distribution from purchase slips
2. Bottom temperature monitoring of major spawning beds
3. Annual fecundity-weight relationship
4. Hatching time estimates
5. Near shore shallow water larval abundance
6. Egg mortality (perhaps impossible)
7. Improved estimate of daily larval mortality (repeated autumn survey at short intervals).

The first three points should be considered each year the surveys are carried out, the remainder special projects. Thus this preliminary look at the larval data suggests what data needs to be collected to optimize the use of larval survey data for assessments.

#### Acknowledgements

We appreciate the excellent data analysis by J. Simon and A. Sinclair in the preparation of this work and the review by H. Powles whose thoughtful suggestions improved the manuscript.

## References

- Caddy, J.F. and T.D. Iles. 1973. Underwater observations on herring spawning grounds on Georges Bank. ICNAF Res. Bull. No. 10: 131-139.
- Cushing, D.H. 1970. The regularity of the spawning season in some fishes. J. Cons. Int. Explor. Mer. 33, 81-97.
- Graham, J.J. and C.W. Davis. 1971. Estimates of mortality and year-class strength of larval herring in western Maine, 1964-67. Rapp. P.-V. Reun. Cons. Int. Explor. Mer. 160:147-152.
- Isaacs, J.D. 1964. Night-caught and day-caught larvae of the California sardine. Science 144:1132-1133.
- Laevastu, T., and I. Hela (1970). Fisheries Oceanography. Fishing news (Books) Ltd. London 238 p.
- Lough, R.G. (1978). Larval herring studies in the Georges Bank - Gulf of Maine area. Ices 1978 mimeograph.
- Lough, R.G., G.R. Bolz, M.D. Grosslein and D.C. Potter 1979. Abundance and survival of sea herring (Clupea harengus L.) larvae in relation to environmental factors, spawning stock size, and recruitment for Georges Bank area, 1968-1977 seasons. ICES/ELH Symp./DS:7
- Messieh, S.N. 1976. Fecundity studies on Atlantic herring from the Southern Gulf of St. Lawrence and along the Nova Scotia coast. Trans. Am. Fish. Soc. 105:384-394
- Sameoto, D.D. 1972. Distribution of herring (Clupea harengus) larvae along the southern coast of Nova Scotia with observations on their growth and condition factor. J. Fish. Res. Board Can. 29:507-515.
- Saville, A. 1956. Eggs and Larvae of haddock (Gadus aeglefinus L.) at Faroe. Scott. Horne Dept. Mar. Res. 1956(4), 27 p.
- Sette, D.E., and E.H. Ashlstrom. 1948. Estimation of abundance of eggs of the Pacific pitchard (Sardinops caerulea) off southern California during 1940 and 1941. J. Mar. Res. 7:511-542.
- Sinclair, M., K. Metzals and W. Stobo. 1979. 4WX herring assessment. CAFSAC Research Document 79/19
- Tibbo, S.N., J.E.H. Legaré, L.W. Scattergood and R.F. Temple 1958. On the occurrence and distribution of larval herring (Clupea harengus L.) in the Bay of Fundy and the Gulf of Maine. J. Fish. Res. Bd. Canada 15:1451-1469.

Table 1. Bay of Fundy larval herring cruises using standard grid adopted by Stobo in 1972.<sup>1</sup>

CRUISE	DATE	GEAR	NUMBER OF SETS
EE PRINCE 109 <sup>2</sup>	Nov. 16-24, 1972	Bongo 333 and 505	130
EE PRINCE 111/112 <sup>2</sup>	Mar. 4-11, 1973	Bongo 333 and 505	129
EE PRINCE 125 <sup>2</sup>	Oct. 28-29, 1973	Bongo 333 and 505	18
EE PRINCE 127 <sup>2</sup>	Nov. 20-27, 1973	Bongo 333 and 505	132
EE PRINCE 128 <sup>2</sup>	Jan. 10-11, 1974	Bongo 333 and 505	19
EE PRINCE 130 <sup>2</sup>	Feb. 8-14, 1974	Bongo 333 and 505	76
EE PRINCE 132 <sup>2</sup>	March 6-12, 1974	Bongo 333 and 505	94(22) <sup>4</sup>
EE PRINCE 145	Oct. 16-23, 1974	Bongo 333 and 505	132
EE PRINCE 147	Nov. 5-12, 1974	Bongo 333 and 505	100
EE PRINCE 151	April 2-11, 1974	Bongo 333 and 505	130
EE PRINCE 160	Nov. 5-13, 1975	Bongo 505	103(13)
EE PRINCE 163	March 24-31, 1976	Bongo 505	131
EE PRINCE 175	Nov. 10-17, 1976	Bongo 505	123
EE PRINCE 180 <sup>3</sup>	March 22-30, 1977	Bongo 505	98
EE PRINCE 186 <sup>3</sup>	Aug. 9-16, 1977	Bongo 505	132
EE PRINCE 190 <sup>3</sup>	Oct. 18-25, 1977	Bongo 505	128
EE PRINCE 193 <sup>3</sup>	March 15-April 1, 1978	Bongo 505	113
EE PRINCE 202 <sup>3</sup>	August 15-20, 1978	Bongo 333 and 505	115
EE PRINCE 207 <sup>3</sup>	Nov. 1-7, 1978	Bongo 505	115

<sup>1</sup> Information in this table was provided by P. Hurley

<sup>2</sup> Length frequency information available

<sup>3</sup> Samples not yet processed

<sup>4</sup> Numbers in brackets indicate the number of unoccupied stations on the standard grid that were estimated from surrounding stations

Table 2 Preliminary Back calculation of egg production in relation to VPA potential egg production.

