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AN ANALYSIS OF SOME BIOLOGICAL CHARACTERISTICS OF THE 4X JUVENILE-HERRING FISHERY

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An analysis of some biological characteristics of juvenile herring from the Bay of Fundy area revealed significant changes in growth and in length at age, and at maturity in the early 1970's. A corresponding shift in the relationship between growth and abundance of juvenile herring, from density dependence to lack of density dependence, is also demonstrated. These events occurred when some of the adult populations adjacent to the Bay of Fundy were in a period of radical decline. An explanation of these phenomena is presented, based on differential reduction in the adult stocks that contribute to the juvenile herring mosaic in the Bay of Fundy.

On se sert d'une analyse de quelques paramètres biologiques du hareng juvénile des environs de la Baie de Fundy pour dévoiler d'importants changements survenus au début des années 1970 en ce qui a trait au taux de croissance, à la taille par âge et la taille à maturité de ces animaux. On démontre aussi qu'au cours de la même période la relation entre la croissance du hareng juvénile et son abondance est devenue indépendante de la densité de population. Ces événements se sont produits alors que quelques unes des populations adultes adjacentes à la Baie de Fundy subissaient un déclin radical. On propose pour ces phénomènes une explication basée sur le concept d'une réduction différentielle des stocks adultes qui contribuent à la mosaïque du hareng juvénile de la Baie de Fundy.

Introduction

The weir fishery for juvenile herring on the New Brunswick side of the Bay of Fundy (NAFO Div. 4Xb, Fig 1), together with the contiguous fishery in Maine, (NAFO Div. 5Y), supplied the oldest fish-processing industry on the North American east coast (Huntsman 1953). More recently, large-scale multinational adult fisheries have developed, which exceeded the juvenile fisheries to a degree that threatened the future of both adult and juvenile populations (ICNAF 1972).

The Canadian herring catch in 4X has been sampled in considerable detail since 1968 for length frequencies and other biological parameters. Prior to 1968, less detailed sampling of the catch was done. The aim of this study is to analyse this 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 management unit.

The herring fishery off southwest Nova Scotia and in the Bay of Fundy exploits a mixture of stocks (ICNAF 1972). The 3 major stocks spawn respectively off southwest Nova Scotia, in the Gulf of Maine, and on Georges Bank. The spawning areas and associated larval distributions of each stock are unique, but there is

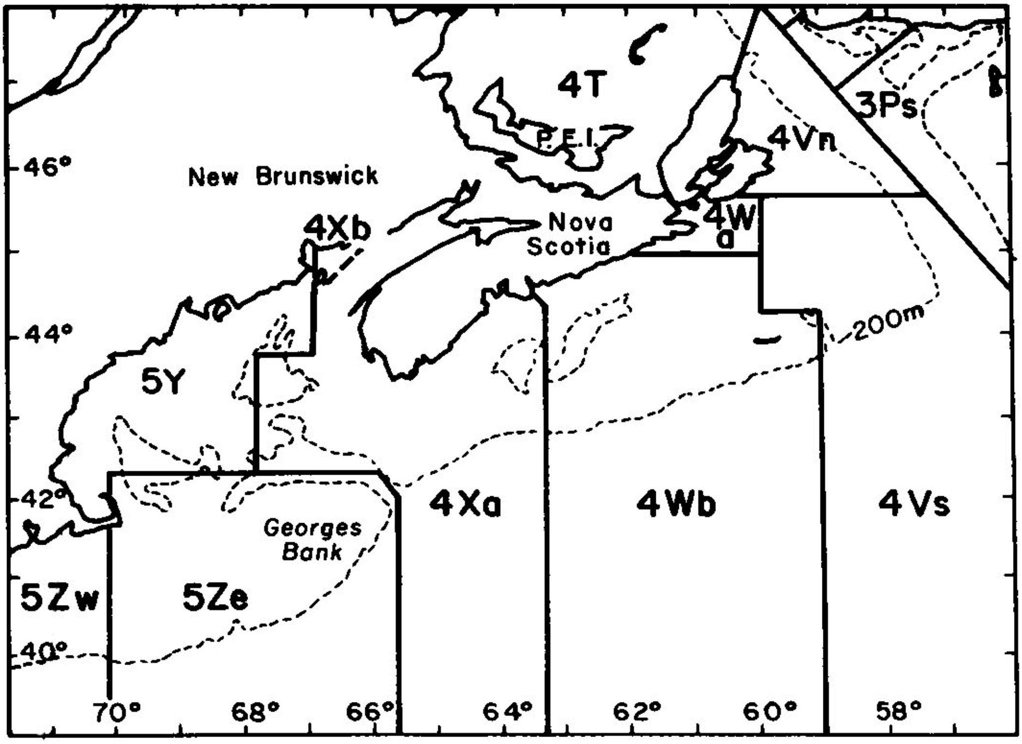

Fig 1. Areas of the 4WX and 5YZ herring fisheries.

mixing, in unknown proportions, of the juveniles (Messieh 1970) and of the adults (Stobo et al. 1975). Specifically, there is mixing of "Gulf of Maine" and "Southwest Nova Scotia" juveniles along the coast of Maine and in the Bay of Fundy. Also there is in direct evidence that juveniles from the Georges Bank stock contributed to catches in the New Brunswick weir fishery in the early 1970's (ICNAF 1973). In addition, there is a much smaller stock of herring that spawns at Grand Manan in 4Xb (Huntsman 1953), whose juveniles are almost certain to be admixed in the Bay of Fundy fishery.

The relative proportions of the 4WX herring catch contributed by the respective spawning stocks and the temporal changes of these proportions are not known. However, it is expected that the growth, maturation and spatial distributions of herring in 4WX have been influenced by both the environment and changes in the relative contributions by each spawning stock.

