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Review of abundance indices for the 4WX herring assessment

by

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ABSTRACT

Early analytical assessments of 4WX herring (1974-82) were calibrated using catch/effort indices from weir and purse seine fisheries. These were replaced in 1983 by use of a larval abundance index (autumn larval abundance related to VPA derived estimates of spawning stock biomass). Recently, biomass estimates from an acoustic survey of overwintering herring has been used as well. This paper presents the results of a re-evaluation of these and other potential abundance indices which may be of use for either calibration of the VPA or predicting recruitment. The most useful approach to tuning in the short term would appear to be use of a combination of acoustic, larval and research ground trawl survey indices. There is no obvious way of providing a recruitment index in the near future.

RÉSUMÉ

Les premières évaluations analytiques du hareng de 4WX (1974-1982) étaient étalonnées à l'aide des indices prises/effort caractérisant les pêcheries fixes et la pêche à la senne coulissante. Ces évaluations ont été remplacées en 1983 par l'utilisation de l'indice d'abondance larvaire (estimations dérivées de l'abondance larvaire automnale reliés à l'APV de la biomasse du stock de reproducteurs). Récemment, on a également utilisé des éstimations de la biomasse à partir de relevés acoustiques du hareng hivernant. Dans le présent article, on présente les résultats d'une réévaluation de ces estimations et d'autres indices d'abondance possibles qui peuvent être utilisés soit pour étalonner l'APV soit pour prévoir le recrutement. L'approche la plus utile pour l'étalonnage à court terme serait l'utilisation d'une combinaison d'indices des relevés acoustiques, des relevés larvaires et des relevés de recherche par chalutage sur le fond. Il n'y a pas de façon absolument évidente de fournir un indice de recrutement dans un avenir rapproché.

INTRODUCTION

Calibration of 4WX herring assessments since 1983 has relied primarily on the relationship between an index of autumn larval abundance (LAI) and VPA derived estimates of the spawning stock biomass (SSB). In recent years, tuning has become increasingly difficult. The LAI/SSB relationship seems to have been poorer, and this has raised concerns over the validity of the relationship, its method of calculation, and use in tuning.

In addition, there has been an increasing need for an estimate of the size of pre- and partially recruited age groups, which have been estimated to comprise the major portion of the population and therefore to have a large impact on forecast ability. In 1988, the Pelagic Subcommittee of CAFSAC recommended a re-evaluation of existing data including acoustic, logbook, and larval survey series to provide more information on abundance and consideration of development of another abundance estimate - preferably one of relevance to recruiting ages which are a major portion of this fishery.

In this paper we document the history of tuning in this assessment and summarize the recent re-evaluation of existing indices and consideration of potential indices for 4WX herring.

HISTORY OF TUNING IN THE 4WX ASSESSMENT

A number of tuning methods have been used since 1974 (Tables 1, 2). Initially, weir catch rates were used to indicate relatively large incoming year-classes, and to modify F values on those year-classes in uncalibrated cohort analyses. From 1978-80, cohort analyses were calibrated, primarily using regressions, with standardized purse seine catch/effort series. This index was rejected, however, in 1981 due to the suspected impact of misreporting and market constraints on purse seine catch rates.

A larval abundance index based upon annual autumn surveys since 1972 was used in 1981, but was rejected in 1982 as a result of an apparent sharp decline in the 1981 point. For that year (1982 assessment), gillnet and N.B. weir CPUE series were used, but these were rejected in 1983 and 1984 in favor of the larval abundance index which has been used since.

Other potential abundance indices have been considered from time to time (Table 2), but have not been used in tuning.

POTENTIAL ABUNDANCE INDICATORS

A review of tuning in other herring assessments at CAFSAC, at ICES (South of 62°N Working Group; Anon. 1988) and in the USA (Fogarty 1990) yields the following list of indices which have been used (or at least considered) within the last 5 years:

Larval abundance index
Larval production estimate
Acoustic abundance of adults
Acoustic recruitment index
Young fish survey (IKMT) recruitment index
Commercial effort (days fished)
Commercial gillnet catch rates
Index fishermen gillnet catch rates
Bycatch in groundfish research surveys
Egg bed surveys

A REVIEW OF ABUNDANCE INDICES FOR THE 4WX ASSESSMENT

1) LARVAL ABUNDANCE

Rationale

Indices based upon larval abundance have several potential advantages including:

i) independent of commercial fishery

ii) efficiently and relatively inexpensively surveyed, using conventional plankton techniques

iii) allow evaluation of a life-history stage at which year-class strength may be determined and, if used to forecast, allow the maximum advance knowledge of recruitment to the fishery.

Additional rationale for herring comes from the persistence or "retention" of larvae in well defined, discrete stock aggregations for considerable lengths of time (Iles and Sinclair 1982; Sinclair and Tremblay 1984; Sinclair and Iles 1985).

Larval abundance estimates or indices may be used in two ways: to forecast recruitment and to hindcast spawning stock size (Fig. 1a).

Hindcasting spawning stock size requires assumptions about hatching rates from deposited spawn, and mortality to the time of survey. Absolute estimates of spawning stock size require an estimate of fecundity to translate egg production into spawning biomass. Such estimates would be used to calibrate the mature age groups of the VPA.

Recruitment forecasting assumes that year-class strength has already been determined at the time of survey or, 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.

Figure 1b illustrates the relative constraints placed on the timing of the surveys as a result of the assumptions involved in forecasting and hindcasting. Surveys used for recruitment forecasting should become more reliable later in the larval stage because of the assumptions 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. 1988). 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 (as has been used in this assessment, e.g. Iles et al. 1985). 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.

Data available

Comprehensive surveys of the Bay of Fundy began in 1969 and standard surveys of 116-163 stations (Fig. 2) have been undertaken annually, during late October and early November, since 1972 (Table 3a). A second spring series was undertaken during March from 1975-84 (Table 3b). Sawtooth oblique tows 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 retrieval time was less than 10 min, the gear was payed out again for successive hauls until a minimum total retrieval time of 10 min was obtained. Samples have been stored in 5% buffered formalin and sorted for all herring and herring-like (includes Clupeidae and Osmeridae) 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 (no. m^{-2}) based on the mean depth during the occupation of each station.

Indices

i) Traditional larval abundance index (LAI)

The traditional larval index has been calculated as the mean of the larval density (no.m^{-2}) for all stations sampled in autumn surveys (see, for example, Iles et al. 1985). Both geometric and arithmetic means have been used. In the 1988 assessment (Stephenson and Power 1988), the index was recalculated on the basis of fewer stations in order to exclude those which had not been sampled in some years or which were outside of the stock area (i.e. coastal Maine). This index included a number of stations outside of the larval retention area and, until 1988, included a few stations in what is now known to be part of the 5Y stock area (see Chenoweth et al. 1989).

In 1989, two additional series were analyzed:

ii) Total larval abundance (TLA)

Total larval abundance (TLA) was estimated for each year by contouring survey data. Larval density (number per m^2; aggregated by 1-mi^2 grid) was contoured at five levels using ACON (GAP Black, pers. comm.). The program creates a response surface using triangulation. Areas were digitized and multiplied by median density per stratum to estimate total number of larvae. Two indices were calculated: TLA-1 based on an area covered in all surveys in the series; and TLA-2 from a shorter time series of surveys (since 1980) which were extended to the southeast to cover the entire larval distribution.

iii) Larval retention area (LRA)

The area of larval occupation was digitized as outlined above for the area occupied by greater than 5 m^{-2} (fall) and 0.5 m^{-2} (spring). Areas of the two aggregations of larvae (upper and lower Bay of Fundy) were calculated separately.

The resulting larval series are presented in Table 4 and Fig. 3. It was concluded that modifications to the larval abundance index (total abundance TLA-1 and TLA-2) offer little, if any, improvement over the traditional index.

1989 larval survey

The 1989 Bay of Fundy larval herring survey was conducted between Oct. 23 and Nov. 9 (E. E. PRINCE 391). Coverage included additional stations to the south and east (to define the extent of the larval aggregation) (Fig. 4a) and duplicate coverage of a 7885 km^2 area off SW Nova Scotia using random station locations (Fig. 5) (Sochasky, MS). All 79 of the traditional index stations (Fig. 4b) were sampled. The LAI from this survey was 54.5 - a considerable decrease from the 1988 value, but the second highest of the 18-yr time series (Table 3a).

Random vs fixed station design

In 1988 and 1989 surveys, a comparison was made of the performance of fixed vs random station sampling within a reference area or stratum which contained the traditional patch of high larval density (43°10' to 44°30'N and 66°10' to 66°50'W). For each year, the results of fixed stations have been compared with results from a similar number of randomly placed stations in the same area (Fig. 5).

	1988		1989	
	random	fixed	random	fixed
n	52	47	51	42
arith. mean	300.81	235.53	150.08	156.03
SE	72.10	38.62	25.13	23.33

Backcalculation of spawning stock biomass from larval abundance

We have attempted to work back from larval abundance to spawning population biomass as follows:

i) Calculate number of larvae (N_t)
   a) using digitized areas of larval abundance x mean abundance
   or b) using mean (and variance) of entire survey x survey area.

ii) Calculate number of larvae at hatching (N_0) assuming an instantaneous mortality rate (Z) = 0.06 (from Chenoweth et al. 1989) by:
   a) assuming a mid-date of hatching prior to mid-September (i.e. $t \geq 45$)
   or b) calculating time (t) since hatching dates from length structure of larvae assuming a growth rate of .24 mm d^{-1} and a hatching size of 5 mm (Chenoweth et al. 1989).

iii) Calculate spawning females, assuming a fecundity relationship from Messieh (1976) for SW Nova Scotia (ln fecundity = -22.71 + 4.75 ln length), then total spawners assuming a sex ratio of 50%.

Backcalculation of this type is very sensitive to errors in mortality rate, and does not include any mortality prior to hatching. We consider it premature to attempt backcalculation until larval mortality is better understood.

2) WEIR CATCH RATES

The 4WX fishery contains two weir components. Approximately 240 weirs are located on the shore and islands west of Saint John on the New Brunswick side of the Bay of Fundy. Approximately 15 others are located between Yarmouth and Digby in southwest Nova Scotia.

The New Brunswick weir fishery has averaged 23,500 t in recent years (since 1970). Fish are predominantly 2-year-olds and are marketed mostly as sardines. The N.B. weir fishery is thought to rely on fish from several populations, including coastal USA (5Y) and, historically, Georges Bank (5Z). For this reason, N.B. weir landings have been excluded from 4WX stock totals and have recently been considered inappropriate for use in tuning the 4WX assessment. There is some rationale for reconsideration of its use in that there is a definite synchrony in strong and weak year-classes among populations (e.g. Anthony and Fogarty 1985). In addition, the weir fishery has appealing features including:

- long time series
- free of gear changes
- relatively stable effort
- lack of misreporting.

The Nova Scotia weir fishery has had landings averaging 5750 t (since 1970) comprised mostly of age 2-3 fish. Historical criticism of an index based on this fishery has focused on the strong influence of market demand producing variable landings. In addition, both weir series may suffer from potential variability in availability (behavior) of fish.

We have re-examined weir indices in relation to stock size, and in terms of their use in predicting year-class size (see section on recruitment indices).