Cruise mid-date	Date of 'peak' hatching <sup>1</sup>	Days of larval mortality	Corrected larval abundance <sup>2</sup>	Larvae hatched <sup>3</sup>	Hatching duration (days)	Eggs spawned <sup>4</sup>	Cohort analysis <sup>5</sup> potential egg production	Ratio <sup>6</sup>
November 20 '72	Sept. 15 '72	67	$1.52 \times 10^{11}$	$2.22 \times 10^{12}$	15	$6.34 \times 10^{12}$	$5.68 \times 10^{13}$	9.0
November 24 '73	Sept. 14 '73	72	$1.16 \times 10^{11}$	$2.07 \times 10^{12}$	14	$5.52 \times 10^{12}$	$5.77 \times 10^{13}$	10.5
November 9 '74	Sept. 14 '74	57	$3.96 \times 10^{11}$	$3.87 \times 10^{12}$	14	$10.31 \times 10^{12}$	$9.46 \times 10^{13}$	9.2
November 9 '75	Sept. 13 '75	58	$2.39 \times 10^{11}$	$2.34 \times 10^{12}$	13	$5.81 \times 10^{12}$	$9.51 \times 10^{13}$	16.4
November 14 '76	Sept. 14 '76	62	$2.13 \times 10^{11}$	$2.54 \times 10^{12}$	14	$6.77 \times 10^{12}$	$8.47 \times 10^{13}$	12.5

<sup>1</sup> assumed date of peak spawning is September 1. Lurcher's bottom temperature during September estimated from St. Andrews temperature. Bottom T (Lurcher's) =  $0.125 + 1.06$  (Surface T (St. Andrews)),  $r = 0.76$ . Hatching time estimated from following relationship,

$$\text{Hatching time} = 4 + 44.7^{-0.167t} \text{ where } t = \text{Lurcher's bottom temperature.}$$

<sup>2</sup> 505 mu mesh samples used. Areal expansion adjusted upwards by 9% to account for larvae outside standard grid.

<sup>3</sup> Daily larval mortality = 0.04 (mean value of Georges Bank estimates of larval mortality during first 3 months, equal to one estimate calculated from present data series (autumn 1972)).

<sup>4</sup> Assumed a daily predation of 7%. This is a major assumption based on Fragmentary information. By changing from 7% to 2% the estimate varies by "50%.

<sup>5</sup> Calculated using fecundity - weight relationship of Messieh (1976), maturity ogive 0.33 (2 yr), 0.89 (3 yr), fully mature at 4. Population numbers from option 1 (with adjusted effort) (table 8 in Sinclair et al. 1979).

<sup>6</sup> Cohort analysis potential egg production + back calculated eggs.

