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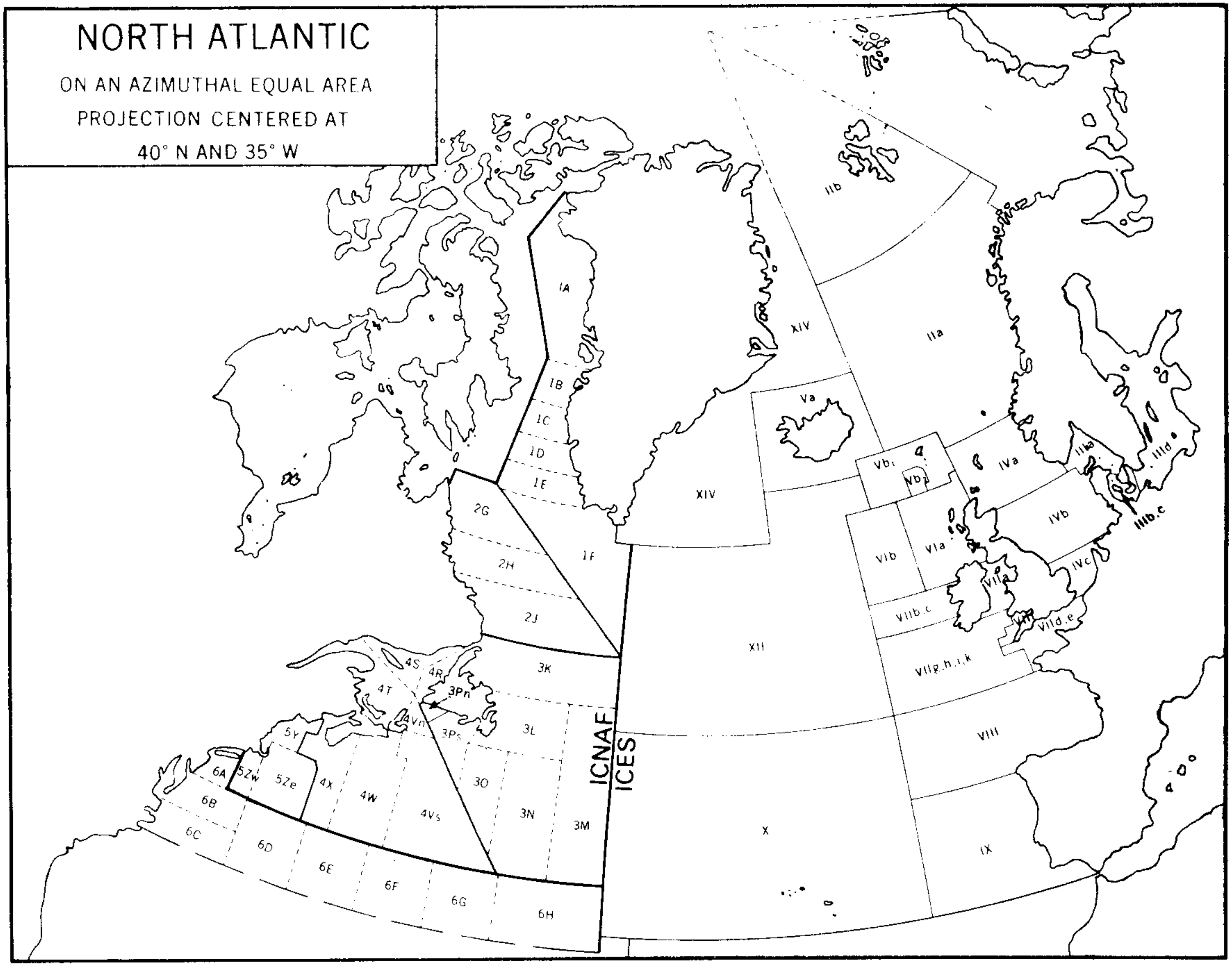

NORTH ATLANTIC

ON AN AZIMUTHAL EQUAL AREA
PROJECTION CENTERED AT
40° N AND 35° W

Contents

Studies on Georges Bank Herring in 1970

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Total Mortality Rates Estimated from Survey Cruise Data for Two Groups of Yellowtail Flounder in the Southern New England and Georges Bank Areas
(ICNAF Subarea 5)

Judith A. Penttila[1] and Bradford E. Brown[1]

Abstract

Total instantaneous mortality rates were estimated by four different procedures for the southern New England and Georges Bank yellowtail flounder fishing grounds (ICNAF Subarea 5). Mortality rates were determined from research vessel survey data from 1963 to 1969 by the following methods: (1) slopes of the catch curves; (2) ratios of the catch per tow in a given season to the catch per tow of the same season for the previous year; (3) Robson-Chapman formula; and (4) Heincke's formula. Each method showed a lower mortality rate for Georges Bank than for southern New England, with an average of the estimates giving Z = 1.00 for Georges Bank and Z = 1.25 for southern New England.

Introduction

The increased level of fishing on yellowtail flounder, *Limanda ferruginea* (Storer), in recent years made it necessary to establish catch quotas in ICNAF Subarea 5 in 1971. Assessment of the effects of fishing was primarily based on analysis of commercial catch and effort data. To improve and corroborate the assessment of these stocks, total instantaneous mortality rates for the southern New England and Georges Bank yellowtail flounder fishing grounds were estimated from analyses of research vessel survey data by four different procedures. These grounds contain two nearly independent groups of yellowtail flounder (Lux, 1963). The data used for these analyses were collected on 14 standardized groundfish survey cruises during the years 1963-69.

Collection of Data

During the years 1963 to the present time, routine surveys have been conducted on the R/V *Albatross IV* in the southern New England and Georges Bank areas two or three times a year. The seasonal distribution of the 14 cruises analyzed in this paper are listed below.

A Number 36 Yankee trawl with a 4-1/2-inch mesh and a 1/2-inch-mesh liner in the codend was used. All hauls were 30 min in duration. (For a detailed account of the survey methods, see Grosslein, 1969.) The surveys were set up on a stratified random sampling design. The strata (Fig. 1) were based on depth and geographic subdivisions. The number of stations per stratum were allocated roughly proportional to the area of the stratum.

	Season		
	Winter	Summer	Autumn
Year	(Jan-Apr)	(July-Aug)	(Oct-Dec)
1963			X
1964	X	X	X
1965	X	X	X
1966	X		X
1967			X
1968			X
1969	X	X	X

Length frequencies of catch and scales for age determination were collected routinely. Fish from which scales were taken for aging were identified by sex. In most cases the entire catch of yellowtail was measured; but in those instances where the catch was quite large, a representative subsample was measured and then the length frequency of the entire catch was estimated. Prior to 1969, the fish from which scales were taken were usually subsamples stratified by length and by sex, except where catches were small enough to permit total sampling. In 1969, the subsamples of fish were stratified by length only. The sex was recorded for all fish for which the age was determined. Method of aging was described by Lux and Nichy (1969).

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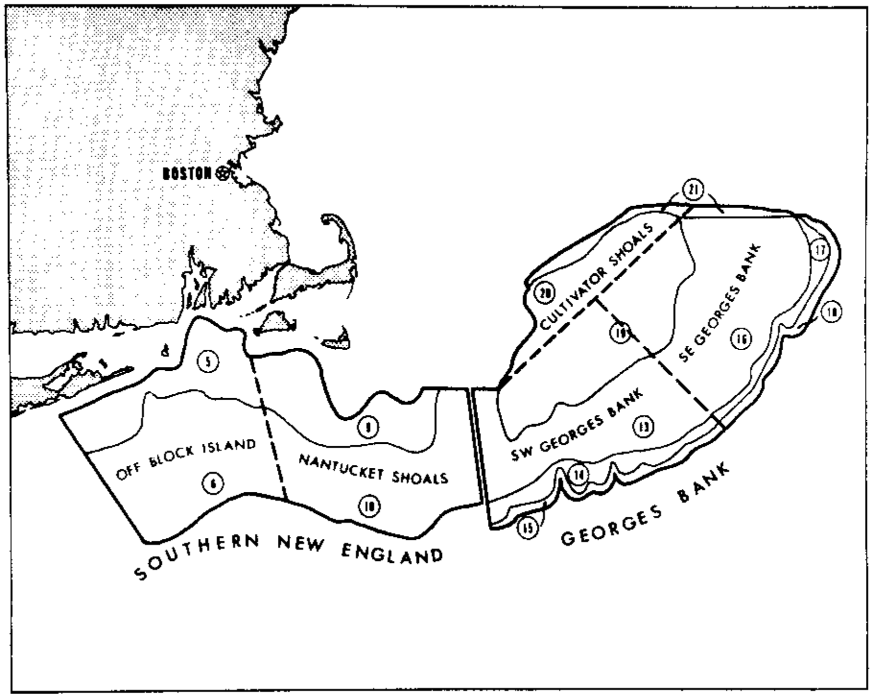

Fig. 1. Strata and areas comprising the southern New England and Georges Bank yellowtail flounder fishing grounds.

TABLE 1. Estimated mean catch/tow per age-group for males and females combined for yellowtail flounder from southern New England

Year and season	Age-group								
	0	1	2	3	4	5	6	7	8
1963									
Autumn	.05	16.34	14.89	14.49	4.25	.45	.00	.08	
1964									
Winter	.00	.44	8.48	8.35	6.64	2.71	1.10		
Summer	.00	.67	9.66	4.52	5.93	3.22	.39	.17	
Autumn	.00	18.62	26.51	4.88	6.19	3.00	1.59		
1965									
Winter	.00	.12	24.47	7.04	1.98	1.26	.59	.03	
Summer	.00	.64	21.27	14.77	1.69	.12			
Autumn	.26	11.54	17.02	6.16	1.80	1.75	.21		
1966									
Winter	.00	.24	6.17	5.71	3.33	.83	1.08	.52	.07
Autumn	.88	35.51	10.94	1.74	.98	.19			
1967									
Autumn	.28	20.05	24.17	11.15	1.40	.42	.07	.11	
1968									
Autumn	.00	10.02	11.95	16.70	1.15	.18			
1969									
Winter	.00	4.67	15.54	22.04	12.41	2.31	.13		
Summer	.00	.21	14.89	40.45	3.82				
Autumn	.00	12.83	13.03	22.79	5.77	.18	.05		

Determination of Age and Length Composition

Females grow faster than males after the age of 2 years (Lux and Nichy, 1969). Because a fixed number of males and females were aged, it was necessary to have length frequency data prior to 1969 separated by sex before the age frequency could be expanded properly to estimate the age composition of the total catch. Males and females were separated in length frequency data for the nine cruises from 1963 to 1966, but not for the five cruises from 1967 to 1969. The average sex ratios for the latter had to be calculated as follows: Summaries were made by strata of the number of males and females in length groups for the nine cruises from 1963 to 1966 on which yellowtail length frequencies were recorded by sex. Five length groups were chosen: 1-25 cm, 26-30 cm, 31-35 cm, 36-40 cm, and greater than 40 cm. Sex ratios were then determined for each length group within each stratum and cruise and year. Sex ratios were averaged over years for each season (winter, summer, and autumn) for each length group and stratum. In those cases where fewer than 100 fish were used to determine a ratio, neighboring strata were combined to give the ratio for a larger area. The areas used were: off Block Island, Nantucket Shoals, Southwest Georges Bank, Southeast Georges Bank, and Cultivator Shoals (Fig. 1). These average sex ratios were used to determine sex composition length frequencies on the five survey cruises from 1967 to 1969. For the 1969 cruises, where age samples were stratified only by length and not by sex, ratios of the fish in the age sample provided a valid estimate of the proportion of males and females in the entire catch.

Age-length frequencies for the entire catch by sex were then determined. Stratified means of numbers caught per tow for southern New England and Georges Bank per one cm length interval, per age group, were estimated separately for males and females. There were cases where lengths of fish in the age samples did not include every length class of all fish caught. The age of those fish in length classes for which age data was not available was determined by using the estimates of neighboring classes. The totals for males and females were then added to give a combined estimate of the mean catch per tow per age-group for each yellowtail ground. These estimates were used to determine the instantaneous mortality rates for southern New England

TABLE 2. Estimated mean catch/tow per age-group for males and females combined for yellowtail flounder from Georges Bank.

Year and season	Age-group										
	0	1	2	3	4	5	6	7	8	9	10
1963											
Autumn	.00	12.46	6.37	9.42	1.24	.34	.07	.17	.00	.07	
1964											
Winter	.00	.23	3.18	4.02	5.45	1.12	.58	.03	.05		
Summer	.00	2.06	3.77	2.15	1.29	.29	.09	.09			
Autumn	.00	1.49	7.74	6.88	4.32	2.04	.40	.10			
1965											
Winter	.00	.00	3.82	8.73	3.25	4.74	.79				
Summer	.00	.32	6.15	6.52	1.43	1.20	.03				
Autumn	.01	.91	5.06	5.38	2.44	1.00	.06	.16			
1966											
Winter	.00	.12	1.42	2.71	2.80	1.58	.80	.11			
Autumn	1.16	8.27	2.98	1.54	.65	.14					
1967											
Autumn	.05	7.44	7.59	2.34	.80	.25	.06	.05			
1968											
Autumn	.00	9.48	9.39	4.96	.88	.76	.02				
1969											
Winter	.00	.88	7.59	8.66	2.86	1.31	.37	.06	.06	.00	.06
Summer	.00	3.79	21.59	12.51	3.18	.19	.48	.14	.06		
Autumn	1.06	6.48	8.49	4.99	1.28	.43	.16	.18			

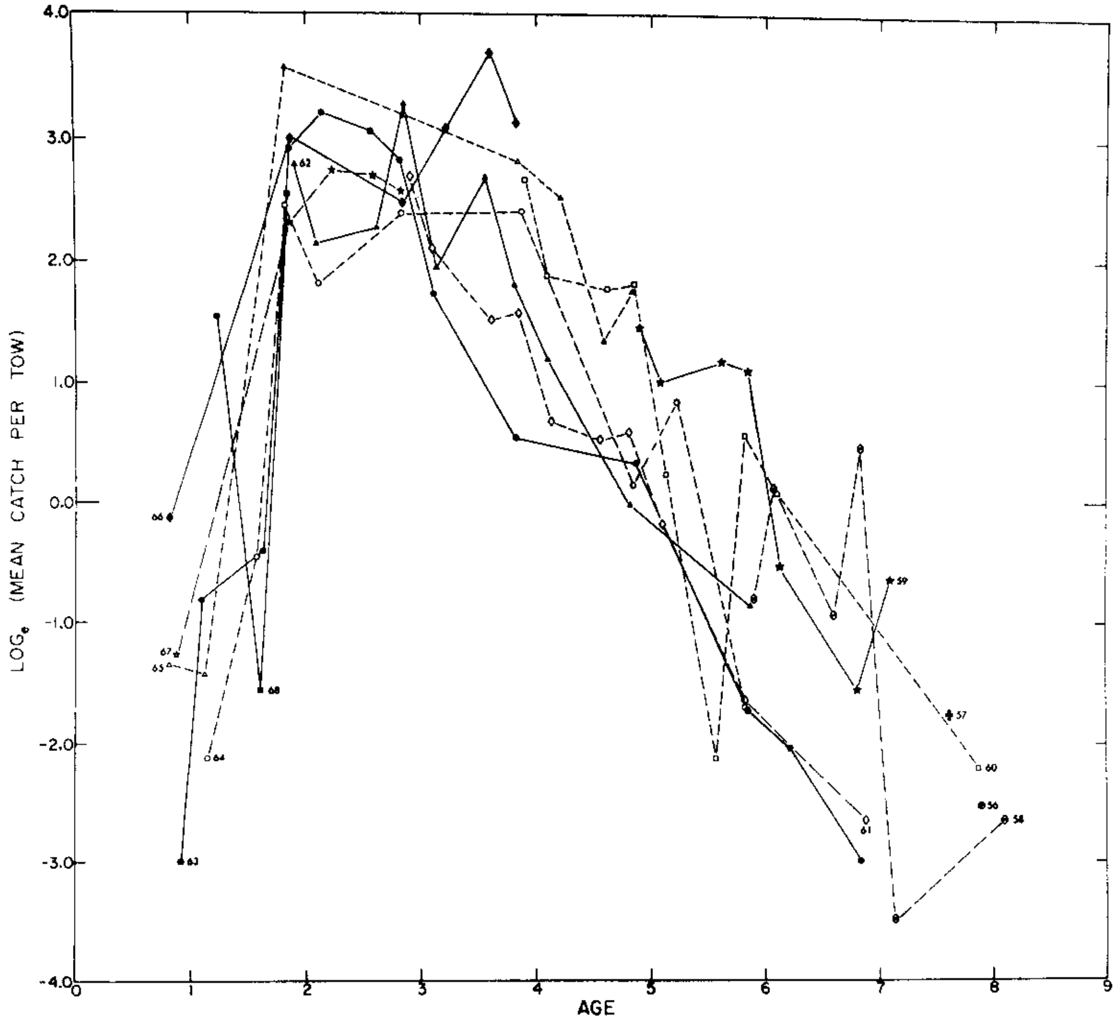

Fig. 2. Logarithm of mean catch/tow versus age for year-classes of yellowtail flounder from survey data for the southern New England ground.

and Georges Bank.

Mortality Estimation Procedures

Four estimators of mortality were used. First, catch curves for the southern New England and Georges Bank grounds were obtained for each year-class by plotting the natural logarithms of the mean catch per tow (Tables 1 and 2) against age (Ricker, 1958) (Figs. 2 and 3). These curves show that recruitment to the net used on the survey cruises was essentially complete at age 3. The instantaneous mortality rate (Z) for each ground was then calculated for each year-class by least squares linear regression of the points for age 3 and older. Correlation coefficients were computed (Table 3). The slope values for each cruise were averaged to obtain overall estimates of Z. The instantaneous mortality rate and correlation coefficient were then estimated from pooled data over all year-classes.

Secondly, the estimated mean catch per tow was used to estimate the annual survival rate for southern New England and Georges Bank within each year-class from the ratio of the catch/tow in a given season to the catch/tow of the same season for the previous year

TABLE 3. Instantaneous mortality rates calculated from the slopes of catch curves from age 3 on, number of points used for the linear regression, and correlation coefficients for each year-class and yellowtail flounder ground.

	Southern New England Ground			Georges Bank Ground		
Year-classes	Number of points	Mortality (Z)	Correlation coefficients	Number of points	Mortality (Z)	Correlation coefficients
1956				2	5.70*	−0.93
1957				4	−0.79*	0.64
1958	6	1.23	−0.63	5	0.48	−0.48
1959	7	1.24	−0.87	8	1.49	−0.76
1960	9	1.20	−0.83	9	1.21	−0.94
1961	9	1.31	−0.83	11	0.94	−0.93
1962	6	1.27	−0.98	10	1.08	−0.91
1963	6	1.23	−0.98	7	0.60	−0.93
1964	4	1.92	−0.92	5	1.03	−0.81
1965	4	1.38	−0.88	4	1.13	−0.87
1966	3	−0.20*	0.17	3	0.76	−0.52
Pooled data All year-classes combined	54	1.17	−0.85	68	1.02	−0.89
Average Z (with * values omitted)		1.35			.97	

TABLE 4. Estimates of survival rates of yellowtail flounder in autumn cruises for the southern New England ground.

	Age-group						
Year	1-2	2-3	3-4	4-5	5-6	Age 3-6 Avg $(r_{i\cdot})$	Z
1963-64	1.62	.33	.43	.71	3.50	0.56	0.58
1964-65	.91	.23	.37	.28	.07	0.27	1.31
1965-66	.95	.10	.16	.11		0.15	1.90
1966-67	.68	1.02	.80	.43	.37	0.65	0.43
1967-68	.60	.69	.10	.13		0.11	2.21
1968-69	1.30	1.91	.35	.16	.28	0.33	1.11
Avg $(r_{\cdot j})$	.92	.60	.31	.36	.50	0.33	$(r_{\cdot\cdot})$
Z	0.08	0.51	1.17	1.02	0.69	Z = 1.11	

TABLE 5. Estimates of survival rates of yellowtail flounder in autumn cruises for the Georges Bank ground.

	Age-group							
Year	1-2	2-3	3-4	4-5	5-6	6-7	Age 3-7 Avg $(r_{i\cdot})$	Z
1963-64	.62	1.08	.46	.61	1.18	1.43	0.62	0.48
1964-65	3.40	.70	.35	.23	.03	.40	0.27	1.31
1965-66	3.27	.30	.12	.06			0.32	1.14
1966-67	.92	.79	.52	.38	.43		0.48	0.73
1967-68	1.26	.65	.38	.95	.08		0.49	0.71
1968-69	.90	.53	.26	.49	.21	9.00	0.31	1.17
Avg $(r_{\cdot j})$	1.03	.67	.34	.45	.20	.90	0.36	$(r_{\cdot\cdot})$
Z		0.40	1.08	0.80	1.61	0.11	Z = 1.02	

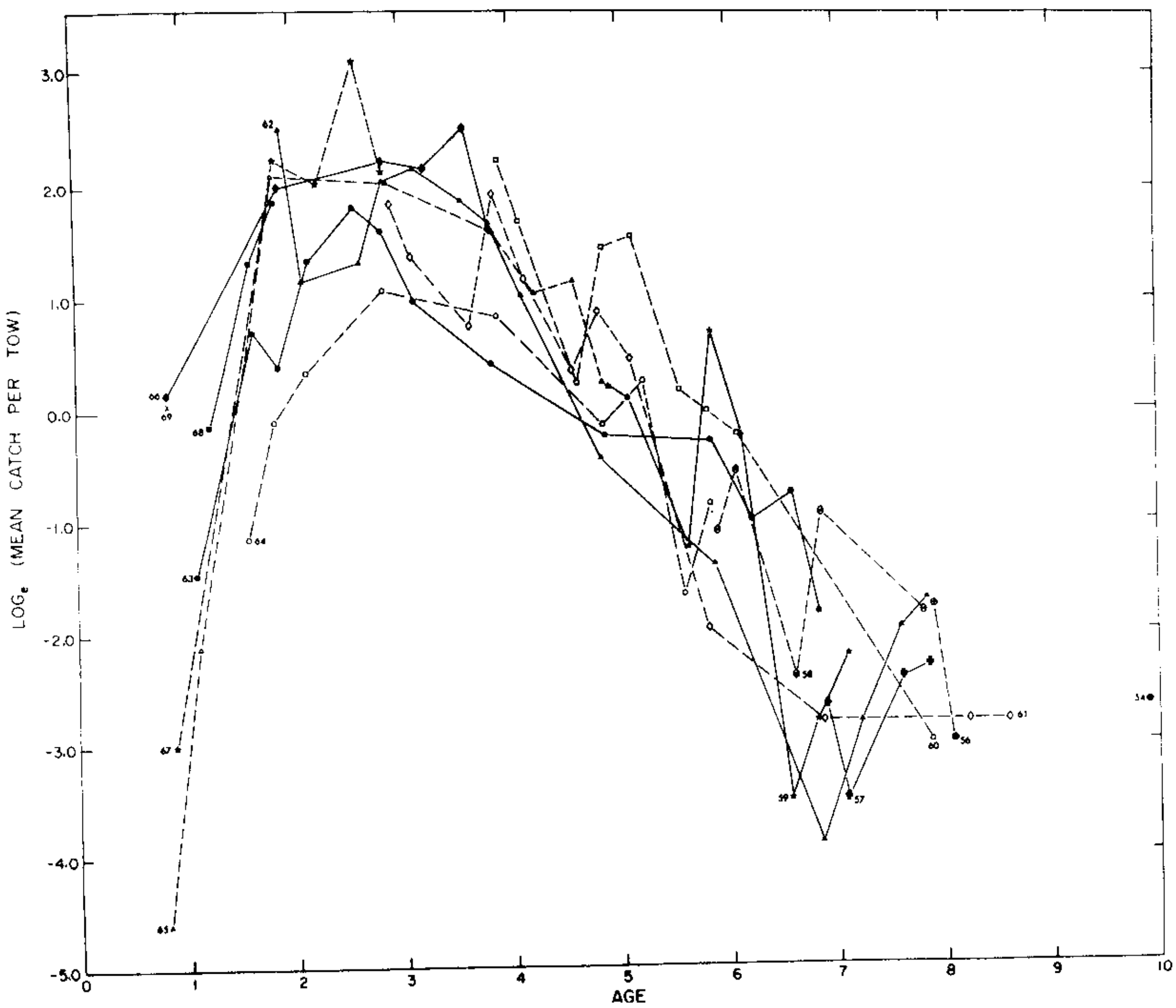

Fig. 3. Logarithm of mean catch/tow versus age for year-classes of yellowtail flounder from survey data for the Georges Bank ground.

(Tables 4 and 5). The formula used was:

$$r_{ij} = \frac{N_{i+1,\,j+1,}}{N_{i,\,j}}$$

where r_{ij} is the individual ratio, $N_{i\,j}$ is the estimated catch/tow for age-group *j* and year *i*. Ratios of sums of numerator and denominator above were also calculated: $r_{\cdot j}$, $r_{i\cdot\cdot}$ and $r_{\cdot\,\cdot}$, where the dot indicates the subscript over which the sums were taken. Annual ratios were determined only for autumn cruises, as there was insufficient data to determine annual ratios for winter and summer cruises.

Annual survival rates were also estimated by Robson - Chapman and Heincke's formulas for data from age 3 on for each cruise (i.e., season) (Robson and Chapman, 1961). A Chi square test was employed to determine if the difference between the two estimates could be attributed to sampling error or considered as real. If the difference is real, then there is a discrepancy in the frequency of the lowest age-group considered relative to frequencies in older age-groups. The annual survival rate estimates are given in Tables 6 and 7.

TABLE 6. Robson and Chapman estimates of annual survival rates, Heincke estimates of survival rates, and Chi square values for the southern New England ground.

Year and season	Estimates of Survival (Robson and Chapman) Z	S	Estimates of Survival (Heincke) Z	S	Chi square values
1963					
Autumn	1.47	.230	1.39	.248	0.172
1964					
Winter	.77	.463	.59	.556	1.453
Summer	.66	.518	.38	.682	3.079
Autumn	.62	.536	.37	.688	2.792
1965					
Winter	.94	.392	1.04	.354	0.189
Summer	2.21	.110	2.22	.109	0.003
Autumn	.91	.402	.97	.379	0.008
1966					
Winter	.69	.503	.68	.505	0.001
Autumn	.88	.416	.91	.402	0.014
1967					
Autumn	1.65	.192	1.88	.152	1.010
1968					
Autumn	2.51	.081	2.60	.074	0.489
1969					
Winter	1.12	.327	.91	.403	3.068
Summer	2.51	.081	2.45	.086	0.259
Autumn	1.69	.184	1.57	.208	0.695
Average over all cruises	1.33	.264	1.28	.278	

TABLE 7. Robson and Chapman estimates of annual survival rates, Heincke estimates of survival rates, and Chi square values for the Georges Bank ground.

Year and season	Estimates of survival (Robson and Chapman)		Estimates of survival (Heincke)		Chi square values
	Z	S	Z	S	
1963					
Autumn	1.43	.239	1.79	.167	1.787
1964					
Winter	.72	.489	.44	.643	2.308
Summer	.77	.462	.80	.450	0.007
Autumn	.82	.440	.70	.499	0.477
1965					
Winter	.74	.478	.69	.501	0.086
Summer	1.24	.290	1.24	.290	0.000
Autumn	.93	.395	.90	.405	0.010
1966					
Winter	.58	.557	.41	.661	0.669
Autumn	.89	.412	1.08	.339	–0.909
1967					
Autumn	.91	.402	1.11	.331	0.338
1968					
Autumn	1.19	.304	1.38	.251	0.437
1969					
Winter	.97	.379	1.04	.353	0.112
Summer	1.29	.274	1.41	.245	0.295
Autumn	1.03	.356	1.23	.291	0.463
Average over all cruises	.96	.383	1.02	.360	

TABLE 8. Summary of yellowtail flounder mortality rates by sex.

	Southern New England		Georges Bank	
	Male	Female	Male	Female
Average of catch curve slopes over year-classes	1.44	1.09	.89	.87
Estimates from slope of pooled catch curve	1.21	1.01	.95	.85
Average of Robson-Chapman estimates for all cruises	1.25	1.17	1.04	.76
Average of Heincke estimates for all cruises	1.24	1.14	1.14	.93
Robson-Chapman estimates for seven autumn cruises	1.47	1.16	1.20	.98
Heincke estimates for seven autumn cruises	1.49	1.14	1.17	1.02
Average of the six estimates	1.35	1.12	1.06	.90

Results and Discussion

The estimated mean catch per tow per age-group for males and females separately gave the following results (Table 8).

For males, the slope of the catch curve for all year-classes combined from age 3 on gave an estimate of the instantaneous mortality rate (Z) of 1.21 for the southern New England ground with a correlation coefficient (*r*) of -0.802. For females, estimates of Z.

1.01 with r = -0.828 were obtained for the southern New England ground. For males from the Georges Bank ground, estimates of Z = 0.95 with r = -0.877 were calculated. The estimates for females from the Georges Bank ground were Z = 0.85 with r = -0.859. Averaging the slopes of the catch curves based on 3 or more points, with negative values omitted, gives a Z of 1.44 for southern New England males and a Z of 1.09 for females. Similarly, for Georges Bank, an average Z of 0.89 for males and 0.87 for females was obtained.

The average Robson and Chapman estimates over the 14 cruises are Z = 1.25 for males and Z = 1.17 for females from southern New England. For Georges Bank, Z = 1.04 for males and Z = 0.76 for females. Similarly, the average Heincke estimates are Z = 1.24 for males and Z = 1.14 for females from southern New England. For Georges Bank, Z = 1.14 for males and Z = 0.93 for females.

Another Robson and Chapman estimate was computed by using the total number of fish caught per tow per age-group pooled over the seven autumn cruises. The totals thus obtained were used to calculate one Robson and Chapman estimate for the autumn cruises. The estimates gave a Z of 1.47 for males and 1.16 for females from southern New England. For Georges Bank, Z = 1.20 for males and Z = 0.98 for females. A Heincke estimate was obtained in a similar manner, giving Z = 1.49 for males and Z = 1.14 for females from southern New England; with Z = 1.17 for males and Z = 1.02 for females from Georges Bank.

Averaging the six estimates gave Z = 1.35 for males and Z = 1.12 for females from southern New England; with Z = 1.06 for males and Z = 0.90 for females from Georges Bank.

The mortality rates for males and females were examined statistically for significance of differences using pooled t tests and for consistency of differences using Wilcoxon rank tests (Table 9). The results are too inconsistent to assume that the male-female differences are statistically significant for either ground.

TABLE 9. Tests for significance of differences between male and female mortality rates. NS = not significant; S = significant (below 5% probability); HS = highly significant (below 1% probability).

	Southern New England			Georges Bank		
Test	Robson-Chapman estimates	Heincke estimates	Slopes of pooled catch curves	Robson-Chapman estimates	Heincke estimates	Slopes of pooled catch curves
Pooled t test	NS	–	NS	NS	–	NS
Wilcoxon paired test	NS	NS	NS	HS	S	NS
Wilcoxon unpaired test	NS	NS	S	NS	NS	NS

Using the slope of the catch curve for all year-classes combined from age 3 on for males plus females, an estimate of the instantaneous mortality rate (Z) of 1.17, equivalent to an annual survival rate (s) of .31, was obtained for the southern New England ground with a correlation coefficient (r) of -0.847. For the Georges Bank ground, estimates of Z = 1.02, s = .36, and r = -0.888 were calculated. Averaging the values of Z from Table 3 based on 3 or more points, with negative slopes omitted, gives a Z of 1.35 for southern New England. Similarly, for Georges Bank, an average Z of 0.97 was obtained.

Ratios for autumn cruises for southern New England gave an estimate of survival, s = .33, from the overall pooled ratio r. ., for ages 3 and older, which is equivalent to an instantaneous mortality rate of Z = 1.11. For Georges Bank, s = .36, Z = 1.02.

The average Robson and Chapman estimate of annual survival rate over the 14 cruises is .264, or Z = 1.33, for southern New England and .383, or Z = 0.96, for Georges Bank. Similarly, the average Heincke estimate of survival rate is .278, or Z = 1.28, for southern New England and .360, or Z = 1.02, for Georges Bank. The highest Chi square value obtained comparing the values from the two estimators, was 3.079, which is below the 5% significance level, indicated that age 3 fish are fully vulnerable to the gear used.

A summary of the instantaneous mortality rates estimated for the southern New England and Georges Bank grounds is shown in the table below.

	Southern New England mortality rates	Georges Bank mortality rates
Average of catch curve slopes over year-classes	1.35	0.97
Estimates from slope of pooled catch curve	1.17	1.02
Estimates from ratios	1.11	1.02
Robson/Chapman estimates	1.33	0.96
Heincke estimates	1.28	1.02
Average of the five estimates	1.25	1.00

The above five estimators used show reasonable agreement within each ground. In each case, the mortality rate is lower for Georges Bank than for southern New England. Averaging the estimates gave Z = 1.25 for southern New England and Z = 1.00 for Georges Bank. The higher total mortality rate for the southern New England ground could well reflect the greater fishing effort (Brown and Hennemuth, 1971) observed during this period. There is a trend towards higher estimates of mortality rates in more recent cruises particularly in the southern New England area using Robson-Chapman and Heincke estimates. Natural mortality for yellowtail flounder has been estimated to be about 0.2, or perhaps even as low as 0.1 (Lux, 1969; Brown and Hennemuth, 1971). Since there is no known reason for the existence of different natural mortality rates for southern New England and Georges Bank, the higher total mortality rate for southern New England may possibly be attributed to greater fishing effort.

Lux (1969) obtained instantaneous mortality rates of 1.03 for southern New England and 1.01 for Georges Bank from catch curve survival ratios for age-groups 4 to 7 from 1960 to 1965 commercial landings data. Lux (1969) also estimated mortality for southern New England from the data of Royce, Buller, and Premetz (1959), obtaining a Z of .78 for age-groups 4 to 6 from 1943 to 1947. These estimates were obtained for earlier periods when fishing effort was less than at present. Brown and Hennemuth (1971) estimated Z using the virtual population method for the 1958 to 1962 year-classes, obtaining average values of 1.36 for southern New England and 1.16 for Georges Bank for ages 4 to 7 using commercial data. Their average Z for ages 3 to 7 for southern New England was 1.25.

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Some Biological Characteristics of the Fortune Bay, Newfoundland, Herring Stock, 1966-71

L. S. Parsons[1] and V. M. Hodder[1,2]

Abstract

The Fortune Bay herring fishery is based on aggregations of immature and prespawning mature spring spawners which appear in inshore areas during the January-May period, with considerable yearly fluctuations in the relative proportions of immature and mature fish in the commercial catches. The length distribution of Fortune Bay spring spawners has exhibited a progression and succession of several modes during the 1966-71 period; the fishery has been supported by three dominant year-classes, those of 1963, 1966, and 1968. These size and age trends contrast sharply with the lack of recent recruitment to the spring-spawning component of the Southwest Newfoundland stock complex. From age 5 onwards mean lengths of Fortune Bay spring spawners at each age are considerably higher than those for southwest Newfoundland spring spawners of the same age. Fortune Bay spring spawners have a significantly larger L_∞ value than those reported for Southwest Newfoundland and southern Gulf of St. Lawrence spring spawners. At any particular age nematode incidence and intensity values were significantly higher for Fortune Bay than for Southwest Newfoundland fish. It is suggested that Fortune Bay spring spawners constitute a relatively discrete spring-spawning stock.

Introduction

Since its inception in 1964-65 the Newfoundland purse seine fishery for herring has been primarily concentrated along southwestern Newfoundland in areas J1 and J2 (Fig. 1) with lesser quantities being caught in Fortune Bay and along western Newfoundland (Hodder, 1971). Traditionally, until the mid-1950's, Fortune Bay (Area I) on the south coast was one of the main centres of the Newfoundland herring fishery. During 1945-50 the average annual herring landings from Fortune Bay were approximately 16,000 metric tons at a time when there was a great demand for salted herring for food immediately following World War II (Templeman, 1966). Annual catches from Fortune Bay subsequently declined to less than 700 tons during the period 1956 to 1964 when the demand for herring as food was very low (Hourston and Chaulk, MS 1968). The great decrease during the 1950's was in part due to economic factors but also in part due to the disappearance of herring from the traditional areas. This disappearance may have been associated with fungus disease *(Ichthyosporidium hoferi)* which destroyed a large portion of the southern Gulf of St. Lawrence herring stocks during 1953-57 (Sindermann, 1958).

With the advent of the purse seine fishery during the mid-1960's, catches in Fortune Bay by purse seiners and bar seiners increased to 5,400 tons in 1967 and fluctuated between 6,400 and 14,700 tons during 1968 to 1971 with peak catches of 14,218 and 14,748 tons in 1968 and 1971 respectively (Table 1). Bar seiners generally account for between 10 and 25% of the combined total. The bulk of the fish caught by the mobile fleet is taken in the January-May period.

Tibbo (1956, 1957), initially at the Newfoundland Fisheries Research Station and later as a member of the Canadian Atlantic Herring Investigations Committee, conducted studies of the Fortune Bay herring population in 1943-44 and again in 1946-48. This paper presents more recent information on the size and age composition and selected biological characteristics of the Fortune Bay herring concentrations during the 1966-71 period.

Materials and Methods

Length, weight, sex, and maturity data were collected from more than 6,600 fish landed by purse seiners at Harbour Breton during the years 1967-71. Most of the samples were examined in the fresh condition immediately after capture but some, particularly in 1969, 1970, and 1971, were examined after being kept in frozen storage for several weeks. In 1971 the specimens were also examined to determine the incidence and intensity of infestation with larval

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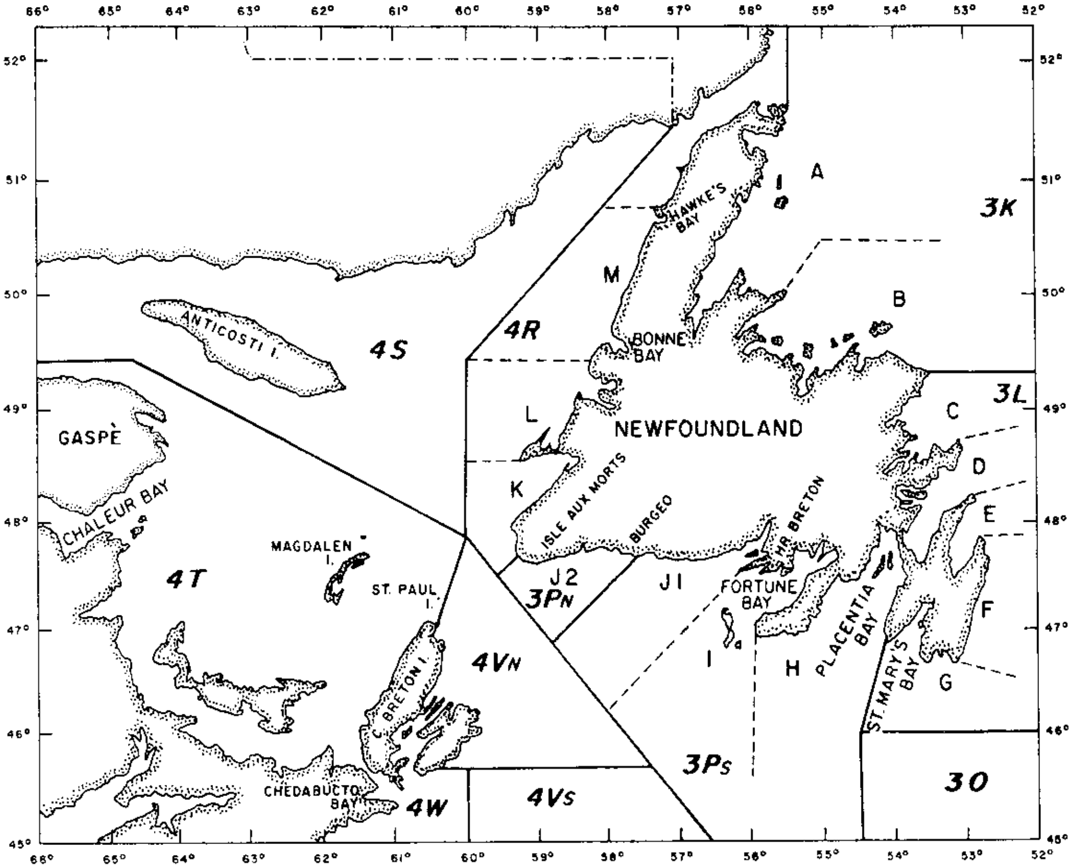

Fig. 1. Map of the Gulf of St. Lawrence-Newfoundland area with place names and statistical areas mentioned in the text.

TABLE 1. Purse seine (PS) and bar seine (BS) catches (metric tons) in Fortune Bay, 1965-71.

Month	Gear	1965	1966	1967	1968	1969	1970	1971
Jan	PS	–	–	–	–	3,368	4,382	5,260
Feb	PS	–	–	–	5,269	1,129	1,342	3,439
Mar	PS	–	–	–	4,073	166	2,180	5,043
	BS	–	–	–	241	–	228	–
Apr	PS	–	–	4,109	1,778	–	67	806
	BS	–	–	263	945	303	236	200
May	PS	19	–	432	–	–	–	–
	BS	–	–	245	1,651	1,248	579	–
June	BS	–	–	372	73	36	–	–
Dec	PS	–	–	–	188	163	–	–
Total	(PS)	19	–	4,541	11,308	4,826	7,971	14,548
Total	(BS)	–	–	880	2,910	1,587	1,043	200
Total		19	–	5,421	14,218	6,413	9,014	14,748

nematodes of the genus *Anisakis.* The examination for nematodes was restricted to the body cavity and viscera.

During two cruises to Fortune Bay in March and May 1966 by the research vessel *Investigator II* samples were obtained from herring catches in anchored gillnets set in coastal waters over depths of 10-30 fathoms. Each set consisted of a string of five nylon herring nets of different mesh sizes (51, 57, 64, 70, and 76 mm). Size and age data for 340 specimens from these catches are included in Figs. 2 and 3 for comparison with commercial catches.

The length used is the greatest total length (to the nearest millimetre) measured from the tip of the lower jaw to the end of the longest lobe of the caudal fin with the lobe extending posteriorly in line with the body. Thawed lengths were adjusted to the fresh condition by applying a conversion factor of 1.02 (Hodder *et al.*, MS 1972). Whole weights were determined to the nearest gram. No weight adjustments were required since the change in weight between fresh herring and herring examined after frozen storage was insignificant.

The stage of maturity was determined by gross examination of gonads using the various stages of gonadal development adopted for use in the ICNAF area (ICNAF, 1964).

The age was recorded as the number of completed summer (opaque) growth zones on the otolith with 1 January as the arbitrary birth date; a fish is considered to be age 1 on 1 January following completion of the first summer's growth.

The 1967 and 1968 Fortune Bay samples were collected under the direction of Dr A. S. Hourston and the sampling data for these seasons have been published previously in a series of Technical Reports (Hourston *et al.*, MS 1968). The present authors have re-examined the otoliths from herring samples taken during these seasons and assigned ages in accordance with current age-reading techniques at the St. John's Biological Station.

Results

Maturity and spawning

Percentages of immature fish in the samples ranged from 2 to 8% during 1966 to 1968 but increased to 31-32% in 1969 and 1970 and decreased to 20% in 1971. The vast majority of the mature fish were definite spring spawners with well-developed gonads (Stage 4); with the exception of the 1966 research vessel samples, recovering spents (autumn spawners) comprised less than 9% of the total fish sampled. Most of the immature herring were also assigned to the spring-spawning group since an examination of the otolith structure of these herring revealed that spring spawners could generally be separated from autumn spawners on the basis of certain otolith characteristics (L. S. Parsons, in preparation).

Reports from Fishery Officers of the Canadian Fisheries Service, Department of the Environment, over the past several years indicate that spring spawning in Fortune Bay usually occurs sometime between mid-April and mid-May, mostly in early May, which is earlier than in most other Newfoundland areas.

Size and age composition

Figure 2 depicts the percentage length composition (to the cm below) of Fortune Bay herring by spawning group from 1966 to 1971. In all years autumn spawners were larger than spring spawners and exhibited a fairly dispersed length distribution. The length-frequency patterns for spring spawners differed considerably among years. In the 1966 research vessel samples there were distinct modes at 27 and 33 cm. In 1967 there was a very distinct mode at 29 cm and the appearance of a few herring 8-14 cm in length. The 33-cm mode of the previous year had virtually disappeared. The length frequency for 1968 spring spawners was sharply peaked at 31 cm and there was a small proportion of 21-22 cm herring. By 1969 the length frequency was again distinctly bimodal with peaks at 26 and 32 cm and a slight trace of 19-22 cm herring. In 1970 the length distribution was markedly trimodal with modes at 23, 29, and 33 cm. There were also three modes in 1971 but the third mode was greatly reduced in comparison with the previous year. The dominant modes were at 27 and 31 cm.

The progression and succession of several modes in the length distribution of Fortune Bay spring spawners during the 1966-71 period indicates the occurrence of several dominant year-classes (Fig. 3). The 1963 year-class of spring spawners, which was dominant in 1966, maintained its dominance during 1967 and 1968 but by 1969 was slightly less abundant than the 1966 year-class which first appeared in the catches during 1967 as 1-year-olds. During 1970 the 1968 year-class first appeared in abundance as 2-year-olds with the catch in numbers being derived in approximately equal proportions from the 1963, 1966, and 1968 year-classes. By 1971 the 1963 year-class was greatly reduced in abundance and the fishery was supported primarily by the 1966 year-class as 5-year-olds and the 1968 year-class as 3-year-olds. Preliminary age composition data for the 1972 season indicate that the 1966 and 1968 year-classes were again dominant as 6- and 4-year-olds respectively.

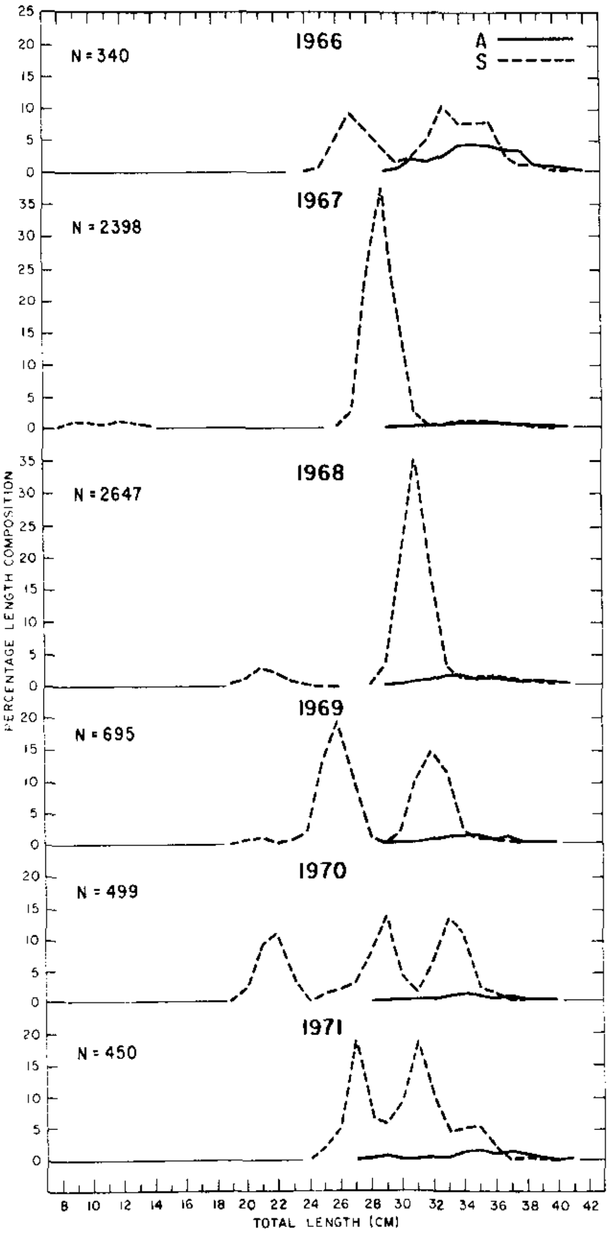

Fig. 2. Length composition of Fortune Bay herring by spawning group during the 1966 to 1971 seasons.

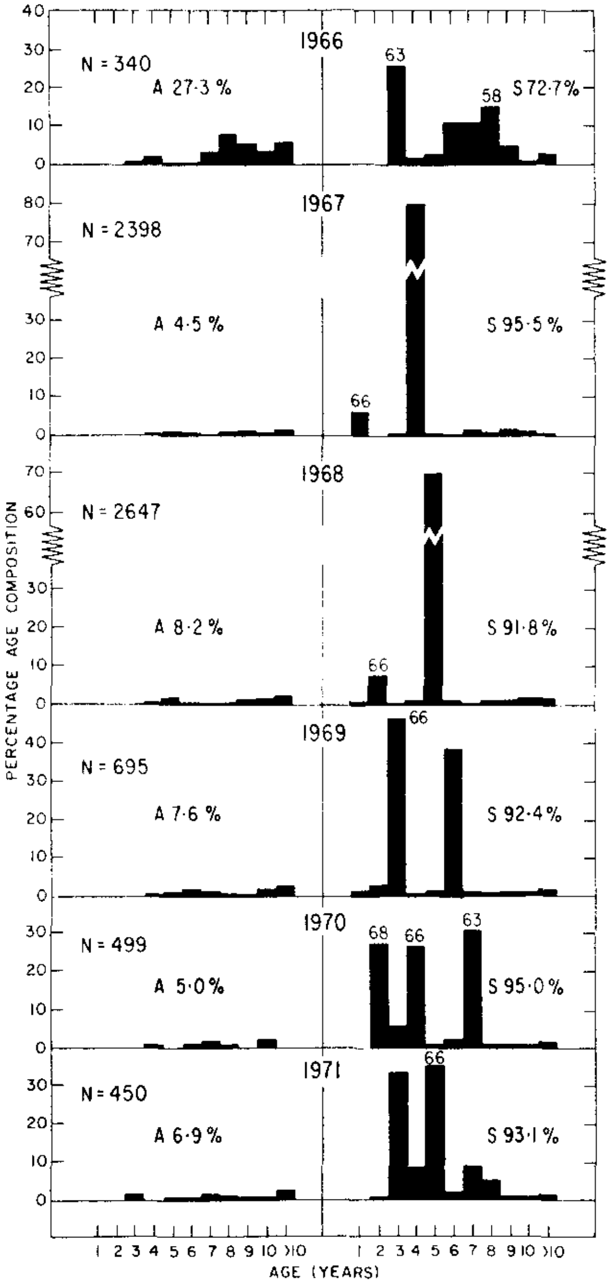

Fig. 3. Age composition of Fortune Bay herring by spawning group during the 1966 to 1971 seasons.

The size and age trends for Fortune Bay spring spawners during the 1966-71 period are in sharp contrast to those exhibited by the Southwest Newfoundland herring stock complex, which overwinters in areas J1 and J2 from late November to early April. There was a gradual increase in the average size of both spring and autumn spawners taken along southwestern Newfoundland from the beginning of the purse seine fishery in 1965 up to the 1969-70 season (Hodder, 1971; Hodder *et al.*, MS 1972). The average size of autumn spawners continued to increase during the 1970-71 season but that of spring spawners decreased from 33.4 cm in 1969-70 to 32.8 cm in 1970-71. The Southwest Newfoundland winter fishery has been largely dependent on a very abundant 1958 year-class of autumn spawners and a smaller 1959 year-class of spring spawners. Basically, there has been a lack of substantial recruitment to the spring-spawning as well as the autumn-spawning component of the stock. However, the 1968 year-class of spring spawners appears to be relatively strong in comparison with other year-classes of the 1960's (Winters and Parsons, MS 1972).

Growth

Figure 4 depicts mean lengths-at-age for Fortune Bay spring spawners during 1943-44 and 1966-71. Mean lengths-at-age for the 1966-71 pooled data and the 1963 year-class alone (at ages 3-8) are very similar. Lengths-at-age for Fortune Bay herring during the 1943-44 period derived from Tibbo (1956) differ somewhat from those of the more recent period. Our observed mean lengths-at-age are less than Tibbo's for the younger fish and greater for the older fish. At ages 5 and 6 we found mean lengths of 31.4 and 32.5 cm respectively compared with 32.8 and 33.7 cm for these ages during 1943-44. Our observed mean length at age 10 was 1.7 cm greater than that reported by Tibbo (1956) for the same age. It should be noted that Tibbo used scales for ageing whereas our age estimates are based on otoliths. This may partially account for these differences between investigators in the average lengths of herring at various ages.

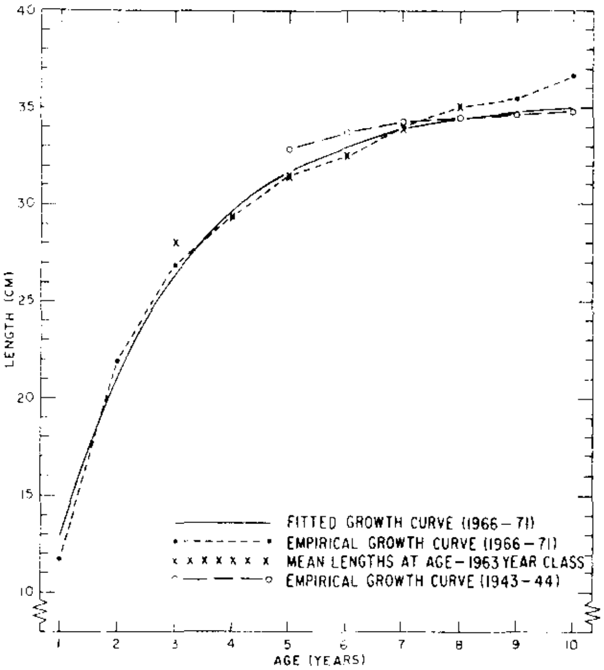

Fig. 4. Fitted and empirical growth curves for Fortune Bay spring-spawning herring.

Comparative mean lengths-at-age for Fortune Bay and southwest Newfoundland spring spawners (from Hodder *et al.*, MS 1972) during 1966-71 are as follows:

	Average length (cm)	
Age	Fortune Bay	Southwest Nfld.
2	21.9	21.5
3	26.9	26.7
4	29.4	29.4
5	31.5	30.5
6	32.5	31.5
7	34.0	32.1
8	35.1	32.8
9	35.5	33.4
10	36.6	34.1
11+	37.7	35.2

Mean lengths at age are similar up to age 4 but from age 5 onwards the mean lengths of Fortune Bay spring spawners at each age are considerably higher than those for Southwest Newfoundland spring spawners of the same age.

A Bertalanffy growth curve was fitted to the pooled length-at-age data for Fortune Bay spring spawners for the 1966-71 seasons by Allen's (1966) method.

$$L_t = L_\infty \left[1 - e^{-k(t-t_o)} \right]$$

where L_t is the body length estimated for time t, L_∞ is the theoretical maximum length, K is the coefficient of growth, and t_o is the theoretical time when body length is zero. The following values were obtained:
$L_\infty = 35.14$ cm, $k = 0.462$, and $t_o = 0.015$.

Fortune Bay spring spawners have a significantly larger L_∞ value than those reported for Southwest Newfoundland spring spawners (34.5 cm) by Hodder *et al.* (MS 1972) and southern Gulf of St. Lawrence spring spawners (32.28 to 33.17 cm) by Messieh and Tibbo (1971). The k value is intermediate between the values reported for Southwest Newfoundland (.348) and the southern Gulf of St. Lawrence (.474 to .525).

Length-weight relation

Length-weight curves for mature spring spawners (generally greater than 26 cm in length) during January, February, and April 1970 and for 1968-71 combined data for immature and mature fish (Fig. 5) were derived by applying logarithmic transformations to the variable of the exponential equation $W = aL^b$ and estimating the constants log a and b by least squares regression. The equations relating whole weight to total length are as follows:

January 1970 $W = 4.993 \times 10^{-7} L^{3.4731}$
February 1970 $W = 5.862 \times 10^{-7} L^{3.4486}$
April 1970 $W = 2.160 \times 10^{-6} L^{3.2216}$
1968-71 (combined) $W = 7.710 \times 10^{-7} L^{3.3926}$

Whole weight increases with length at a rate faster than would be expected from the cube relation of weight to length. At all sizes there was a slight increase (approximately 2%) in average weight from January to February 1970. Between January and April there was an overall increase (approx. 3%) in average weight at sizes less than 33 cm and an overall decrease (approx. 3%) at the larger sizes (> 33 cm). Hodder *et al.* (MS 1972) have found that on the average the mean weight values over the 28-37 cm length range for southwest Newfoundland herring decrease between November and April by about 6% for spring spawners and 4% for autumn spawners. The overall exponent for the length-weight relation for Fortune Bay spring spawners during 1968-71 (3.3926) is similar to that for southwest Newfoundland spring spawners (3.328) (Hodder *et al.*, MS 1972).

Nematode incidence and intensity

Nematode incidence (percentage of fish infested) and intensity (average number of nematodes per fish) in Fortune Bay spring spawners during January to April 1971 were compared with nematode abundance in Southwest Newfoundland spring spawners during the same period (Fig. 6). Nematode incidence and intensity increase with fish size and age in both areas. However, at any particular size values were generally higher for Fortune Bay than for southwest Newfoundland spring spawners. There are considerable differences in the nematode incidence-fish age relationship between these areas. Nematodes were fairly abundant in Fortune Bay

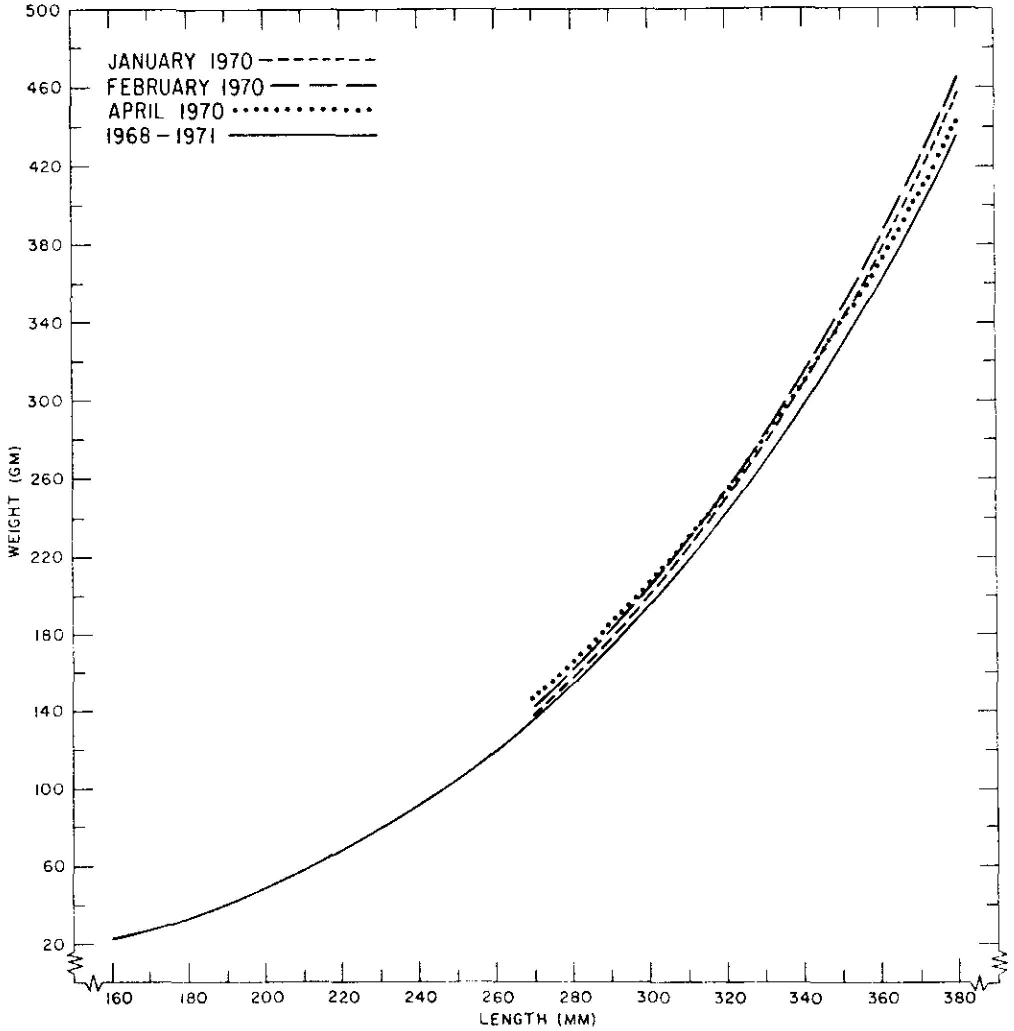

Fig. 5. Length-weight curves for Fortune Bay spring spawners. (The 1970 monthly curves are based only on mature fish (> 26 cm) but the 1968-71 curve is based on both immature and mature fish.)

fish of ages 3, 4, and 5 (26-38% infested) but absent in Southwest Newfoundland fish of these age groups. At ages 6 to > 10 differences between Fortune Bay and Southwest Newfoundland spring spawners in percentages of fish infested ranged between 18 and 48% (Fig. 6).

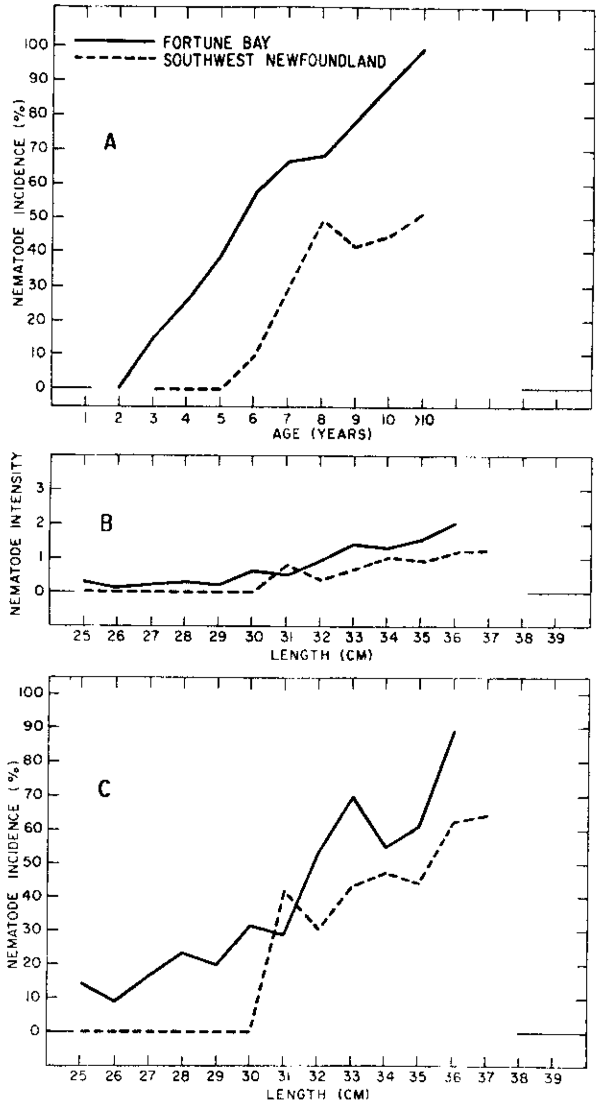

Fig. 6. Nematode incidence (percentage of fish infested) and intensity (average number of nematodes per fish) in relation to fish age (A) and length (B and C) for Fortune Bay and Southwest Newfoundland spring spawners during the winter of 1971.

Discussion

The size and age composition of Fortune Bay herring has changed considerably since Tibbo's investigations during 1943-44 and 1946-48. In 1943 and 1944 Fortune Bay herring had an average size of 34.90 cm and an average age of 9.42 years. In 1946 to 1948 the mean length and age had increased to 35.63 cm and 11.79 years respectively (Tibbo, 1956, 1957). In both periods a relatively large number of year-classes were well represented. During the 1967-71 period of exploitation by a mobile purse seine fleet, the catches have contained a high proportion of relatively young fish (less than 8 years old), a large proportion of the catches in numbers being derived from immature fish and fish maturing to spawn for the first time.

Three good year-classes of herring have supported the Fortune Bay fishery since 1967, namely, the 1963, 1966, and 1968 year-classes. From year-class composition and landing trends it would appear that a year-class contributes greatest to the fishery at age 5 when most of the fish are mature. Peaks in the landings from Fortune Bay occurred in 1968 when herring of the 1963 year-class were 5 years old and in 1971 when herring of the 1966 year-class were 5 years old.

Tag recaptures (Winters, 1970, MS 1971; Beckett, MS 1971) and comparisons of various biological characteristics (Hodder and Parsons, 1971*a* and *b*; Parsons and Hodder, 1971*a*) have shown a seasonal migration of herring eastward from the southern Gulf of St. Lawrence in the autumn to overwintering areas along southwestern Newfoundland and westward again into the Gulf in the spring. These herring concentrations, which are fished by purse seiners in the fjords and bays along the southwest coast in Areas J1 and J2 (Fig. 1) from late November to April consist of two intermixed spawning groups, autumn spawners comprising 70% of the population, spring spawners the remainder (Hodder, 1971; Parsons and Hodder, 1971*b*). The small Fortune Bay fishery based almost exclusively on spring spawners also takes place during winter and spring and could involve some fish which are a part of the southern Gulf-Southwest Newfoundland stock complex.

Parsons (1973), in a study of the meristic characteristics of herring inhabiting Newfoundland and adjacent waters, reports that Fortune Bay spring spawners differ significantly in mean numbers of vertebrae and pectoral fin rays from those in adjoining areas. Fortune Bay spring spawners have the highest vertebral average and the lowest pectoral fin ray average among spring spawners of the Newfoundland area. Tibbo (1956, 1957) reported that Fortune Bay herring had the highest mean vertebral number in the Newfoundland area during 1943-44 and 1946-48 (55.877 and 55.772 respectively). On the basis of these differences Parsons (1973) concludes that Fortune Bay herring probably do not intermix to any great extent with those in adjoining areas.

The present study indicates that Fortune Bay spring spawners, which have had a succession of several dominant year-classes (those of 1963, 1966, and 1968) from 1966 to 1971, have differed considerably in size and age composition and growth from Southwest Newfoundland spring spawners, which were dominated by the 1959 year-class from 1965 to 1970. They also differ considerably in nematode incidence, Fortune Bay spring spawners having significantly higher percentages of fish infested with nematodes at any particular age than those from Southwest Newfoundland.

These differences in meristic characteristics, year-class dominance, growth, and nematode abundance suggest that Fortune Bay spring spawners do not intermingle to any great extent with the herring stock complex which overwinters along southwestern Newfoundland but rather constitute a relatively discrete spring-spawning stock. However, virtually nothing is known of the biology and distribution of Fortune Bay herring during the summer and autumn (July-December). Herring concentrations appear in abundance in Fortune Bay during January and disappear again in May or early June after spawning in shallow coastal waters (1-10 m). The location of their summer feeding grounds is presently unknown. Recent taggings (April, 1972) will probably shed further light on the seasonal migrations of this stock and the degree of intermixing with stocks in adjacent areas.