Catch-per-unit effort has been calculated as numbers per weir for ages 1-3 in the N.B. weir fishery (Table 5a) and for ages 1-3 and all ages in the Nova Scotia weir fishery (Table 5b) (Fig. 6).

3) ACOUSTIC SURVEY

Background

Early attempts to survey juvenile and summer aggregations of 4WX herring acoustically were unsuccessful due to:

1) inconsistent distribution of fish
2) large survey area
3) interference with an intense commercial fishery on spawning grounds.

By contrast, surveys of overwintering aggregations were able to find and survey herring, particularly in Chedabucto Bay, N.S. (summarized by Buerkle 1987). Surveys in 1981 and 1982 were designed to cover the area of the historical winter purse seine fishery as estimated from catch reports since 1971. This area extended about 160 km along the shore of N.S. from Liscomb Island to Forchu Head and offshore about 50 km.

1981-83. The 1981 survey covered the area but found the herring concentrated in one small (30 km^2) area. The 1982 attempt failed completely; the boat was unable to survey because of windy weather. The 1983 survey was a more weather-resistant survey track and again covered the area but found negligible quantities of fish. The fishery, however, was making good catches at night in an area where the survey found no fish during the day. The 1981 and 1983 results led to the conclusion that herring are concentrated in small areas and are not reliably available for acoustic detection during the day.

1984-85. In 1984, the emphasis was changed from surveying the whole area to replicate night time surveys in the areas of fish concentration as identified by the commercial fishing effort. The 1984 and 1985 surveys were successful in producing nightly replicate estimates of fish abundance in the areas of fish concentration. They also surveyed the larger area of the historical fishery but found no significant quantities of herring outside the areas of major concentration. This supported the conclusion that surveying the area is ineffective and that the surveying effort should be focused on the known areas of fish concentration.

1986-87. The 1986 and 1987 surveys produced replicate estimates of herring abundance in the areas of commercial fishing in Chedabucto Bay and surrounding areas but did not survey the whole area of the historical winter fishery.

1988. A survey in January 1988 was hampered by equipment failure, and no abundance estimate was made.

1989. A successful acoustic survey of Chedabucto Bay was undertaken in January 1989 (Buerkle 1989). That survey employed a random parallel design recommended by CAFSAC and improvements in processing, particularly with respect to bottom echo detection.

An extension of the survey to Sydney Bight gave no indication of herring east of Chedabucto Bay. An additional experimental survey in February documented three aggregations in the Grand Manan area of the Bay of Fundy and estimated a total of approximately 100,000 t. Biomass of the Chedabucto Bay aggregation was estimated to be 450,000 t (Table 6).

1990. The annual Chedabucto Bay survey undertaken between January 4 and 26 (Buerkle 1990; Table 6, Fig. 7) indicated a biomass of approximately

194,000 t, compared with 450,000 t in 1989. This may have been the result of unusual distribution of the fish (fishermen report higher abundance in December), and brings into question the validity of Chedabucto Bay as an index area.

Possible improvements to the acoustic survey

The acoustic survey has become one of the most valuable abundance indicators. Work on acoustic techniques and on application to 4WX herring has resulted in improvements in survey design and protocol which have increased the validity of the surveys.

The winter survey may be missing a portion of the population, and should be expanded if herring distribution varies. Alternatively, it may be possible to survey spawning grounds. Earlier attempts were hampered by incomplete knowledge of the distribution of spawning aggregations and by the high density of vessels on spawning grounds during the survey. However, the situation has changed in the last 5 yr in that 1) spawning areas have been documented using the new purse seine logbook (Power and Stephenson 1990) and 2) there have been fewer vessels fishing on the spawning grounds with the recent inactivity of the gillnet fleet (Stephenson and Power 1989). A survey of spawning grounds would be valuable too in providing information on individual components of the 4WX stock complex, which would be useful in management of spawning units.

4) PURSE SEINE CATCH/EFFORT DATA

The purse seine segment dominates the 4WX herring fishery and, in recent years, has taken more than 80% of the stock catch.

While a considerable amount of data has been collected routinely from the 4WX purse seine fishery, the quality and quantity of this information has not always been adequate. Previous assessments of this stock (e.g. Stephenson et al. 1985) discussed the high degree of misreporting that has at times occurred in the purse seine fishery. In some years, statistical information was incomplete, as was information from logbooks. As part of an effort to improve the quality of biological information, a new purse seine logbook was designed and implemented for the 1985 4X summer fishery (Power and Stephenson 1986). At the same time, several operational initiatives were put into effect, including submission of logs on a weekly basis as a condition of license, which reduced misreporting and improved logbook return. The result was a significant improvement in the amount of catch information from the purse seine fishery (Power and Stephenson 1986, 1987).

Several logbook formats had been in use in the 4WX fishery prior to 1985. These formats lacked places for information on a number of important activities for the herring purse seiners, especially searching time. The revised log had several improvements, including fields for search time, markets sought and set specifics laid out on one page for each trip or fishing night.

The historical data series allowed only rough CPUE calculations of catch per night or catch per set, and these were in some areas based upon a small portion of the total fishery (i.e. incomplete logbook information; Table 7). Since 1985, we have been calculating what we hope may be more relevant and useful indices: catch per hour of search time and sets per hour searched (Table 7). These are available by fishing ground and month in other documents (Power and Stephenson 1986, 1987, 1990; Stephenson and Power 1988).

5) GROUNDFISH SURVEY BYCATCH

Fogarty et al. (1990: SAW 9) used a US (NEFC) bottom trawl survey abundance index (mean weight of herring (kg)/tow) to tune the most recent US herring assessment.

Bottom trawl surveys of the Scotian Shelf and Bay of Fundy have been conducted in spring, summer and fall for a number of years:

Survey	Target dates	Years
Spring	March	1979-84
Summer	July	1978-89
Fall	October	1979-84

Standard protocol involves tows of standard length with a Western IIA bottom trawl at random stations within consistent strata (as summarized by Doubleday 1981) and often results in a herring bycatch. Indices based on number of herring per standardized tow (from STRAP) have been calculated for the entire area (4VWX) and strata 80-95 of 4X (Table 8, Fig. 8). Concern regarding this index has been expressed because of the low numbers of herring taken in some years, over possible set, vessel and strata effects and that the peak years in groundfish survey results were offset from those of the larval index.

Relative performance indices

Of the available indices, larval survey, acoustic survey and ground trawl survey are considered to be most useful. These are compared in Fig. 9.

RECRUITMENT INDICES

There is no established recruitment index for the 4WX assessment. This is a major deficiency, particularly as the fishery relies so heavily on incoming year-classes. Herring of age 2 form a significant portion of the 4WX fishery and ages 3 or 4 often dominate the catch. Therefore, an early recruitment prediction is required.

As outlined in Fig. 1, recruitment prediction from young stages (early larvae, for example) may be poor because of the potential for variable mortality during larval and juvenile stages. Late stages, however, have proven to be hard to survey in comparison with early larvae.

The following is an assessment of the existing and potential surveys as recruitment indicates:

1) Larval survey - spring

The existing series of spring larval survey data (1975-84) does not appear to forecast recruitment (as VPA-derived age 1 or 2; Fig. 10). There are two possible explanations:

1) year-class strength has not been determined by the late larval stage (i.e. not during the juvenile stage, after metamorphosis);
2) there was a problem with sampling or coverage in the spring survey such that the results do not reflect actual larval abundance. This could have been the result of

   - inefficiency of the gear (bongo)
   - incomplete coverage of larval area
   - partial metamorphosis prior to survey.

Plots of spring distribution of larvae indicate that larvae are still aggregated in the areas off southwest Nova Scotia and Digby and it seems that coverage should have been adequate. Metamorphosis of fall-spawned larvae does not normally occur prior to late April (Sinclair and Tremblay 1984) so the timing should have been valid. By the time of the survey, these larvae are large, however, and results may have been affected by gear avoidance.

Given the apparently predictable spring distribution of larvae, an improved late larval survey should be considered for a potential recruitment index. This survey should use gear that is appropriate for large larvae (possible Tucker trawl or fine IKMT) and should address related issues of fine-scale distribution (vertical movement, patchiness, etc.) and condition of larvae as well as hydrographic correlates.

2. Juvenile "brit" survey

Previous attempts to survey juvenile herring in the Bay of Fundy have been considered unsuccessful and there is no time series of data. Occasional cruises undertaken with midwater (Boris) trawls and acoustics have concluded that juvenile herring are elusive and unpredictable in distribution.

A recent series of collaborative DFO/Dept. of Marine Resources (Maine) surveys along the coast of eastern Maine and southwestern N.B. has documented some consistency in distribution of early juveniles ("brit") - but relatively few have been seen, they have been hard to catch quantitatively, and are presumed to be of 5Y stock origin.

3. Weir index

Weir catches have been dominated by age 2 fish, which are suitable for the sardine market. We have investigated the question of whether weir catches predict what will happen in the "adult" fisheries. Table 9a, b summarize the catches (in number) of ages 1-3 and the cumulative catches of cohorts over their first 3 yr in both the N.B. and N.S. weir fisheries. Figure 11 shows that catches of adult fish (e.g. age 5) only generally reflect the catches of age 2 fish 3 yr earlier.

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Stobo, W. T., D. F. Gray, and K. Metuzals. 1978. Herring assessment in Div. 4WX. Can. Atl. Fish. Sci. Advis. Comm. Res. Doc. 78/25: 17 p.

Table 1. History of tuning in the 4WX herring assessment.

1974	ICNAF Res. Doc. 74/13 (Miller and Halliday, 1974)	Cohort with assumed F's. N.B. weir catch at age 2 used to indicate strong year-classes.
1976	ICNAF Res. Doc. 76/45 (Miller and Stobo, 1976)	Cohort with assumed F's. Catches of 1973 year-class in both N.B. and N.S. weirs used to modify F for that year-class.
1977	CAFSAC Res. Doc. 77/11 (Miller and Stobo, 1977)	Cohort analysis with assumed F's.
1978	CAFSAC Res. Doc. 78/25 (Stobo et al., 1978)	Cohort analysis calibrated with a CPUE index based upon both the N.S. purse seine and weir fisheries. Terminal F's and F's on older age groups adjusted to improve regression with standardized effort.
1979	CAFSAC Res. Doc. 79/19 (Sinclair et al., 1979)	Cohort analysis calibrated with two purse seine CPUE indices (one incorporating a learning factor) and supported by N.S. weir CPUE.
1980	CAFSAC Res. Doc. 80/47 (Sinclair and Iles, 1980)	Cohort analysis calibrated with purse seine CPUE (three indices, with and without learning factor). Recruitment indices based upon environmental conditions (wind and sea level) and weir catches considered).
1981	CAFSAC Res. Doc. 81/10 (Sinclair and Iles, 1981)	Problems with purse seine CPUE index cohort analysis calibrated in relation to autumn larval survey index (G mean of 15 stations) and N.B. weir catch rate index.
1982	CAFSAC Res. Doc. 82/36 (Sinclair et al., 1982)	Sharp decline in larval abundance index. Gillnet and N.B. weir catch rates chosen to tune VPA.
1983	CAFSAC Res. Doc. 83/89 (Iles and Sinclair, 1983)	SPA tuned by combination of larval adundance index (G mean vs 5+ biomass) and N.B. weir catch rates.
1984	CAFSAC Res. Doc. 84/72 (Iles et al., 1984)	SPA tuned with autumn larval abundance (Geom. mean larval abundance in year N regressed with both mature and 5+ biomass estimates for Jan. 1 of year N+1).
1985	CAFSAC Res. Doc. 85/78 (Stephenson et al., 1985)	As above.
1986	CAFSAC Res. Doc. 86/43 (Stephenson et al., 1986)	As above; tuning based upon the best combination of high correlation, low intercept and minimum residuals.
1987	CAFSAC Res. Doc. 87/75 (Stephenson et al., 1987)	As above.
1988	CAFSAC Res. Doc. 88/69 (Stephenson and Power, 1988)	As above using arithmetic mean of reduced number of stations in "Adaptive Framework."