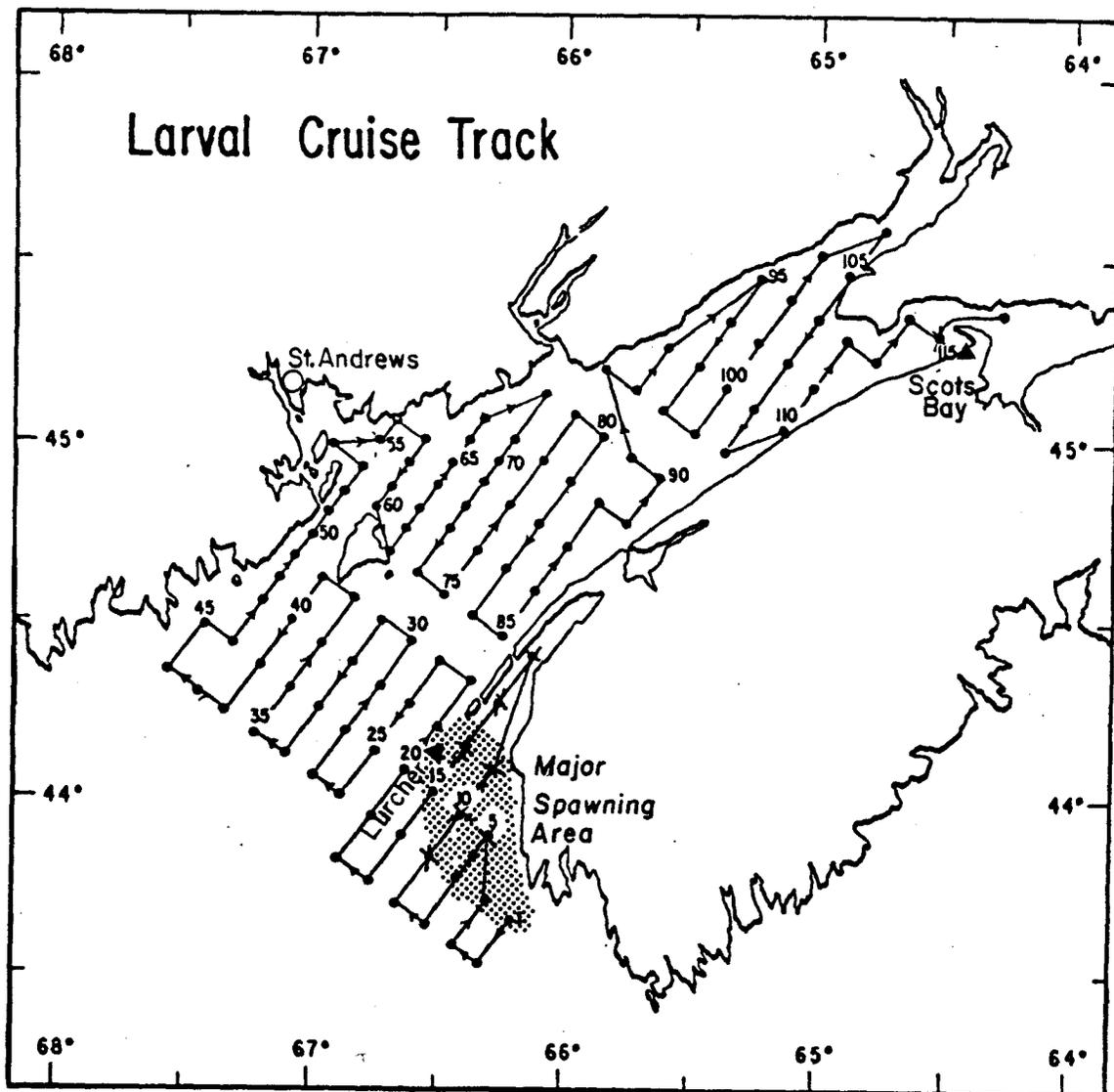


Fig. 1. The larval sampling stations in the Bay of Fundy are presented along with the proposed cruise track. Selected station numbers are also given for reference.