Acknowledgements

We are indebted to officials at the Harbour Breton herring plant who provided space for sampling and permitted the frequent sampling of purse-seiner landings. We are grateful to the technicians, assigned to the Pelagic Fish Division of the St. John's Biological Station, who assisted with the examination of the specimens, age determination and subsequent analysis of the data.

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American Plaice, *Hippoglossoides platessoides platessoides* Fabr., Spawning in the Northwest Atlantic Area

By M. M. Nevinsky[1] and V. P. Serebryakov[1]

Abstract

The temporal and spatial distributions of American plaice spawning in Subareas 2, 3, and 4 are based on ichthyoplankton collections at 3,127 stations during 1959-70 and the maturity condition of the gonads of 9,000 adult specimens taken from commercial catches during 1954-70.

American plaice seem to spawn in most parts of the area in depths of 50 to 250 m. The main spawning areas are on the northern shallows of the Grand Bank, off southern Newfoundland, on St. Pierre and Green Banks, off Cape Breton and on Banquereau Bank. The temperatures of the near-bottom and the surface water layers over the spawning grounds were from 0° to 6°C and 6° to 18°C respectively. The most intensive spawning was observed in April, May, and June with near-bottom temperatures from 0° to 2.5°C.

The spawning grounds are situated in the areas of action of branches of the Labrador Current or in those of cold water from the Gulf of St. Lawrence. Larvae at different stages of development were found in the same general areas as the eggs, i.e. mostly over the spawning grounds. The low current velocities over the spawning areas and the peculiarities of larvae distribution indicate that the passive migration period of the American plaice is not long during their early stage of development.

Introduction

In the Northwest Atlantic area, American plaice, *Hippoglossoides platessoides platessoides* Fabr., are distributed from Greenland to Cape Cod. The fishery is most intensive off Newfoundland. Until recently, relatively few papers concerning the biology and ecology of American plaice have been published. Huntsman (1918), Bigelow and Schroeder (1953), and Powles (1965) reported on these subjects for American plaice inhabiting the Bay of Fundy, the Gulf of Maine and the Gulf of St. Lawrence, and Pitt (1963, 1964, 1966, 1967, 1969) has several papers on plaice of the Newfoundland and Grand Bank areas. However, only a paper by Pitt (1966) is devoted completely to the spawning of American plaice. Also, the volume of data on the distribution of eggs and larvae of American plaice is not great (Dannevig, 1918; Jensen, 1925; Frost, 1938; Serebryakov, 1962, 1963, 1964; Kennedy and Powles, 1964; Wells, 1968; L'Herrou and Minet, 1971). In this paper the authors attempt to elucidate the character of the distribution of American plaice eggs and larvae as to the precise times and places of their spawning off Labrador, Newfoundland, and Nova Scotia.

Materials and Methods

This study is based mainly on the collections of ichthyoplankton taken by PINRO (Polar Research Institute of Marine Fisheries and Oceanography) research vessels from 1959 to 1970 and on the analysis of the maturity condition of the gonads of adult fish. The ichthyoplankton samples were taken mainly with conical plankton nets. Usually, vertical hauls from bottom to surface or 15-minute horizontal hauls were made at stations on standard hydrological sections and tracks as well as at special ichthyoplankton stations while circling or drifting. During 1959-70 a total of 3,127 stations were occupied on the continental shelf from Labrador to Nova Scotia. Stages of egg and larval development were determined according to the Rass (1949) system.

Data on the maturity stages of the gonads of adult fish were obtained during 1954-70 from the field examination of specimens taken on surveys conducted by PINRO research vessels and by scouting vessels of the Northern Prospective Fish Scouting Service. A total of 9,000 specimens were examined, but the material used in the following analysis only includes fish with gonads

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classified as III, IV, V, VI, and VI-II in the maturity scale. The stages of gonad maturity were determined by the six-point scale (Sorokin, 1957).

Results

Labrador (ICNAF Subarea 2)

Ripe running fish (Stage V) were observed in the catches taken in this area as early as January and March (Table 1), the percentage of fish with running gonads increased greatly in May and spent fish began to appear in the catches. In June most of the fish were in the spent condition.

Ichthyoplankton samples, taken mainly from April to July, contained only single eggs in April and May (Figs. 2 and 3). In the second half of June the densest concentrations of eggs were taken off Sundal Bank over 400-500-m depths (Fig. 4) and on the northeastern part of Hamilton Inlet Bank over 200-300-m depths. However, a few eggs were found northeast of Hamilton Inlet Bank over the continental slope where depths are 500 m and greater. In July egg concentrations were found closer to the coast on the western and northern parts of Hamilton Inlet Bank (Fig. 5). Most of the eggs taken in June and July were in the first stage of development (Fig. 7). In June and August two larvae about 6 mm long were caught in the vicinity of Hamilton Inlet Bank over depths of 100 m and more than 500 m, respectively, (Figs. 4 and 6). Because of the small volume of data available, it can only be supposed that some spawning takes place on some parts of the south Labrador Shelf at depths of 150-500 m from the middle of June to the end of July.

TABLE 1. The maturity of American plaice gonads, South Labrador, 1960-70.

Month	Maturity stages in %					No. of fish
	III	IV	V	VI	VI-II	
January	34.1	53.4	11.8	–	0.7	161
February	63.1	36.9	–	–		133
March	46.1	42.4	11.5	–	–	26
May	0.9	66.7	27.2	–	5.2	114
June	–	–	9.0	9.0	82.0	22
September	22.1	24.4	–	–	53.5	86

Northeastern part of the Newfoundland Shelf (ICNAF Division 3K)

Ichthyoplankton collections were made in this area from April to July. No American plaice eggs were taken in April, but some concentrations of mostly stage I eggs (Fig. 7) were found over depths of 200-250 m during the second half of May (Fig. 3). In June eggs in later stages of development (III-IV) were taken at stations near Ritu Bank and off the northeast coast of Newfoundland over 200-400-m depths (Fig. 4). None were taken in this area in July. However, larvae 4.0 to 6.5 mm long were found early in May and late in July in the shoreward part of the surveyed area over 160- and 250-m depths, and in June a 5.0-mm larvae was taken farther northeastward near the edge of the Newfoundland Shelf over a depth of 335 m (Figs. 3-5). From the distribution of eggs it would, therefore, appear that spawning occurs from the second half of May through June, especially on the shallower parts of the Shelf at depths of 200-250 m, although pre-spawning fish were observed in the catches during the first quarter of the year off Labrador (Table 1).

Grand Bank (ICNAF Divisions 3L, 3N, and 3O)

American plaice eggs can be found in this area from the end of March to September (Figs. 1-6). In March eggs were distributed mainly over depths of 50-100 m on the northeastern parts of the Bank. In the latter part of April the greatest egg concentrations were found along the eastern part of the Bank mainly over depths of 50-200 m but some eggs were taken over the southern slopes. In the latter part of May eggs were found in great abundance over the northern part of the Bank just east of the Avalon Peninsula of Newfoundland, where the depths were 100-200 m, and smaller quantities were caught along the southeastern and southwestern slopes of the Grand Bank over depths of 50-500 m. In early June plaice eggs were observed along the southern and southwestern slopes of the Bank mainly over depths of 50-300 m, but some eggs, carried by water currents, were found at great distances south of the Bank over 4,000-5,000-m depths (Fig. 4). Similar cases were recorded in July and August. During the third

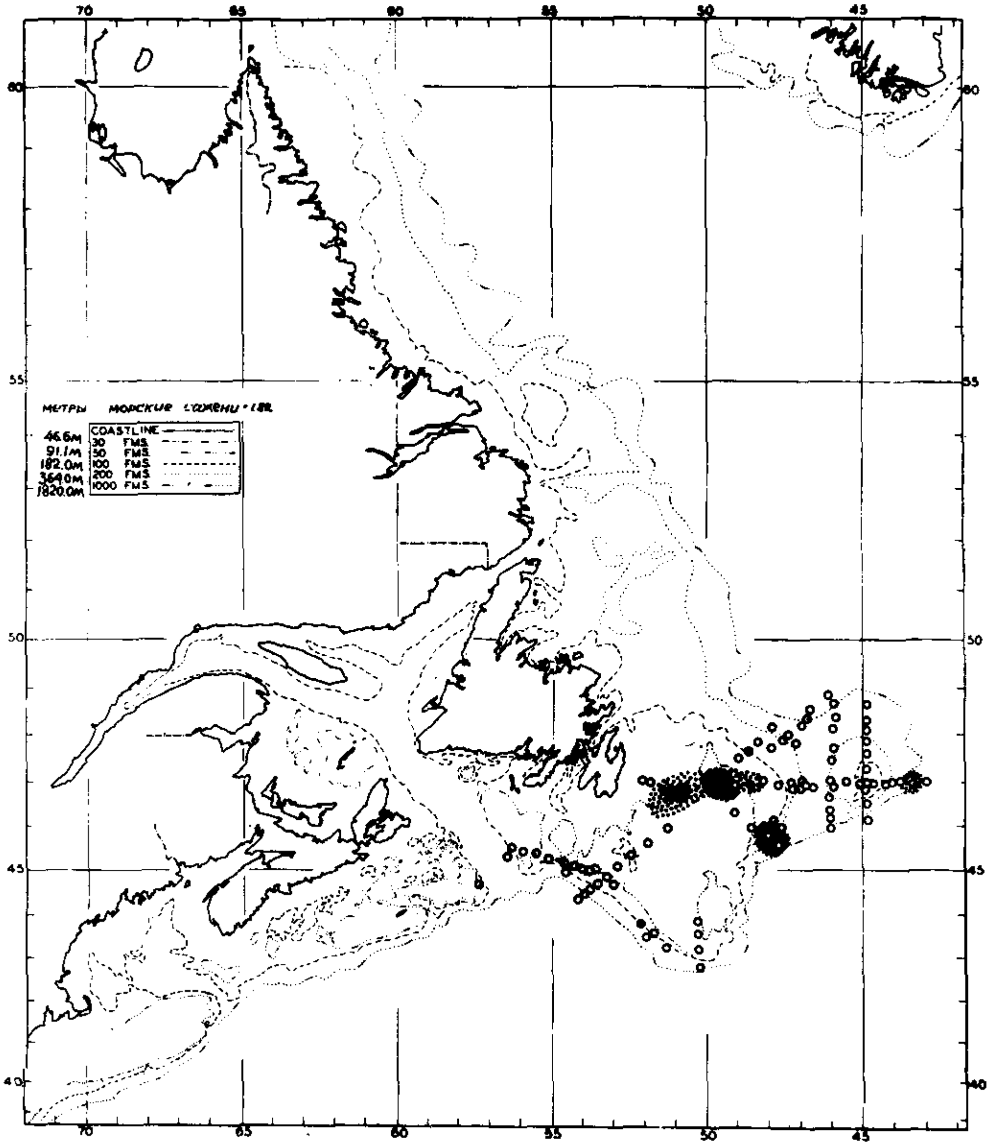

Fig. 1. Distribution of the American plaice eggs and larvae in March. (o – stations; ▒ – 1-10 eggs; ▨ – 11-100 eggs; ▤ – 101-500 eggs; ▦ – 501-1,000 eggs; ■ – more than 1,000 eggs; o–1 – number of larvae at stations.)

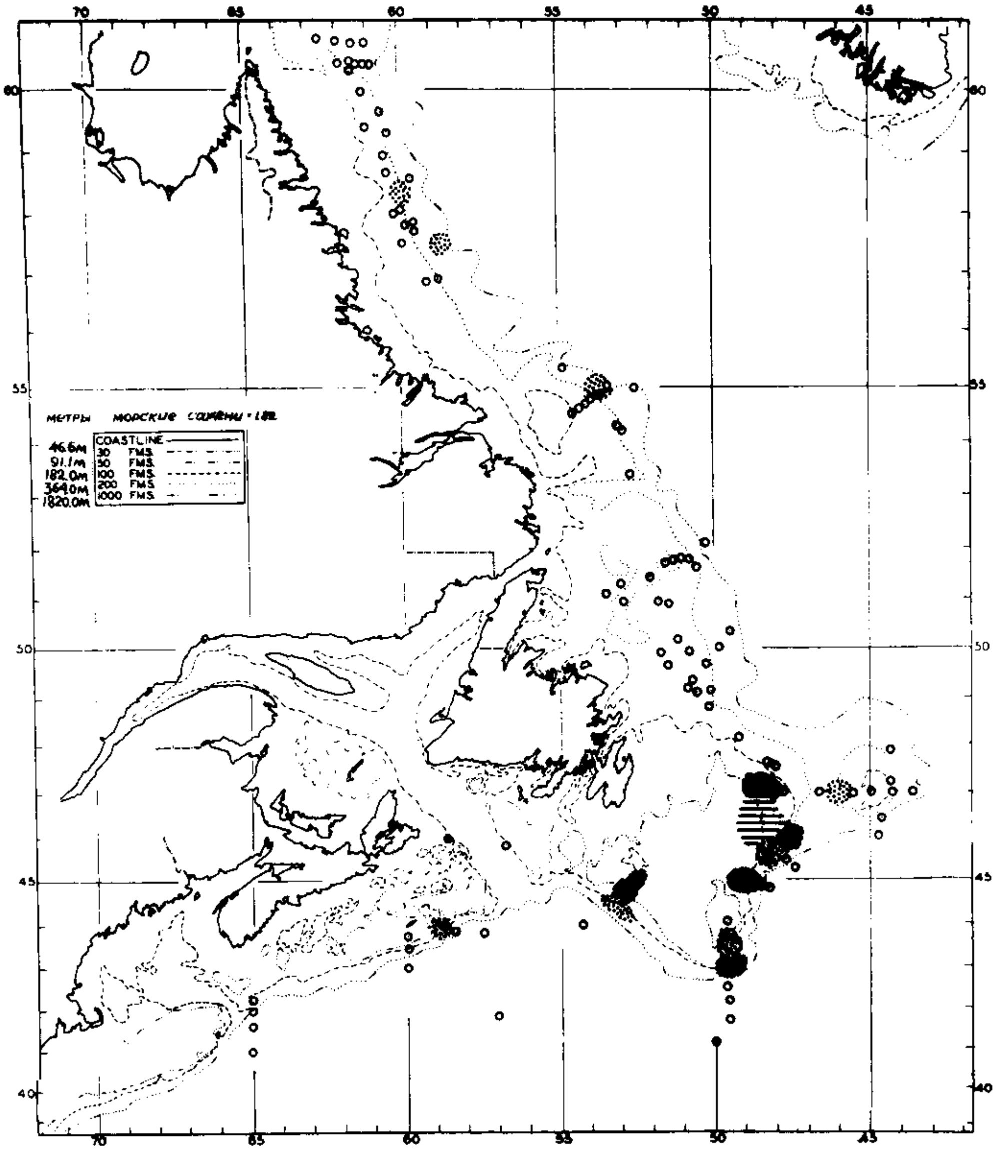

Fig. 2. Distribution of the American plaice eggs and larvae in April. (○ – stations; ░ – 1-10 eggs; ▨ – 11-100 eggs; ▤ – 101-500 eggs; ▩ – 501-1,000 eggs; ■ – more than 1,000 eggs; ○⌐ – number of larvae at stations.)

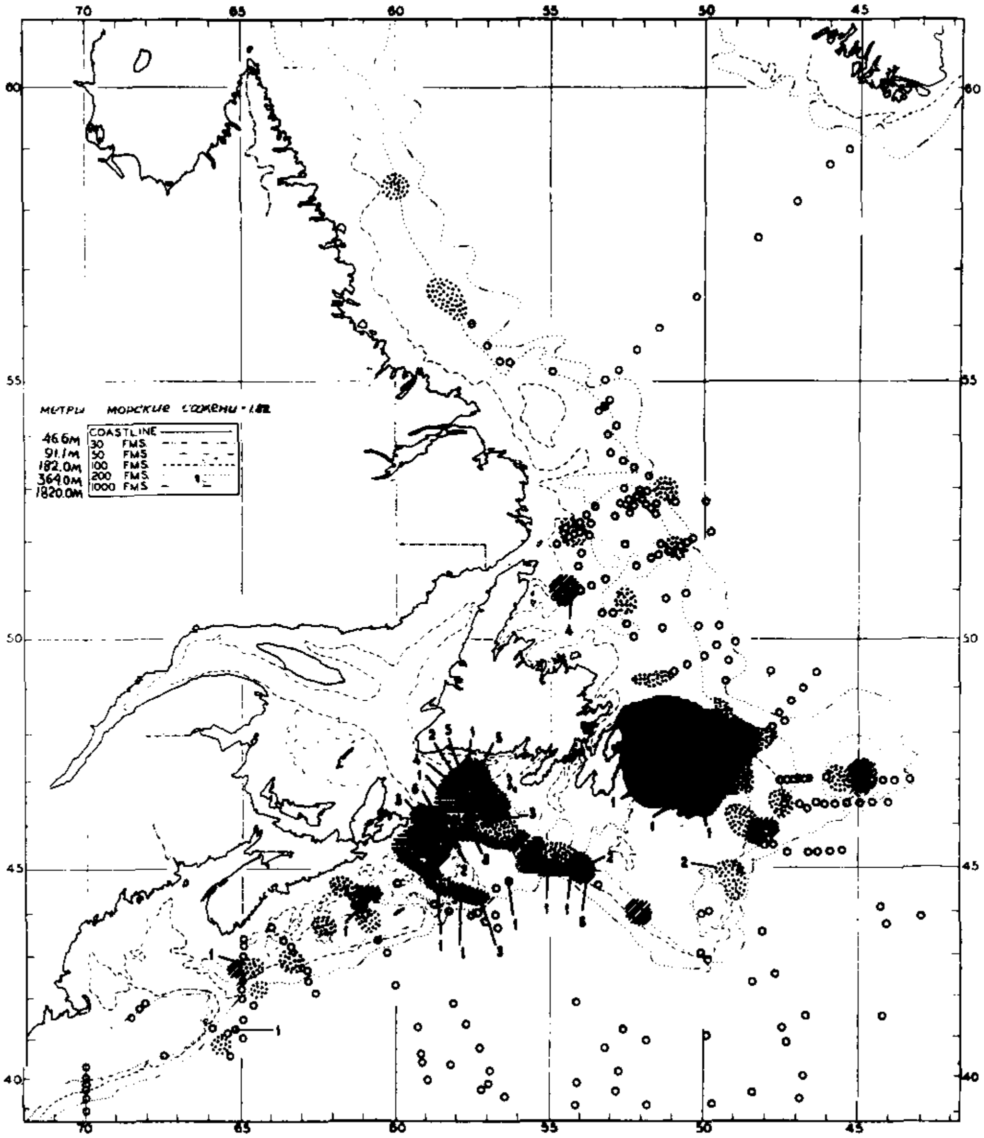

Fig. 3. Distribution of the American plaice eggs and larvae in May. (o – stations; ░ – 1-10 eggs; ▨ – 11-100 eggs; ▤ – 101-500 eggs; ▩ – 501-1,000 eggs; ■ – more than 1,000 eggs; •–1 – number of larvae at stations.)

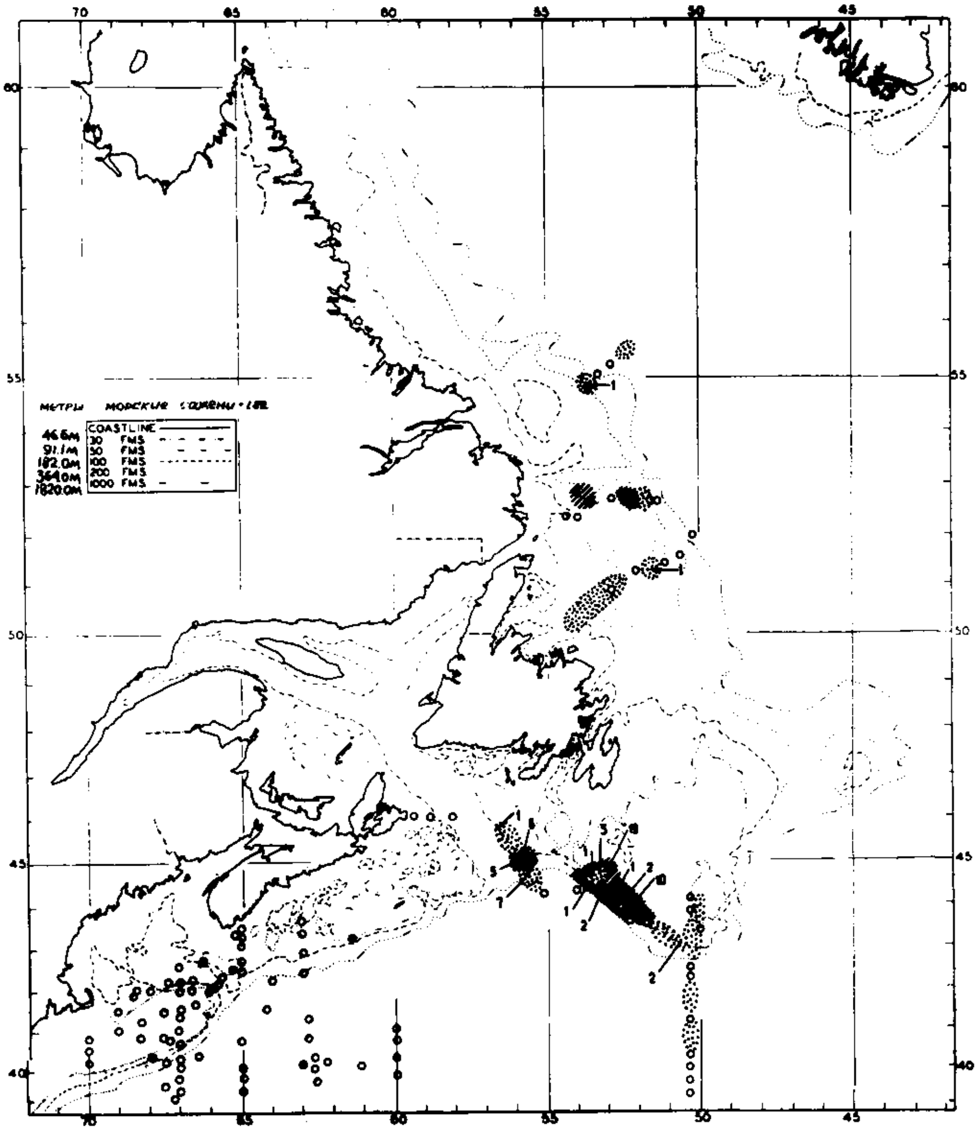

Fig. 4. Distribution of the American plaice eggs and larvae in June. (○ stations; ░ – 1-10 eggs; ▨ – 11-100 eggs; ▤ – 101-500 eggs; ▦ – 501-1,000 eggs; ■ – more than 1,000 eggs; ⊸1 – number of larvae at stations.)

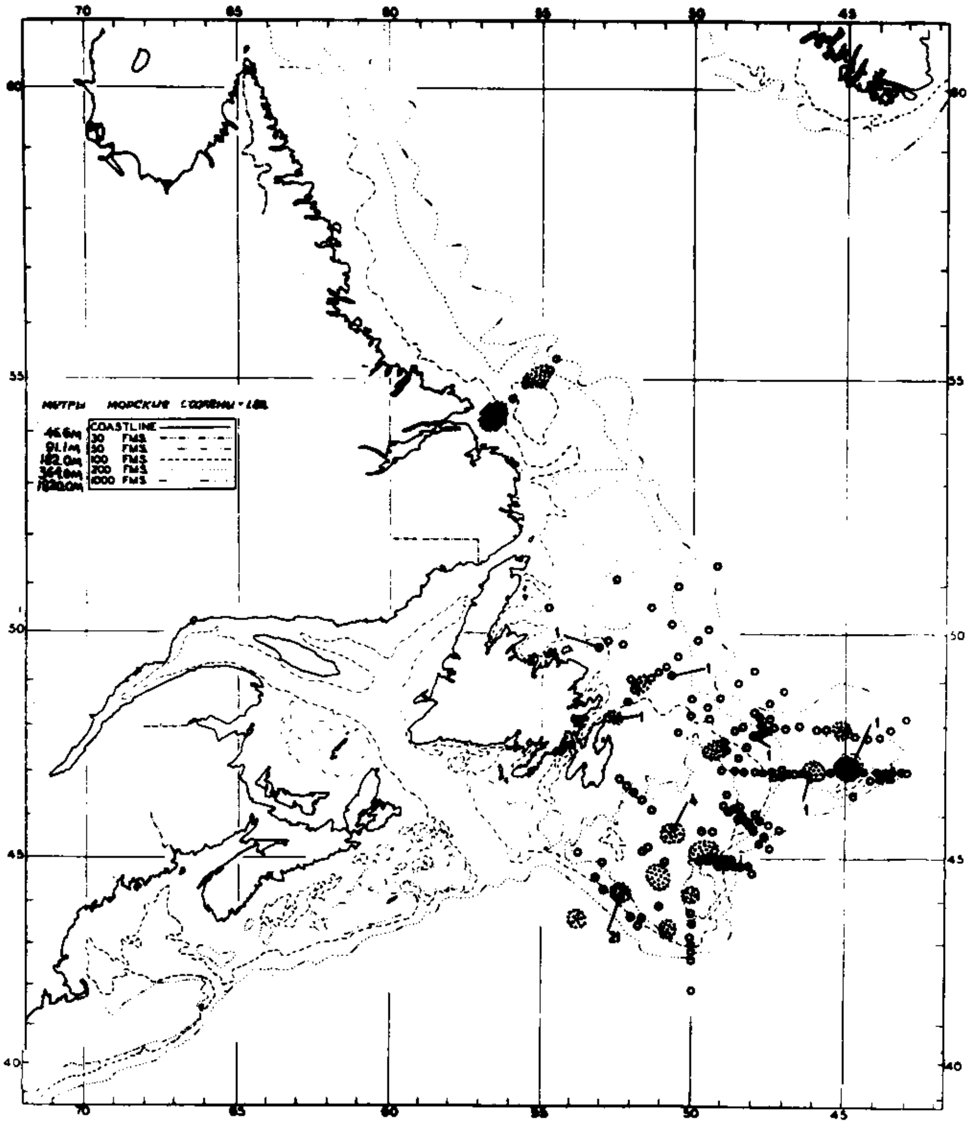

Fig. 5. Distribution of the American plaice in July. (o – stations; ▒ – 1-10 eggs; ▨ – 11-100 eggs; ▤ – 101-500 eggs; ▦ – 501-1,000 eggs; ■ – more than 1,000 eggs; o—1 – number of larvae at stations.)

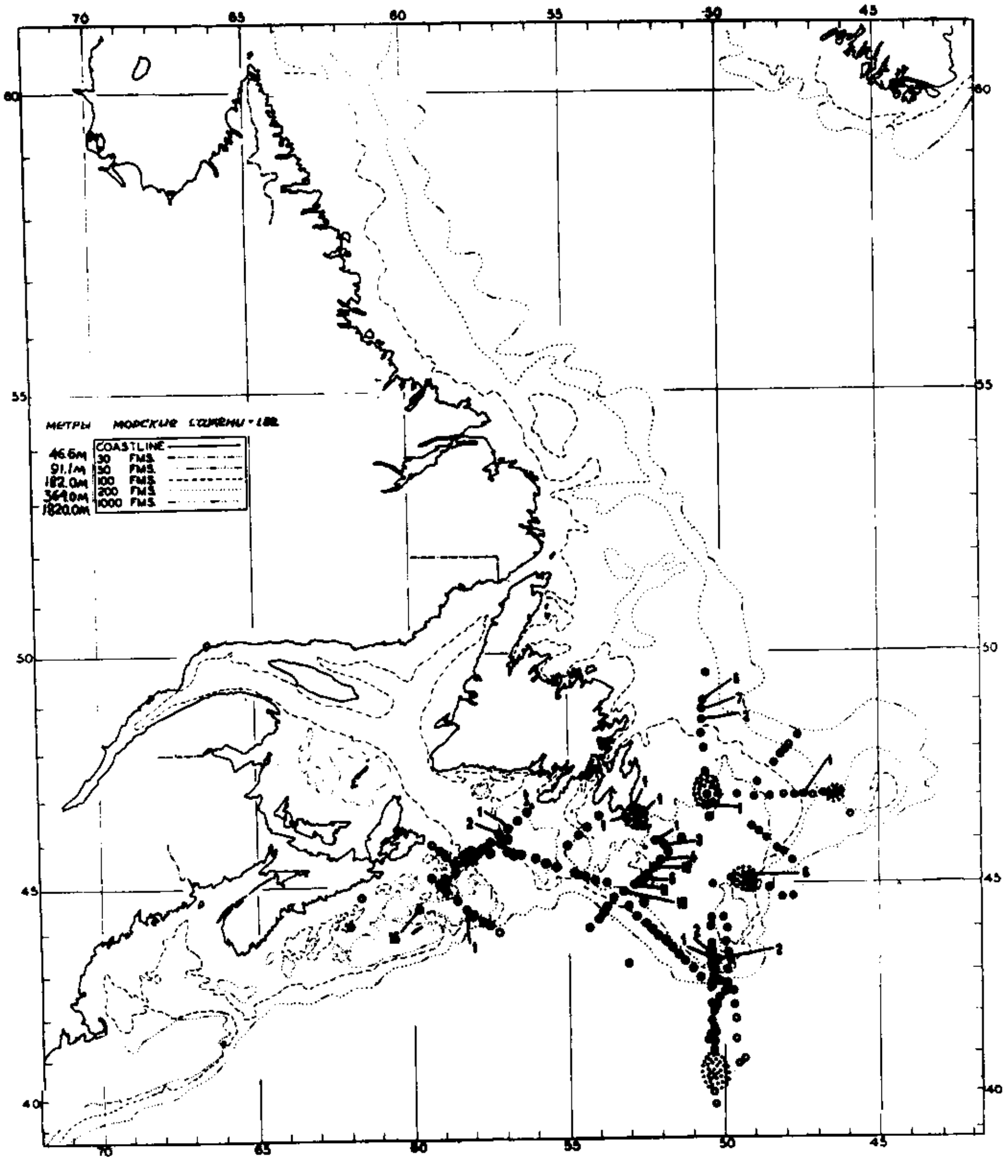

Fig. 6. Distribution of the American plaice eggs and larvae in August – September. (○ – stations; ▒ – 1-10 eggs; ▨ – 11-100 eggs; ☰ – 101-500 eggs; ▦ - 501-1,000 eggs; ■ – more than 1,000 eggs; ○⊣ -- number of larvae at stations.)

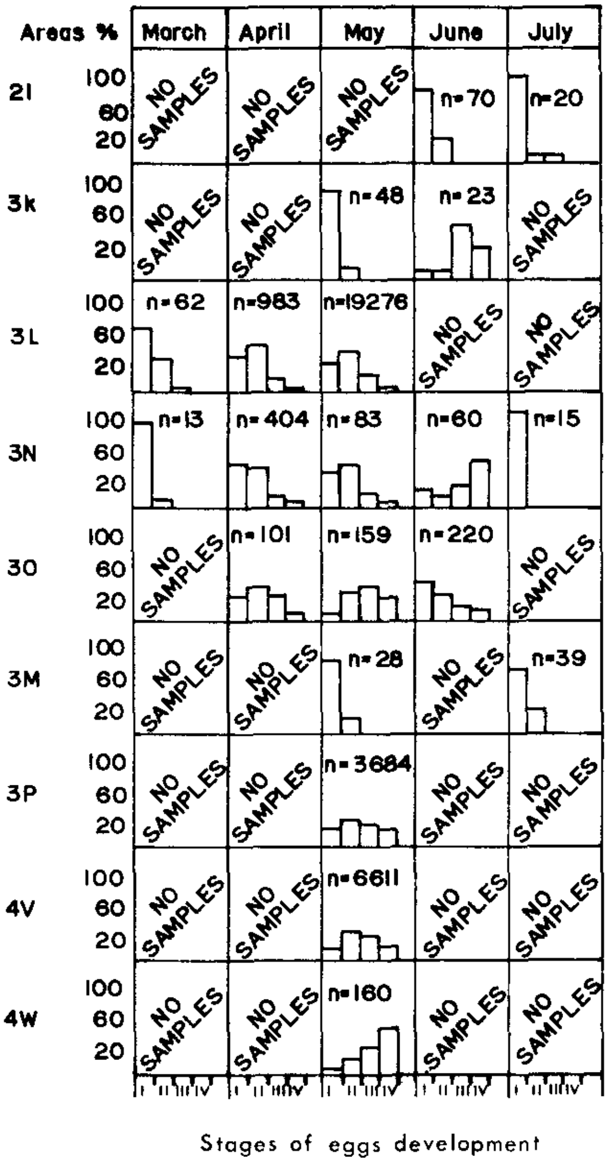

Fig. 7. The correlation of the development stages of the American plaice eggs in the areas of the Northwest Atlantic.

quarter (July-September) scattered eggs were observed over the shallow parts of the Grand Bank and near the Avalon Peninsula over depths of 50-200 m (Figs. 5 and 6).

Eggs taken in March were predominantly stage I, while those taken in April were mainly stages I and II in almost the same proportions (Fig. 7). In May all four stages of egg development were represented in the samples from the various parts of the Grand Bank, with stages I and II eggs dominant on the northern and eastern parts of the Bank and stages III-IV eggs on the southwest slope. In June all four stages were again represented, with stages III-IV eggs predominant in the southeastern Grand Bank samples and stages I-II in those from the southwest slope. In July, however, samples taken on the southeastern part of the Bank contained only stage I eggs.

Larvae were found in most areas of the Bank from May to mid-September over depths of 50-800 m (Figs. 3 and 6), and larval lengths varied between 4 and 22 mm, with most being pre-larvae in the size range 4-8 mm.

The analysis of the distribution of maturity stages in adult American plaice shows that specimens with ripe gonads were taken in January and February (Table 2). On the northern part of the Bank (Div. 3L) the greatest number of spawning fish (stage V) were observed in March, April, and May, but the observation for March is inconclusive due to the small volume of data. In the southern Grand Bank areas the maximum numbers of spawning fish were recorded in March, May, and June for Div. 3N and in April and May for Div. 3O.

From the distribution of eggs, larvae and spawning adults, it is possible to conclude that the spawning period for American plaice on the Grand Bank extends from about mid-March to September. The most intensive spawning apparently occurs on the northern part of the Bank from mid-April to mid-May mainly at depths of 50-200 m. Spawning seems to be much less intensive on the southern parts of the Bank, the peak period being from mid-April to the end of May on some parts of the southeastern slope in depths of 50-150 m, and from mid-April to mid-June on the southwestern part of the Bank at depths of 50-100 m.

Flemish Cap Bank (ICNAF Division 3M)

Some American plaice eggs were taken in this area from the second half of March to August (Figs. 1-5), the greatest numbers being observed over the central part of the Bank (bottom depths of 150-200 m) in the second half of May and in July (Figs. 3 and 5). Most of the eggs were in stage I of development (Fig. 7). The few larvae taken in July were 5-6 mm long.

From the analysis of maturity data on adults (Table 3), spawning fish were observed in this area as early as March and also in September.

From the small amount of data available, it is difficult to determine the spawning period. Apparently, the main spawning of this small stock of American plaice occurs on the central part of the Bank at depths of 150-200 m from the middle of May to the end of July.

TABLE 2. Maturity stages of the American plaice in the waters of the Grand Bank, 1954-70.

Division	Month	Maturity stages in % III	IV	V	VI	VI-II	No. of fish
3L	I	58.6	38.0	3.4	–	–	87
	II	18.6	72.4	9.0	–		311
	III	–	52.5	38.7	2.3	6.8	44
	IV	13.1	40.6	31.7	4.6	10.0	281
	V	45.8	20.0	29.5	–	4.7	190
	VII	31.8	11.6	6.4	7.8	42.4	467
	VIII	33.1	23.8	3.2	4.3	35.6	650
	IX	75.5	23.7	0.8	–	–	123
3N	I	59.8	31.7	8.5	–	–	224
	II	45.2	45.2	9.6	–	–	73
	III	2.0	44.1	23.5	1.0	29.4	102
	V	25.6	25.6	18.6	0.8	29.6	125
	VI	36.2	21.4	26.8	3.4	12.2	354
	VII	58.3	11.1	0.8	11.1	18.7	235
	VIII	56.4	5.3	–	10.6	27.8	133
3O	II	60.0	31.0	3.6	–	5.4	55
	III	17.4	60.9	17.4	–	4.3	69
	IV	22.2	15.6	57.8	–	4.4	45
	V	26.1	30.4	43.5	–	–	23
	VI	45.0	19.3	8.6	3.7	23.4	406
	VII	29.3	23.6	5.6	7.5	34.0	106
	IX	27.2	23.8	5.4	–	43.6	92

TABLE 3. The maturity stages of American plaice, Flemish Cap area, 1954-70.

Month	Maturity stages in % III	IV	V	VI	VI-II	No. of fish
III	55.5	19.5	22.2	–	2.8	72
VI	58.0	37.7	4.3	–	–	69
IX	42.9	30.4	7.1	–	19.6	56

St. Pierre and Green Banks (ICNAF Subdivision 3Ps)

No American plaice eggs were taken in this area during March and April, but in May they were widely distributed from near the Newfoundland south coast to the southern slope of the Shelf over depths of 50-500 m (Fig. 3). The greatest concentrations of eggs were found on Burgeo Bank, the northwestern and southern parts of St. Pierre Bank, and the southern part of Green Bank over depths of 50-200 m. Also, large numbers were found over the Laurentian Channel. In June small quantities were taken at stations on the southern part of St. Pierre Bank over depths of 50-500 m, but a few occurred south of the Bank over oceanic depths of 2,000-3,000 m (Fig. 4).

While all four developmental stages were represented in the samples taken during the first part of May, most eggs were in the early stages (I-II), but later in May stages III and IV were predominant (Fig. 7).

The greatest numbers of larvae, 3-8 mm in length, were caught in the St. Pierre Bank area during the last half of May and June (Figs. 3 and 4). However, a few larvae, 7-12 mm in length, were taken at the end of August over the northwestern part of the Bank (Fig. 6).

From the available maturity data for adults, ripe running fish (stage V) were observed in June, but pre-spawning fish (stage IV) can be found during practically the whole year (Table 4).

TABLE 4. Maturity stages of American plaice gonads, Saint Pierre area, 1960-70.

Month	Maturity stages in % III	IV	V	VI	V-II	No. of fish
II	43.5	26.4	3.7	–	26.4	53
V	68.0	16.0	–	–	16.0	25
VI	26.2	8.9	20.2	7.3	37.4	326
IX	50.8	39.2	9.2	–	0.8	1,566
X	39.3	21.4	39.2	–	–	178
XII	47.5	49.5	1.0	–	2.0	97

Information available on the distribution of eggs and larvae suggests that spawning takes place in the St. Pierre Bank area during May and June with the peak spawning in May. The main spawning areas seem to be on and around Burgeo Bank, just off the south coast of Newfoundland, on the northwestern part of St. Pierre Bank, and along the southern slopes of St. Pierre and Green Banks, mainly at depths of 50-250 m. It is doubtful that spawning occurs in the deep water of the Laurentian Channel; the eggs found here probably drifted from the Gulf of St. Lawrence or from the banks on either side of the Channel. Eggs found over the southern part of St. Pierre Bank could have drifted southeastward to the Green Bank area and to the southwest slope of the Grand Bank.

Nova Scotian Shelf (ICNAF Divisions 4V, 4W, 4X)

From the limited coverage in April a single plaice egg was taken on the southern slope of Banquereau Bank (Fig. 2). In May, however, good concentrations of eggs were found on the northern part of the Scotian Shelf just east of Cape Breton and on Scatari and Misaine Banks over depths of 50-200 m, while smaller quantities were taken on Banquereau Bank, along the Laurentian Channel over depths of 50-200 m (Fig. 3). Also, a few eggs were taken along the continental slope off Banquereau, Browns, and Georges Banks over oceanic depths of 2,000-3,000 m (Fig. 3).

During the second 10-day period of May, eggs in early stages of development (stages I-II) were dominant in the Banquereau Bank area (Div. 4V), whereas in late May the proportions of eggs in early and later stages were quite similar (Fig. 7). In the Emerald Bank area (Div. 4W), however, eggs in late stages of development predominated, with the proportion of stage IV eggs especially high.

Larvae, ranging from 4 to 13 mm in length, were observed on Banquereau Bank in May (average size 6.0 mm) and in August (average size 7.8 mm) (Figs. 3 and 6). Individual larvae taken in the vicinity of Emerald and Browns Banks were 4-8 mm in length.

Analysis of the distribution of eggs and larvae suggests that the most intensive spawning occurs in May on the northern part of the Scotian Shelf, just east of Cape Breton and on the northern part of Banquereau Bank, at depths of 50-200 m. Less intensive spawning apparently takes place in the Emerald and Browns Bank areas at about the same time. However, these conclusions should be considered preliminary, because of the absence of data on the distribution of spawning fish.

Discussion and Conclusions

Frost (1938) and Huntsman (1918) reported that American plaice spawning takes place in July on the Grand Bank and even later off the Labrador coast. However, Pitt (1966) reported that the peak spawning period was in early April for the Flemish Cap stock and ranged from the end of April for the stocks on the Grand Bank and adjacent areas to early June for the Labrador-Northeast Newfoundland Shelf populations. As far as it is possible to judge from the present data on the distribution of eggs and spawning fish, American plaice spawn on most areas of the continental shelf from Labrador to the Gulf of Maine (Fig. 8). The most intensive spawning areas are on the northern part of the Grand Bank, off southern Newfoundland from Burgeo Bank southeastward over St. Pierre and Green Banks, and on the northern part of the Scotian Shelf from off Cape Breton southeastward to Banquereau. Spawning takes place in these areas mainly in April, May, and June. In other areas of the Northwest Atlantic (Table 5) as well as in the Northeast Atlantic (Milinsky, 1944), spawning occurs during approximately the same period, with an extension of the spawning period into July in the north (Labrador and West Greenland). On Flemish Cap, however, eggs were taken earlier than in any other area and also later than in most (March-July). The American plaice, therefore, can be classed as a spring-spawning fish.

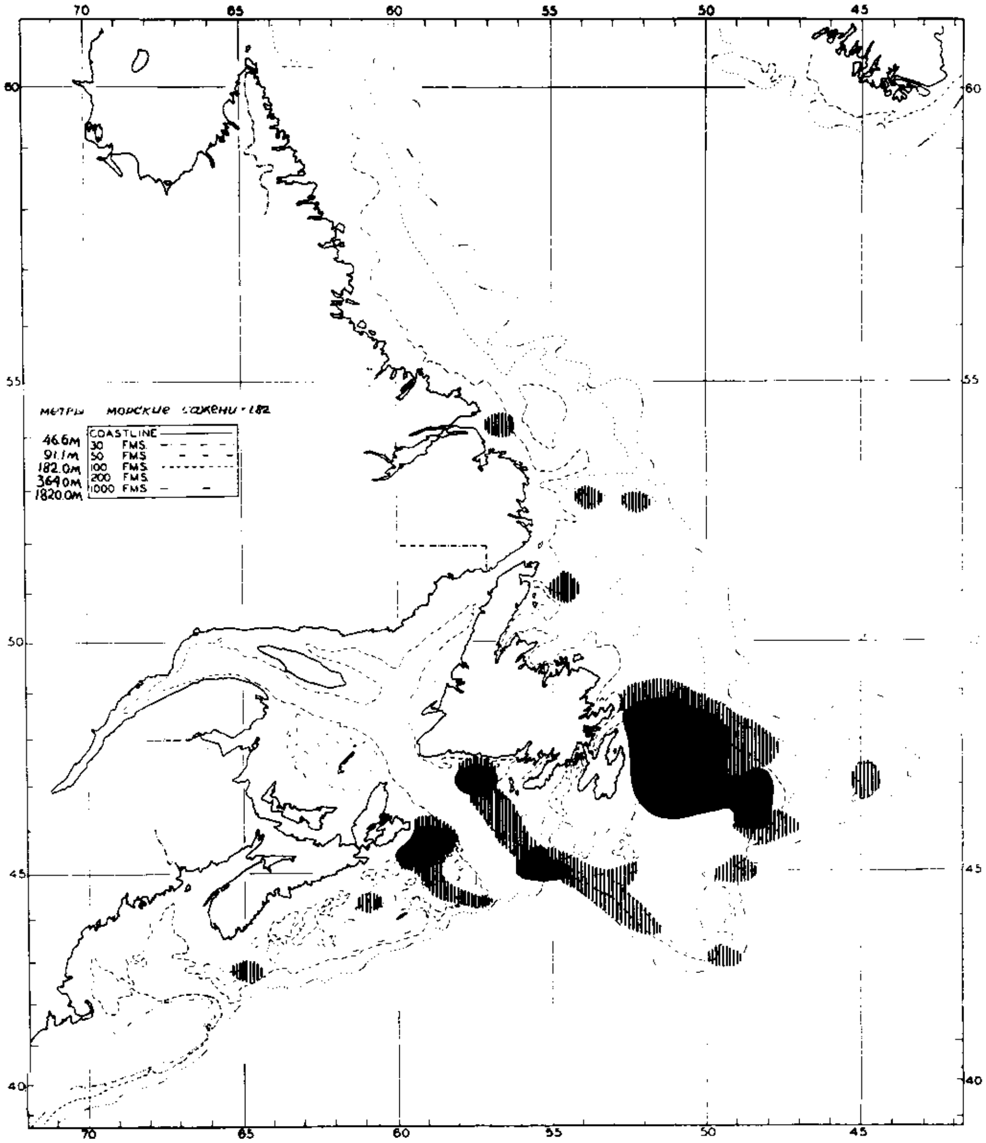

Fig. 8. Distribution of the American plaice spawning grounds. (■ – intensive spawning; ▥ – not intensive spawning.)

TABLE 5. Spawning period of American plaice in the Northwest Atlantic, ::::: – less intensive spawning; ////// – intensive spawning.

Areas and authors	Months							
	II	III	IV	V	VI	VII	VIII	IX
West Greenland (Jensen, 1925)				//////	//////	//////		
Labrador (Frost, 1938; Pitt, 1966; authors' data)				//////	//////	//////	:::::	
Newfoundland (Huntsman, 1918; Frost, 1938; Pitt, 1966; authors' data)			//////	//////	//////	:::::	:::::	
St. Lawrence Gulf (Huntsman, 1918; Frost, 1938; Powles, 1965)			//////	//////	//////	:::::		
Northern part of Grand Bank (Pitt, 1966; authors' data)		:::::	::::: //////	//////	:::::	:::::	:::::	
Southern part of Grand Bank (Frost, 1938; Bigelow & Schroeder, 1953; Pitt, 1966; authors' data)		:::::	::::: //////	//////	//////	:::::	:::::	
Flemish Cap Bank (Pitt, 1966; authors' data)		//////	//////	//////	//////	//////		
Saint Pierre & Green Banks (Pitt, 1966; L'Herrou & Minet, 1971; authors' data)		:::::	//////	//////				
Nova Scotia (Frost, 1938; L'Herrou & Minet, 1971; authors' data)		:::::	//////	//////	//////			
Bay of Fundy (Huntsman, 1918; Bigelow & Schroeder, 1953)			//////	//////	:::::			
Gulf of Maine (Bigelow & Schroeder, 1953)		:::::	//////	//////	:::::	:::::		

Hydrological data collected by the survey vessels indicate that water temperatures in the spring ranged from 0° to 6°C in the near-bottom water layers and from 6° to 18°C in the surface layers. The most intensive spawning was observed at near-bottom temperatures in the order of 0° to 2.5°C in the more northerly spawning areas and 0.4° to 6.0°C in the southern areas, and at surface temperatures in the range of 10° to 18°C. The range of near-bottom termperatures given above nearly encompass those given by Pitt (1966), who reported that average bottom temperatures during spawning ranged from 3.5°C for Flemish Cap to −1.3°C for the northern part of the Grand Bank, with intermediate values for the eastern and southwest slopes of the Grand Bank and for St. Pierre Bank.

The spawning areas on the continental shelf seem to be located at depths of 50-250 m in areas of eddying and turbulence caused by the cold Labrador Current in the Grand Bank area and by the cold waters flowing out of the Gulf of St. Lawrence in the northern Scotian Shelf area. Plaice larvae in different stages of development (3-22 mm in length) were generally observed in the same habitats as eggs, i.e., over or near the spawning areas. Thus, the low current velocities in the Grand Bank spawning areas and the occurrence of both eggs and larvae near these areas suggest that plaice in the early stages of development do not drift far from the spawning grounds. However, this conclusion cannot be drawn for the Nova Scotian area where current velocities are higher and could carry the early stages of plaice considerable distances off the shelf areas.

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Meristic Characteristics of Atlantic Herring, *Clupea harengus harengus* L., Stocks in Newfoundland and Adjacent Waters

By L. S. Parsons[1]

Abstract

Numbers of vertebrae, gill rakers, pectoral, anal, and dorsal fin rays were examined for approximately 5,100 herring, ranging from Gabarus Bay, Nova Scotia to the Strait of Belle Isle including most coastal areas of Newfoundland. Sexual dimorphism in meristic numbers was negligible. Mean numbers of gill rakers and of pectoral and anal fin rays were generally higher for autumn-spawning than for spring-spawning herring. Gill-raker number apparently increases with fish size in juvenile herring but not in adults. Correlation of the other meristic characters with fish length was negligible. Mean numbers of vertebrae and anal fin rays differ significantly between year-classes from the same locality in some instances. Geographic trends in the mean numbers of gill rakers and anal fin rays of spring spawners indicated a negative correlation between meristic number and water temperature during early development.

Dorsal fin-ray averages are unsatisfactory for stock differentiation, but mean numbers of pectoral and anal fin rays, gill rakers, and vertebrae appear useful to varying degrees for this purpose. Meristic comparisons suggest that the total herring stock in the Newfoundland area consists of a number of essentially discrete units or local stocks which intermingle to a limited extent, if at all. Stock relationships incidated by the combined results of the four meristic characters utilized agree in most instances with those derived by other methods.

Introduction

The fishery for Atlantic herring in Newfoundland waters increased spectacularly during the past decade. With the advent of a purse seine fishery, seasonal catches in the coastal waters of Southwest Newfoundland (Cape Ray to Hermitage Bay) increased rapidly from less than 10,000 metric tons in 1965 to about 130,000 metric tons in 1969 (Hodder, 1971). Although over the years the bulk of the herring has been caught in the coastal waters of southern and western Newfoundland, herring appear seasonally in practically all bays and inlets around the Newfoundland coast and are fished to a limited extent in all areas.

The tremendous increase in fishing pressure on herring stocks frequenting the coastal waters of Newfoundland and adjacent areas, coupled with the possibility that the same stock or group of stocks was being fished at different times and places, emphasized the importance of identifying and delimiting the unit stocks of herring which occur in the Newfoundland area. In January 1969 a study of the meristic characteristics of herring inhabiting Newfoundland and adjacent waters was undertaken to determine whether there are sufficient morphological differences between herring from the various areas to delineate separate stocks. This paper presents the results of that investigation, the primary objective being to determine whether the total herring stock in the Newfoundland area is a single, widely distributed population, the members of which intermingle freely and undertake extensive migrations along the coast, or whether it consists of a number of essentially discrete units or local stocks which intermingle to a limited extent, if at all.

Materials and Methods

Herring populations ranging from Gabarus Bay, Nova Scotia, in the south to the Strait of Belle Isle in the north including most coastal areas of Newfoundland (Fig. 1) were sampled from January 1969 to July 1970; altogether approximately 5,100 specimens were examined. Herring samples, usually of 50 specimens but sometimes in multiples of 50, were collected from catches of purse seines, midwater trawls, gillnets, and codtraps. Samples taken by purse seine are directly comparable with each other and may be regarded as representative of the schools from which they were obtained since the amount of selection by the gear is negligible. However, samples obtained from gillnets and

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codtraps cannot be regarded as completely representative of the size and age composition of the schools because of the selective action of these gears (Hodgson, 1933; Tester, 1935; Olsen, 1959).

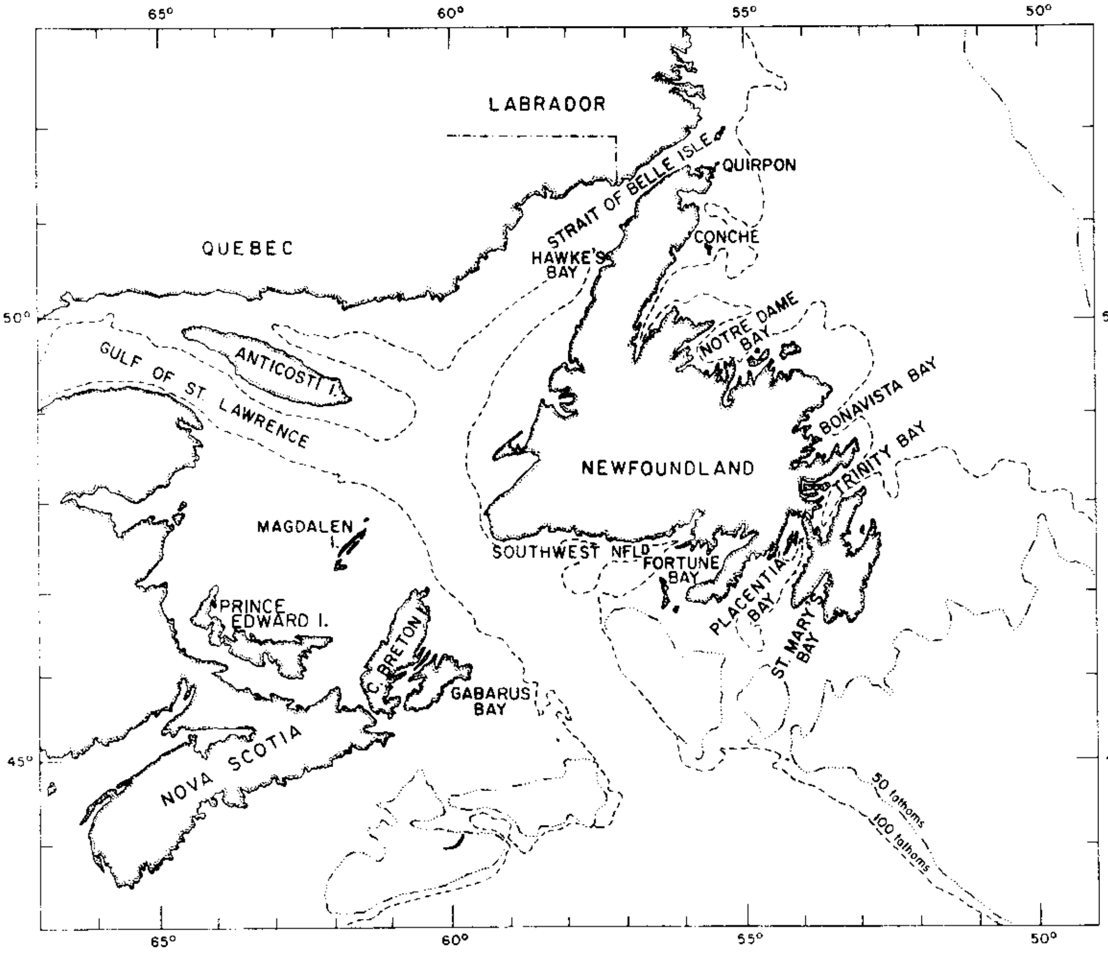

Fig. 1. Area map showing the localities and place names mentioned in the text.

The length, sex, stage of maturity (according to the 1964 ICNAF maturity scale for herring) and weight of the fish were recorded and otoliths taken for subsequent age determination. The length used is the greatest total length measured from the tip of the lower jaw to the end of the longest lobe of the caudal fin with the lobe extending posteriorly in line with the body.

Individual adult fish were assigned to spawning season on the basis of gonad development in relation to time of capture. Spring- and autumn-spawning herring differ markedly in the timing of the cycle of gonad development. Although the stage of maturity may not be a reliable indicator of spawning season in all cases, generally the distinction between the major spring- and autumn-spawning groups is clearcut; very few borderline cases were observed during the course of the present investigation.

In most areas (excluding Fortune Bay and Gabarus Bay) only small proportions of immature herring were present in the samples (Table 1). In those areas where virtually all adults belonged to one spawning group (e.g. Fortune Bay and Gabarus Bay) most of the immature herring were also assigned to the predominant spawning group since an examination of the otolith structure of these herring revealed that spring spawners could generally be separated from autumn spawners on the basis of the relative sizes of the first and second growth zones on the otolith (L. S. Parsons, unpublished data). However, no attempt was made to classify the few immature herring in areas where substantial proportions of both spring and autumn spawners were represented among the adults and these have been excluded from the data analyses which follow.

TABLE 1. Frequency and percentage of autumn and spring spawners in the various areas.

	Frequency			Percentage		
Areas	Autumn spawners	Spring spawners	Immatures[a]	Autumn spawners	Spring spawners	Immatures[a]
Gabarus Bay, N.S.	335	14	1	95.7	4.0	0.3
Magdalen Islands	368	112	20	73.6	22.4	4.0
Southwestern Nfld.	359	137	4	71.8	27.4	0.8
Fortune Bay	370	27	...	93.2	6.8	–
Placentia Bay	177	297	1	37.3	62.5	0.2
St. Mary's Bay	124	439	–	22.0	78.0	–
Trinity Bay	111	333	–	25.0	75.0	–
Bonavista Bay	92	306	6	22.8	75.7	1.5
Notre Dame Bay	20	528	–	3.6	96.4	–
Conche	80	78	16	46.0	44.8	9.2
Quirpon	135	81	4	61.4	36.8	1.8
Strait of Belle Isle	188	12	–	94.0	6.0	–
Hawke's Bay	159	238	49	35.7	53.4	10.9

[a]Includes only those immature herring which have not been assigned to either spawning group.

The proportions of spring spawners in Gabarus Bay and Strait of Belle Isle samples and autumn spawners in Fortune Bay and Notre Dame Bay samples were relatively insignificant (less than 7%). Hence, for the purpose of this study Gabarus Bay and Strait of Belle Isle herring are considered to be autumn spawners and Fortune Bay and Notre Dame Bay herring are considered to be spring spawners.

The age of each specimen was recorded as the number of completed summer (opaque) growth zones on the otolith. January 1 was selected as the arbitrary birth date; a fish is considered to be age I on January 1 following completion of the first summer's growth. Autumn-spawned herring would thus be several months older than spring-spawned herring of the same assigned age. Specimens of age X and greater were grouped into a X+ category.

Messieh (1969) and Hourston and Parsons (MS 1969) have questioned the validity of using otolith nucleus type as indicative of time of hatching for Northwest Atlantic herring. Because of the difficulty of determining time of hatching, in this study specimens were assigned to year-classes on the basis of spawning time. It is assumed that the vast majority of spring-spawning herring were hatched in the spring and autumn-spawning herring in the autumn (Parsons and Hodder, 1971*a*; Parsons, 1972). An autumn-spawning herring of a certain age was assigned to the year-class immediately preceding that of a spring-spawning herring of the same assigned age.

Five meristic characters were examined in this study – the numbers of vertebrae, gill rakers on the first lower left gill arch and of pectoral, anal and dorsal fin rays. The gill rakers on the lower branch (hypobranchial and ceratobranchial) of the first left gill arch and the anal and left pectoral fin rays were counted with a binocular microscope. Vertebral counts, excluding the hypural plate, and dorsal fin-ray counts were determined from radiographs. All pectoral fin rays and all rakers on the lower limb of the first left gill arch, including rudimentary rakers and the raker in the bend of the arch, were counted. In the dorsal and anal fins all rays including rudimentary rays were counted; the last split rays originating from the same base were counted as one.

For each type of statistical test employed a significance level of 0.01 was used except where otherwise stated.

Results

Variation among samples

Frequencies of vertebrae, gill rakers, and pectoral, anal, and dorsal fin rays for samples from the same general areas were compared for spring and autumn spawners separately by analysis of variance adjusted for unequal sample sizes (Freund, Livermore, and Miller, 1962). No significant between-sample differences within areas were found for vertebrae, gill rakers, and pectoral and anal fin rays. Therefore, samples were combined for subsequent analyses involving these characters. There were, however, significant between-sample differences in dorsal fin-ray averages within several areas for both spring and autumn spawners.

Dorsal fin-ray counts, particularly of smaller fish, tend to be unreliable because of difficulties in distinguishing the first rudimentary ray. A small rather rounded bone was frequently present anterior to the first obvious rudimentary ray as found in *Oncorhynchus nerka* by Fukuhara *et al.* (1962) and in *Salmo salar* by Templeman (1967). If this bone was round and not elongated as in other rudimentary rays, it was not counted. However, checks by the author revealed differences between individuals in applying these criteria and even the same individuals experienced difficulty in distinguishing the first rudimentary ray consistently. Since these inconsistencies were an obvious source of variation in dorsal fin-ray averages, this character was discarded.

Variation with length

To evaluate possible bias in meristic averages resulting from the different selective properties of the various gears employed in the collection of samples,

TABLE 2. Correlation coefficients of each meristic character with length. Numbers of fish are in parentheses. (** indicates significance at the 1% level.)

Areas	Vertebrae	Gill rakers	Pectoral fin rays	Anal fin rays	Dorsal fin rays
		Spring spawners			
Magdalen Islands	−0.128 (112)	0.221 (110)	0.065 (112)	0.260** (110)	0.102 (107)
Southwestern Nfld.	0.138 (137)	0.156 (136)	0.016 (137)	0.017 (132)	−0.053 (127)
Fortune Bay	0.053 (397)	0.485** (392)	0.210** (394)	0.087 (395)	0.159** (363)
Placentia Bay	0.140 (296)	0.256** (283)	0.220** (294)	0.191** (255)	0.137 (289)
St. Mary's Bay	0.228** (417)	−0.034 (415)	0.271** (413)	−0.137 (392)	−0.022 (385)
Trinity Bay	0.261** (333)	−0.059 (320)	0.128 (331)	−0.065 (332)	−0.055 (319)
Bonavista Bay	0.193** (304)	0.041 (301)	0.111 (303)	−0.050 (302)	0.021 (296)
Notre Dame Bay	0.378** (548)	−0.008 (525)	−0.038 (544)	0.003 (541)	0.039 (517)
Conche	0.065 (77)	0.080 (75)	0.177 (74)	−0.027 (75)	0.065 (74)
Quirpon	−0.073 (80)	0.054 (80)	0.127 (79)	0.140 (75)	0.005 (77)
Hawke's Bay	0.039 (238)	0.106 (236)	0.039 (237)	0.061 (238)	0.020 (211)
ρ	0.119	0.167	0.123	0.039	0.061
ρ^2	0.014	0.028	0.015	0.002	0.004
		Autumn spawners			
Gabarus Bay, N.S.	0.115 (350)	0.132 (338)	0.106 (350)	0.125 (349)	0.106 (316)
Magdalen Islands	−0.013 (368)	−0.002 (364)	0.116 (366)	0.041 (367)	0.012 (352)
Southwestern Nfld.	−0.046 (359)	0.078 (349)	0.047 (359)	−0.073 (353)	0.130 (340)
Placentia Bay	0.023 (177)	0.089 (165)	0.158 (177)	−0.150 (144)	0.129 (174)
St. Mary's Bay	0.126 (124)	0.024 (121)	−0.067 (120)	0.031 (100)	0.059 (123)
Trinity Bay	0.138 (110)	0.024 (109)	0.052 (111)	−0.069 (111)	0.146 (105)
Bonavista Bay	−0.070 (91)	−0.050 (86)	0.074 (90)	0.009 (89)	−0.007 (86)
Conche	0.151 (75)	−0.023 (75)	0.380** (80)	0.105 (80)	0.432** (67)
Quirpon	0.024 (135)	−0.002 (134)	0.240** (134)	−0.090 (129)	0.209 (124)
Strait of Belle Isle	0.037 (200)	0.168 (197)	0.212** (200)	0.126 (199)	0.135 (184)
Hawke's Bay	0.115 (159)	0.123 (157)	0.240** (159)	0.180 (156)	−0.089 (150)
ρ	0.059	0.075	0.129	0.048	0.093
ρ^2	0.003	0.006	0.017	0.002	0.009

ρ is an estimated population correlation coefficient (null hypothesis: $\rho = 0$).

correlation coefficients relating meristic number to total length were calculated for spring and autumn spawners separately within each area and the t-distribution was used to test the null hypothesis that there was no correlation between the two variables ($r = 0$).

Both positive and negative correlations were obtained (Table 2). The correlation coefficients differed significantly from zero in only 4 of 22 possible instances for vertebrae, 2 instances for gill rakers, 7 instances for pectoral fin rays, and 2 instances for anal fin rays. The population correlation coefficients (ρ) were calculated for spring and autumn spawners for each meristic character (Table 2). According to Fukuhara *et al.* (1962) the expression $100\,\rho^2$ is an approximate measure of the variability in the observations for a particular character due to corresponding variability in length. For vertebral number this variability is 1.4% for spring spawners and only 0.3% for autumn spawners, for gill-raker number 2.8% for spring spawners and 0.6% for autumn spawners, for pectoral fin-ray number 1.5% for spring spawners and 1.7% for autumn spawners and for anal fin-ray number only 0.2% for both spring and autumn spawners. It is evident from this that the correlation between fish length and numbers of vertebrae, pectoral and anal fin rays respectively is negligible.

Scatter plots of gill-raker number against fish length indicated that gill-raker number increases with fish size in juvenile herring but there is no significant relationship between gill-raker number and fish length in adult herring. Therefore, all immature fish were excluded from the gill-raker frequencies for Fortune Bay and Placentia Bay spring spawners to eliminate any possible bias in area comparisons.

Variation between sexes and spawning groups

There were no significant sex differences for any of the meristic characters examined, so males and females were combined for subsequent comparisons.

In five of the nine areas where both spawning groups were present spring spawners had a slightly higher vertebral average than autumn spawners but in the other four areas the situation was reversed (Table 3). The difference between spring and autumn spawners was not significant (t-test) for any of the nine areas. Hence, it seemed reasonable to conclude that in general the difference between mean vertebral numbers of spring and autumn spawners from the same area is negligible and the two spawning groups were combined for area comparisons involving vertebral number.

TABLE 3. Vertebral numbers of autumn- and spring-spawning Atlantic herring from various Newfoundland and adjacent areas.