Table 2. Use of tuning and recruitment indices in the 4WX herring assessment. Y = used; O = considered; X = rejected.

	74	76	77	78	79	80	81	82	83	84	85	86	87	88
Tuning														
N.B. weir CPUE								Y	Y					
N.S. weir CPUE				Y	Y									
Purse seine CPUE				Y	Y	Y	X							
Gillnet CPUE								Y						
Larval abundance							Y	X	Y	Y	Y	Y	Y	Y
Acoustic survey										0	0	0	0	0
Recruitment index														
Environmental						0								
N.B. weir	Y	Y				0								
N.S. weir		Y				0								

Table 3a. 4WX autumn larval herring cruise summary.

Year	Cruise	Mid-date	No. of days	No. of sets	LAI[1]	TLA-1 ($x10^{10}$)	TLA-2 ($x10^{10}$)	LRA >5 m^{-2} (km^2)
1972	P109	Nov. 23	14	130	9.4	22.26		9247
1973	P127	Nov. 24	8	132	6.6	15.54		6815
1974	P147	Nov. 9	8	102	49.5	104.59		13216
1975	P160	Nov. 10	10	103	8.6	21.60		9023
1976	P175	Nov. 15	15	124	13.5	32.73		10249
1977	P190	Oct. 22	8	128	6.3	17.30		8215
1978	P207	Nov. 8	19	116	4.5	9.44		2956
1979	P232	Nov. 1	9	115	7.1	17.30		6432
1980	P246	Nov. 12	19	131	26.2	57.32	66.00	9936
1981	P263	Nov. 16	13	151	2.7	5.33	5.54	4590
1982	P280	Nov. 2	14	170	12.4	31.40	46.47	10846
1983	P298	Nov. 6	15	164	13.1	28.74	63.59	10761
1984	P315	Nov. 9	16	181	12.6	29.93	48.03	10713
1985	P329	Nov. 3	24	243	41.8	83.72	228.04	14005
1986	P344	Nov. 3	21	187	21.3	53.11	75.62	12321
1987	P361	Nov. 2	23	258	31.2	65.50		10975
1988	P377	Nov. 2	16	206	98.2	194.07	336.75	13417
1989	P391	Nov. 1	16	226	54.5			

[1]Arithmetic mean of 79 stations

Table 3b. 4WX spring larval herring cruise summary.

Year	Cruise	Mid-date	No. of days	No. of sets	LAI[1]	TLA ($x10^9$)	LRA >.5m^{-2} (km^2)
1975	P151	Apr. 5	10	130		22.38	11285
1976	P163	Mar. 28	8	131		14.18	7894
1977	P180	Mar. 26	11	98		16.47	8819
1978	P193	Mar. 23	18	113		9.39	4603
1979	P217	Mar. 26	6	114		7.19	4208
1980	P234	Mar. 12	19	116		21.76	7480
1981	P250	Mar. 8	10	152		39.99	10761
1982	P268	Mar. 14	10	150		6.04	3849
1983	P287	Mar. 21	13	159		22.42	6911
1984	P301	Mar. 7	20	111		13.15	7447

Table 4a. Area and abundance of herring larvae, Bay of Fundy fall survey.

Year	Patch A (upper Bay) Area >5 (km²)	larvae ($x10^{10}$)	Patch B (lower Bay) Area >5 (km²)	larvae ($x10^{10}$)	TLA-1 ($x10^{10}$)	TLA-2 ($x10^{10}$)
1972	5065	13.27	4182	8.99	22.26	
1973	3894	7.47	2921	8.07	15.54	
1974	6203	32.12	7013	72.47	104.59	
1975	6498	16.27	2525	5.33	21.60	
1976	5108	12.73	5141	20.00	32.73	
1977	4332	8.56	3883	8.74	17.30	
1978	530	0.45	2426	8.99	9.44	
1979	2426	4.57	4006	12.73	17.30	
1980	5532	23.60	4404	33.72	57.32	66.00
1981	1709	2.27	2881	3.06	5.33	5.44
1982	6694	16.23	4152	15.17	31.40	46.47
1983	5587	10.12	5174	18.62	28.74	63.59
1984	5920	8.98	4793	20.95	29.93	48.03
1985	6529	17.83	7476	65.89	83.72	228.04
1986	6945	23.63	5376	29.48	53.11	75.62
1987	5010	11.42	5965	54.08	65.50	
1988	5580	15.02	7837	179.05	194.07	336.75

Table 4b. Area and abundance of herring larvae, Bay of Fundy spring survey.

Year	Patch A (upper Bay) Area >.5 (km²)	larvae ($x10^{9}$)	Patch B (lower Bay) Area >.5 (km²)	larvae ($x10^{9}$)	TLA ($x10^{9}$)
1975	5425	9.41	5860	12.97	22.38
1976	4249	8.53	3645	5.65	14.18
1977	5725	13.19	3094	3.28	16.47
1978	1864	4.00	2739	5.39	9.39
1979	2969	5.73	1239	1.46	7.19
1980	4365	17.58	3115	4.17	21.76
1981	6581	31.61	4180	8.39	39.99
1982	2451	3.40	1398	2.64	6.04
1983	4052	11.93	2859	10.49	22.42
1984	3536	6.69	3911	6.46	13.15

Table 5a. Annual New Brunswick weir and shut-off catch, effort and catch-per-unit effort.

Year	Effort (# weirs)	Catch (ages 1-3 numbers x 10^{-3})	Catch of ages 1-3 per weir
1965	195[1]	918,809	4,711
1966	195	587,047	3,010
1967	195	379,361	2,037
1968	195	813,108	4,169
1969	195	548,138	2,810
1970	195	362,393	1,858
1971	195	313,291	1,606
1972	195	675,095	3,462
1973	195	306,819	1,573
1974	195	292,786	1,501
1975	195	537,085	2,754
1976	195	355,683	1,824
1977	195	649,597	3,331
1978	223	1,160,275	5,203
1979	228	692,000	3,035
1980	241	330,588	1,371
1981	241	366,837	1,522
1982	241	498,823	2,069
1983	241	159,499	661
1984	241	114,565	475
1985	241	451,555	1,873
1986	241	259,238	1,075
1987	241	213,006	883
1988	241	468,896	1,945

[1]1965-79 effort values from Res. Doc. 80/47.

Table 5b. Annual Nova Scotia weir catch (numbers) effort and catch-per-unit effort.

Year	Effort (# weirs)	Catch ($x10^{-3}$) (total numbers)	Catch per weir	Catch ages 1-3 (numbers x 10^{-3})	Catch of ages 1-3 per weir
1965	25	82,461	3298	30,098	1203
1966	25	69,994	2799	42,033	1681
1967	25	136,269	5450	86,018	3440
1968	25	187,607	7504	150,273	6010
1969	25	162,232	6489	143,596	5743
1970	25	90,997	3639	44,970	1798
1971	25	49,169	1966	21,965	878
1972	25	119,650	4786	108,537	4341
1973	25	84,586	3383	75,860	3034
1974	25	99,265	3970	74,664	2986
1975	25	209,579	8383	200,386	8015
1976	25	54,161	2166	38,282	1531
1977	25	74,737	2989	57,768	2310
1978	25	159,588	6383	140,862	5634
1979	25	188,578	7543	183,950	7358
1980	25	25,440	1017	17,280	691
1981	25	31,536	1261	26,921	1076
1982	25	20,445	817	18,621	744
1983	25	14,096	563	12,385	495
1984	25	59,670	2386	55,243	2209
1985	25	66,316	2652	59,597	2383
1986	25	27,507	1100	23,659	946
1987	25	54,466	2178	20,427	817
1988	25	54,436	2177	23,010	920
1989					

Table 6. Acoustic backscatter and biomass estimated in January Chedabucto Bay herring acoustic surveys (from Buerkle 1989, 1990).

Year (Jan)	Average total scattering ($m^2 sr^{-1}$)	Biomass ('000 t)	SE
1984	64,429	208.4	20.5
1986	129,307	290.4	69.3
1987	170,658	492.1	50.6
1989	159,741	450.2	71.1
1990	102,308	193.5	49.8

Table 7. Historical logbook coverage of 4X summer purse seine fishery.

Year	Total # nights fishing	Total # of success nights	% successful nights	Total # of sets	Total log catch(t)	Total statistics catch(t)	% logged catch	Catch per night	Catch per successful night	Catch per set	Total logged search hours	Catch per hour searched	Sets per hour searched
1967	-	-	-	-	-	117832	-	-	-	55.4[a]	-	-	-
1968	-	-	-	-	-	133267	-	-	-	52.8[a]	-	-	-
1969	-	-	-	-	-	84525	-	-	-	41.7[a]	-	-	-
1970	-	-	-	-	-	74849	-	-	-	39.0[a]	-	-	-
1971	-	-	-	-	-	35071	-	-	-	32.6[a]	-	-	-
1972	-	-	-	-	-	61158	-	-	-	45.0[a]	-	-	-
1973	403	363	90	550	17603	36618	48	43.7	48.5	32.0	-	-	-
1974[b]						76859				53.4[a]	-	-	
1975[b]						79605				57.4[a]	-	-	
1976[b]						58395				44.6[a]	-	-	
1977	1137	863	76	1203	32143	68538	47	28.3	37.2	26.7	-	-	-
1978	701	551	79	950	21734	57973	37	31.0	39.4	22.9	-	-	-
1979	641	261	41	422	8565	25265	34	39.4	96.8	20.3	-	-	-
1980	1273	1134	89	1399	32921	44986	73	35.3	39.7	23.5	-	-	-
1981	638	539	84	706	18764	53799	35	29.4	34.8	26.6	-	-	-
1982	229	160	70	320	6751	64344	10	29.5	42.1	21.1	-	-	-
1983	1348	1207	90	1772	47071	63379	74	34.9	39.0	26.6	-	-	-
1984	530	503	95	730	26560	58354	46	50.1	52.8	36.4	-	-	-
1985	1802	1539	85	2297	83323	87167	96	46.2	54.1	41.2	5157	26.6	0.62
1986	1424	1258	88	1852	51625	56139	92	36.3	41.0	31.5	4519	18.1	0.59
1987	1796	1540	86	2218	68257	77306	88	38.0	44.3	34.6	5753	19.5	0.59
1988	1916	1666	87	2908	85741	98371	87	46.5	53.5	29.5	5868	22.7	0.55
1989	1609	1333	83	1916	64207	68089	94	39.9	48.2	33.5	5333	15.0	0.51

[a]From Stephenson et al. (1986), CAFSAC Res. Doc. 86/43.

