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An analysis of some biological characteristics of the 4X juvenile herring fishery

by

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Introduction

The Canadian herring catch in 4X (fig. 1) has been sampled since 1968 in considerable detail for length frequencies and other biological parameters. Prior to 1968 less detailed sampling of the catch was carried out. The aim of this study is to analyse this accumulated data base with particular reference to the juvenile fishery. Analysis of the juvenile population responses to changes in abundance and to the degree of mixing of separate spawning stocks provides information of a qualitative nature that may be useful in the analytical assessment of the 4WX herring mananagement unit. Prior to the data analysis a brief synopsis of stock intermixing and recent trends in the fishery are presented.

Stock intermixing considerations

The herring fishery off south-west Nova Scotia and in the Bay of Fundy exploits a mixture of stocks. The three major spawning stocks which may be (or may have been) involved are those which spawn respectively off south-west Nova Scotia, in the Gulf of Maine and on Georges Bank. Their life histories are such that the spawning areas and associated larval distributions are unique to each stock, but there is mixing (in unknown proportions) of the juveniles and of the adults during the summer feeding migrations (Messieh 1970, and Stobo, et. al. 1975). Specifically, there is mixing of "Gulf of Maine" and "S. W. Nova Scotia" juveniles along the coast of Maine and the Bay of Fundy. Also, since the distribution of Georges Bank juveniles has not been identified, it is possible that they intermix in the same geographical area. There is probably mixing of "Gulf of Maine" and "S. W. Nova Scotia" adults during summer feeding at the mouth of the Bay of Fundy in the vicinity of the tidally induced temperature fronts.

The relative proportions of the Canadian catch by gear type that is contributed by the respective spawning stocks, and how these proportions have changed with time as the relative abundance of the stocks have fluctuated, is not known. However, it is expected that the growth, maturation and temporal distributions of herring in 4WX will be influenced not only by the environment, both abiotic and biotic, but also by changes in the relative contributions to the stock complex.

A review of the historical catches in ICNAF SA 4 and 5 indicates the major recent events of the component spawning stocks. The recent 5Y adult and juvenile catches and the 5Z adult catches are shown in fig. 2 (data from Sissenwine and Waring, 1979). The Georges Bank fishery collapsed due to overfishing in the first half of this decade and, from larval and adult surveys, shows no sign of recovery to date. The Gulf of Maine adult fishery (5Y adult) has also seriously declined by approximately 50% since 1972-73. The appearance of the strong 1976 and 1977 year classes has resulted in increasing catches in the 5Y juvenile fishery. Some of the increases in the 5Y juvenile catches, especially prior to 1978, are due to increases in effort by mobile gear. The catch distribution of juveniles in 4Xb parallels that in coastal Maine (Fig. 2), but is different than the 4Xa juvenile catch distribution (Nova Scotia side of Bay of Fundy). The 4WX adult catch did not decline dramatically in parallel with adult catches in SA5 (Fig. 2) but has fallen to a historical low point in 1978.

Methods

Length and weight: - Mean lengths and weights at age for a given month and gear type were estimated using both the length frequency samples and the detailed biological samples. Removals at age by 1 cm length intervals were calculated from the sample length frequencies, the derived age-length keys and length-weight relationships. This data is routinely generated each year in preparation for the stock assessment.

Maturity:- Mean length at 50% maturity by sex was calculated from the detailed biological samples. A maturity stage-length key was constructed using only August samples from the purse seine fleet. Fish at or above stage 3 (following Parrish and Saville, 1965) were considered mature. The mean length at 50% maturity was calculated from a linear regression of percent mature against length. Data in 1970 was insufficient to calculate a 50% point. All other correlations were significant ($p<.01$).

Results

I. The 4X juvenile herring fisheries: -

A. Age composition of the 4Xb juvenile fishery.

The New Brunswick weir fishery traditionally exploits sardine size herring predominantly at age 2. The monthly age composition of the catches from 1965 to 1978 are shown in fig. 3. The fishery usually begins in May and continues to November or December. Initially 2 and 3 year olds make up most of the catches but in the latter months one year olds enter the fishery.

The 1963, '66, '70 and '76 year classes have been dominant in the 4WaXa fishery (Sinclair et. al. 1979). The same year-classes have been strong in the New Brunswick weir fishery (4Xb). The 1963 year class dominated the catches in 1965-66, and at age 4 in 1967 it was still an important part of the fishery. The strength of the 1966 year class is apparent from the age composition distribution during 1969 (fig. 3). The 1970 year-class was an important part of the catch from age 1 to 3, and the 1976 year-class was very strong at age 1 (the strongest of any year-class at that age). It is interesting to note that the 1977 year-class appeared strongly in the 1978 catch in spite of the large number of two year olds from the 1976 year class. This suggests that the 1977 year-class may also be above average in size, or that the size of the 1976 year-class has been overestimated.

B. Summer length increments for 4Xb juveniles.

(i) Length-dependent bias.

The monthly length frequencies of two year olds were normally distributed during the early part of the fishery each year, but became bi-modal by August or September. A representative series of length frequencies (fig. 4) show the typical seasonal trend. The shift of a single mode from May to July was taken to indicate growth of a unit population. In August a second mode appeared and remains through October. Clearly the mean lengths calculated from August to October would not be representative of changes in length of a homogenous population. However, the modes on the right hand side in August and September follow the displacement in the normal distribution from May to July. The appearance of a second mode at smaller lengths in August and September was typical for most years and adjustments were made in the calculated mean lengths to account for this bi-modality. In the following analysis only the growth of the larger first arriving population is considered. Also, since weight frequencies are not available in parallel with length frequencies, growth of two year olds can only be directly analysed in units of length rather than weight.

The data base only provides a complete time series of length frequencies for the months May to September. Therefore the calculation of summer growth (length increment) was limited to this time period. The major part of the annual growth, however, occurs within these months. Iles (1967) demonstrated that, when length increment is used as a measure of growth, it is critical to correct the increments for a length dependent bias. When such corrections are not made, erroneous conclusions regarding growth compensation or growth rates may be drawn.

To correct for length-dependent growth, the summer length increment was plotted against initial length in May (fig. 5). The points fall into two distinct groups which are separated temporally. One group includes the years 1965 to 1970, excluding 1967, and these points give a significant negative correlation ($r^2= 0.912$, $p<0.01$). A second group includes the years 1972 to 1978, excluding 1973; and also gives a significant negative correlation ($r^2= 0.972$, $p<0.01$). The excluded years (1967, 1971, and 1973) appear anomalous. A dummy variable was used in a mutiple regression to incorporate the complete data set. The other independent variable was initial length and the dependent variable was length increment. The anomalous points were included with the more recent years. The earlier points were assigned a dummy value of 1 while the rest were assigned a value of 0. Subsequently all points were adjusted to a standard initial length of 130 mm. The results are shown in table 1.

The occurrence of two distinct relationships between length increment and initial length was an unexpected result, and it suggests a change in growth pattern of age two herring on the New Brunswick side of the Bay of Fundy in the early 1970's. This marked change is supported by the temporal trend in the adjusted length increment (fig. 6a). The unadjusted increments indicate a similar trend but have much larger short-term variability due to the initial length differences (fig. 6b).

(ii) Temperature effects.

Monthly mean surface temperatures from the St. Andrews Biological Station summed from May to September were plotted against the unadjusted length increments to investigate its effect on growth (fig. 7). The higher summer growth observed during recent years occurred at intermediate temperatures, suggesting that this factor was not the predominant one in the growth changes.

Also, when the length dependent bias is considered, it appears that the adjusted length increments are not strongly affected by temperature (fig. 8).

(iii) Population abundance effects.

Two estimates of two-year-old population abundance were calculated for the New Brunswick weir fishery. Due to the uncertain stock identity of the New Brunswick weir catches, it is not necessarily valid that the number of two-year-olds estimated by cohort analysis for the 4WXa fishery is an appropriate index of 4Xb population size. An alternative measure is the catch per unit effort (CPUE) estimates for the New Brunswick weir fishery. However, CPUE estimates are crude due to scanty effort information on the weir fishery. In spite of these uncertainties, the two measures are considered.

The catch matrix for the years 1965 to 1978 for the 4WXa fishery (Sinclair *et al*. 1979) was adjusted to include the fall-winter juvenile removals by the purse-seiners in 4Xb and one-third of the numbers at age removed by the 4Xb weir fishery [approximately a third of the long distance returns of the juveniles tagged in the New Brunswick weirs are from 4WaXa, the larger proportion being returned from ICNAF SA5, (W. Stobo, pers. comm.)]. The numbers at age for the 4WX fishery were estimated using cohort analysis (Pope 1972). The estimate of two-year-olds and the CPUE estimates (catch of two-year-olds per actively-fished weir) are shown in table 2.