	Autumn (A)												Spring (S)												Difference
Areas	50	53	54	55	56	57	58	59	N	$\bar{x}_A$	SD	SE	52	53	54	55	56	57	58	59	N	$\bar{x}_S$	SD	SE	$\bar{x}_A - \bar{x}_S$
Gabarus Bay, N.S.		3	15	160	150	21	1		350	55.497	0.725	0.039													
Magdalen Islands			13	139	193	22	1		368	55.617	0.666	0.035			4	44	51	13			112	55.652	0.732	0.069	−0.035
Southwestern Nfld.			6	150	181	22			359	55.610	0.628	0.033	1		2	52	72	10			137	55.635	0.706	0.060	−0.025
Fortune Bay															5	101	233	54	4		397	55.877	0.683	0.034	
Placentia Bay	1		2	73	83	16	2		177	55.644	0.821	0.062			8	127	141	19	1	1	297	55.599	0.696	0.040	0.045
St. Mary's Bay			1	42	66	12	1		122	55.754	0.672	0.061		1	13	152	215	35	1		417	55.655	0.697	0.034	0.099
Trinity Bay			1	36	59	9	3	2	110	55.845	0.837	0.080		1	10	129	164	24	5		333	55.646	0.737	0.040	0.199
Bonavista Bay			3	32	48	8	1		92	55.696	0.722	0.075			11	129	144	21	1		306	55.582	0.688	0.039	0.114
Notre Dame Bay															12	219	256	59	2		548	55.672	0.709	0.030	
Conche			1	27	37	10			75	55.747	0.699	0.081				23	44	10			77	55.831	0.637	0.073	−0.084
Quirpon			1	42	82	10			135	55.748	0.595	0.051				29	44	7	1		81	55.753	0.662	0.074	−0.005
Strait of Belle Isle			5	81	100	12	2		200	55.625	0.683	0.048													
Hawke's Bay			2	57	92	7	1		159	55.673	0.611	0.048		2	5	77	122	28	4		238	55.761	0.783	0.051	−0.088

N = number of specimens; $\bar{x}$ = average vertebral number; SD = standard deviation; SE = standard error.

Autumn spawners had higher gill-raker and pectoral fin-ray averages than spring spawners in all nine areas where both spawning groups were represented (Tables 5 and 7). Gill-raker differences were significant (t-test) for all areas except Conche; pectoral fin-ray differences were significant in all instances. These highly significant differences in mean gill-raker and pectoral fin-ray numbers necessitated the separation of spring and autumn spawners in subsequent analyses involving gill rakers and pectoral fin rays.

Autumn spawners also had higher anal fin-ray averages than spring spawners in six of the nine areas (Table 9). For Magdalen Islands, Southwest Newfoundland and Placentia Bay herring these differences were significant. Although these differences were less than for gill-raker and pectoral fin-ray numbers, they were sufficient to warrant separation of spring- and autumn-spawning herring in area comparisons of anal fin-ray numbers.

Variation among year-classes

One-way analyses of variance adjusted for unequal sample sizes were performed to test year-class variation in meristic numbers within each area. Year-class comparisons based on very small numbers of fish in each category would be virtually meaningless. Therefore, a minimum number of specimens (25) equivalent to half the normal sample size (50) was arbitrarily chosen and only those year-classes which were represented in a particular area by at least 25 specimens were included in comparisons of year-class means within each area.

Vertebral number. Significant year-class heterogeneity was evident only in Notre Dame Bay where the 1961 year-class which had a mean number of 56.117 (60 specimens) differed significantly from the 1963 year-class which had a mean of 55.424 (328 specimens). Since no single year-class was adequately represented in all areas, area comparisons were performed with all year-classes pooled. For comparison with these results the 1963 year-class, which was best represented in all areas, was selected and area comparisons were also made based only on specimens belonging to this year-class.

Gill-raker number. There was evidence of significant year-class heterogenity among spring spawners from both Fortune and Placentia bays. The observed significance was due to the relatively low gill-raker means for juvenile herring of the 1966 year-class which was well represented in the samples from these areas. Although the year-class means for Gabarus Bay did not differ significantly when tested by analysis of variance, two-year-old fish of the 1967 year-class had a gill-raker average considerably lower than the averages for older fish belonging to the earlier year-classes. In all three instances the differences between year-classes were attributed to an increase in gill-raker number with fish size in juvenile herring and the lack of a significant relationship between gill-raker number and fish length in adult herring. Therefore, 2-year-old herring of the 1967

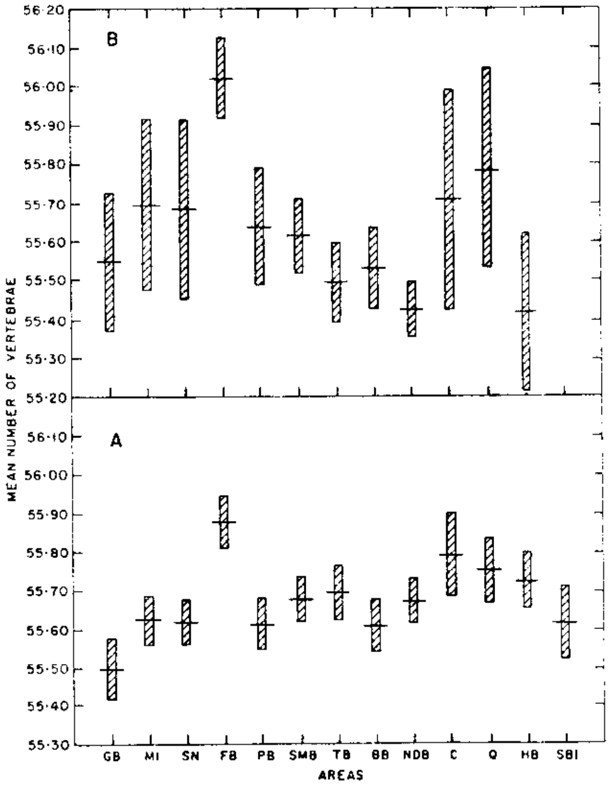

Fig. 2. Mean numbers of vertebrae by area (spring and autumn spawners combined) for the pooled year-classes **(A)** and the 1963 year-class only **(B)**. (In Figs. 2-6 horizontal lines indicate means; vertical bars indicate two standard errors on each side of the mean.)

TABLE 4. Results of the Duncan new multiple range test applied to the ranked mean numbers of vertebrae (spring and autumn spawners combined) of herring from various Newfoundland and adjacent areas. (Any two means not included in the same bracket are significantly different; any two means included in the same bracket are not significantly different.)

Pooled year-classes		1963 year-class	
Area	Mean	Area	Mean
Fortune Bay	55.877	Fortune Bay	56.020
Conche	55.789	Quirpon	55.786
Quirpon	55.750	Conche	55.708
Hawke's Bay	55.725	Magdalen Islands	55.694
Trinity Bay	55.695	Southwest Nfld.	55.684
St. Mary's Bay	55.677	Placentia Bay	55.639
Notre Dame Bay	55.672	St. Mary's Bay	55.614
Magdalen Islands	55.625	Gabarus Bay, N.S.	55.547
Southwest Nfld.	55.617	Bonavista Bay	55.531
Placentia Bay	55.616	Trinity Bay	55.495
Strait of Belle Isle	55.615	Notre Dame Bay	55.424
Bonavista Bay	55.608	Hawke's Bay	55.417
Gabarus Bay, N.S.	55.497		

year-class were excluded from the gill-raker frequencies for Gabarus Bay in addition to the exclusion of all immature fish from the gill-raker frequencies for Fortune Bay and Placentia Bay spring spawners. Since there was no evidence of year-class heterogeneity among adult herring, year-classes were pooled for area comparisons.

Pectoral fin-ray number. There was no evidence of significant year-class heterogenity in pectoral fin-ray averages among either spring or autumn spawners.

Anal fin-ray number. Analyses of variance revealed significant year-class heterogeneity only among Placentia Bay spring spawners. Despite this heterogeneity area comparisons were performed with all year-classes pooled because of the wide fluctuations in year-class strength in the various areas and the fact that no single year-class was adequately represented in all areas. Area comparisons were also performed for spring spawners based only on specimens belonging to the 1963 year-class.

Variation among areas

The combined data for each meristic character (spring and autumn spawners separate) were tested for differences among areas by analysis of variance. To test the individual differences ranked means of meristic numbers were compared using Duncan's new multiple range test (Steel and Torrie, 1960) modified for unequal sample sizes as proposed by Kramer (1956). In the tabular presentation of the results any two means included in the same bracket are similar but any two means not within the same bracket are significantly different.

Vertebral number. Vertebral means (for the pooled year-classes) ranged from 55.497 for Gabarus Bay, Nova Scotia, to 55.877 for Fortune Bay, Newfoundland (Fig. 2). No geographic trend was evident. An analysis of variance of the vertebral frequencies revealed significant heterogeneity among areas. Duncan's multiple range test indicated that Fortune Bay herring differ in mean vertebral number from herring in all other areas except Conche and Quirpon (Table 4). Gabarus Bay fish differ in mean vertebral number from Fortune Bay, Conche, Quirpon, Hawke's Bay, Trinity Bay, St. Mary's Bay, and Notre Dame Bay fish but are similar to all others.

Vertebral comparisons based only on the 1963 year-class also indicated that Fortune Bay fish differ from all others except Conche and Quirpon. Notre Dame Bay fish also appear to be different from Quirpon and St. Mary's Bay fish. Although herring of the 1963 year-class from Hawke's, Notre Dame, Bonavista and Trinity bays appear to have relatively low vertebral

TABLE 5. Gill-raker numbers of autumn- and spring-spawning Atlantic herring from various Newfoundland and adjacent areas. (** indicates significance at the 1% level.)

	Autumn (A)																	Spring (S)															Difference
Areas	43	44	45	46	47	48	49	50	51	52	53	54	55	N	$\bar{x}_A$	SD	SE	43	44	45	46	47	48	49	50	51	52	53	N	$\bar{x}_S$	SD	SE	$\bar{x}_A - \bar{x}_S$
Gabarus Bay, N.S.			3	9	12	39	73	71	44	28	6	5		290	49.655	1.676	0.098																
Magdalen Islands			3	22	36	77	93	74	33	21	2	3		364	48.997	1.634	0.086	1	4	10	24	30	24	13	2	2			110	47.036	1.490	0.142	1.961**
Southwestern Nfld.		1	2	11	42	66	77	84	40	18	6		2	349	49.166	1.656	0.087			12	20	28	39	25	10	2			136	47.610	1.436	0.123	1.556**
Fortune Bay																				5	9	17	26	8	16	2	4	3	100	48.370	1.798	0.180	
Placentia Bay		2	1	5	17	33	35	36	19	11	5	1		165	49.218	1.781	0.139			3	7	36	40	45	32	14	4	1	182	48.621	1.503	0.111	0.597**
St. Mary's Bay		1	1	3	9	15	32	28	20	6	3	1		119	49.437	1.676	0.154	1	1	12	28	57	106	107	65	27	10	1	415	48.494	1.577	0.077	0.943**
Trinity Bay				5	17	17	23	25	19	10	3			109	49.511	1.658	0.159			2	7	40	78	98	59	25	10	1	320	48.863	1.362	0.076	0.678**
Bonavista Bay		1		1	5	13	25	20	13	5	3			86	49.488	1.577	0.170			1	7	32	66	98	61	25	8	3	301	48.973	1.359	0.078	0.515**
Notre Dame Bay																				6	20	73	118	132	109	48	16	3	525	48.842	1.492	0.065	
Conche			2	2	6	15	16	19	8	7				75	49.200	1.644	0.190				2	11	17	22	14	7	2		75	48.853	1.363	0.157	0.347
Quirpon		1	3	5	10	23	26	24	20	19	2		1	134	49.448	1.933	0.167				2	10	23	20	11	9	4	1	80	48.950	1.509	0.169	0.498**
Strait of Belle Isle		1		3	19	40	46	34	29	18	6	1		197	49.421	1.699	0.121																
Hawke's Bay	1		2	7	14	27	41	34	17	11	3			157	49.146	1.716	0.137	2	3	8	23	42	53	48	37	15	4	1	236	48.229	1.740	0.113	0.917**

N = number of specimens; $\bar{x}$ = mean gill-raker number; SD = standard deviation; SE = standard error.

TABLE 6. Results of the Duncan new multiple range test applied to the ranked mean number of gill rakers of herring from various Newfoundland and adjacent areas (based on pooled year-classes).

Spring spawners		Autumn spawners	
Area	Mean	Area	Mean
Bonavista Bay	48.973	Gabarus Bay, N.S.	49.655
Quirpon	48.950	Trinity Bay	49.541
Trinity Bay	48.863	Bonavista Bay	49.488
Conche	48.853	Quirpon	49.448
Notre Dame Bay	48.842	St. Mary's Bay	49.437
Placentia Bay	48.621	Strait of Belle Isle	49.421
St. Mary's Bay	48.494	Placentia Bay	49.218
Fortune Bay	48.370	Conche	49.200
Hawke's Bay	48.229	Southwest Nfld.	49.166
Southwest Nfld.	47.610	Hawke's Bay	49.146
Magdalen Islands	47.036	Magdalen Islands	48.997

means whereas the means for Conche and Quirpon are relatively high, exceeded only by that for Fortune Bay, these differences are generally not statistically significant probably because of the very small numbers of specimens involved in some areas.

Gill-raker number. Gill-raker means among spring spawners ranged from 47.036 for Magdalen Islands to 48.973 for Bonavista Bay (Table 5; Fig. 3). Among autumn spawners the means ranged from 48.997 for Magdalen Islands to 49.655 for Gabarus Bay. Analyses of variance of the gill-raker frequencies showed significant heterogeneity among both spring and autumn spawners. Duncan's new multiple range test revealed that Magdalen Islands and southwestern Newfoundland spring-spawning herring differ in mean number of gill rakers from spring spawners in all other areas (Table 6). Spring spawners from eastern Newfoundland (Trinity Bay to Quirpon) and southeastern Newfoundland (St. Mary's, Placentia, and Fortune bays) plus Hawke's Bay (Northwest Newfoundland) form sets that are different from each other, fish from eastern Newfoundland having higher gill-raker averages than those from southeastern Newfoundland and Hawke's Bay which in turn have higher averages than Southwest Newfoundland and Magdalen Islands fish. The gill-raker mean for Southwest Newfoundland spring spawners is intermediate between those for Magdalen Islands and Hawke's Bay spring spawners and significantly different from both.

Among autumn spawners differences in mean numbers of gill rakers are much less evident. Autumn-spawning herring from Gabarus Bay which have the highest gill-raker average differ significantly from Magdalen Islands, Hawke's Bay, and Southwest Newfoundland autumn spawners which have the lowest gill-raker averages.

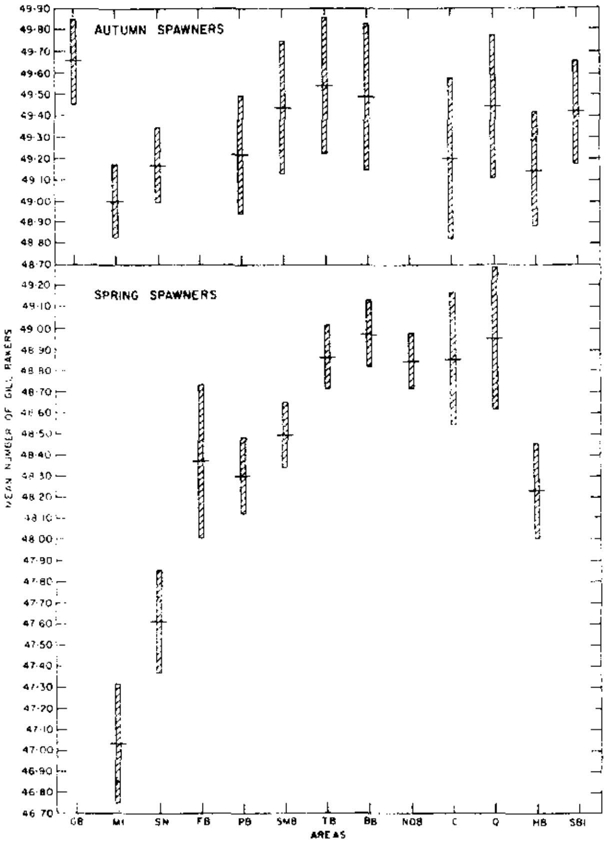

Fig. 3. Mean numbers of gill rakers by area and spawning group.

Pectoral fin-ray number. Mean numbers of pectoral fin rays among spring spawners ranged from 16.954 for Fortune Bay fish to 17.446 for St. Mary's Bay fish (Table 7; Fig. 4). Among autumn spawners the means ranged from 18.418 for Quirpon fish to 18.622 for Trinity Bay fish. No geographic trend in mean pectoral number was evident among either spawning group. There was significant area heterogeneity among spring spawners but not among autumn spawners. Comparisons of the ranked means of pectoral fin rays for spring spawners indicated that Fortune Bay fish differ from those in all other areas (Table 8). St. Mary's Bay spring spawners are similar in mean pectoral fin-ray number to spring spawners from Hawke's Bay, Quirpon, and Conche but differ significantly from those in all other areas. Notre Dame Bay spring spawners differ significantly from Conche, Quirpon, and Hawke's Bay spring spawners as well as those from St. Mary's and Fortune bays.

Anal fin-ray number. Mean numbers of anal fin rays among spring spawners (year-classes pooled) ranged from 17.598 for Southwest Newfoundland herring to 18.026 for Bonavista Bay herring (Table 9; Fig. 5). Among autumn spawners the means ranged from 17.929 for St. Mary's Bay fish to 18.300 for Magdalen Islands fish. Analyses of variance of anal fin-ray frequencies revealed significant heterogeneity among both spring and autumn spawners. Among spring spawners fish from eastern and northwestern Newfoundland (Trinity Bay to Quirpon plus Hawke's Bay) and fish from southern Newfoundland and the Magdalen Islands form two sets that appear to be different from each other (Table 10). Eastern Newfoundland and Hawke's Bay spring spawners have higher anal fin-ray averages than those from southern Newfoundland and the Magdalen Islands. Comparisons based only on the 1963 year-class show greater similarity than those based on the pooled year-classes. Fortune Bay herring of the 1963 year-class differ significantly from Bonavista Bay and Trinity Bay spring spawners of the same year-class (t-test).

Among autumn spawners Magdalen Islands fish differ significantly in mean number of anal fin rays from Gabarus Bay, Placentia Bay, St. Mary's Bay, Trinity Bay, and Bonavista Bay autumn spawners. Autumn-spawning herring from the other areas are not significantly different from each other.

Vertebral abnormalities

It is customary in meristic studies to exclude vertebral columns with fused vertebrae when computing means. In the present study such abnormal vertebral columns were noted so that the effect of their exclusion from the means could be studied. Of 5,092 herring 108 (2.12%) possessed fused vertebrae. The frequency of abnormalities per fish (number of fish in parentheses) was 1(82), 2(20), 3(5), and 6(1). When each partially developed fused centrum was counted as one complete vertebra, the vertebral means based on fish with normal plus those with abnormal vertebrae were not significantly different in any area from those means based only

TABLE 7. Pectoral fin-ray numbers of autumn- and spring-spawning Atlantic herring from various Newfoundland and adjacent areas. (** indicates significance at the 1% level.)

	Autumn (A)											Spring (S)												Difference
Areas	15	16	17	18	19	20	21	N	$\bar{x}_A$	SD	SE	13	15	16	17	18	19	20	21	N	$\bar{x}_S$	SD	SE	$\bar{x}_A - \bar{x}_S$
Gabarus Bay, N.S.		2	34	144	138	30	2	350	18.474	0.828	0.044													
Magdalen Islands		6	33	136	158	33		366	18.489	0.843	0.044		1	9	68	29	5			112	17.250	0.704	0.067	1.239**
Southwestern Nfld.		2	31	128	156	39	3	359	18.579	0.848	0.045			13	88	34	2			137	17.182	0.609	0.052	1.397**
Fortune Bay													3	103	216	56	13	3		394	16.954	0.796	0.040	
Placentia Bay		1	12	64	79	19	2	177	18.616	0.832	0.063			37	160	87	10	1		295	17.247	0.726	0.042	1.369**
St. Mary's Bay			7	46	48	16	1	118	18.559	0.822	0.076			26	201	164	20	2		413	17.446	0.707	0.035	1.113**
Trinity Bay		1	11	37	44	16	2	111	18.622	0.944	0.090	1	1	35	189	90	13	2		331	17.245	0.769	0.042	1.377**
Bonavista Bay		1	5	36	37	11	1	91	18.604	0.855	0.090		1	25	183	87	7	1	1	305	17.266	0.697	0.039	1.338**
Notre Dame Bay													2	79	319	124	18	1	1	544	17.154	0.737	0.032	
Conche		1	9	22	38	10		80	18.588	0.896	0.100			8	38	25	3			74	17.311	0.720	0.084	1.277**
Quirpon	1	1	17	52	49	13	1	134	18.418	0.936	0.081		1	11	36	22	9		1	80	17.388	0.987	0.110	1.030**
Strait of Belle Isle		2	13	78	87	19	1	200	18.555	0.813	0.057													
Hawke's Bay		1	16	56	62	23	1	159	18.585	0.902	0.072			18	118	93	7	1		237	17.388	0.690	0.045	1.197**

N = number of specimens; $\bar{x}$ = mean pectoral fin-ray number; SD = standard deviation; SE = standard error.

TABLE 8. Results of the Duncan new multiple range test applied to the ranked mean numbers of pectoral fin rays of spring-spawning herring from various Newfoundland and adjacent areas (based on pooled year-classes).

Spring spawners	
Area	Mean
St. Mary's Bay	17.446
Hawke's Bay	17.388
Quirpon	17.388
Conche	17.311
Bonavista Bay	17.266
Magdalen Islands	17.250
Placentia Bay	17.247
Trinity Bay	17.245
Southwest Nfld.	17.182
Notre Dame Bay	17.154
Fortune Bay	16.954

on fish with normal vertebrae. Hence, it appears that vertebral means are not significantly affected by inclusion or exclusion of the small number of vertebral columns with fused vertebrae.

Similar findings were reported by Ford and Bull (1926) for Northeast Atlantic herring and Templeman (1948, 1970) for capelin, *Mallotus villosus*, and Greenland halibut, *Reinhardtius hippoglossoides*. The percentages of fish with fused vertebrae in those studies are very similar to that found for Atlantic herring in the present study. Ford and Bull (1926) reported that 1.53% of their specimens had fused vertebrae. Templeman (1948, 1970) found 2.09 and 1.89% with fusions among capelin and Greenland halibut respectively. Pitt (1963) stated that an average of about 2% of American plaice, *Hippoglossoides platessoides*, had fused vertebrae. These percentages are much lower than that reported by McHugh (1942) for juvenile Pacific herring, *Clupea pallasii* (6.65%).

Discussion and Conclusions

In most Newfoundland areas and also in the southern Gulf of St. Lawrence two major spawning groups of herring occur, one spawning in spring and the other in late summer or autumn (Parsons, 1970; Parsons and Hodder, 1971*a*; Messieh and Tibbo, 1971). Spring-spawning herring are predominant in some areas and autumn spawners in others. These two spawning groups may be characterized as low- and high-temperature spawners respectively (Blaxter, 1958). Spring spawning generally occurs some time between late April and mid-June and late summer-autumn spawning in August-

TABLE 9. Anal fin-ray numbers of autumn- and spring-spawning Atlantic herring from various Newfoundland and adjacent areas. (** indicates significance at the 1% level.)

	Autumn (A)											Spring (S)											Difference
Areas	15	16	17	18	19	20	21	N	$\bar{x}_A$	SD	SE	15	16	17	18	19	20	21	N	$\bar{x}_S$	SD	SE	$\bar{x}_A - \bar{x}_S$
Gabarus Bay, N.S.		10	75	155	96	12	1	349	18.080	0.874	0.047												
Magdalen Islands	1	2	63	155	115	28	3	367	18.300	0.907	0.047		7	35	53	15			110	17.691	0.763	0.073	0.609**
Southwestern Nfld.	1	8	67	153	106	16	2	353	18.164	0.902	0.048		10	49	58	14	1		132	17.598	0.798	0.069	0.566**
Fortune Bay												2	26	114	176	70	7		395	17.777	0.893	0.045	
Placentia Bay	1	3	34	71	33	2		144	17.958	0.818	0.068	1	20	86	117	27	5		256	17.641	0.861	0.054	0.317**
St. Mary's Bay		5	27	40	22	4		98	17.929	0.933	0.094	1	22	117	190	65	7		402	17.783	0.849	0.042	0.146
Trinity Bay	1	4	31	43	28	4		111	17.946	0.952	0.090	1	12	75	155	80	8	1	332	17.991	0.874	0.048	−0.045
Bonavista Bay		5	19	44	20	2		90	17.944	0.866	0.091		6	73	149	60	15	1	304	18.026	0.863	0.050	−0.082
Notre Dame Bay												1	15	145	261	105	14		541	17.917	0.829	0.036	
Conche		2	16	38	21	1	2	80	18.113	0.914	0.102		4	23	28	16	3	1	75	17.920	1.021	0.117	0.193
Quirpon		5	28	55	34	6	1	129	18.085	0.944	0.109		4	21	30	14	6	1	76	18.000	1.058	0.122	0.085
Strait of Belle Isle		1	46	88	56	8		199	18.121	0.826	0.059												
Hawke's Bay		7	35	61	40	12	1	156	18.115	1.009	0.081	2	12	55	101	61	7		238	17.958	0.940	0.061	0.157

N = number of specimens; $\bar{x}$ = mean anal fin-ray number; SD – standard deviation; SE – standard error.

TABLE 10. Results of the Duncan new multiple range test applied to the ranked mean numbers of anal fin rays of herring from various Newfoundland and adjacent areas (based on pooled year-classes).

Spring spawners		Autumn spawners	
Area	Mean	Area	Mean
Bonavista Bay	18.026	Magdalen Islands	18.300
Quirpon	18.000	Southwest Nfld.	18.164
Trinity Bay	17.991	Strait of Belle Isle	18.121
Hawke's Bay	17.958	Hawke's Bay	18.115
Conche	17.920	Conche	18.113
Notre Dame Bay	17.917	Quirpon	18.085
St. Mary's Bay	17.783	Gabarus Bay, N.S.	18.080
Fortune Bay	17.777	Placentia Bay	17.958
Magdalen Islands	17.691	Trinity Bay	17.946
Placentia Bay	17.641	Bonavista Bay	17.944
Southwest Nfld.	17.598	St. Mary's Bay	17.929

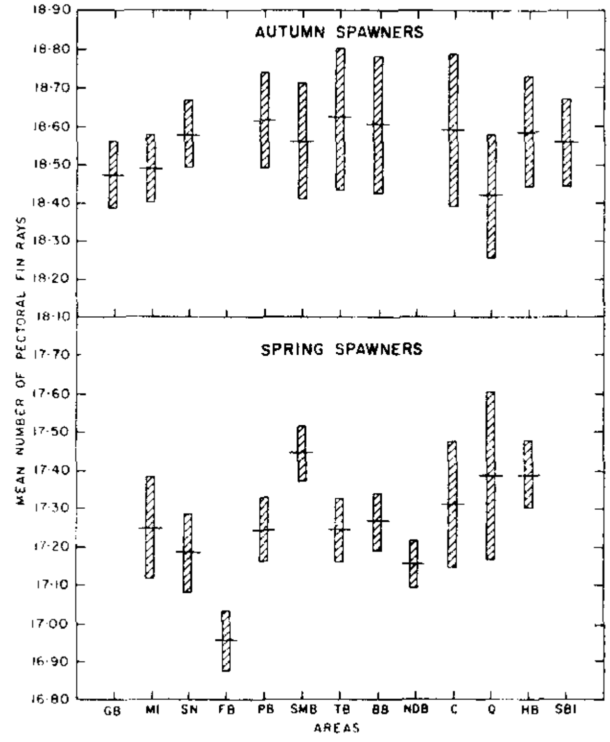

Fig. 4. Mean numbers of pectoral fin rays by area and spawning group.

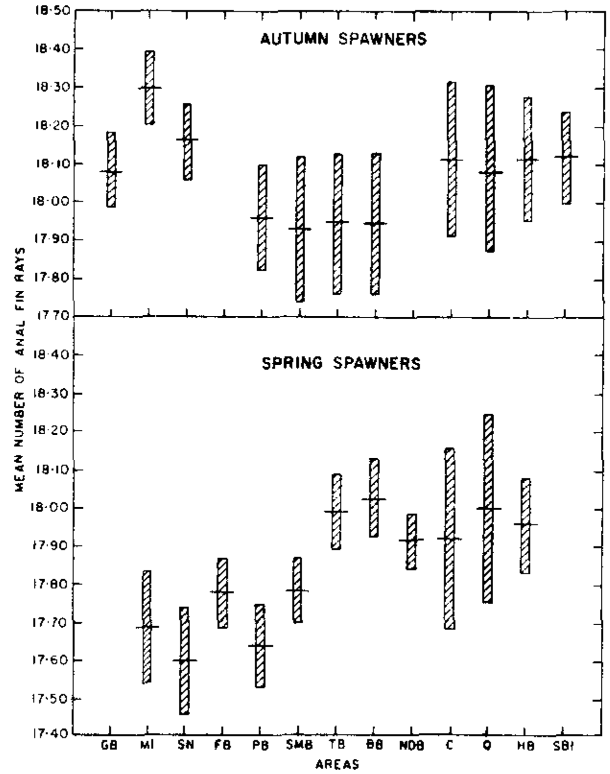

Fig. 5. Mean numbers of anal fin rays by area and spawning group (year-classes pooled).

September. Evidence from other sources (Jean, 1956; Tibbo and Legaré, 1960; Das, MS 1968) indicates that in the Northwest Atlantic mean water temperature on the spawning grounds is approximately 5°C lower in the spring than it is in the autumn. Temperatures during spring spawning generally range from 2° to 12°C and during late summer-autumn spawning from 8° to 16°C.

Parsons and Hodder (1971*a*) have shown that spring- and autumn-spawning herring which overwinter along Southwest Newfoundland exhibit distinct differences in mean numbers of fin rays and gill rakers, and Messieh and Tibbo (1971) have reported similar fin-ray differences between spring and autumn spawners in the southern Gulf of St. Lawrence. The present study provides evidence that such differences are widespread, for spring- and autumn-spawning herring in practically all areas around Newfoundland differ in these meristic characteristics. Although there is generally no significant difference between mean vertebral numbers of spring and autumn spawners, mean numbers of gill rakers and of pectoral and anal fin rays are generally higher ($P < 0.01$) for autumn-spawning than for spring-spawning herring, with gill-raker and pectoral fin-ray numbers exhibiting the greatest degree of difference between spawning groups.

Parsons and Hodder (1971*a*) have related differences in the mean numbers of fin rays of spring- and autumn-spawning Atlantic herring to water temperatures during early development and to differences in the developmental rates of spring- and autumn-hatched larvae. Parsons (1972) has shown that from 79 to 91% of individual spring and autumn spawners can be correctly classified to their respective spawning groups by the use of a linear discriminant function based on three meristic characters, from which it is concluded that the vast majority of autumn spawners are the progeny of herring which spawned in the autumn and spring spawners of herring which spawned in the spring.

In view of the highly significant meristic differences between spawning groups within areas, it is necessary to consider spring and autumn spawners separately for between-area comparisons of all meristic characters except vertebral number. Comparisons of herring stocks in various regions have often been based solely on one meristic character, i.e. vertebral number. However, since meristic characters are susceptible during the early life history of individual fish to local environmental fluctuations, which may produce recognizable variations in some meristic characters but not in others, no single character is likely to be adequate to delineate the interrelationships of several stocks. The fact that spring- and autumn-spawning herring differ significantly in mean numbers of pectoral and anal fin rays and gill rakers, despite similarities in mean vertebral numbers, demonstrates the necessity for considering several characters in attempts at stock differentiation. Statistical comparisons of mean numbers of pectoral and anal fin rays, gill rakers and vertebrae indicate that all four meristic characters are useful to a limited degree for determining the interrelationships of herring stocks in the Newfoundland area. Gill-raker and anal fin-ray numbers appear to be the most useful.

Combined results for all four meristic characters indicate that Southwest Newfoundland and Magdalen Islands spring-spawning herring differ from southeastern Newfoundland (Fortune, Placentia, and St. Mary's bays) spring spawners which in turn are different from eastern Newfoundland (Trinity Bay to Quirpon) spring spawners. Southwest Newfoundland spring spawners have a gill-raker average which is intermediate between that for Magdalen Islands and Hawke's Bay spring spawners, indicating a possible mixing of spring spawners from more than one area along Southwest Newfoundland. However, when all four characters are considered, it appears that Hawke's Bay spring spawners are relatively distinct from spring spawners to the south (Southwest Newfoundland and Magdalen Islands) and the northeast (Quirpon and Conche). The distinct vertebral and pectoral fin-ray averages of Fortune Bay herring indicate that these herring probably do not intermingle to any great extent with those in adjoining areas. From their pectoral fin-ray average St. Mary's Bay spring spawners also appear to be relatively distinct from those in adjoining areas. There are no apparent meristic differences among spring spawners from Trinity, Bonavista, and Notre Dame bays but Notre Dame Bay spring spawners differ significantly in mean number of pectoral fin rays from Conche, Quirpon, and Hawke's Bay spring spawners. Spring-spawning herring from Conche and Quirpon were similar in all meristic characteristics.

Fewer meristic differences are evident among autumn spawners than among spring spawners. Comparisons of mean vertebral numbers indicate that autumn spawners from Gabarus Bay in northeastern Nova Scotia, which have the lowest vertebral average (55.497), are different from Hawke's Bay, Quirpon, Conche, Notre Dame Bay, and Trinity Bay herring. Gabarus Bay autumn spawners have the highest gill-raker average among autumn spawners and are significantly different from Magdalen Islands, Southwest Newfoundland, and Hawke's Bay autumn spawners, which have the lowest gill-raker averages (in order of increasing magnitude). Magdalen Islands autumn spawners are also significantly different in mean numbers of anal fin rays from Gabarus Bay and southeastern Newfoundland (Placentia, St. Mary's, Trinity, and Bonavista bays) autumn spawners. These results suggest that autumn-spawning herring from northeastern Nova Scotia (Gabarus Bay) do not intermingle much with autumn spawners from Southwest Newfoundland and the southern and northern Gulf of St. Lawrence. Magdalen Islands autumn spawners are similar in meristic characteristics to autumn spawners from Southwest Newfoundland and Hawke's Bay but apparently intermix very little, if at all, with southeastern Newfoundland autumn spawners.

A negative correlation between mean vertebral number and water temperature has been shown previously for herring (Hubbs, 1925; Rounsefell and Dahlgren, 1932; Tester, 1938; Rünnstrom, 1941; Bückmann, 1950). Tibbo (1956), from investigations conducted in 1942-44, found that the mean number of vertebrae tended to decrease from south to north in the Newfoundland area, which is the reverse of what is usually found elsewhere. He concluded that this was due to a progressive increase in temperature at spawning from south to north, development of Notre Dame Bay herring taking place later in the season at higher temperatures and being reflected in a lower mean number of vertebrae. Apart from Fortune Bay and Gabarus Bay herring vertebral means were similar throughout the area studied in the present investigation, with no geographic trend evident. Tibbo (1956) characterized three distinct herring populations on the basis of vertebral means. Labrador and Notre Dame Bay herring had similar relatively low mean numbers of vertebrae (55.459 and 55.429 respectively). Vertebral means of combined samples from those two areas differed significantly from the means for Bay of Islands (55.564) and Fortune Bay (55.779) which in turn were significantly different from each other. The vertebral mean for Placentia Bay (55.685) was statistically similar to the means for Fortune Bay and Bay of Islands. Although the mean number of vertebrae of Notre Dame Bay herring increased significantly from 1942-44 (55.429) to 1969-70 (55.672), in both periods Fortune Bay herring had the highest mean vertebral numbers in the Newfoundland area (55.779 and 55.877 respectively). Tibbo (1957*a*) reported a relatively high mean vertebral number of 55.772 for Fortune Bay herring during the 1946-48 period. Hodder (1967) also found a high vertebral mean (55.82) for Fortune Bay herring during 1965-66. From vertebral data reported by Anthony and Boyar (1968) for Gulf of Maine and adjacent Nova Scotian areas, Tibbo (1957*b*) for the Atlantic coast of Nova Scotia, and Day (1957*a*, *b*, *c*) and Tibbo (1957*c*) for the northern and southern Gulf of St. Lawrence, it appears that the present mean vertebral number of Fortune Bay herring (55.877) is matched only by that for herring from Ile Verte in the Estuary of the Gulf of St. Lawrence (55.883) and hence is among the highest in the Northwest Atlantic.

Jean (1967) attributed the high vertebral average of Ile Verte herring to a negative correlation between vertebral number and water temperature, based on the premise that Ile Verte herring spawn and develop in very cold water. The consistently high vertebral averages of Fortune Bay herring may also be related to a relatively low temperature at spawning. Spring spawning in Fortune Bay usually occurs some time between mid-April and mid-May, mostly in early May, which is earlier than in most other Newfoundland areas (unpublished data, St. John's Biological Station). Hydrographic data indicate that in relatively shallow-water in Fortune Bay temperatures around the 20th of April generally range from 1.9°c at 10 m to 2.5°C at the surface. By the 20th of May bottom temperatures in 2-6 fathoms in the vicinity of the spawning grounds range from 2.5° to 3.8°C. Hence it seems likely that incubation temperatures could be as low as 2° to 4°C. It is possible that, as a result of the earlier spawning spring-spawned herring eggs in Fortune Bay develop and hatch at lower temperatures than in other Newfoundland areas where spawning is later (mid-May to mid-June) and temperatures at spawning may be higher. The available hydrographic data for most Newfoundland inshore areas are inadequate to permit valid comparisons of temperature at spawning in the various areas, but it is known that in 1970 bottom temperatures on the spawning grounds in St. Mary's Bay during and immediately after spawning in late May ranged from 4° to 10°C (G. H. Winters, personal communication).

Despite the lact of a geographic cline in vertebral means, the present results show geographic trends in the mean numbers of gill rakers and anal fin rays which appear to be correlated with water temperatures during early development. The period of fixation of gill-raker number in Atlantic herring is not known but is possibly related to complex ecological factors, in particular those connected with the optimum utilization of available food. It has been shown for several species that a correlation exists between gill-raker number and feeding habits (Reshetnikov, 1961; Martin and Sandercock, 1967). Although the precise time of fixation of the number of rays in the anal fin is also unknown, it probably occurs during the larval period since anal fin formation is completed at about 30 mm (Lebour, 1921).

A general negative correlation between the mean number of gill rakers and water temperature is readily apparent from the hydrography of the Newfoundland area. The frigid (< 0°C) portion of the Labrador Current of Arctic origin exerts the dominant hydrographic influence along the east coast of Newfoundland (Smith *et al.*, 1937; Hachey *et al.*, 1954; Templeman, 1966). To the north of the Grand Bank the Labrador Current divides, one branch passing through the Avalon Channel and along the coast southward toward Cape Race and the second flowing along the eastern slope of the Grand Bank. The volume of very cold water in the Labrador Current declines from north to south (May *et al.*, 1965) and is less prominent along southeastern than along eastern Newfoundland. Its influence upon coastal hydrography is relatively weak west of Fortune Bay. A relatively warm current flows northward along the west coast of Newfoundland. A portion of this current flows out along the south shore of the Strait of Belle Isle, whereas a cold branch of the Labrador Current enters the Strait along its north shore.

Spring-spawning herring from the generally cold waters of eastern Newfoundland have higher gill-raker averages than spring spawners from southeastern Newfoundland where water temperatures are somewhat intermediate. The lowest gill-raker averages occur along Southwest Newfoundland and in the vicinity of the Magdalen Islands, generally warm areas which are relatively unaffected by the cold waters of the Labrador Current. The mean number of anal fin rays is also higher for eastern Newfoundland spring spawners than for spring spawners from southern Newfoundland and the Magdalen Islands. Hawke's Bay spring spawners are somewhat anomalous in that they are similar in mean number of gill rakers to southeastern Newfoundland spring spawners but are similar to eastern Newfoundland spring spawners in the mean number of anal fin rays. Despite the geographic trend in gill-raker and anal fin-ray averages among spring spawners, no such trend is evident among autumn spawners. It is possible that temperature conditions on the spawning grounds and in the larval nursery areas are more uniform throughout the Newfoundland area during the autumn than during the spring or early summer.

The results of the present study utilizing meristic differences as indicators of stock heterogeneity compare favourably with other methods of stock differentiation. Stock relationships suggested by meristic comparisons agree in most instances with those indicated by the level of infestation of herring in various areas with the larval nematode *Anisakis* (Parsons and Hodder, 1971*b*). Comparisons of other biological characteristics of herring from southwestern Newfoundland, Magdalen Islands, Banquereau, Canso Bank and Chedabucto Bay (Hodder and Parsons, 1971, *a, b;* Parsons and Hodder, 1971*b*) and tagging results (Winters 1970; MS 1971) have shown that the winter fishery along southwestern Newfoundland is largely dependent on herring that are not indigenous to that area but rather are derived from spring and autumn spawnings in the southern Gulf of St. Lawrence. This Southwest Newfoundland-southern Gulf stock complex apparently does not intermix to any great extent with herring concentrations fished in winter by Canadian vessels in the Chedabucto Bay-Canso Bank area and by European vessels on Banquereau. The recapture of herring tagged at Hawke's Bay in December during the 1970-71 and 1971-72 winter fisheries along Southwest Newfoundland and from the southern Gulf of St. Lawrence fishery during the summer of 1971, combined with the lack of meristic differences among Magdalen Islands, Southwest Newfoundland and Hawke's Bay autumn spawners, indicates that the autumn-spawning component of the herring which support the Hawke's Bay autumn fishery includes herring which are en route from the southern Gulf to Southwest Newfoundland (Winters and Parsons, MS 1972).

Differences in pectoral fin-ray number between spring-spawning herring from Placentia and St. Mary's bays indicate that two discrete spring-spawning stocks frequent these bays. However, previous evidence, namely, the migration of "red" herring which had been exposed to phosphorus poisoning in Placentia Bay, into St. Mary's Bay in the spring of 1969 (Hodder, Parsons, and Pippy, 1972), suggests that herring in these two bays intermix during the overwintering and prespawning period.

The results reported here suggest that the total herring stock in the Newfoundland area consists of a number of essentially discrete units or local stocks which intermingle to a limited extent, if at all. Although meristic differences appear to be useful indicators of herring stock heterogeneity in Newfoundland and adjacent waters, the existence of significant morphological differences does not imply that no intermingling occurs between two areas but merely indicates that the samples were not derived from a single completely mixed stock. No one method is sufficient to completely delineate the degree of heterogeneity of fish stocks; conclusions regarding stock interrelationships should be based on a variety of techniques. Although morphological differences generally show stock heterogeneity within a broad area, only direct methods, i.e. tagging, will demonstrate actual intermixing between stocks. Recent tagging experiments by the St. John's Biological Station will probably reveal whether intermingling occurs between groups considered to be discrete on the basis of morphological characteristics.

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A Groundfish Survey of Faroe Bank

By B. W. Jones[1] and J. G. Pope[1]

Abstract

A groundfish trawl survey of Faroe Bank was made in June 1971. Faroe Bank is relatively small in area but the stocks of some of the important species are known to be self-contained. Two replicate surveys, each of 32 stations, were made, based on a stratified random sampling design. The sampling intensity of the combined surveys was one station per 25 square miles. Thirty-seven fish species were recorded and five of these were subjected to an analysis of variance of catch weight with depth strata, quadrant and time of day. Catch variation with depth was the most significant and no diurnal variation was observed. Age determinations were made for sub-samples of cod and haddock. No differences were found between age-length keys for different quadrants or depth strata and all age determinations were amalgamated before making length to age conversions. Coefficients of variation of numbers of cod at each age in the survey were compared with market samples of North Sea plaice. The accuracy of research ship surveys is discussed.

Introduction

With increasing interest in the possibility of using groundfish trawl surveys by research ships as a means of monitoring population changes in demersal fish stocks, the present survey was planned as a feasibility study. The objective was to assess the likely accuracy of such surveys, and the appropriate manpower requirements at sea and in the laboratory. The survey was done in June 1971.

Gears and Methods

The research vessel *Cirolana* was used. Her characteristics were: Length – 72.5 m O.A., 62.5 m B.P.; Beam – 14.0 m moulded; Tonnage – 2,323 tons displacement, 1,593 tons G.R.T.; Shaft horsepower – 2,200 (P_s = 1,641kW).

A Granton trawl was used with Headline – 23.8 m, with 60 × 0.15 m diameter floats; Groundrope – 36.6 m; Bosom – 6.1 m, with 7 × 0.53 m steel bobbins; Bunts – each 6.1 m, with 3 × 0.53 m and 4 × 0.46 m steel bobbins; Legs – 13.7 m, with 1 × 0.46 m steel bobbins; Dan Leno – 0.61 m ball; Bridles – 27.4 m; Doors – Fearnought type 3.35 × 1.53 m, 926 kg; Distance between wing ends – 15 m (estamated); Distance between doors – 34 m (estimated); Average speed of tow – 3.8 knots; Codend – 120 mm nominal mesh size, with blinder of 19 mm nominal mesh size.

Area of survey

The Faroe Bank was chosen as the area of survey. Its area is approximately 1,600 square nautical miles extending to the 370 m (200 fathom) isobath. Its small size made it possible to survey the complete area. The cod stock on Faroe Bank is known to be a self-contained unit (Jones 1966; Jamieson and Jones 1967), and it seems likely that the same can be said of the haddock. Faroe Bank is fished by English trawlers, and fishery statistics are recorded separately for this area.

Experimental design

Faroe Bank was divided into four quadrants (A-D) of approximately equal area (Fig. 1) and four depth strata (1-4) of (1) $<$110m, (2) 110-146 m, (3) 146-183 m, and (4) 183-366 m (corresponding depths in fathoms: 60, 80, 100, and 200). The whole bank was covered with a grid of potential stations spaced at 3 mile intervals. Sampling was arranged in the form of two complete replicate surveys, each of 32 stations. For each survey two stations were randomly preselected from each stratum in each quadrant, making eight stations per quadrant. The day was divided into four 6-hr. periods, 0000-0600, 0600-1200, 1200-1800, and 1800-2400 hrs. Each pair of stations was allocated to a specific time period in the form of a latin square, so that each depth and quadrant was sampled at each division of the day. Thus, on analysing the results of each survey, it was possible to consider the significance of the effects of

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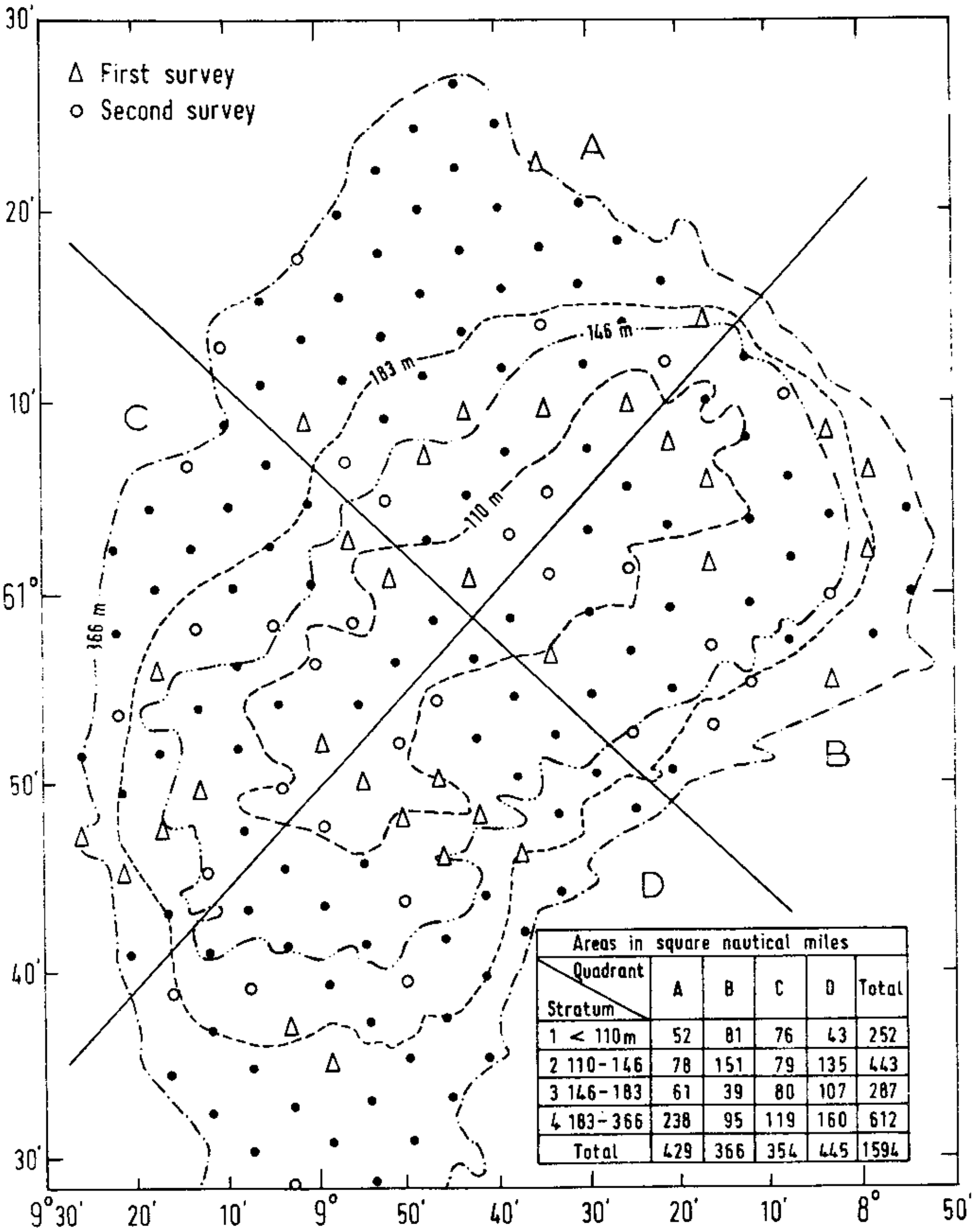

Areas in square nautical miles					
Stratum \ Quadrant	A	B	C	D	Total
1 < 110m	52	81	76	43	252
2 110-146	78	151	79	135	443
3 146-183	61	39	80	107	287
4 183-366	238	95	119	160	612
Total	429	366	354	445	1594

Fig. 1. Chart of Faroe Bank showing quadrants, depth strata, the grid of potential stations, and stations worked on the first and second surveys.

depth, quadrant and time on each species. The latin square used in the first survey was chosen at random from statistical tables; it is set out in Table 1. The latin square used for the second survey was derived from that of the first, by advancing all times by 1200 hrs. This allowed the two surveys to be combined to form one in which each depth stratum of each quadrant was sampled twice in the period 0600-1800 hrs. and twice in the period 1800-0600 hrs. This facilitated an investigation of the interactions between the various factors. Making two replicate surveys also enabled considerations of repeatability to be examined and allowed the estimation

TABLE 1. Latin squares of quadrants, strata, and times used in the two surveys

Survey 1

		Stratum (m)			
	Quadrant	<110	110-146	146-183	183-366
Station No.	A	15 16	11 10	12 13	24 17
Time period		06-12	18-24	00-06	12-18
Station No.	B	5 4	9 3	8 2	7 6
Time period		18-24	12-18	06-12	00-06
Station No.	C	21 14	22 23	33 25	19 18
Time period		00-06	06-12	12-18	18-24
Station No.	D	32 31	27 28	26 34	29 30
Time period		12-18	00-06	18-24	06-12

Survey 2

		Stratum (m)			
	Quadrant	<110	110-146	146-183	183-366
Station No.	A	54 56	60 59	62 53	57 58
Time period		18-24	06-12	12-18	00-06
Station No.	B	68 69	65 66	63 64	71 70
Time period		06-12	00-06	18-24	12-18
Station No.	C	45 52	46 47	48 49	50 51
Time period		12-18	18-24	00-06	06-12
Station No.	D	41 40	44 36	67 43	39 38
Time period		00-06	12-18	06-12	18-24

of crude values of the variance of numbers at age. The relative complexity of this survey design was made practicable by two factors:

1) the relative compactness of Faroe Bank, which enabled steams between almost any pair of stations to be made in the average interhaul time;

2) the ability of RV *Cirolana* and her fishing crew to work round the clock and to average around eight stations per day, which made sampling one quadrant at a time practicable. This method of working was statistically preferable in case the survey had to be curtailed due to bad weather or other causes.

Tows were of 1 hr. duration wherever possible.

Catch processing

The catch was sorted into species and the total catch of each species was basketed and weighed, using a hanging spring balance of 100 kg capacity or of lesser capacity if the quantity was small. Lengths of all fish of every species were measured unless the catch was sufficiently large for it to be sub-sampled. Otoliths were taken from cod, haddock and lemon sole. Otolith samples were stratified in 5 cm length groups and a maximum of 10 otoliths per length group were taken in each sample. Eight otolith samples – one from each quadrant (first survey) and one from each stratum (second survey) – were taken for each species. One otolith was taken from each fish and the otoliths were stored in tubes, one tube for each 5 cm group of each sample. Fish which were otolithed were individually weighed; the stomach contents were also weighed and the stage of digestion and main food organisms recorded.

Data recording

In the event of groundfish surveys becoming a regular commitment, it would be essential for the data to be computer analysed. It was considered that the development of special computer programs for analysis of this initial survey could not be justified. Nevertheless it was desirable that recording forms should be designed in a format that could be used directly as documents for computer punching and that these recording forms could be given field trials on the present survey. Two such forms were designed, one to record the catch data and the other to record length composition data. An existing form was available as a station log-sheet.

Hydrography

At the hauling position of each trawl station a bathythermograph lowering was made with a Nansen bottle for bottom temperature and salinity. Surface temperature was recorded continuously on the ship's thermograph.

Results

In general there were few problems due to the bottom being unsuitable for trawling. On a few stations it was necessary to move slightly from the predetermined position to avoid obvious hazards. Very little trawl damage was sustained although the trawl came fast on a few occasions. On some of these hauls the duration of tow was considered adequate to give a reasonable sample, otherwise the tow was repeated.

As far as was possible, the stations of each survey were completed quadrant by quadrant, and within each quadrant the sequence of stations was determined by the time periods in which the stations had to be worked. Because the stations were all relatively close, steaming time between stations was not an important factor and an average of eight hauls per day was maintained in good weather conditions.

Hydrography

Bottom temperatures were to some degree correlated with depth. Temperatures ranged from 9.18°C on the top of the bank to 7.76°C in the deeper water. There was evidence of a slight overall warming during the cruise. Hydrographic results have been described by Ellett (in press).

TABLE 2. Species recorded during the survey.

1	Cod	*Gadus morhua*
2	Haddock	*Melanogrammus aeglefinus*
3	Saithe	*Pollachius virens*
4	Blue Whiting	*Micromesistius poutassou*
5	Norway Pout	*Trisopterus esmarkii*
6	Poor Cod	*Trisopterus minutus*
7	Silvery Pout	*Gadiculus argenteus thori*
8	Common Ling	*Molva molva*
9	Blue Ling	*Molva dypterygia*
10	Tusk	*Brosme brosme*
11	Greater Fork-beard	*Phycis blennoides*
12	Catfish	*Anarichas lupus*
13	Spotted Catfish	*Anarichas minor*
14	Dab	*Limanda limanda*
15	Long Rough Dab	*Hippoglossoides platessoides*
16	Megrim	*Lepidorhombus whiffagonis*
17	Lemon Sole	*Microstomus kitt*
18	Plaice	*Pleuronectes platessa*
19	Halibut	*Hippoglossus hippoglossus*
20	Angler	*Lophius piscatorius*
21	Redfish	*Sebastes* sp.
22	Greater Silver Smelt	*Argentina silus*
23	Sandeel	*Ammodytidae*
24	Gurnard	*Triglidae*
25	Dragonet	*Callionymus lyra*
26		*Triglops* sp.
27		*Lycenchelys* sp.
28	Black-mouthed Dogfish	*Galeus melastomus*
29	Velvet Belly	*Etmopterus spinax*
30		*Centrophorus squamosus*
31	Skate	*Raja batis*
32	Shagreen Ray	*Raja fullonica*
33	Cuckoo Ray	*Raja naevus*
34	Thornback Ray	*Raja clavata*
35	Sandy Ray	*Raja circularis*
36	Rabbit-fish	*Chimaera monstrosa*
37	Lamprey	*Petromyzon marinus*
38	Squid	*Loligo* sp.

TABLE 3. Weight of catch (kg) of the main species at each station. Survey 1.

	Station																														
Species	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Cod	6	58	42	65	5	–	11	106	–	96	19	69	22	101	116	–	–	–	370	71	43	5	–	26	177	195	–	5	96	251	–	14
Haddock	6	31	13	41	5	–	7	97	35	30	22	32	17	239	46	+	+	–	104	24	25	–	10	67	186	286	10	7	17	24	10	14
Saithe	7	612	62	79	148	84	19	11	396	385	103	203	13	226	60	67	170	35	15	757	121	66	118	155	299	190	172	392	124	261	176	50
Blue Whiting	–	–	2	1	2	78	5	–	1	–	5	–	–	–		35	65	44		–		25	–	–	–	–	+	1	–	–	6	–
Norway Pout	13	5	–	1	–		–	1	10	5	+	12	+	2	1	–			1	17	2	–	1	+	2	–	11	+	+	+	8	1
Silvery Pout		–	–	–	2		+	–	9	–	6	–	–	–	–	5	2	+	–		–	41	–	–	–	4	–	5	–	–	–	–
Common Ling	16	+	+	12	45	84	64		–	17	53	7	–		8	18	4	7	–	14	–	13	–	–	–		4	12	–	–	48	–
Tusk	2	–		7	19	28	–	+	–		5		–		2	11	15	9	1	7	–		–		1		–	14	–	–	14	–
Megrim	–	–		–	–	–	–		+	2	–	2	–	–	–	+	–	–		–	+	1	–	+	+	6	+	+	–		–	1
Lemon Sole	1	1	+	1	+	–	+	3	2	1	1	4	4	+	2	+	+	–	5	+	1	–	–	1	1	1	+	+	2	3	–	+
Halibut	–		7	1	15	–	5	–	2	3	5	1	–	14	22	7		–	2	3	3	4	6	–	7	8	13	2	1	2	18	
Angler	–		–	–		–		–	15	–		–	–	–	–	–		–		–	16	30		–		3	–	–	+	–	–	
Redfish	11		14	3	7	2	14	4	+	10	26	9	2	4	46	8	2	8	8	12	1	4		–	+	–	+	10		1	13	–
Greater Silver Smelt	–		–		18	412	75	–	1	1	157	8	+	1		109	46	13	+		+	4		+		–	244	34		–	116	3
Rabbit-fish	–		–		65	246	15	–		–	2	–		–	–	2	113	124	–		–	20	–	–	–		–	–	–	–		–
Squid	–	–	–	4	4	3	1	66	4	4		5	6	74	–	12	11	3	15		8	7	–	2	5	8	–		12	10	1	2
Depth (m)	163	111	107	96	298	321	170	102	163	135	164	120	108	104	118	287	279	339	104	138	134	279	174	160	121	127	211	228	106	106	172	171

TABLE 4. Weight of catch (kg) of the main species at each station. **Survey 2.**

Species	Station																															
	36	38	39	40	41	43	44	45	46	47	48	49	50	51	52	53	54	56	57	58	59	60	62	63	64	65	66	67	68	69	70	71
Cod	44	–	9	187	153	40	49	268	26	63	7	–	–	–	79	7	28	152	–	–	2	17	–	109	399	16	292	15	189	50		–
Haddock	64	4	17	25	71	8	29	56	30	33	137	39	50	–	27	13	28	90		–	36	11	1	21	51	14	91	13	36	29	5	2
Saithe	201	74	290	106	124	30	47	80	25	144	54	136	177	19	97	144	79	18	31	39	49	64	49	153	275	288	196	136	56	102	24	40
Blue Whiting	–	23	46	–		–	–	–	–		+	2	7	19	–	1	–	–	7	38	1	–		–		–	–		–	–	1	–
Norway Pout	–	–	–	1	1	10	1	–	2	+	9	5	–	–	1	7	1	+		–	–	1	–	4	1	4	3	1	+	+	2	3
Silvery Pout		1		–	–	–		–		–	–	–	1	11	–	1		–	10	7	–	–	–	–	–	–	–		–		+	–
Common Ling	5	21		10	–	–		–	5	6	–	10	2	6	8	19	+	9	5	12		–		6	39	11	6		5	10	43	–
Tusk	–	8	13	4	–	–	–	3	1		–		18	5	2		–		16	23	2	–		–	–	4	–	–	–	–	6	–
Megrim	+	+	–	+	–	+	+	–	–	–	2	1	1		+	1	–	–	+	+	1	+	2	+	+	–	+	+		–	1	+
Lemon Sole	–	–	+	1	1	–	+	+	+	1	1	–	+	–	+	1	+	3	–		+	+	–	+	+	3	3	–	+	1	+	–
Halibut		6	–	+	11	2	2	3	10	–	15		13	–		14	–	–	40		3	–	2	8	10	–	6	2	2	–	–	7
Angler	1	–		–		–	4	–	–	5	–	–		–	–		–		–	–	12	26	–		–	–		–		–	–	–
Redfish	–	1	1	5	1	1	–	2	3	1	+	–	1	14	8	+	1	1	39	23	–	1	–	5	5	24	7	+	10	+	16	1
Greater Silver Smelt	–	120	151	–	–	1	–	–	–	1	2	1	56	23		4		–	3	51	+	–		–	–		–	7		–	345	18
Rabbit-fish	–	28	232		–	–	–	–		–	–		–	+		–	–		73	54		–	–	–	–		–	–		–	–	–
Squid	–	1	2	8	8	–	5	10	4	11	3	–	1	5	7	1	19	58	2	16	2	4	–	2	–	–		–	6	12	1	
Depth (m)	140	301	224	115	108	163	120	104	131	116	160	175	225	334	110	172	103	102	340	344	138	137	179	147	157	134	135	173	106	107	208	215

TABLE 5. Stations where catches of the less important species were recorded.

Species	Stations recorded
Poor Cod	21, 31, 40, 44, 46, 54, 65, 68
Blue Ling	19, 38, 39, 50, 51, 58, 70
Greater Fork-beard	7, 18, 19, 24, 39, 51, 57, 58
Catfish	10, 32, 40, 49, 50
Spotted Catfish	4, 21
Dab	4, 13, 16, 26, 27, 28, 36, 41, 43, 44, 47, 48, 49, 56, 60, 64, 66, 68, 70
Long Rough Dab	10, 11, 12, 16, 18, 24, 26, 29, 34, 48, 50, 53, 57, 60, 62, 64, 67, 69, 70, 71
Plaice	32
Sandeel	5, 60
Gurnard	10, 13, 22, 23, 25, 26, 27, 28, 32, 34, 36, 41, 43, 46, 48, 52, 59, 63, 66, 67, 69
Dragonet	26, 48, 62, 69
Triglops sp.	27, 56, 65
Lycenchelys	19, 39, 57
Black-mouthed Dogfish	7, 13, 17, 18, 19, 24, 39, 51, 57, 58
Velvet Belly	18, 19, 39, 51, 57, 58
Centrophorus squamosus	19, 57
Skate	27, 45, 59, 62
Shagreen Ray	60, 62
Cuckoo Ray	13
Thornback Ray	9, 45, 54
Sandy Ray	34, 50, 54
Lamprey	57

Catch composition

Thirty-seven fish species were recorded during the survey and these are listed in Table 2. The weight (kg) of fish caught at each station is tabulated for the main species in Tables 3 and 4. The stations at which the remaining species were caught are listed in Table 5.

For many species, distribution was related to depth. Maximum catch-rates of cod and haddock were taken in the depth range 100-150 m, but saithe had a wider depth distribution. Chimaera, blue whiting, and greater silver smelt, on the other hand, were associated with the deeper water around the edge of the bank.

Statistical analysis

The significance of differences between strata mean weights of catch were investigated for the two surveys, using an analysis of variance. Species investigated by this technique were cod, haddock, saithe, common ling, and halibut. Tables 6-10 show the results of the analyses. To obtain approximately homoscedastic variables the transformation $\log_e (W + 1)$ was applied to the weight (kg) of catch from each haul (W). Cod showed significant differences between depths and between quadrants, being seldom caught below 183 m in any quantity and the greatest catches being taken in quadrant D. Haddock showed a similar distribution, with similarly significant results for depth. None of the other species showed any consistently significant results, although ling did show significantly greater weights of catch with increasing depth in the first survey.

The important point about these investigations is that the results found at Faroe Bank will help in the design of future surveys. It is particularly interesting that in no case did the catches vary with the time of the haul.

TABLE 6. Analysis of variance: Cod.

Cause	Degrees of freedom	Sum of squares	Mean squares	F ratios	Significance
		1st Survey			
Quadrants	3	8.4	2.8	3.6	*
Depths	3	95.8	31.9	40.9	***
Times	3	2.6	0.9	1.1	
Errors	22	17.2	0.8		
		2nd Survey			
Quadrants	3	16.3	5.4	4.3	*
Depths	3	81.6	27.2	21.6	***
Times	3	7.7	2.6	2.0	
Errors	22	27.7	1.3		

Levels of significance: * 5%; ** 1%; *** 0.1%. (This footnote also applies to Tables 7-10 inclusive.)

TABLE 7. Analysis of variance: Haddock.

Cause	Degrees of freedom	Sum of squares	Mean squares	F ratios	Significance
		1st Survey			
Quadrants	3	6.8	2.3	3.5	*
Depths	3	48.4	16.1	25.0	***
Times	3	5.0	1.7	2.6	
Errors	22	14.2	0.6		
		2nd Survey			
Quadrants	3	6.2	2.1	2.0	
Depths	3	25.7	8.6	8.5	***
Times	3	1.9	0.6	0.6	
Errors	22	22.2	1.0		

TABLE 8. Analysis of variance: Saithe.

Cause	Degrees of freedom	Sum of squares	Mean squares	F ratios	Significance
		1st Survey			
Quadrants	3	7.8	2.6	2.1	
Depths	3	5.9	2.0	1.6	
Times	3	0.2	0.1	0.1	
Errors	22	27.7	1.3		
		2nd Survey			
Quadrants	3	2.8	1.0	1.5	
Depths	3	1.7	0.6	0.9	
Times	3	1.1	0.4	0.6	
Errors	22	14.0	0.6		

TABLE 9. Analysis of variance: Common Ling.

Cause	Degrees of freedom	Sum of squares	Mean squares	F ratios	Significance
		1st Survey			
Quadrants	3	12.3	4.1	2.7	
Depths	3	20.5	6.8	4.4	*
Times	3	8.1	2.7	1.7	
Errors	22	34.1	1.6		
		2nd Survey			
Quadrants	3	8.0	2.7	1.7	
Depths	3	14.1	4.7	3.0	
Times	3	4.9	1.4	0.9	
Errors	22	34.3	1.6		

TABLE 10. Analysis of variance: Halibut.

Cause	Degrees of freedom	Sum of squares	Mean squares	F ratios	Significance
		1st Survey			
Quadrants	3	3.3	1.1	1.1	
Depths	3	0.3	0.1	0.1	
Times	3	6.8	2.3	2.2	
Errors	22	22.6	1.0		
		2nd Survey			
Quadrants	3	0.2	0.1	0.0	
Depths	3	5.6	1.9	1.3	
Times	3	1.1	0.4	0.3	
Errors	22	32.7	1.5		

Hence results can be grossed up without any weighting being made for diurnal variations. This result is perhaps not surprising, since at Faroe Bank at the time of the survey the night is extremely short. If this is the reason for the lack of diurnal variation then it suggests that midsummer would be a suitable time for groundfish surveys in high latitude regions.

Accuracy of age data

For cod and haddock the otolith samples were aged and the length compositions converted to age compositions. Age-length keys for different quadrants and strata were compared but no differences were observed. The age-length keys were therefore amalgamated before being applied to each length composition. The resultant age compositions are given in Tables 11 and 12.