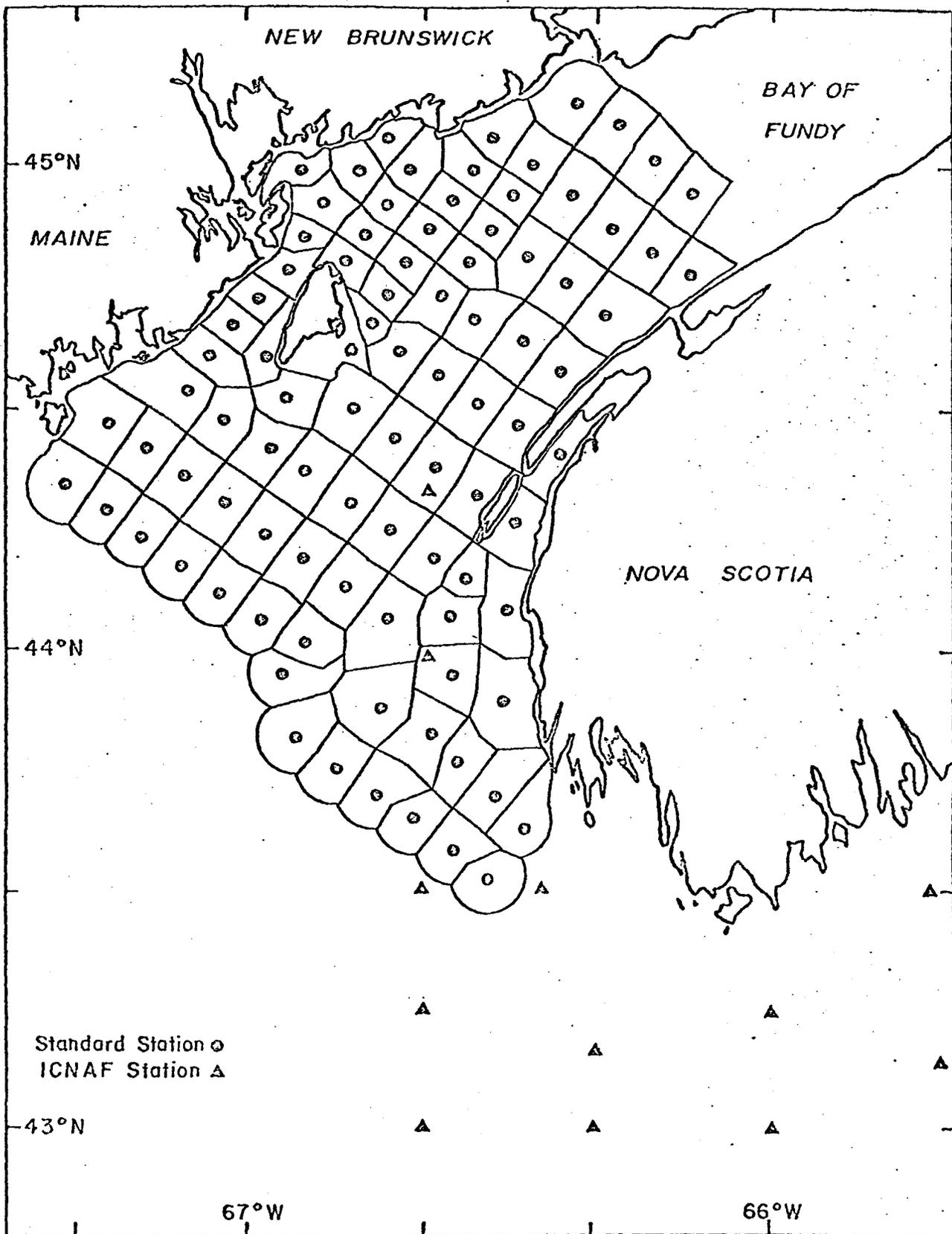
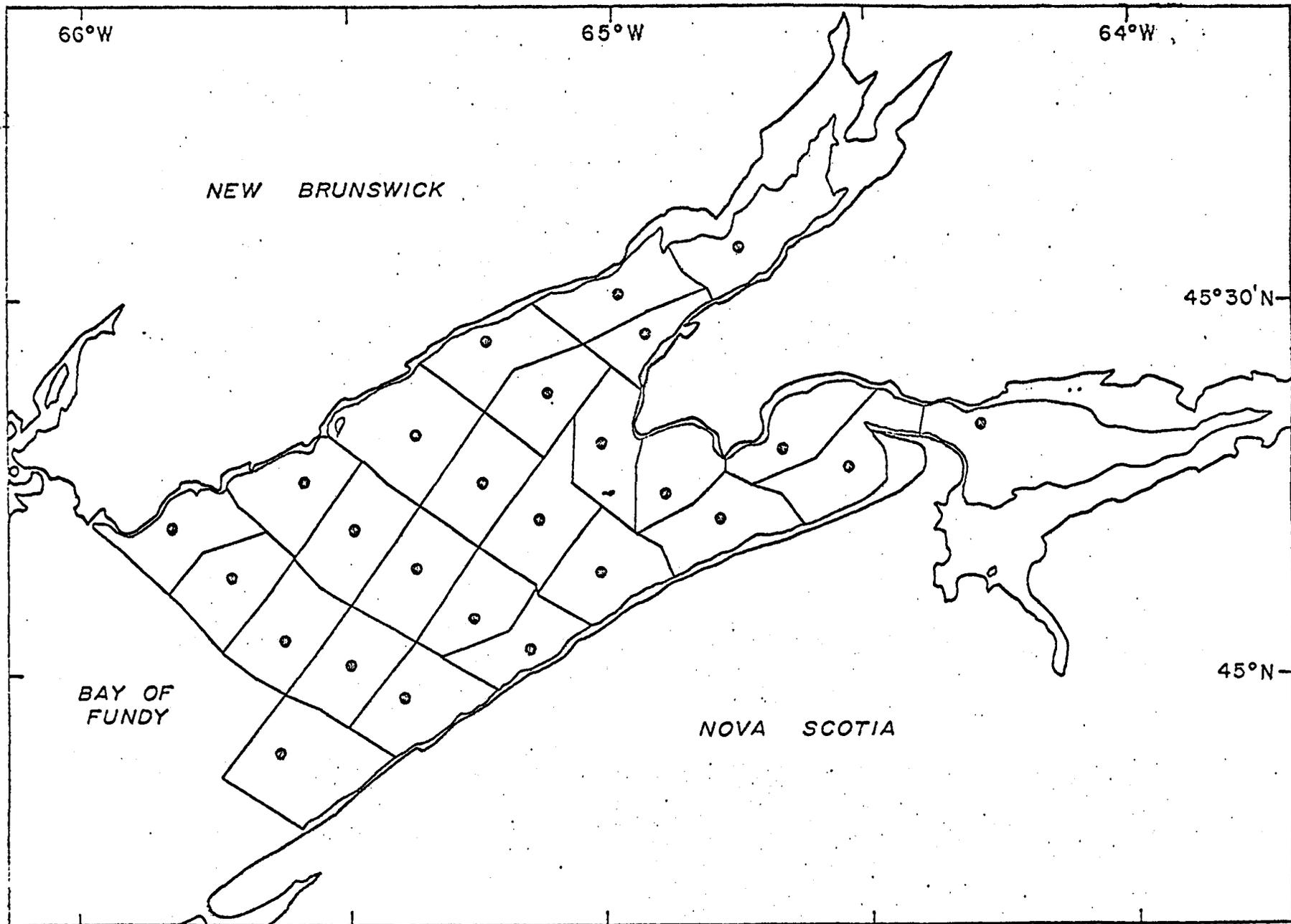


Figure 2. Standard areas represented by each of the stations occupied in the survey.



Continued

Figure 2. Standard areas represented by each of the stations occupied in the survey.