The adjusted length increments are examined in relation to the population abundance estimates in fig. 9 and 10. Although there is some shifting of individual points depending upon the population index that is used, the overall pattern is similar. As observed in fig. 5, the data points fall into two groups separated temporally. The relationship between summer growth and population abundance is inverse during the earlier time period, and if anything, slightly positive in recent years (the straight lines in fig. 9 and 10 were drawn by eye). The four largest year-classes (1963, 1966, 1970 and 1976) were split with regard to growth: the two earlier years showing low summer growth, and the more recent exceptional year-classes showing relatively higher summer growth. The 1978 and 1977 points in fig. 10 are questionable since the population numbers were taken from the last two years of the cohort analysis. However, the 1978 point, the 1976 year-class, is probably reasonably accurate since all indications are that this year-class is close to the size of the 1970 year-class (Sinclair *et al*. 1979).

The age 2 growth analysis presented here suggests a dramatic change in the growth pattern of juveniles supporting the New Brunswick weir fishery in the early 70's. The change included a new relationship between summer length increment and initial length, an increase in adjusted summer length increment, and a different response to population abundance from density dependence to lack of density dependence. Temperature effects were found to be insignificant for summer growth of two-year-olds but its effect cannot be ruled out.

C. 4Xa juvenile fishery.

It has not been possible to attempt a similar analysis on the growth of age 2 herring on the Nova Scotia side of the Bay of Fundy. The nature of the purse-seine fishery for age 2 fish has varied due to management through the time period under consideration. On a monthly basis during the summer, there are not always age 2 fish caught, and the degree of selectivity with respect to length by the purse seine fleet may have changed in parallel with management changes. Because of these factors, a time series of summer growth of two-year-olds fished by the purse seine fleet is not available. Similarly, two-year-olds are not always caught in the Nova Scotia weirs each month during the summer. In certain years, however, catches of two-year-olds are made regularly such that seasonal growth can be analyzed.

From May to September, the weirs in St. Mary's Bay catch a broad range of ages. In contrast, the Annapolis Basin weirs in 1978 fished predominantly in the autumn, and the catch was comprised almost exclusively of juveniles. As was the case in the New Brunswick weirs, there appear to be two distinct populations of two-year-olds, one arriving in St. Mary's Bay in the early summer mixed in with the adult population, and the second arriving in the Annapolis Bay and Bay of Fundy side of Digby Neck in the autumn. The differences in length and weight of these two populations of age 2 fish during 1978 are shown in fig. 11. The decrease in mean length and mean weight of age 2 fish caught in St. Mary's Bay weirs in August and September is probably due to the arrival of smaller fish of the same age as was the case on the New Brunswick side of the Bay of Fundy (fig. 4).

D. "Between gears" comparisons of juvenile mean lengths.

Mean July lengths of herring caught by New Brunswick weirs, Nova Scotia weirs, and 4Xa purse seine fishery were compared in order to investigate the possible relationships of the fish in the respective catches. Comparisons were made at age 2 and 3 (fig. 12). When two fisheries are exploiting fish of similar sizes (of the same population), the points would be expected to fall along the 45° line which passes through the origin. At age 2 there appears to be little relationship between the mean lengths of the various fisheries. The fish caught by the mobile gear are consistently larger than those from the weir fisheries. This may indicate, however, that smaller fish of any year class tend to be closer inshore rather than that different populations are being fished. Also, the Nova Scotia weir two-year-olds are generally larger than those caught by the New Brunswick weirs, but there is a temporal trend in their relative lengths. All points from 1967 to 1971 fall to above the dotted line in fig. 12, and from 1972 to 1978 below the dotted line. The temporal trend in the ratio of lengths of Nova Scotia age 2:New Brunswick age 2 weir-caught fish is shown in fig. 13. The New Brunswick fish have become relatively larger in the years since 1971, approximately the time at which the change in growth pattern was noted in the juvenile growth analysis.

The mean length of age 3 fish in the purse seine catch is again larger than the weir-caught fish. The lower limits of mean length of age 3 fish susceptible to be caught by the purse seine fleet, which is synonomous with the mean length at recruitment to the adult population, seems to be about 242 mm (the horizontal dotted lines in the age 3 graphs). The lengths of weir fish (age 3) range from 200 to 265 mm., whereas all of the purse seine lengths except for 1968 lie above the 242 mm line. The plot of Nova Scotia weir versus New Brunswick weir mean length at age 3 indicates that the points lie closer to the 45° line than do the age 2 points, which suggests that the weirs fish the same age 3 population. The respective length frequency distributions of two- and three-year-olds in the 1978 weir and purse seine catches (fig. 14) add support to the suggestion that juvenile fish recruit to the adult population as a function of length. The larger two- and three-year-olds become available to the mobile purse seine fleet earlier than the smaller individuals of the same cohorts.

In summary, the analysis suggests that the Nova Scotia and New Brunswick weirs fish different age 2 populations but the same age 3 populations. The purse seiners select for larger age 2 fish than do either of the weirs. This does not necessarily indicate that the larger two-year-olds have recruited to the adult population but that the purse seiners are fishing in areas of juvenile distribution and that the larger individuals are more available to the gear. The age 3 plots, however, suggest that the fixed and mobile gears fish respectively the juvenile and recruited portions of the cohort.

II. Maturation:

Length at 50% maturity for both males and females has fluctuated over a considerable range since 1969 (the first year for which adequate maturation staging was carried out) (fig. 15). As was observed in the growth analysis of the juveniles, there appears to be a marked change in maturation in the early 1970s, a shift towards maturation at smaller lengths (starting with the recruitment of the 1970 year-class). The relationship between length at recruitment to the purse seine fishery (as estimated by mean length of age 3 fish in purse seine July catch) and length at 50% maturity is shown in fig. 16. Except for the 1969 point, there is a clear positive relationship between the two parameters. This suggests that the recruitment of juveniles to the adult population is linked to the maturation schedule, and that there is considerable range in the length at which the fish sexually mature and recruit.

<u>Summary of results</u>

1. Age composition of the New Brunswick weir catch reflects qualitatively the relative strengths of the year-classes of the 4WX stock as indicated by VPA. Some indication of year-class strength is evident from the age 1 autumn proportion of the catch.

2. Two distinct groups of two-year-olds enter both the New Brunswick and Nova Scotia weir areas: the first group in the spring, and the second, which is comprised of smaller two-year-olds, in the late summer. On the Nova Scotia side of the Bay of Fundy, there is some indication of spatial segregation in the two groups: the first group being fished in St. Mary's Bay, and the second in Annapolis Basin.

3. From consideration of mean length of fish caught in July, it is suggested that the weirs on each side of the Bay of Fundy fish different populations at age 2 but the same age 3 population.

4. Larger two-year-olds appear to be more available to the purse seiners even though fish at this age have not recruited to the adult schools.

5. Recruitment of age 3 herring to the adult population is a function of length and maturation. The larger three-year-olds recruit to the adult population first, and there is evidence that reproductive development is strongly associated with recruitment to the adult schools from the juvenile nursery areas.

6. The following changes in the biological characteristics of the herring populations occurred in the early 1970s:

   (i) The relationship (both intercept and slope) between age 2 summer length increment and initial length for the New Brunswick weir population changed.

   (ii) Increase in relative size of New Brunswick weir two-year-olds. A similar increase in size of Gulf of Maine juveniles was reported by Anthony and Waring (1977).

   (iii) Response of juvenile summer growth to population abundance from density dependence to lack of density dependence.

   (iv) Length of 50% maturity decreased for both females and males in conjunction with a decrease in stock biomass.

Discussion

The observed changes in the biological characteristics of the juvenile population of the New Brunswick side of the Bay of Fundy could be reflecting stock composition changes, responses to population density fluctuations or environmental changes. From tagging results, the juveniles in this area are believed to be a mixture of two or more spawning groups in SA 4, 5 and 6. The adult spawning stock on Georges Bank collapsed and that in the Gulf of Maine was severely reduced in the early 70's (fig. 2). Also, fishing pressure on juveniles in 4X was high in the late 60's and early 70's when there was a meal fishery, and Anthony (1972) noted a dramatic drop in the Maine juvenile fishery in 1970-71. There was a parallel decline in the Canadian 4Xb juvenile fishery but not in the 4Xa component.

The shift in the relationship between length increment and initial length suggests a change in fundamental growth characteristics associated with stock composition changes rather than a unit population response to abundance or environmental shifts. The trend towards increasing size in New Brunswick weir-caught two-year-olds may indicate an increasing contribution of the larger southwest Nova Scotia-spawned juveniles or, again, a growth response to population decline. The latter explanation in both cases is less tenable in that the CPUE of the New Brunswich weirs has remained high. The results indicate the dynamic nature of the biological characteristics of the juvenile population in the Bay of Fundy.