A review of the historical catches in NAFO 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 Figure 2 (after Sissenwine & Waring 1979). The Georges Bank fishery collapsed because of overfishing in the first half of the 1970's and, based on larval and adult surveys, there is no indication of recovery (Anthony & Waring 1980). The Gulf of Maine adult fishery (5Y adult) has also declined by about 50% since 1972. The 5Y juvenile catch fell to a low in 1972 which preceded the decline in the 5Y and 5Z adult fisheries. Since then the 5Y juvenile catch has been increasing because of an increase in mobile gear effort and the appearance of large 1976 and 1977 year-classes. The catch distribution of juveniles in 4Xb parallels that of coastal Maine but is different from 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 fell to an all-time low in 1978.

Materials and Methods

Length and Weight

Mean lengths and weights at age for a given month were estimated routinely from catch samples in preparation for the stock assessment. Length-frequency samples were weighted by catch and combined. Monthly age-length keys were constructed and removals at age by 1-cm length intervals were calculated.

Maturity

Mean length at 50% maturity by sex was calculated from the detailed biological samples. A maturity stage-length key was constructed from purse-seiner samples taken in August. During August, the purse-seiner fleet concentrates on pre-spawning and spawning schools. Fish at or above stage 3 (Parrish & 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 were insufficient to calculate a 50% point. All other correlations were significant ($p<0.01$).

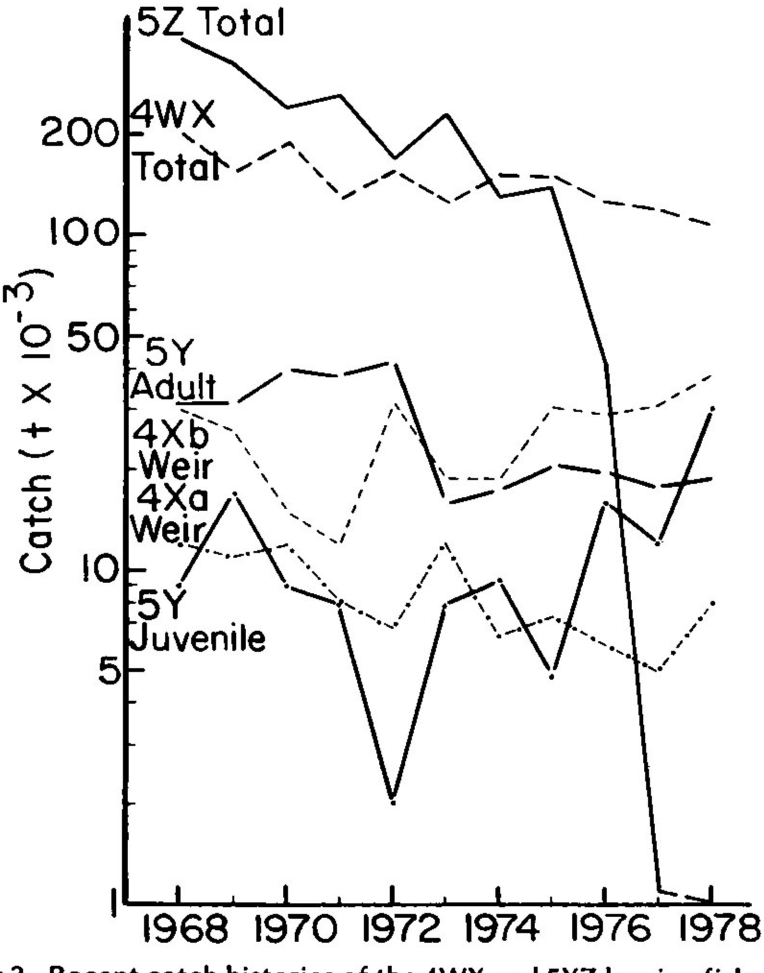

Fig 2. Recent catch histories of the 4WX and 5YZ herring fisheries.

Results

Age Composition

The New Brunswick weir fishery traditionally exploits sardine size herring predominantly at age 2. The monthly age compositions of the catches from 1965 to 1978 are shown in Figure 3. Initially 2- and 3-year-olds make up most of the catches but in the later months 1-year-olds enter the fishery. Large year-classes such as those of 1963, 1966, 1970, and 1976 (Sinclair & Iles 1980) tend to show up earlier in the life history and persist in the fishery longer. It is interesting to note that the 1977 year-class appeared strong in the 1978 catch in spite of the large number of 2-year-olds from the large 1976 year-class. As age 2 fish make up the bulk of the juvenile fishery, this study concentrates on the growth of 2-year-olds.