[b]Entirely 4W logs.

Table 8. Summaries of the occurrence of herring in groundfish trawl surveys.

Year	Cruise	Date	Stratum	Total no. sets (N)	No sets with herring (N^h)	Total no. herring	No./set (N)	No./set (N^h)
a) Spring survey (area 4VWX)								
1979	H013-14	5-29/03	40-95	116	24	851.68	7.34	35.49
1980	H033-34	5-27/03	44-92	105	30	806.07	7.68	26.87
1981	H048-49	24/02-16/03	40-85	118	16	476.91	4.04	29.81
1982	H071-72	2-24/03	65-95	68	29	4822.17	70.91	166.28
1983	H094-95	21/03-14/04	43-95	140	37	727.56	5.20	19.66
1984	N024-25	2-26/03	43-95	132	32	354.81	2.69	11.09
b) Summer survey (area 4VWX)								
1978	A279-280	9-31/07	40-95	141	6	34.37	0.24	5.73
1979	A292-293	6-27/07	40-95	146	5	71.01	0.49	14.20
1980	A306-307	7-27/07	40-95	145	4	94.48	0.65	23.62
1981	A321-322	4-25/07	40-95	143	5	195.99	1.37	39.20
1982	H080-81	10-30/07	40-95	150	14	130.44	0.87	9.32
1983	N012-13	5-27/07	40-95	144	27	232.84	1.62	8.62
1984	N031-32	1/07-2/08	40-95	143	42	844.73	5.91	20.11
1985	N048-49	4-25/07	40-95	152	19	418.56	2.75	22.03
1986	N065-66	7-17/07	40-95	176	39	2185.52	12.42	56.04
1987	N085-87	29/07-6/08	40-95	188	35	9075.92	48.28	259.31
1988	N105-106	4-27/07	40-95	177	33	296.94	1.68	9.00
1989	N123-124	5-27/07	40-95	170	48	1297.63	7.63	27.03
c) Summer survey (Strata 80-95 of 4X)								
1978	A279-280	9-31/07	80-95	32	4	4.84	0.15	1.21
1979	A292-293	6-27/07	80-95	33	4	61.01	1.85	15.25
1980	A306-307	7-27/07	80-95	31	3	93.51	3.02	31.17
1981	A321-322	4-25/07	80-95	32	3	193.85	6.06	64.32
1982	H080-81	10-30/07	80-95	36	7	31.90	0.89	4.56
1983	N012-13	5-27/07	80-95	34	14	82.04	2.41	5.86
1984	N031-32	1/07-2/08	80-95	34	14	228.93	6.73	16.35
1985	N048-49	4-25/07	80-95	34	8	20.23	0.60	2.53
1986	N065-66	7-17/07	80-95	34	17	995.18	29.27	58.54
1987	N085-87	29/07-6/08	80-95	44	20	372.41	8.46	18.62
1988	N105	4-13/07	80-95	46	15	145.66	3.17	9.71
1989	N123	5-16/07	80-95	44	22	262.05	5.96	11.91
d) Fall survey (area 4VWX)								
1979	H026-27	15/10-8/11	40-92	126	9	45.16	0.36	5.02
1980	H042-43	30/09-24/10	40-94	138	4	119.17	0.86	29.79
1981	H064-65	30/09-22/10	43-95	127	14	150.11	1.18	10.72
1982	H084-85	28/09-24/10	40-95	145	25	346.80	2.39	13.87
1983	N017-18	4-27/10	40-95	175	39	3118.90	17.82	79.97
1984	N036-37	9/10-1/11	40-95	170	45	453.00	2.66	10.07

Table 9a. New Brunswick weir catch at ages 1, 2 and 3 and cumulative catch for each year-class at ages 1+2+3.

Year	Catch at age 1	Catch at age 2	Catch at age 3	Year-class	Cumulative catch ages 1-3
1965	992	852368	65449	1964	209500
1966	3899	151087	432061	1965	250398
1967	127374	194566	57421	1966	987501
1968	2409	758766	51933	1967	387919
1969	71191	375586	101361	1968	457455
1970	3553	348916	9924	1969	193689
1971	92253	183690	37348	1970	878765
1972	8102	660547	6446	1971	200636
1973	31803	149051	125965	1972	335075
1974	3259	246044	43483	1973	570860
1975	16880	562977	57228	1974	226482
1976	51791	199268	104624	1975	228209
1977	514970	124293	10334	1976	1651389
1978	213778	894372	52125	1977	723683
1979	2135	447818	242047	1978	26311
1980	263106	5395	62087	1979	631023
1981	53336	294720	18781	1980	470436
1982	30210	395416	73197	1981	182785
1983	2532	135283	21684	1982	131331
1984	14353	82920	17292	1983	519470
1985	20295	385381	45879	1984	204568
1986	3210	136292	119736		
1987	35677	129348	47981		

Table 9b. Nova Scotia weir catch at ages 1, 2 and 3 and cumulative catch for each year-class at ages 1+2+3.

Year	Catch at age 1	2	3	Year-class	Cumulative catch ages 1-3
1965	0	20705	9373	1964	26706
1966	106	2412	39515	1965	37815
1967	4285	18873	24294	1966	226023
1968	13852	117585	18836	1967	56194
1969	5	39438	104153	1968	56849
1970	265	41801	2904	1969	7693
1971	98	6464	15043	1970	164682
1972	411	107162	964	1971	22952
1973	0	18438	57422	1972	99672
1974	0	70561	4103	1973	195634
1975	1931	169344	29111	1974	22336
1976	240	11752	26290	1975	52951
1977	1110	48005	8653	1976	182755
1978	35381	100775	4706	1977	152525
1979	154	102926	80870	1978	4098
1980	31	3031	14218	1979	29313
1981	0	26008	913	1980	16606
1982	1432	13915	3274	1981	17036
1983	0	9694	2691	1982	62124
1984	0	49333	5910	1983	56139
1985	102	46704	12791	1984	24043
1986	0	14224	9435		
1987	0	10710	9717		

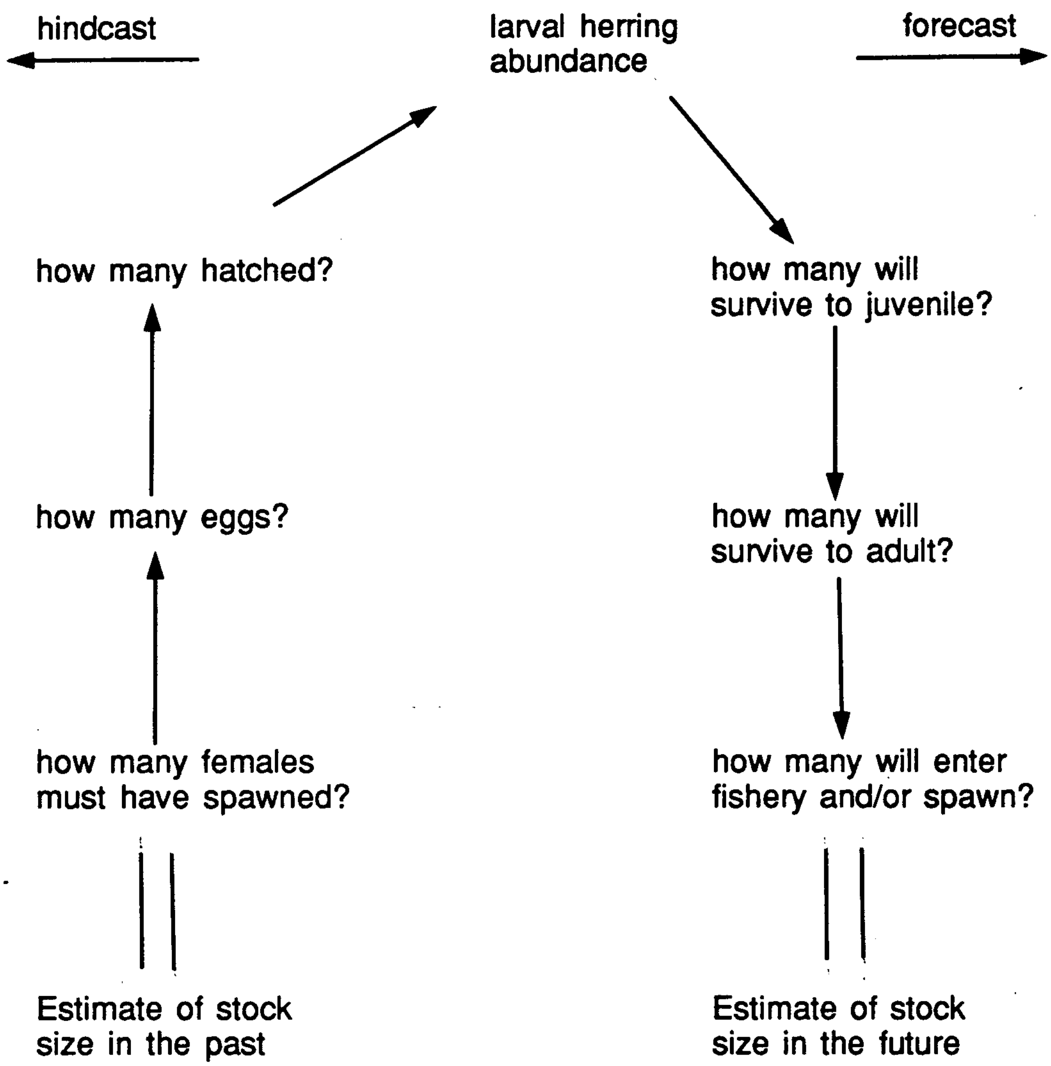


Fig. 1a. Potential estimates of stock abundance from larval herring surveys (from Stephenson 1988).

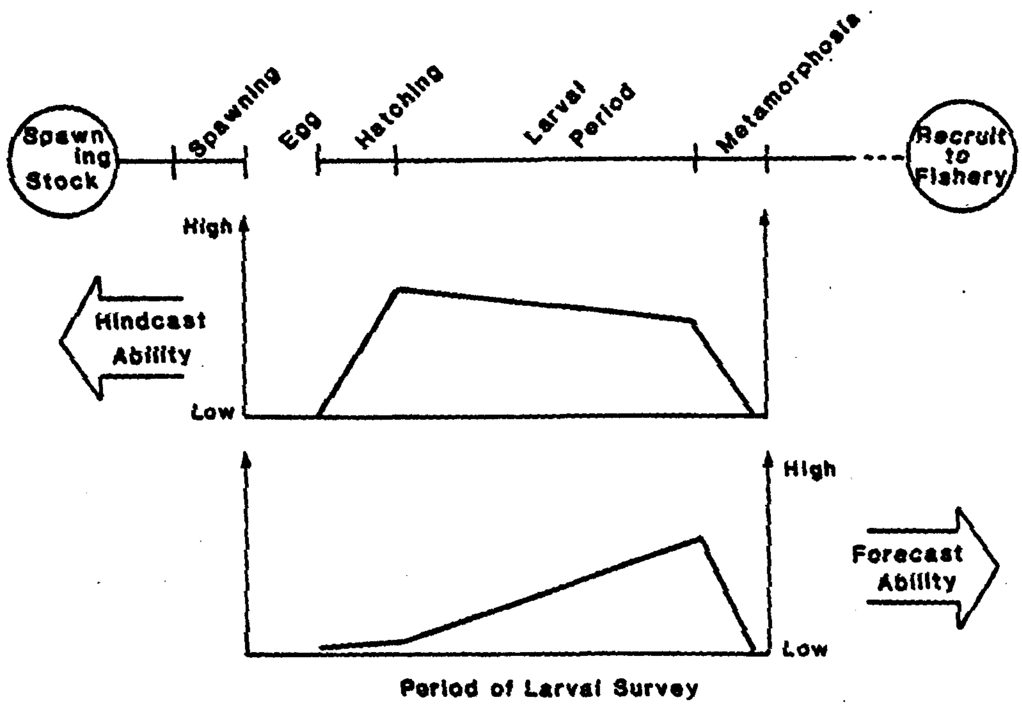


Fig. 1b. Schematic representation of the effect of larval survey timing on the relative ability to hindcast spawning stock size and to forecast recruitment to the fishery (from Iles et al. 1985).