A possible interpretation of the results is that as one or more of the components of the juvenile population decreased due to "recruitment overfishing" of the adult stock(s), the void was filled by a geographical shift in the range of the other component(s) without necessarily an increase in the overall population size of this latter component(s). This is biologically sound in that the New Brunswick weir area is probably the optimal juvenile environment. In terms of management, shifts in the relative stock composition of the "New Brunswick weir" juvenile population present problems. The fishery appears resilient in that voids can be filled, but the assignment of fishing mortality of juveniles to various spawning components and/or management units is problematic.

The juvenile growth analysis indicates that 4WX year-class strength cannot be predicted with any confidence from 4Xb summer growth increment and initial length or weight. Although growth at the juvenile stage and subsequent maturation and recruitment appear to be density-dependent, the relationships identified in this analysis do not permit their use as predictors of year-class strength. They can be used, however, in conjunction with other "predictors" such as the age composition of juvenile catch and environmental regressions.

Acknowledgements

A part of the data base analysed in the study has been generated over the years by K. Metuzals, D. Miller and W. Stobo with the computer assistance of D. Fitzgerald. We gratefully acknowledge their contributions.

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Table 1. Initial length and summer length increments of New Brunswick weir age 2 herring.

YEAR	INITIAL LENGTH (mm)	LENGTH Increment (mm)	D	ADJUSTED LENGTH INCREMENT (mm)
1965	128.5	31.5	1	30.3
1966	117.9	44.3	1	34.7
1967	133.6	41.1	0	44.0
1968	126.6	34.6	1	31.9
1969	120.9	45.2	1	37.9
1970	122.0	41.0	1	34.6
1971	134.8	41.7	0	45.5
1972	156.0	33.7	0	54.4
1973	132.2	42.3	0	44.1
1974	132.3	52.7	0	54.5
1975	133.3	50.3	0	52.9
1976	142.8	40.3	0	50.5
1977	123.0	58.0	0	52.4
1978	127.1	56.9	0	54.6

Multiple regression of initial length (L) on length increment (ΔL) using a dummy variable (D).

$$\Delta L = 153.9 - 0.797L - 16.441\ D$$

$$r^2 = 0.769.$$

Table 2. Sum of monthly mean surface temperatures from May-September, age 2 population abundance and catch per unit of effort estimates for the Bay of Fundy juvenile fishery.

YEAR	TEMPSUM °C	AGE 2 ABUNDANCE x 10^{-6}	CPUE INDEX
1965	49.6	4526	2.217
1966	50.6	2763	.393
1967	47.7	2215	.506
1968	54.0	4709	1.973
1969	56.0	1040	.977
1970	58.1	1465	.907
1971	59.3	1245	.478
1972	54.9	5505	1.718
1973	55.3	926	.388
1974	54.8	1826	.640
1975	52.3	1612	1.204
1976	64.0	217	.518
1977	53.9	564	.323
1978	56.2	5107	1.758

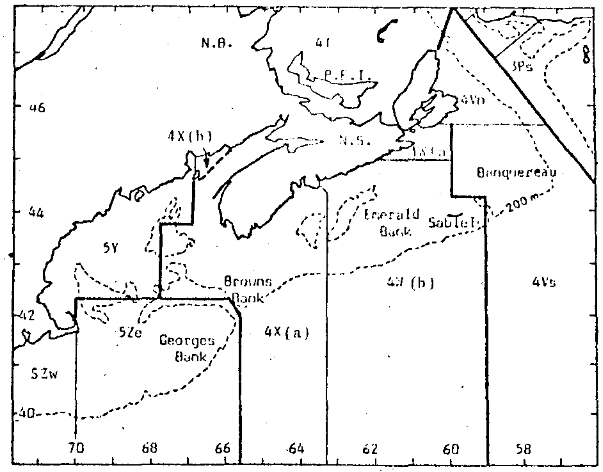

Figure 1. The areas of the 4WX, 5YZ herring fisheries.

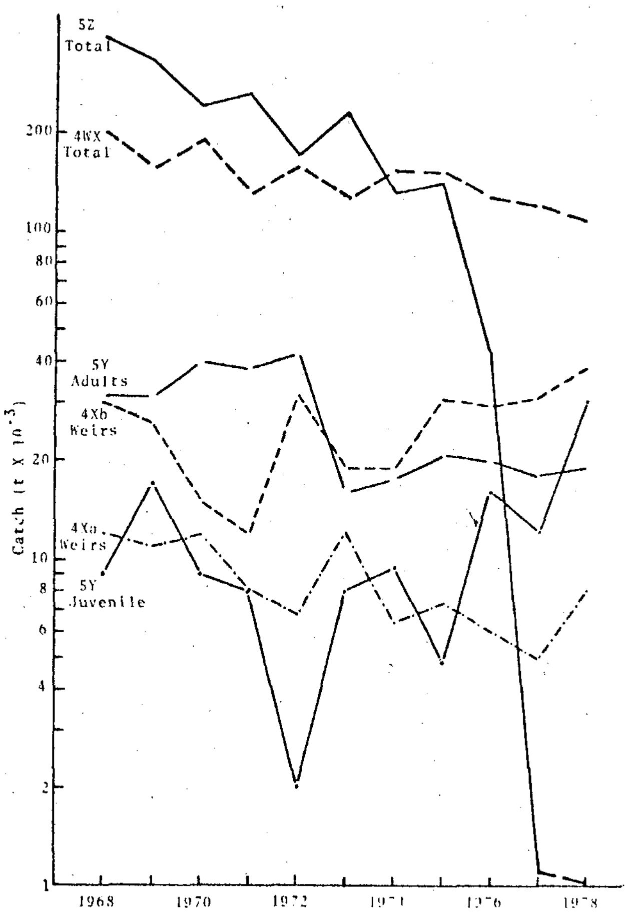

Figure 2. Recent catch histories of the 4WX, 5YZ herring fisheries.