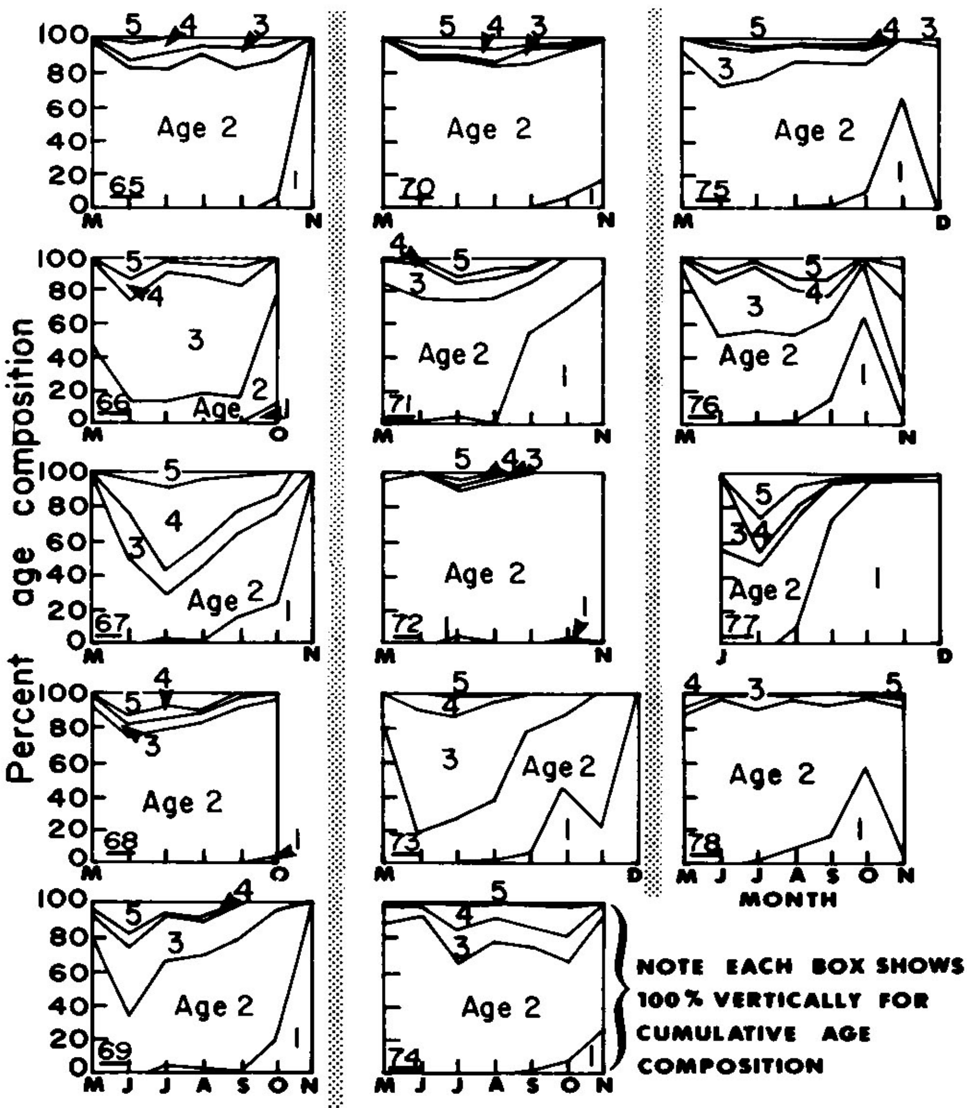

Fig 3. Monthly age composition of the 4Xb weir catches from 1965 to 1978.

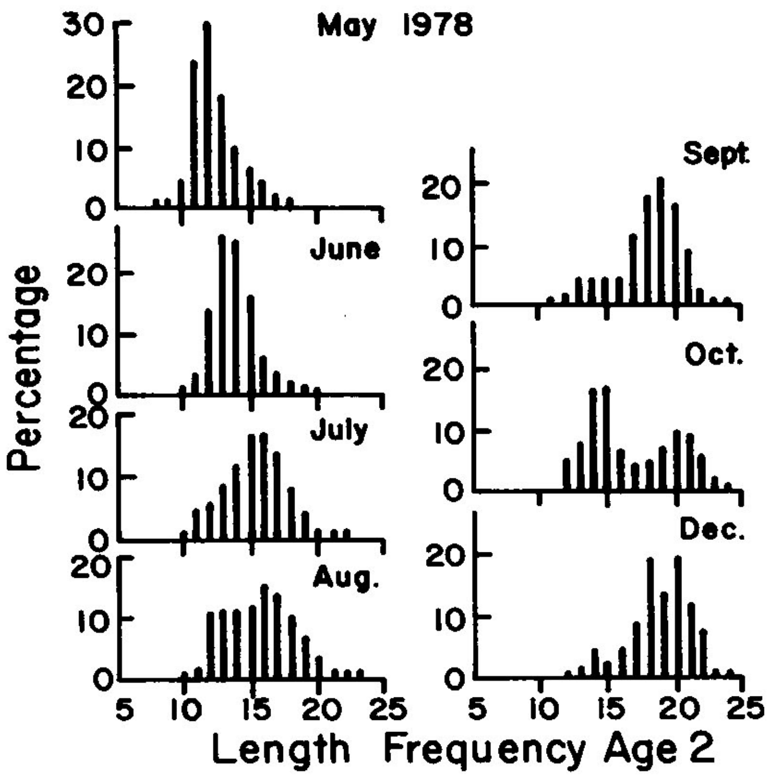

Fig 4. Monthly length frequencies of New Brunswick weir removals, age 2 in 1978.

Growth of 2-year-old Fish

Each year the monthly length frequencies of 2-year-olds were approximately normally distributed during the early part of the fishery but tended to become bimodal by August or September. A representative series of length frequencies (Fig 4) shows a 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 appears and remains through October. Clearly the mean lengths (to include both modes) 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 growth of only the larger population that was present at the beginning of the season is considered.

A complete time series of length frequencies is available for the months May to September and the calculation of summer growth (length increment) was limited to this time period. However, the major part of the annual growth occurs within these months (Huntsman 1919). Iles (1967) demonstrated that, when length increment is used as a measure of growth, it is essential to correct the increments to the same initial length. When such corrections are not made, as for example by Moores and Winters (1978) and de Veen (1976), erroneous conclusions regarding growth compensation or growth rates may result.