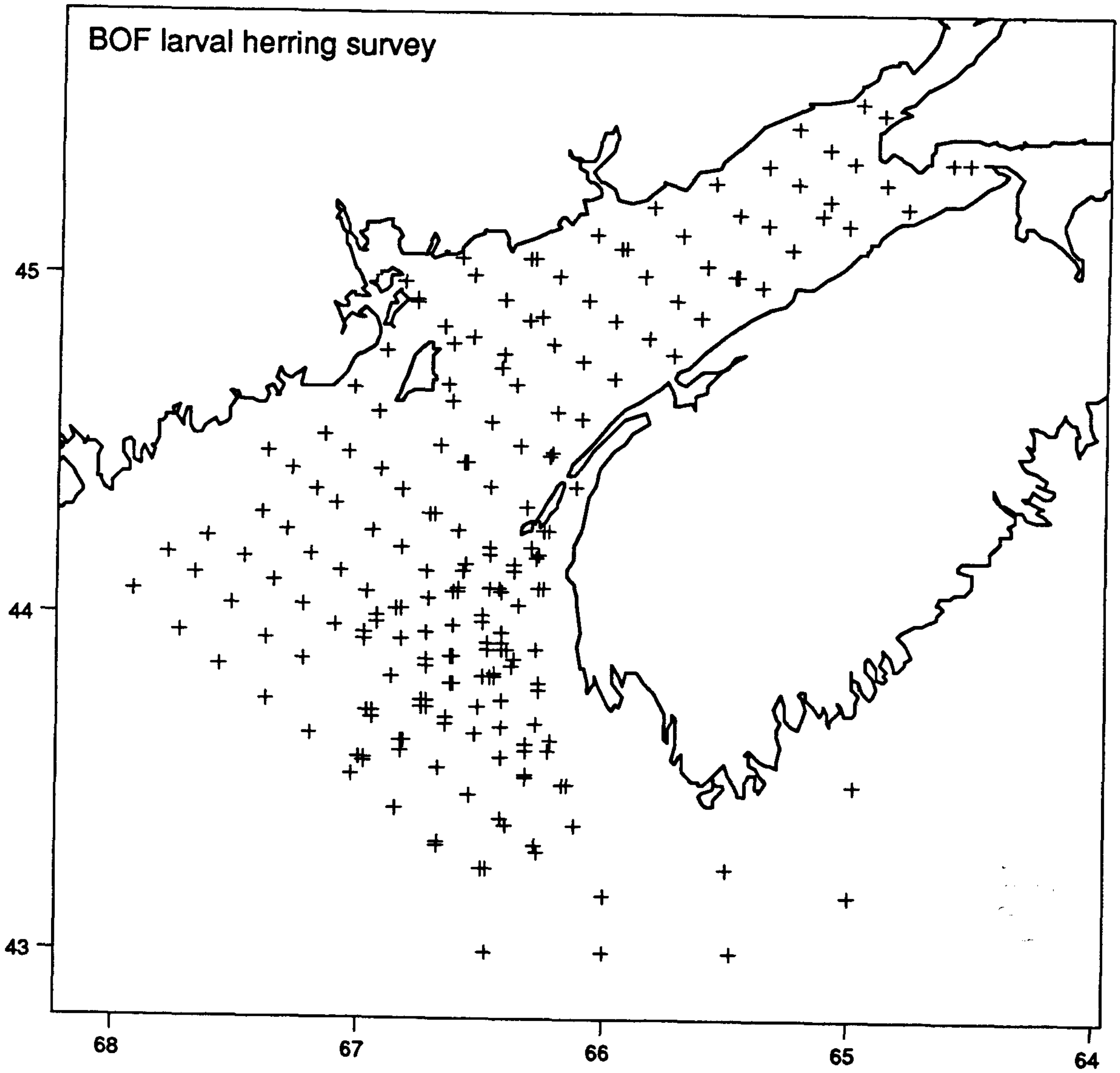


Fig. 2. Standard survey stations; Bay of Fundy larval herring cruises 1972-88.

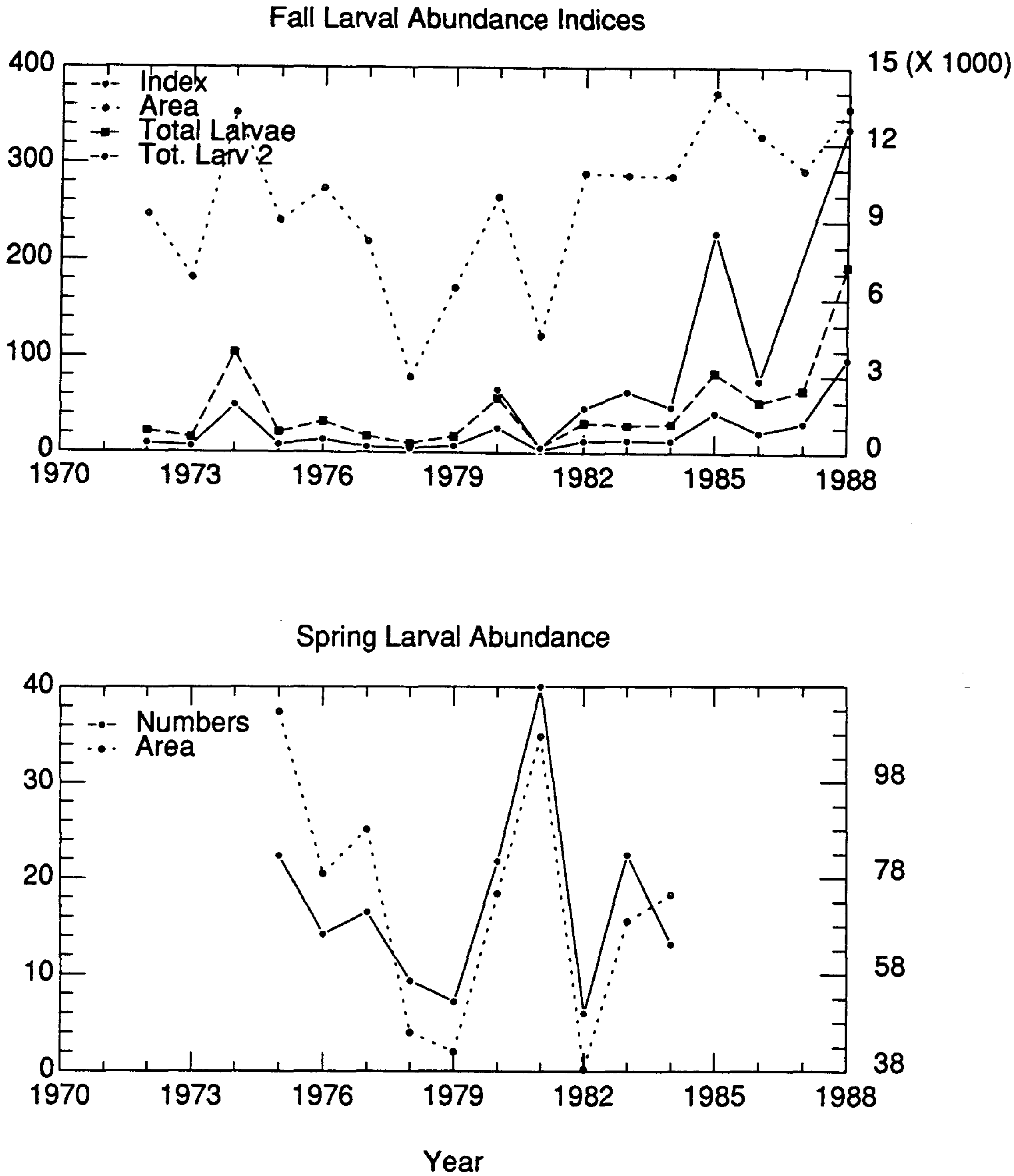
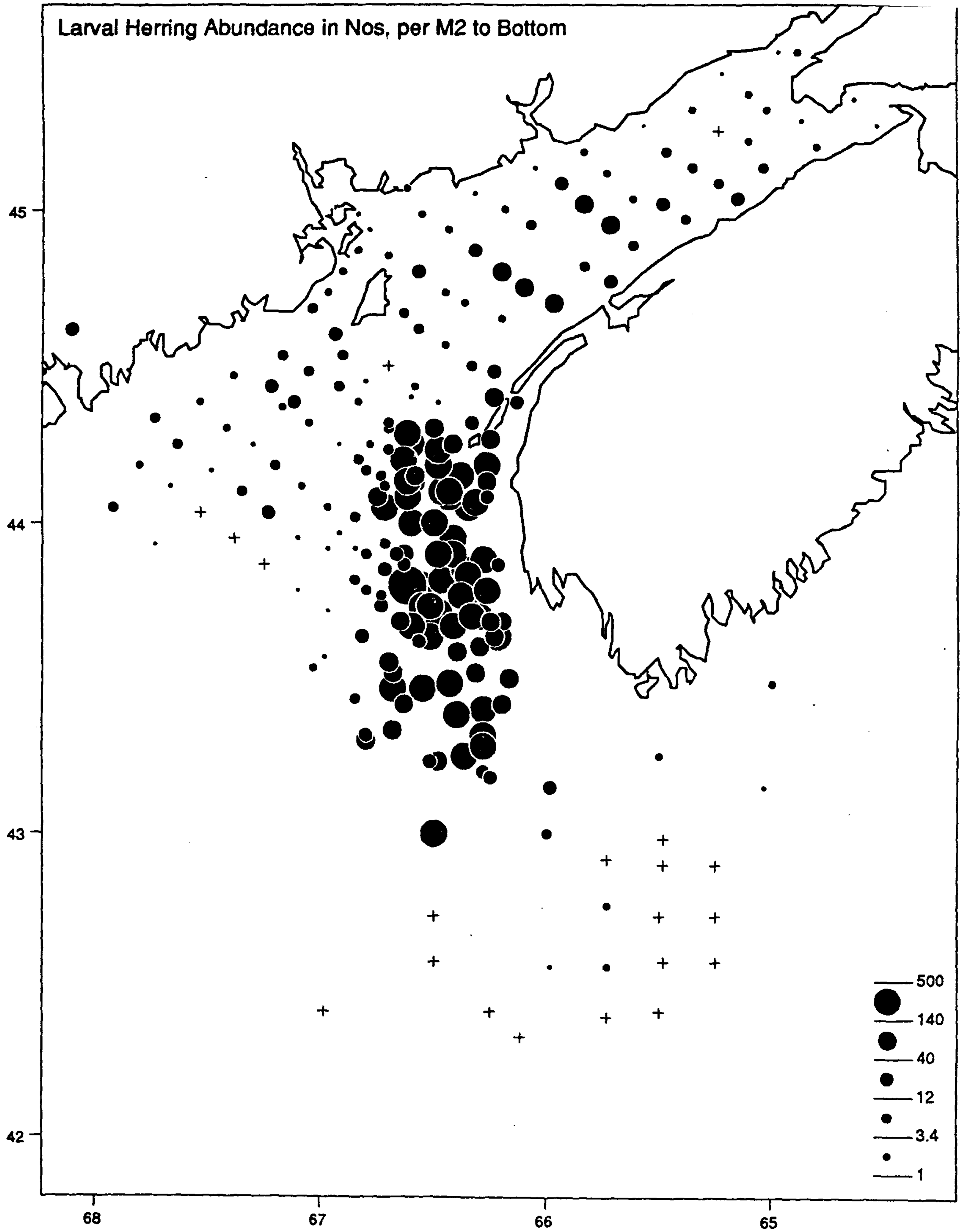


Fig. 3. Time series of larval abundance (total numbers and traditional index) and of area of larval distribution from fall and spring surveys of the Bay of Fundy.