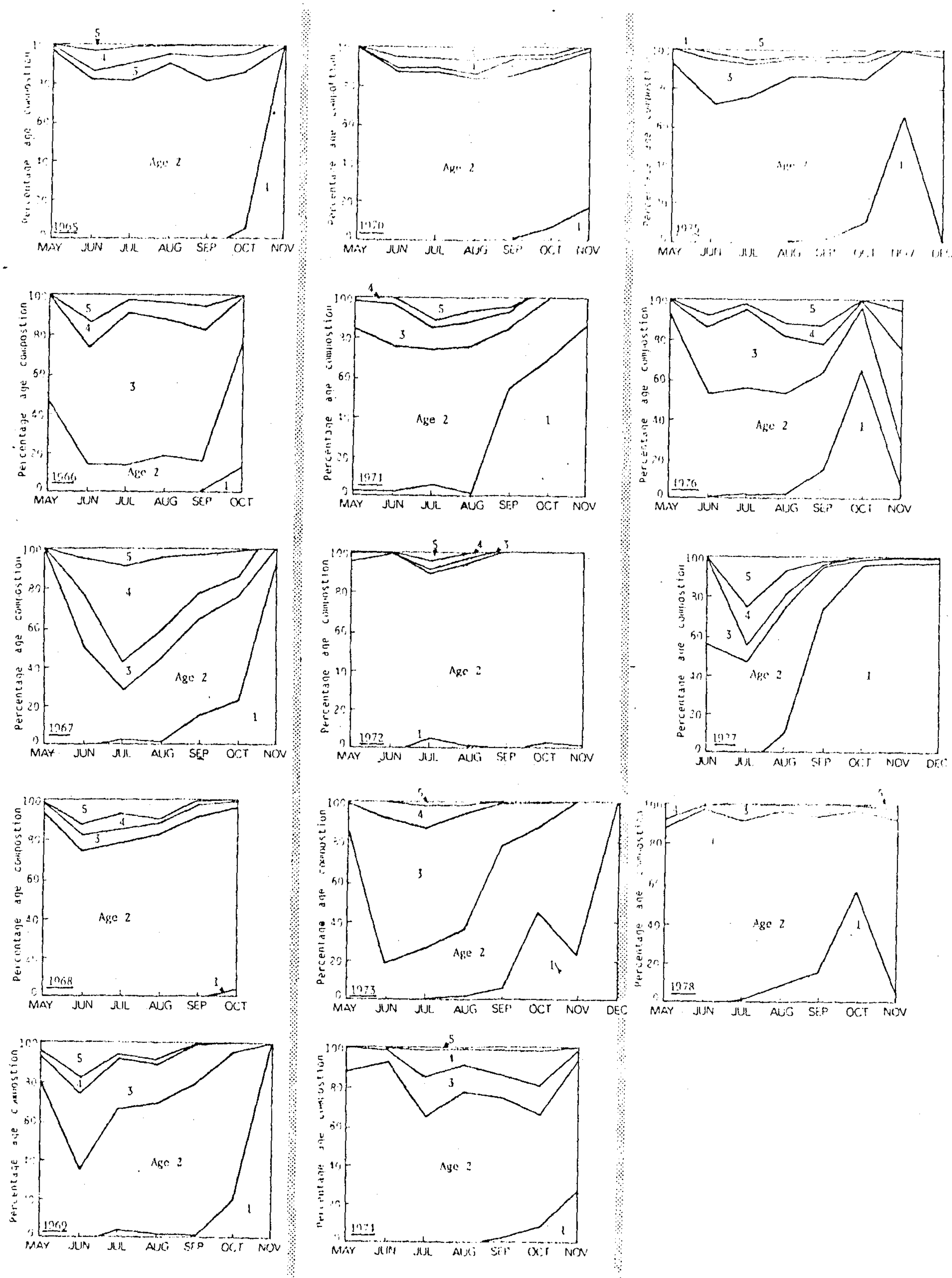

Figure 3. Monthly age composition of the 4Xb weir catches from 1965-78.

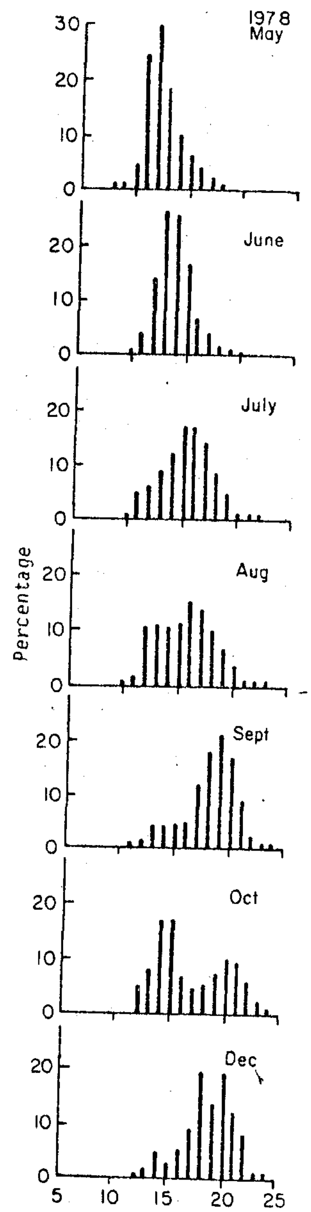

Figure 4. Monthly length frequencies of N. B. weir removals, age 2 in 1978.

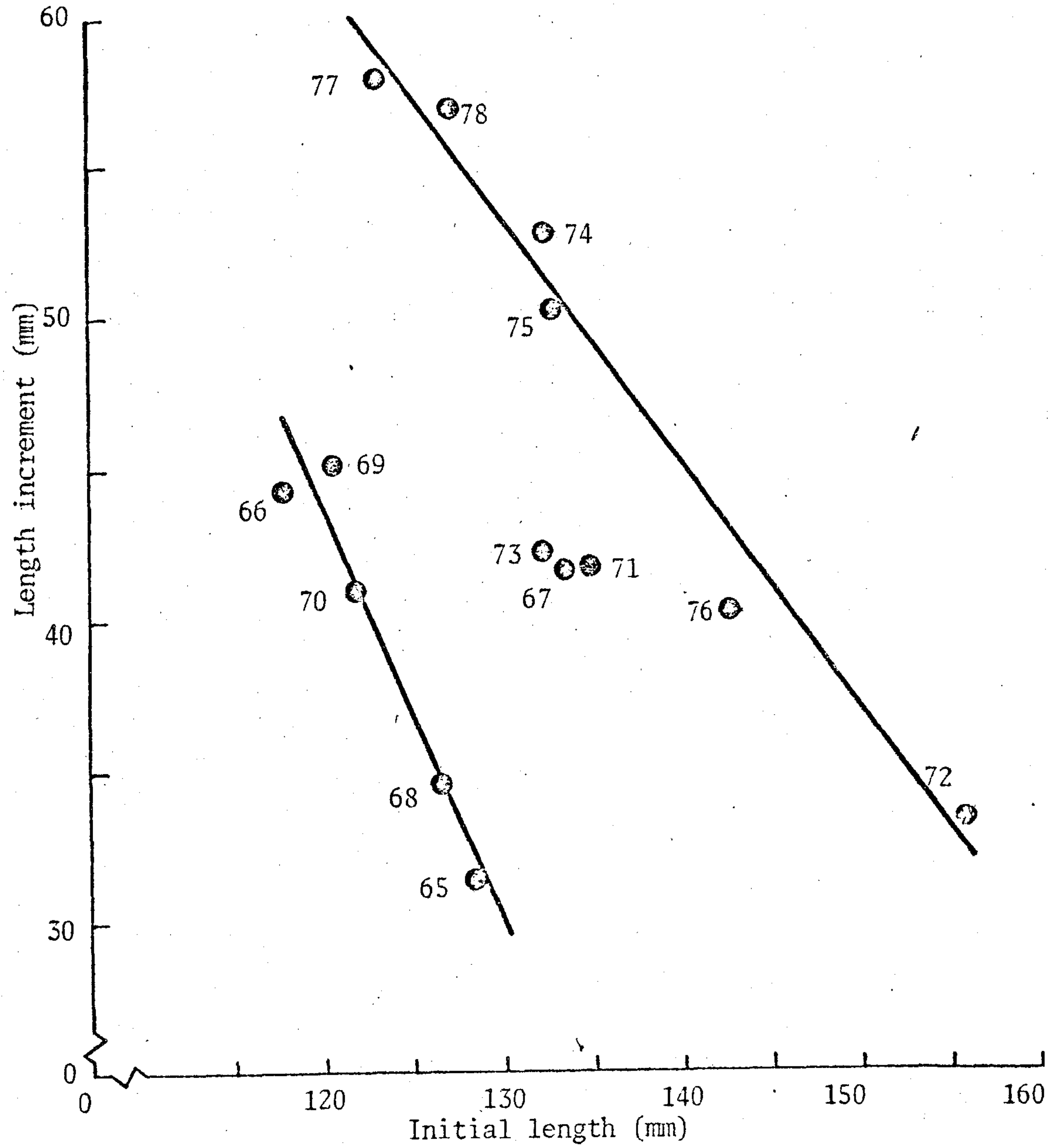

Figure 5. Initial length vs length increment of age 2 herring from the 4Xb weir fishery (year is indicated rather than year-class).