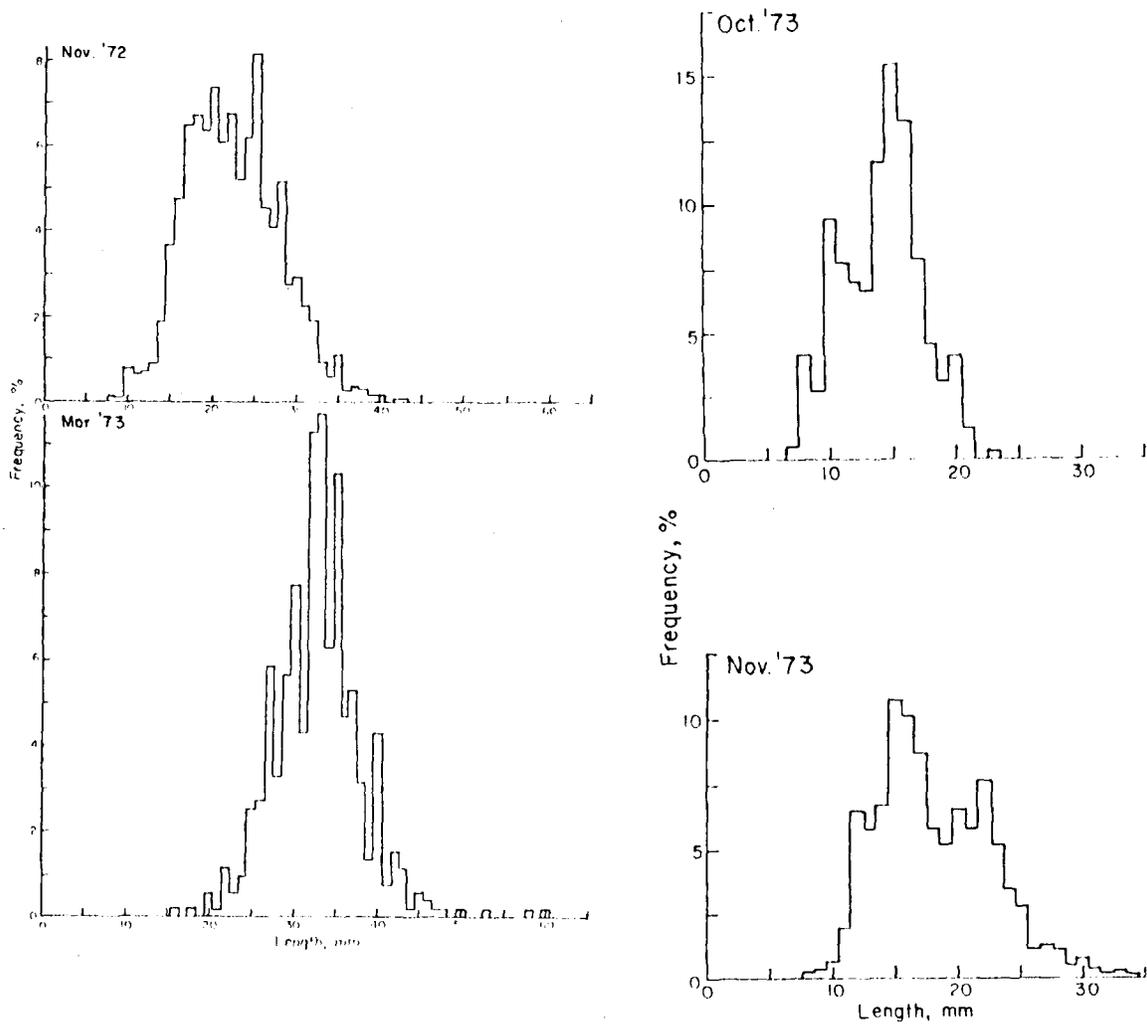


Figure 3. Bay of Fundy herring larvae % length frequencies for four cruises.