The variance of numbers at age has been obtained for cod from considerations of the within strata haul-to-haul variance of the length composition and the variability of the age-length key. The coefficients of variation of the number of cod at each age are given in Table 13(a). For purposes of comparison of the accuracy

TABLE 11. Age compositions of cod. Numbers per 100 hrs fishing.

		Numbers per 100 hrs fishing										
	Mean length	Quadrant				Stratum				Survey		
Age-group	(cm)	A	B	C	D	1	2	3	4	1	2	Total
1	20.3	13	63	31	288	106	288	-	-	134	63	98
2	51.6	250	319	150	288	494	413	100		222	281	252
3	75.0	64	124	270	273	464	180	75	13	165	200	182
4	86.8	202	435	234	416	632	357	290	6	331	312	322
5	93.8	21	68	36	53	78	64	35	–	45	45	45
6	102.1	8	33	19	36	49	32	15	–	22	26	24
7	103.0	19	68	36	63	90	60	33	–	41	51	46
8	107.6	13	38	20	25	44	35	16	–	19	29	24
9	108.9	29	40	33	29	78	34	20	–	30	36	33
10	107.1	7	22	14	15	26	23	9	6	12	18	15
11	111.3	10	13	12	8	29	10	7	–	10	12	11
12	112.5	1	2	3	1	2	4	0	–	1	2	2
13	117.5	5	2	5	–	8	2	1	–	3	3	3

TABLE 12. Age compositions of haddock. Numbers per 100 hrs fishing.

		Numbers per 100 hrs fishing										
	Mean length	Quadrant				Stratum				Survey		
Age-group	(cm)	A	B	C	D	1	2	3	4	1	2	Total
1	19.2	10,069	5,712	7,981	8,246	3,398	18,839	8,388	1,384	7,825	8,179	8,002
2	29.6	882	689	637	1,075	1,437	1,351	416	79	940	701	821
3	43.2	1,764	1,640	1,314	2,747	3,759	2,782	869	57	2,305	1,428	1,867
4	53.1	382	329	623	774	579	840	518	171	588	466	527
5	57.7	126	88	182	160	187	185	139	43	149	129	139
6	68.6	28	26	28	52	38	74	17	4	43	23	33
7	66.5	18	13	20	27	22	37	16	5	23	16	20
8	71.1	26	17	15	41	32	56	10	1	34	15	25
9	72.9	23	16	10	39	26	54	8	1	32	13	22
10	71.9	6	1	2	6	7	6	1		5	2	4
11	–	–	–	–	–	–	–	–	–	0	0	0
12	82.5	2	-	–	2	2	2	–	–	2	0	1

TABLE 13. Accuracy of age-length data.

(a) Faroe Bank Cod

	Age (years)												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Number from survey	63	161	118	205	28	17	30	15	21	9	8	1	1
Coefficient of variation (%)	22	11	18	11	33	44	29	42	35	56	62	150	103

(b) North Sea Plaice (Lowestoft market samples in January and February 1950)

	Age (years)												
	1	2	3	4	5	6	7	8	9	10	11	12+	13
Number X 10^{-3}		215	1114	1870	689	321	153	172	127	70	52	88	
Coefficient of variation (%)		18.3	8.2	6.1	9.6	14.2	19.3	17.7	20.0	27.7	33.3	19.3	

of research vessel survey data with market samples, the coefficients of variation of North Sea plaice for Lowestoft market samples in January and February 1950 (Gulland 1955) are also given in Table 13(b).

Comparison with Georges Bank survey

Table 14(a) shows results for one of the surveys, set out together with similar data from Georges Bank (Grosslein 1971). The variances from Faroe Bank are broadly similar to those from Georges Bank, bearing in mind that the Faroe units are kg per hour haul, whereas those for Georges Bank are lb per 30 min haul.

The intensity of sampling on Faroe Bank was approximately one station per 50 sq miles on each survey. This compares with approximately one station per 300 sq miles on the Georges Bank surveys.

TABLE 14. Results for one of the surveys with similar data from Georges Bank (Grosslein, 1971).

(a) Mean transformed catch per haul [$\log_e$ (kg + 1)] and variance estimates from second survey at Faroe Bank

Species	Mean	Variance	Standard deviation	Coefficient of variation (%)	95% confidence limits
Cod	2.77	0.0393	0.1982	7	2.37-3.17
Haddock	2.91	0.0315	0.1775	6	2.55-3.27
Saithe	4.63	0.0394	0.1985	4	4.23-5.03
Ling	1.46	0.0487	0.2207	15	1.02-1.90
Halibut	1.11	0.0465	0.2156	19	0.68-1.54

(b) Stratified mean catch per haul (lb $\log_e$ scale) for haddock and cod on Georges Bank (*Albatross IV* autumn surveys, strata 13-25) Grosslein, 1971.

Cruise	Mean	Variance	Standard deviation	Coefficient of variation (%)	95% confidence limits
			Haddock		
63- 7	3.34	0.052176	0.2284	7	2.88-3.80
64-13	3.86	0.080315	0.2834	7	3.29-4.43
65-14	4.02	0.042355	0.2058	5	3.61-4.43
66-14	2.43	0.044512	0.2110	9	2.01-2.85
67-21	2.45	0.052075	0.2282	9	1.99-2.91
68-17	1.15	0.029587	0.1720	15	0.81-1.49
69-11	1.10	0.021536	0.1467	13	0.81-1.39
70- 6	1.35	0.0345	0.1857	14	0.98-1.72
			Cod		
63- 7	1.75	0.084829	0.2912	17	1.17-2.33
64-13	1.29	0.056270	0.2372	18	0.82-1.76
65-14	1.32	0.041737	0.2043	15	0.91-1.73
66-14	1.20	0.040673	0.2017	17	0.80-1.60
67-21	1.74	0.047301	0.2175	12	1.30-2.18
68-17	1.04	0.031888	0.1786	17	0.68-1.40
69-11	1.32	0.025381	0.1593	12	1.00-1.64
70- 6	1.35	0.0332	0.1822	13	0.99-1.71

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Assessment of American Plaice Stocks on the Grand Bank, ICNAF Divisions 3L and 3N

By T. K. Pitt[1]

Abstract

Calculations of natural mortality by various methods indicated that values of 0.25 for males and 0.20 for females were appropriate. Assessment of the Grand Bank stocks suggested that the optimal level of fishing in ICNAF Division 3L was reached in 1967 (F = 0.55 males and 0.46 females) with landings at 37.5 thousand tons. For ICNAF Division 3N optimal levels were at F = 0.40 (males) and 0.50 (females) producing about 15,000-20,000 tons. It was suggested that landings should not exceed 40,000 and 20,000 tons for Divisions 3L and 3N respectively.

Introduction

The purpose of this paper is to present an assessment of the commercially exploited American plaice stocks on the Grand Bank and thus provide information for the rational management of this fishery. A major portion of this paper is devoted to estimations of natural mortality, a vital but often controversial parameter required in stock assessment.

The main fishery for American plaice, *Hippoglossoides platessoides*, in ICNAF Subarea 3 occurs in Divisions 3L and 3N and began in the late 1940's with the introduction of the otter trawler. The fishery has remained mainly Canadian, but in Div. 3N, European trawlers, principally those of the USSR and Poland have gradually increased their share of the catch since 1965 so that by 1968 they were taking about 50% of the total (Fig. 1). In recent years plaice have become the major species sought by the Newfoundland otter trawler fleet.

In preparing the assessment of Grand Bank plaice, certain difficulties were encountered because of the frequent inadequacy of the sampling of the commercial fishery for age determinations. The only age-length keys and length measurements available were those based on otolith samples collected at the St. John's Biological Station. Sometimes research data were used when commercial data were lacking or inadequate. Another difficulty was the lack of information on discards which probably resulted in an underestimation of the numbers caught at the lower ages included in the commercial landings. In this respect no information was available on catches of plaice by draggers fishing cod primarily for salting; obviously there must have been a fair amount of discards in these operations. However, the best available data have been utilized in this assessment which gives an indication of the status of the plaice fishery on the Grand Bank.

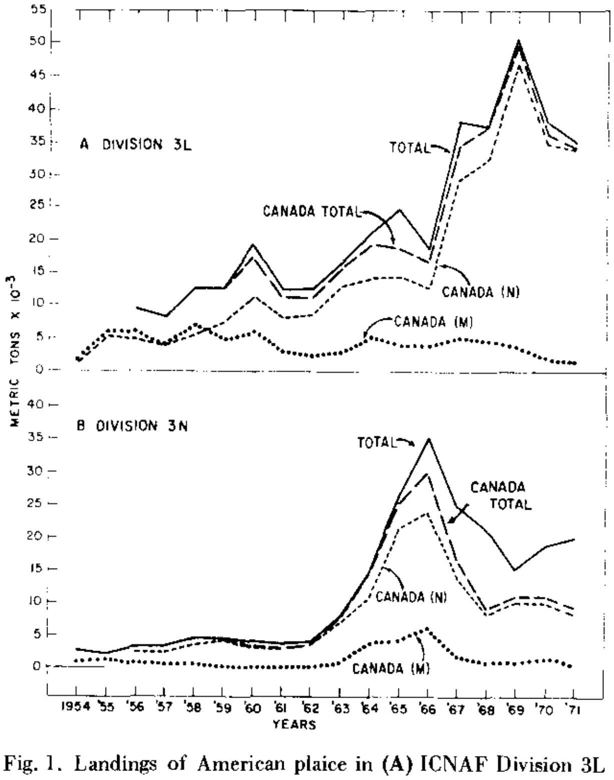

Fig. 1. Landings of American plaice in (A) ICNAF Division 3L and (B) ICNAF Division 3N.

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[1] Fisheries Research Board of Canada, Biological Station, St. John's, Newfoundland.

Materials and Methods

Calculation of numbers caught

Prior to 1970 the USSR and most other European countries reported their flatfish landings merely as "unspecified flounder". At the 1971 Annual Meeting of ICNAF, however, the USSR presented a breakdown of their 1970 flounder landings indicating that in Div. 3N, plaice represented about 47% of the total flounder landings. It was also indicated that this was the approximate proportions in previous years in the latter division. So it was on this basis that the quantity of plaice included in the "unspecified flounder" was estimated. Division 3L landings were primarily by Canada.

Calculation of effort and catch-per-unit-effort

The calculation of fishing effort was based on the nominal catch-per-unit-effort of plaice by Canada (N) stern trawlers (501-900 tons) (Fig. 2). Since the decline of the haddock fishery in the early 1960's most of Canada (N) effort in Divs. 3L and 3N between 75 and 200 m has been confined to plaice, yellowtail, and cod. In calculating the catch per hour for Canada (N) from which total effort was estimated, all tows containing plaice in sufficient numbers to be recorded as a commercial catch on the vessels' log sheet were used. Catches per hour where plaice accounted for more than 50% of the catch were also calculated (Fig. 2).

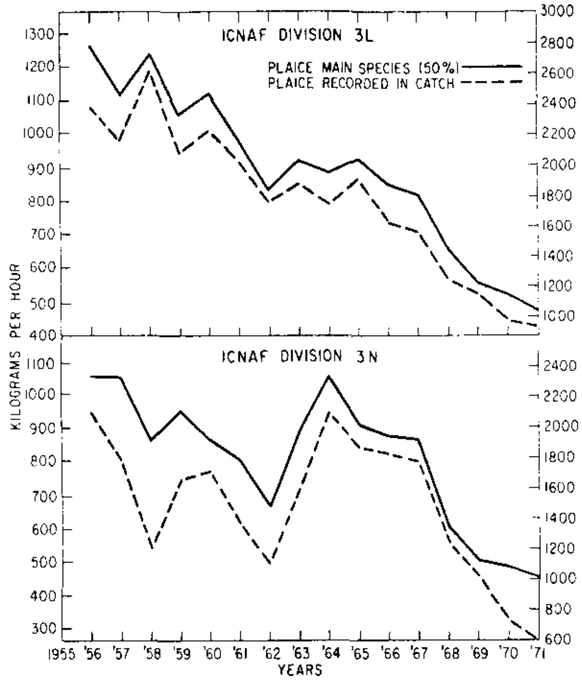

Fig. 2. Plaice landings per hour by Canada (N) fleet in Canada (N) stern trawler units.

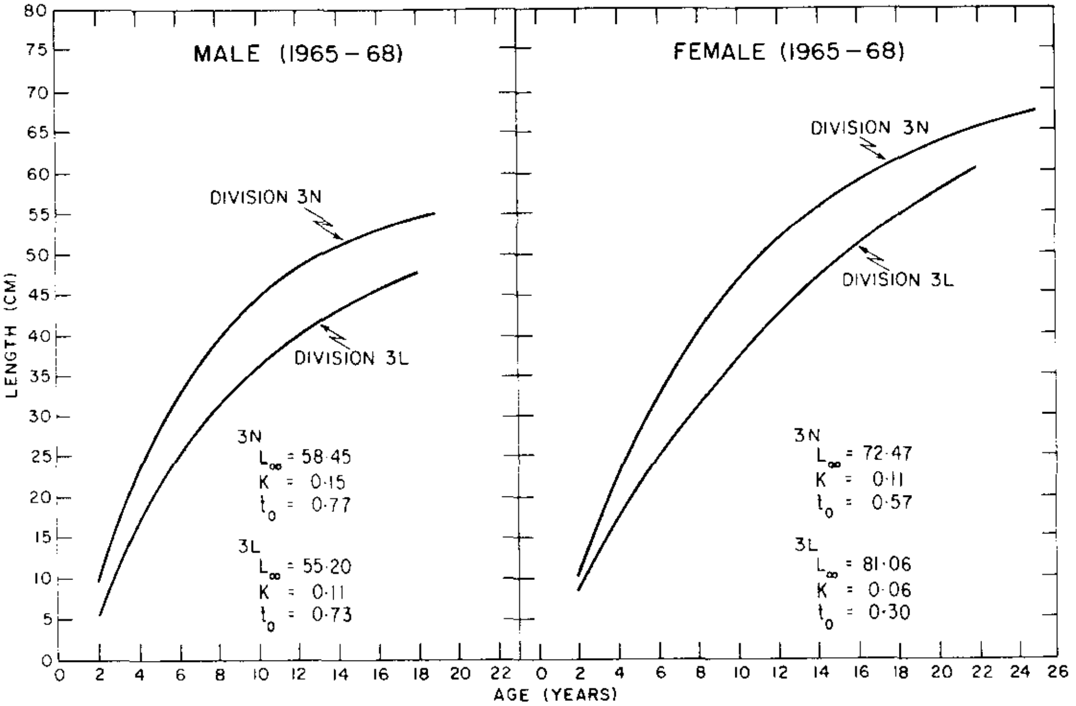

Fig. 3. Growth curves of male and female American plaice from ICNAF Divisions 3L and 3N.

Separation of stocks

Plaice from Divs. 3L and 3N were treated as separate stocks. Tagging indicated that on the Grand Bank, plaice are relatively sedentary (Pitt, 1969) with minimal migrations noted between the northern and southern parts of the Bank. Thus very few plaice tagged on the eastern slope just north of 46°N (3L) were recovered as far south as 45°30'N (3N). Similarly of the plaice tagged at 45°N, only a minor number were recaptured north of 46°N (3L).

Another reason for separating Grand Bank plaice into two main stocks was the difference in the growth pattern (Fig. 3). Plaice from Div. 3L were consistently smaller at comparable ages than those from Div. 3N and also fewer of the older age-groups were caught in 3N.

Although Divs. 3L and 3N were dealt with separately, there is a strong possibility that 3N depends on 3L for recruitment probably as pelagic larvae.

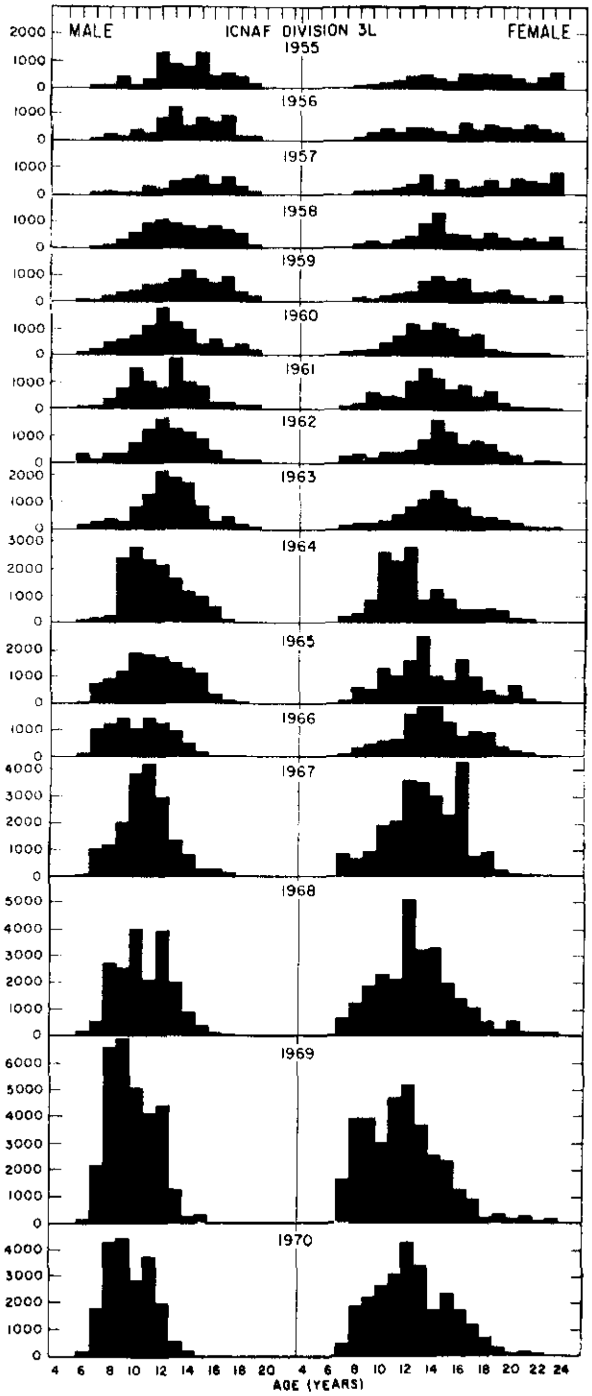

Fig. 4. Numbers of male and female plaice caught in ICNAF Division 3L.

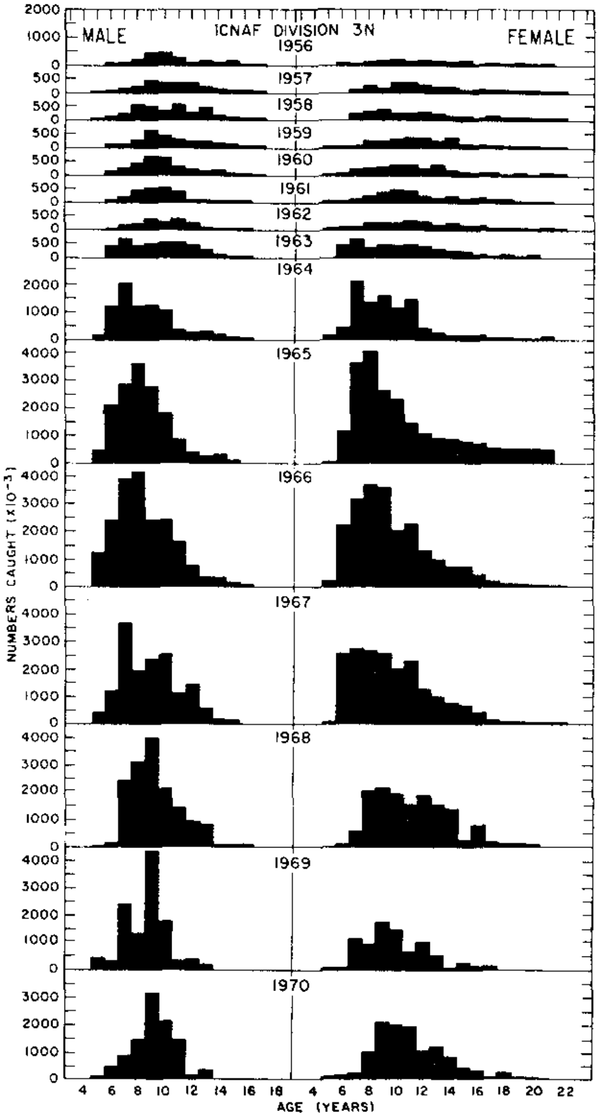

Fig. 5. Numbers of male and female plaice caught in ICNAF Division 3N.

Vertebral numbers (Pitt, 1963) gave no significant difference between north and south bank areas. Preliminary results from biochemical research being conducted at the St. John's Station indicated no significant genetic differences between the two ICNAF divisions. Since the adults apparently migrate very little, the intermixing of the areas probably occurs during the larval period.

Separation of males and females

From the beginning, the necessity of separating males and females appeared evident since each produced parameters that were quite different. Growth curves (Fig. 3) indicated that the males were smaller at corresponding ages from about age 7 or 8. Females generally live longer than the males; very few 20-year-old males were encountered whereas females up to age 30 were sometimes encountered (Figs. 4 and 5). The 50% maturity point of males is at age 7 (about 25 cm) in Div. 3L and age 5 (about 27 cm) in Div. 3N, whereas for females it is 14 years (43 cm) and 12 years (50 cm) in 3L and 3N respectively (Pitt, 1966). The commercial the lower size ranges which produced higher values of F at younger age-groups than for the females but the explanation for this is not forthcoming at present. Some commercial and research figures are shown to illustrate this (Fig. 6).

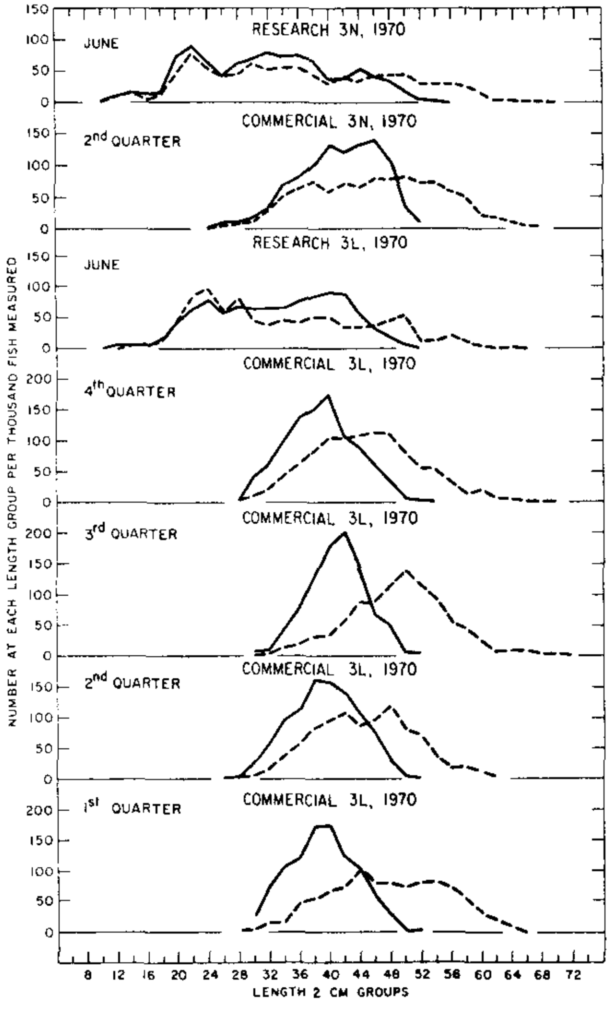

Fig. 6. Length frequencies of 1970 commercial and research plaice. Division 3L commercial data by quarter with 2nd quarter research data for comparison. Division 3N 2nd quarter commercial and research data only are available *(males – solid lines, females – broken lines).*

Calculation of fishing mortality

The virtual population method developed by Fry (1949, 1957) and modified by Gulland (1965) can be used to estimate F values only for year-classes that have passed completely through the fishery; hence recent annual values of F cannot be obtained. Jones (1961, 1968) described a method of calculating F using the actual catches of successive ages of a year-class based on Baranov's (1918) catch equation. The method in a more convenient form was similar to that described by Ricker (1948). The method of calculation and a comparison of Jones' method with that of Gulland's (1965) virtual population method was described in detail by Schumacher (1970) and his procedure for utilizing the annual catches of successive ages to compute values of F was used here (Tables 1-4). The method requires estimates of natural mortality (M) and the rate of exploitation,

$\frac{F_n}{Z_n}(1 - e^{-Z_n})$, at the older age-group.

The estimation of M is described in a later section. For the exploitation rate, a few trial values for some of the older age-groups suggested a value for F of 0.45 giving exploitation rates of 0.324 and 0.331 for males and females respectively.

Because of the absence of male plaice beyond age 14 in the 1970 commercial catches, estimates of F for 1968 for fully recruited males in Div. 3L (Table 5) were derived from calculated stock size at the beginning of 1968 and the catch in 1968. This method was also used to get estimates of F for 1969 and 1970 for the fully recruited age-groups (Table 5).

Calculation of yield per recruit

Yield per recruit curves using the partial recruitment values of Tables 1 to 4 were calculated for the males and females for both areas on the basis of 500,000 recruits each of males and females at age 3. The yield curves were then combined to give an average yield per

TABLE 1. Estimates of fishing mortality of male plaice, ICNAF Division 3L.

Age	Year														% from fully recruited
(years)	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	age-groups (1965-68)
7	0.001	0.001	<0.001	0.002	0.002	0.008	0.004	0.004	0.008	0.004	0.018	0.014	0.014	0.002	2
8	0.006	0.001	0.006	0.004	0.008	0.018	0.018	0.014	0.016	0.008	0.034	0.040	0.020	0.05	8
9	0.006	0.008	0.002	0.014	0.014	0.022	0.040	0.020	0.016	0.13	0.06	0.07	0.08	0.06	14
10	0.010	0.016	0.008	0.032	0.032	0.030	0.08	0.05	0.06	0.21	0.16	0.07	0.29	0.22	38
11	0.030	0.030	0.016	0.05	0.05	0.08	0.07	0.10	0.12	0.23	0.22	0.18	0.44	0.27	55
12	0.14	0.11	0.030	0.10	0.10	0.18	0.08	0.07	0.26	0.33	0.29	0.24	0.60	0.97	100
13	0.10	0.18	0.10	0.09	0.09	0.27	0.34	0.19	0.33	0.34	0.47	0.58	0.46	1.20[a]	100
14	0.13	0.09	0.14	0.39	0.39	0.15	0.39	0.38	0.30	0.36	0.55	0.40	0.68	0.67[a]	100
15	0.24	0.20	0.04	0.43	0.43	0.25	0.20	0.74	0.52	0.65	0.38			0.86[a]	100
16	0.18	0.20	0.15	0.44	0.44	0.38	0.25	0.18	0.44						
Average 7-16	0.09	0.08	0.05	0.12	0.14	0.14	0.15	0.18	0.22	0.24	0.24	0.24	0.32	0.48	
Average 12-16	0.15	0.16	0.10	0.21	0.29	0.25	0.25	0.31	0.40	0.42	0.42	0.41	0.55	0.92[a]	

[a] Calculated from stock and catch.

TABLE 2. Estimates of fishing mortality of female plaice, ICNAF Divison 3L.

Age	Year														% from fully recruited
(years)	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	age-groups (1965-68)
8	0.001	0.001	0.002	0.002	0.002	0.002	0.001	0.006	0.002	0.006	0.004	0.002	0.006	0.001	2
9	0.002	0.004	0.001	0.005	0.004	0.004	0.016	0.002	0.004	0.016	0.010	0.004	0.006	0.018	5
10	0.004	0.018	0.004	0.002	0.006	0.022	0.016	0.012	0.006	0.06	0.032	0.014	0.020	0.016	10
11	0.014	0.016	0.012	0.022	0.010	0.032	0.026	0.016	0.018	0.07	0.030	0.020	0.07	0.04	28
12	0.04	0.032	0.018	0.028	0.08	0.05	0.06	0.036	0.05	0.12	0.07	0.05	0.10	0.21	34
13	0.05	0.05	0.06	0.06	0.06	0.13	0.08	0.06	0.11	0.06	0.15	0.10	0.15	0.12	50
14	0.08	0.04	0.018	0.16	0.08	0.13	0.14	0.12	0.15	0.12	0.16	0.17	0.23	0.20	68
15	0.05	0.08	0.09	0.08	0.13	0.12	0.11	0.20	0.12	0.12	0.20	0.24	0.33	0.25	100
16	0.13	0.16	0.12	0.12	0.17	0.19	0.16	0.15	0.18	0.18	0.35	0.28	0.30	0.30	100
17	0.11	0.15	0.11	0.22	0.14	0.26	0.19	0.21	0.28	0.28	0.20	0.35	0.51	0.49	100
18	0.12	0.24	0.27	0.25	0.31	0.13	0.35	0.43	0.20	0.20	0.32	0.30	0.69	0.69	100
19	0.19	0.16	0.42	0.32	0.34	0.29	0.21	0.37	0.27	0.27	0.18	0.37	0.47	0.34	100
20	0.13	0.24	0.31	0.33	0.38	0.26	0.41	0.39	0.35	0.35	0.76	0.20	0.38	0.72	100
Average 8-20	0.07	0.09	0.11	0.12	0.13	0.13	0.14	0.15	0.14	0.15	0.18	0.16	0.25	0.28	
Average 15-20	0.14	0.19	0.25	0.25	0.27	0.23	0.26	0.30	0.27	0.27	0.35	0.30	0.47	0.50	
Fishing effort (thousands of hours)	7.3	8.4	8.6	10.2	17.5	18.4	13.8	16.2	18.0	26.0	28.0	23.5	51.6	63.2	

TABLE 3. Estimates of fishing mortality of male plaice, ICNAF Division 3N (M = 0.25).

Age (years)	Year 1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	% from fully recruited age-groups (1965-68)
5														
6	0.006	0.002	0.006	0.010	0.006	0.002	0.002	0.004	0.05	0.038	0.034	0.018	0.002	5
7	0.020	0.014	0.022	0.012	0.032	0.010	0.007	0.032	0.09	0.16	0.10	0.07	0.05	26
8	0.06	0.06	0.07	0.040	0.05	0.07	0.016	0.022	0.08	0.23	0.37	0.17	0.08	53
9	0.10	0.18	0.19	0.13	0.13	0.07	0.08	0.04	0.09	0.23	0.26	0.39	0.29	74
10	0.12	0.13	0.21	0.28	0.20	0.14	0.06	0.17	0.24	0.18	0.33	0.48	0.60	100
11	0.07	0.16	0.34	0.33	0.30	0.18	0.14	0.17	0.17	0.34	0.26	0.21	0.58	100
12	0.06	0.16	0.19	0.30	0.37	0.17	0.16	0.28	0.14	0.31	0.59	0.41	0.37	100
13	0.15	0.17	0.31	0.23	0.31	0.29	0.22	0.32	0.33	0.21	0.59	1.50[a]		100
14	0.19	0.30	0.29	0.39	0.36	0.17	0.36	0.54	0.36	0.52	0.50	0.75		100
Average 6-14	0.09	0.13	0.16	0.15	0.19	0.12	0.11	0.19	0.15	0.22	0.30	0.27	0.28	
Average 10-14	0.12	0.18	0.27	0.30	0.30	0.19	0.19	0.29	0.25	0.31	0.45	0.46	0.52	

[a] Not used in averages.

TABLE 4. Estimates of fishing mortality of female plaice, ICNAF Division 3N (M = 0.20).

Age (years)	Year 1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	% from fully recruited age-groups (1965-68)
6	0.004				0.002	<0.001	0.002	0.010	0.010	0.030	0.030	0.010	0.001	4
7	0.002	0.006	0.012	0.004	0.014	0.006	0.004	0.021	0.05	0.11	0.06	0.034	0.006	13.0
8	0.016	0.018	0.026	0.014	0.020	0.016	0.012	0.014	0.05	0.14	0.15	0.04	0.04	22.0
9	0.028	0.018	0.041	0.039	0.024	0.05	0.020	0.026	0.06	0.14	0.18	0.08	0.07	30.0
10	0.05	0.08	0.041	0.034	0.05	0.05	0.020	0.05	0.12	0.16	0.15	0.09	0.16	35.0
11	0.04	0.12	0.07	0.07	0.06	0.08	0.04	0.05	0.21	0.16	0.23	0.20	0.12	45.0
12	0.10	0.10	0.13	0.10	0.08	0.05	0.06	0.06	0.10	0.28	0.30	0.25	0.30	70.0
13	0.04	0.12	0.11	0.15	0.24	0.05	0.05	0.09	0.05	0.41	0.41	0.33	0.47	100
14	0.09	0.06	0.18	0.11	0.15	0.30	0.14	0.09	0.09	0.34	0.23	0.31	0.40	100
15	0.20	0.12	0.07	0.17	0.12	0.19	0.25	0.22	0.21	0.33	0.31	0.26	0.30	100
16	0.03	0.22	0.16	0.08	0.20	0.21	0.21	0.36	0.26	0.28	0.42	0.96	0.53	100
17	0.18	0.11	0.32	0.17	0.08	0.25	0.12	0.28	0.43	0.21	0.28	0.66	0.60	100
18	0.08	0.18	0.09	0.36	0.18	0.08	0.33	0.40	0.29	0.36	0.33			100
Average 6-18	0.06	0.10	0.11	0.11	0.09	0.10	0.10	0.13	0.16	0.24	0.24	0.27	0.26	
Average 13-18	0.10	0.14	0.15	0.17	0.15	0.18	0.18	0.24	0.23	0.32	0.33	0.50	0.46	
Fishing effort (thousands of hours)	3.0	3.5	8.5	6.0	4.4	5.3	7.9	10.9	19.1	31.0	42.4	30.7	37.7	

TABLE 5. Estimates of F for 1969 and 1970 from regressions of F on effort (Figs. 17 and 18) and from stock size and catch data.

		Mean value of F			
		1969		1970	
ICNAF Div.	Sex	From line	Calculated from stock size[a]	From line	Calculated from stock size[a]
3L	M	1.0	0.89	0.95	0.65
3L	F	0.67	0.55	0.65	0.48
3N	M	0.43	0.45	0.59	0.50
3N	F	0.38	0.36	0.57	0.48

[a]Calculated from stock and catch in 1968.

recruit (Fig. 7). The weights of fish used in calculating yield per recruit were average weights calculated from 1967 to 1968 commercial age-length curves.

Yield per recruit at various values of F for fully recruited age-groups for males, females, and combined male and female are presented for both divisions as well as the average yield curve for combined male and female showing percent of maximum yield (Fig. 8). The optimal fishing levels were calculated in the method suggested by Gulland (1972).

Estimation of stock size

Stock size was calculated for age 10 and over from Div. 3L and for age 8 and over from Div. 3N. Males and females were calculated separately and combined for presentation here to give some indication of total stock size (Tables 7 and 8).

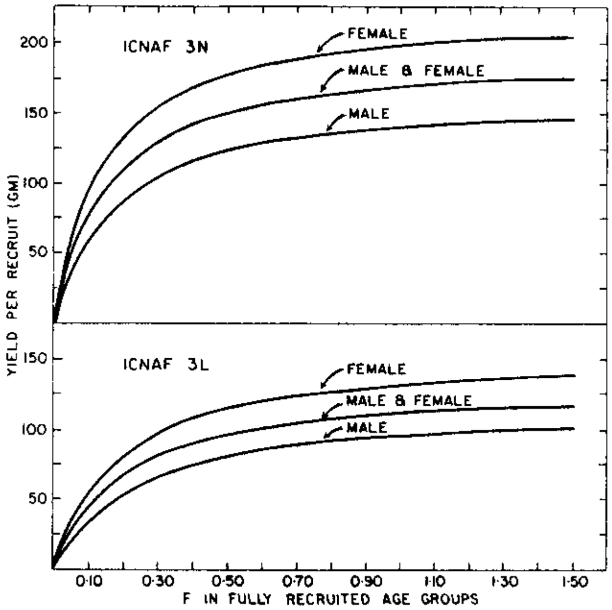

Fig. 7. Yield per recruit with partial recruitment as shown in Tables 1-4 from ICNAF Divisions 3L and 3N.

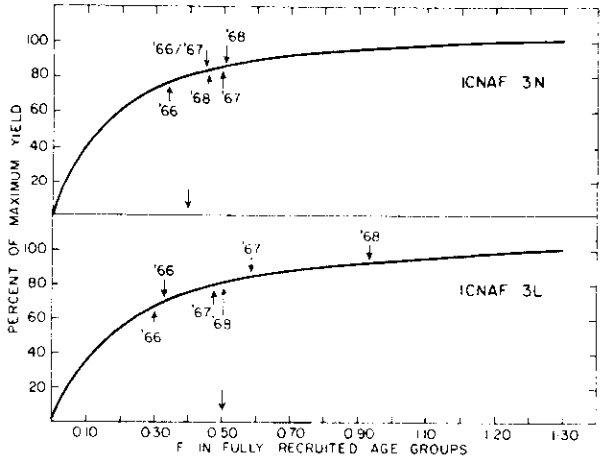

Fig. 8. Yield curves showing percentage of maximum yield for the combined male and female calculations (Fig. 7) for Divisions 3L and 3N with arrows above the curve indicating calculated F values for males and below for females. Optimal fishing level indicated at the bases.

Estimates of Natural Mortality Coefficients

Huntsman (1918) estimated the total mortality rate for male and female plaice combined from an unexploited population in the Gulf of St. Lawrence to be 12.5% per annum using the Jackson (1939) method ($Z = 0.14$). When these data were used to fit a catch curve, however, Z was calculated at 0.21 for ages 9 to 22 and 0.18 for ages 9 to 24 (Fig. 9). Powles (1969) for the same area with samples collected at the beginning of the otter trawler fishery estimated Z at 0.13 by the Jackson method. However, using a modification of this method by Robson and Chapman (1961) he obtained a value of 0.26 ± 0.092. A line fitted to Powles' data (Fig. 9) gave a total instantaneous mortality coefficient of 0.29 for ages 10 to 19 and 0.26 for ages 9 to 19. From tagging data and using a method developed by Paloheimo (1958), Powles (1969) calculated M at 0.11 to 0.16 (sexes combined), which he used in his assessment.

Growth curves (Pitt, 1967) produce different parameters for the two sexes; also as previously shown a study of catch curves seemed to indicate that the total instantaneous mortality rates were probably dissimilar. For the males, fish over 20 years of age rarely occurred, whereas for the females, fish of 25 years or older were frequently encountered. Separate estimates of natural mortality for the males and females were therefore considered necessary.

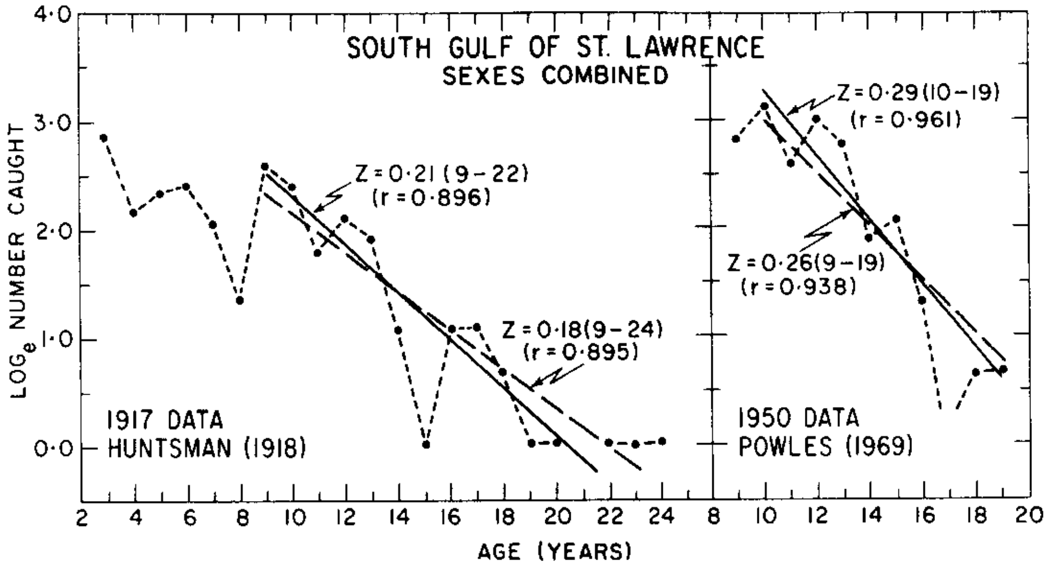

Fig. 9. Total mortality estimates from unexploited stocks for the Gulf of St. Lawrence (Huntsman, 1918; and Powles, 1969).

Estimates of natural mortality from age composition of unexploited populations

The relatively small population in St. Mary's Bay on the Southeast Coast of Newfoundland was unexploited at least until the mid-1960's. Tagging data indicated that this population was discrete and hence not affected by exploitation of plaice on the Grand Bank. Hamilton Inlet Bank (ICNAF Div. 2J) also supports a small plaice population that is apparently discrete from the Grand Bank. Although there is no fishery for plaice in this area, plaice sometimes, at least, occupy the same niche as cod, and some are removed by the cod fishery. However, prior to 1960 the fishing intensity in this area was much less than in recent years, producing less than 40,000 tons of cod annually in 1954-60 (May, 1967). Thus up to 1959 fishing mortality of plaice was probably minimal.

The catch curves from research samples from these two areas, St. Mary's Bay, 1957-60 (Fig. 10) and Hamilton Inlet Bank (Div. 2J), 1957-59 (Fig. 11) gave estimates of total instantaneous mortality as follows:

St. Mary's Bay	—	Males	= 0.27
	—	Females	= 0.18
Hamilton Inlet Bank	—	Males	= 0.30
	—	Females	= 0.22

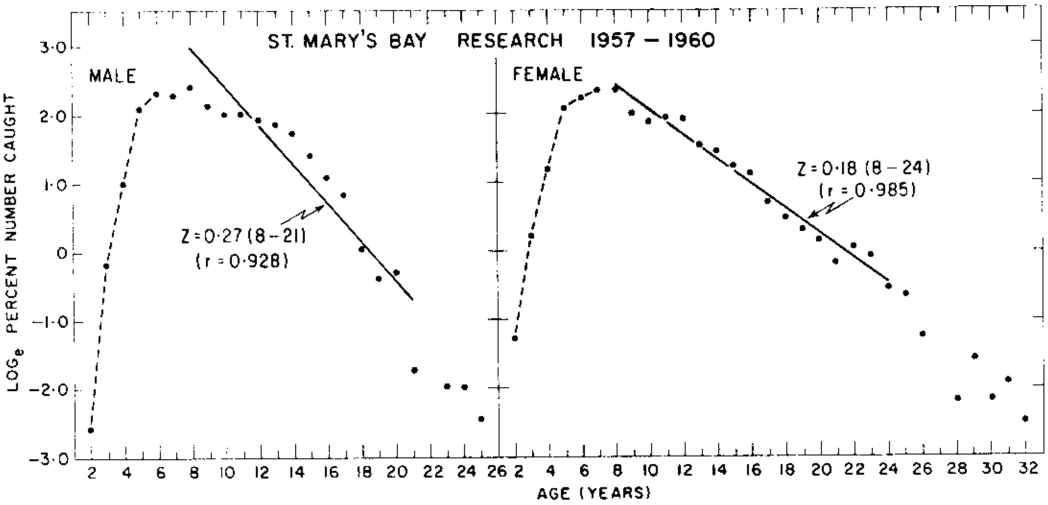

Fig. 10. Catch curves of unexploited stock, St. Mary's Bay, Newfoundland, with estimates of total mortality.

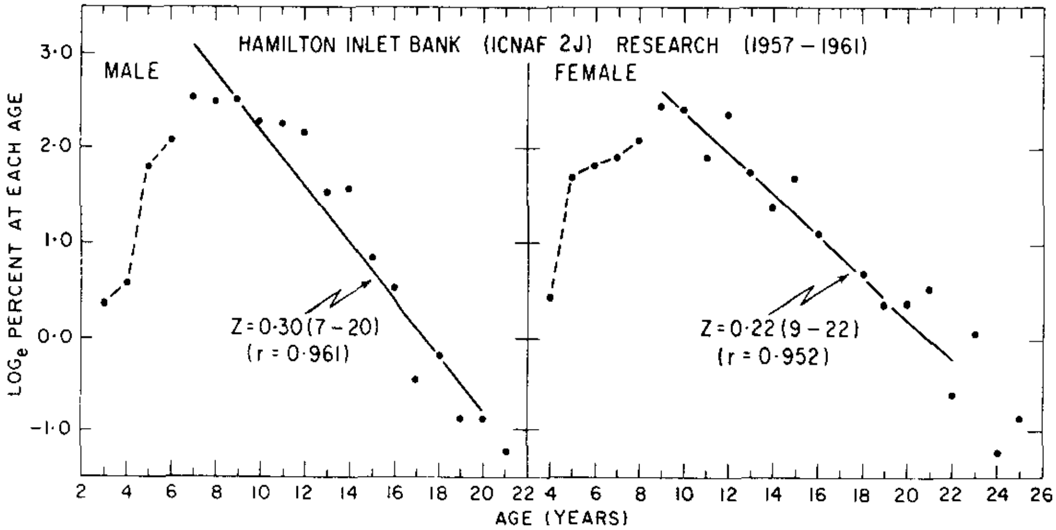

Fig. 11. Catch curves from research vessel samples, ICNAF Division 2J, and estimates of total mortality.

For the latter area some fishing mortality may be included, but it was probably less than 0.05.

Estimates of M from catch and effort data (Division 3L and 3N)

The Beverton and Holt (1957) iterative method was applied to 14-, 15- and 16-year-old males and 17-, 18- and 19-year-old females from ICNAF Divisions 3L and 3N using the procedure described by Ricker (1958). Instantaneous natural mortality estimates of 0.27 (Div. 3L) and 0.56 (Div. 3N) for males and 0.23 (3L) and 0.16 (3N) for females were calculated (Fig. 12). The high value for 3N males (0.56) and poor correlation of the data (r = 0.268) was apparently caused by the unrealistically low survival rates calculated for the early years of the fishery. The only explanation that can be given for these is the possible inadequacy of the sampling during this period. By editing the data drastically as shown in Fig. 12 the value of M was reduced to 0.22 (r = 0.756).

In Fig. 12 the estimates of M using Paloheimo's (1961) linear formula are also shown. This method involves the plotting of Z for the age-group against $\frac{1}{2}(f_n + f_{n+1})$ instead of f_n (f_n = effort in year$n$) as in the previous method. Values of M were similar to those calculated from the more laborious interative method; 0.22 (Div. 3L) and 0.53 (Div. 3N) for males, and 0.23 (3L) and 0.18 (3N) for females (Fig. 3). Again elimination of the early values for the Div. 3N males gave a lower value for M, 0.17 and an improvement in the correlation coefficient from 0.332 to 0.855.

The final method (Figs. 13 and 14) used was a plot of total instantaneous mortality coefficients obtained from catch curves of a number of year-classes (Figs. 15 and 16) against the mean effective effort calculated by method of Paloheimo (1961) as indicated above, but in this case a mean value for the span of years used was calculated, i.e.

$$f^1 = \frac{\sum_{n=1}^{r-1} \frac{1}{2}(f_n + f_{n+1})}{r-1}$$

where f^1 = mean effective effort and r = number of age-groups included.

Values for M were (males) 0.24 and 0.39, (females) 0.23 and 0.21 for Divs. 3L and 3N respectively. Since basically the same data were used as in the previous methods the value for Div. 3N males was again relatively high.

The various estimates are summarized in Table 6. Except for the high values for Div. 3N males estimates of natural mortality for male plaice tend to be about 0.25. For females a lower value of 0.20 would appear to be reasonable. However, for all the methods where Z is plotted against effort the standard errors of the estimate of M are relatively high. The high values calculated for Div. 3N males do not seem to be realistic, so that for purposes of stock assessment, values of 0.25 for males and 0.20 for females for both ICNAF divisions are appropriate.

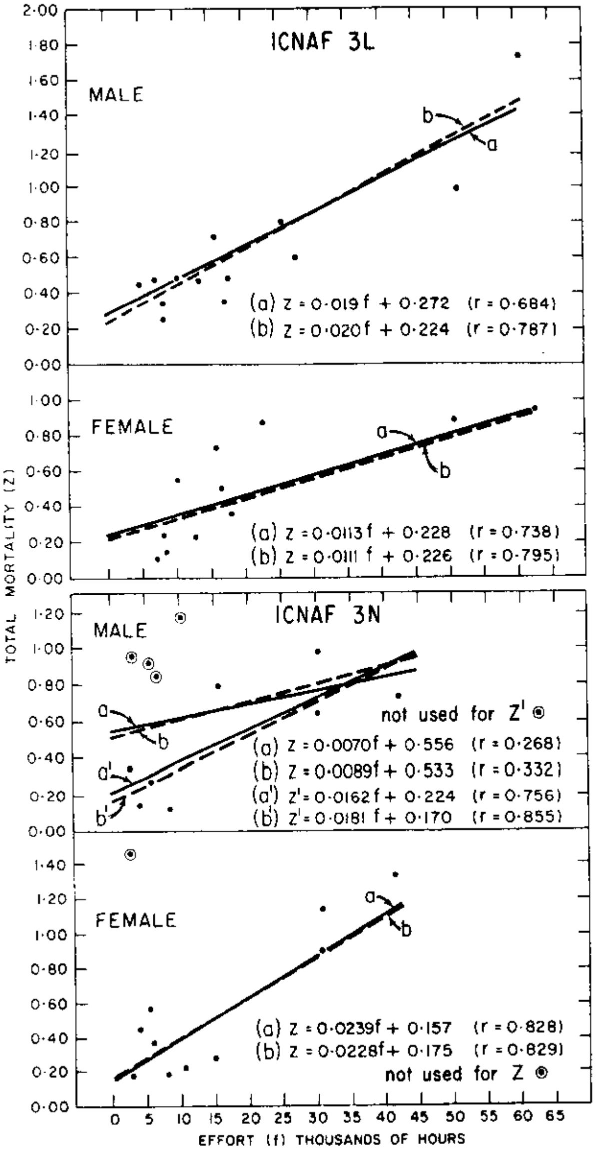

Fig. 12. Estimates of M by **(a)** the Beverton and Holt (1957) iterative method and **(b)** Paloheimo's (1961) linear formula.

Assessment of the Stocks

Fishing mortality and yield per recruit curves

Generally speaking, estimates of F at corresponding ages were higher for the males than for the females (Tables 1-4). This can perhaps be attributed to the apparent greater vulnerability of males at smaller sizes and earlier ages than the females.

The regression of the average value of F for all age-groups and for those fully recruited on the annual fishing effort (Figs. 17 and 18) gave highly significant

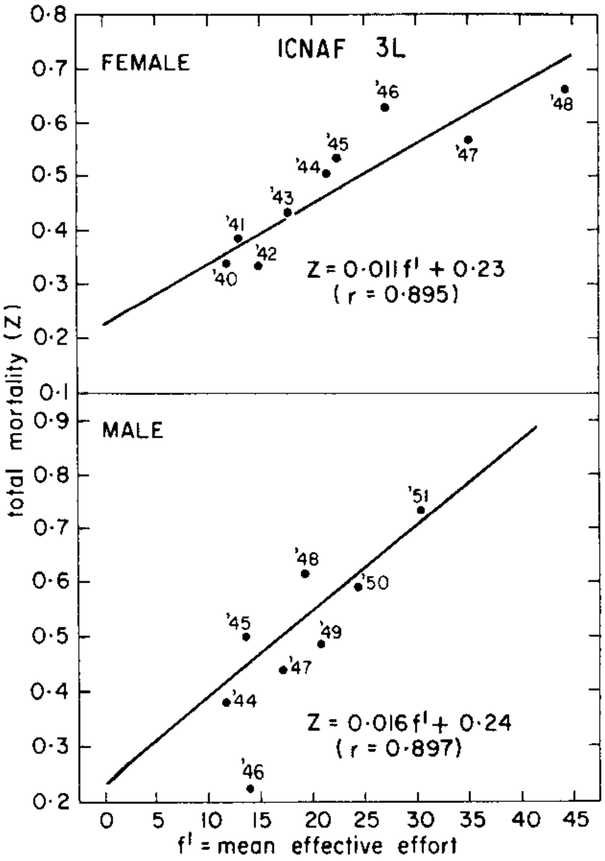

Fig. 13. Estimation of natural mortality in Division 3L using Z from catch curves of a series of year-classes (Fig. 15).

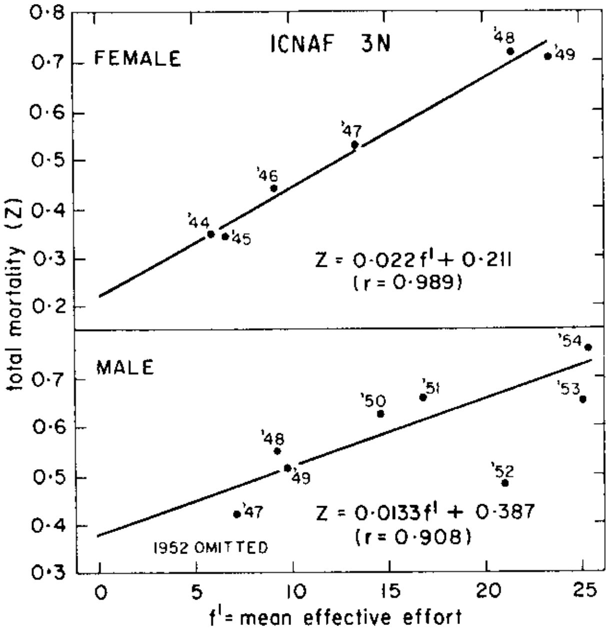

Fig. 14. Estimation of natural mortality in Division 3N using Z from catch curves of a series of year-classes (Fig. 16).

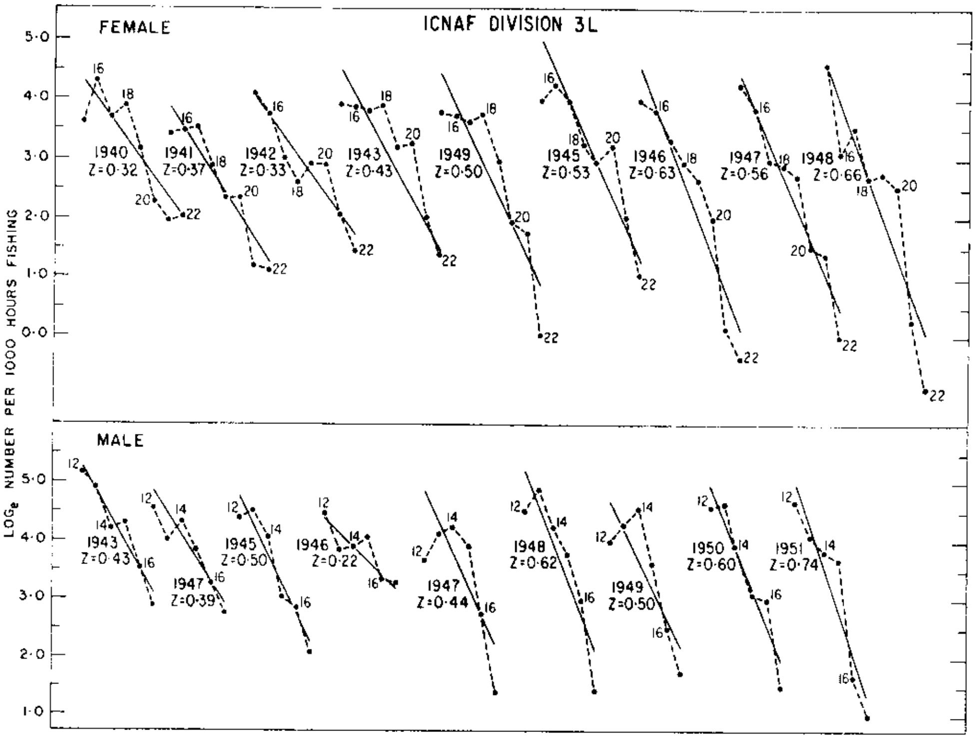

Fig. 15. Catch curves of American plaice from Division 3L, 1940-48 year-class for females and 1943-51 for males. Solid lines indicate interpretation of the slopes fitted from ages 15 to 22 (females) and 12 to 17 (males).

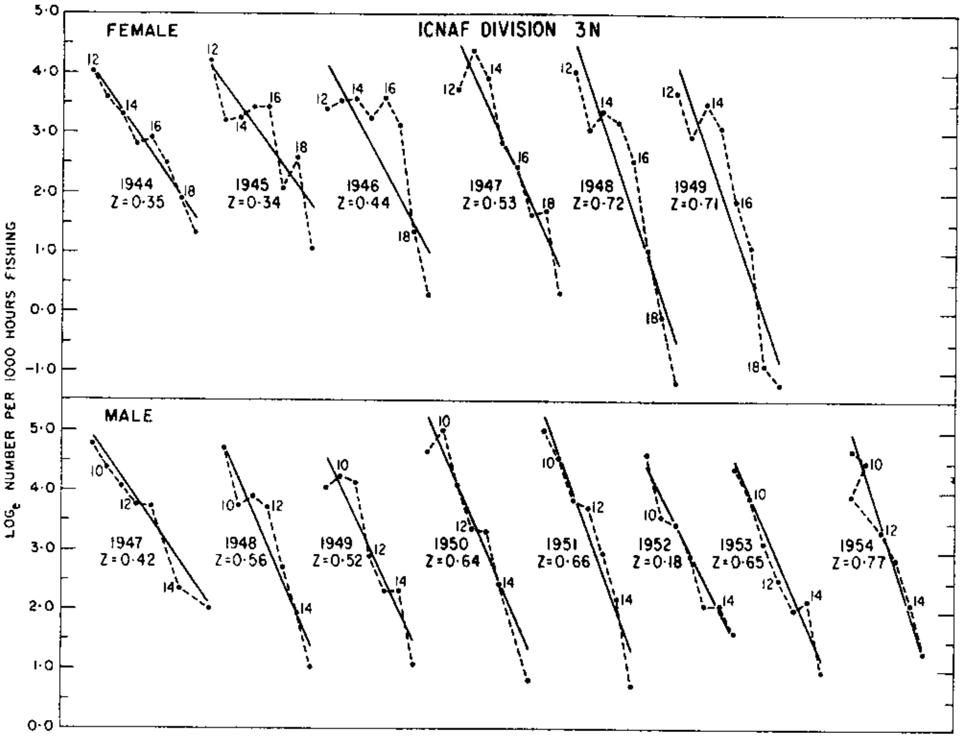

Fig. 16. Catch curves of American plaice from Division 3N, 1944-49 year-class for females and 1947-54 for males. Solid lines represent interpretation of slopes fitted from ages 12 to 19 (females) and 9 to 15 (males).

TABLE 6. Summary of estimates of natural mortality of American plaice.

Method	Division 3L Male	Division 3L Female	Division 3N Male	Division 3N Female
Beverton and Holt	0.27	0.23	0.22	0.16
Paloheimo linear formula	0.22	0.23	0.17	0.18
Z from year-classes	0.25	0.23	0.39	0.21
Average	0.25	0.23	0.26	0.18

Total instantaneous mortality from catch curves of unexploited stocks

St. Mary's Bay – Males = 0.27
– Females = 0.18

Hamilton Inlet Bank – Males = 0.30
– Females = 0.22

correlations. However, for each plot of total average F positive intercepts were produced. Since only one type of gear was used to fish plaice and also since plaice probably do not have marked seasonal distributional patterns, it was felt that the calculation of effort was probably a good measure of fishing intensity. The values of F calculated for the early years appeared to be too high in proportion to the level of fishing effort. It was also possible that effort was underestimated in those early years. Another possible reason why the regression line did not pass through the origin was that M was too low. However, M would have to be increased drastically to produce an appreciable lowering in the values of F. Standard errors of the estimates were all about 0.04.

The estimates of F for 1969 and 1970 from stock size and catches for fully recruited age-groups were compared with those estimates from the fitted lines (Figs. 17 and 18). For all estimates except the 1969 Div. 3N males the F's from the fitted line were higher than the calculated values; the disparity between the two being greater in Div. 3L (Table 5).

Catch-per-unit-effort

Except for a slight rise in 1963-65 the catch per hour of Canada (N) trawlers in Div. 3L has declined steadily since 1958 from about 1,200 kg per hour to 450 kg in 1970 and 430 kg in 1971 (total plaice, Fig. 2). The slight increase in 1963-65 can probably be attributed to the introduction of the stern trawler and the greater demand for this species.

Up to 1962 the main effort in Div. 3N was for haddock. At this time the effort for plaice was relatively low; however, some large catches were made on the virgin stock at the southern part of the bank. With the reduction in the haddock stocks, effort was diverted to plaice and the fleet began fishing previously unfished concentrations along the eastern slope. It was probably this diversion of effort and the introduction of the more efficient stern trawlers that resulted in the increase in catch per hour in the mid-1960's. However, from the peak of about 950 kg (total plaice) in 1964 the catch per hour has declined very rapidly to about 340 kg in 1970 and 281 kg in 1971 (Fig. 2).

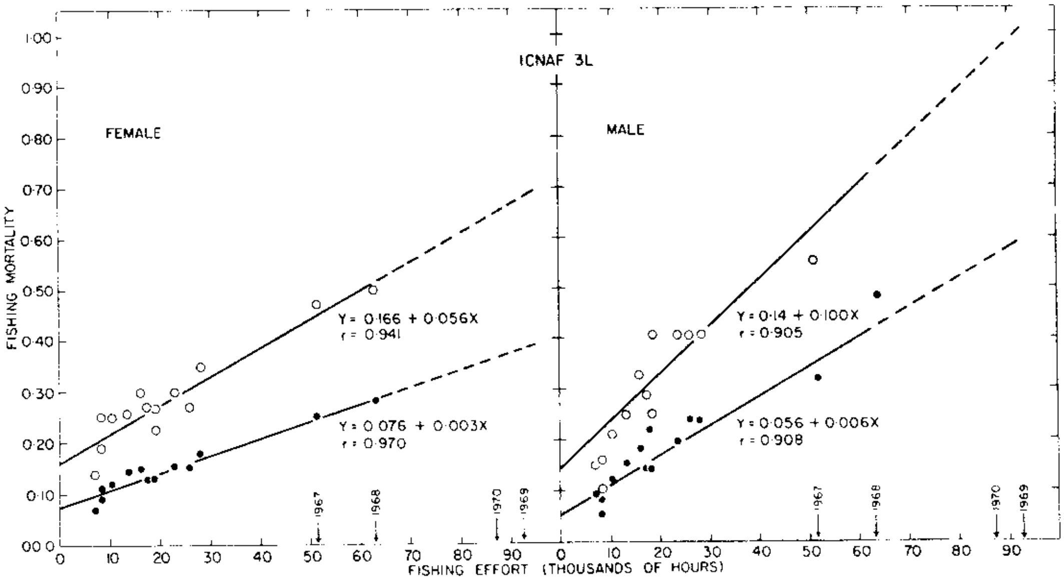

Fig. 17. Regression of mean annual fishing mortality on fishing effort for Division 3L. Open circles are for fully recruited age-groups and solid circles for all age-groups (1955-68 for females, 1955-67 for males).

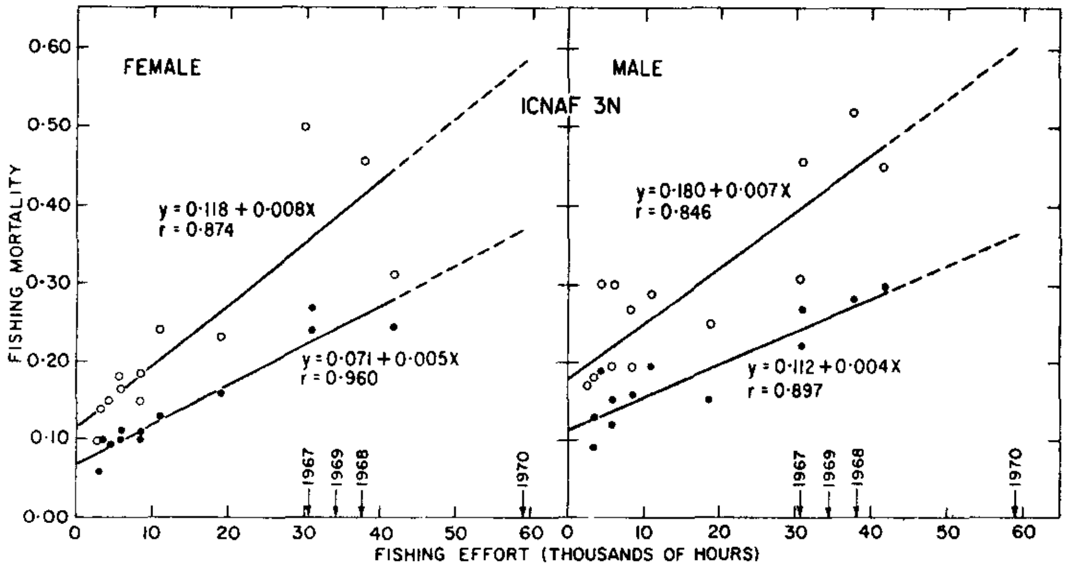

Fig. 18. Regression of mean annual fishing mortality on fishing effort for Division 3N. Open circles are for fully recruited age-groups and solid circles for all age-groups (1956-68 for females, 1956-68 for males).

Stock size (Tables 7 and 8)

For Div. 3L the stock size calculations indicate that the total stock size remained relatively stable until 1966, when an apparent rapid increase occurred in 1967 and 1968. However, since the most recent years and the younger age-groups produce the most unreliable estimates of F from the method used here this may not be real. The size of the fully recruited stock 15 years and up in Div. 3L has however, been reduced by more than a half. In Div. 3N there appears to have been a gradual increase in the total stock size until 1967 when it again began to decline. The size of the fully recruited stock in Div. 3N remained roughly at the same level from 1957 to 1962 when it appeared to increase and remained at approximately the same level until 1967 when the number of fully recruited fish again declined. The 1963-65 period corresponds to an increase in the catch-per-unit-effort, as just noted, which was attributed to a diversion of the effort to previously unexploited areas. If only a portion of the stock was being fished prior to 1964-65, the stock size calculated represented a

TABLE 7. Numbers of plaice present in the stock at the beginning of years 1955-68 (X 10^{-6}) ICNAF Division 3L.