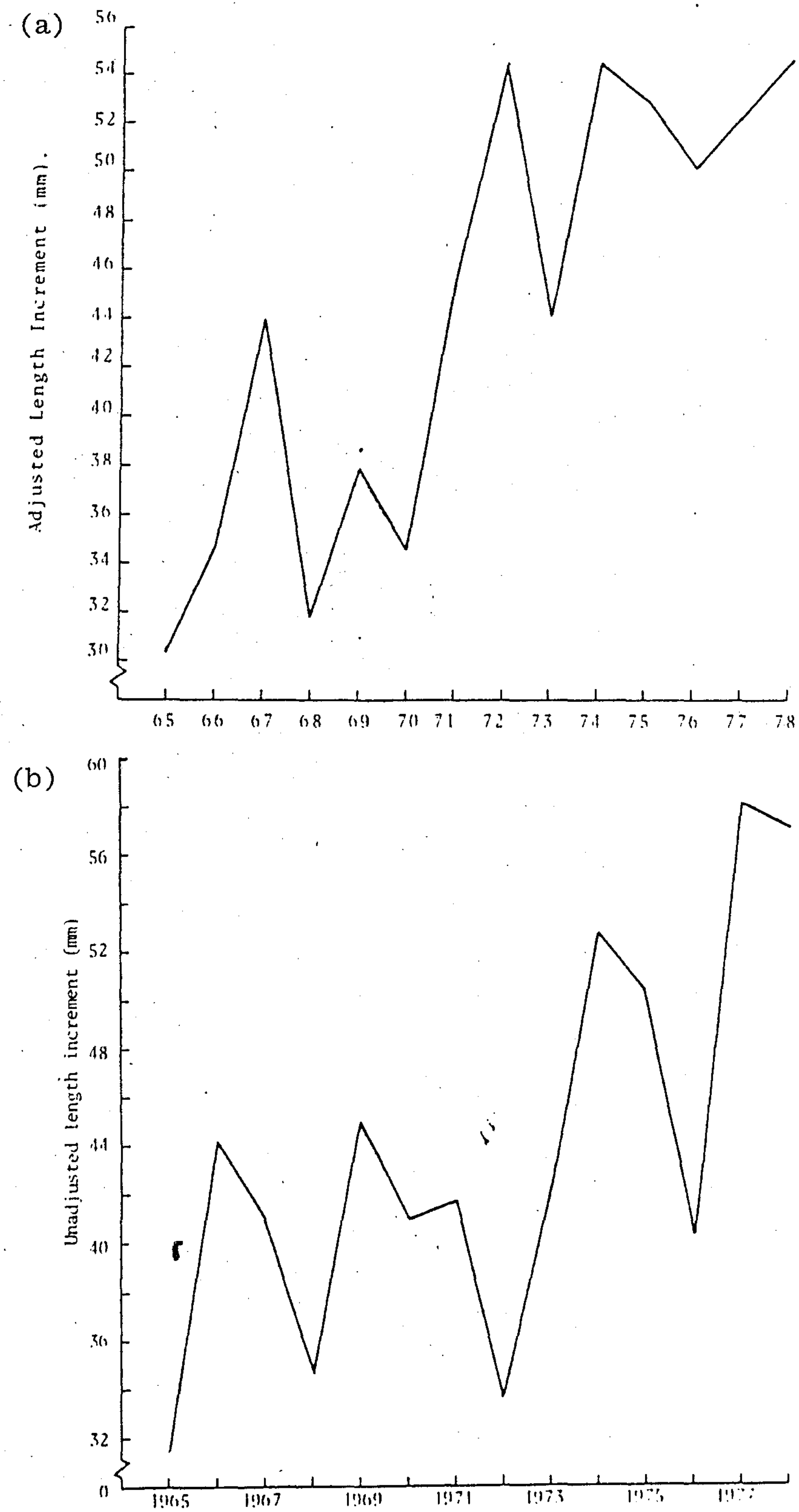

Figure 6. a) adjusted for length dependent bias
b) unadjusted.

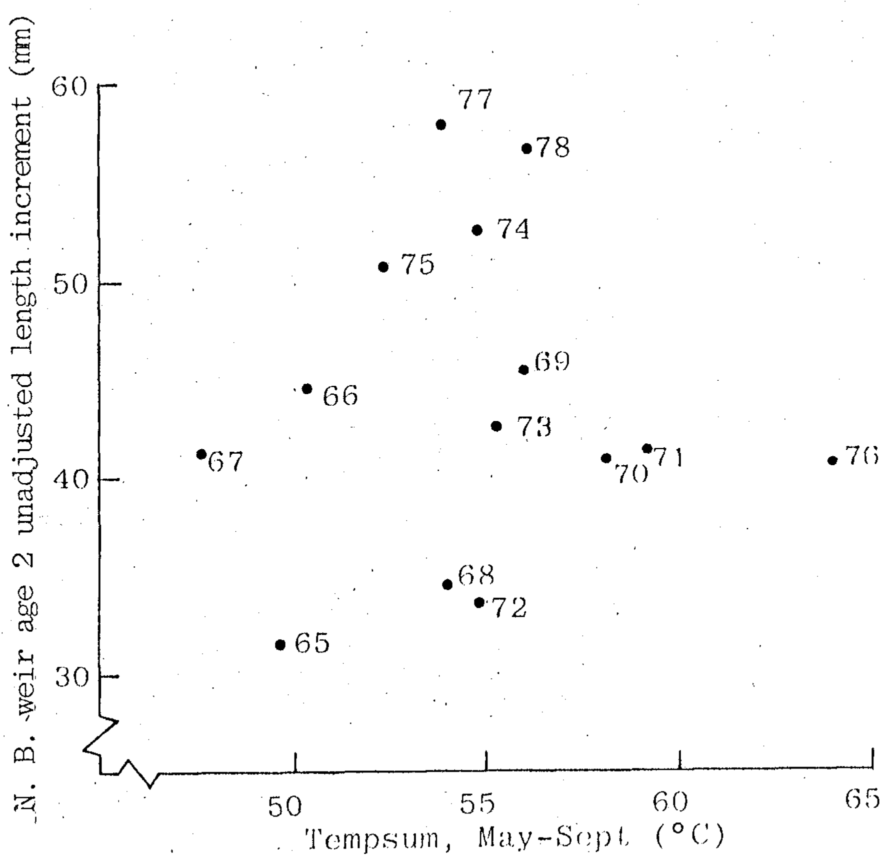

Figure 7. Unadjusted 4Xb age 2 length increment vs monthly mean St.Andrews temperature summed over the growing season.

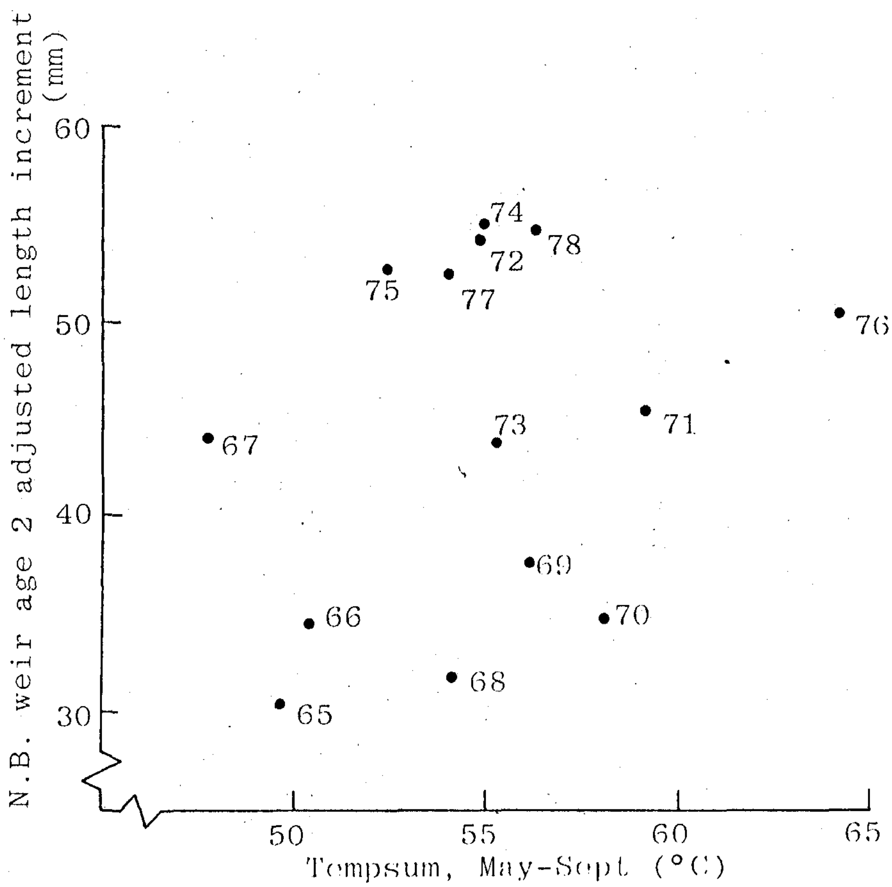

Figure 8. Adjusted 4Xb age 2 length increment vs monthly mean St. Andrews temperature summed over the growing season.

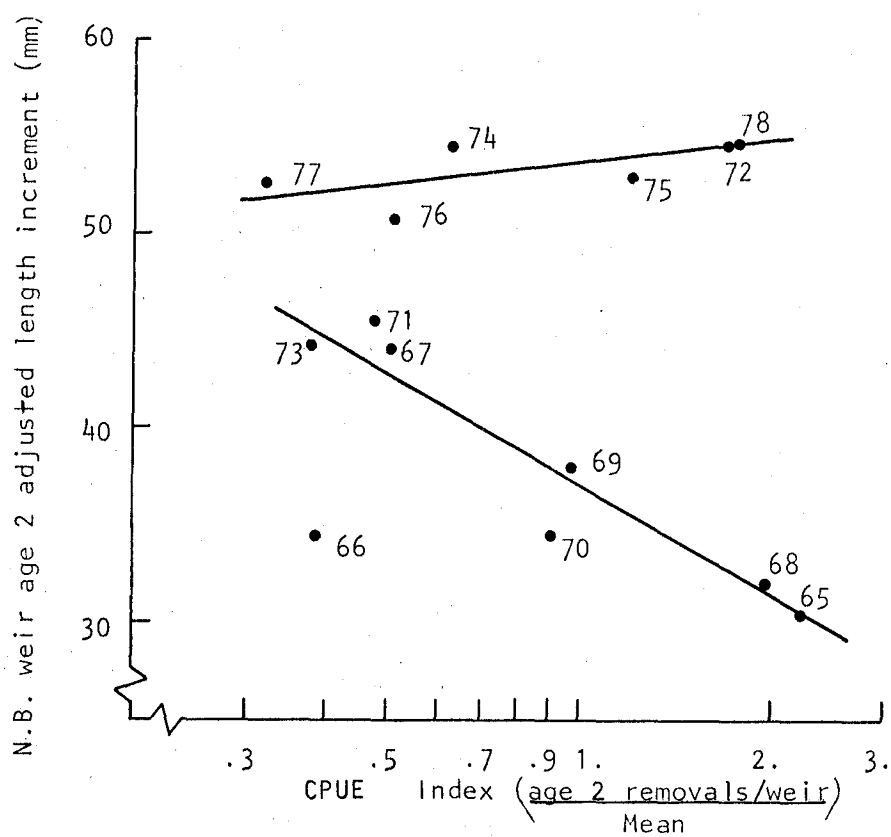

Figure 9. Plot of adjusted length increment of 4Xb 2-year old herring and CPUE index from 4Xb weirs (year is indicated rather than year-class).