P391 (NOV. 1989) - All Stations in Survey

Fig. 4a. Abundance (no. larvae m^{-2} to bottom) for all stations in the November 1989 Bay of Fundy larval herring survey (E.E. PRINCE 391).

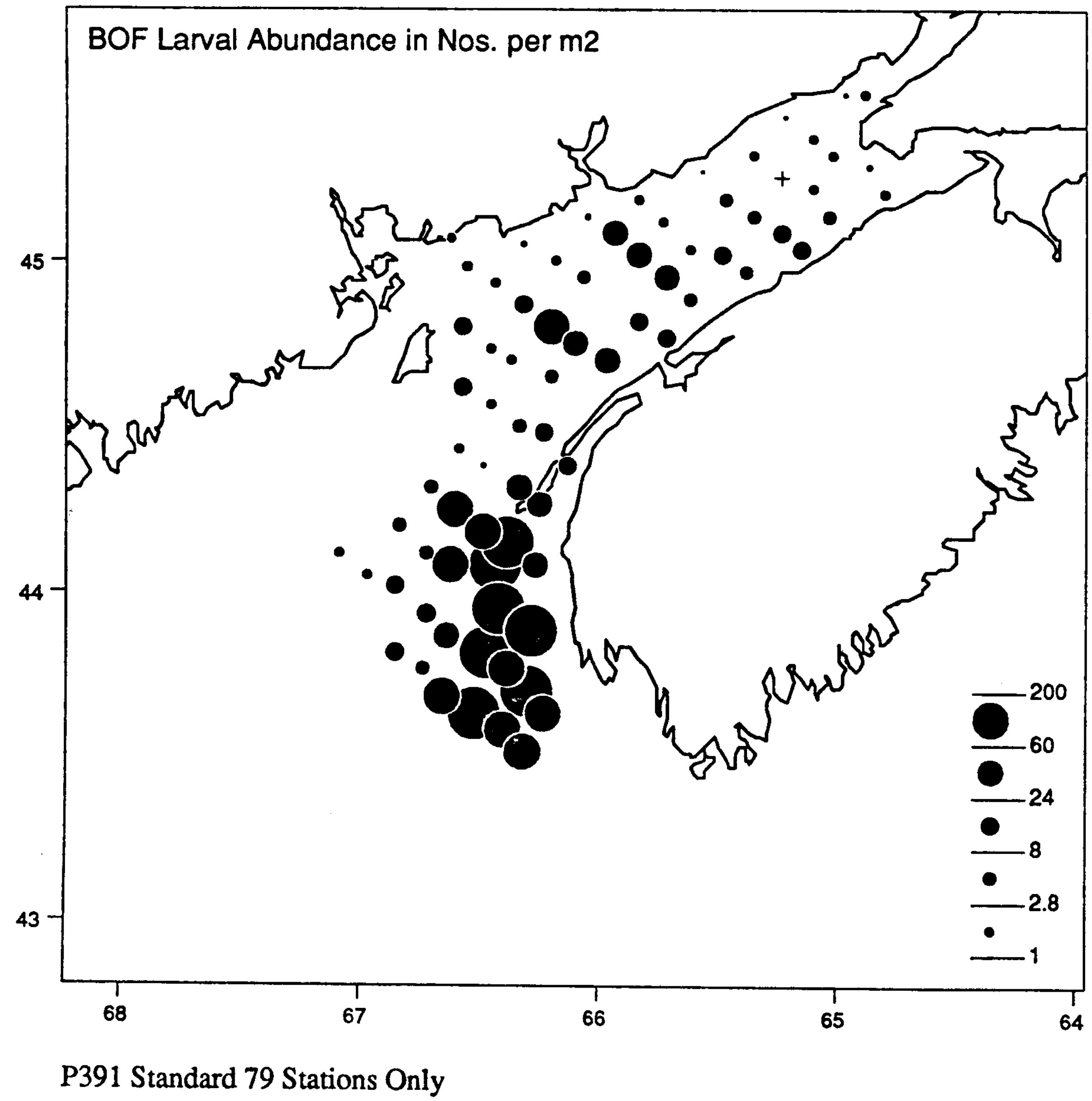


Fig. 4b. Abundance (no. larvae m^{-2} to bottom) at 79 "index" stations on the 1989 survey (P391).

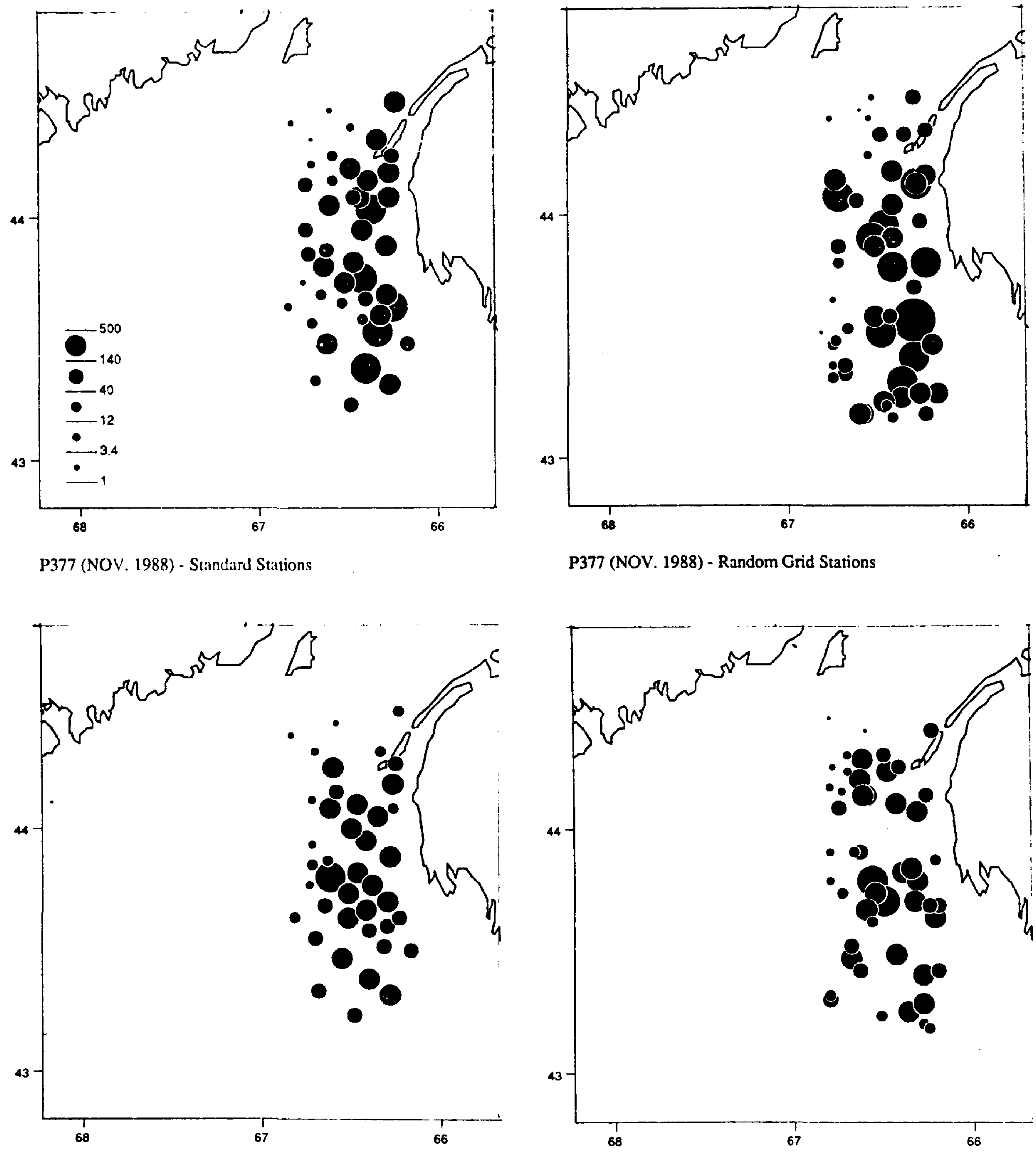


Fig. 5. Distribution of stations and larval abundance (no.m^{-2}) in fixed (left) and random (right) surveys of the larval herring concentration off southwest Nova Scotia in 1988 (upper) and 1989 (lower).