Age	Year													
(years)	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968
10	51.0	61.6	74.3	84.2	45.2	44.7	53.4	65.2	84.9	63.4	61.2	56.5	124.0	170.1
11	31.9	38.8	38.2	31.8	45.2	39.3	34.1	41.2	59.3	57.2	49.6	46.3	48.3	78.2
12	24.1	25.5	28.8	30.4	25.3	39.0	30.1	35.4	31.0	38.7	37.0	40.9	37.6	35.0
13	18.8	17.9	19.6	22.7	23.0	18.7	27.4	24.0	20.7	22.3	26.1	26.6	31.8	26.1
14	12.8	14.2	13.9	14.3	17.0	17.1	11.9	20.6	20.0	13.1	15.5	16.5	18.4	21.8
15	13.4	9.1	12.2	11.1	9.5	11.9	10.9	8.8	14.0	13.8	7.8	9.7	10.6	11.0
16	7.9	9.2	6.2	9.5	7.9	6.5	8.3	8.5	6.1	10.1	7.3	4.6	6.1	6.2
17	9.1	7.2	6.2	4.3	6.0	5.2	3.9	5.8	5.7	3.8	4.8	4.2	2.9	3.7
18	7.8	5.1	5.3	4.6	2.5	3.5	3.0	2.6	3.7	3.8	2.1	4.3	1.8	1.2
19	4.1	4.7	2.5	3.2	3.3	1.3	2.2	1.7	1.4	2.5	1.6	1.3	2.5	0.9
20	3.4	2.5	2.6	1.2	0.9	1.0	0.5	1.0	0.9	0.7	1.4	1.1	0.8	1.3
21	1.8	2.4	2.4	1.4	0.7	0.5	0.6	0.3	0.6	0.5	0.6	0.7	0.5	0.4
22	3.6	1.7	2.2	1.6	0.9	0.4	0.3	0.4	0.2	0.3	0.3	0.3	0.3	0.4
22+	3.6	2.5	1.4	1.9										
Total 10+ years	193.3	202.4	215.8	222.2	187.4	189.1	186.6	215.5	248.5	230.2	215.3	213.0	285.6	356.2
Total 15+ years	54.7	44.4	41.0	38.8	31.7	30.3	29.7	29.1	32.6	35.5	25.9	26.2	25.5	25.1

TABLE 8. Numbers of plaice present in the stock at the beginning of years 1956-68 (X 10^{-6}) ICNAF Division 3N.

Age (years)	Year												
	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968
9	9.3	9.6	13.5	18.1	20.4	18.1	17.9	32.4	39.5	36.9	38.0	28.6	28.4
10	7.9	7.4	7.9	10.1	12.5	15.5	16.0	14.2	23.7	29.8	25.7	24.7	18.5
11	9.2	5.9	6.8	5.8	7.5	9.4	11.9	14.7	10.8	14.6	18.3	17.0	16.0
12	3.5	6.0	4.1	3.8	4.7	5.5	7.2	9.2	9.3	8.6	9.5	10.5	11.1
13	4.3	2.6	4.1	3.5	2.5	4.6	4.1	5.1	6.9	5.4	4.7	2.8	5.8
14	2.9	3.3	1.9	2.5	1.9	1.5	2.2	3.1	3.5	4.7	3.7	1.7	1.1
15	2.4	1.4	2.4	1.3	1.5	1.1	0.9	1.6	1.8	2.5	3.0	1.8	0.9
16	0.9	1.5	1.0	1.7	0.7	1.1	0.7	0.5	1.0	0.6	1.7	2.8	0.9
17	0.9	0.7	0.8	0.6	1.2	0.4	0.7	0.5	0.3	0.6	0.5	1.1	0.5
18	0.5	0.6	0.4	0.6	0.3	0.9	0.2	0.5	0.3	0.2	0.2	0.4	0.5
19	0.4	0.4	0.4	0.3	0.5	0.2	0.5	0.1	0.3	0.2	0.2	0.2	0.3
20	0.9	0.3	0.3	0.3	0.3	0.4	0.2	0.3	0.1	0.1	0.1	0.3	0.1
21	0.7	0.6	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.04	0.09	0.08	0.1
21+		0.4	0.4		0.2	0.1	0.1	0.3					
Total 9+ years	45.0	40.7	44.2	48.8	54.4	59.0	62.9	82.7	97.7	104.2	105.7	92.0	83.1
Total 13+ years	13.9	11.8	11.9	11.0	9.3	10.5	9.9	12.2	14.4	14.3	14.2	11.2	10.2

portion of the stock only. In Div. 3L, on the other hand, the whole area has been fished fairly evenly since the start of the fishery.

Discussion

Division 3L

Even with the big disparity between the estimated value of F for the fully recruited males and females in 1968, 0.92 and 0.50 respectively, the position on the yield curve ranges from 80 to 85% of the maximum yield (Fig. 8). The optimum F in Div. 3L occurs at 0.50 which is about 80% of the maximum yield. In 1968 total landings were about 37,000 tons. The 1969 catch of about 50,000 tons gave probable fishing mortality rates of 0.89 to 1.0 for males and 0.67 to 0.55 for the females (Table 5); thus apparently well beyond the "optimum yield". For 1970 with 40,000 tons landed the ranges of F were apparently 0.65 to 0.95 for males and 0.48 to 0.65 for females, again above the optimal level, but less than 90% of the maximum.

The catch per hour by Canada (N) trawlers (Fig. 2), which accounts for 90-95% of the catch has declined drastically especially since 1967. The 1971 landings in Div. 3L were down slightly to about 37.0 thousand tons with the catch per hour by Canada (N) declining only slightly from 450 kg in 1970 to 431 kg per hour in 1971.

It is suggested that the landings of plaice from Div. 3L should not exceed 40,000 tons and possibly should be even lower at 35,000 tons. This is close to the 1967 level (F = 0.55 for males and 0.46 for females) with total landings at 37.5 thousand tons.

Division 3N

For Div. 3N the 1967 and 1968 estimates of F for males and females were in the 0.46 to 0.52 range (Tables 3 and 4) with landings of 25,000 and 21,000 tons. The levels of fishing in these years were apparently beyond the calculated optimal value (0.40) (Fig. 8). The probable values of F in 1969 when 15,000 tons were landed were males 0.44 and females 0.37 or close to the optimum F. In 1970 with 20,000 tons landed probable F levels were 0.50 to 0.59 for males and 0.48 to 0.57 for females, again beyond the optimal level.

The catch per hour by Canada (N) has declined very rapidly since 1964 and slipped to 280 kg in 1971 (Fig. 2) with total landings about 22,000 tons.

A total landing of not more than 20,000 tons is suggested at the most and even 15,000 tons may be more realistic.

General

Minimal fluctuation in year-class strength apparently occurs with probably no complete failure as reported in some species. This is on the plus side and helps preserve a stable stock provided fishing pressure is not too great. However, because of the slow rate of growth of this species, the restoration of the fishable biomass is relatively slow. Furthermore, it is not known what effects a drastic reduction in the spawning stocks would have on the population. This may be doubly important in the case of a stock like Div. 3N which probably depends on recruitment from the more northerly Div. 3L stock.

Acknowledgements

The author is indebted to members of the St. John's Station for suggestions in the presentation of the data. I am particularly indebted to Mr A. T. Pinhorn of this Station for the many discussions and suggestions in the preparation of this manuscript. I am also very grateful to Messrs C. A. Rose and C. Butt for the laborious work of age reading and in the calculations involved.

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Note on the Occurrence of Larval *Anisakis* in Adult Herring and Mackerel from Long Island to Chesapeake Bay

By B. Lubieniecki[1]

Abstract

Samples of herring and mackerel collected in April and May 1971 from Long Island to Chesapeake Bay (ICNAF Divisions 6A and 6B) were found to have lower levels of infestation by larval nematodes of the genus *Anisakis* (2-11% incidence for herring and 9-30% incidence for mackerel) than those reported for herring in ICNAF Subareas 3 and 4 and in most areas of the Northeast Atlantic. The absence of significant variability in the infestation of both herring and mackerel suggests that the populations of the two species in the area investigated are homogeneous. The relationships between nematode intensity and fish length showed gradually increasing trends in intensity with fish size, the trend for mackerel being more pronounced than that for herring.

Materials and Methods

In April and May 1971, 1,200 herring and 2,200 mackerel were examined for larval nematodes. Samples of 100 specimens each were taken mainly from midwater trawl catches in various parts of Divisions 6A and 6B of ICNAF Statistical Area 6. Total length measurements of the fish ranged from 20 to 37 cm for herring and from 21 to 48 cm for mackerel. Based on the maturity scale adopted by ICNAF (1964), the herring examined were classed as stages III and IV and the mackerel as stages IV, V, and VI. All specimens were examined in the fresh condition, and nematode larvae were collected from various body organs and cavities as follows: liver, intestine and mesenteries, pyloric caecae, stomach, gonads, peritoneal cavity, and musculature. Nematodes were examined microscopically and identified as *Anisakis* by the following characteristics: (1) ventriculus between oesophagus and intestine with oblique joint between vestriculus and intestine, (2) excretory pore situated ventrally of the boring tooth in front of the head, and (3) three anal glands near the rectum.

Results

In both herring and mackerel the greatest numbers of larval nematodes were found encapsulated on the intestine and mesenteries and on the stomach (Fig. 1) with considerably fewer larvae on the liver, plyloric caecae and gonad and in the peritoneal cavity and the flesh. About 1% of the nematodes were found in the flesh of herring but none were found in the flesh of mackerel.

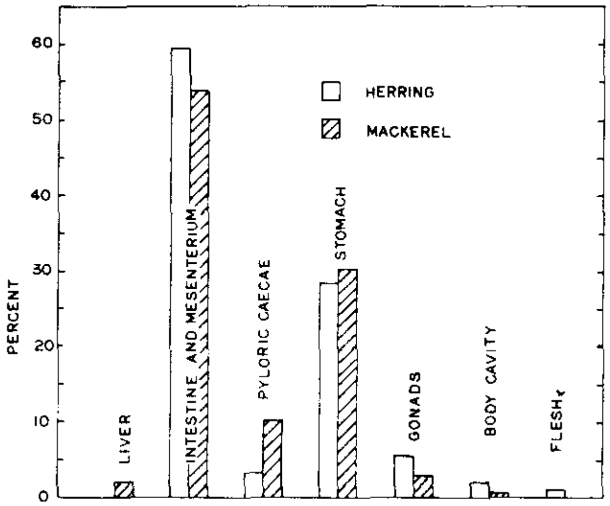

Fig. 1. Site of larval nematodes in herring and mackerel.

The geographical distribution of the herring and mackerel samples (Fig. 2) indicate that both the incidence (percentage of fish infested) and mean intensity of infestation (average number of nematodes per infested fish) varied only slightly throughout the area studies. The incidence in herring ranged from 2 to 7% in all samples except in the two (10 and 11%) taken east of Long Island in the northern part of the area. The incidence in mackerel generally ranged from 9 to 23% but one sample taken southeast of Long Island had a

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value of 30%. The nematode intensity in herring varied from 1.0 to 2.1 with no obvious geographical trend, while in mackerel intensity values ranged from 1.1 to 2.6 with most of the higher values in the northern part of the area (Fig. 2).

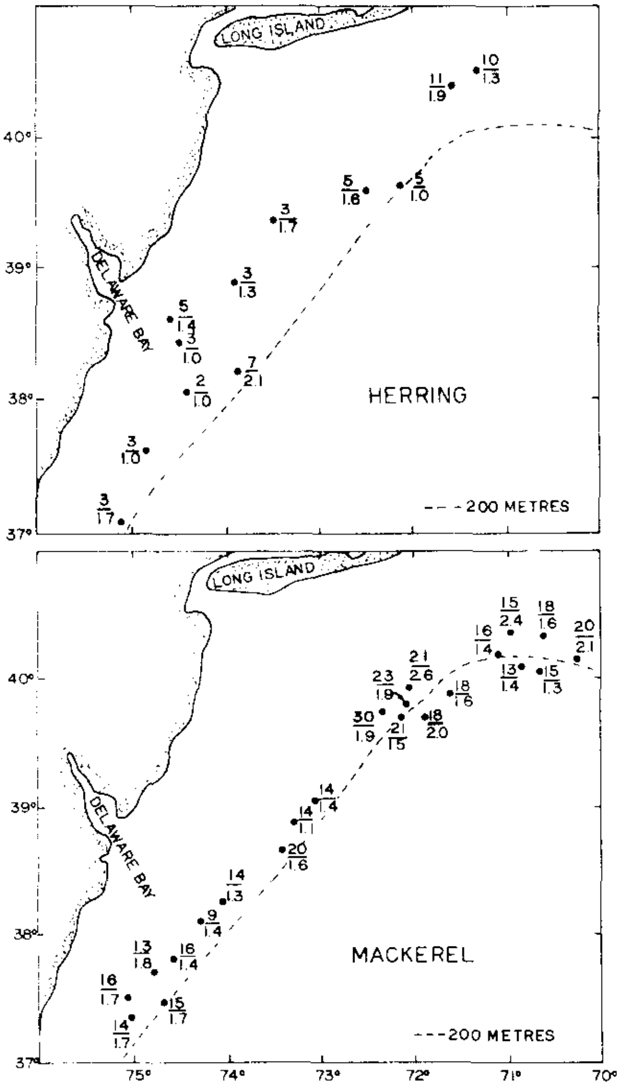

Fig. 2. Larval nematode incidence (numerator) and mean intensity (denominator) of infestation in herring and mackerel at sampling locations in ICNAF Statistical Area 6.

The relationships between nematode intensity and fish length (Fig. 3) indicate that for both herring and mackerel there is a gradually increasing trend in intensity with increase in fish size. In mackerel the mean number of larvae per infested fish increased from about 1.0 to 26-31 cm fish to about 3.0 in 44-45 cm fish, while in herring the trend is less obvious over most of the range of sizes of fish examined. The highly fluctuating intensity values for fish in the upper parts of the size ranges are due to the very small numbers of specimens of these sizes in the samples.

Conclusions

The above results show that herring and mackerel have a similar degree of infestation of larval *Anisakis*, which is very low when compared with somewhat higher levels of infestation reported by Parsons and Hodder (1971) for herring in the Newfoundland and Nova Scotian areas and with the much higher levels reported by Khalil (1969) for herring in British coastal waters.

Parsons and Hodder (1971) concluded, from the incidence and intensity of infestation of adult herring by larval *Anisakis* in Canadian Atlantic waters, that the parasite is valuable as a biological indicator of stock heterogeneity. If their conclusion is considered relevant to other herring stocks of the Northwest Atlantic and to other species infested by *Anisakis*, the absence of significant variability in the infestation of both herring and mackerel in the present data suggests the presence of homogeneous populations of the two species in the area investigated.

The slightly higher larval incidence in the mackerel samples compared with those of herring (Fig. 2) may in part be attributed to the somewhat higher intensity in the larger sizes of mackerel (Fig. 3) and in part to differences in diet. In general, more food was found in the stomachs of mackerel than of herring, and macroplanktonic crustaceans (some of which are assumed by some investigators to be the first intermediate host) were more often found in mackerel whereas *Sagitta* occurred more frequently in herring. As far as the final host is concerned, of the many marine mammals suspected by some authors as being final hosts, the common dolphin, *Delphinus delphis* L., the false killer whale, *Pseudorca crassidens* (Owens), and other unidentified whales were observed during the research cruise in the region investigated – 37°N to 41°N lat.

Acknowledgements

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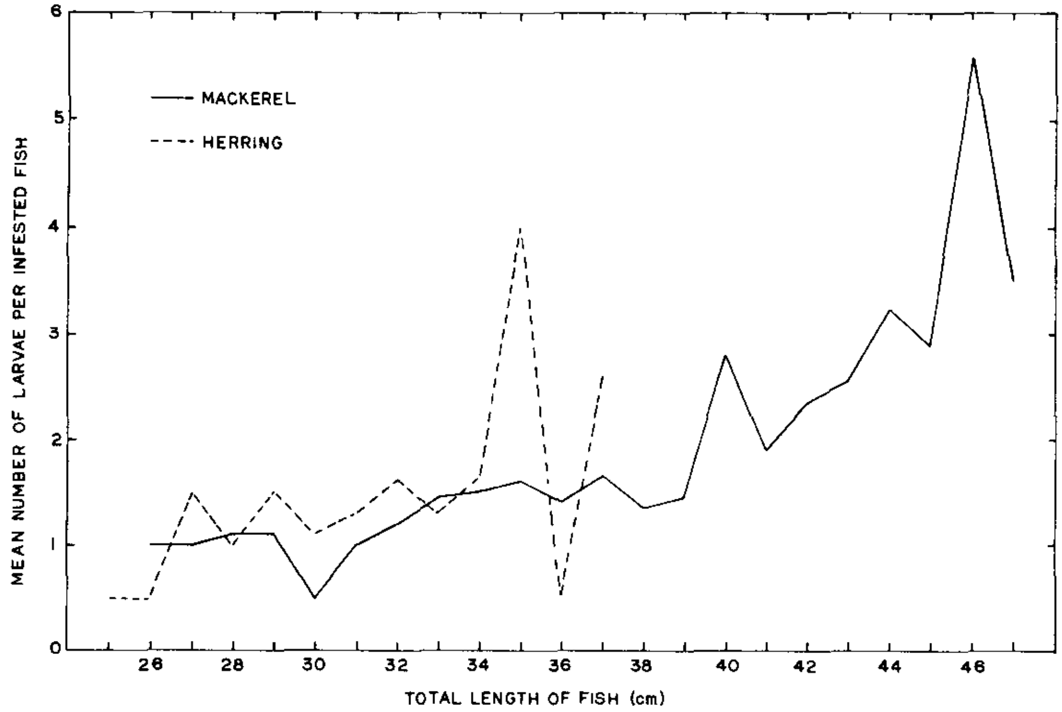

Fig. 3. Relation between mean number of *Anisakis* larvae per infested fish and total length of fish in samples taken in ICNAF Statistical Area 6.

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Distribution and Abundance of the Greenland Halibut, *Reinhardtius hippoglossoides* (Walbaum), in the Northwest Atlantic

By Wilfred Templeman[1]

Abstract

This paper provides information on research catches of Greenland halibut, *Reinhardtius hippoglossoides,* in the Northwest Atlantic in relation to area, depth, and temperature, and also deals with commercial landings of Greenland halibut from this area.

Greenland halibut are most plentiful in northern areas from the Northeast Newfoundland Shelf and the deep cold bays off the east coast of Newfoundland to off Baffin Island and to West Greenland, where temperatures ranging from – 1°, or more usually – 0.5°, to 3°C occur more deeply over large areas than farther south or at the continental slope. Farther southward, where such cold water is less abundant and shallower, Greenland halibut are commercially scarce. Essential also is a neighbouring deepwater spawning area with slightly higher temperatures, where Greenland halibut may be plentiful, especially at spawning season. Young fish are abundant where currents take the gradually descending fry from the spawning ground into moderately deep and moderately cold water.

The largest commercial landings from the Northwest Atlantic in recent years were from ICNAF Division 3K, possessing a broad shelf with deep water colder than in the same depths at the continental slope.

Smaller Greenland halibut are shallower and the depth range of Greenland halibut extends from usually more than 90 m to 1,460-1,600 m. They were not found at 1,810-2,360 m. Good commercial catches are often taken between 300 and 900-1,100 m. Peak landings of 40,000 metric tons of Greenland halibut were taken in the Northwest Atlantic in 1969. Landings decreased to 29,000 metric tons in 1971. Great catch decreases occurred rapidly in a bottom gillnet fishery for Greenland halibut in Trinity Bay, Newfoundland.

Introduction

The Greenland halibut, *Reinhardtius hippoglossoides* (Walbaum), was exported from Newfoundland at least as early as 1857. By 1916, Newfoundland exports of salted Greenland halibut (turbot) equalled 590 metric tons (subsequently called tons) fresh. Newfoundland landings remained at the 250-900 ton level until 1964 when the landings began to increase to supply a market for the fresh Greenland halibut in the United States and to a smaller degree in Europe. The only other significant early fishery for Greenland halibut was by Greenlanders in the West Greenland fjords, which by 1915 produced about 400 tons in yearly landings and which from 1915 to 1958 varied between less than 100 and about 1,100 tons, increasing to a peak of 3,045 tons in 1965. From 1964, European countries fishing in deep water for redfish and roundnose grenadiers increasingly landed Greenland halibut which is often an important by-catch in these deepwater fisheries. Landings of Greenland halibut from the Northwest Atlantic reached their peak of 40,000 tons in 1969 and have since declined (Fig. 5; Lear, MS 1970*b*; Templeman, 1966; Smidt 1969, MS 1969; ICNAF, 1952-72; Hodder, MS 1973).

This paper provides and reviews information on catches of Greenland halibut in the Northwest Atlantic by research and exploratory vessels, relative to area, depth and temperature, and also deals with commercial landings of this fish in relation to ICNAF subareas and divisions and by various countries. The Northwest Atlantic place names used in the text are shown in Fig. 1 and ICNAF subareas and divisions in Fig. 6.

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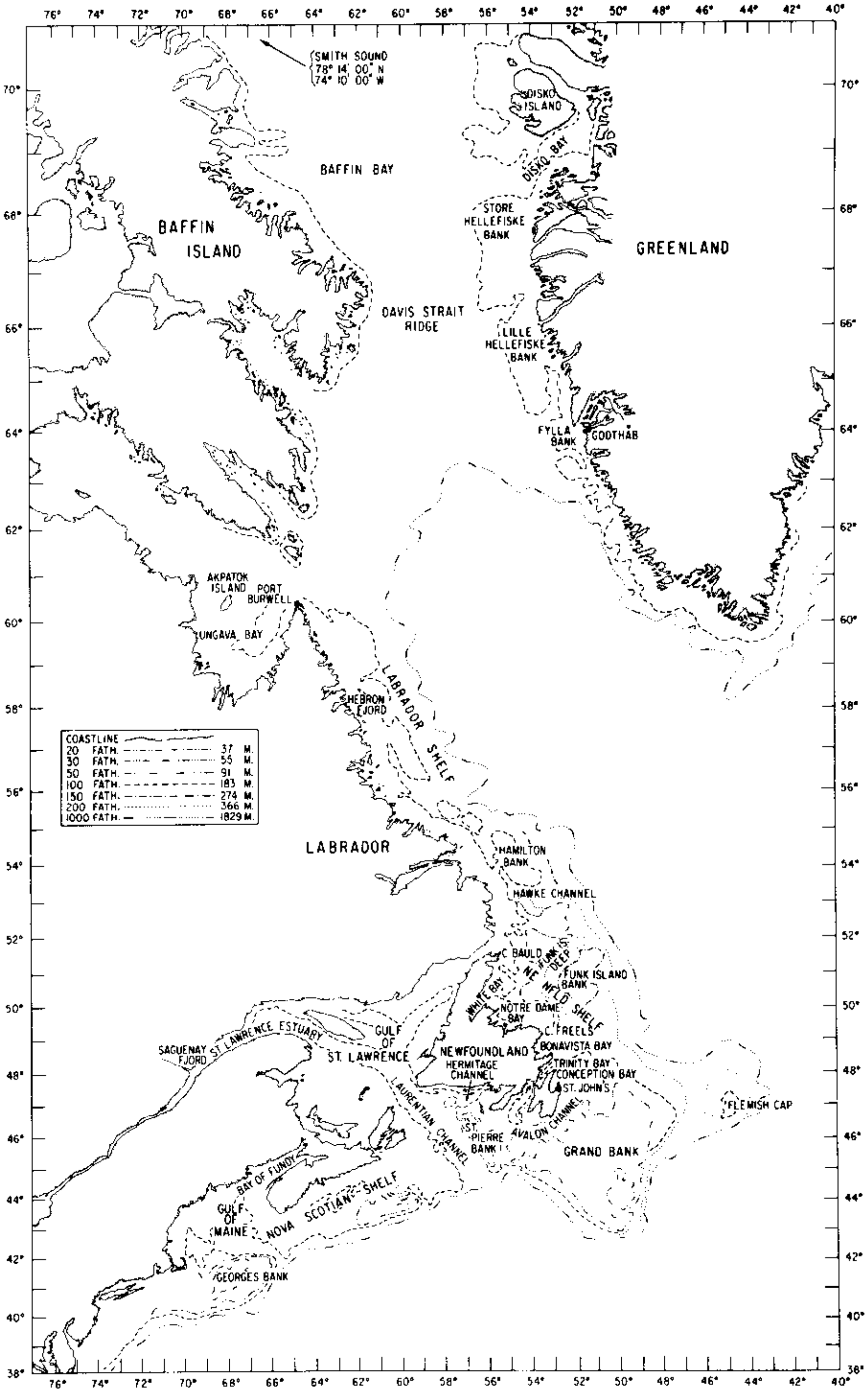

Fig. 1. Map showing places mentioned in the paper.

Materials and Methods

The information on distribution and abundance of Greenland halibut in relation to area, depth and temperature was obtained from the catches of the Canadian research vessels *A. T. Cameron* and *Investigator II*. Mainly used were data from otter-trawling sets of the *A. T. Cameron* (1958-66) using a No. 41-5 Yankee otter trawl (24.1-m headrope) towed usually at about 3½ knots. In the deepest sets at about 730 m the towing speed was sometimes 3 knots. In areas where data from these *A. T. Cameron* catches were lacking, information was obtained from catches of the *Investigator II* (1947-65) using a No. 36 Yankee otter trawl (18.3m-headrope) usually towed at 3½ knots, and from catches of the *A. T. Cameron* and *Investigator II*, using a ¾ 35 trawl (11.9-m headrope) towed on a single wire at 2½ knots *(A. T. Cameron)* and at 3½ knots *(Investigator II)*. For all sets the trawl was towed for 30 min on bottom. The codend was usually lined by a 29-mm-mesh nylon liner, but for sets during the early years of the surveys by the *Investigator II*, the codend liner consisted of 45-mm-mesh manila. The research vessel sets were exploratory and were made at positions unselected for abundance of Greenland halibut. Otter-trawling sets in which the trawl was so badly injured, or for other reasons in such poor fishing order as to interfere seriously with taking or retaining a normal catch were not used in the distribution maps (Figs. 2 and 3). Occasionally when trawl data were lacking in an area, data from longline sets were used. For purposes of the distribution maps (Figs. 2 and 3), the longline catch of Greenland halibut from 450 hooks (3.7 m apart) was arbitrarily used as the equivalent of a 30-minute set by the No. 41-5 trawl. Catches of Greenland halibut taken by the *A.T. Cameron* were recorded by total weight (weighed on the ship) and number of fish. Usually, weight estimates only are available from the catches of the *Investigator II*. Otter-trawling on the slopes was as far as possible carried out on a depth contour at predetermined depths in fathoms. At the end of the set a near-bottom temperature was taken, approximately at the depth of the set.

The catches shown in Fig. 3 off Baffin Island south of 67°N and west of 58°W, in Ungava Bay and off the northern third of Labrador were taken by the *A. T. Cameron*, 18 August-14 September 1959 (Templeman and Squires, MS 1960; F.R.B., 1961; Templeman 1961, 1966). The Northeast Newfoundland Shelf including Funk Island Bank and Funk Island Deep, the eastern and southwestern Grand Bank, the Gulf of St. Lawrence, and the Nova Scotian Shelf were first investigated by the *A. T. Cameron* in 1959; the southern two-thirds of the Labrador Shelf and St. Pierre Bank in 1960, Flemish Cap in 1958 and 1961. Apart from Baffin Island, Ungava Bay, and Northern Labrador, the area was investigated by the *A. T. Cameron* at least several additional times in subsequent years to 1966. The fishing in West Greenland was in late July-August 1965. Sets extended from the shallowest water of the banks to about 730 m on the slope. The *Investigator II* explorations in 1947-65 covered the same area many times except West Greenland, off Baffin Island, Ungava Bay, and the Nova Scotian Shelf using smaller trawls, but the results are used here only when *A. T. Cameron* data are lacking. These investigations were before great catches of Greenland halibut on the continental shelf and slope of the Northwest Atlantic had seriously reduced these populations. Subsequent trawling by the *A. T. Cameron* has not often reached as great depths as were annually trawled in 1958-66 so that the period up to 1966 is a convenient one for comparison of research vessel catches of Greenland halibut by area and depth.

Commercial landings of Greenland halibut were also reviewed from ICNAF statistics (ICNAF, 1952-72; Hodder, MS 1973). Some assumptions and calculations are necessary for assessing the landings of Greenland halibut from these statistics. In 1967-68 for the USSR and 1966-68 for non-members (apart from Subarea 1 in 1966 for which Greenland halibut, only, were reported by non-members) landings of Greenland halibut were included with those of Atlantic halibut. For 1969 the USSR and non-member A (the German Democratic Republic, GDR) reported Greenland halibut but no halibut. For 1966 the nominal landings of halibut (Greenland halibut in Subarea 1) by non-members were divided between halibut and Greenland halibut for each division of Subareas 1 and 2 on the basis of landings of Greenland halibut and halibut from these divisions by the Federal Republic of Germany, Ger (FR), and where division information was lacking, by the ratios of these species in Ger. (FR) landings for the subarea; and in Subarea 3 similarly, using Polish landings. For each year of 1967-69 for the USSR and for non-members, the nominal landings of halibut (or Greenland halibut) were divided between Greenland halibut and halibut in the various ICNAF divisions in the above manner in proportion to the averages from division totals for 1967-69 of these two species for Ger. (FR) in Subarea 1 and for Poland in the other subareas. Landings of 57 tons of Greenland halibut in 1969 and 17 tons in 1970 by non-member B (Bulgaria) were assigned to the total ICNAF landings only.

The USSR landings for 1970 and the GDR landings for 1970 and 1971 were reported as Greenland halibut, no halibut being reported. In 1971, the USSR reported both Greenland halibut and halibut for Divisions 3M, 3N, and 3O but only Greenland halibut for the more northern divisions. By 1970, nominal landings of halibut from Subareas 1 and 2 and the northern divisions of Subarea 3 had become very small. For 1970 and 1971, the nominal landings of Greenland halibut reported by the USSR and the GDR for the northern divisions as far south as Div. 3L were accepted as Greenland halibut, and it was assumed that the included landings of halibut were negligible. Nominal USSR and GDR landings in 1970 south of 3L, where a greater proportion of the landings consists of halibut, were divided between Greenland halibut and halibut by the ratios of the landings of these two species by the USSR in these divisions in 1971. Landings of 660 tons of Greenland halibut by Norway from 3NK in 1970 were considered to be mainly from longlines and have been allotted 600 tons to 3K and 60 tons to 3L. Nominal landings by Romania of 107 tons of Greenland halibut but no Atlantic halibut from Division 5Z in 1970 and of 22 tons from this division in 1971 were deleted from the Greenland halibut statistics. It is assumed that the nominal USSR landings of halibut for 1968-69 and of Greenland halibut for 1969-70 (Konstantinov and Noskov, 1972) from the Baffin Island area were all Greenland halibut. Norwegian landings of Greenland habilut from Subarea 1 in 1971 were assigned to division on the basis of the average Ger. (FR) landings of this species in 1967-70 from the divisions of Subarea 1.

Distribution of Research Vessel Catches of Greenland Halibut

Research vessel catches of Greenland halibut were greatest in the deeper water of the Davis Strait Ridge and were next largest in the slope water farther south off

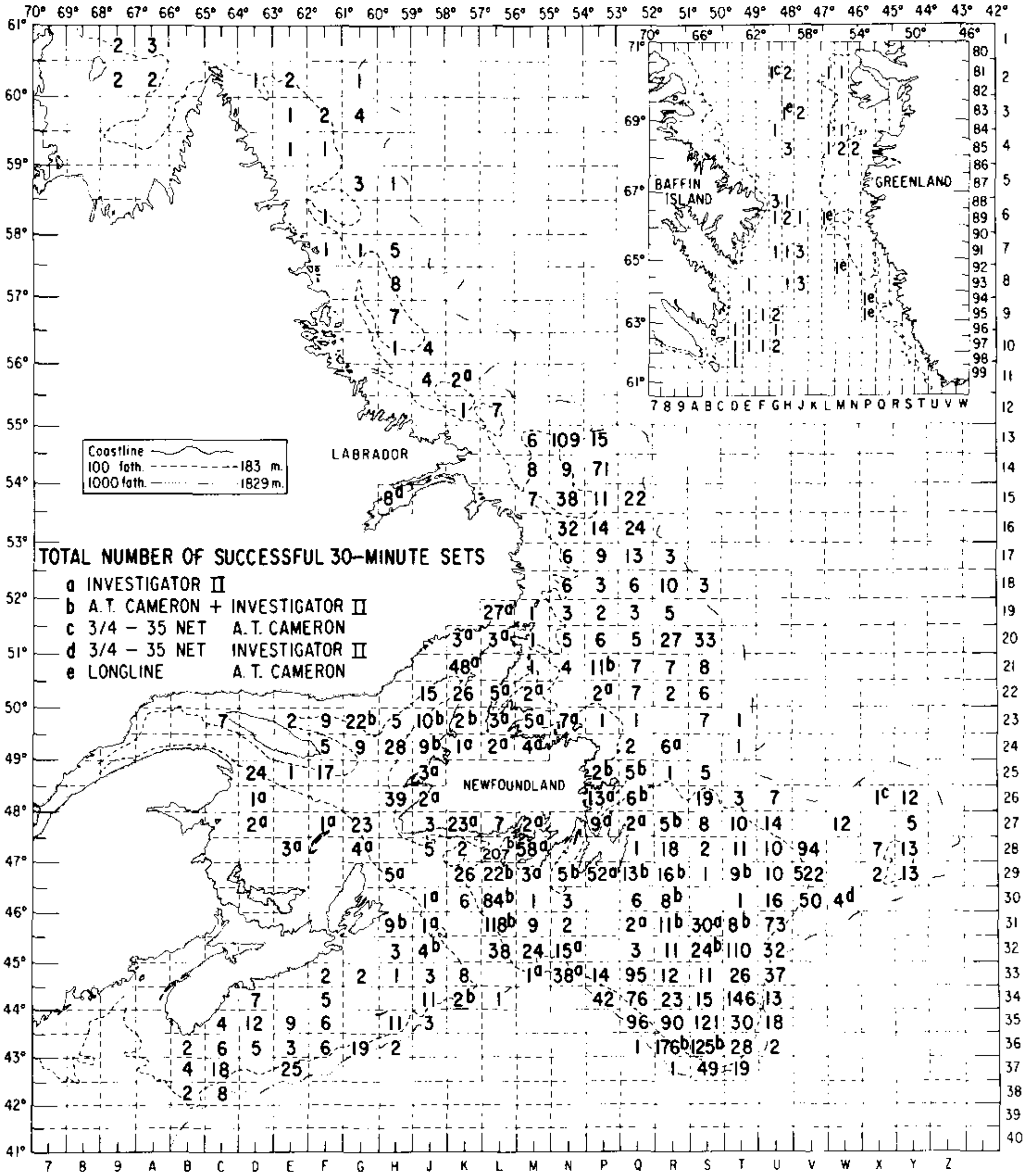

Fig. 2. Number of successful (net not badly *injured* and fishing properly on bottom) otter-trawling sets of the research vessels *A. T. Cameron* and *Investigator II* in various rectangles and used for the averages in Fig. 3. (The large number of sets in several rectangles is the result of selection experiments. Sets without an indicator letter are those of the *A. T. Cameron.*)

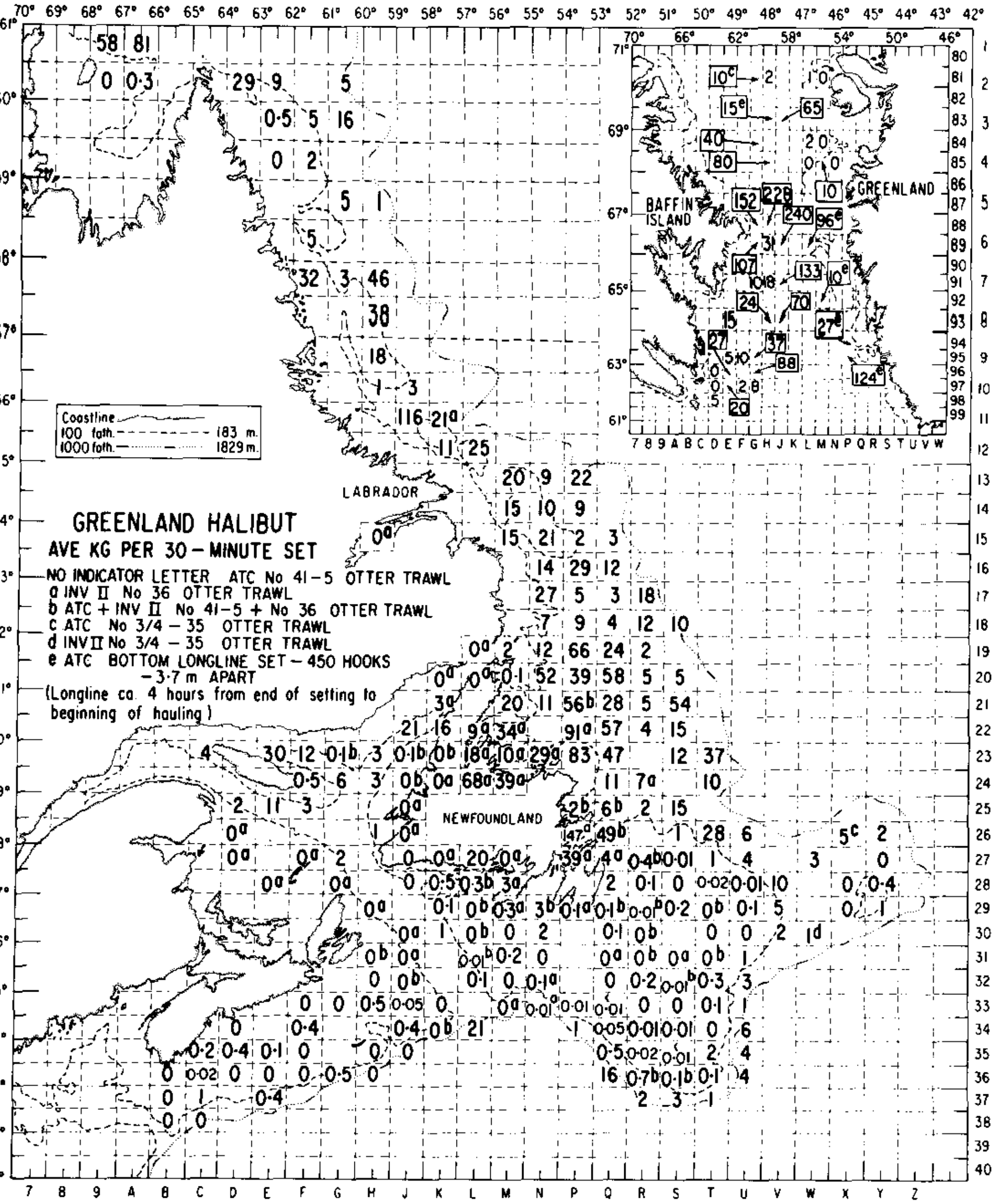

Fig. 3. Average catch of Greenland halibut, kg whole weight by ½ degree latitude, 1 degree longitude rectangle per 30-min on bottom otter-trawling set of the *A. T. Cameron* in 1958-66. (Where information from the *A. T. Cameron* is lacking, sets of the *Investigator II* for 1947-65 were used.

Baffin Island, off West Greenland, in Ungava Bay, off Labrador, the Northeast Newfoundland Shelf, Notre Dame Bay, and Trinity Bay (Figs. 2 and 3). Southward from these areas, the catches of Greenland halibut were much smaller and much more irregular. Small quantities were taken on the eastern and southeastern slopes of the Grand Bank in the path of the eastern cold branch of the Labrador Current. Farther west, occasional moderate catches were obtained, as at the mouth of the Laurentian Channel, in Hermitage Channel on the south coast of Newfoundland and in the northern and western extremities of the northern channels of the Gulf of St. Lawrence. Greenland halibut were scarce at Flemish Cap, in all bank areas less than 180 m in depth, and along the seaward slope and the deep water areas of the Scotian Shelf.

TABLE 1. Average weight (kg) of Greenland halibut catches per successful 30-min trawl set in relation to depth and bottom temperature for various areas of the Northwest Atlantic, based (apart from "Inshore Nfld.") on *A.T. Cameron* catches during 1958-66. (Number of sets in parenthesis.)

	West Greenland	Baffin Island North of 65°30'N	Baffin Island South of 65°30'N	Ungava Bay	Northern Labrador (2G,2H)	Southern Labrador and Eastern Newfoundland (2J,3K,3L)	Flemish Cap (3M)	Southern Grand Bank and St. Pierre Bank (3N,3O,3P)	Gulf of St. Lawrence (4R,4S,4T)	Scotian Shelf (4V,4W,4X)	Inshore Nfld.[a]
Depth	July-Aug.	Aug.	Aug.-Sept.	Sept.	July-Oct.	Jan.-Dec.	Mar.-Nov.	Jan.-Nov.	Jan.-Dec.	Nov.-Dec.	Jan.-Dec.
Fathoms (Meters)	Catch °C	Catch °C	Catch °C	Catch °C	Catch °C	Catch °C	Catch °C	Catch °C	Catch °C	Catch °C	Catch °C
0-25 (0-47)	0(2) 4.9	–	–	–	–	–	–	0(70) 2.5	0(3) 2.0	0(2) 6.3	0(9) 5.9
26-50 (48-92)	0(1) 1.7	–	–	0(1) 2.0	–	0(26) 0.2	–	0.1(643) 1.9	0(10) 0.8	0(18) 3.4	0(11) 2.2
51-75 (93-138)	0(2) -0.3	–	–	0(2) 0.6	0.6(3) 0.4	0.1(60) -0.3	–	0.1(160) 2.0	0(18) 0.3	0(41) 4.2	0.1(30) 0.2
76-100 (139-184)	0(1) 2.4	–	–	–	5(13) 0.4	9(145) 0.7	0(10) 3.6	0.6(277) 2.7	4(29) 2.0	0.1(39) 4.9	1(20) 0.3
101-125 (185-229)	0(1) 3.0	–	2(2) -0.9	0.5(1) -0.6	6(10) 1.0	5(204) 1.7	0(6) 3.8	0.5(133) 3.6	4(61) 3.4	0.2(25) 5.9	2(53) 0.4
126-150 (230-275)	3(1) 0.8	200(1) -1.1	–	–	18(9) 2.5	10(150) 2.3	0(5) 3.8	2(75) 4.3	10(46) 4.4	0.2(16) 5.3	21(21) -0.5
151-200 (276-367)	1(2) 3.2	94(3) -0.2	14(3) 1.5	61(3) 0.4	41(8) 2.4	7(695) 2.9	0(14) 4.0	2(70) 3.3	8(48) 4.7	0(17) 5.2	74(29) 0.4
201-250 (368-458)	45(3) 2.3	2(1) 3.6	39(2) 1.5	–	68(7) 3.8	12(46) 3.5	1(8) 3.8	2(20) 3.4	4(6) 4.8	1(13) 4.8	155(3) 0.4
251-300 (459-550)	155(2) 2.3	64(3) 1.5	31(3) 3.3	90(2) 1.5	87(1) 4.1	41(31) 3.6	0.4(6) 3.8	4(20) 3.5	15(2) 4.4	1(8) 4.6	–
301-350 (551-641)	240(1) 1.0	192(1) 1.0	2(1) 4.1	–	77(2) 4.3	25(20) 3.7	2(7) 3.7	15(8) 3.6	–	5(5) 4.5	–
351-400 (642-732)	75(3) 2.2	228(1) 1.2	19(2) 3.9	–	55(1) 3.5	29(14) 3.6	2(5) 3.7	12(12) 3.7	–	0.7(6) 4.3	–
401-500 (733-915)	121(1) 3.4	–	–	–	89(2) 4.2	35(9) 3.7	10(4) 3.5[b]	9(6) 3.9	–	1(5) 4.3	–
501-825 (916-1510)	6(2) 0.2[c]	–	–	–	–	–	2(3) 3.5[c]	–	–	–	–

[a] Newfoundland east and southeast coast bays and neighbouring coastal areas, *A.T. Cameron* and *Investigator II* (1947-66). [b] Part of catch in 3/4 35 otter trawl. [c] 3/4 35 otter trawl.

Successful sets are those in which the trawl was not injured enough to reduce the catch considerably.

Research vessel catch of Greenland halibut by depth and temperature

Greenland halibut are often relatively numerous in deepwater areas where low temperatures of about −1° to 3°C are found at considerable depths, as in West Greenland, Baffin Island, and the deep bays of eastern Newfoundland, and also in deepwater areas of the continental slope at slightly higher temperatures (Table 1, Fig. 4). Their presence in the latter locations, as in

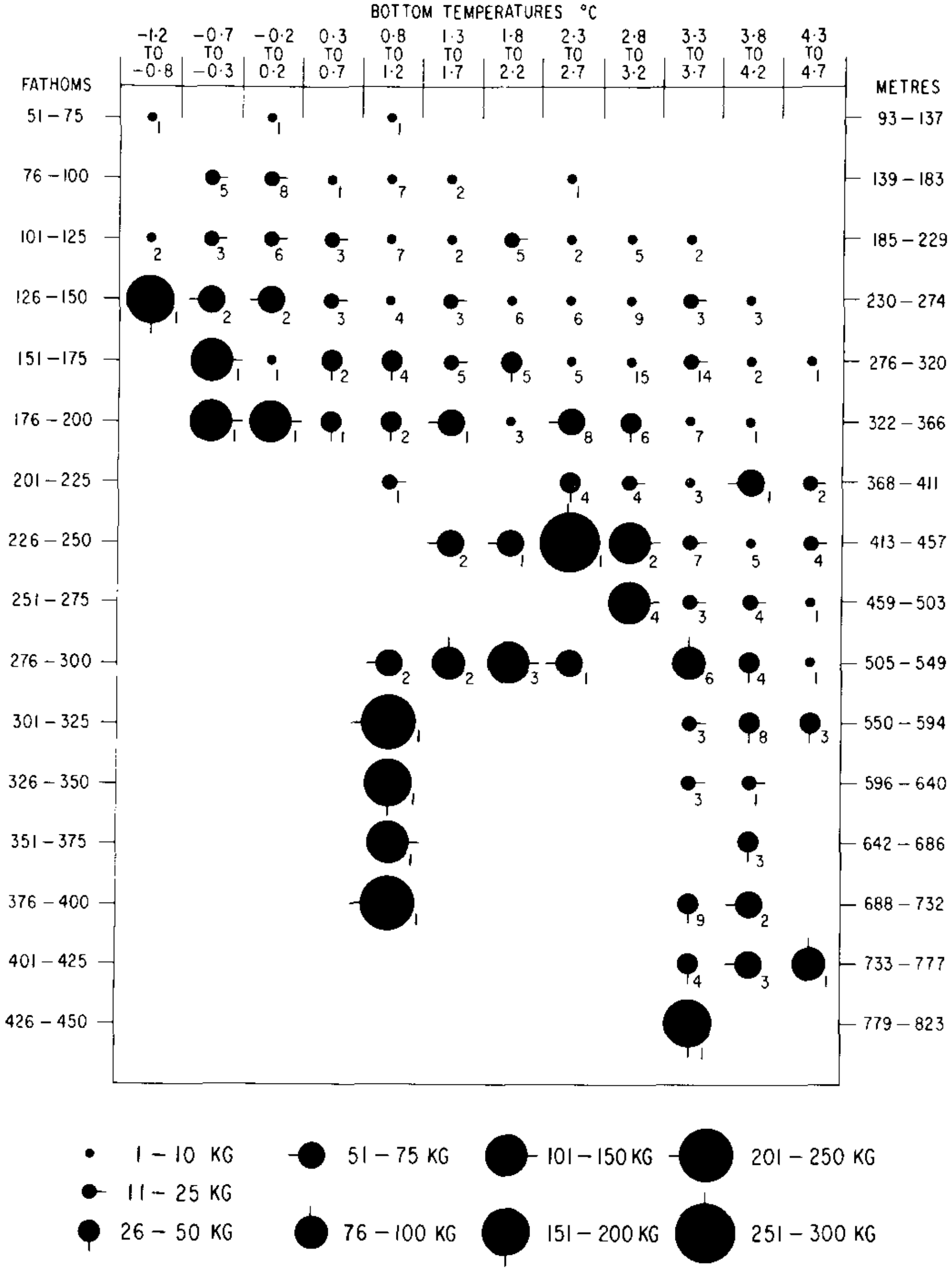

Fig. 4. Average catch of Greenland halibut, kg whole weight, per 30-min on bottom otter-trawling set of the *A. T. Cameron* at various depths and bottom temperatures, 1958-66 off West Greenland, Baffin Island, Ungava Bay, Subarea 2 and Division 3K. (The number of sets included in the average is at the lower right of each indicator sign and the results of large numbers of repeated hauls in one place in selection experiments are omitted.)

Divs. 2G, 2H of Table 1, is often related to spawning on the continental slopes and to migrations to and from these spawning grounds. Many of the larger Greenland halibut apparently also remain between spawning seasons in these deepwater areas. In all areas where the larger Greenland halibut are numerous or moderately numerous in these deep and warmer water localities on the continental slopes, water with temperatures below 3°C extends rather deeply, and there are large areas with low bottom temperatures in deep water within the seasonal migratory range of the fish. In the warmer-water areas (3M, 3N-4X), where temperatures above 3°C are found at all depths greater than 180 m, Greenland halibut are not abundant, and in the most southern Canadian areas (4V-4X), where autumn and early winter temperatures at all depths within the usual range of this fish are still higher, Greenland halibut are very scarce.

In addition to the catches by otter trawl, some bottom longline catches (Table 2) show that a few moderately large Greenland halibut are present at still greater depths, at least to 1,460-1,600 m. No Greenland halibut were taken in 21 longline sets with about 500-550 hooks per set, distributed along the continental slope from southern Labrador to off New Jersey in 1,810-2,360 m, in which many other bottom-related fishes were taken. Also, on a midwater longline, fishing at 180-460 m for pelagic redfish north of Flemish Cap at 48°30′15″N, 44°56′45″W over water 730 m deep, a 3-kg Greenland halibut was taken.

Fish size by depth and area

Greenland halibut, taken by otter trawl at depths of 48-229 m, and in some areas more deeply, were usually of a small average size (less than 1 kg), although there were occasional exceptions at one or more levels as off South Labrador to East Newfoundland (Table 3). At greater depths the fish were larger. The largest average sizes, in areas with relatively abundant fish, were taken off Labrador and eastern Newfoundland 2G-3L at depths of 459-915 m. The fish taken by otter trawl at the greatest depths off West Greenland were smaller than those in depths immediately shallower (Table 3), but larger fish were taken by longline at these and at still greater depths (Table 2).

TABLE 2. Greenland halibut taken in bottom longline sets by the *A. T. Cameron.*

Date	Locality	Position		Depth (*m*)	No. of fish	Total weight (*kg*)	Temp. °C (Temp. depth, *m*)
		Lat N	Long W				
31 July 1965	Off Disko Bay	69°28′	59°25′	1280	5	15.4[a]	0.10 (1271)
7 Aug. 1965	W slope Store Hellefiske Bank	66°01′	56°56′	650	20	96.2[a]	2.77 (658)
8 Aug. 1965	W slope Lille Hellefiske Bank	64°58′	55°26′	800	3	9.5[a]	4.45 (810)
14 Aug. 1965	W slope Fyllas Bank	63°39′	53°02′	730	6	26.8[a]	4.57 (849)
13 Aug. 1965	W slope Fyllas Bank	63°30′	53°10′	1460	17	124.4[a]	3.68 (1432)
12 July 1965	N of Flemish Cap	48°30′	44°57′	180-460	1	2.7[b]	3.59 (549)
17 Apr. 1968	N of Flemish Cap	48°57′	44°55′	1370-1460	14	79.0[c]	3.62 (1370)
18 Apr. 1968	E of Flemish Cap	46°50′	43°45′	1460-1630	6	37.7[c]	3.57 (1370)
19 Apr. 1968	E of Grand Bank	45°47′	46°27′	1370-1500	2	10.8[c]	3.66 (1550)
20 Apr. 1968	Off SE Grand Bank	43°44′	48°50′	1460-1550	9	34.5[c]	3.75 (1280)
21 Apr. 1968	Off SW Grand Bank	44°15′	53°14′	1460-1600	2	7.7[c]	3.98 (1420)

[a] 450 hooks on longline. [b] 130 hooks on longline, midwater set, 180-460 m over bottom depth of 730 m. [c] 550 hooks on longline, squid bait.

Small Greenland halibut were numerous near Disko Island in late July-early August 1965. At the mouth of Ungava Bay 4-6 September 1959, it was evident from cod food that there were large numbers of small 1-year-old Greenland halibut in the area. At 365 m the cod were taking some small Greenland halibut but feeding mainly on capelin. At 185 m, the most abundant food in cod stomachs consisted of small 8-12 cm Greenland halibut with sometimes 20-30 or more in one stomach.

Information on Distribution from ICNAF and Other Statistics

Although research vessels can produce an overall picture of distribution, only the commercial fishery can provide the information on the quantities of Greenland halibut of commercial size which may be taken in an area year by year. The statistics for countries fishing the Northwest Atlantic (ICNAF 1952-72) show the recent

TABLE 3. Average weight (kg per fish) of Greenland halibut taken by the *A. T. Cameron*, 1958-66, in a No. 41-5 otter trawl on bottom at various depths. (Exceptions are noted below the table. Number of fish included in average, in parenthesis.)

Depth	Greenland	Baffin Island North of 65°30′N	Baffin Island South of 65°30′N	Ungava Bay	Northern Labrador (2G,2H)	Southern Labrador and Eastern Newfoundland (2J,3K,3L)	Flemish Cap (3M)	Southern Grand Bank and St. Pierre Bank (3N,3O,3P)	Gulf of St. Lawrence (4R,4S,4T)	Scotian Shelf (4V,4W,4X)	Inshore Nfld.[a]	Overall average
Fathoms (Meters)	July-Aug.	Aug.	Aug.-Sept.	Sept.	July-Oct.	Jan.-Dec.	Mar.-Nov.	Jan.-Nov.	Jan.-Nov.	Nov.-Dec.	Jan.-Aug.	Jan.-Dec.
26-50 (48-92)	–	–	–	–	–	–	–	0.2 (56)	–	–	–	0.2 (56)
51-75 (93-138)	–	–	–	–	1.4 (1)	0.9 (4)	–	0.8 (20)		–	–	0.8 (25)
76-100 (139-184)	–	–	–	–	0.8 (74)	1.2 (198)	–	0.8(156)	1.2(110)	0.1 (6)	–	1.0 (544)
101-125 (185-229)	–	–	0.5 (10)	–	0.4(141)	1.3 (267)		0.5 (98)	0.7(277)	0.2(31)	0.3(19)	0.8 (843)
126-150 (230-275)	0.05 (77)	1.8(111)	–	–	1.6 (75)	1.2 (316)		0.2(492)	0.6(611)	0.2(13)	1.9(29)	0.7(1724)
151-200 (276-367)	0.4 (5)	0.6(457)	0.4(237)	1.5(122)	1.8(187)	1.2(2335)	–	0.7(127)	0.6(450)		–	1.0(3920)
201-250 (368-458)	1.2(132)	0.5 (4)	1.2 (67)	–	1.5(314)	1.1 (451)	3.6 (2)	0.8 (55)	0.9 (14)	5.7 (2)	–	1.2(1041)
251-300 (459-550)	1.8(175)	1.6(123)	2.1 (45)	1.0(134)	3.6 (16)	1.4 (875)	2.5 (1)	1.3 (50)	0.9 (34)	2.8 (4)	–	1.4(1457)
301-350 (551-641)	2.4(100)	1.8(109)	2.3 (1)	–	2.6 (44)	3.4 (145)	2.0 (8)	1.6 (73)	–	4.5 (6)	–	2.5 (486)
351-400 (642-732)	1.2(176)	1.3(178)	2.5 (15)	–	1.4 (41)	2.6 (156)	1.4 (6)	1.3 (83)	–	2.0 (2)		1.6 (657)
401-500 (733-915)	2.7 (45)	–	–	–	2.6 (70)	3.0 (97)	1.5(19)[b]	1.6 (31)	–	3.2 (2)	–	2.6 (264)[b]
501-800 (916-1464)	0.8 (15)[c]	–	–	–	–	–	4.5 (1)[c]	–	–	–	–	1.0 (16)[c]

[a] Newfoundland east and southeast coast bays and neighbouring coastal areas, *A. T. Cameron* and *Investigator II* (1947-66). [b] Five fish (5.0 kg) taken with 3/4 35 otter trawl included in this average. [c] Catch from 3/4 35 otter trawl.

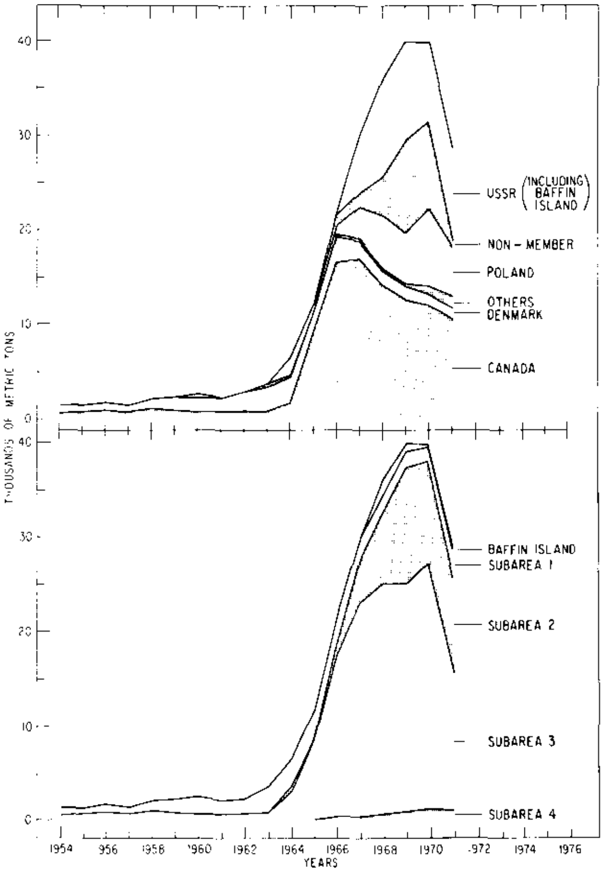

Fig. 5. Landings (whole weight) of Greenland halibut by various countries and in various subareas of the ICNAF area and from off Baffin Island, 1954-71.

development of the Greenland halibut fishery (Fig. 5). Up to 1963 this was almost entirely a small Canadian fishery, mainly by longline in the deepwater bays along the east coast of Newfoundland, and a similar fishery by Greenlanders in the Greenland fjords. The total landings from the ICNAF area increased from 1,420 tons in 1954 to 3,720 tons in 1963, almost entirely due to increasing landings by Greenlanders. As a result of greatly increased Canadian landings after 1964, and increased landings by Poland, USSR, and GDR after 1966, peak landings of 40,000 tons were taken in the Northwest Atlantic in 1969 and landings were almost as great (39,800 tons) in 1970. In 1971, however, the annual landings declined to 29,000 tons due mostly to the decreased catches by the GDR.

In the years with the highest landings, 1967-71, the greatest landings of Greenland halibut, and by far the greatest by European nations from the continental shelf and slope, were from Division 3K (Fig. 6). The landings of Greenland halibut in 3K by Canadians were almost entirely from and near Notre Dame and White bays. The second greatest landings were from 3L but only a very small part of these were from the shelf and slope, almost all being Canadian landings from Trinity and Bonavista bays. Division 2J was next in importance, and landings declined northward from 2J and southward, eastward and westward from 3L.

The Danish (Greenland) fishery in West Greenland (Subarea 1) for Greenland halibut has been partly a primary fishery by longline for this fish, with by-catches mainly from the shrimp fishery, and conducted in and near the Greenland fjords (Smidt 1969, MS 1969). These Greenland landings have usually made up most of the landings from Subarea 1 (70% for the period 1967-71) and the Subarea 1 landings have not changed greatly in recent years, rising from 880 tons in 1954 to 3,060 tons in 1965, declining to 1,650 tons in 1969, and rising again to 3,040 tons with a considerable increase in the Norwegian landings from the shelf fishery in 1971. The larger amounts taken by the Greenlanders in Division 1A are related to the great shrimp fishery and its by-catch of Greenland halibut in the Disko Bay area (Smidt, 1969).

The Canadian fishery for Greenland halibut (Figs. 5 and 6) was until recently almost entirely a special fishery for this fish, and in recent years increasingly for a combination of Greenland halibut, witch flounder and American plaice, in and near the deep cold-water bays of the east coast of Newfoundland. The earlier fishery was by longline and the more recent fishery by gillnet (Lear, MS 1970*b*). This fishery, after a rapid rise from 1964, reached its peak of 17,000 tons in 1967 and declined gradually to 10,400 tons in 1971. The most rapid expansion of the fishery was in Trinity Bay, reaching a peak of 11,340 tons in 1967 and declining to 3,050 tons by 1969 and to 2,310 tons in 1971. In this bay, the average catch of Greenland halibut decreased from 158 kg per 91-m bottom gillnet in 1966 to 23 kg in 1969 (Lear, MS 1970*b*). After the decline of the Trinity Bay fishery, landings rapidly increased in Notre Dame Bay, reaching 5,900 and 5,500 tons in 1969 and 1970 (Lear, MS 1970*b*) and declining to 3,620 tons in 1971. Bonavista Bay also contributed yearly landings between 1,100 and 1,770 tons during 1965-69, but landings increased to 2,440 tons in 1970 and 2,900 tons in 1971.

The USSR and Polish fisheries for Greenland halibut and those of non-members of ICNAF began as incidental fisheries mainly related to the deepwater fishery for redfish. Their Greenland halibut landings have increased as their vessels fished deeper for redfish and to 600-1000 m and more by the USSR and the GDR for the roundnose grenadier. Sometimes, Greenland halibut has apparently been the primary object of the fishery (Pechenik and Troyanovskii, 1970). Beginning in 1968, small landings of Greenland halibut were made by the USSR from off Baffin Island which is outside of the ICNAF area.

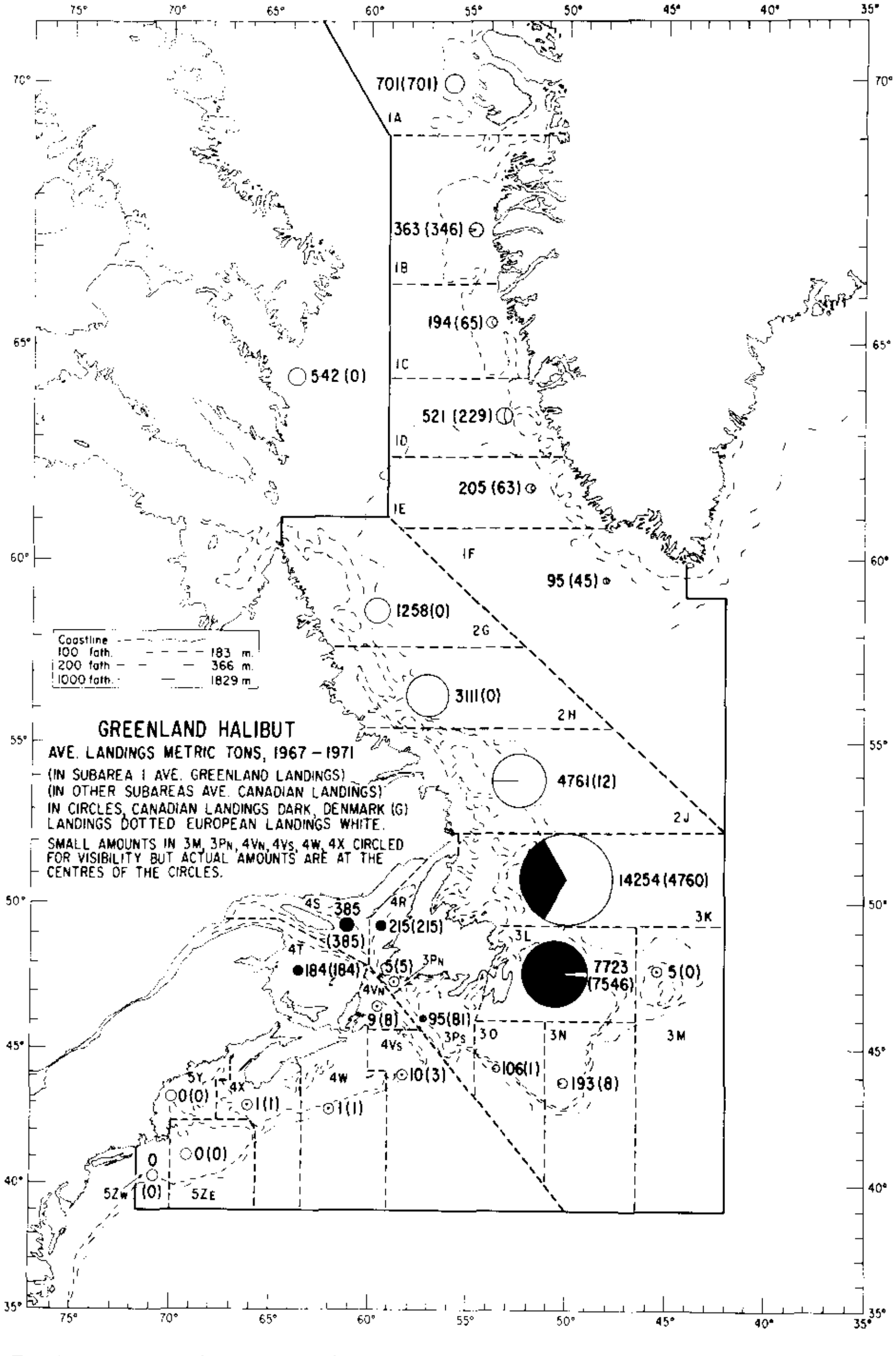

Fig. 6. Average yearly landings (whole weight) of Greenland halibut in the various divisions of the ICNAF area and from off Baffin Island, during the period of greatest landings 1967-71. (The areas of the circles are in proportion to the landings.)

Discussion and Conclusions

Distribution by area

This paper presents information on Greenland halibut distribution from about 70°30'N off Disko Island and southward to the southern part of the Scotian Shelf north of 42°30'N (Fig. 3). Other workers have published information on Greenland halibut distribution in various parts of the Northwest Atlantic and some have provided such information for and beyond the fringe areas of the present study.

The Greenland halibut is widely distributed along the West Greenland Coast (especially in the fjords) and in the Davis Strait, and the Godthåb Expedition in 1928 took it by bottom trawl as far north as Smith Sound, 78°14′N, 74°10′W, at 670 m (Smidt, 1969). Dunbar and Hildebrand (1952) reported small Greenland halibut 8-16 cm in total length from near Port Burwell, Ungava Bay, especially from cod stomachs. The deeper waters, from which the catches of larger Greenland halibut were obtained by the *A. T. Cameron*, were not investigated. One hundred and eighteen Greenland halibut, average weight 1.3 g, were reported from food of Brünnich's murres at Akpatok Island, Ungava Bay (Tuck and Squires, 1955). The Greenland halibut was not reported from Hudson Bay in Vladykov (1933), Edwards (1961), and McAllister (1964). Gordon and Backus (1957) recorded two specimens of Greenland halibut (8 and 11 cm in length) from the bottom in 110-125 m at about 1.7°C in Hebron Fjord, Labrador. In the deeper water of the estuary of the St. Lawrence River, the Greenland halibut was reported as far west as 69°30′ – 69°35′W (Vladykov and Tremblay, 1935; Steele, MS 1958), between 70°44′ – 70°48′W (Bergeron and Legendre, 1970); and in Saguenay Fjord of this estuary (Drainville, 1970).