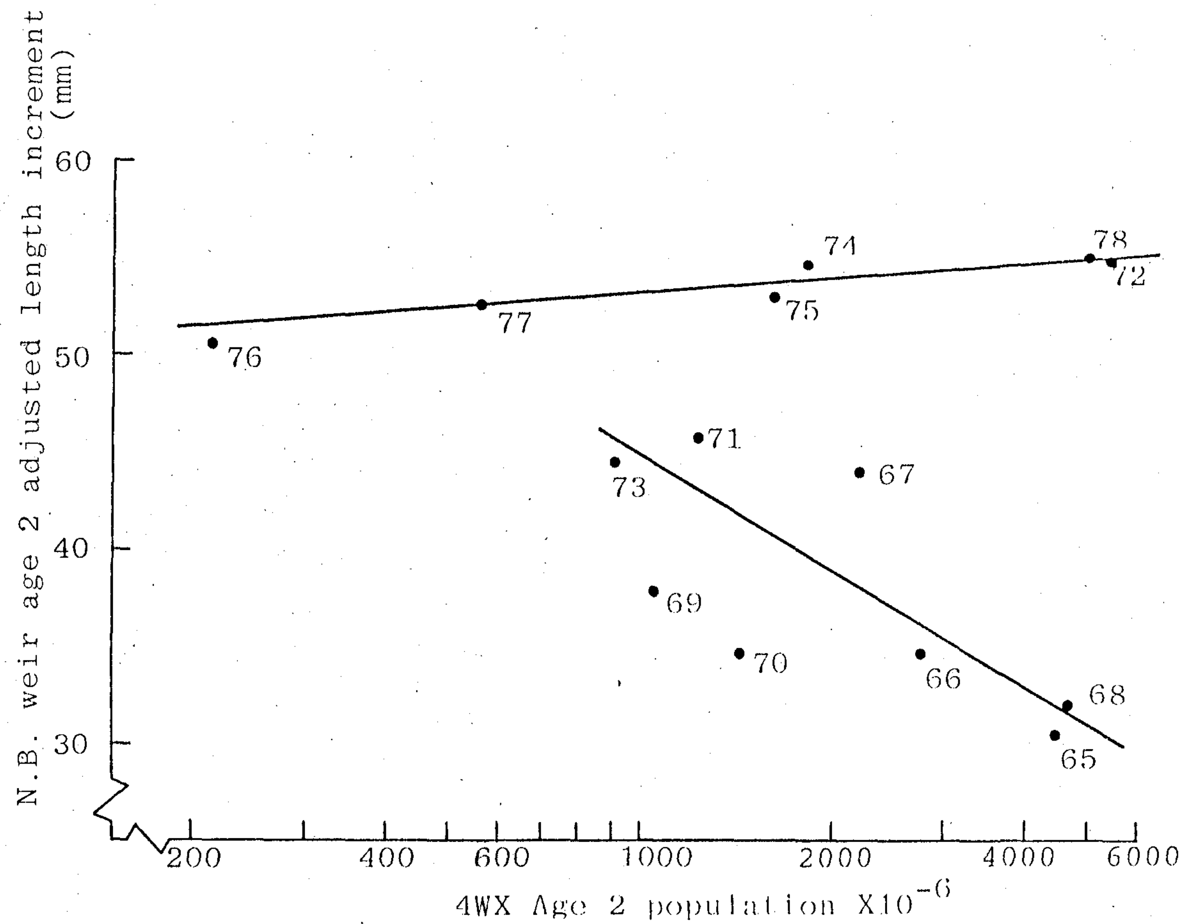

Figure 10. Plot of adjusted length increment of 4Xb 2 year old herring and age 2 population numbers of the 4WX stock (year rather than year-class is indicated),

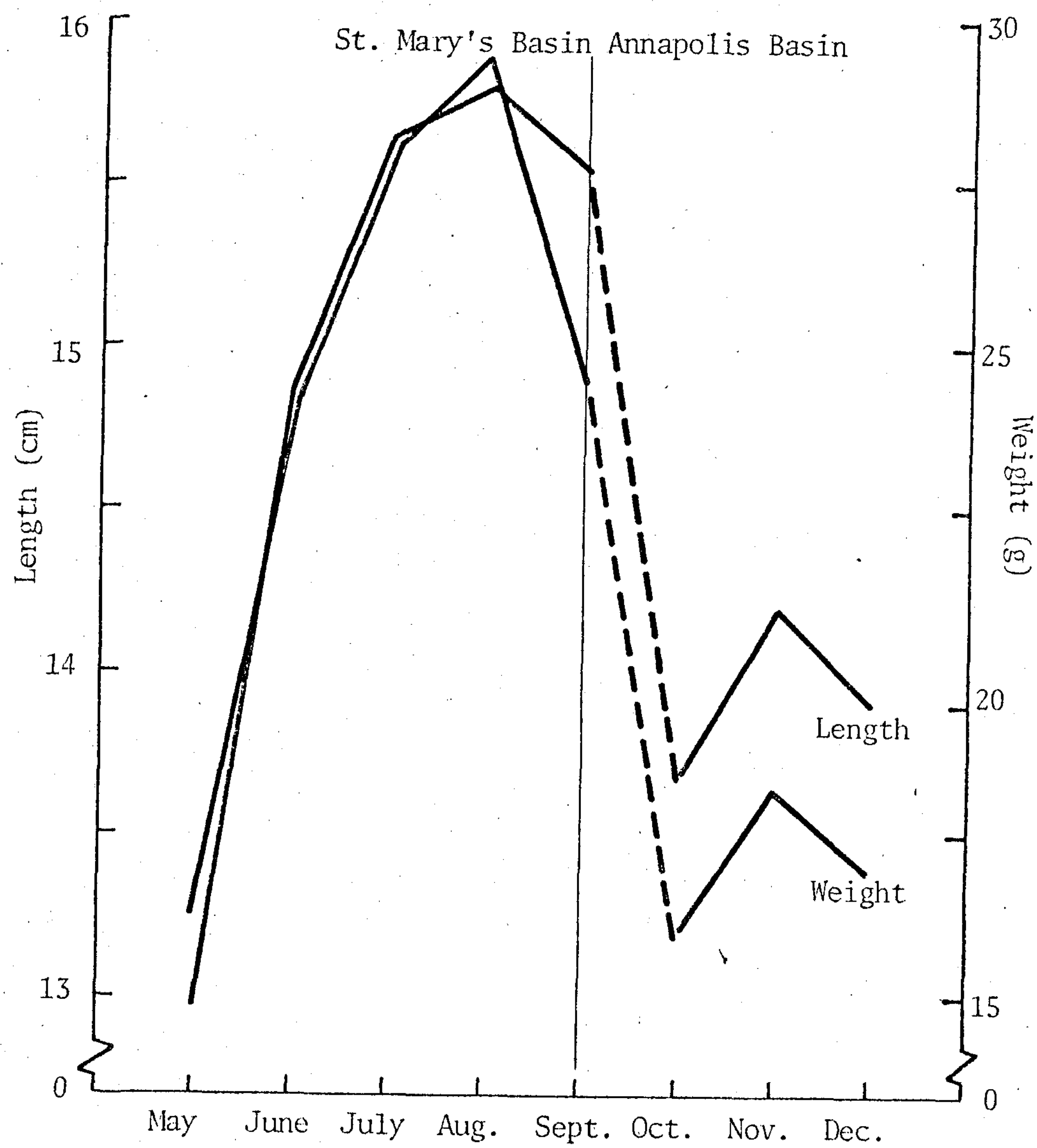

Figure 11. Comparitive mean lengths and weights of 4Xa weir herring showing the arrival of a second size group in the fall.