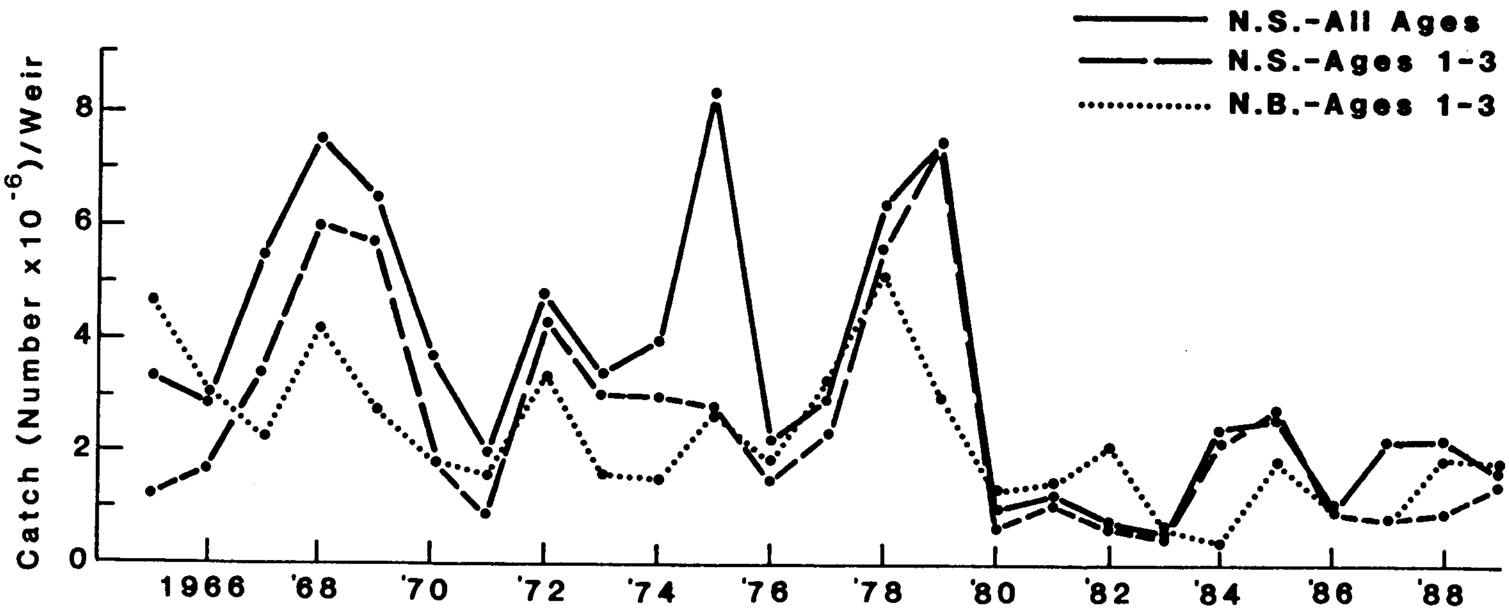


Fig. 6. Catch (numbers x 10^{-3}) per weir in Nova Scotia and New Brunswick weir fisheries.

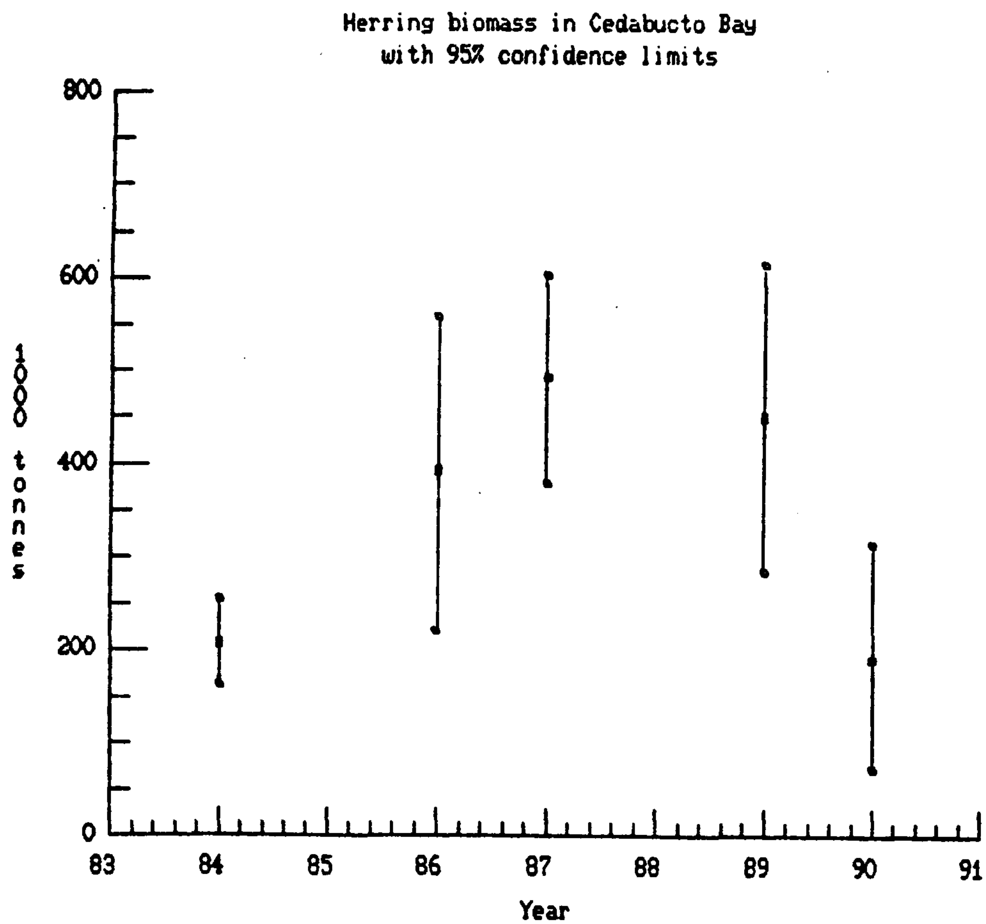


Fig. 7. Herring biomass (±95% CI) from Chedabucto Bay January surveys 1984-90 (from Buerkle 1990).

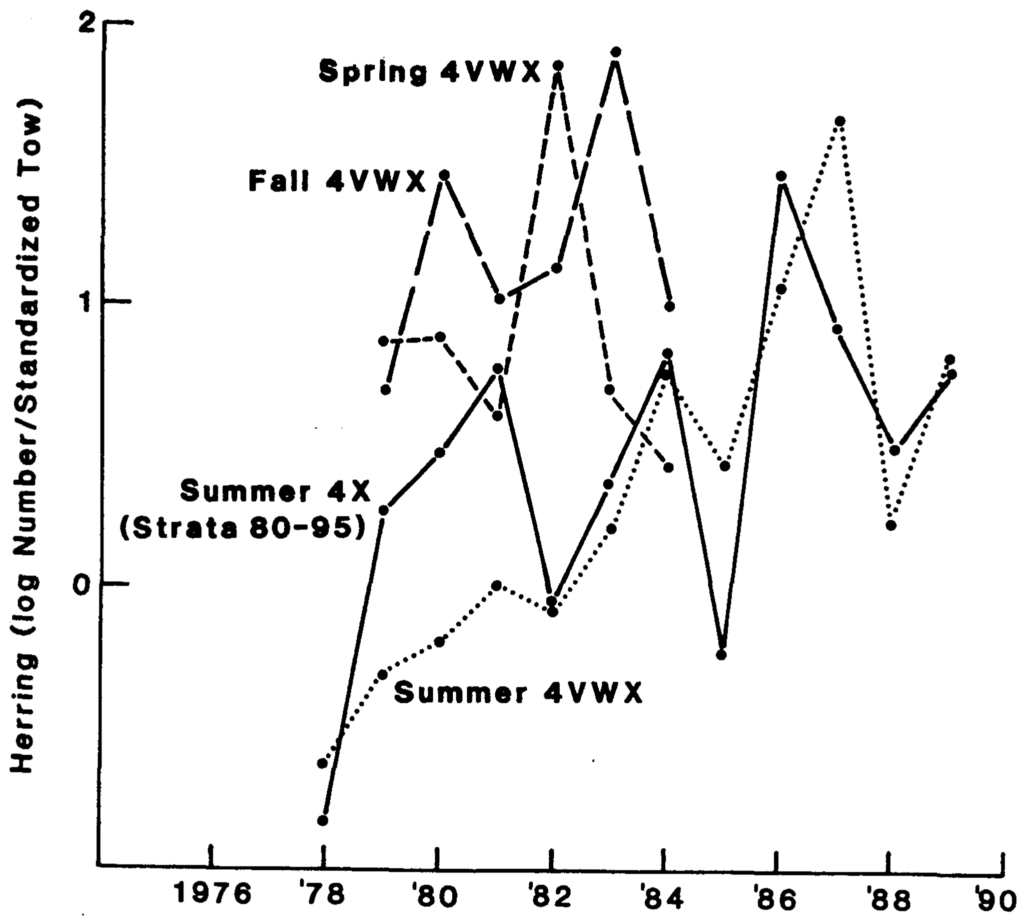


Fig. 8. Occurrence of herring (number) per set (A) in Canadian trawl surveys of the Bay of Fundy and Scotian Shelf.

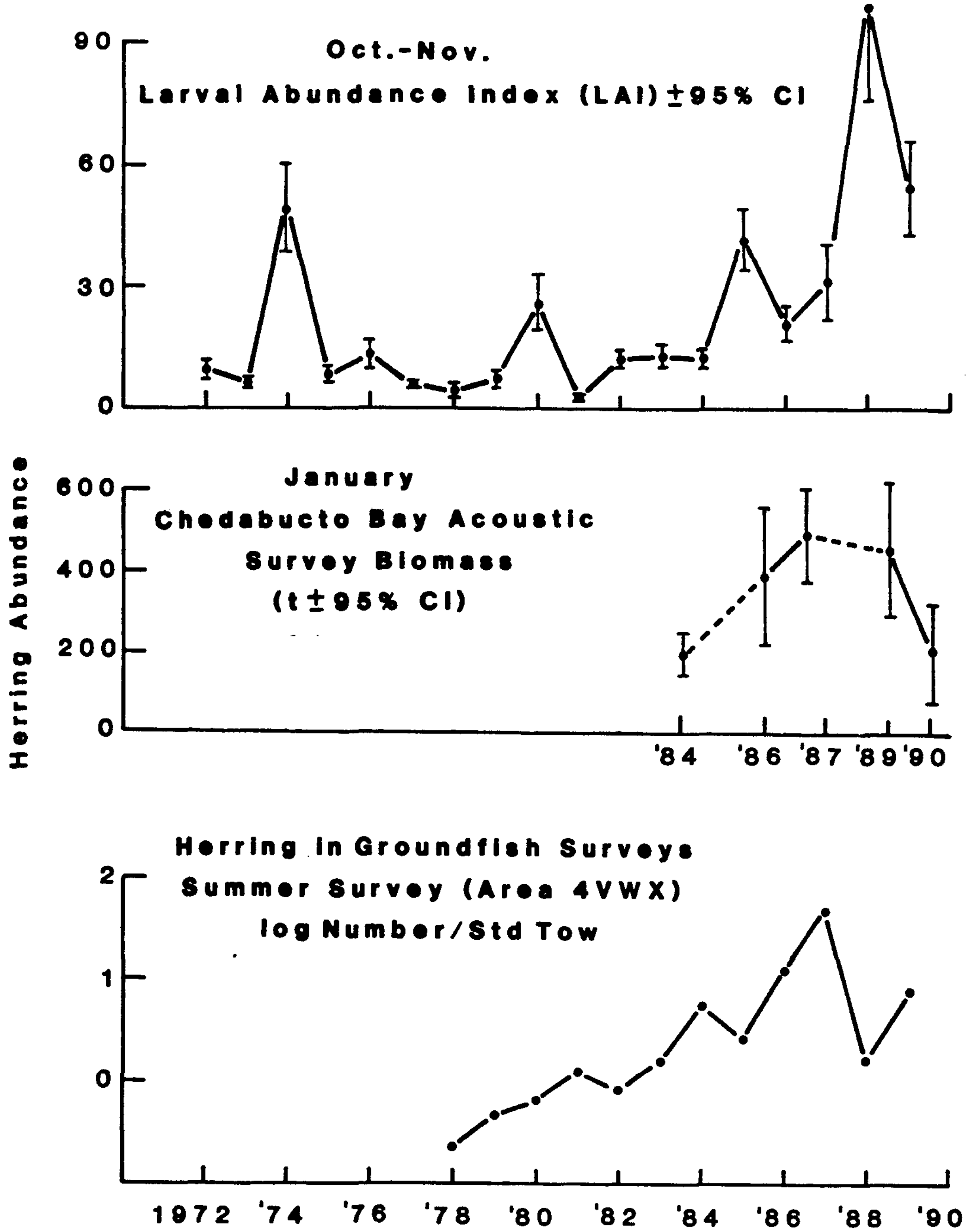
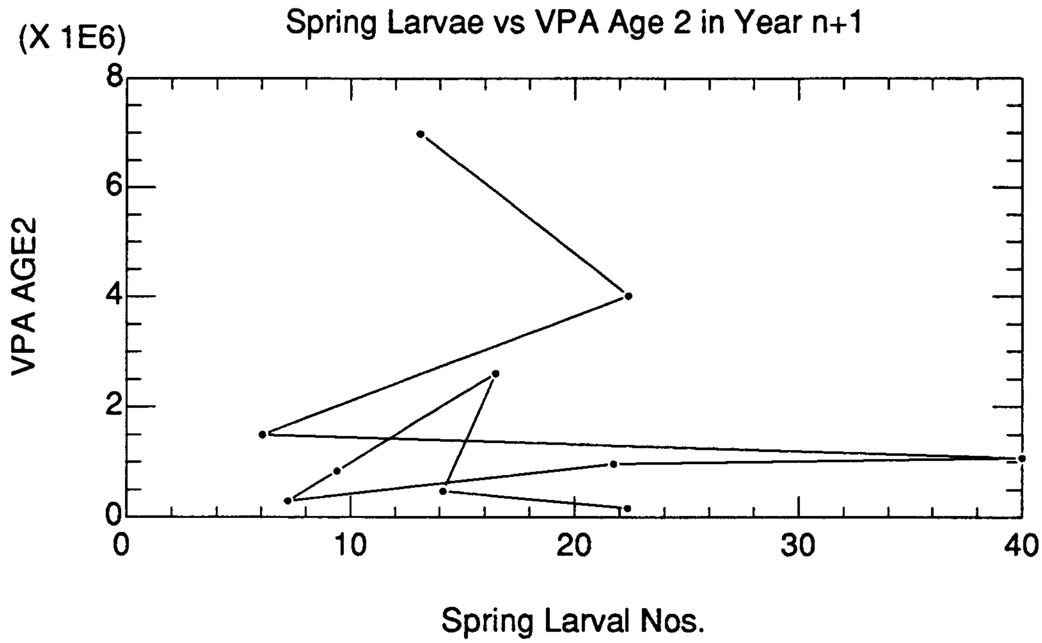