On the southern fringe of the distribution, Schroeder (1955) took 20 Greenland halibut between 63°47′ and 65°10′W, i.e. in the general vicinity of the southeastern tip of the Scotian Shelf from which I obtained my most southern specimens, and one east of Georges Bank at 67°59″W. The depth range was 560-970 m and the fish length 33-91 cm. The record at 67°59′W is the most southern, the depth at this latitude placing it in the general vicinity of 40°15′N. Four Greenland halibut, 26-32 cm long, were taken in February 1963 in the Gulf of Maine, at 65-100 m and between 43°37′ – 43°48′N and 67°27′ – 69°45′W (Boyar, 1964). Also, in March 1968, two Greenland halibut, 27 and 42 cm long, were taken at 27-46 m in the Bay of Fundy at 45°05′30″N, 66°44′30″W (Barrett, 1968).

Other workers have been concerned with investigations delineating the areas of commercial abundance.

Surveys by USSR exploratory trawlers were carried out from 1965 at depths of 500-1,400 m along the Northeast Newfoundland and Labrador shelves and along the Baffin Island coast to Davis Strait. In 1965-66 the exploratory fishing was at 500-650 m and in 1967-68 depths down to 1,300 m were trawled. The area off Baffin Island was investigated in 1967 (Pechenik and Troyanovskii, 1970; Anon., 1971). The resulting information summarized in Pechenik and Troyanovskii (1970, fig. 41) shows deepwater slope concentrations of Greenland halibut off the southern part of Baffin Island, northern Labrador, in Hawke Channel, off Funk Island Bank, and off Notre Dame Bay. These agree approximately with areas where the best catches of Greenland halibut were taken by research vessels of the St. John's Station (Fig. 3). Landings of Greenland halibut by the USSR increased with the development of a large fishery for the roundnose grenadier, *Coryphaenoides rupestris* (Gunnerus), especially in Division 3K and in the southern part of Subarea 2, and in 1971 in Division 2G.

Norwegian experimental fishing for Greenland halibut by longline, 24 March-2 July 1971, extended from West Greenland along the southern slope of the Davis Strait Ridge and south along the continental slope off Baffin Island, Labrador and the Northeast Newfoundland Shelf to the northern slope of the Grand Bank (Olsen, 1971). Longline catches were interfered with by Greenland sharks and by deepwater otter trawlers. The best catches, taken during 6-11 May off southern Labrador (53°12′ – 52°25′N, 52°08′ – 51°19′W) and during 17-24 June off the southern part of Baffin Island (62°48′ – 61°06′N, 61°20′ – 60°34′W) in depths of 530-750 m, ranged in different sets from 17 to 43 and 26 to 70 kg respectively per line of 144 fathoms (256 m) in length and possessing 200 hooks. After the experimental period was over, the vessel fished again at Baffin Island and caught Greenland halibut (average weight 4.3 kg) at the rate of 1,800 kg per 4,000 hooks.

Distribution by depth

Occasional Greenland halibut have been reported from 48-92 m (Table 1) and from 27-46 m (Barrett, 1968). Most of the larger quantities of Greenland halibut were found between 280 and 915 m (Table 1). Deeper than 640 m the catches were not truly comparable with those of shallow depths, as the *A. T. Cameron* often had to slow down to keep the trawl on bottom and at the greatest depths use a smaller trawl on a single wire. In the deep bays of eastern Newfoundland, Greenland halibut were most abundant in longline catches at 300-570 m, in gillnet catches in 230-530 m, and in otter-trawl catches by the *A. T. Cameron* in January-March 1967-68 at depths of 290-580 m (Lear and Pitt, MS 1971). On the slopes of Flemish Cap and eastern Grand Bank, they were taken by bottom longline in water as deep as 1,460-1,600 m (Table 2) but were not taken at 1,810-2,360 m.

In West Greenland fjords, where the larger immature Greenland halibut are especially plentiful, the densest populations are at the greatest depths, 350-600 m (Smidt, 1969). The generally increasing size with depth (Table 3) is similar to the report by Smidt (1969) that small-sized Greenland halibut under 20 cm, fished in prawn trawl, were more frequent in shallower depths of 200-250 m, whereas the larger fish taken on longline were most abundant at depths greater than 350 m. A Greenland halibut, 77 cm long, is reported by Jensen (1935) from 1,600 m in Davis Strait. In the USSR fishery off Baffin Island and northern Labrador, concentrations of Greenland halibut yielding 3-5 tons per hour of trawling were found at 550-650 m and also at 900-1,000 m. The accumulation of large Greenland halibut in very deep water on the continental slope of the Newfoundland area is greatest in November-January at and near the spawning season. No information, however, is given for February-May (Pechenik and Troyanovskii, 1970).

Successful commercial fishing for Greenland halibut, up to 20-26 tons per hour, was found east of Iceland at 270-550 m between September and December. Catches up to 10-15 tons per hour were taken northwest of Iceland at 450-650 m in April-June, and north of Iceland at 450-850 m from June to October (Pechenik and Troyanovskii, 1970). In July-August 1967, USSR trawlers fishing north of Iceland, and in May-early June 1967 a GDR exploratory trawler fishing northwest of Iceland, found the main concentrations of Greenland halibut in a narrow band at 500-600 m (Konstantinov, 1968; Paschen, 1968).

In USSR investigations in the Barents Sea 1964-67, the greatest concentrations of spawning Greenland halibut were found at depths of 600-800 m (Nizovtsev, 1969), and commercial fishing in this area is at times as deep as 1,100 m (Pechenik and Troyanovskii, 1970).

Although the large catches of Greenland halibut have been reported as taken on and near the bottom by otter trawls, longlines and gillnets indicating that these fish must spend much time near bottom, there is good evidence that Greenland halibut move to midwater and even near the surface for feeding as in the instance reported in this paper where it was taken by longline in midwater north of Flemish Cap. Twelve Greenland halibut, 21-29 cm long, were taken in herring nets extending from 11 to 16 m below the surface over depths of 165-200 m in Conception Bay, Newfoundland (Lear and Pitt, MS 1971). The Greenland halibut killed in large numbers in Trinity Bay, Newfoundland (Templeman, 1965) probably died when they pursued capelin into water of intermediate depths where the temperature was below −1°C. In the West Greenland fjords, Greenland halibut often move into mid-water in numbers and feed on capelin as much as 100 m off the bottom where they are caught pelagically and in abundance by the Greenlanders using handlines only 200 m long in areas where the bottom depth is 300 m (Jensen, 1935). Greenland halibut 20-40 cm long have frequently been taken in salmon drift nets set at the surface in the open sea off West Greenland (Smidt, 1969). The larger Greenland halibut are mainly fish feeders and many of their favourite fish foods such as capelin live in mid water (de Groot, 1970).

Distribution by temperature

It is apparent from the data presented in this paper that, apart from spawning concentrations in deep water at higher temperatures, Greenland halibut in the Northwest Atlantic are most abundant where bottom water temperatures of about −1°, or more usually −0.5°, to 3°C occur in deep water over large areas. Also, for the Newfoundland area (Lear and Pitt, MS 1971), in the eastern bays Greenland halibut were most abundant in longline catches at 1.67° to 2.81°C (300-570 m). In Notre Dame and Trinity bays in 1966-68, they were most abundant (over 45 kg per 91-m gillnet of 212 to 263 mm mesh, per 24 hr fishing on bottom) at depths from 230 to 530 m and bottom temperatures from −0.38° to 2.18°C. The best Greenland halibut catches in these bays by otter trawl, during 1966-69, occurred in Trinity Bay in March 1967 at 1.1° to 2.8°C at 290-580 m, 570-1,050 kg per 30-min tow on bottom.

In USSR fishing for Greenland halibut north of Iceland in July-August 1967, the greatest concentrations were found where the near bottom temperature was about −0.5°C, between 500 and 600 m (Konstantinov, 1968). The *Ernst Haeckel* found good quantities of Greenland halibut east of Iceland in September 1967 at bottom temperatures of 0° to −0.3°C (Paschen, 1968).

Spawning and larvae-fry-area-depth-temperature relationships for large populations of Greenland halibut

Most of the information presented above on the relationship between Greenland halibut concentrations and water temperatures does not pertain to spawning concentrations occurring in deep water in winter but to the ordinary mixture of immature and mature fish during the remainder of the year. In West Greenland, the Greenland halibut apparently do not spawn in the fjords where immature fish are abundant nor in Baffin Bay north of the Davis Strait Ridge where temperatures are almost everywhere in deep water below 2°C and where both young and older fish are commonly present, but migrate out of the fjords and southward from Baffin Bay to spawn in winter, south of about 66°45′N, probably in depths of about 600-1,000 m, at higher temperatures, about 3.5° to 4.5°C, and higher salinities (Jensen, 1935). Comparisons at 800 m (Dunbar, 1951) show temperatures from −0.49° to 0.65°C and salinities from 34.43 to 34.52°/₀₀ for Baffin Bay and temperatures from 2.99° to 4.03°C and salinities from 34.85 to 34.95°/₀₀ in the Labrador Sea south of the Davis Strait Ridge. The higher temperatures aid ovarian and embryonic development and the higher salinity may be important for the bathypelagic adjustment of the Greenland halibut egg in relation to depth, as the eggs appear to float and hatch in the deeper layers rather than at the surface, Jensen, 1935; Smidt, 1969).

Also, Greenland halibut with large eggs close to spawning condition are extremely uncommon in the Newfoundland east coast bays, where bottom temperatures of the deep water are lower than in similar depths on the continental slope, and Greenland halibut tagged in summer-autumn in White Bay, Newfoundland, were recaptured in winter-spring much farther eastward on the continental shelf and several on the continental slope (Pitt, MS 1971; Templeman, 1971; Templeman and Fleming, 1972).

In the Northwest Atlantic where Greenland halibut are abundant over great areas, it is noteworthy that the larvae and fry are spread by the currents into large areas of cold and moderately cold water and at intermediate depths. The West Greenland Current takes large numbers of Greenland halibut fry northward across the Davis Strait Ridge and coastward with its turning to the right into the colder water of intermediate depths close to the coast. As a result there is a great nursery ground for Greenland halibut over a large area, about 200-250 m deep, in the vicinity of Disko Island. There is another nursery ground south of Godthåb and there are presumably many others. Later, after settling near the coast, many of the young enter the fjords but many remain to grow up on the coastal and bank slopes (Jensen, 1935; Smidt 1968, 1969).

Large numbers of 8-12 cm Greenland halibut in Ungava Bay were reported in this paper. Also Lear (MS 1970*a*) reported numerous small 0+ Greenland halibut 6-8 mm long from cod stomachs taken on the southeast slope on Hamilton Bank of Division 2J at 265 m in October 1967, and numerous 1+ Greenland halibut, about 12-16 cm long, were taken by the *A. T. Cameron* on the northern slope of Hamilton Bank in 228 m in October 1967 and along the Labrador Shelf in October 1966. No large numbers of similarly small Greenland halibut have yet been taken from the deep bays of the Newfoundland east coast where the larger immature Greenland halibut have been so plentiful. However, with the large trawl rollers used by the *A. T. Cameron*, it is to be expected that most small Greenland halibut would pass under the net or out through the large meshes of its forward parts.

In the Newfoundland area, although there is little or no information on the larvae and pelagic fry of Greenland halibut compared with that available for West Greenland, a hypothesis regarding the movements of larvae and fry may be proposed from the known distribution of the immature fish and from the greater information available regarding areas of settlement of cod fry. The southward moving Labrador Current swings to the right and the young of Greenland halibut and cod are led toward the shelf and coastal slopes and into the deep bays of the east coast of Newfoundland. Because it swings toward the coast, the inner colder portion of the Labrador Current extends deeper near the coast and in the east coastal bays and over the inner part and deep holes and channels of the great pocket of the Northeast Newfoundland Shelf lying between Cape Bauld and Cape Freels (Smith *et al.*, 1937; Templeman, 1967). Here, and in the deep Newfoundland bays, Greenland halibut are especially abundant for their southern location, compared with, for example, the slopes of the Grand Bank in the same latitudes.

Divisions 3K and 2J, where the largest offshore commercial catches of Greenland halibut are taken, contain very suitable areas for this fish. The wide continental shelf in these divisions is interspersed with channels and deeps in most of which, and in the adjacent deep coastal bays, the bottom temperatures of the deep water are lower than those of the same depth at the continental slope (Smith *et al.*, 1937, fig. 91 P2; Templeman and Fleming, 1963; Bailey, MS 1958.) The deep water of Bonavista and Trinity bays in 3L is a natural extension of the deep coastal cold water area of 3K and it is likely that most of the mature Greenland halibut from these bays migrate to the continental slope of 3K or farther northward to spawn. There are additional populations of Greenland halibut north of 2J and 3K to assist in supplying larvae for these divisions. The angular shape of the western and southwestern coastal boundary and coastal shelves, with their extension eastward along the relatively shallow water of the northwestern Grand Bank, presumably create surface and especially effective deeper water eddies between southern Labrador and the northwestern Grand Bank which help to retain the larvae and especially the larger fry as they sink deeper. The coastward set of the main currents assists in this retention. The slightly higher temperatures and the greater depths at the continental slope in 2J and 3K and to the northward provide suitable conditions for spawning. The shallow southern boundary of the Grand Bank and the relatively shallow Avalon Channel tend also to reduce the dispersal of the immature fish southward beyond Trinity Bay (Smith *et al.*, 1937; Templeman, 1966, figs. 9 and 10; Templeman, 1967). South of Trinity Bay and around the Grand Bank and Flemish Cap there is no large area with sufficiently low temperatures at Greenland halibut depths to be suitable for large populations of this fish in the commercial sense. Because of the by-catch nature of much of the offshore fishery for Greenland halibut, areas northward of 3K and 2J have apparently not yet been fished as heavily as these divisions for this species, apart from 2G in 1971.

The small quantities of Greenland halibut in the Gulf of St. Lawrence are related to the favourable presence of an intermediate cold layer below 0°C, but limited by the shallow depth of the cold layer which is unfavourable. In the Gulf, water temperatures as high as 2°C usually occur close to or above 150 m and at less than 200 m (Lauzier and Bailey, 1957) and the 0°C or lower layer still shallower. Also, the bottom area of deep water at these temperatures is not great, being mainly at the sides of the deep channels.

It is concluded from the evidence presented that Greenland halibut are most abundant where there is a large area of deep, moderately cold water for the life of the fry to immature and maturing stages in the general vicinity of slightly warmer deep water into which the mature fish migrate for spawning.

Addendum

After the completion of the foregoing paper, provisional statistics for 1972 became available in ICNAF Summary Document 73/17 by the Assistant Executive Secretary. The total landings of Greenland halibut from the ICNAF area for 1972 were 34,776 tons, taken from Subareas 1 - 5 in the following tonnages: 3,937; 12,522; 17,613; 702; 2. The landings increased from the 29,000 tons taken from the Northwest Atlantic in 1971 but were below the peak landings of 40,000 tons in 1969 and the 39,800 tons of 1970. Landings increased in Subarea 1 by about 900 tons, in Subarea 2 by 2,300 tons, in Subarea 3 by 3,200 tons, and in Subarea 4 declined by about 280 tons. If there were landings from the Baffin Island area for 1972 (unknown to me at present) they are additional, because the data quoted for 1969-71 include small landings by the USSR from off Baffin Island.

Acknowledgements

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Age and Growth of the American Plaice, *Hippoglossoides platessoides*, off Cape Breton Island in ICNAF Subdivision 4Vn

By J. P. Minet[1]

Abstract

Investigations in 1970 and 1971 on American plaice, *Hippoglossoides platessoides*, off Cape Breton Island in ICNAF Subdivision 4Vn reveal that they grow slower than American plaice in the Gulf of Maine and on the southern part of the Grand Bank, but faster than the stock on St. Pierre Bank. Their growth pattern is very similar to that observed for plaice on the Magdalen Shallows area of the Gulf of St. Lawrence. These differences and similarities are discussed in relation to the prevailing hydrological conditions.

Introduction

The American plaice, *Hippoglossoides platessoides*, is an Arctic-boreal species of the Northwest Atlantic. It is found on most parts of the continental shelf from Cape Cod, USA to the latitude of Egedesminde, West Greenland (68°50′N). However, the most important concentrations are found on the banks around Newfoundland (especially on the eastern Grand Bank), in the Gulf of St. Lawrence, and on the offshore banks of Nova Scotia, and landings from these areas have more than tripled between 1960 and 1970, with the total landing from ICNAF Subareas 2, 3, and 4 in 1970 being 111,000 tons. The fishery on that part of the Scotian Shelf to the east of Cape Breton Island (ICNAF Subdivision 4Vn), from which the material for this paper was obtained, is relatively small with a catch of 2,000 tons in 1970 compared with a yield of 8,000 tons from the Scotian Shelf as a whole.

Previous research on the age and growth of the American plaice has been reported by Powles (1965) for the Gulf of St. Lawrence (ICNAF Division 4T), by Pitt (1967) for the Labrador and Newfoundland banks (ICNAF Subareas 2 and 3), and by Lux (1969) for the Gulf of Maine (ICNAF Subarea 5).

Materials and Methods

The material for this study was collected on two cruises by ISTPM research vessels, the *Thalassa* in April – May 1970 and the *Cryos* in May 1971. Both stern trawlers used the same type of bottom trawl with 31.2 m headline, 17.7 m groundrope, 140-mm mesh in the wings and body and 50-mm mesh in the codend. Trawl hauls were of 30 minutes duration each. The locations of trawl hauls are shown in Fig. 1.

From catches taken at the various stations, 3,612 individuals were sexed and measured (total length to the cm below) in 1970 and 2,734 in 1971. In addition, at certain stations, 550 pairs of otoliths were taken in 1970 and 445 pairs in 1971, as well as the individual weight of 782 fish in 1970 and 442 in 1971, for age-length, length-weight and age-weight studies.

Method of age determination

Research by Powles (1965, 1966) and by Pitt (1967) has established that age determination of American plaice by otolith reading is valid. Ages were, therefore, determined by the microscopic examination of otoliths which were preserved dry in envelopes. Most of the readings were done with a X20-powered binocular microscope, using transmitted light, by counting the number of hyaline rings on the whole otolith, as described by Powles (1965). In order to reduce the errors in estimating ages of older fish from otoliths whose outer rings are very close together, the readings were made from otoliths cut in half, mounted in modelling clay and kept wet with ethyl alcohol, using reflected light, as described by Pitt (1967). Since the samples were taken in the latter part of the spawning period, which is March – May in Subdivision 4 Vn, the number of rings counted was considered to be the age of the fish and no adjustment of the readings was necessary.

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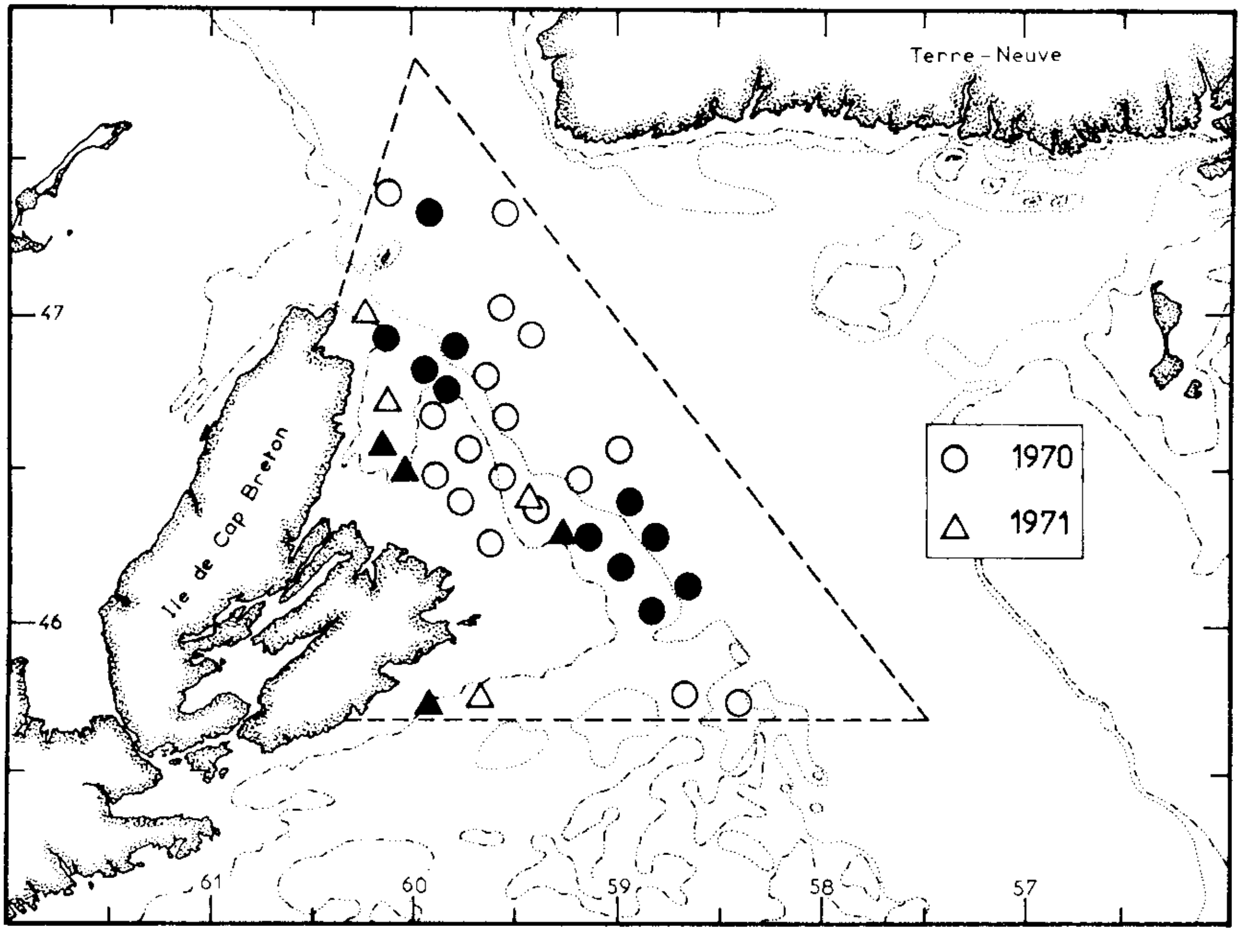

Fig. 1. Positions of stations occupied in ICNAF Subdivision 4 Vn.
○ △ – samples for sex and length, 1970 and 1971 respectively;
● ▲ – samples for sex and length, otoliths and weights of individual fish, 1970 and 1971 respectively.

Method of calculating growth curves

As one of the primary factors in population dynamics studies, growth was considered by Beverton and Holt (1957) to be best represented by the von Bertalanffy growth equation, which has become widely accepted for use in growth studies in recent years. In this model growth in length with age is represented by the expression

$$l_t = L_\infty [1 - e^{-K(t-t_o)}]$$

where l_t is the length at age t (in years), L_∞ is the theoretical maximum length, K is a constant expressing the rate of change in length with respect to age, and t_o is the theoretical age at zero length. The parameters of this equation were calculated by the Walford (1946) method.

The representation of growth in weight (weight-age relationship) is given by the expression

$$W_t = W_\infty [1 - e^{-K(t-t_o)}]^n$$

where W_t is the weight at age t (in years) W_∞ is the theoretical maximum weight, K and t_o are the same as in the length-age equation above, and n is the exponent in the weight-length relationship

$$W_t = qL_t^n.$$

Values of n and q, as determined from the weight-length data, enable the calculation of W_∞ from the equation $W_\infty = qL_\infty^n$, given a value for L_∞.

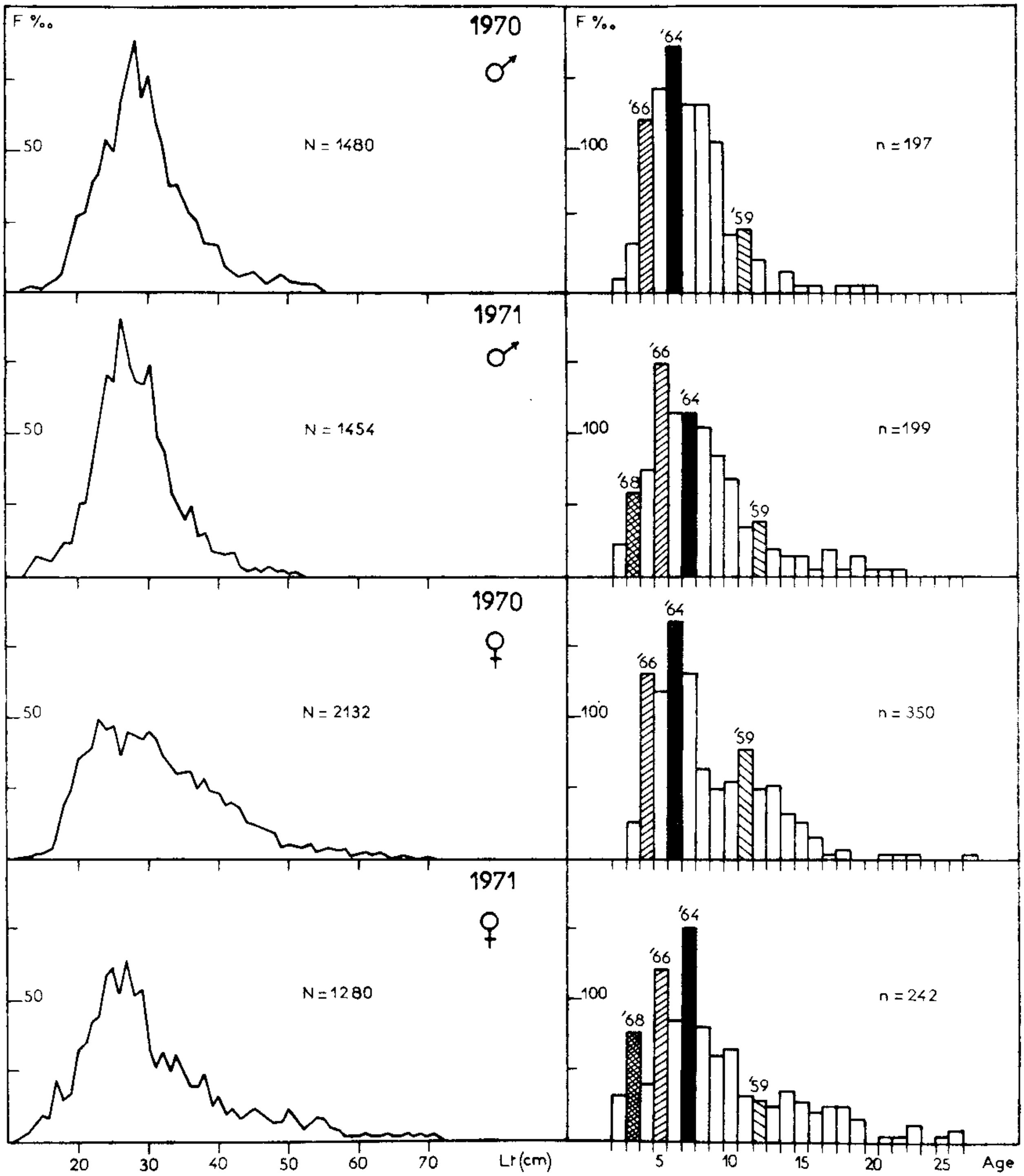

Fig. 2. Length and year-class distribution of the American plaice, *Hippoglossoides platessoides*, in relation to sex and year. (N = number of fish measured; n = number of otoliths read.)

Results

Distribution of length and year-class

The length and age compositions of American plaice sampled in 1970 and 1971 (Fig. 2) indicate very little change in the stock structure between the 2 years, with most of the fish ranging between 20 and 40 cm in length and between 3 and 12 years of age. The frequency distributions for males have a more pronounced peak and a considerably narrower length range than those for females.

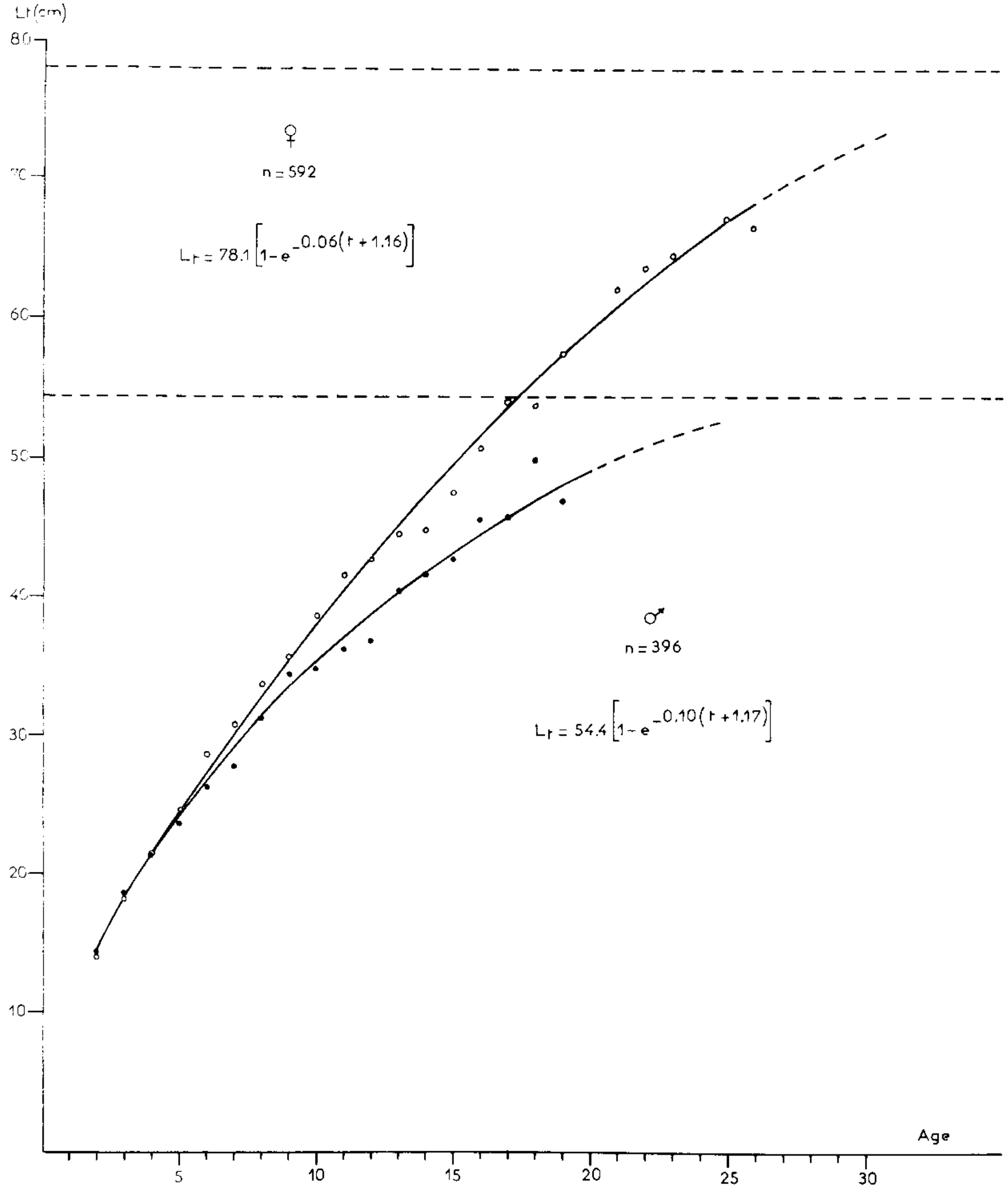

Fig. 3. Linear growth curves for female and male American plaice, *Hippoglossoides platessoides,* in Subdivision 4Vn, based on 1970 and 1971 data.

The length range of males (12-54 cm) was essentially the same in 1970 and 1971 with modal lengths at 28 and 26 cm respectively. The age groups represented in the samples ranged from 2 to 22 years. Of the important year-classes, that of 1964 (age-group 6) was dominant in 1970 while the 1966 year-class (age-group 5) was more abundant than any other in the 1971 samples.

For females, also, the length ranges in 1970 and 1971 were about the same (10-72 cm) with rather less pronounced modal groups between 24 and 30 cm. The age groups represented ranged from 2 to 27 years. The 1964 year-class (age 6 in 1970 and age 7 in 1971) was dominant in both years, followed by the 1966 year-class. The 1959 year-class, which was the most abundant of the older age-groups in 1970, declined substantially in importance in 1971; however, the 1968 year-class, which was completely lacking as 2-year-old fish in the 1970 samples, assumed some prominence as 3-year-olds in 1971.

Growth in length

Bertalanffy growth curves (Fig. 3) were determined from the data of samples taken in 1970 and 1971 for males and females separately, as follows:

$l_t = 54.4\ [1 - e^{-0.10\,(t + 1.17)}]$ for males,

$l_t = 78.1\ [1 - e^{-0.06\,(t + 1.16)}]$ for females.

The difference in growth between the sexes is not only reflected in the very different L_∞ values but also in the rate of change in length with age (k).

The growth in length with age is almost identical for males and females up to 4-5 years of age (Fig. 3); but thereafter, females grow considerably faster than males. Thus, males in the area studied attain commercial size (about 32 cm in total length) at age 9, while females reach this size about a year earlier.

Length-weight relationship

The exponential relationship between weight and length for males and females separately (Fig. 4), as determined from the regression of log W on log L, were found to be

$W = 0.004105\ L^{3.194}$ for males,

$W = 0.001881\ L^{3.423}$ for females.

Up to about 30 cm in length males and females are very similar in average weight; thereafter, the rate of increase in weight for females is greater than that for males. Although the constant of proportionality (q) for females in the length-weight equation is less than one-half of that for males, the contribution to the weight factor by the larger exponent for females ($n = 3.42$) is more than offset by the lower value of q (0.00188).

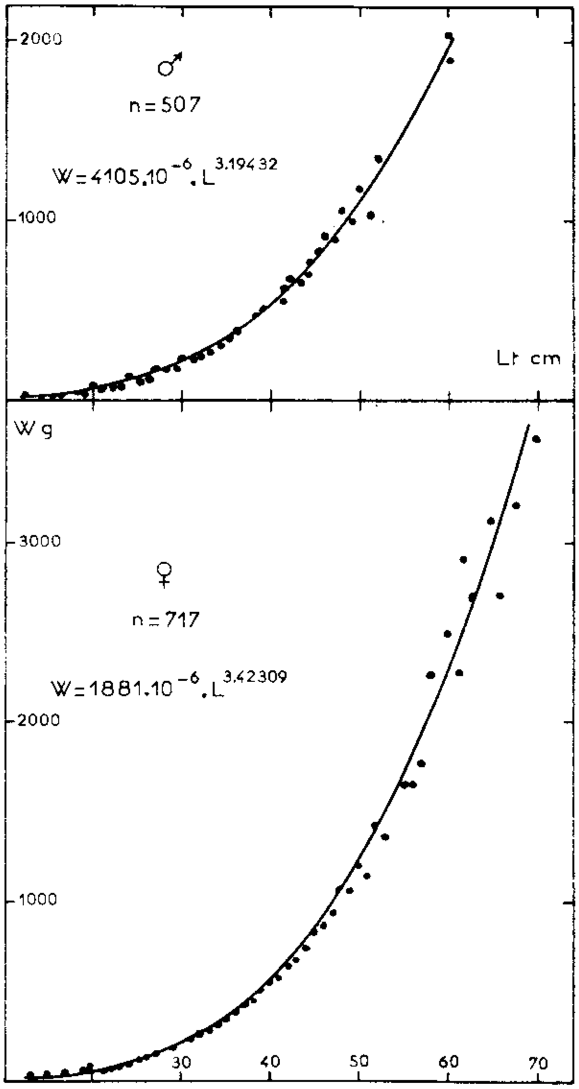

Fig. 4. Length/weight curves for male and female American plaice, *Hippoglossoides platessoides*, in Subdivision 4Vn (n = total number of individuals measured and weighted.)

Growth in weight

Curves of growth in weight at age (Fig. 5) were determined, using the parameters of the age-length and length-weight relationships, as follows:

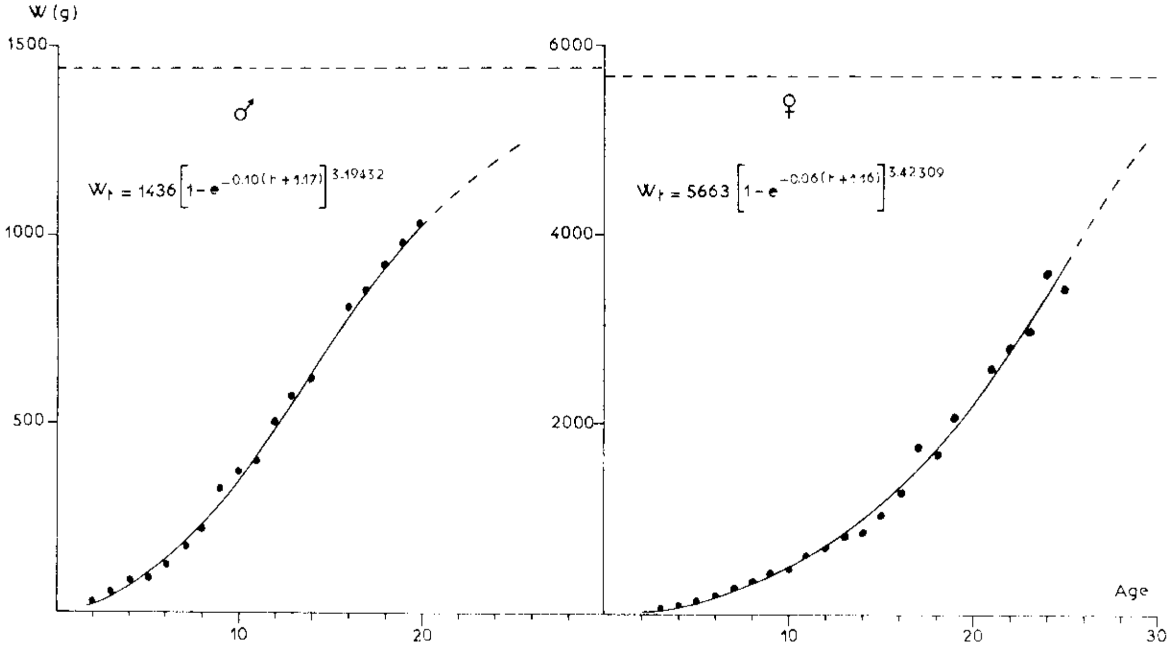

Fig. 5. Ponderal growth curves for male and female American plaice, *Hippoglossoides platessoides*, in Subdivision 4Vn.

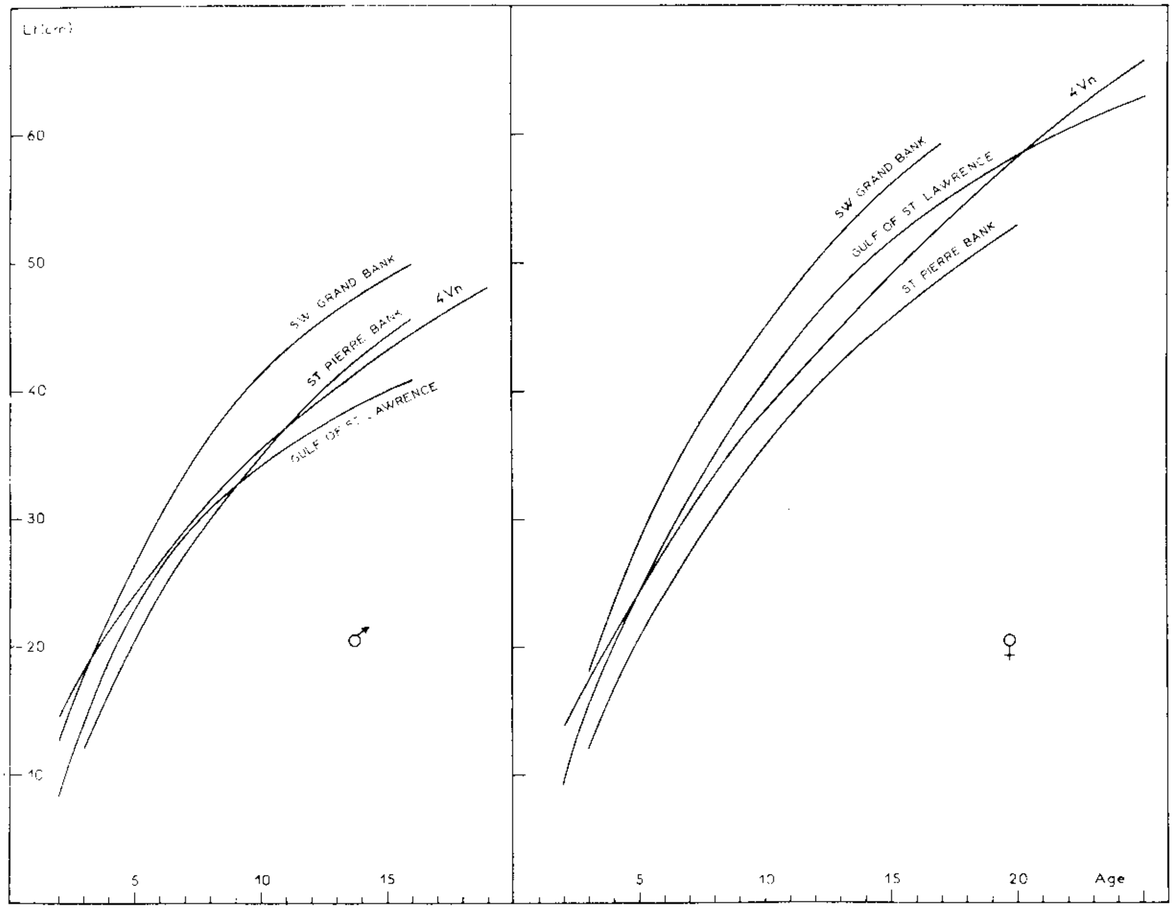

Fig. 6. Comparison of growth curves of American plaice, *Hippoglossoides platessoides*, in areas adjacent to Subdivision 4Vn. (Data for Gulf of St. Lawrence are from Powles, 1965; those for St. Pierre Bank and Southwest Grand Bank from Pitt, 1967.)

$$W_t = 1436\,[1 - e^{-0.10\,(t\,+\,1.17)}]^{3.194} \text{ for males,}$$

$$W_t = 5663\,[1 - e^{-0.06\,(t\,+\,1.16)}]^{3.423} \text{ for females.}$$

The difference in weight at age between the sexes starts to become apparent at about ages 9 and 10 and increases thereafter, with the asymptotic weight (W_∞) for females being nearly four times that for males.

Discussion and Conclusions

In their studies of the American plaice, *Hippoglossoides platessoides*, Pitt (1967), Powles (1965) and Lux (1969) have shown that males and females differ considerably in growth. Similar differences are prevalent for American plaice of the Cape Breton Island area (ICNAF Subdivision 4Vn). Up to about 4-5 years of age, the growth rate of males and females is essentially the same, but at older ages females grow faster than males. The main reason for this is that males reach sexual maturity at a considerably earlier age than females, e.g. males mature at 4-5 years of age when they are about 22-23 cm in length, whereas females are generally older than 8 years of age and greater than 30 cm in length before they begin to mature sexually. Therefore, in the years following sexual maturity the growth rate for males is less than that for females due to the partial utilization of energy in the development of sexual products by males at the expense of growth in size.

A comparison of growth curves for American plaice in different areas of the Northwest Atlantic indicates that in the Cape Breton Island area their growth is considerably slower than that described by Lux (1969) for the Gulf of Maine and faster than that observed by Pitt (1967) for the Labrador Shelf. Such differences can be regarded as normal considering the hydrological conditions of the areas in question. Instead, it is more interesting to compare the results of this study with those of adjacent areas: Gulf of St. Lawrence, St. Pierre Bank, and Southwest Grand Bank (Fig. 6).

The growth of American plaice off Cape Breton is very similar to that observed by Powles (1965) for plaice on the Magdalen Shallows area of the Gulf of St. Lawrence, but it is faster than that observed by Pitt (1967) for plaice on St. Pierre Bank. However, the growth of plaice of Southwest Grand Bank is considerably faster than that described for the above-mentioned areas.

The similarity in growth of American plaice from the Gulf of St. Lawrence and off Cape Breton Island is readily explained by the similarity of hydrological conditions of the two areas, particularly water temperature, the Cape Breton Shelf being washed by waters flowing from the southern part of the Gulf of St. Lawrence (l'Herrou and Minet, 1971). The St. Pierre Bank area, on the other hand, is under the influence of relatively colder water of Labrador Current origin which flows around the southeast corner of Newfoundland and westward over St. Pierre Bank. The American plaice stock on the southwest slope of the Grand Bank is subjected to more temperate water of Atlantic origin.

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Otolith Structure and Growth in Northern Sand Lance, *Ammodytes dubius*, from the Scotian Shelf

By J. S. Scott[1]

Abstract

The otolith of northern sand lance, *Ammodytes dubius*, first forms in the post-larva at mean fish length about 2.4 cm in the Western-Emerald Banks area of the Nova Scotia Banks. During growth in the juvenile it first shows fine growth rings and later shows alternating narrow hyaline and opaque zones which may represent daily and fortnightly growth increments, respectively. Its form changes from disc-like to irregularly ovate and deposition of opaque material leads to formation of the opaque nucleus by the end of its first summer. Summer growth in later years is represented by opaque annuli, length frequencies of which were used in conjunction with otolith length/fish length relationships to produce back-calculated otolith and fish growth curves. The back-calculated fish growth curve for the Western-Emerald area fell well below the curve calculated from empirical values. Growth curves from Western-Emerald and Banquereau areas of the Nova Scotia Banks confirm observed differences in maximum fish lengths between the areas and indicate that differences are due to different growth characteristics, probably related to mean bottom temperatures.

Introduction

In considering the morphometrics of *Ammodytes* from the east coast of North America, Richards *et al.* (1963) noted that adult northern sand lances with high meristic counts were longer on the whole than adults with lower meristic counts from further south. This generalization holds good for inshore southern lance, *A. hexapterus*, and for comparison between *A. hexapterus* and northern offshore lance, *A. dubius*. In contrast, however, observations on samples from Nova Scotia to Greenland indicated that, on the whole, *A. dubius* decreased in length from south to north. Exceptionally large fish were found on the Southwest Nova Scotia Banks, smaller fish on the northeast part of the banks and off Newfoundland and Greenland (Scott, 1968).

Length differences between fish samples may be due to several factors but principally inadequate sampling, length segregation of the fish within the area sampled, or different growth characteristics in the populations sampled. Persistent differences in observed lengths of *A. dubius* between areas (Scott, 1972) indicated that the first two factors were not responsible. Growth characteristics were therefore examined.

Age-estimation of European sand lances has been investigated by several authors (Macer, 1966; Reay, 1972) but, except for Scott (1968), there is no record of work on ageing of North American sand lances. In common with the European species of *Ammodytes*, age estimation in *A. dubius* is dependent on interpretation of growth structures in the otolith since scales show less well-defined growth patterns. Accuracy of estimates from otoliths depends on clarity of zones, which varies between species and areas, and on time of zone formation. In a previous study of *A. dubius* growth (Scott, 1968) some 40% of otoliths were rejected as unreliable, mainly because of difficulties in interpreting their central structure. Material from juvenile *A. dubius* has made possible the examination of early otolith growth, revealing detail of the central structure of the otolith, including zone formation and fine structure similar to that which Pannella (1971) identified as daily growth increments in Silver hake, *Merluccius bilinearis*. Recent fish samples from the Northeast Nova Scotia Banks enabled comparison of otolith and fish growth to be made between the Northeast and the Southwest Nova Scotia Banks. The results serve to assess the validity and probable source of observed differences in fish size between the two areas.

Material and Methods

Adult *A. dubius* were taken by bottom trawls with fine mesh (1/4 inch) codend liner at various times and places on the Nova Scotian Banks from 1968 to 1972. Juveniles were obtained mainly from stomachs of Winter flounder, *Pseudopleuronectes americanus*, caught on

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Southwest Nova Scotia Banks in July, 1972. Representative samples of adult *A. dubius* and Winter flounder were quick frozen in polythene bags immediately after capture, refrigerated, and later thawed for laboratory examination. Comparison of length frequencies and mean lengths of a number of adult *A. dubius* samples before and after freezing indicated that effects of freezing were variable, causing shrinkage in some samples, lengthening in some, no effect in others, with no apparent correlation with length of storage. The average result was a shrinkage of about 1% which was considered negligible for present purposes. In length frequency and age estimations, total length of both juvenile and adult *A. dubius* to the nearest millimetre was recorded.

The juveniles from Winter flounder stomachs were exceptional in that the majority were virtually unaffected by digestion. They were readily identified and measured, and otoliths obtained from individuals. Partly digested juveniles and detached otoliths had previously been found in American plaice, *Hippoglossoides platessoides*, from the same general area but were unusable; free juveniles, caught by trawl, were of limited use only as they were preserved in formalin which attacked the otoliths. These occurrences confirmed the locality in which the Winter flounder were feeding on the juveniles. Lengths were recorded of 237 well-preserved juveniles which were taken from the stomach of Winter flounder and ranged from 3.5 to 7.2 cm in length.

Otoliths were removed from the juveniles obtained from the stomachs of the Winter flounders and from trawl – caught adults and were preserved in 50% glycerin in water with thymol to prevent mould. They were examined and measured in 100% glycerin under a stereomicroscope. Measurements were recorded in eyepiece units (EPU); 1 EPU = 0.07 mm.

Photographs and measurements of fine structure were made from material mounted in glycerin or Canada balsam, without coverslip, using a binocular microscope with screw micrometer eyepiece and photo tube. A few otoliths from adults were ground on their longitudinal median planes on a carborundum wheel to expose central structures. All drawings of otoliths were made with a camera lucida attachment and with the anterior end, as oriented in the fish, pointing to the top of the page and the proximal surface (flat or concave) facing upwards.

The term "band" is used here to describe opaque zones in the central part (nucleus) of the otolith; "annulus" to describe similar but much wider zones surrounding the nucleus. Both bands and annuli consist of groups of "rings" formed of material which varies seasonally in composition and rate of deposition.

Juvenile otoliths were extracted from 10 individuals in each 0.5 cm length group in the length range

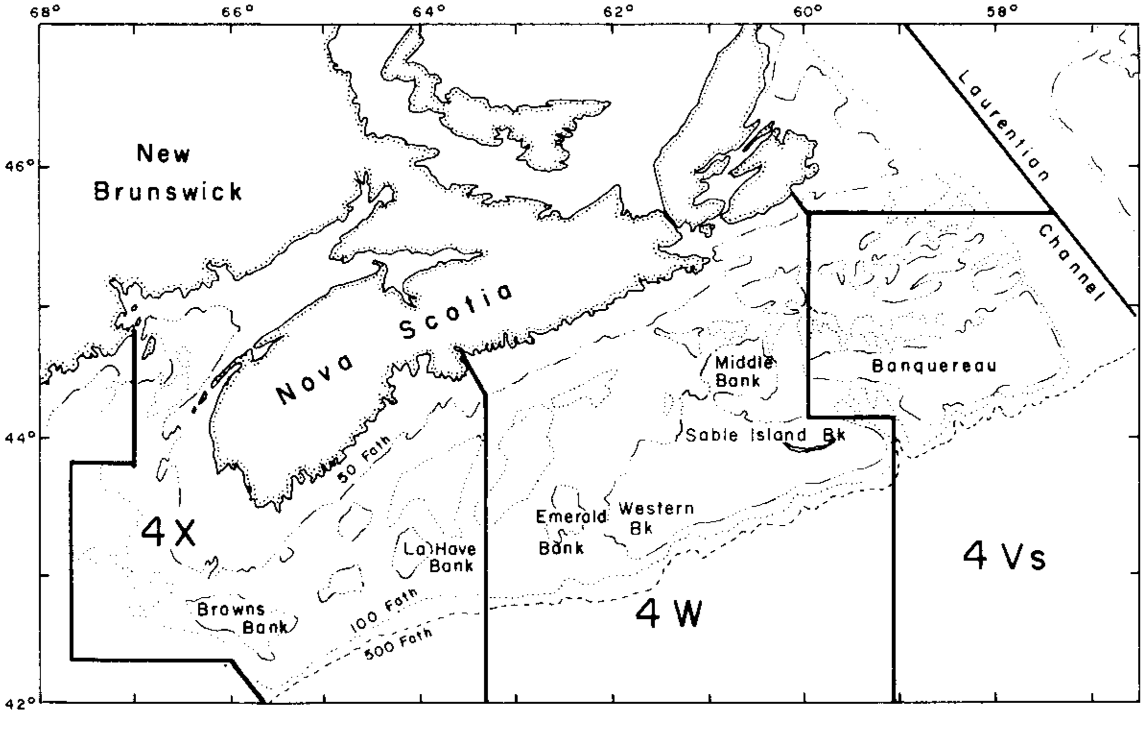

Fig. 1. The Scotian Shelf, with ICNAF Divisions.

3.5-6.9 cm and from the one individual (7.2 cm) found in the 7.0-7.4 cm length group, a total of 71 fish.

Adult *A. dubius* material comprised 943 otoliths and respective fish lengths from Emerald-Western area (Southwest Nova Scotia Banks) and 140 from Banquereau (Northeast Nova Scotia Banks) (Fig. 1). Total otolith length and outside long diameter of each opaque annulus, annular length, (Fig. 2) were recorded for one of each pair of otoliths. Annular lengths were designated by the letter L and numbered consecutively from the nucleus (L_1) outwards. Annuli subsequent to L_6 were often detectable only at the side of the otolith and their diameters were calculated by interpolation between last-measured annulus and total length of otolith. This assumed approximately equal growth intervals, as would be expected from the estimated growth curve for fish older than 4 years (Scott, 1968). Length-frequency distributions were prepared for fish, otoliths and otolith annuli (annular L/F). Mean annular lengths were derived from annular L/F distributions and, using relationships between otolith length and fish length, were used to convert annular lengths to fish lengths-at-age from which growth curves were prepared. This technique permits estimation of growth of younger fish than were included in samples of adult *A. dubius*.

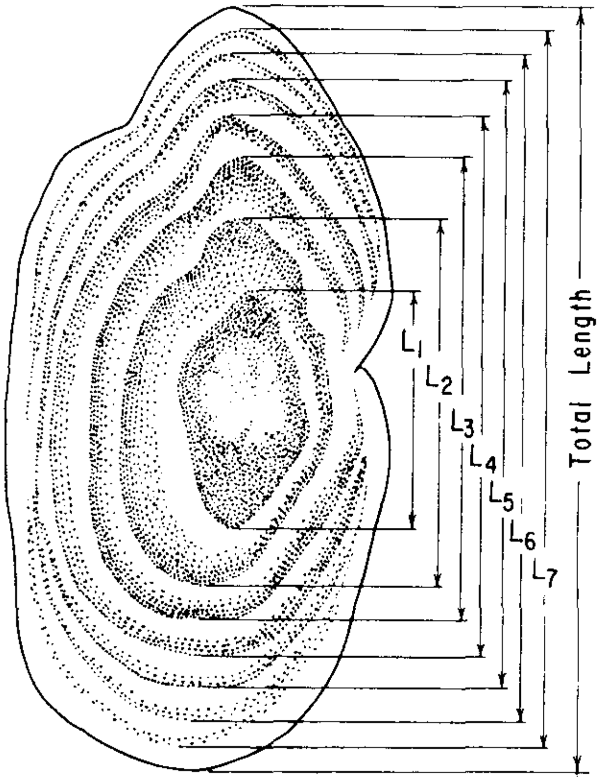

Fig. 2. *Ammodytes dubius* otolith showing notation for measurement of annular (L_1-L_7) and total lengths. Semi-diagrammatic.

Results

Otolith structure

The smallest otolith found, in a fish 3.8 cm long, was a clear disc 0.2 mm in length, convex on the distal side and flat on the other, with a small protrusion at the anterior margin (Fig. 3a). No zoning was evident under the stereomicroscope. Under high power, the anterior protrusion appeared as the external margin of an irregular wedge of optically-denser material than the rest of the otolith (Fig. 4). With increasing otolith size (Fig. 3a-e) the protrusion became more obvious, the otolith outline more irregular and a crescentic outgrowth of material appeared at the posterior margin. It was at this stage, corresponding to fish length about 4.5 mm, that the first indication of deposition of opaque material appeared as a well-defined band in the posterior crescent and irregular cloudiness at the anterior end of the otolith. Further otolith growth was correlated with increasing irregularity of form, change from sub-circular to ovate outline, and spread of opacity from anterior and posterior extremities towards the midsection (Fig. 3f-h). This was associated with formation of hyaline and opaque bands.

Finer structures in otoliths of the length range 0.30-0.41 mm could not be distinguished clearly enough to make measurements of the constituent parts of the bands possible. Examination of the smallest otoliths under high magnification revealed the presence of thin, concentric growth rings (Fig. 4) similar to those which group to form annuli as the otolith develops (Hickling, 1931; Pannella, 1972). Counts of ring diameters in eight otoliths from fish 3.8-3.9 cm long gave ring numbers 64, 69, 74, 79, 71, 70, 60, 72, averaging 70. (In regions of the otolith where rings could not be clearly distinguished, ring numbers were interpolated on the basis of ring intervals in adjacent zones.) Rings were not distinguishable in adult otoliths by the techniques used for examination.

Although there were ill-defined indications of banding in the anterior part of the otolith, the posterior part showed clear, well-defined bands of opaque material separated by narrow hyaline bands (Fig. 3h). The number of bands was correlated with the size of the otolith, ranging from a single opaque band in otoliths about 0.4 mm long to 6 opaque bands in otoliths about 0.9 mm long, i.e. in fish of length 4.5 to 6.7-6.8 cm respectively. Increasing opacity with increasing size of otolith made band determination in the nucleus of larger otoliths difficult – bands were barely discernible in the otolith from a fish 8.6 cm long (Fig. 3i), not part of the samples considered here.

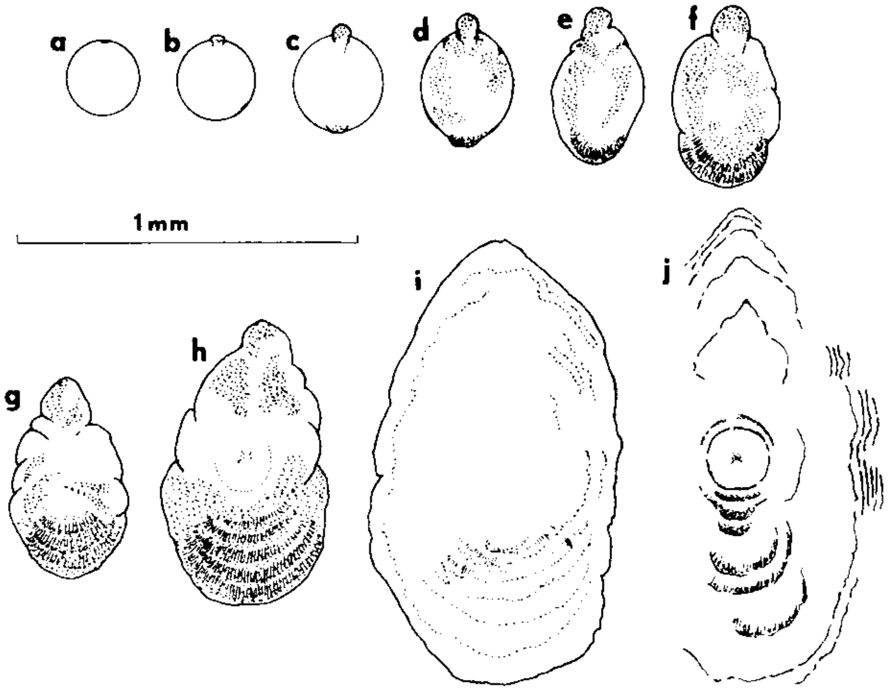

Fig. 3. Change of form and formation of zones with growth in otolith of *Ammodytes dubius*. a-d: semi-diagrammatic, e-j: drawn with camera lucida; a-i: juvenile otoliths at fish lengths 3.8, 4.0, 4.2, 4.4, 4.5, 5.2, 5.0, 6.7, 8.6 cm; j: central structure (nucleus) of adult.

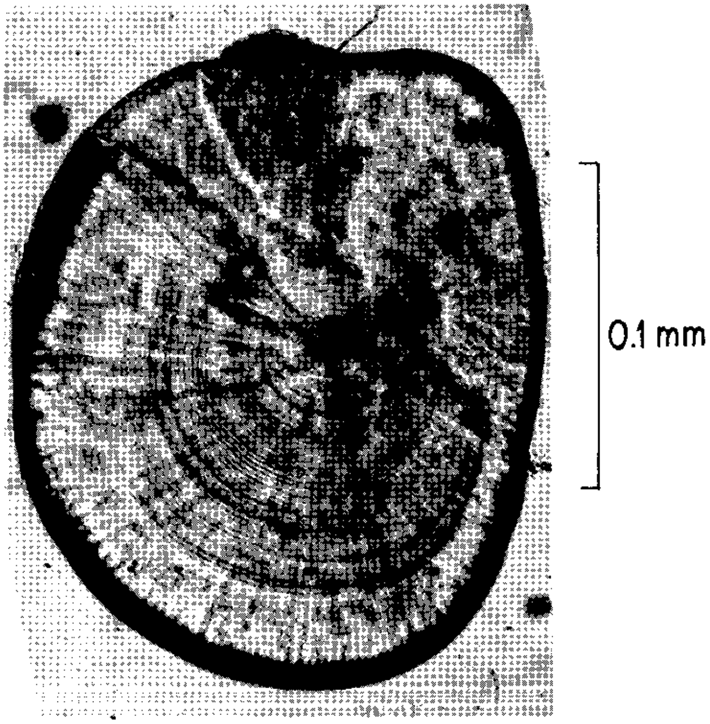

Fig. 4. Otolith from juvenile *Ammodytes dubius* showing concentric growth rings and anterior wedge.

The bands occurred at regular intervals. In 10 specimens measured, the average distances (mm) of outer edges of opaque bands from the centre of the otolith (ranges in parentheses) were: 0.20 (0.19-0.21), 0.25 (0.24-0.26), 0.31 (0.30-0.32), 0.36 (0.32-0.38), 0.40 (0.37-0.41).

The structure of the adult otolith comprised a generally opaque nucleus with fine banding as described for juvenile otoliths above. Typically, this was succeeded by alternating hyaline and opaque annuli of diminishing width and clarity (Fig. 5). Examination of the central structure of a section of an otolith from an adult *A. dubius* (Fig. 3j) showed concentric features representative of the different growth phases shown in juvenile otoliths. The centre of the nucleus was a clear disc, slightly smaller than the smallest otolith found in juveniles. This was surrounded by increasingly irregular growth zones, similar in form to the outlines of juvenile otoliths of corresponding size.

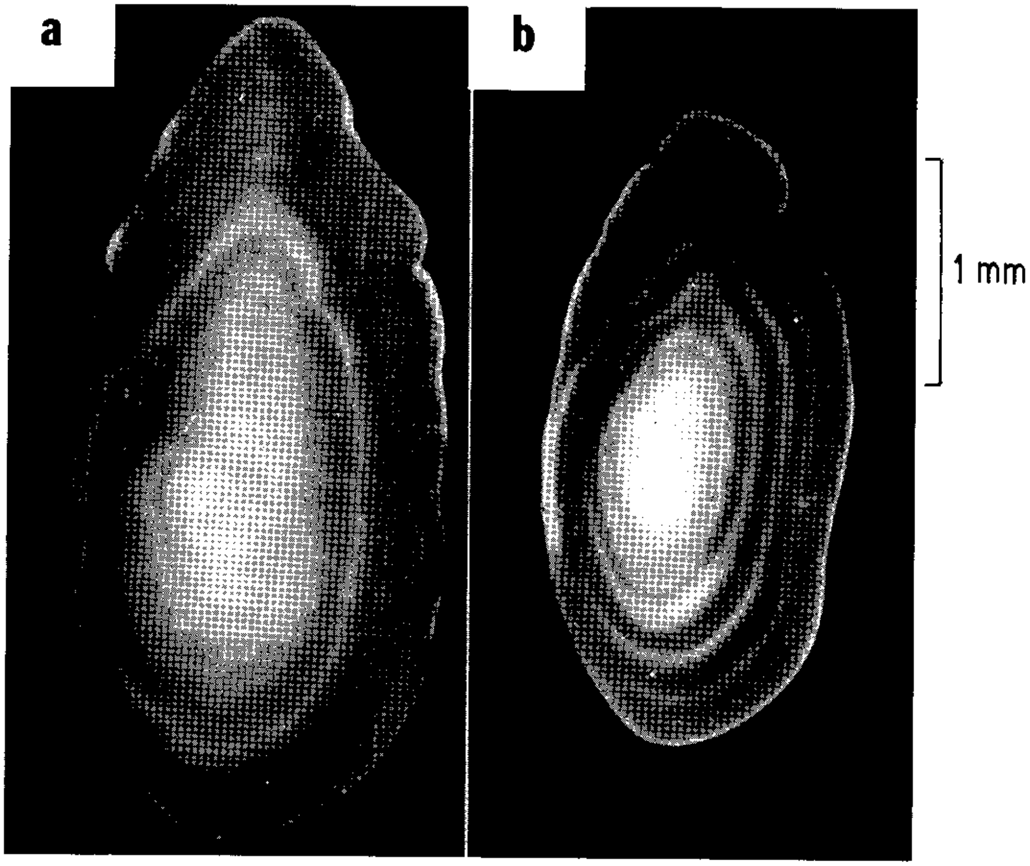

Fig. 5. Age 5+ otoliths from (a) Emerald Bank (b) Banquereau showing differences in size, and clarity and diameters of annuli.

Although quality of zoning in adult otoliths varied greatly both within and between samples, in general, otoliths from the northeast part of the Scotian Shelf showed better-defined and clearer annuli than those from the southwest (Fig. 5). The Emerald Bank specimen is also larger with larger corresponding annuli than that from Banquereau, illustrating the difference in otolith growth between the areas.

Otolith annular lengths from the two areas were compared by examining annular length-frequency distributions of samples from Emerald Bank and Banquereau (Fig. 6) and mean values of successive annular lengths for all samples combined from Emerald-Western Banks and Banquereau (Table 1). These criteria were similar for Emerald Bank and the combined Emerald-Western area, so otolith characteristics of fish from the two areas were regarded as identical for purposes of comparison with Banquereau.

TABLE 1. Mean otolith annular lengths and corresponding back-calculated fish lengths for *A. dubius* from Emerald-Western and Banquereau areas of Nova Scotia Banks. L – mean annular length (mm), *l* – back-calculated fish length (cm).