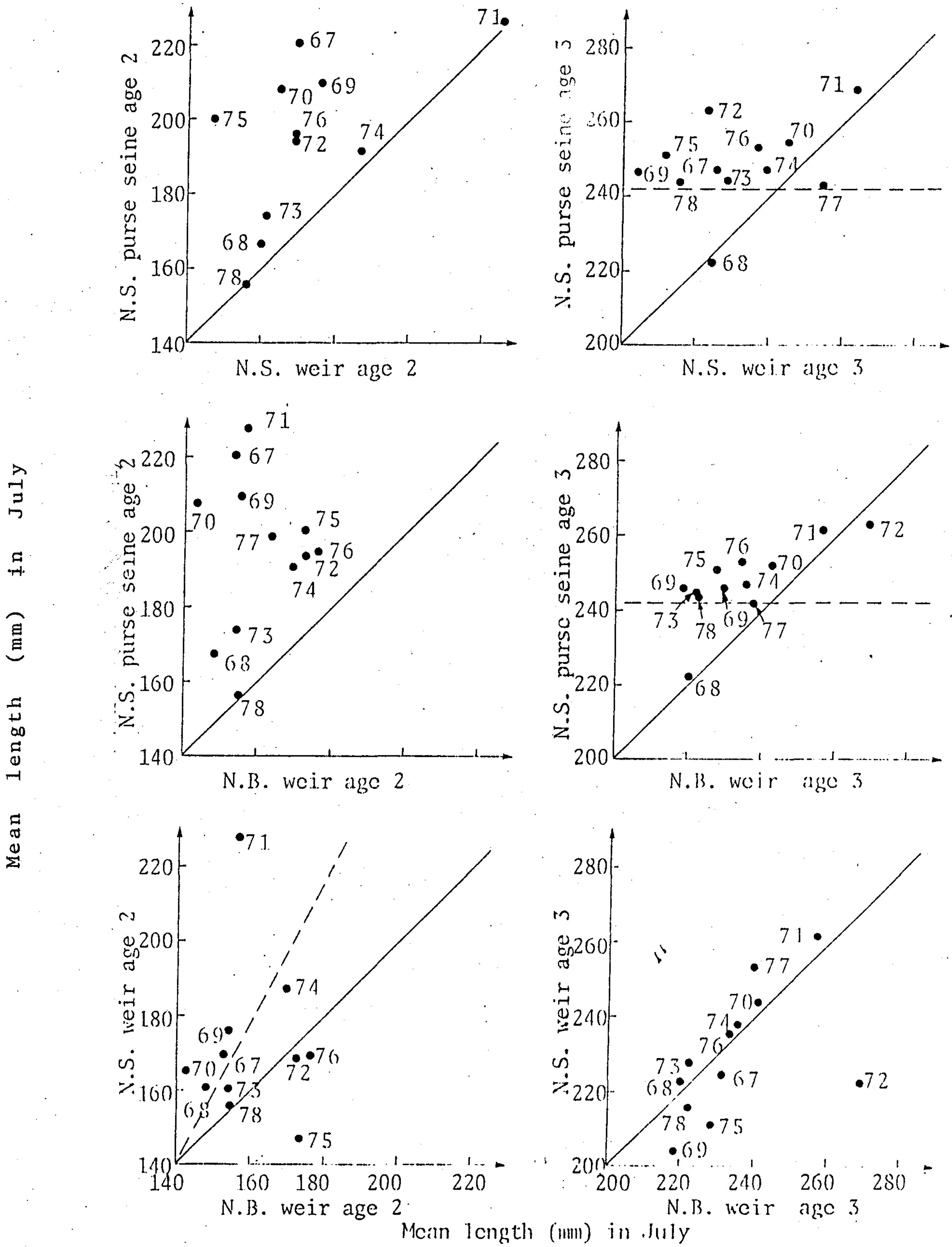

Figure 12. Comparison of mean July lengths of ages 2 and 3 herring caught with 3 gear types. (year rather than year-class is indicated).

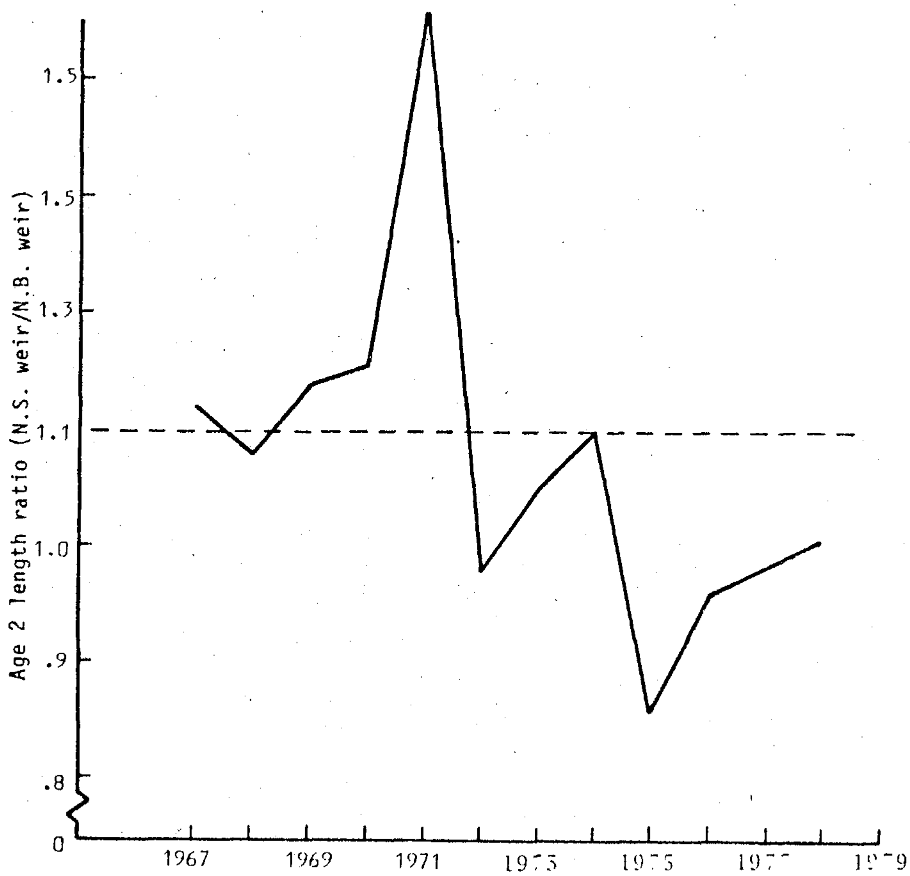

Figure 13. Trend in the ratio of 4Xa and 4Xb weir mean July lengths, age 2, showing a closer correspondence in mean length since 1972.