Fig. 9. Comparison of time series of potential abundance indices for 4WX herring.



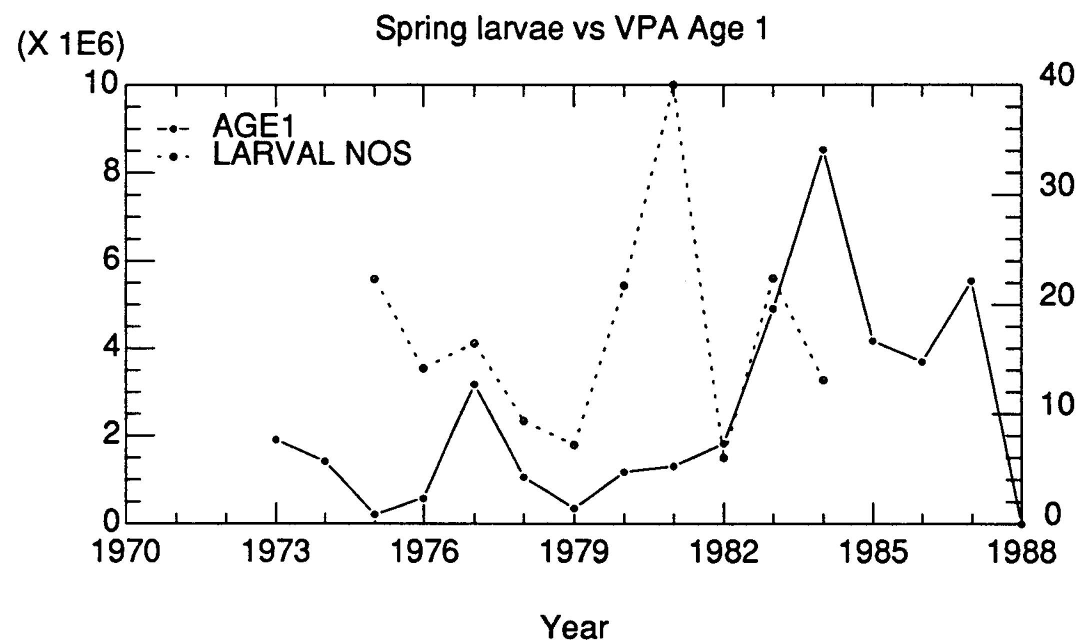


Fig. 10. Spring larval abundance compared with year-class strength as VPA age 1 or age 2 (from 1988 assessment).

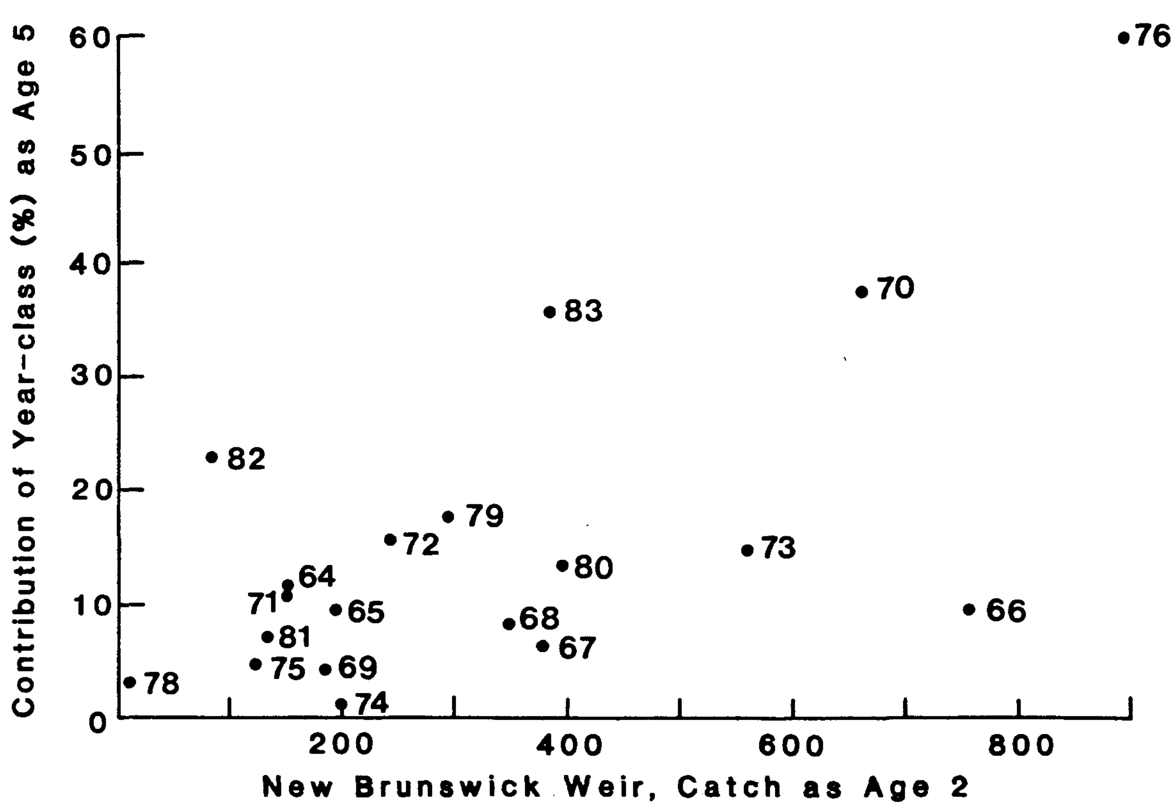


Fig. 11a. Catch at age 2 in New Brunswick weirs vs the contribution of that year-class of the 4WX fishery as age 5 (3 yr later).

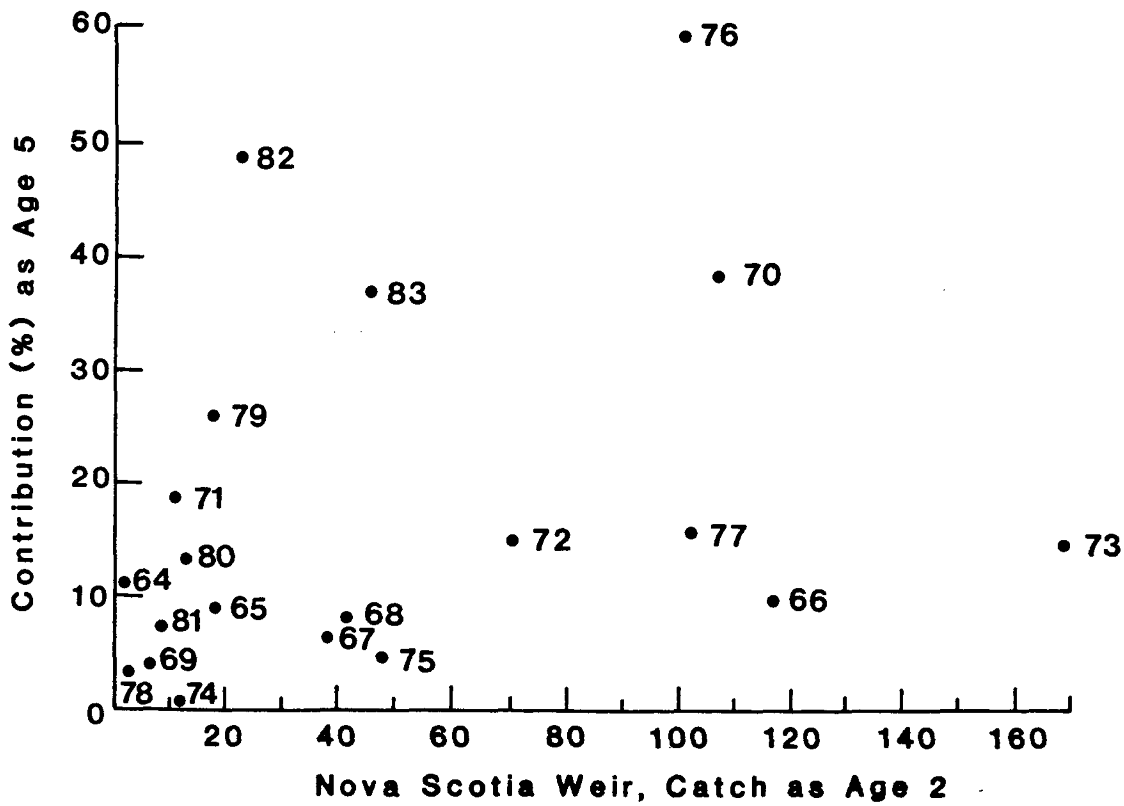


Fig. 11b. Catch at age 2 in Nova Scotia weirs vs the contribution of that year-class to the 4WX fishery as age 5 (3 yr later).