To allow for length-dependent growth, the summer increment was adjusted for initial length, taken as that for May. When length increment was plotted against initial length (Fig 5), 2 temporally distinct groups appeared, which differed in

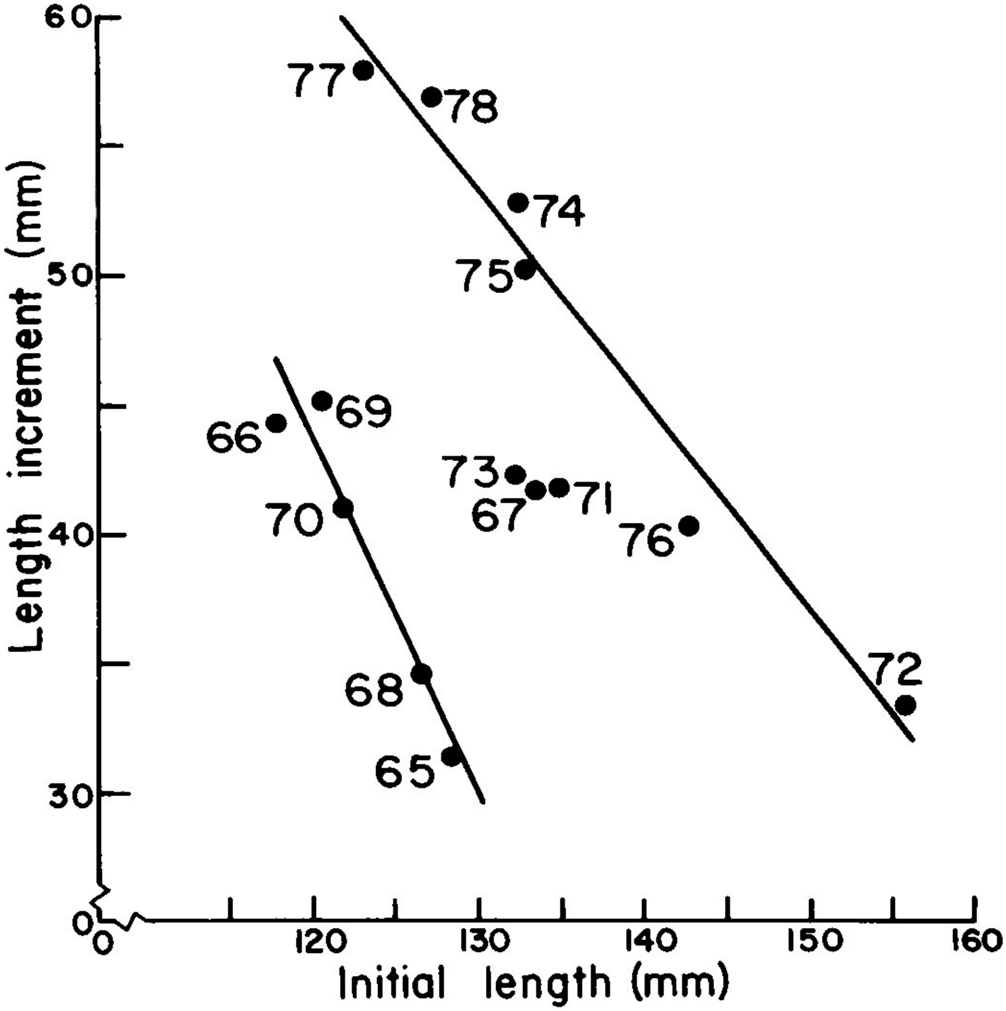

Fig 5. Initial length vs. length increment of age 2 herring from the 4Xb weir fishery.

their growth characteristics. The first group included the years 1965 to 1970, but excluding 1967, and the second the years 1972 and 1974 to 1978. The linear regression of the first group had an r^2 of 0.912 ($p < 0.01$) and of the second group an r^2 of 0.972 ($p < 0.01$). The 1967, 1971, and 1973 points are intermediate between the 2 groups.

A dummy variable (Draper & Smith 1966) was used to account for this apparent discontinuity. The data set was split into 2 groups, the 1967 point being included with the first group and the 1971 and 1973 points with the second group. A multivariate regression gave the equation:

$$\Delta L = 143.0 - 0.7L - 14.7D$$

where ΔL = length increment
L = initial length
D = dummy variable

The length increments were adjusted to a standard initial length of 130 mm using the coefficient of L by:

$$\Delta L' = L - .7\,(130 - L)$$

$$\text{where } \Delta L' = \text{the adjusted length increment}$$

The results of the regression and the length data are presented in Table I.

There is, then, good evidence of a change in the growth characteristics of 4Xb 2-year-old herring in the early 1970's, one that is shown in Figure 6. In the years 1965, 1966, and 1968 to 1970, the adjusted length increments were below 40mm while in the years 1972 and 1974 to 1978 the increments were above 49 mm. Again the 1967, 1971, and 1973 points are intermediate.

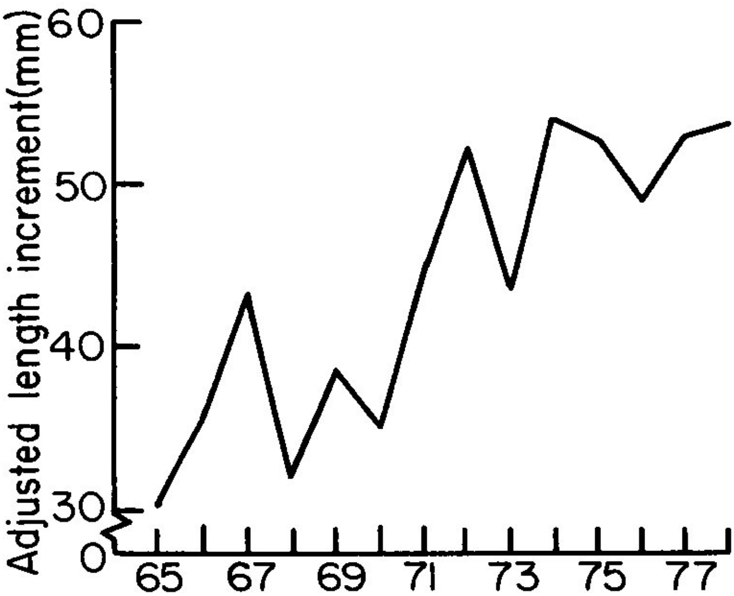

Fig 6. Trend in adjusted length increments of the 4Xb 2-year-olds.