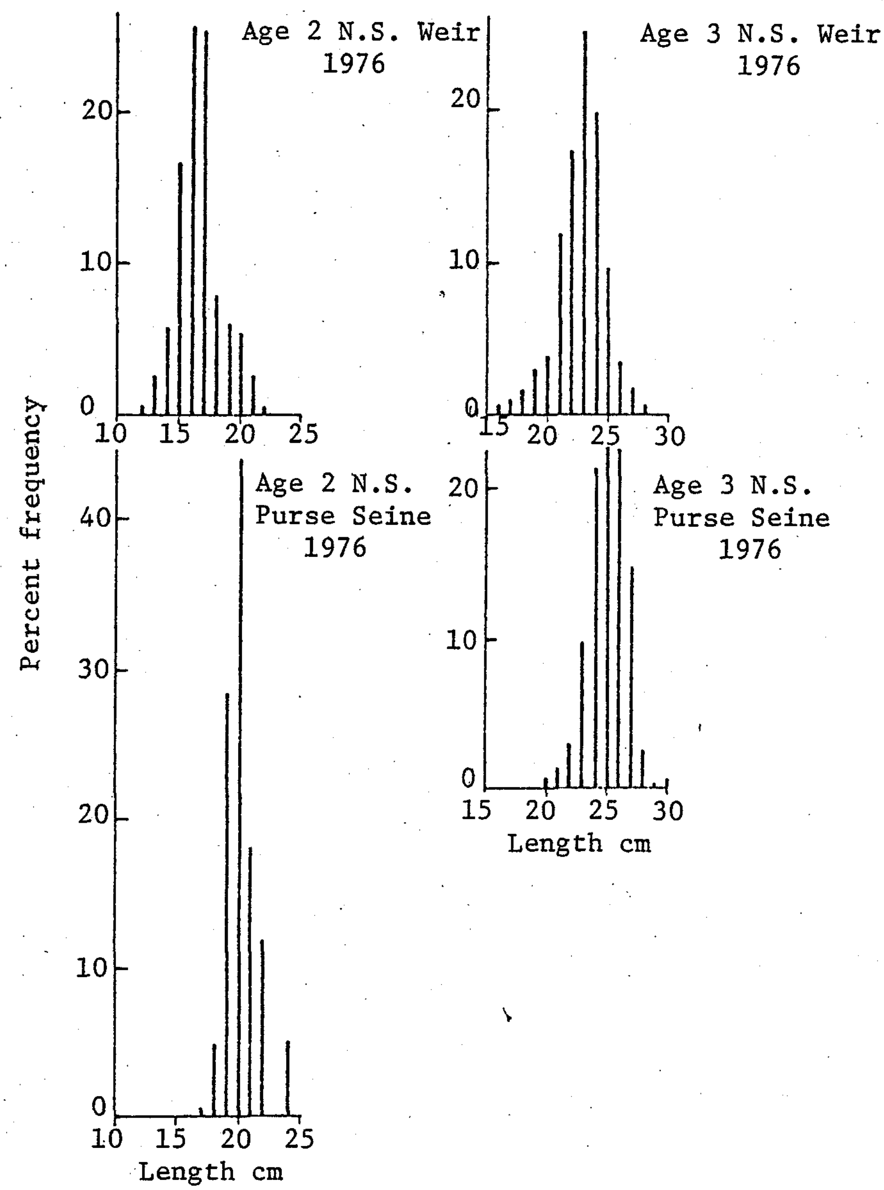

Figure 14. Comparisons of length frequencies of age 2 and 3 herring caught by N. S. weirs and N. S. purse seines in 1976.

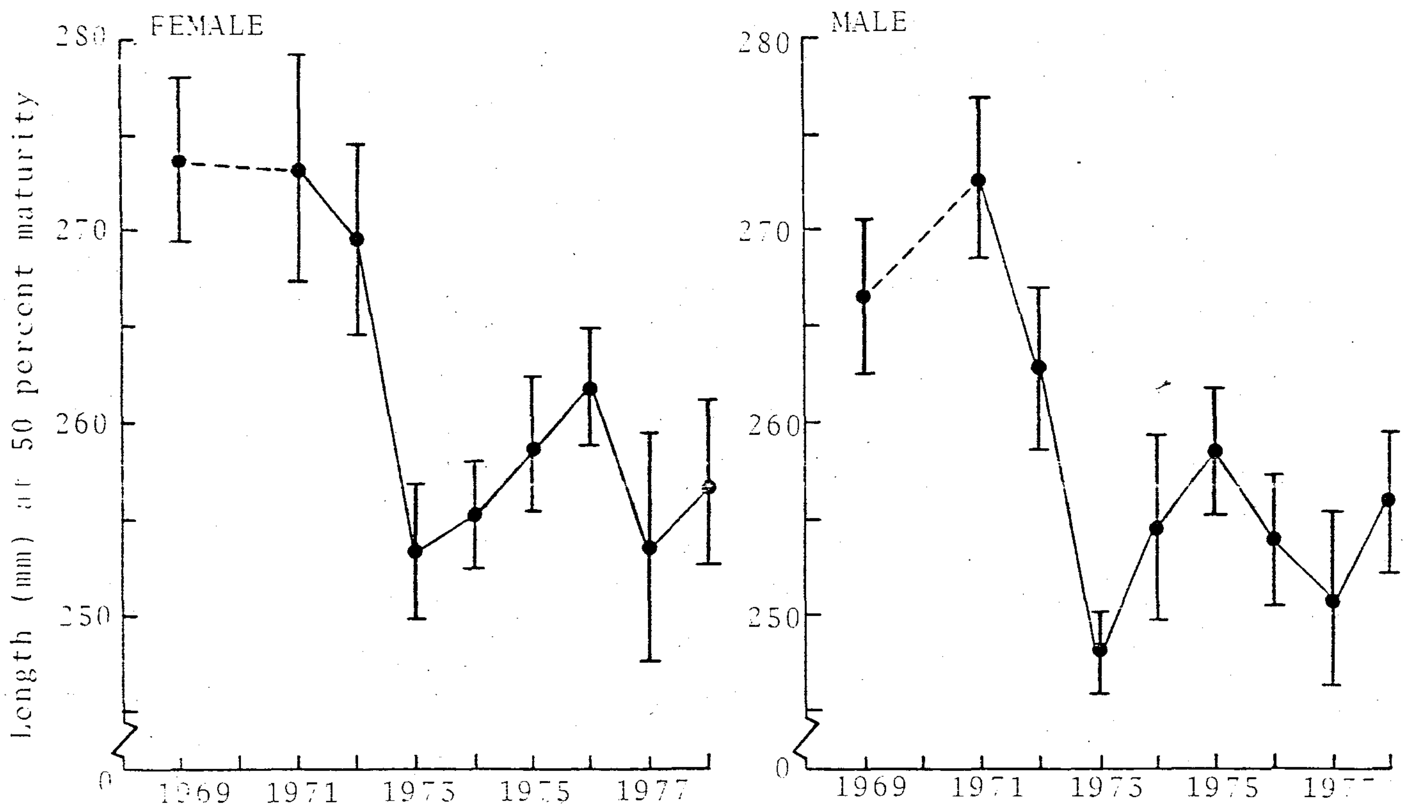

Figure 15. Changes in male and female length at 50% maturity.Error bars show the 95% confidence limits.

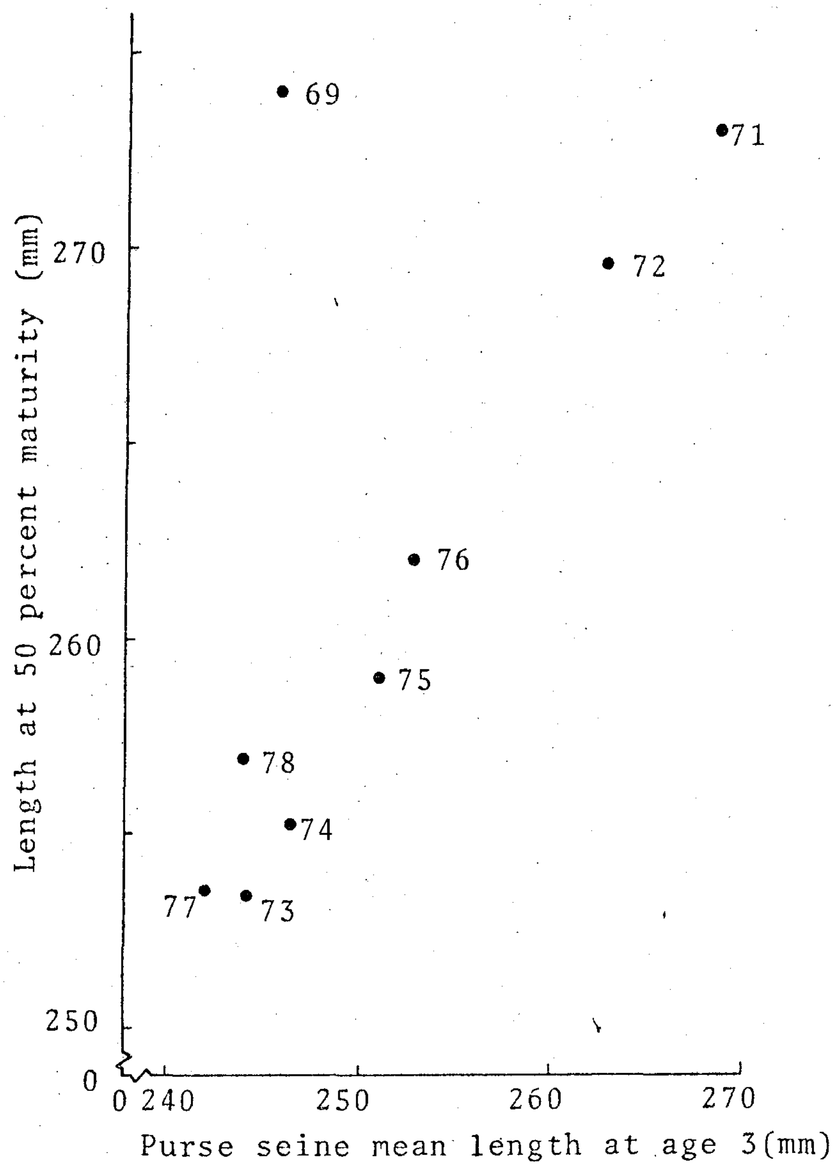

Figure 16. Relationship between mean length at 50% maturity and mean length at age 3 in the 4Xa purse seine fishery.