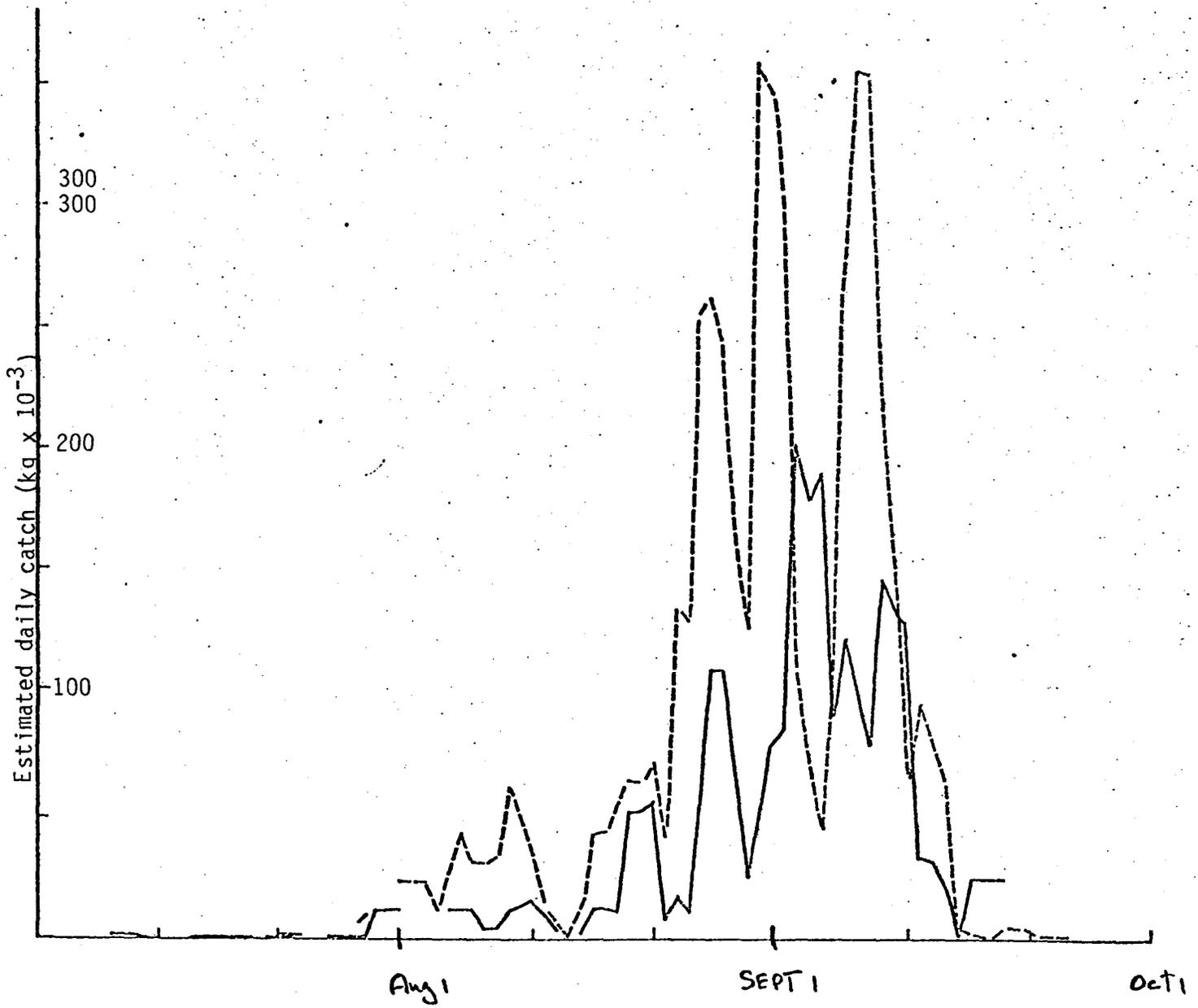
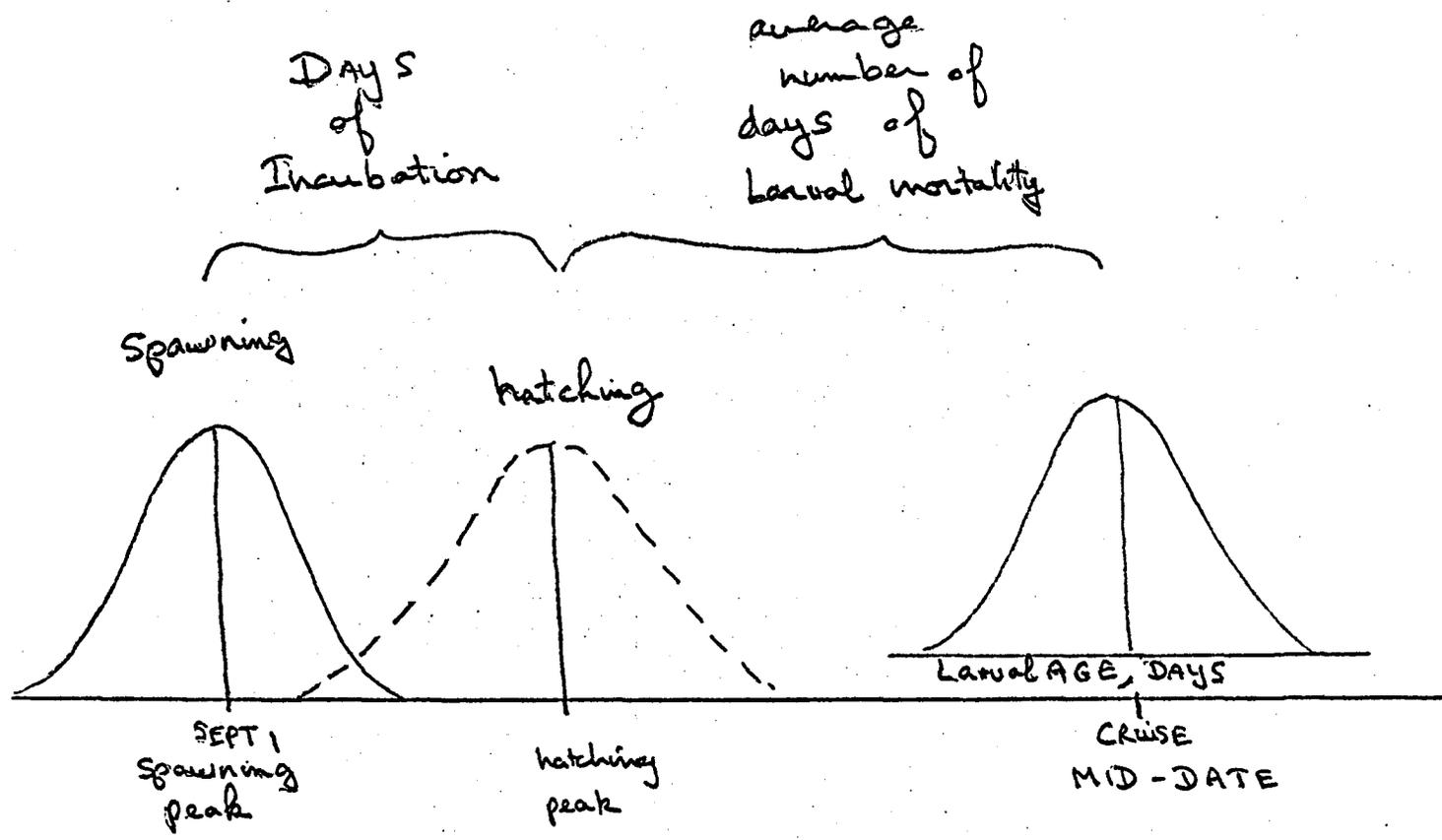


Figure 4 1977 Drift gillnet catch on spawning fish off S.W. Nova Scotia (dotted line represents statistical district 33, solid line district 34)