Temperature Effects

Monthly mean-surface temperatures from the St. Andrews Biological Station summed from May to September were plotted against the adjusted length increments to investigate the effect of temperature 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. However, this is not meant to rule out possible temperature effects on growth.

Effects of Population Abundance

Two estimates of 2-year-old population abundance were calculated for the New Brunswick weir fishery. Because of the uncertain stock identity of the New Brunswick weir catches, it is not necessarily valid to assume that the number of 2-year-olds estimated by cohort analysis for the 4WXa (Nova Scotia) fishery is an appropriate index of the 4Xb (New Brunswick) population size. An alternative measure is the catch per unit effort (CPUE) estimates for the New Brunswick weir

Table I. 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	30.4
1966	117.9	44.3	1	35.7
1967	133.6	41.1	1	43.7
1968	126.6	34.6	1	32.2
1969	120.9	45.2	1	38.7
1970	122.0	41.0	1	35.3
1971	134.8	41.7	0	45.1
1972	156.0	33.7	0	52.2
1973	132.2	42.3	0	43.9
1974	132.3	52.7	0	54.3
1975	133.3	50.3	0	52.6
1976	142.8	40.3	0	49.4
1977	123.0	58.0	0	53.0
1978	127.1	56.9	0	54.8

Results of Regression

Variable	Coeff.	SE	*t*-Value
Initial length	−0.7	0.154	−4.60
Dummy	−14.7	2.951	−4.97

Intercept – 143.0

Multiple r^2 – 73.11

fishery. However, CPUE estimates are crude because of scanty information on effort in the weir fishery. In spite of these uncertainties, the 2 measures are considered.

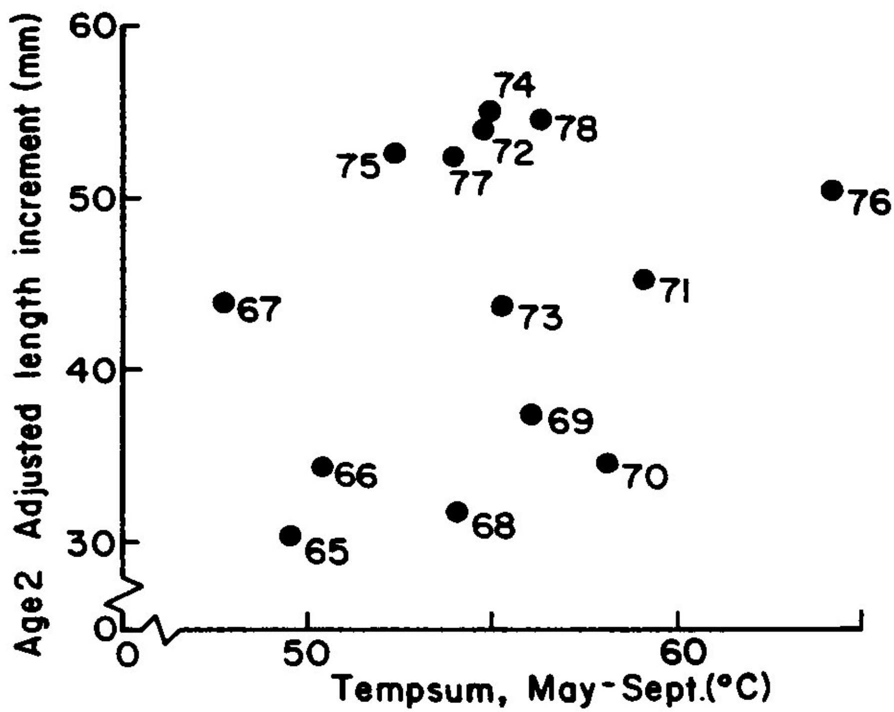

Fig 7. Adjusted 4Xb age 2 length increment vs. monthly mean St. Andrews temperature summed over the growing season.

The catch matrix for the years 1965 to 1978 for the 4WXa fishery (Sinclair et al. 1979) was adjusted to include the autumn-winter juvenile removals by the purse-seiners in 4Xb and one-third of the numbers at age removed by the 4Xb weir fishery.[1] The numbers at age for the 4WX fishery were estimated using cohort analysis (Pope 1972). The estimates of 2-year-olds and the CPUE estimates (catch of 2-year-olds per actively fished weir) are shown in Table II.

In Figures 8 and 9, the adjusted length increments are plotted against the population abundance estimates. Although the position of individual points depends upon the population index that is used, the overall pattern is similar for both indices. The data points fall into 2 groups separated temporally as already shown in Figure 5. The relationship between summer growth and population abundance is inverse during the earlier time period, and perhaps slightly positive in recent years. The temporal separation and the 2 relationships that emerge are independent of year-class size. Each group contains 2 of the largest year-classes recorded in the fisheries (1963, 1966, 1970 & 1976). The 1977 and 1978 population estimates in Figure 9 are from the most recent years of cohort analysis and are thus less precise, but the 1978 point represents a year-class (1976) known to be very large (Fig 3) from other evidence (Sinclair & Iles 1980).

[1] About a third of the long-distance returns of the juveniles tagged in New Brunswick weirs are from 4WXa, the larger proportion being returned from NAFO 5A5 (Stobo, in verb.).

Table II. Age 2 population abundance from 4WX and catch per unit of effort estimates for the New Brunswick weir juvenile fishery.