Annulus	Emerald-Western		Banquereau	
	L	*l*	L	*l*
L_1	1.3	8.0	0.9	5.4
L_2	2.0	13.5	1.6	10.5
L_3	2.6	19.0	2.0	13.5
L_4	2.9	21.5	2.2	15.3
L_5	3.1	24.0	2.4	17.0
L_6	3.2	26.0	2.6	18.2
L_7	3.4	27.8	2.6	18.7
L_8	3.4	27.8	2.7	19.1
L_9	3.5	28.2	2.8	19.8

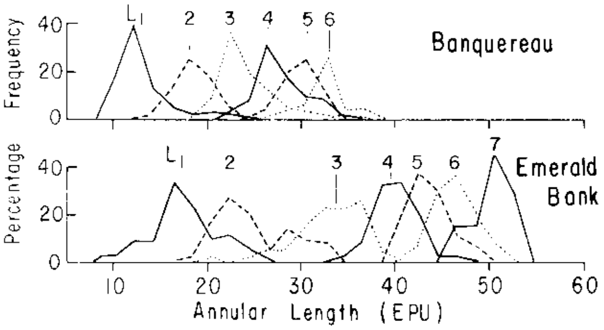

Fig. 6. Otolith annular length-frequency distributions from Banquereau and Emerald-Bank areas of Nova Scotia Banks (1 EPU = 0.07 mm).

The comparisons confirmed that otoliths of *A. dubius* from the Emerald-Western area attained greater maximum length, with greater diameters of respective opaque annuli, than did *A. dubius* otoliths from Banquereau.

It was difficult to determine the time of formation of opaque zones from the nature of the otolith edge, especially in the thin edges of older otoliths. From most reliable samples, percentage occurrences of opaque as opposed to hyaline edges were found to vary in different months (Table 2) with highest proportion in summer, lowest in winter.

Results indicated that, in mature *A. dubius*, hyaline are winter and opaque are summer growth zones, as is usual in Northwest Atlantic fishes. Each opaque annulus was therefore assumed to represent a summer's growth, and successive opaque annuli successive years' growths. Change from deposition of opaque zones to hyaline zones is a gradual transformation in a fish population. In *A. dubius* most of the change takes place between August and November, so October was taken as the terminal month for formation of opaque zones for estimation of age in adult *A. dubius.*

TABLE 2. Monthly percentage occurrence of opaque edges in otoliths of *A. dubius* from Southwest Nova Scotia Banks. (numbers examined in parentheses.)

Month		Percentage with opaque edge
February	(100)	0
March	(50)	0
May	(31)	100
July	(41)	100
August	(42)	93
November	(60)	17

Growth

The relationship of otolith length to fish length for *A. dubius* from Emerald-Western and Banquereau areas (Fig. 7A) did not vary between areas, but the ratio otolith length/fish length decreased from juvenile to adult. Extrapolation from juvenile data from Western Bank (Fig. 7B) indicated that time of first formation of the otolith was when the fish was about 2.4 cm long and the nucleus (L_1), representing first summer's growth, corresponded to mean fish length about 8.3 cm.

A major difficulty in identifying annuli lay in determining which annulus represented the second summer's growth. The centre of the adult otolith was surrounded by a number of opaque and hyaline zones between the nucleus and the regular opaque zones identified as annual summer growth annuli. Examination of otoliths of 14 fish in the 12.0-17.0 cm length range, caught in August 1967, showed that each had a wide opaque margin inside which was a well-defined hyaline zone. Between the latter and the nucleus (L_1) was a series of opaque and hyaline zones of varying width and clarity. Mean otolith length was 2.2 mm and mean fish length 15.6 cm. Allowing for additional growth between time of capture (August) and end of the summer growth period (October), these lengths accord well with annulus length 2.6 mm at back calculated fish otoliths by its clarity, was assumed to represent second summer's growth and was labelled L_2. Succeeding opaque annuli from the centre were assumed to otoliths by its clarity, was assumed to represent second summer's growth and was labelled L_2. Succeeding opaque anuli from the centre were assumed to represent succeeding summers'

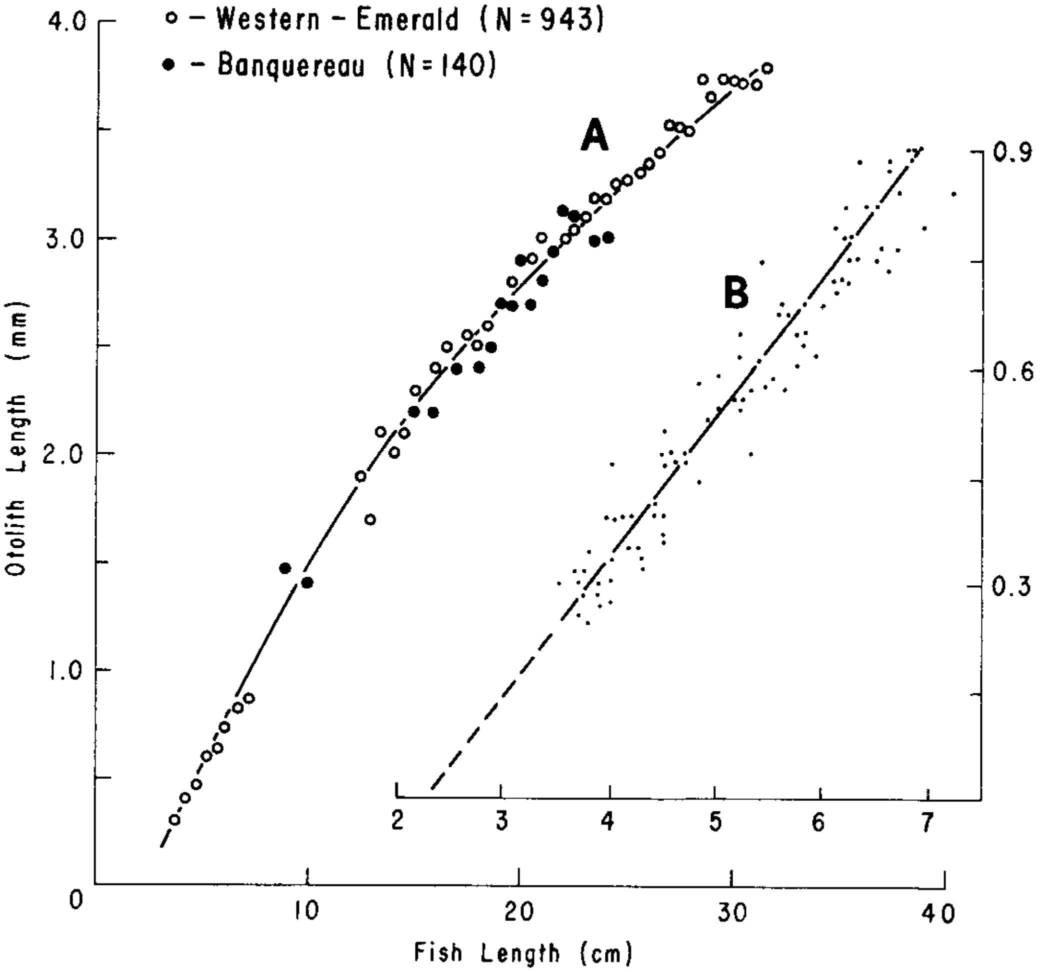

Fig. 7. Relationship of otolith to body length in *Ammodytes dubius*. A. Mean otolith length against mean body length per 1 cm fish length group for Western-Emerald and Banquereau areas of Nova Scotia Banks (numbers of fish sampled in parentheses). B. Scatter diagram for juveniles from Western Bank.

growths. On this basis, otolith growth curves were constructed for *A. dubius* from the Emerald-Western and Banquereau areas (Fig. 8). They indicate a considerable difference in *A. dubius* otolith growth rates between the two areas.

The fish length corresponding to the diameter of each annulus (Table 1) may be read from the otolith length-fish length curve (Fig. 7A) and plotted against a time scale to complete the fish growth curve subsequent to annulus L_2. The curve so obtained is compared in Fig. 9 to the growth curve derived by Scott (1968) from conventional age-length determinations.

A. dubius shows a general trend of decreasing length from south to north with obvious distinction between fish from the Banquereau-Middle Banks area in the northeast and the Emerald-Western-Browns Banks area in the southwest (Scott, 1972). From mean annular lengths (Table 1) and relationship between otolith length and fish length (Fig. 7A) for Banquereau material, a growth curve for Banquereau fish was derived and is compared to that for Emerald-Western area fish in Fig. 9. The difference between the curves indicates that *A. dubius* from the latter area has a higher growth rate and attains a greater maximum length than *A. dubius* from Banquereau.

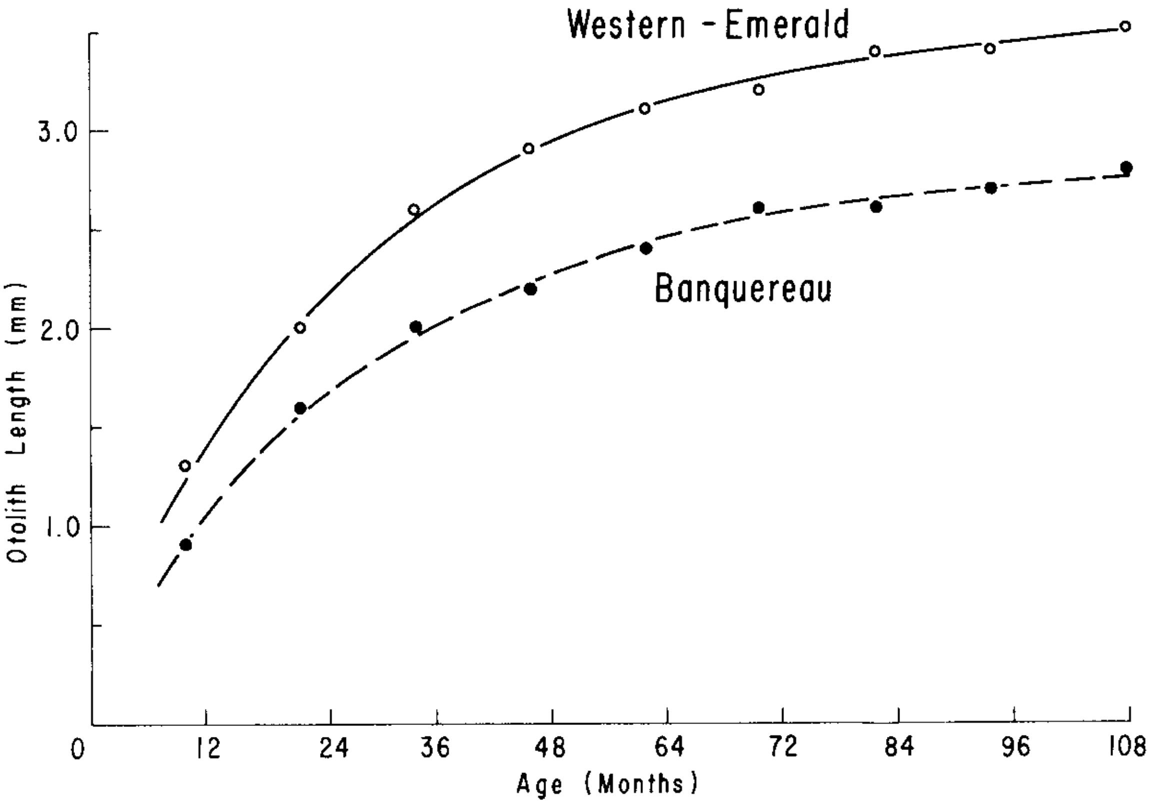

Fig. 8. Relationship of mean annular length to assumed age in otoliths of *Ammodytes dubius* from Western-Emerald and Banquereau areas of Nova Scotia Banks.

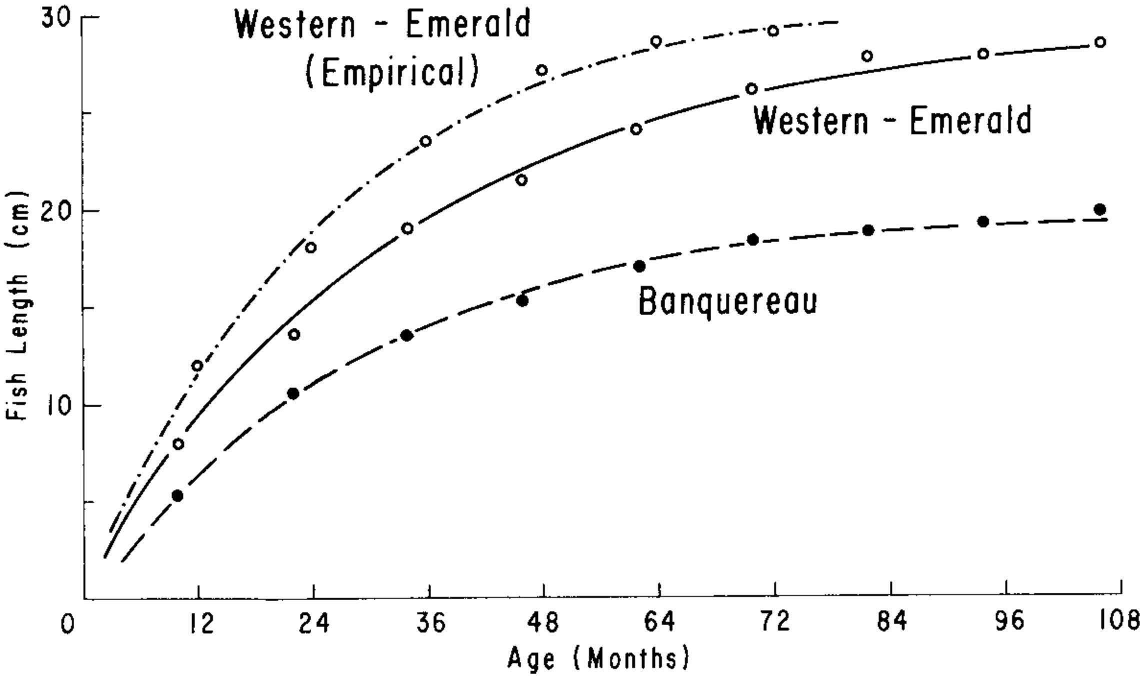

Fig. 9. Empirical growth curve of *Ammodytes dubius* from Western-Emerald area and back calculated growth curves from otoliths from Western-Emerald and Banquereau areas of Nova Scotia Banks.

Discussion

The only study of periodicity in fine structure of otoliths appears to be that of Pannella (1971) who interpreted growth bands in Silver hake, *Merluccius bilinearis*, as daily growth increments and their periodic grouping as representing weekly (7-8 bands), 2-weekly (15 bands), monthly (29 bands) periods, fast-growth zones (230-260 bands), and slow-growth zones (100-110 bands). A fast-growth and slow-growth zone combine to give a zone of 330-370 bands representing an annual cycle.

The present material supports Pannella's suggestion that daily growth increments may be a universal feature of fish otoliths. The average number of rings, 70, in an otolith from fish 3.9 cm long is the same order as the number of days from time of first formation of the otolith at fish length 2.4 cm to the time the fish attains a length of 3.9 cm, according to the growth curve in Fig. 9. The rings may therefore represent daily growth increments. Intervals between ring diameters did not show any consistent periodicity similar to that found by Pannella, but the regular increments in diameters of opaque zones in juvenile otoliths are suggestive of periodic growth or other periodic physiological change in juveniles. This periodicity appears to be related to some short-term phenomenon similar to that causing the basic 15-day cycles in Pannella's material.

Back-calculated fish lengths-at-age from otolith zone measurements fell well-below those from empirical data (Fig. 9). Such differences are not unusual. For instance, Halliday (1969) found lower values for back-calculated compared with empirical values in *Argentina sphyraena* and Hickling (1933) found higher values in Hake, *Merluccius merluccius*. In effect, the measured annular diameters were not identical with otolith total lengths at time of formation of the annuli. Resorption, overgrowth, penetration of hyaline by opaque material (Reay, 1972), and refraction may all contribute to the difference.

Marked differences between Emerald-Western and Banquereau otolith growth and back-calculated fish growth are consistent with observed differences in maximum lengths between the two areas. The differences are characteristic of the areas, and are not due to size segregation of the fish within areas or sampling error. They are presumably due to the different environmental conditions, principally temperature, which exist between the areas: mean annual bottom temperatures, 1958-1968, ranged from 5.18°C in the Southwest Scotian Shelf, through 4.66°C in the central part, to 2.25°C on Banquereau (Fisheries Research Board research cruise data).

Greatest length of *A. dubius* larva taken in plankton on the Scotian Shelf during 1968-72 was about 3.5 cm in July (Unpublished research cruise data). After July, larvae were no longer captured in plankton hauls (Sameoto, 1971). Length 3.5 cm corresponds almost exactly to the length of smallest juveniles (3.8 cm) taken from Winter flounder stomachs in July 1972, indicating that the change from planktonic to bottom-oriented existence occurs when the larva reaches a length of about 3.5 cm. The correspondence between maximum planktonic and minimum demersal lengths indicates that there is no prolonged midwater juvenile phase in growth of *A. dubius*. Like the adult (Scott, 1972), the juvenile is evidently associated with the seabed in suitable areas, except possibly when feeding.

Acknowledgements

I thank Drs D. W. McLeese and A. V. Tyler for helpful criticism of the manuscript.

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The Selectivity of Polish Large-Mesh Topside Chafing Gear Made of Thick Netting Yarn

By F. Bucki[1], W. Strzyzewski[1], and G. Zdziebkowski[1]

Abstract

Results of investigations with a Polish large-mesh chafing gear made of thick (10-mm diameter) netting yearn of knotless construction show that its use in regular fishing practice would not reduce significantly the selectivity factor (3.67 with chafer and 3.86 without chafer).

Introduction

The selectivity of fishing gear is essential for the protection of the younger age-groups of exploited fish stocks. Therefore, studies on the construction of fishing gear which combine great strength and durability with high selectivity have been pursued by Polish scientists.

Preliminary investigations on reinforcement of otter trawl codends and its effect on selectivity were conducted in 1965 by Strzyzewski (1966). He showed that a codend covered by topside chafing gear with a mesh size twice that of the codend itself gave a selection factor only 3.8% less than that for unprotected codends.

Later investigations of the effect of large-mesh chafing gear by Trescher and Naumov (1967), Bohl (1967), Holden and Jones (1967), and Monteiro (1968) supported these findings.

However, the Polish commercial fisheries demanded a stronger chafing gear of the same type. Nets were continually bursting when hauled because the material of the chafing gear was too weak to withstand the forces acting on it. This stimulated a further search for means of strengthening the codend. Unfortunately, material which would make codends strong enough not to require chafing gear was not yet available. Thus, the solution lay in strengthening the Polish large-mesh chafer while retaining the highest possible selectivity of the codend. The possibility of using thick netting yarn and eliminating the knots in the manufacture of the chafer and testing its selective effect was considered.

Selection experiments using a knotless Polish chafer made of 10-mm diam netting yarn were carried out in 1967 (Bucki *et al.*, 1968). The codend was made of double braided netting twine of 3.5-mm diam. The selection factor obtained was comparatively high (3.71) and further experiments were considered necessary to obtain more data.

The selection experiments reported here continue the 1967 experiments on a larger scale. Selectivities of (i) unprotected codends, (ii) codend reinforced with a Polish large-mesh chafer made of the same netting yarn as for the codend, and (iii) codend with a chafer made of netting yarn of 10-mm diam, were compared.

TABLE 1. Specifications of codends and chafers investigated.

		Codend					
		A	A_1	B	B_1	C	C_1
Codend:	mesh size (mm)	108.8	128.3	111.3	126.9	108.8	125.9
	braiding	double	double	double	double	double	double
	nominal diameter of netting yarn (mm)	3.50	3.50	3.50	3.50	3.50	3.50
Chafer:	mesh size (mm)	–	–	223.0	253.0	216.0	250.0
	braiding	–	–	double	double	single	single
	nominal diameter of netting yarn (mm)	–	–	3.5	3.5	10.0	10.0

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[1] Sea Fisheries Institute, Gdynia, Poland.

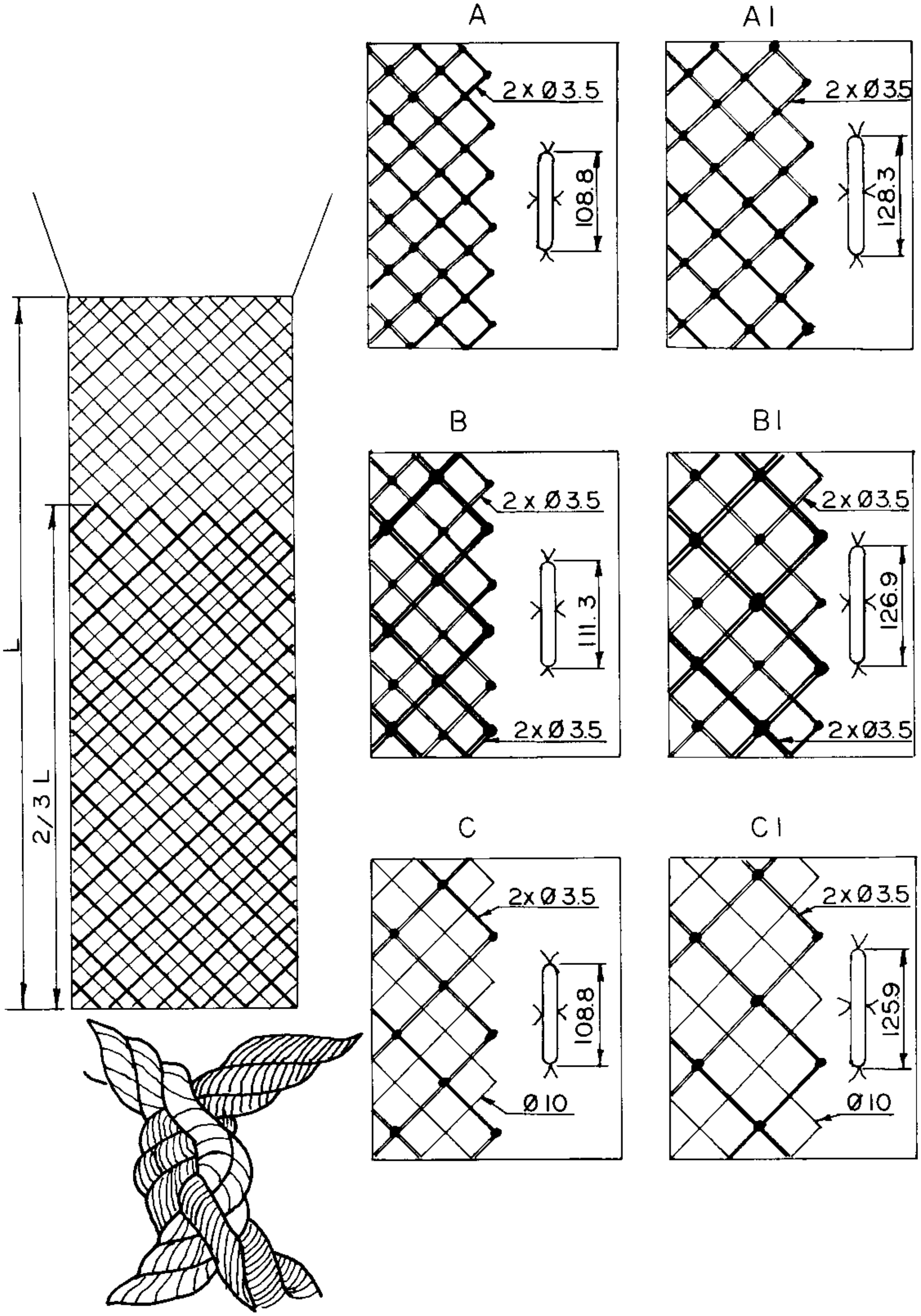

Fig. 1. Showing the attachment of a Polish large mesh topside chafer to the codend, the six variants of codend used for cod selection experiments, and knotless single braided netting yarn.

Materials and Methods

The investigations were carried out on board M/T *Apus*, a stern trawler 82.0 m long of 2,824 gross tons and 2,400 H.P., using its regular commercial trawl in ICNAF Division 2J from 11 to 18 February 1970. The codends of the trawl could be removed and replaced according to the requirements of the program. For the experiments they were provided with covers made of twine 1.8-mm thick with mesh size (lumen) of 40 mm. Selective cover was attached to the upper part of the codend, thus leaving free space for fish. The specifications of the codends used for investigation are given in Table 1 and in Fig. 1.

The characteristics of the netting yarns from which the codends and their chafers were made are given in Table 2.

The chafer covered two-thirds of the length of the codend and was fastened according to Bohl's (1967) proposal and ICNAF recommendation (1969).

The mesh was measured with an ICES guage under a load of 4.0 kg. Thirty such measurements were made after each haul.

The duration of the haul was from the moment the shooting of the warps was completed until the moment they were hauled back on deck.

The observations were carried out both day and night between 11 and 18 February 1970 on the fishing ground within the coordinates 53°15'N-54°15'N and 053°45'W-053°20'W and 053°00'W.

TABLE 2. The characteristics of the netting yarns used for the codends and chafers.

	Codends A,A_1; B,B_1; C,C_1 Chafers B,B_1	Chafers C, C_1
Material	Polyamide	Polyamide
R tex (g/1,000 m)	R 7,500 tex	R 47,000 tex
Runnage (m/kg)	133	21
Construction	twisted	twisted
Wet knot breaking load (kg)	173.0	974.5
Diameter (mm)	3.46	10.8
Elongation at half the wet knot breaking load (%)	24.4	23.6

Table 1 shows that the six variants of codends used for the experiments consisted of three each of two different mesh sizes. The primary netting material for all six codends was double braided netting yarn 3.5 mm in diameter. Chafers of the B and B_1 variant were made of the same double braided netting yarn 3.5 mm in diameter as their codends, whereas the chafers of the C and C_1 variant were made of single netting yarn of 10-mm diam.

The meshes of the chafers made of 10-mm netting yarn were knotless. This increased the filtration area of the mesh openings as compared to chafers with knots.

The netting yarn used in making both codends and chafers had almost the same elongation, 24.4% for the netting yarn of 3.5-mm diam and 23.6% for the yarn of 10-mm diam. For the netting yarn of 3.5-mm diam, it was 24.4% and for the cord of 10 mm, 23.6%. The manner in which the chafer was attached to the codend is shown in Fig. 1.

During the investigation, length measurements were made on 88,868 cod and girth measurements on 629 individuals. The measurement of girth was made using a measuring tape slightly adhering to the fish body. On the basis of these measurements the relationship between length (L) and girth (G) was established as $G = 0.5049\,L$.

Results

There were differences between selection factors obtained from particular hauls. These were probably due to the large variation in size composition of the investigated stock of fish.

TABLE 3. Selection factors obtained from particular hauls with different codends.

Codend variant	Number of hauls	Selection factors obtained				
A	8	3.53;	3.51;	3.75;	3.83;	3.92;
		4.10;	4.17;	4.33.		
A_1	7	3.25;	3.31;	3.39;	3.50;	3.59;
		3.60;	3.71.			
B	5	3.61;	3.61;	3.76;	3.92;	4.09.
B_1	7	3.20;	3.21;	3.21;	3.36;	3.36;
		3.57;	3.70.			
C	10	3.47;	3.48;	3.64;	3.67;	3.75;
		3.77;	3.78;	3.80;	3.90;	4.17.
C_1	9	3.35;	3.39;	3.41;	3.42;	3.55;
		3.60;	3.69;	3.71;	3.79.	

TABLE 4. Cod selection experiments using six variants of codends in ICNAF Division 2J (53°15'N, 053°45'W – 053°20'W, 053°00'W – 052°30'W) fron 11 to 18 February 1970.

	Codend					
	A	A_1	B	B_1	C	C_1
Number of hauls	8	7	5	7	10	9
Duration of a haul (min)	36.0	46.0	11.0	10.0	21.5	11.0
Speed (knots)	4.2	4.2	4.2	4.2	4.2	4.2
Depth (m)	405–440	380–480	410–430	395–440	370–450	390–420
25-75% selection range (cm)	18.1	13.8	18.1	17.9	27.4	17.2
Number of cod in selection range						
in the codend	4,565	1,468	1,519	2,289	12,954	2,831
in the cover	6,313	2,554	1,856	3,239	15,117	4,671
Total number of cod						
in the codend	7,807	3,062	4,699	4,700	20,810	5,881
in the cover	7,677	8,198	2,110	3,577	15,389	5,158
Weight of the catch (kg)						
in the codend	3,571	978	2,927	4,859	8,119	3,279
in the cover	1,553	1,079	602	3,418	3,157	1,212
Mesh size (mm)	108.8	128.3	111.3	126.9	108.8	125.9
Range of the mesh size (mm)	105–113	124.5–134	108–116	120–133	106–112	122–132
Number of measurements	240 (8 X 30)	210 (7 X 30)	270 (9 X 30)	210 (7 X 30)	300 (10 X 30)	270 (9 X 30)
50% retention length (cm)	42.1	44.5	42.5	42.5	40.1	44.2
Selection factor	3.86	3.48	3.81	3.32	3.67	3.51

Data on the results of observations on six variants of the codends are given in Table 4. From this the following selection factors are noted:

Codend variant A (mesh size, 108.8 mm) – selection factor 3.86,

Codend variant B (mesh size, 111.3 mm) – selection factor 3.81,

Codend variant C (mesh size, 108.8 mm) – selection factor 3.67.

If codend variant A (without chafer) is assumed to be the standard for comparison with selection factor equal to 100, then the selection factor for codend variant B equals 99 and for codend variant C equals 95.

Codend variant A_1 (mesh size, 128.3 mm) selection factor 3.48,

Codend variant B_1 (mesh size, 126.9 mm) – selection factor 3.32,

Codend variant C_1 (mesh size, 125.9 mm) – selection factor 3.51.

Assuming the selection factor for the codend variant A_1 to be 100, the selection factors for codend variant B_1 equals 96, and for codend variant C_1 equals 101.

It appears, therefore, that the codend variant C_1 (mesh size 125.9 mm) with knotless chafer, made of netting yarn 10 mm, showed even higher selectivity than the unprotected codend variant A_1.

This may be accidental, due to the large range of sizes of investigated fish. However, it does point to the higher filtration property of the codend variant C_1 which was rigged with a chafer of a thicker netting yarn.

From the above data, it appears that the selectivity remains at a high level when the codend and the chafer are made of the netting yarn of the same diameter (3.5 mm) and also when the chafer is knotless and made of thicker netting yarn (10 mm). These experiments confirm previous results, obtained from the experiments conducted in 1965 and 1967. In 1965 Strzyzewski (1966) found the selection factor for the unprotected codend to be 3.92 (100%), while for the codend with chafer – both made of the same netting yarn – it was 3.77 (96%). From 1967 investigations Bucki (1968) found the selection factor for the codend protected with chafer, made of netting yarn 10-mm diam, to be 3.71, which is even higher than in the present experiments (3.67).

Conclusions

Results of investigations show that, for all practical purposes, there is no difference in gear selectivity between an unprotected codend and a codend protected by the Polish chafer.

The difference in selectivity between the knotless chafer, made of single thick netting yarn and the chafer with knots, made of double netting yarn of the same diameter as in the codend, is negligible. Therefore, it is possible to use thicker netting yarns for this type of chafer.

Adherence of the meshes of chafer, made of thicker netting yarn over the meshes of the codend (bar of chafer mesh against bar of codend mesh) is as good in the case of chafer made of netting yarn of the same diameter as in the codend.

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Studies on Georges Bank Herring in 1970

Introductory Note

By The Editor

USSR scientists have carried out quantitative surveys on the extent and intensity of spawning on Georges Bank since 1964, using bottom grabs to sample deposited spawn. These surveys have shown a progressive contraction in the area of the spawning grounds and in the total number of eggs laid, from which a corresponding reduction in adult stock size was deduced.

The need for a more direct study of the spawning grounds by *in situ* observation has been emphasized, and plans were made during the summer of 1970 by scientists from USSR, Canada, and USA to carry out a combined survey during the autumn of that year. The USSR contributed the research vessel *Alferas* to carry out herring spawning studies as in previous years by locating the main spawning grounds, Canada contributed the submersible *Pisces I* to observe and study the spawning beds, and USA contributed the research vessel *Albatross IV* which carried the submersible and other auxiliary equipment.

Scientists from the participating countries have prepared reports dealing with those aspects of the project with which each was most concerned. Their reports, whose titles are listed below, are presented on the following pages (p. 125-162).

Studies on Georges Bank Herring Spawning in 1970

A. M. Pankratov[1] and I. K. Sigajev[1]

Abstract

Spawning studies on Georges Bank during September-October 1970 indicate that spawning began in early September and continued for a longer period than in previous years, that the area of the spawning grounds detected was about one-half the size of those in 1969, and that spawning tends to begin first on the eastern part of the Bank and progressively later on the western part of the Bank and in the Cape Cod area.

Introduction

One of the main objectives of the third cruise by SRTM-8006 *Alferas* from 12 July to 5 December, 1970, was to conduct a complex of studies on the intensity of herring spawning on Georges Bank. The program included the following steps:

1) The collection of material on the distribution and biology of prespawning herring in the northern part of Georges Bank;

2) The location of herring spawning grounds;

3) The estimation of the area of the spawning beds and of the number of eggs deposited on the spawning grounds; the study of the character of egg depositions and survival and of the effect of predators;

4) The subsequent distribution of herring larvae on Georges Bank.

Methods

Material on the distribution, behaviour, and biology of herring was collected by means of trawl stations (32.5 m trawl) carried out from the end of August until the end of October. Areas of intensive fishing for herring by the commercial fleet were mapped out and echo-sounding surveys of the whole northern part of Georges Bank conducted.

Biological analysis included length measurements, determination of sex and maturation stage (by the 8-grade table) and of intestinal fat using the Hjort criteria; the feeding intensity was recorded and the Fulton and Clark coefficient of body fat content determined. Otoliths were taken for subsequent age determination.

The search for herring spawning beds, using a 1.2 m drag, was directed towards areas selected as a result of the first stage of the research program. As soon as the drag brought aboard herring eggs with substratum, an OKEAN – 50 grab was substituted. Sampling then continued until the whole area of an egg patch was delimited so that the total number of eggs on one spawning ground could be estimated. The vessel then moved to sample another likely area.

Sampling for herring larvae over the spawning period covered a large triangular area in the northern part of Georges Bank where herring spawning had been observed in recent years. In November, the whole area of Georges Bank and the region west of the Bank up to Hudson Canyon was surveyed as part of the regular ichthyoplankton survey.

Larval sampling was carried out using an IKS – 80 net (ichthyoplankton conical net, with a mouth diameter of 80 cm) towed for 10 min in the surface 1-m stratum with the vessel circulating at lowest speed.

Results

In the last ten days of August herring were concentrated on the eastern slopes of Georges Bank at depths of 50-100 m. By that time feeding had virtually

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ceased and intestinal fat had declined to the "O" stage. Gonads were in stages IV and IV-V. Echo-sounder surveys showed that the largest concentrations of spawning herring occurred during September. From late August to early October the prevailing size range was from 26 to 34 cm herring, with a peak at 29 cm and a mean size of 29.5 cm. The sex ratio of prespawning and spawning concentrations was close to 1:1.

Maturation stages for herring sampled in September are given in Table 1, and Fig. 1 shows the length distribution.

TALBE 1. Maturation stages of Georges Bank herring, September 1970.

1970	No. fishes analyzed	juv.	♂	♀	II ♂	II ♀	III ♂	III ♀	IV ♂	IV ♀	IV-V ♂	IV-V ♀	V ♂	V ♀	V-VI ♂	V-VI ♀	VI ♂	VI ♀	VII ♂	VII ♀
11 Sept	100	–	42	58	1	–	–	1	5	4	36	52	–	1	–	–	–	–		
15 Sept	100	5	51	44	–	–	–	–	1	–	16	20	25	7	9	15		2	–	–
20 Sept	100	–	35	65	–	–	–	–	–	–	–	–	–	–	–	1	–	5	35	59
26 Sept	100	1	62	37	–	–	–	–	–	–	1	–	10	1	29	6	12	29	1	
27 Sept	100	11	47	42	–	–	–	–	–	2	18	25	20	9	6	8	–	–	1	–
28 Sept	100	1	61	38	–	–	–	–	–	–	–	1	29	2	26	29	5	6	1	–

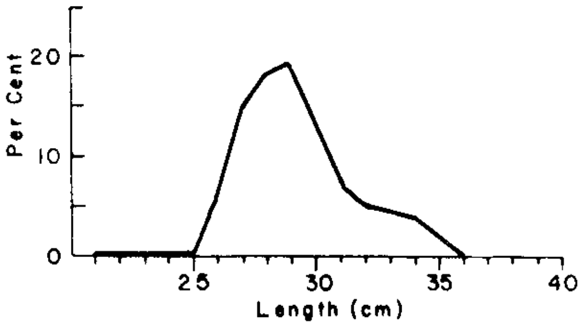

Fig. 1. Length-frequency distribution of Georges Bank herring, 1970.

According to data collected by *Alferas*, herring spawning in 1970 was prolonged compared with previous years. It began in the first 5 days of September and continued until the end of October. The spawning grounds were found in the northern part of Georges Bank at approximately the same locations as in previous years. Egg deposition in the centre of spawning beds was not uniform but formed a discontinuous layer. Also, the thickness of the egg layer diminished from the centre to the periphery. The maximum density of eggs recorded was 24.4 kg/m^2 but samples from the outlines were much less dense. Eggs taken from the centre of spawning grounds had apparently been laid in several layers which could be easily separated by washing. Table 2 shows estimates of egg density for the two spawning beds in the eastern part of the area and for one on the western part. The eggs spawned on the eastern grounds (Fig. 2) were developing in homothermal environments at 13° to 14°C, while on the western spawning ground (Fig. 3) the bottom temperature was 11° to 12°C. Eggs throughout the mass were in the same or similar stage of development and it may thus be suggested that spawning takes place over a short period of 2-3 days.

Egg survival is high. The number of dead eggs in each sample did not exceed 1%.

Dense concentrations of cod which had fed heavily on eggs were found in the area after spawn had been laid. Flatfish, haddock, skates, dogfish and invertebrates (starfish, sea urchins, polychaetae, and hermit crabs) were also in abundance on the spawning grounds.

The estimated time of spawning was 16-17 September on the first eastern ground, 18-19 September on the second eastern ground, and 29-30 September on the western ground, which means that the main body of the herring spawned within a period of 2 weeks, that is 16-30 September. Eggs on the eastern grounds were mainly in the second and third stages of development, while on the western grounds they were in the first and second stages. Assuming an incubation period of about 150 degree days, the larvae from the eggs on the first eastern spawning ground would have been hatched on 25-26 September, on the second eastern ground on 27-28 September, and on the western ground on 12-13

TABLE 2. Egg density (kg/m^2) in 1970 on (A) eastern spawning ground No. 1; (B) eastern spawning ground No. 2; (C) western spawning ground.

Sta. No.	Lat	Long	Egg density (kg/m^2)
	A. Eastern spawning ground No. 1		
6	41°53.90′	67°14.60′	0.15
7	41°54.10′	67°14.50′	9.10
48	41°54.30′	67°15.20′	0.80
49	41°54.26′	67°15.15′	0.03
50	41°54.21′	67°14.97′	0.04
51	41°54.10′	67°14.55′	0.90
57	41°54.28′	67°15.18′	0.10
59	41°53.90′	67°15.00′	12.20
60	41°54.00′	67°14.80′	15.50
88	41°54.16′	67°14.92′	7.30
99	41°54.26′	67°15.17′	0.12
97	41°54.43′	67°15.50′	0.02
100	41°54.20′	67°15.10′	24.40
116	41°53.65′	67°14.67′	0.06
117	41°53.65′	67°14.80′	0.02
118	41°53.87′	67°14.93′	0.27
119	41°53.90′	67°15.00′	18.80
120	41°53.98′	67°15.08′	8.80
132	41°54.12′	67°14.35′	0.02
137	41°53.60′	67°14.96′	0.20
155	41°54.30′	67°15.58′	0.04
	B. Eastern spawning ground No. 2		
3	41°52.33′	67°15.31′	6.40
5	41°52.10′	67°15.25′	0.20
9	41°52.53′	67°15.10′	0.75
14	41°52.53′	67°15.50′	0.23
15	41°52.40′	67°15.55′	2.90
28	41°52.10′	67°15.40′	2.60
30	41°52.12′	67°15.36′	0.55
	C. Western spawning ground		
4	41°58.90′	67°33.10′	0.70
39	41°58.60′	67°32.50′	2.90
40	41°58.60′	67°32.60′	6.87
41	41°58.65′	67°32.70′	0.08

October. To confirm the time of hatching on the first eastern ground, a subsequent egg sample was taken (in the fourth stage of development) and incubation was completed in Petri dishes and polyethylene jars. Mass hatching of larvae was observed after one hour in the water at 16.4°C; the mean length of the newly hatched larvae was 4.5 mm and the larvae survived for about 1 hr.

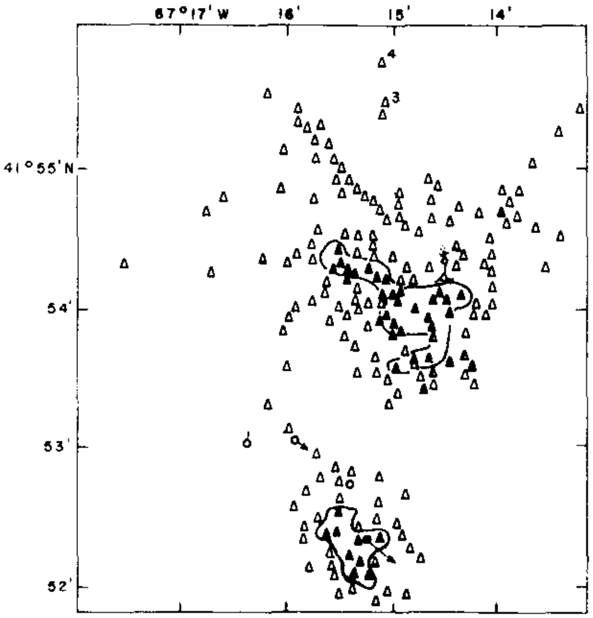

Fig. 2. The eastern spawning grounds.

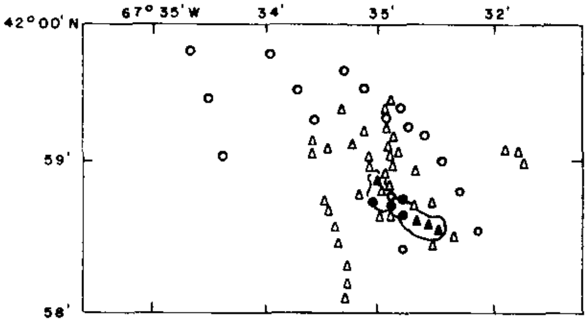

Fig. 3. The western spawning grounds.

Estimates of the herring population which spawned in this area (Figs. 2 and 3) were made from the equation (Noskov and Zinkevich, 1967):

$$N = \frac{q^{AB}}{C \times 10^9}$$

in which

N = size of the spawning population (thousand tons);

A = abundance of eggs on the spawning ground (in numbers);

B = mean weight of herring specimens (grams) (equal to 200 gm);

C = 118,000 eggs (mean fecundity);

q = coefficient to account for the number of males (sex ratio 1:1);

A = DSZ, where
  D = mean number of eggs in the area, kg/m^2,
  S = area of spawning ground in m^2,
  Z = mean number of eggs in 1 kg of deposited spawn – 500,000.

The area of the first eastern spawning ground was 1,099,621 m^2 (1.1 km^2), that of the second eastern ground 526,444 m^2, and of the western one 299,163 m^2. It is calculated that 9.282, 1.374, and 1.339 thousand tons of herring had spawned on these grounds respectively. Observations on the distribution of herring larvae began on 14 October, by which time larval hatching on the eastern grounds was completed and was coming to the end on the western ground. From 14 October, *Alferas* began a series of six surveys within a large triangle covering all of the known spawning areas of recent years. Work in this triangle continued to the end of October and besides samples of plankton and ichthyoplankton, water temperatures and water samples for salinity were taken at each station. Larval distribution throughout the period 14-28 October is shown in Fig. 4. The first surveys in this triangle showed that hatching was coming to the end on the western spawning ground and the following surveys revealed the process of larvae drifting into the survey area, presumably from spawning grounds located southwest of those detected. Larval size varied between 6-18 mm.

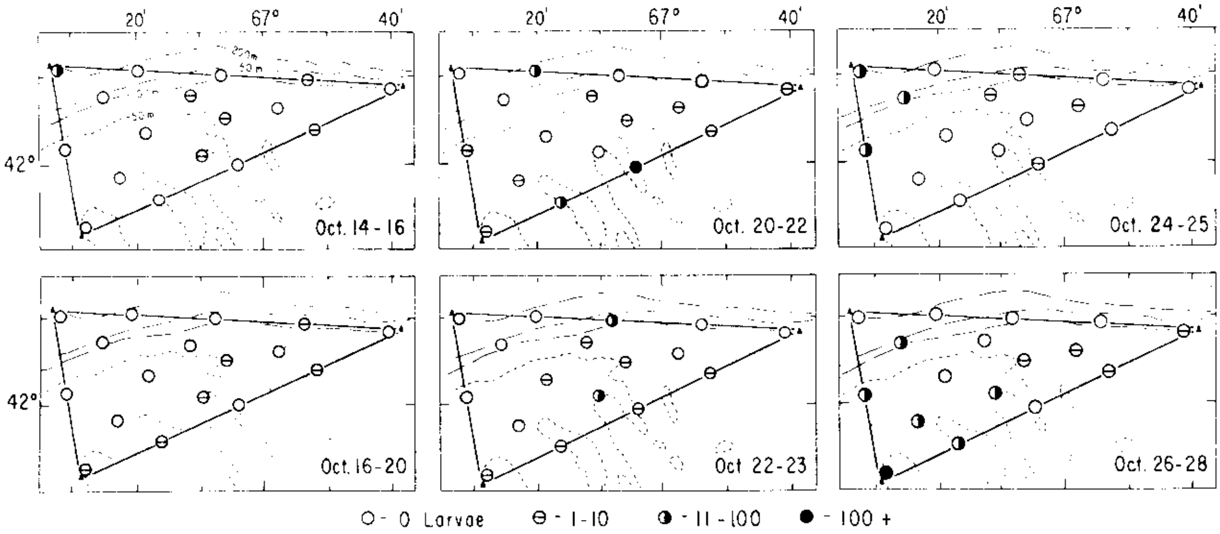

Fig. 4. Approximate distribution of herring larvae over the triangular survey area, 14-28 October 1970.

Table 3 shows the range of surface and bottom water temperature for six surveys in the triangle.

The pattern of herring larval distribution in the autumn for the whole area of Georges Bank, Gulf of Maine, and American shelf as revealed by the ichthyoplankton surveys made during November is given in Fig. 5.

Biggest larval catches were recorded on the north-eastern slopes of Georges Bank. Larval size varied from 6 to 19 mm. The largest larvae of 23.5 mm were caught on the Nantucket Shoals and in the area south of Long Island.

TABLE 3. Surface and bottom temperatures in the triangular survey area.

October	Water temp. °C at the surface	Water temp. °C at the bottom
14-16	14.0-16.0	10.0-15.0
16-20	12.0-14.0	10.0-14.0
20-22	12.0-13.6	10.0-13.4
22-23	12.5-13.7	9.0-13.5
24-25	13.0-13.5	9.0-13.4
26-28	12.2-13.4	8.0-13.4

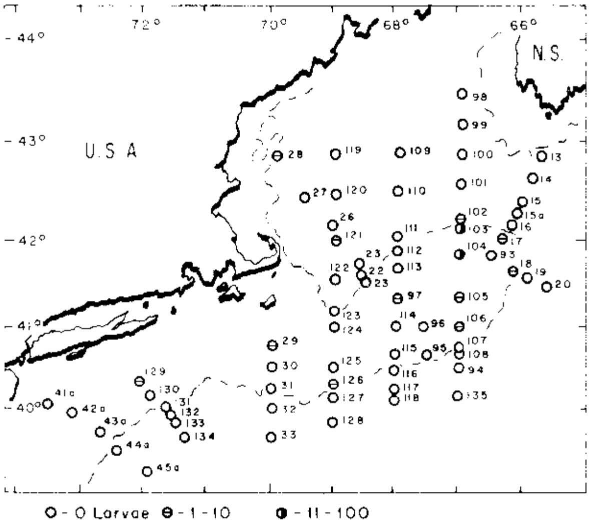

Fig. 5. Approximate herring larval distribution, November 1970.

Summary

Preliminary analysis of the results of herring spawning studies on Georges Bank in 1970 shows some differences compared with previous years. One of these is the long duration of spawning which lasted for about 2 months. The cause of this phenomenon will probably become clearer after further and more detailed analysis of all the data.

The area of spawning grounds detected by *Alferas* appeared to be half the size of those in 1969. It may be suggested that the three detected spawning grounds are the main ones, since they are located in the same areas as in recent years and also because the main body of commercial fleet fishing for prespawning herring was found only in this area. It is quite possible that, apart from the spawning grounds detected in 1970, there were other smaller ones, but the search for them would have entailed additional expense and time.

Observations on herring larvae in the triangle indicate the existence of herring spawning grounds west and south of those detected and also confirm the fact that herring spawning begins in the eastern part of the Bank and gradually shifts further to the west, covering the area of the northwestern slopes and later the Cape Cod area.

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NOSKOV, A. S., and V. N. ZINKEVICH. 1967. Abundance and mortality of herring (*Clupea harenqus* L.) on the Georges Bank according to the results of eggs counting in spawning areas in 1964-1966. *Annu. Meet. int. Comm. Northw. Atlant. Fish. 1967,* Res. Doc. No. 98, Serial No. 1897 (mimeographed).

Underwater Observations on Herring Spawning Grounds on Georges Bank

By J. F. Caddy[1] and T. D. Iles[1]

Abstract

Direct observations were made from a submersible on herring spawning grounds on Georges Bank (Subdivision 5Ze) in September-October, 1970. Egg beds at different stages of development from fertilized eggs to hatched egg residues were observed, photographed, and sampled. Egg deposition was restricted to level areas of scoured glacial gravel in 50 m depth, and no eggs were seen on sand or shell gravel. Only a small fraction of the gravel substrates in the area were being utilized for spawning.

Eggs had been laid in uniform sheets 1-2 cm thick with discrete margins, probably at a single spawning. The egg mass had attracted a feeding community of fish and invertebrates, and mortality due to predation was estimated to be 8% within 1-2 days of hatching. Schooling larvae were observed close to the bottom shortly after hatching. Spawn residues persisted for at least 10 days after hatching, and led to local anoxic conditions on the grounds.

Introduction

Studies by scuba on inshore beds in the Gulf of St. Lawrence (Tibbo, Scarratt, and McMullon, 1963) showed that *in situ* methods can be used for surveys of herring spawning grounds. In September-October 1970, direct observations were made on offshore spawning grounds in deeper water from the Canadian research submersible *Pisces I*, carried by the U.S. research vessel, *Albatross IV*.

Previous Studies

Quantitative surveys of herring spawning beds on Georges Bank have been carried out by Russian scientists since 1964 (Noskov and Zinkevich, 1970) using dredges and bottom grabs to sample spawn. These surveys have shown a progressive contraction in the spawning area and total number of eggs laid, from which a corresponding reduction in adult stock size was deduced. This conclusion was substantiated by a joint USA-USSR grab and dredge survey in 1969 (Anthony, Sauskan, and Sigaev, 1970). In presenting evidence for a declining stock, Noskov and Zinkevich (1970) drew attention to the desirability of a more direct study of the spawning grounds by *in situ* observation.

Methods

Preliminary survey

Two herring spawning beds were discovered by grab and dredge from the USSR research vessel *Alferas* (Pankratov and Sigajev, 1971) between 20 and 23 September 1970. These authors estimated the dates of hatching for the northern and southern spawning grounds as 25-26 September and 27-28 September, respectively. This agrees well with observations by Graham and Chenoweth (1971), of large numbers of early yolk sac larvae over the northern spawning ground on September 28.

The northern bed was at lat. 41° 54′ N. long. 67° 15′ W, and the southern bed at lat. 41° 52.5′, long. 67° 00′ (Pankratov and Sigajev, 1971). The position of the first of these egg patches, subsequently referred to as the northern spawning ground, was marked with a radar buoy at lat. 41° 53′ N., long. 67° 15′ W., on 23 September. This buoy was located by the *Albatross IV* on 24 September, and grab and dredge operations confirmed the position of the northern spawning ground relative to the buoy (Graham and Chenoweth, 1971).

Submersible Operations

The *Pisces I* is an 8-ton, 2- to 3-man submersible of 2,000′ (840 m) depth capability and a 72-hr life support

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endurance with a maximum underwater speed of 3 knots. It was launched and retrieved from the modified after-deck of *Albatross IV* by a 15-ton boom crane, tether lines being attached to the *Pisces I* skids to prevent undue pendulum movement during launch and retrieval (Fig. 1). Even so, the pendulum length of more than 3 m from the boom of the crane to the submersible was such as to restrict operating conditions to sea-state 2 and less.

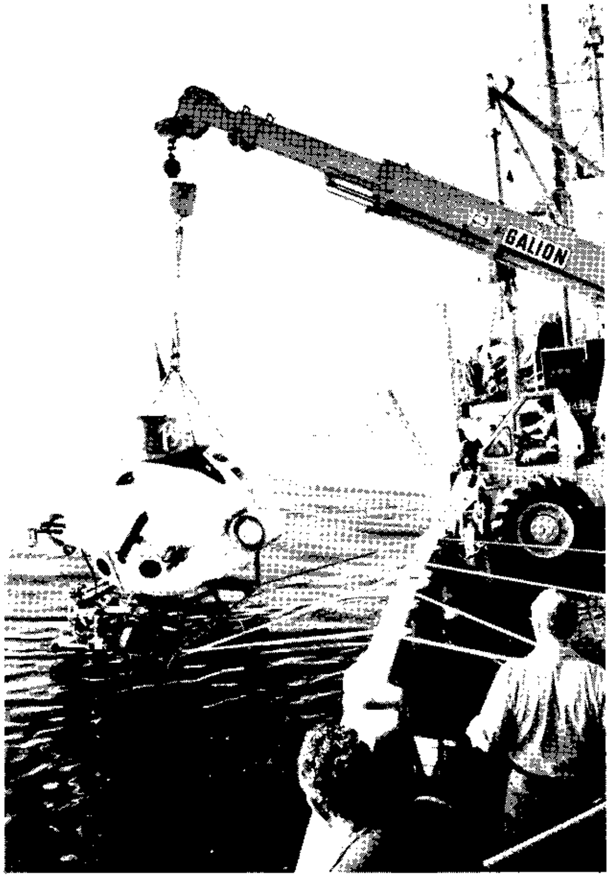

Fig. 1. Launch of ***Pisces I*** from ***Albatross IV***. Tether lines attached to the skids prevent undue pendulum action during launch and retrieval.

Because of strong bottom currents (estimated to be between 0.5 and 1 m/sec) in the operating area and a rotary tidal regime with no slack-water period, transects of the sea bed were passive, by tidal drift.

A radar buoy attached to *Pisces I* by 275 m of light warp served to mark its position, and *Albatross IV* kept within 400 m of this buoy during bottom transects by the submersible. The direction and distance from *Albatross IV* to both the USSR marker buoy and the *Pisces I* radar buoy were monitored by Azimuth and radar at 10-min intervals, and at 5-min intervals while *Pisces I* was on herring spawn. Contact between *Pisces I* and *Albatross IV* was maintained by hydrophone, and observations on major changes in bottom terrain or egg density relayed to the surface together with information on direction of drift (gyrocompass) and estimated bottom speed. Sounder records were kept continuously while *Pisces I* operated and these were annotated at the time of radar fixes.

These sources of information were subsequently collated and used to plot dive tracks and estimate distances travelled during each dive (Table 1).

TABLE 1. Estimated distances travelled over the three types of terrain during the 12 dives.

Dive No.	Herring spawn on gravel (m)	Gravel: No. herring spawn (m)	Sand (m)
1			300
2			700
3	800		400
4		2,200	200
5		800	500
6			1,100
7			900
8	2,400	300	
9		500	1,200
10	700	1,400	100
11		2,400	
12	900	400	
Total distances (m)	4,800	8,000	5,400

Observational and Recording Techniques

At 35- to 60-m depths ambient light was too dim for satisfactory viewing without two 1000 w floodlamps. Visibility varied from about 3 m to not more than about 7.5 m because of suspended debris.

Observations made through the 15 cm diameter viewpoint in the front of *Pisces I* were recorded on magnetic tape, subsequently transcribed verbatim, and interpolated with minute time checks. Observers and pilots were briefed before each dive on priorities for each type of observation. Tapes were run through after each dive to check priorities and to clear up problems of identification of fauna or bottom type. The pilots provided valuable background continuity to the record and relayed instrument readings (depth, course, estimated speed) and other observations to the scientist observer for recording.

Photography

Black and white or colour photographs were taken automatically at 15-sec intervals by a 70-mm camera mounted on the front of the submersible, and movie and still photographs were taken through the viewports.

Underwater photography of herring spawn presented major difficulties because of (a) the light-absorptive properties of the spawn when viewed by the submersibles quartz-iodide lights, and (b) the great amount of suspended organic debris over the egg beds later in development. It was impossible to distinguish spawn from smooth sediments in the black and white photographs, and in the only good colour photographs the spawn showed blue-green against yellow-brown gravel, where predators had eaten away the spawn down to the underlying substrate. An estimate of the area of spawn cleared by predators was made on dive 3 from 62 enlarged photographs of the spawn mat. The outlines of the characteristic steep-sided holes in the spawn made by predators were drawn on tracing paper having a density of 0.0062 gm/cm^2, the tracings of the holes cut out, and weighed to 0.001 gm. This weight was compared for each photograph with the weight of paper overlying the intact area of spawn. An estimate of percent predation is then given by:

$$\text{Percent predation} = \frac{\text{Area of holes}}{\text{Area of spawn + holes}} \times 100$$

Sampling

A sampling rack containing four rectangular pipe samplers (4.2 cm × 9.2 cm internal measurements) was mounted below the viewport of the submersible (Fig. 2). A buoyant toggle on each sampler allowed the mechanical arm to lift it from the rack, scrape it across the sea floor, and replace it in the rack after taking a qualitative sample. Divers plugged each sampler with a sponge immediately *Pisces I* surfaced, to prevent washing out of the sediment and herring spawn due to surface swell.

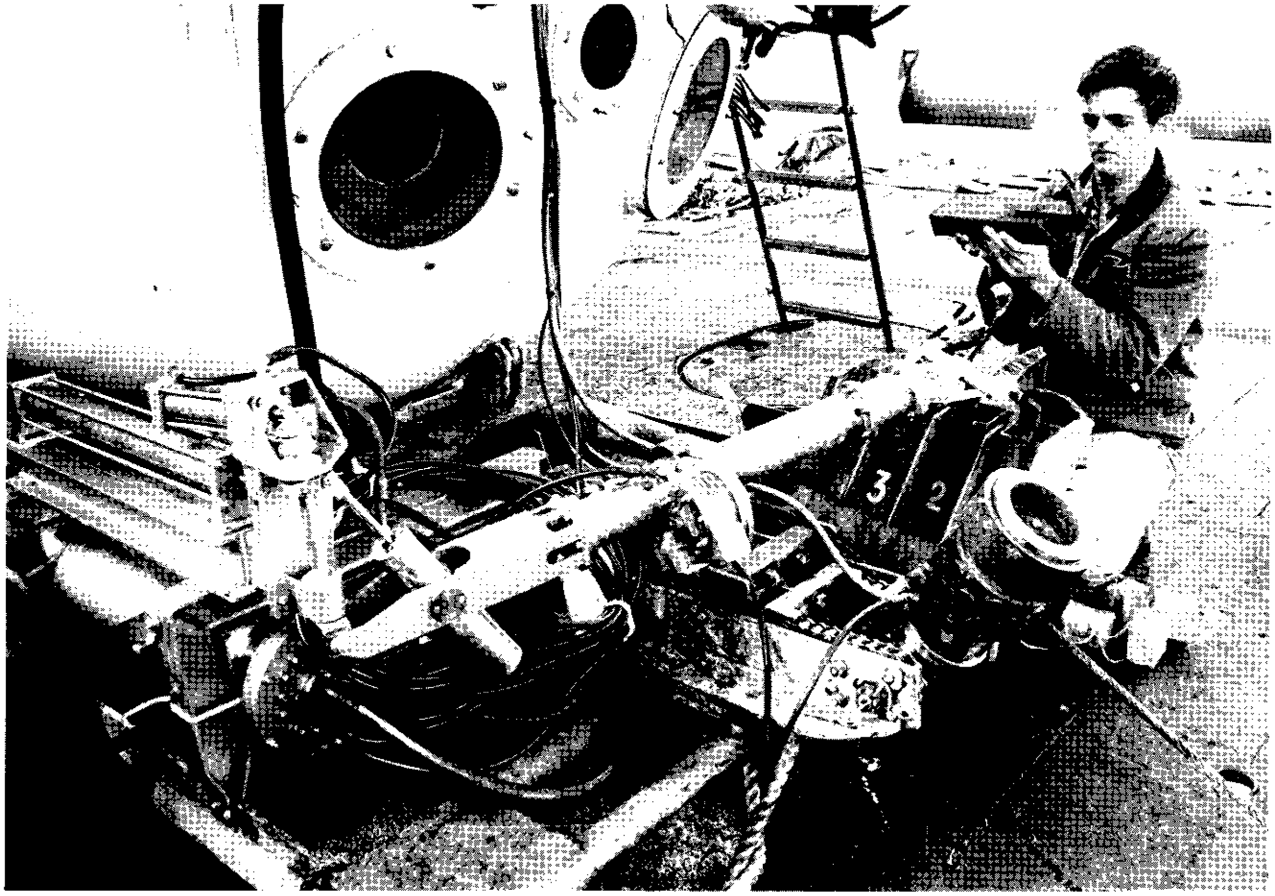

Fig. 2. Front view of *Pisces I* with the senior author examining one of the four steel scoops used for sampling herring spawn and sediments. The buoyant toggle on the second sampler is seen within the jaws of the hydraulic arm.

Results

Substrate type

Three types of substrate were found.

1. *Gravel bottom.* Rusty brown rounded pebbles 2- to 10-mm diameter, formed the underlying substrate of the spawning bed. Occasional ice-rafted boulders up to 50 cm or more in diameter were embedded in the gravel. In some areas, a 10% admixture of shell gravel was observed, made up of *Ensis*, *Spisula* and *Placopecten*. This had accumulated locally to form patches of shell a few square metres in extent. The most characteristic topographical feature was the level, almost horizontal nature of the gravel with only occasional shallow depressions and low ridges (Fig. 3).

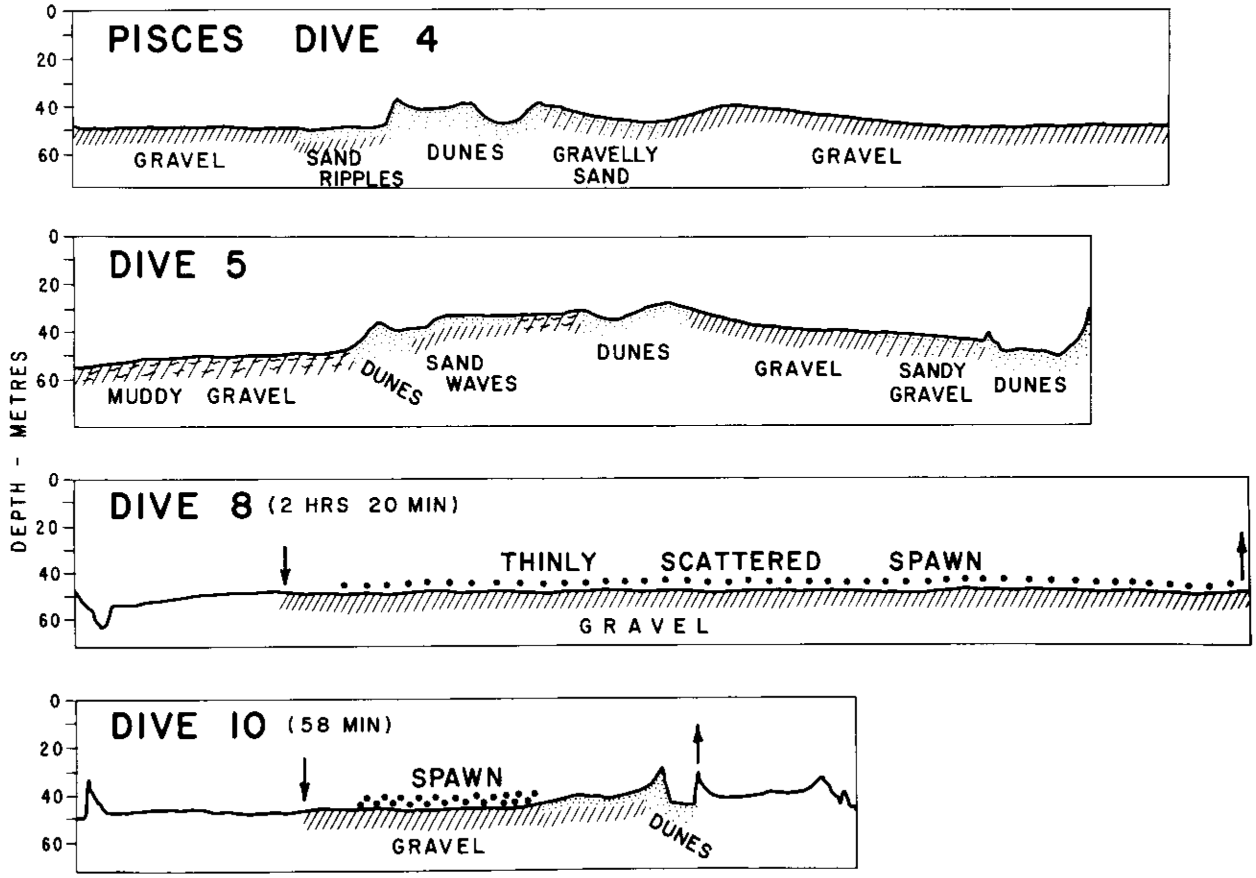

Fig. 3. Sounder records made from *Albatross IV* during four dives, annotated later with observations on bottom type made from *Pisces I*. (Albatross remained within 400 m of *Pisces I* during bottom transits.)

2. *Sandy gravel.* A transitional area between an all-gravel surface and sand bottom was crossed on several occasions. Fine sand streaks on the gravel surface merged into ripples and then mega-ripples of 0.6 m amplitude and about 3.5 m wavelength, with coarse gravel showing between the ripples. The ripples lay predominantly in an east-west direction, sloping gradually on the north side and steeply on the south face at angles of close to 30°. Sand was being continuously transported across the crests of these ripples.

3. *Sand waves.* Proceeding southward from the buoy, the sand mega-ripples build up in height to form sand waves or dunes. Maximum dune height was at least 10 m, with a steep drop off on the south face of each dune (Fig. 3). The currents in the troughs between the sand waves and in their lee were much weaker than near the crests, and often diverged widely from thyprevailing current direction. Although it was apparent that these systems of sand waves were traversing the gravel substrate, muddy reefs of tubiculous polychaetes often carpeted the lower face of the larger dunes suggesting that their movement was slow.

On three dives, concave gouges, 30-60 cm across and about 8 cm deep, exposed gray sand below the gravel surface, the gravel being heaped up on either side. These gouges continued in a straight line beyond the limits of visibility and on one dive occurred every 20 m or so for half the dive duration. It was concluded that they were caused by spreader boards of otter trawls.