Figure 5 Representation of assumptions involved in back-calculation method



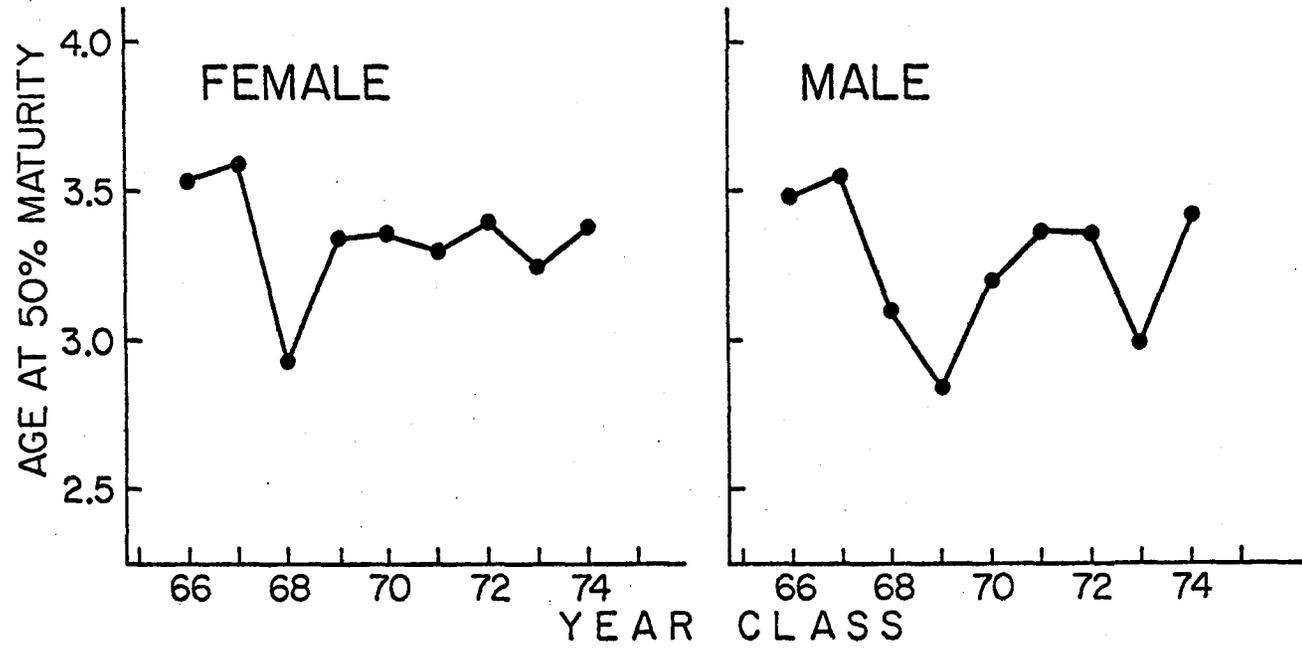


Figure 6. Age at 50% maturity for year-classes 1966 to 1974

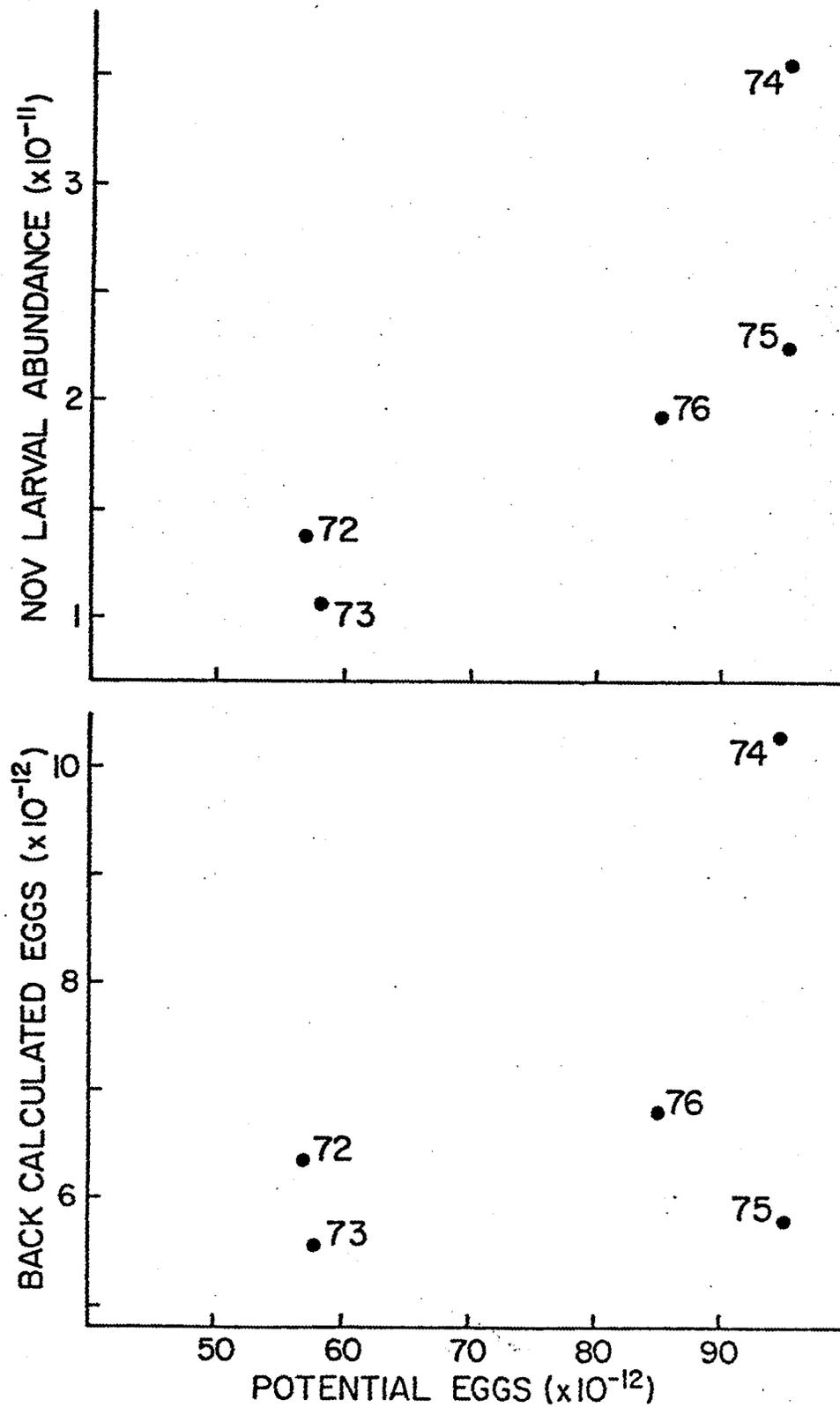


Figure 7. Relationship of November larval abundance (upper) and back-calculated eggs (lower) to