Year	Age 2 Abundance $\times 10^6$	CPUE Index
1965	4526	2.217
1966	2763	.393
1967	2215	.506
1968	4709	1.973
1969	1040	.977
1970	1465	.907
1971	1245	.478
1972	5505	1.718
1973	926	.388
1974	1826	.640
1975	1612	1.204
1976	217	.518
1977	564	.323
1978	5107	1.758

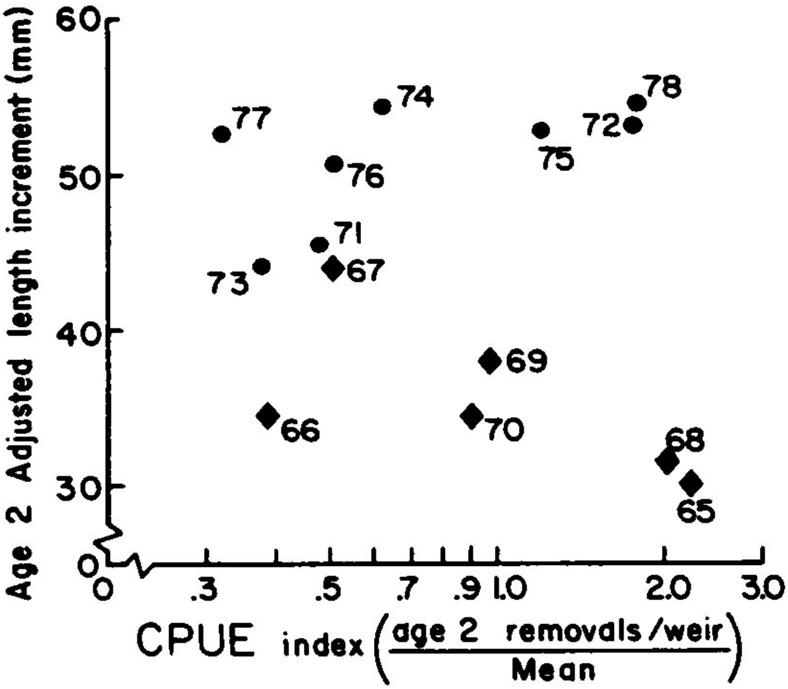

Fig 8. Plot of adjusted length increment of 4Xb 2-year-old herring and CPUE index from 4Xb weirs.

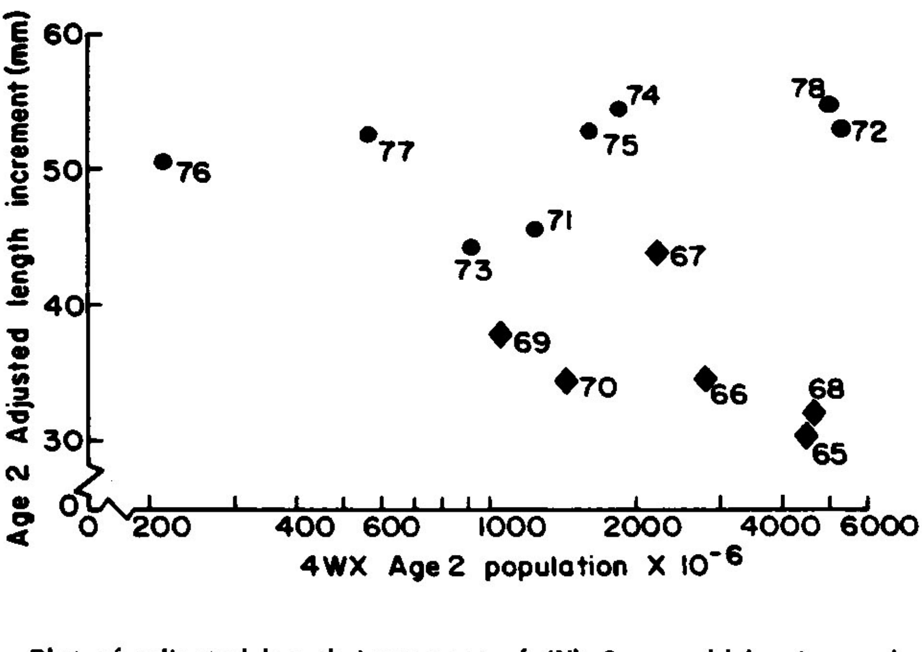

Fig 9. Plot of adjusted length increment of 4Xb 2-year-old herring and age 2 population numbers of the 4WX stock.

The age-2 growth analysis presented here suggests a significant change in the growth pattern of juveniles supporting the New Brunswick weir fishery in the early 1970's. The change included a different relationship between summer-length increment and initial length, an increase in summer growth, and a different response to population abundance from density dependence to lack of density dependence. Direct effects of temperature on growth over the period are not suggested by the data.

Comparisons of Sizes at Age between Fisheries

Fisheries using different gear in different areas and times of year might be expected to exploit different components even of the same year-class and stock. Any systematic difference should then be significant.

In Figure 10 the mean lengths in July for ages 2 and 3 are compared separately and amongst the 3 major fisheries: the New Brunswick weir, the Nova Scotia weir, and the Nova Scotia purse-seine. The frame of reference is the 45° line and the significant features to be explained would be any obvious asymmetry about that line.

At age 2 the mobile gear (the purse-seine) exploits larger fish of the same age than does the fixed gear (the weir). This is shown in Figures 10a and 10b where all points lie on or above the line of reference. Furthermore, prior to 1972 larger individuals were caught in the Nova Scotian weirs than the New Brunswick weirs (Fig 10c), but in recent years the mean lengths have been more comparable. The temporal trend in the ratio of lengths of Nova Scotian age-2 to New Brunswick age-2 herring caught in weirs is shown in Figure 11. The New Brunswick fish have become relatively larger in the years since 1971, about the time when the change in growth pattern was noted.

At age 3 the mobile gear again exploits larger fish and it appears that the lower limit of mean length of recruitment to the mobile fishery is around 242 mm (Fig 10d and 10e). The lengths of weir fish at age 3 range from 200 to 265 mm, whereas all of the purse-seiner lengths except for 1968 are over 242 mm. In the weir fisheries (Fig 10f), the respective mean lengths at age 3 lie closer to the 45° line than at age 2, suggesting that the segregation between the 2 sides of the Bay of Fundy that was shown at age 2 no longer exists at age 3.

It is a well-established characteristic of herring biology that distribution, migration, and recruitment to the adult population are to a significant degree length-dependent. This can lead to a segregation of larger and smaller individuals within a year-class, which is reflected by the exploitation of the different components by different gear. It is very likely that this occurs between the purse-seine and weir fisheries in the Bay of Fundy.

Maturation

Length at 50% maturity for both males and females has fluctuated over a considerable range since 1969 (the first year for which adequate maturity staging was done; Fig 12). As was observed in the growth analysis of the juveniles, there appears to be a marked change in maturation in the early 1970's, a shift towards maturation at smaller lengths (starting with the recruitment of the 1970 year-class).

In summary, the following changes in the biological characteristics of the Bay of Fundy juvenile herring population occurred in the early 1970's:

(i) There occurred a change in the relationship (both intercept and slope) between age 2 summer-length increment and initial length of the New Brunswick weir population.

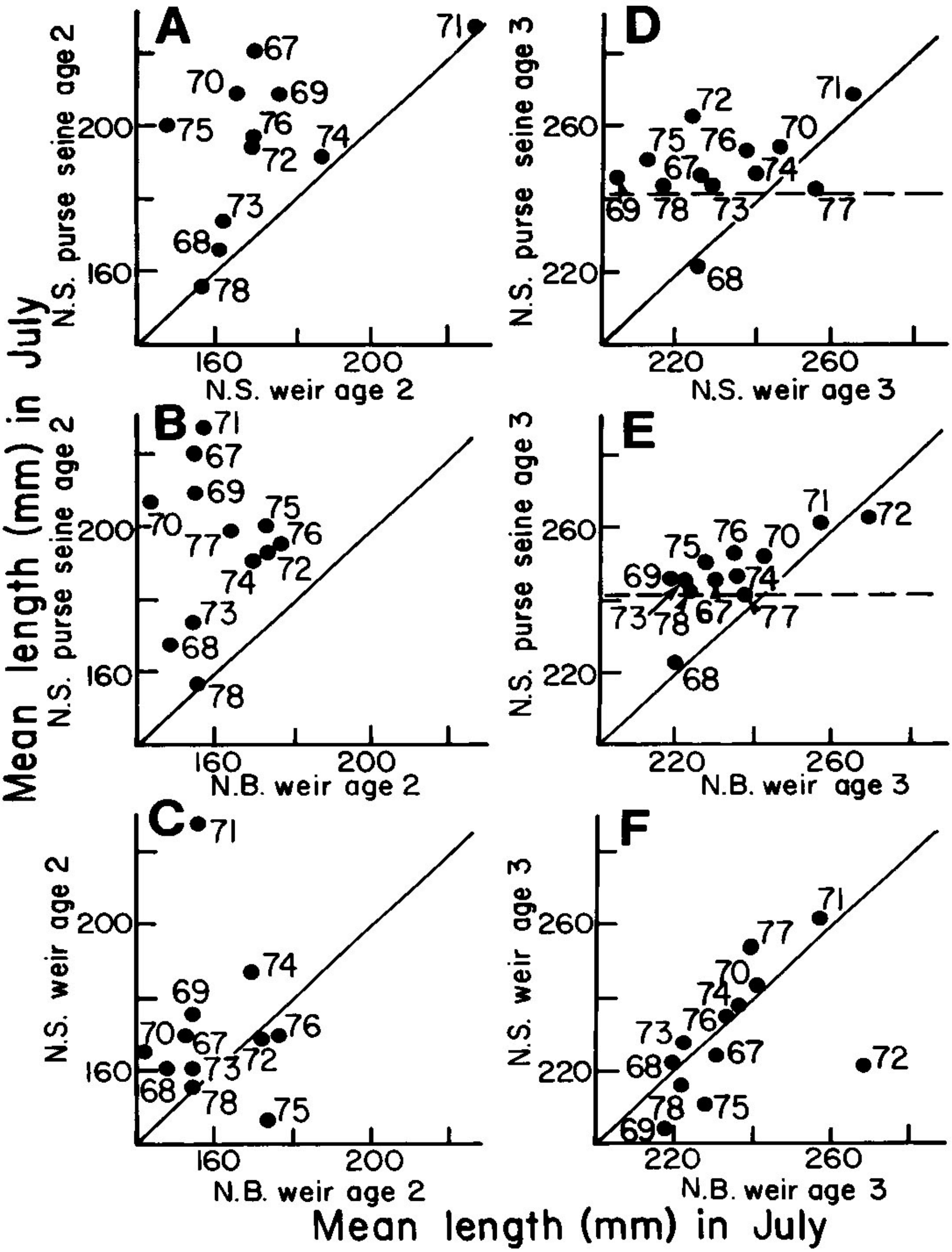

Fig 10. Comparison of mean July lengths of ages 2 and 3 herring caught in the New Brunswick weir, Nova Scotia weir, and Nova Scotia purse-seine fisheries.

(ii) There was an increase in the relative size of New Brunswick weir 2-year-olds. A similar increase in size of Gulf of Maine juveniles was reported by Anthony and Waring (1977).
(iii) The relationship between juvenile summer growth and population abundance changed from density dependence to lack of density dependence.
(iv) length at 50% maturity decreased for both females and males in conjunction with a decrease in stock biomass.

Discussion

Fisheries may be looked upon as major perturbing agents whose biological effects can be studied experimentally using sophisticated fisheries statistics and sampling as a major data source. In recent years, changes in fishing patterns in the study area have occurred to a degree that probably has affected population sizes far more than natural events. The spawning population on Georges Bank over the period 1966 to 1976 declined from 1.5 million t to less than 150 thousand t, and smaller but similar declines were reported for the Gulf of Maine (Anthony 1972; ICNAF 1974). In the 1960's a very large purse-seiner fishery for juveniles in the Bay of Fundy developed, and subsequently was reduced drastically by management controls in the early 1970's (Miller & Iles 1975).