potential egg production as estimated from cohort analysis.

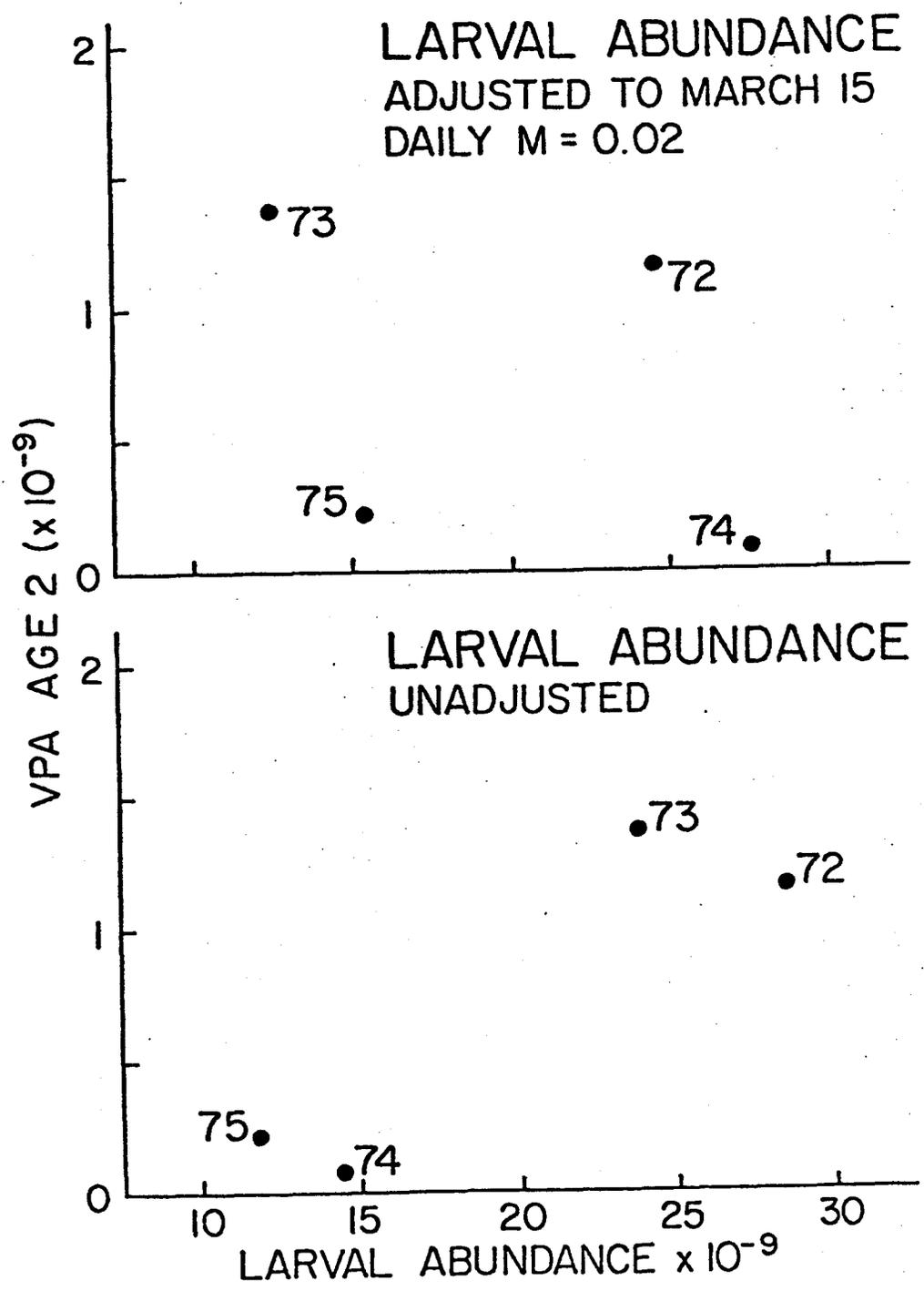


Figure 8. Relationship between cohort analysis age 2 year-class estimates and spring survey larval abundances (unadjusted in lower half and adjusted to a common date in upper half). The years indicated are the survey years.