The information presented here demonstrates that there have been biological changes occurring in the New Brunswick weir fisheries that are temporally associated with the fishery changes and are thus likely biological consequences of differential reduction of individual stock components.

The most likely explanation is that reduction of parent stock results in "recruitment overfishing" and a subsequent decline of the overfished stock at the juvenile stage in the traditional nursery grounds. The decline in abundance of juveniles would precede a "crash" in the adult fishery. In the New Brunswick weir fishery area, a major production area for young herring (Huntsman 1953; Iles 1975; 1979), there is the real possibility that an ecological gap resulted from recruitment failure associated with the Georges Bank and Gulf of Maine stocks. This gap may have been filled by juvenile components from other spawning stocks, namely southwest Nova Scotia, either by an extension of their normal range at the early life-history stage, or by increased survival rates of juveniles. This argument is supported by the change in growth characteristics of 4Xb juveniles that preceded the decline of the 5Y and 5Z adult fisheries by about 3 years and by the similarity of mean length of fish caught in weirs on both sides of the Bay of Fundy since 1972.

Whatever the explanation, it is likely that changes in components of the juvenile-stock structure in the area can be large and relatively rapid, an expression of the resilience in the production system as a whole. The implication is that the accurate assignment of juvenile catches to the appropriate reproductive unit will not be possible unless the juvenile fisheries are monitored in detail and on a time scale appropriate to the mixing phenomena.

Another conclusion to be drawn is that at the present state of our knowledge it is not possible to predict directly, with any precision, year-class size solely from growth parameters of the early life history as has been done for the Californian sardine (Iles 1973). This does not exclude the possibility of other methods becoming established.

The study of stock components of herring within the same area and involving the same life-history stages is of key importance to the development of a satisfactory theory of interactions between taxonomic groups with similar niche requirements (Iles 1980).

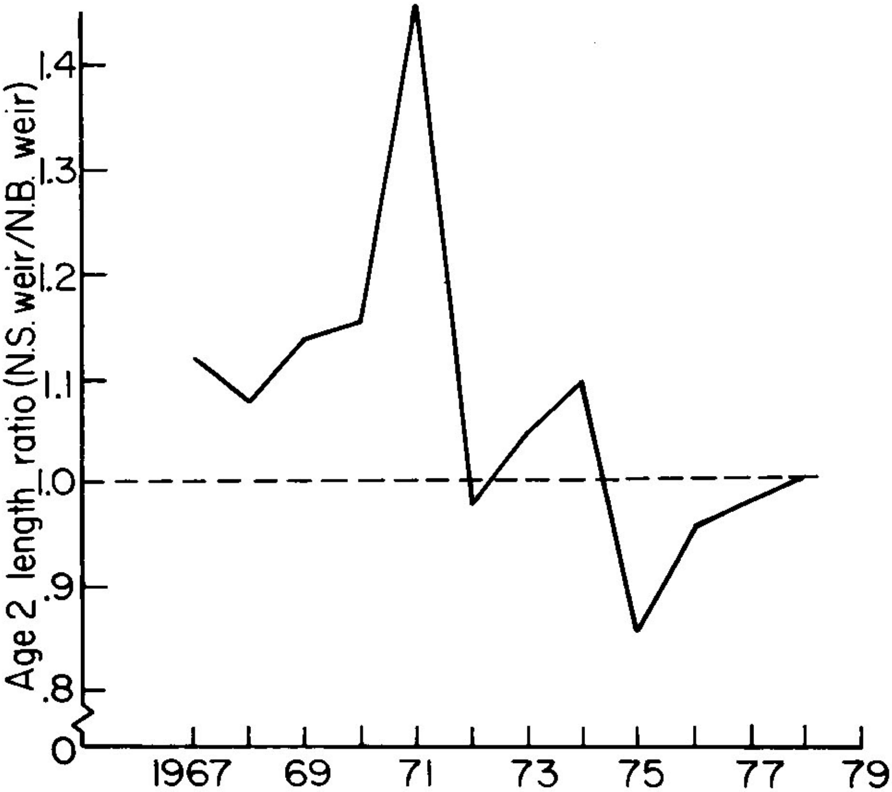

Fig 11. Trend in the ratio of 4Xa and 4Xb weir mean July lengths, age 2, showing a closer correspondence in mean length since 1972.

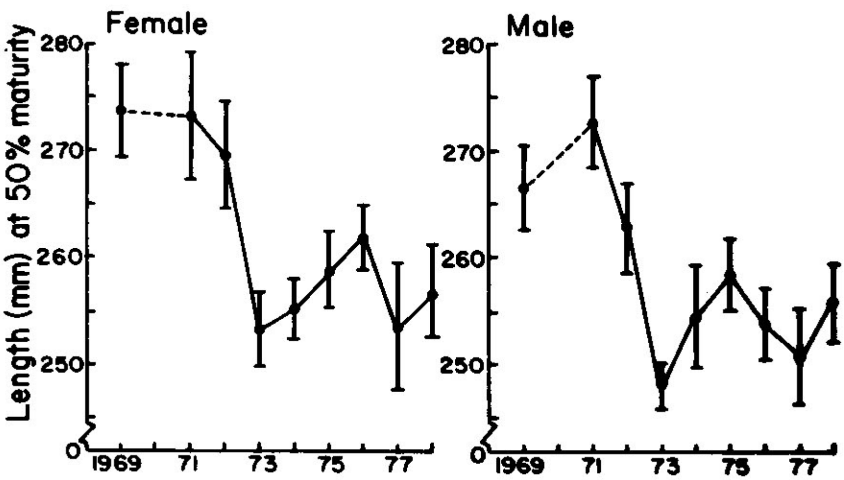

Fig 12. Changes in male and female lengths at 50% maturity. Error bars show the 95% confidence limits.

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