Sediment Preferences of Spawning Herring

Herring spawn was found during four dives, but only on type 1 sediment, i.e., on mineral gravel. It became thin and finally absent with admixture of sand. Although spawn was firmly attached to gravel and epifaunal growths, such as hydroids, bryozoa, (*Dendrobeana murrayana* sp), and reefs of tubiculous polychaetes (*Filograna implexa*) it was rarely seen on shell gravel, and egg coverage invariably decreased as shell increased in proportion.

Ontogeny of a Herring Spawning Bed

The northern spawning ground mapped by dredge and grab from the *Alferas* was relocated by *Albatross IV* on 25 to 27 September using the same techniques. During the following 9 days, 12 dives were made in the area in an attempt to place *Pisces I* on herring spawn. Spawn was observed on dive 3 over the southern spawning ground, and during dives 8, 10, and 12 over the northern ground (Fig. 4).

Observations made during dives over a period of seven days showed marked differences in the appearance of the spawning beds. Although the observations were not all made on the same egg patch, they appear to represent the last stages in the ontogeny of a spawning bed just prior to, and following hatching.

Dive 3 (29 September): On the southern spawning ground, 1-2 days before the estimated date of hatching, a bed was located 3.7 km south of the buoy – the spawn formed a uniform dark layer over the bottom, approximately 400 m across and 1-2 cm thick, covering up to 95% of the underlying gravel. The edges of the bed were discrete. Many predators were present and signs of predation were evident (Fig. 5).

Dive 8 (2 October): 2.5 km north of the buoy. Thinly scattered traces of spawn extended over a distance of approximately 2.4 km. These were either the decomposing or unhatched residues of a large spawning bed, or a scattering of spawn on the periphery of a dense spawning area such as that located on dive 3. A great deal of organic material in suspension prevented successful photography.

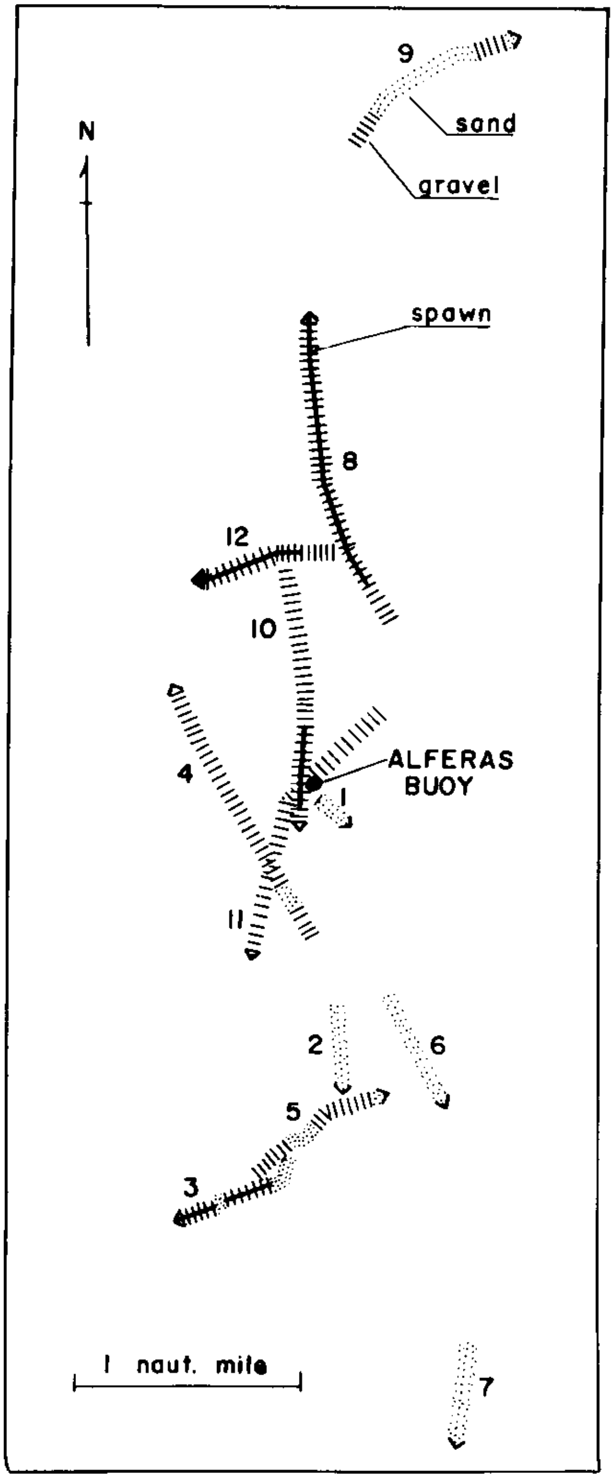

Fig. 4. Estimated dive positions and distances travelled during *Pisces* dives 1-12, plotted in relation to the *Alferas* buoy.

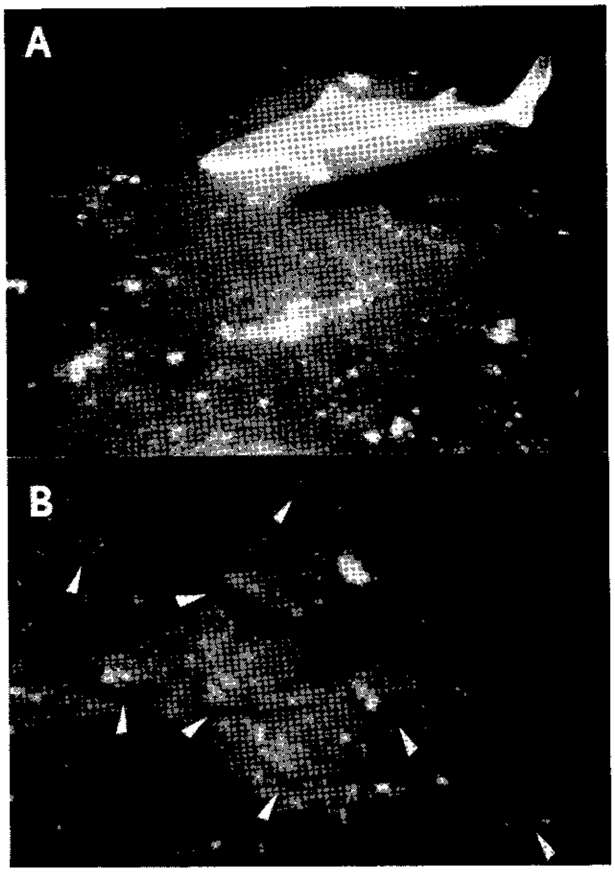

Fig. 5. A. Spiny dogfish (*Squalus acanthias*) swimming over a dark mat of herring spawn (Dive 3). Patches of lighter coloured gravel show through holes in the spawn mat made by predators. (Photo: R. P. Bradley). B. Close up view of spawn mat showing steep-sided gouges in the spawn mat considered to result from the activities of spawn predators, (Dive 3).

Dive 10 (2 October on the norther spawning ground 4 days after the estimated date of hatching): Bottom coverage by spawn varied between 40 and 80%. Splotches of white in the dark spawn suggests that decomposition of the hatched egg cases or unfertilized eggs had already begun. There was much suspended debris in the water.

Dive 11 (6 October): Diving in the vicinity of the northerly spawning bed seen on dive 10, 4 days previously, large amounts of suspended organic debris and a dense aggregation about 50 m across, of early fish larvae with yolk sacs, were observed being carried by the current within 15 cm of the bottom. Since no other fish larvae were abundant in plankton tows made in the same area, it is assumed that these were herring larvae. If these larvae had hatched from the northerly spawning ground, it is unlikely that their estimated age was more than 10-11 days.

Dive 12 (6 October, 10-11 days after the estimated date of hatching): Decomposing anoxic residues of the northern spawning bed were observed. A thin layer of flocculent debris covered the anoxic blackened gravel. Samples taken during this dive contained decomposing eggs and egg shells and gave off a putrid smell. Early herring larvae with yolk sacs were seen close to bottom.

Associated Fauna on the Spawning Grounds

All observers reported an increase in fish abundance over areas of spawn. The combined records from all dives were analyzed separately for transects over each of three substrate types: spawn-free sand, herring spawn on gravel, and spawn-free gravel. Because it was not always possible to count individual specimens, each

TABLE 2. Estimated frequencies of observation per kilometer of dive transit for 10 common benthic fish and invertebrates over three types of terrain.

Species	Total No. observations	Frequency of observations (No./km)		
		Herring spawn on gravel	Gravel: No. herring spawn	Sand
Hake (*Urophycis chuss*)	104	14.4	4.2	0.2
Sculpin (*Myoxocephalus* sp)	153	17.6	6.1	3.7
Spiny dogfish (*Squalus acanthias*)	103	9.0	3.1	6.5
Skate (*Raja* sp)	124	10.7	3.6	8.1
Starfish (*Asterias vulgaris*)	103	8.2	3.9	6.1
Moon-snail (*Polinices heros*)	43	3.4	1.1	3.3
Scallop (*Placopecten magellanicus*)	170	10.5	11.1	5.7
Hermit crab (*Pagurus* sp)	134	7.1	6.2	9.2
Sea urchin (*Strongylocentrotus droebachiensis*)	41	1.9	3.4	0.9
Bar clams (Dead shells) (*Spisula solidissima*)	41	1.5	2.9	2.0

recorded observation of a species, whether one or many specimens, was counted as a single occurrence. This procedure does not allow a calculation of absolute abundance, but does eliminate the disproportionate effect of aggregations of species only observed on a relatively few occasions. The numbers of observations for each species were adjusted for the distance travelled over the three types of terrain, using the distances in Table 1, namely 4,800 m on spawn, 8,000 m on gravel with no spawn, and 5,400 m on sand. It was considered that the relative frequency of sightings of each species on the three bottom types was reasonably approximated by this procedure. The estimated frequencies of observation of the 10 most common species for each km of travel across the three types of terrain are given in Table 2.

The four most common fish species seen, (red hake, sculpin, dogfish, and skate) were all more abundant over herring spawn than elsewhere. This also appeared to be true for the invertebrate predators, starfish (*Asterias vulgaris*), and moon snails (*Polinices heros*) (Fig. 6A). Non-predatory forms, such as scallops (*Placopecten magellanicus*) and sea urchins (*Strongylocentrotus droebachiensis*) appeared to be independent of spawn in their distribution, while dead shells of bar clams (*Spisula solidissima*) were rather less frequently observed with spawn than elsewhere. Sediment preferences of the 10 most common species were investigated independently of herring spawn by comparing their frequency on sand with their frequency on gravel without eggs (Fig. 6B). Hake, sea urchins, and scallops were much more abundant on egg-free gravel than sand. However, spiny dogfish, skate, starfish, and moon snails were more frequent on sand than egg-free gravel, in contrast to their apparent preference for gravel when covered with herring spawn. This suggests that for these species at least, some migration onto the spawn bed had followed herring spawning.

Although certain species seem to have migrated onto areas of spawn, one of the most commonly observed animals, namely the hermit crab (*Pagurus* sp) appeared to be independent of both substrate type and presence or absence of spawn. Despite this, it was present in great densities (estimated at 5/m^2) and could undoubtedly have played a considerable part as a predator on herring spawn. Some large predatory fish which were frequently seen on the spawning beds were probably attracted to the area by the presence of other species, e.g. monkfish (*Lophius americanus*) and halibut (*Hippoglossus hippoglossus*).

Predation on Herring Spawn

Although few species were observed actively feeding on herring spawn, many effects of predation were observed. These took the form of steep-sided craters or depressions in the egg layer up to 0.3 m across, exposing the light brown gravel beneath (Fig. 5). These holes in the otherwise uniform spawn layer were sufficiently characteristic to be identified in colour photographs taken with the external automatic camera during dive 3, and an estimate of the proportion of spawn removed by predators was made from these photographs. An analysis of 62 photographs revealed that approximately 8% of the spawn had been removed by predation within 1-2 days of hatching.

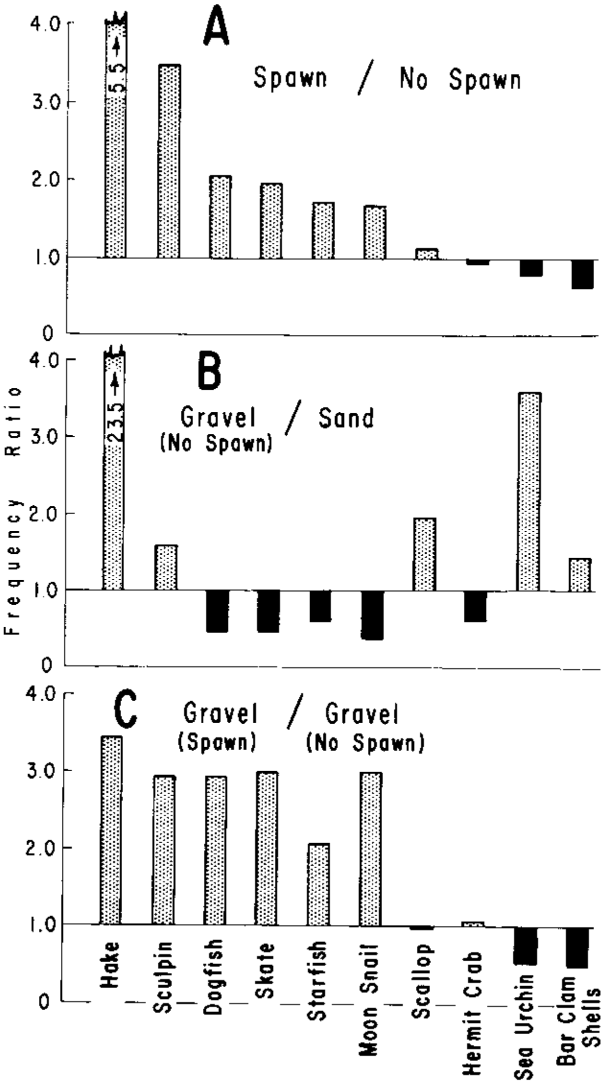

Fig. 6. Ratio of sightings per kilometer travelled of 10 most common species seen during 12 dives over different substrate types. A. Species ranked according to apparent preference for areas of herring spawn in contrast to all other substrates. B. Comparison of frequencies of observation on gravel without spawn, and on sand without spawn. C. Comparison of frequencies of observation on gravel with and without a covering of spawn.

Identification of the species responsible for predation was not possible without being able to examine stomach contents for spawn, but red hake were seen actively feeding on spawn, and moon snails, hermit crabs, and starfish were occasionally seen occupying holes in the egg mat. Active demersal fish, such as cod and haddock, were rarely seen from *Pisces I*, although they were abundant in the area (Pankratov and Sigajev, 1971), and are known to be active predators on herring spawn. These species have been shown to be repelled by underwater lights (Ryzhenko, 1961), which may account for the infrequent sightings.

Geography and Sediments of the Spawning Area

Herring spawn was only found on a very specific substrate type; namely, a flat surface of fairly well-sorted, rounded gravel, 2-10 mm in diameter, of glacial origin (Schlee and Pratt, 1970). A sparse epifauna of bryozoa and calcareous worm reefs was noted on 2 dives, but, in general, encrusting invertebrates were sparse or absent, possibly because of the continuous transport of sand particles and small sand waves across the gravel plain. This is in contrast to the shallow-water grounds observed in the Gulf of St. Lawrence by Tibbo *et al.* (1963) where red algae form the spawning substrate, and to those off Southwest Nova Scotia (McKenzie, 1964) where sand and red algae form the spawning substrate. The Georges Bank spawning ground appears to show more resemblance to that described for the west coast of Scotland by Hemmings (1965).

Large areas of ground were crossed which were free of spawn, although they appeared to observers to be identical to areas where spawning had occurred. It seems most unlikely that the availability of suitable spawning substrate is or has ever been a limiting factor in the reproduction of Georges Bank herring.

Ontogeny of a Spawn Bed

Submersible operations were preceded by a period of approximately 1 week during which the eastern spawning beds were mapped by means of dredge and grab from *Alferas*. As a result, the areas of spawn were well advanced towards hatching when first seen from *Pisces I* on 29 September. Despite the late stage of development, the egg mat was firm and cohesive, with discrete margins. The size and uniformity of coverage of the bottom by eggs in a region swept by strong currents suggests a coordinated spawning behaviour involving large numbers of individuals.

Patchiness and friability of the egg mat was more pronounced on dive 10, when hatching appeared to be well advanced, and areas of decomposing egg debris occurred as white patches in the spawn mat. Although it was impossible to estimate the percentage coverage by unfertilized eggs, there were few dead eggs in the scoop samples taken from *Pisces I*. This supports the estimate of less than 1% given by Pankratov and Sigajev (1971). Egg mortalities were undoubtedly much lower than the 40-80% estimates given by Runnstrom (1941) for egg masses of comparable thickess. but probably exceeded the estimated 8% of the spawn mat removed by predators. No signs of the 'layering' of eggs noted by Pankratov and Sigajev (1971) were seen.

Because of uneven hatching and predation, and increased friability of the spawn mat, it seems likely that estimates of spawn density (and hence the size of the spawning community) by remote sampling techniques would decline continuously from spawning to hatching. Further *in situ* studies may provide weighting factors based on development stage of the eggs, which could be used to correct for changes in bottom coverage during ontogeny of the bed.

The observation of newly hatched larvae within 1 m of the bottom supports the hypothesis of Saville (1971) that recently hatched herring larvae are not regularly sampled by standard plankton nets, since the larvae stay close to the sea floor. This is likely to have serious effects on the precision with which larval surveys can be used to pinpoint spawning grounds, unless some means of sampling the hypoplankton can be found.

One surprising observation in an area of coarse gravel swept by strong bottom currents, was that spawn residues persist for a period of 10 days or so after hatching of the bulk of the eggs, and result in anoxic conditions in the underlying substrate. Persistence of egg residues presumably results in the spawning ground being unavailable to later spawners, since it was concluded by Hempel (1971), that although 'layering' of the spawn may take place as a result of spawnings a few days apart, patches of eggs at an advanced stage of development seems to be avoided by spawning herring.

Use of Submersibles for Survey Work

Although the observations made from *Pisces I* did not allow an accurate determination of the size and extent of spawning areas, the 1970 experience with *Pisces I* reinforces impressions from earlier studies (e.g. Wigley 1968, Caddy 1970) that submersibles can play a valuable role - (a) in confirming hypotheses; (b) in generating new lines of approach; and (c) as a calibrating tool.

Provided that problems are clearly defined and areas of operation accurately located, the versatility of submersibles is as great as the variety of equipment that can be installed on them, and their continuing use in fisheries can be expected to expand in scope and value.

Acknowledgments

It is impossible to thank individually the many persons who made contributions towards the success of this venture, but the authors particularly acknowledge the assistance and co-operation of the submersible pilot, R. P. Bradley and his crew of C. Newell and R. Clifford who acted as support divers. Without their assistance, the submersible venture would not have been possible. P. W. G. McMullon and F. B. Cunningham prepared the figures.

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Distribution and Abundance of Larval Herring, *Clupea harengus harengus* Linnaeus, Over Egg Beds on Georges Bank

By Joseph J. Graham[1] and Stanley B. Chenoweth[1]

Abstract

This paper describes the hatching and early life history of larval herring spawned on the northeastern part of Georges Bank during the autumn of 1970. As part of an international cooperative survey, a USSR vessel located and mapped the distribution of egg beds and marked the vicinity for dives by a Canadian submersible from an American mothership. Collections of eggs and observations from the submersible suggested that hatching began before the mothership arrived over the beds on 26 September. Hatching was considerably reduced by 1 October and completed by 6 October. Two distinct larval size modes, one at 7 mm and the other at 13 mm, occurred in length frequencies of larvae obtained within the survey area surrounding the egg beds. We concluded that larvae with a length mode at 7 mm originated from the egg beds and that their growth in length was negligible over a 4-day period. Estimated mortality of larvae less than 10 mm was 75% over the period from 1 October to 5 October. Mortality at this very early stage was considerably higher than the larval mortality observed during winter along the Maine coast.

Introduction

This is a report of a cooperative survey by the USA, Canada, and the USSR to study herring egg beds on Georges Bank, 24 September - 6 October, 1970. Each country contributed an important component of the operation. The USSR located and defined the boundaries of two adjoining egg beds on the northeastern part of Georges Bank in the western North Atlantic and placed a buoy to mark them for further operations. The Canadians provided a submersible, *Pisces I*, for observations of the egg beds. The USA provided a mothership, *Albatross IV*, for the Canadian submersible, confirmed the location of the egg beds, positioned the submersible for its dives, and conducted a study of larval herring hatched from the egg beds.

Spawning of herring and the distribution of egg beds and larvae over the entire area of Georges Bank were examined by USSR scientists. Observations from the submersible over the beds in the northeastern part of the Bank were analyzed by the Canadian scientists. This paper is concerned with the hatching and early planktonic life of larval herring from the beds surveyed by the submersible. References to the results obtained by the USSR and Canadian scientists during the cooperative survey are from contributions published in this volume (Pankratov and Sigajev, 1972; Caddy and Iles, 1972).

Methods

Samples of eggs were obtained from the bottom with a Naturalist dredge and a Smith-McIntyre grab sampler. The dredge samples a width of 1 m and the grab samples an area of 0.5 m^2. The dredge was fished for 5 min from the drifting vessel. When eggs were obtained in the dredge, the grab was lowered over the side to obtain additional bottom samples. The dredge was towed 21 times and the grab was lowered 9 times. The quantity of eggs in the sample was expressed as light, medium, and heavy. A light catch referred to eggs scattered within the gravel or cobble; a medium catch contained small clumps (about 1 cm^2 or less); and a heavy catch contained larger clumps. Eggs were preserved in 3% buffered formalin for examination in the laboratory.

Two pairs of Bongo sampling nets (Posgay, Marak, and Hennemuth, 1968) were used to capture larval herring. A large pair of Bongo samplers was mounted on the towing wire above a depressor and a smaller pair was mounted 71 cm above the large pair. The nets of the small Bongos had a mouth diameter of 20 cm and those of the larger Bongos had a mouth diameter of 61 cm. The smaller pair had mesh openings of .253 mm and .366 mm and the larger pair had mesh openings of .333 mm and .505 mm. A single meter was installed in the .366 net to determine the distance towed; the volume of water strained was calculated by multiplying this

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distance by the cross sectional area of the mouth of a given net. The catch was expressed as the number of larvae captured per 100 cubic meters of water strained during a given tow. The gear was towed at 5 knots for 15 min in a step oblique sequence, 5 min each at depths of 30, 20 m, and the surface. These depths were changed to 20, 10 m and the surface when the scientist on watch believed the nets might contact the bottom. The depth of the water at plankton stations varied from 31 to 259 m. Seventy plankton stations were occupied, most during darkness to permit dives by the submersible during the day (Table 1, Fig. 1). For the purposes of this paper only larvae from the small Bongo nets with the .366 mm mesh and those from the large net with a mesh of .505 mm were counted. Larvae captured in the small Bongo net were measured in November and December, 1970; those from the large Bongo net were measured 6 months later. Those measured later were slightly smaller possibly due to shrinkage while in the preservative for the additional time.

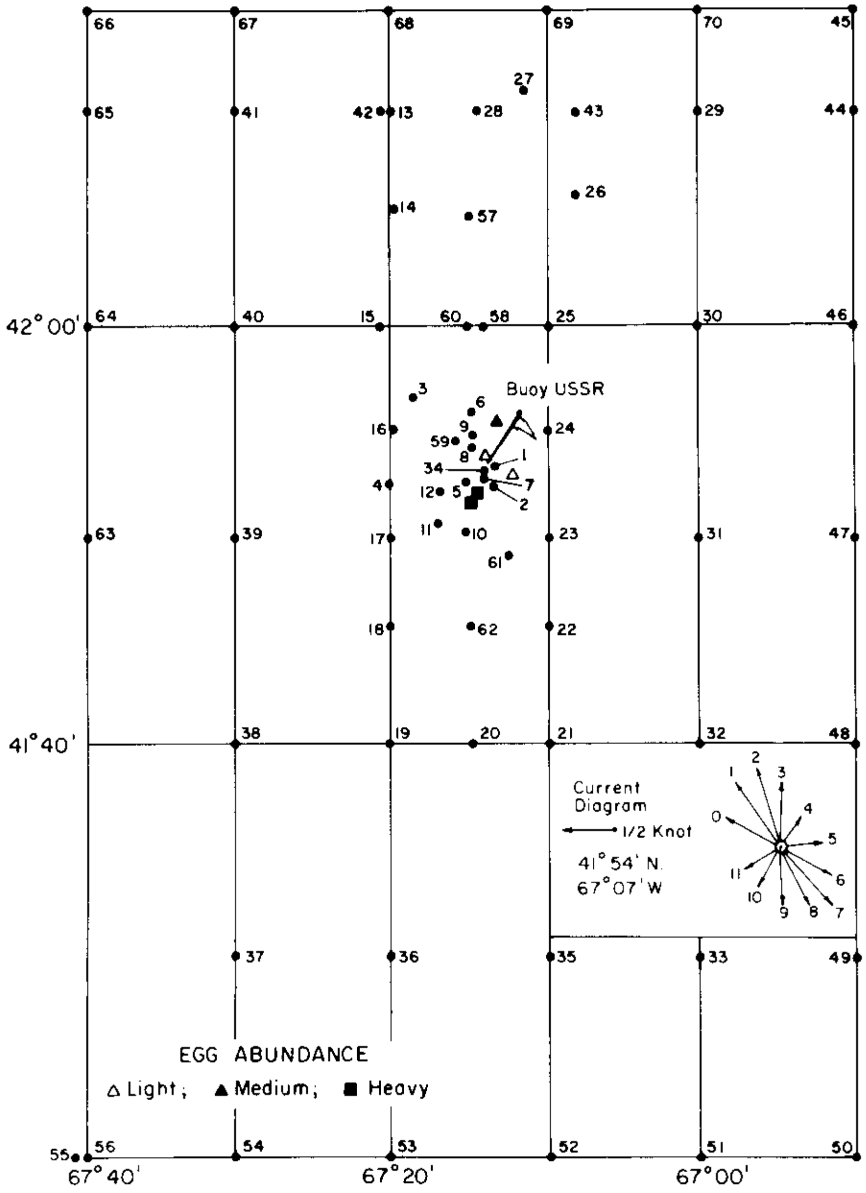


Fig. 1. Numbered stations were occupied for plankton sampling. Locations of herring egg samples obtained with a dredge or grab are also indicated. The tidal current diagram is from Chart 3075 of the U.S. National Ocean Survey, National Oceanic and Atmospheric Administration, Department of Commerce (Formerly, U.S. Coast and Geodetic Survey).

TABLE 1. Plankton sampling stations occupied between 25 September and 5 October 1970; their positions are plotted in Fig. 1. Samples were lost from both small and large Bongo samplers at Stations 3 and 34; samples were lost from the large sampler only on Stations 6, 9, 40, 51-3, and 56-7.

Sept.	Station No.	Oct.	Station No.
25	1	1	19-24
28	2-4	2	25-29
29	5-7	3	30-35
30	8-18	4	36-54
		5	55-70

Extrusion of recently hatched larvae (4-9 mm) through the meshes because of the high towing speed (5 knots) was not evident in our data. Both the average catch rates as well as the size distribution were essentially the same for the large and small meshed nets.

The nets did not clog during towing; only one sample contained an appreciable amount of clogging organisms.

A bathythermograph cast was made and a bucket temperature was taken at each station; surface water was collected for salinity determination.

Location of spawning beds

Evidence from samples obtained with the dredge and grab from *M/V Albatross IV* was sufficient to place the Canadian submersible on the two adjacent egg beds detected during the USSR bottom survey within the northeastern spawning ground. Only 5 of the 30 samples contained eggs; 2 had light amounts of eggs on 26 September, 1 had medium and 2 had heavy amounts of eggs on 27 September (Fig. 1). No eggs were found in samples taken during 29 September and 1 and 2 October. The largest clump of eggs was 15 cm^2 and 5.2 cm thick.

The egg beds were located in an area of complex temperature and salinity distribution (Fig. 2). A tongue of colder (14° C.) and more saline (32.15 $^{\circ}/_{\circ\circ}$) surface water extended westward into the survey area. In the southwestern portion of the survey area at mid-depth and at the bottom, a body of warm water was evident. Bottom temperatures in the vicinity of the egg beds at about 48 m varied from 13° to 15° C, as during the prior USSR survey of the beds.

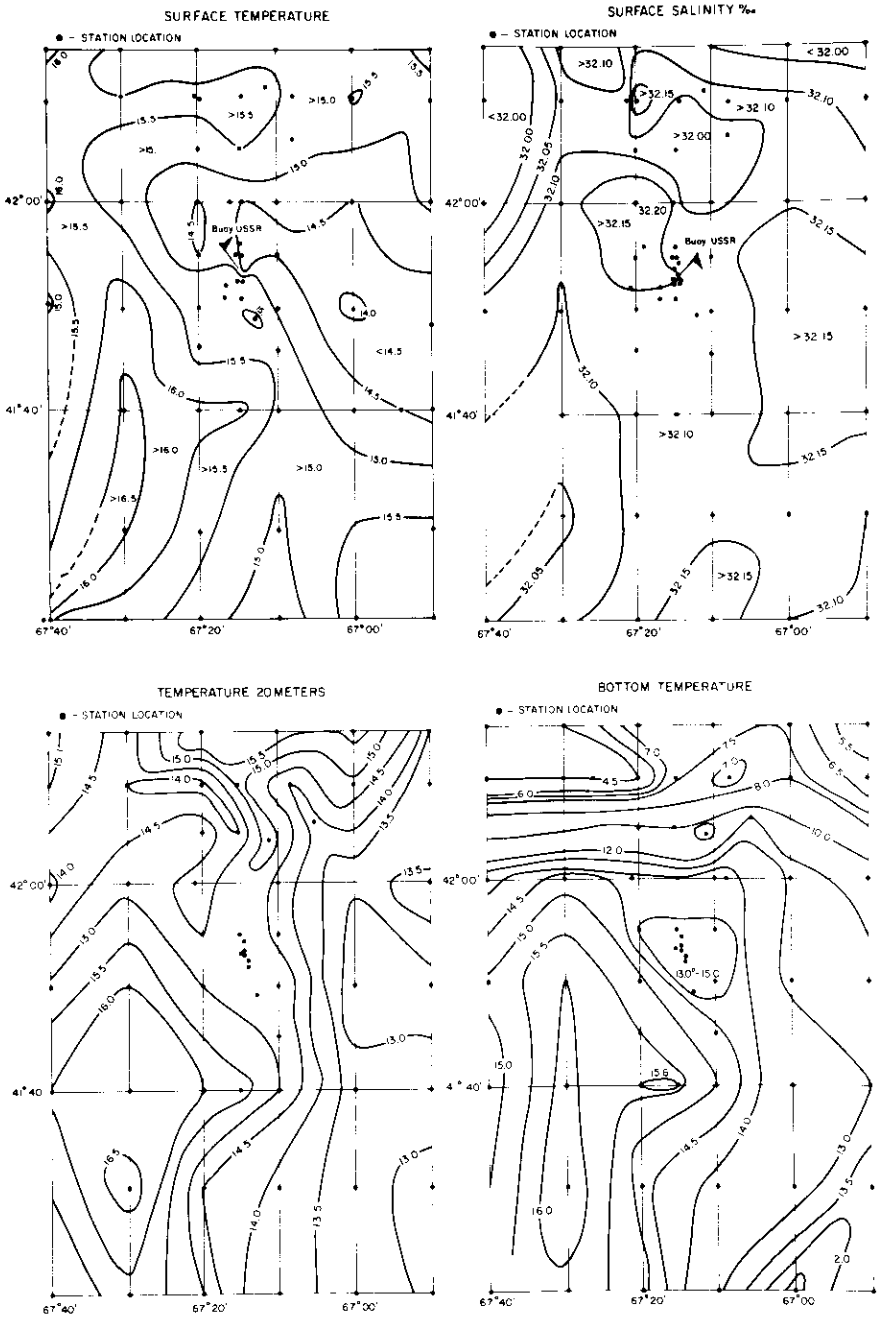
Observations on hatching

Hatching was completed during the survey with the submersible (25 September - 6 October). This conclusion is supported by: (1) the description of the ontogeny of the egg beds (Canadian scientists); (2) the decline during this period of the number of yolk sac larvae in our catches; and (3) the development of the eggs on the beds (USSR scientists). On 6 October scientists aboard the Canadian submersible, *Pisces I*, found the egg beds to be in decayed condition. At that time, samples brought to the surface by the submersible contained only a few eggs. These eggs and the residual material were putrified. Observations from the viewing ports of the submersible on 2 October suggested that even then the beds were already in a decayed condition.

The number of yolk sac larvae in the plankton samples also declined indicating that hatching was completed during the survey with the submersible. Eggs obtained from the bottom on 27 September began to hatch when placed in sea-water aboard the *Albatross IV*. The following day, the largest percentage of yolk sac larvae obtained in an individual plankton sample from the vicinity of the beds was 10.4 (Fig. 3). On 30 September the largest percentage was 8.8, by 1 October it was 4.7 and decreased to 0.17 on 2 October. The vicinity of the beds was again sampled on 5 October and at that time no yolk sac larvae were obtained.

However, on 6 October some yolk sac larvae were observed near the bottom (48 m) from the submersible, below our maximum sampling depth (30 m) with Bongo samplers. On Dive 11 (6 October), scientists aboard the *Pisces I* reported that large amounts of suspended organic debris and a dense aggregation, about 50 m across, of early herring larvae with yolk sacs were being carried across the bottom by currents. The larvae were within 15 cm of the bottom and possibly too far away for positive identification. But individual larvae with yolk sacs were observed from the submersible while on the bottom during Dive 12 on the same day. These individuals were indentified with certainty by observing their size and shape and the position of the anus, when they were a few centimeters from the viewing port and illuminated by the lights of the submersible.

Our results approximated the estimated hatching dates obtained by Soviet scientists. These estimates suggested that eggs would hatch on the first egg bed on 25-26 September and on the second bed on 27-28 September. They also reported that the eggs on each bed were uniformly developed and that spawning probably occurred over a short period of 2-3 days.



SURFACE TEMPERATURE

SURFACE SALINITY ‰

TEMPERATURE 20 METERS

BOTTOM TEMPERATURE

Fig. 2. Distribution of temperature (° C) at the surface, 20 m, and the bottom, and salinity (°/oo) at the surface, during the larval survey.

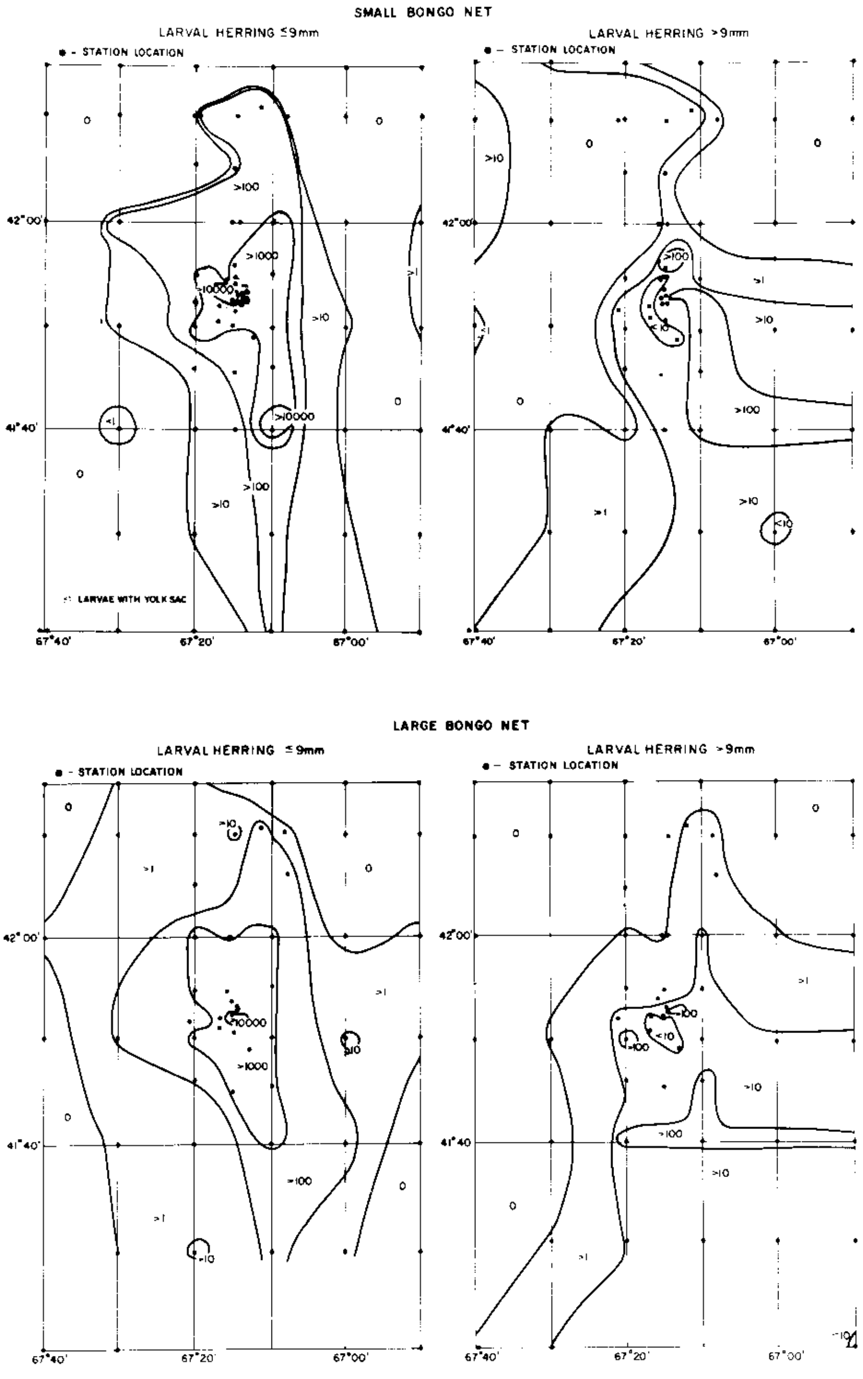


Fig. 3. Distributions (Numbers per 100 m^3) of two size groups (<10 mm and >9 mm) captured by small and large Bongo nets within the area surrounding egg beds.

Distribution and origin of larvae

During the cruise, 52,733 larvae were captured in the small Bongo net and 425,663 larvae were captured in the large net. Catches from both nets fell into two size groups with virtually no overlap (Table 2, Fig. 4); the smaller size group (4-9 mm) with a mode at 7 mm and the larger (10-22 mm) with a mode at 13 mm. The smaller larvae were four times more abundant and their greatest density was near the egg beds with a slight southerly dispersion from the beds (Fig. 3). This distribution, the presence of yolk sacs, and the decline in

TABLE 2. Catches of larval herring.

Net size	Larval modal size (mm)	Number of larvae	Average catch per 100m^3	Largest catch per 100m^3
Small	7	49,996	1,312	11,670
Small	13	2,737	422	960
Large	7	417,916	1,533	11,046
Large	13	7,747	334	406

hatching suggest that the small larvae originated from the egg beds. The distribution of larger larvae was similar to that of the smaller larvae, except their center was farther southeast of the bed. The larger larvae might also have originated from the same vicinity in an earlier hatch, but the available data are insufficient to determine their origin. If they had originated from these beds they would have been approximately 3 weeks old. Influences of the currents on their distribution are not well understood, but tidal currents are very strong in the area (Fig. 1).

Larval growth

Sampling was not sufficiently repetitive to obtain a measure of growth for larvae from the entire survey area, but a measure of short term growth was obtained from larvae captured in the vicinity of the egg beds between 1-5 October (Table 3). The size frequencies of larvae from these samples collected with the small Bongo net showed an increase in length that averaged 0.4 mm in 4 days. Samples from the large Bongo net did not show any increase in average size. Therefore, the best estimate of the average growth increment for the 4 days is 0.2 mm. Considering the data given for Georges Bank

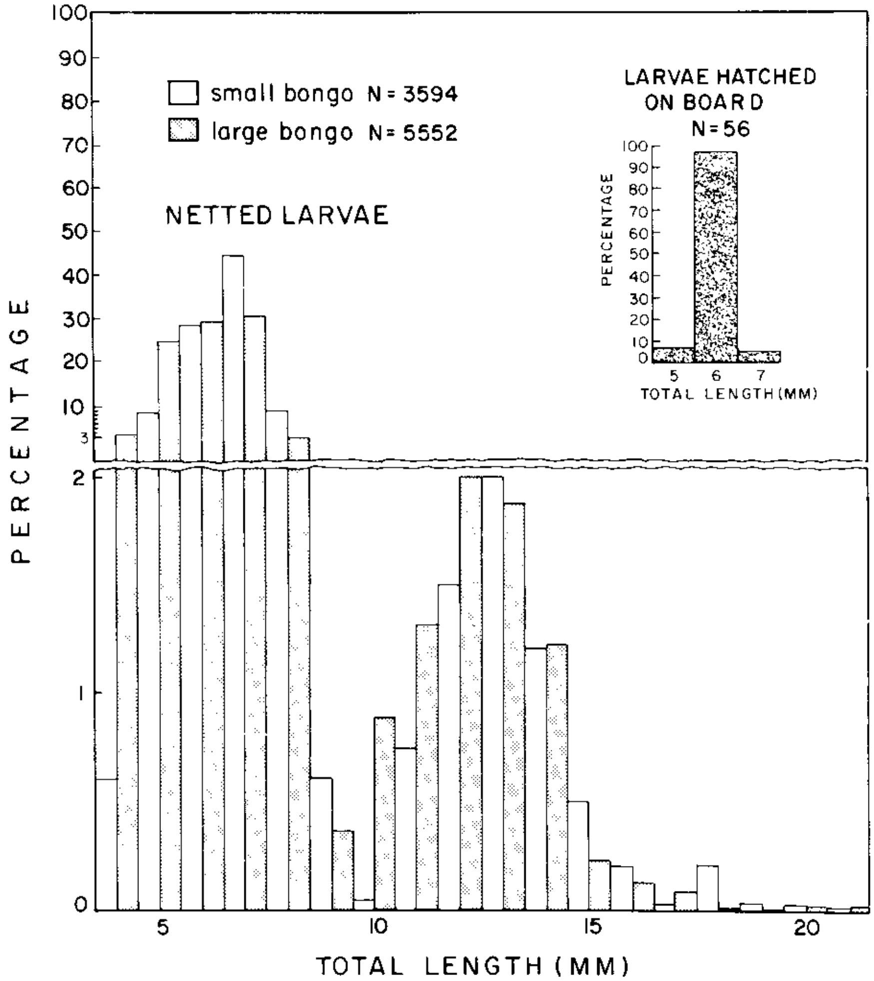


Fig. 4. Length frequency distribution of larval herring captured in large and small Bongo nets and of larvae hatched from eggs brought aboard the *M/V Albatross.*

TABLE 3. Length frequencies in percent of larval herring (≤ 9 mm) captured in small and large Bongo nets on 1 and 5 October.

	1 October N = 479						5 October N = 499					
	Stations						Stations					
Size (mm)	20	21	22	23	24	Total	58	59	60	61	62	Total
						Small Bongo						
5				4.0	1.0	1.0	1.0					0.2
6	13.3	9.4	2.9	11.0	11.9	8.8	6.1		2.0	3.0	4.0	3.0
7	68.9	80.2	59.1	70.0	59.4	66.6	35.0	36.0	59.0	60.0	55.0	49.1
8	17.8	10.4	38.0	15.0	23.8	22.8	50.5	61.0	38.0	35.0	40.0	44.9
9					4.0	0.9	7.1	3.0	1.0	2.0	1.0	2.8
Mean	7.0	7.0	7.4	7.0	7.2	7.1	7.5	7.7	7.4	7.4	7.4	7.5

	1 October N = 400					5 October N = 601					
	Stations					Stations					
Size (mm)	21	22	23	24	Total	58	59	60	61	62	Total
					Large Bongo						
5	65.0		5.0	2.0	18.0	29.3		22.0	4.5	13.0	12.1
6	26.0	17.0	47.0	35.0	31.2	45.4	30.0	51.0	46.0	43.0	43.4
7	6.0	73.0	48.0	51.0	44.5	20.2	54.0	27.0	48.0	38.0	39.1
8	3.0	10.0		12.0	6.2	5.1	16.0		1.5	6.0	5.0
9									1.0		0.3
Mean	5.5	6.9	6.4	6.7	6.4	6.0	6.9	6.0	6.6	6.4	6.4

– Gulf of Maine area (Boyar *et al.*, 1972) and for the western coast of the Gulf of Maine (Graham, Chenoweth and Davis, 1972) an average growth of 0.7 mm to 1 mm could be expected in 4 days. However, such estimates are difficult to substantiate; the sampling error is larger when comparing catch rates for size groups and a growth of 1 mm must be assumed for the brief period of 4 days.

Mortality

Because the source of the larvae less than 10 mm is known, an estimate of mortality was made for this group using data gathered on 1 and 5 October in the vicinity of the egg beds. Mean catch rates for all sizes (5-9 mm) in Table 4 were used to calculate the estimates of mortality given in Table 5. For samples from the small Bongo the mortality was 82%; for the large Bongo, 68%; and for the combined samples, 75%. Even higher estimates are obtained from the data in Table 4 by using specific size groups. For example, the catch rates for larvae 7 and 8 mm in length captured on 1 October were summed and those for larvae 8 and 9 mm captured on 5 October were summed, and treated as in Table 5. Larvae from the small Bongo sampler had a 90% mortality, those caught in the large Bongo sampler, 95%. When this sequence was repeated for larvae 5 and 6 mm in length the mortality was much lower, 4 and 41%, respectively.

We consider the estimates of mortality to be maximal. Dispersal of the larvae from the egg beds would reduce the catches made on 5 October and inflate the mortality estimate. On the other hand, recruitment of newly hatched larvae after 1 October would decrease the estimate of mortality. The ontogeny of the egg beds, the decline in yolk sac larvae, and the condition of larval development, all suggest that recruitment was negligible. Although the presence of yolk sac larvae near the bottom on 6 October cannot be ruled out entirely, no observations of yolk sac larvae were reported during the previous dives when hatching was at its height. Also, the relative abundance of yolk sac larvae showed no relation to the distance of the Bongo samplers from the bottom, as might be expected if recently hatched larvae remained close to the bottom for a time.

One explanation for the high mortality (75%) is that the larvae did not survive the transition from yolk

TABLE 4. Catches per 100 m^3 for lengths of larval herring captured in small and large Bongo nets on 1 and 5 October. The catch from the large Bongo net was lost at station 20 during 1 October.

Small Bongo

	1 October N = 11,961						5 October N = 2,767					
	Stations						Stations					
Size (mm)	20	21	22	23	24	Mean	58	59	60	61	62	Mean
5				162	15	35	8					1
6	13	1,097	104	445	177	367	47		10	45	31	26
7	67	9,363	2,060	2,831	882	3,040	27	152	291	901	425	359
8	17	1,214	1,324	607	353	703	389	257	187	526	309	334
9					594	119	55	13	5	30	8	22
Total	97	11,674	3,488	4,045	2,021	4,264	526	422	493	1,502	773	742

Large Bongo

	1 October N = 33,624					5 October N = 50,184					
	Stations					Stations					
Size (mm)	21	22	23	24	Mean	58	59	60	61	62	Mean
5	2,666		178	55	725	494		74	87	73	146
6	1,066	1,316	1,672	967	1,255	768	801	172	887	241	574
7	246	5,652	1,707	1,409	2,254	341	1,442	91	926	213	603
8	123	774		332	307	85	427		29	34	115
9									19		4
Total	4,101	7,742	3,557	2,763	4,541	1,688	2,670	337	1,948	561	1,443

TABLE 5. Mortalities of larval herring less than 10 mm in length calculated from the mean catch rates for all larvae given in Table 3.

Small Bongo Sampler (10 samples, N = 14,728)

1 October	5 October
4,264	742

Mortality: 4,264 – 742 / 4,264 = 83%

Large Bongo Sampler (9 samples, N = 83,808)

1 October	5 October
4,541	1,443

Mortality: 4,541 – 1,443 / 4,541 = 68%

Small + Large Bongos (19 Samples, N = 98,536)

1 October	5 October
8,805	2,185

Mortality: 8,805 – 2,185 / 8,805 = 75%

sac absorption to feeding (Blaxter and Hempel, 1963). This possibility was also advanced previously by Dragesund and Nakken (1971) to explain the high spring mortality of larval herring as they increased in size from 10 to 12 mm on the coastal banks of Norway. This was the maximum length (10.5-11.5 mm) reportedly attained on yolk by larvae of this spawning group (Blaxter and Hempel, 1963). They concluded that 94% of the larvae died during this growth period.

Comparision of the results of this study on Georges Bank with the results obtained on the coasts of Norway and the western Gulf of Maine supports further the contention by Saville (1971) that estimates of larval mortality in all stages from hatching to metamorphosis are necessary to test and identify the existence of a critical stage in larval life. The mortality estimates for recently hatched larvae are so high that they appear critical, possibly determining the recruitment of a given year-class to the adult populations. However, in contrast to the estimate of high mortality, 75% within 4 days, obtained during the study on Georges Bank, Graham and Davis (1971) suggested that in approximately 30 days only 31 to 50% of the larval population in estuarine water of the western Gulf of Maine died as they grew during the winter from about 20 to 25 mm in length. Since some dispersion might also have occurred during the winter measurements, their estimates are also maximal. A tentative comparison of annual variations in winter mortality (instantaneous rate) to the percentage of 2-year-old fish for a given year-class suggested that years of low mortality were usually related to subsequent greater percentages of 2-year-olds in the fishery (Graham, Chenoweth, and Davis, 1972). Thus, some evidence is available that suggests the determination of the strength of a given year-class may occur at a later period in the larval life of the herring.

Summary

This paper describes the hatching and early life history of larval herring spawned on the northeastern part of Georges Bank during autumn, 1970. The operations to obtain these descriptions were part of an international cooperative survey during which the USSR vessel located and mapped the distribution of egg beds and placed a buoy in their vicinity prior to dives by a Canadian submersible from an American mothership.

Samples of eggs from the beds were obtained with a dredge and a grab; samples of larvae from the water overlying the beds and the surrounding area were obtained with small and large Bongo nets attached to the same towing wire. Most tows were during darkness to permit dives by the submersible during the daylight.

Few eggs were dredged from the bottom; the largest clump was 15 cm^2 and 5.2 cm thick.

The egg beds were located in an area of complex temperature and salinity distributions. Temperatures immediately over the beds in 48 m varied from 13° to 15° C.

Hatching began just prior to the arrival of the mothership on the beds, 26 September, declined markedly by 2 October, and ceased sometime before 6 October. The decayed condition of the beds and the decline in the percent catch of yolk sac larvae from 28 September through 2 October confirmed estimates of hatching dates by USSR scientists determined from data collected during their earlier bottom surveys.

In total, 478,396 larvae were captured at 70 stations. The larvae fell into two size groups, one of small larvae (4-9 mm) with a mode at 7 mm and the other of larger larvae (10-22 mm) with a mode at 13 mm. Average catch rates for the two groups were 1,422 and 378 (per 100 m^3), respectively. Both size groups were distributed with their center of abundance within the vicinity of the egg beds and a dispersion in a southerly direction.

We concluded that the larvae with a mode of 7 mm originated from the egg beds, but could not be certain of the origin of the larger larvae.

Growth of the smaller larvae (<10 mm) indicated by shifts in their size frequencies was negligible over a 4-day period. Mortality for larvae less than 10 mm in length was estimated as 75% over the period from 1 to 5 October.

Acknowledgements

We are indebted to the Canadian scientists and to Dr J. F. Caddy for his consideration during the submersible operations aboard the *M/V Albatross IV*: and the USSR scientists and to Mr I. K. Sigajev for his advice concerning bottom sampling.

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Sedimentology of Herring Spawning Grounds on Georges Bank

By Georges Drapeau [1],[2]

Abstract

Herring spawning on Georges Bank takes place on a gravel bottom in a high energy environment. Herring spawn were observed exclusively on gravel patches devoid of sand at an average depth of 40 metres in an area where tidal currents reach an intensity of 1 m/sec and storm wave oscillations on the bottom exceed 70 cm/sec. It is inferred that a gravel substratum is chosen by the herring to ensure stability of eggs laid on the bottom and that strong currents prevent siltation and also maintain an adequate level of oxygenation of the egg mass.

Introduction

This paper describes herring spawning grounds on Georges Bank and the role of sediment texture in controlling herring spawning. Direct geological observations of the spawning grounds were made aboard the submersible *Pisces I* from International Hydrodynamics for which *Albatross IV* from the U.S. Bureau of Commercial Fisheries was the tender ship. The spawning survey on Georges Bank (Fig. 1) in the autumn of 1970 was a joint venture of AtlantNIRO, Kaliningrad, U.S.S.R., the National Marine Fisheries Service Biological Laboratory, West Boothbay Harbor, U.S.A., the Fisheries Research Board of Canada, Biological Station, St. Andrews, New Brunswick, and the Atlantic Oceanographic Laboratory of the Bedford Institute, Dartmouth, Canada.

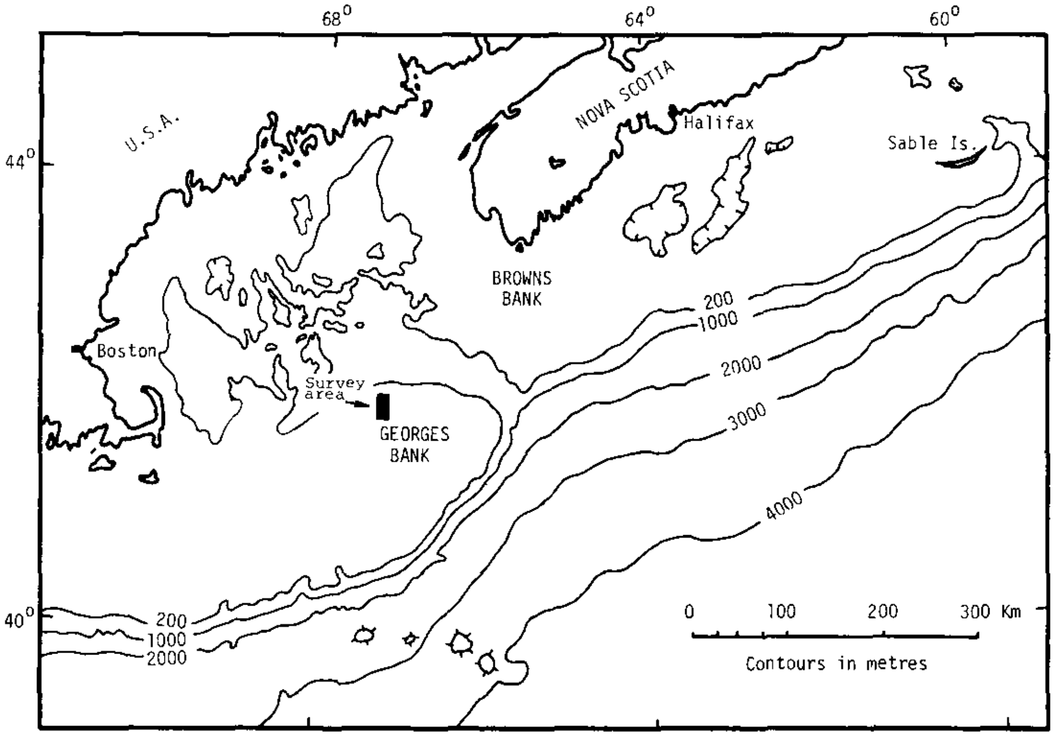

Fig. 1. Bathymetry of Georges Bank and vicinity and location of the survey area. (From U.S. Geological Survey, Miscellaneous Investigations Map I-451.)

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Spawning Grounds in Other Areas

Different herring populations may be characterized by the time and location of spawning. Spawning grounds are often first indicated by the appearance in commercial catches of ripe or newly spent herring, by herring spawn in stomach contents of other fish, or by the presence of recently hatched herring larvae in plankton catches. Direct observations of the spawning beds themselves have seldom been made, and have usually been confined to spawning grounds near the shore. Bolster and Bridger (1957) took grab samples over a herring spawning ground in the Sandattié region on the southern side of the Strait of Dover and found that the eggs were attached to flints overlying a gravelly sea floor. Bottom grab samples and photographic surveys of Ballantrae Bank in the Firth of Clyde (Parrish *et al.*, 1959) showed that the extent of the egg patch was sharply delimited by the nature of the substratum, the herring spawning preferentially on small cobbles and pebbles and not on large cobbles, boulders or rocks. Scuba divers investigating spawning grounds on Ballantrae Bank (Hemmings, 1965) reported herring spawn lying in a uniform carpet over gravel ridges. In the western North Atlantic, Tibbo *et al.* (1963) observed spring herring spawns on gravel, boulders, and algae in Baie des Chaleurs; also McKenzie (1964) located herring spawns on a flat bottom covered with sand and a few stones, 2 km offshore Black Point on the southwest coast of Nova Scotia.

Georges Bank Herring

Parrish and Saville (1965) divided the herring stocks of the Northeast Atlantic into two broad groups, the oceanic and the shelf herring, for which they provide the following definitions. The oceanic group spawns mostly between February and May along the Atlantic coast of northern Europe, especially the west coast of Norway, south and west coast of Iceland and west coast of Scotland. This spawning takes place in temperatures less than 12°C and mostly between 6° and 8°C. By contrast, the shelf group spawns mostly between August and December, on coastal and offshore banks in the North Sea and adjacent areas, in temperatures less than 15°C, and mostly between 8° and 12°C. By extension, a similar division is outlined by Parrish and Saville for the herring stocks of the Northwest Atlantic. On the western side of the Atlantic the main concentrations of herring are the summer-autumn spawning herring whose distribution extends from the Gulf of Maine to the Scotian Shelf, and to the southern part of the Gulf of St. Lawrence. This includes the herring stocks spawning on Georges Bank, which are comparable in many respects with the Shelf herring of the Northeast Atlantic. Groups of winter-spring spawners are also found in the Northwest Atlantic, where the main centres of spawning are grouped in the northern regions of the Gulf of St. Lawrence and off the west and south coasts of Newfoundland. Parrish and Saville (1965) consider it unlikely that the Northwest Atlantic supports a large population of oceanic winter-spring spawners comparable to the Atlanto-Scandian herring in the Northeast Atlantic, because of adverse environmental conditions such as sharp temperature boundaries and ice coverage. Although not enough data are available to correlate the different stocks of herring with different types of spawning grounds, it seems that a preference for a gravelly bottom is common to widely separated stocks such as, for example, those spawning on Georges Bank and Ballantrae Bank.

Surficial Geology of Georges Bank

The surficial sediments on Georges Bank are directly related to glacial processes in that these sediments were originally transported either directly by glaciers, or deposited as glacier outwash (Schlee and Pratt, 1970). According to these authors, the Pleistocene continental ice front would have progressed southward beyond the spawning area under study (Fig. 2). These sediments of glacial origin were modified when the sea transgressed from lower to higher levels following the melting of continental glaciers. For instance, data compiled by Milliman and Emery (1968) indicate that sea level was near the present height 35,000 years ago, then lowered to a minimum level of 130 m below mean sea level some 16,000 years ago and since raised to the present level. The transgression of the sea had a major impact on the distribution of the glacial sediments, the patterns of which are outlined in Fig. 2. Four types of surficial sediments are presently covering Georges Bank (Schlee and Pratt, 1970). Parts of the area, some 30 km across, are covered with more than 50% gravel and are surrounded by mixtures of sand and gravel. Four-fifths of the eastern portion of Georges Bank are covered with sand, most of which ranges in size from 1.0 to 0.25 mm. Patches of fine sand (0.25 to 0.063 mm) are found in the centre of the Bank.

Results of Geological Observations

The sediment cover in the spawning area was observed in detail during the dives aboard *Pisces I* and additional information was provided from an examination of bottom sediment grab samples. The results are shown in Fig. 3, which outlines the types of surficial sediments occurring in the vicinity of the spawning grounds. These surficial sediments vary in size from medium-sized sands to boulders 0.5 m in diameter. A large portion of the survey area is covered with

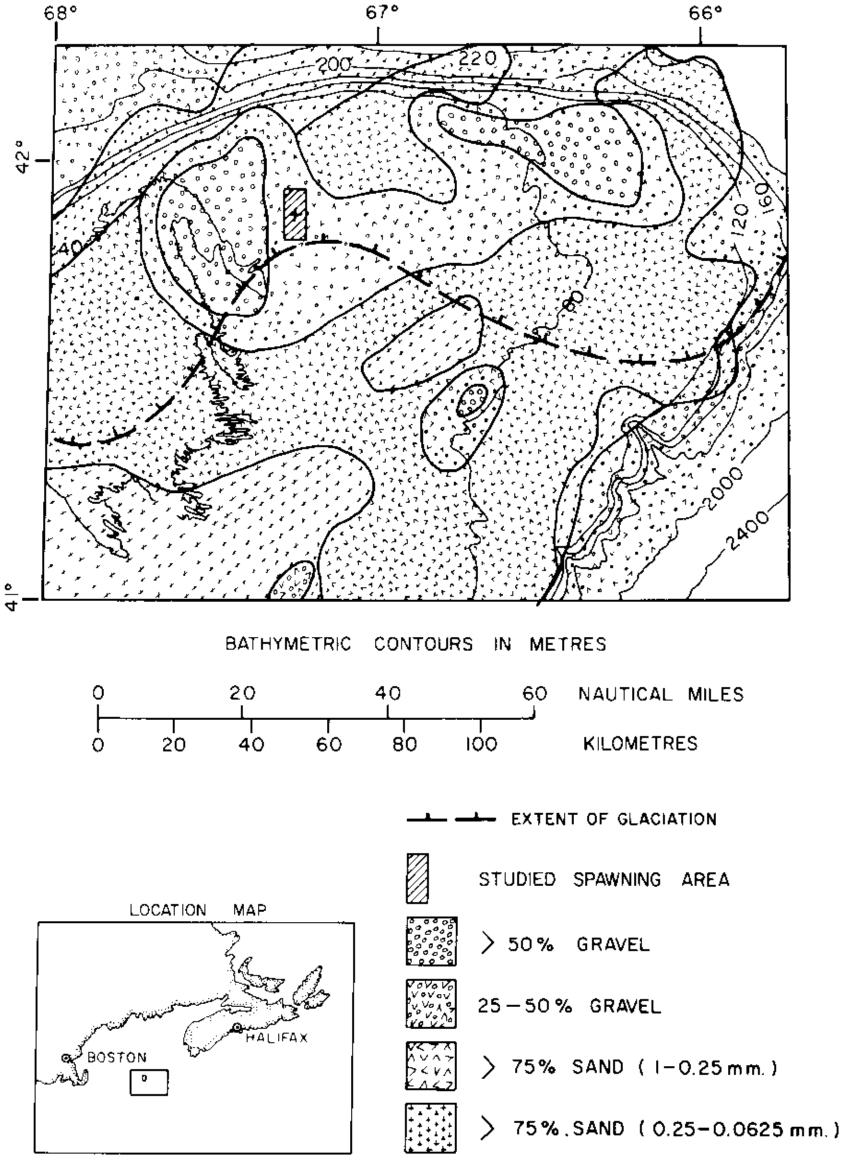

Fig. 2. Map showing the texture of unconsolidated sediments covering the eastern portion of Georges Bank as well as the assumed extent of Pleistocene glaciation. (Compiled from Schlee and Pratt, 1970.)

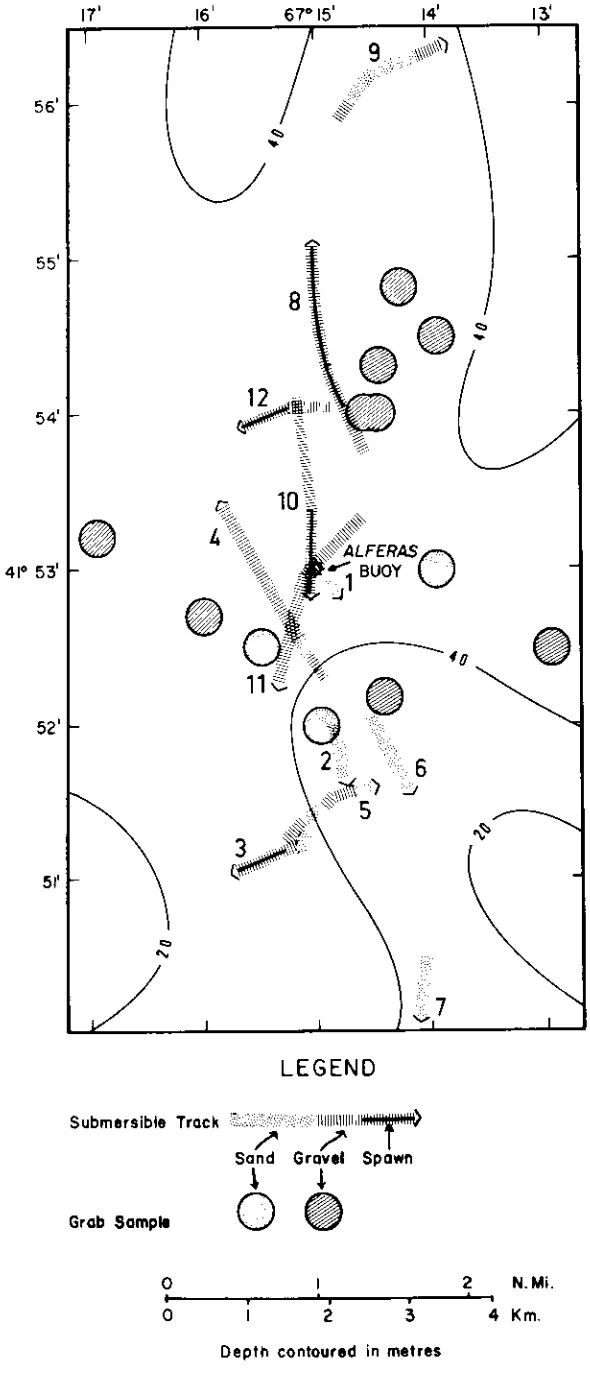

Fig. 3. Map of the survey area outlining the types of surficial sediments: (1) observed from *Pisces I* (submersible tracks are plotted and numbered 1 to 12) and (2) obtained by bottom grab sampling. (Modified from Caddy *et al.*, 1971.)

pebble-sized gravel (2 to 20 mm in diameter) intermingled with lesser quantities of cobble-sized gravel (4 to 12 cm in diameter) (Fig. 6). Boulders up to 0.5 m in diameter were also seen occasionally from *Pisces I*. The gravel is polymictic, fairly well rounded, and in many respects similar to the glacial drift covering the mainland. Two assemblages of sand-sized sediments were encountered in the study area. In places, gravels are mixed with sand and grade into sediments whose dominant texture is a coarse sand (0.5 to 2 mm) containing a fair quantity of granules (2 to 4 mm). Like the gravel, this sand is iron-stained and resembles the glacial drift of the mainland. In the areas where sand ripples and waves have developed (Fig. 4), the sand is naturally better sorted, medium to coarse in size (0.25 to 1 mm), and more greyish in colour. Photographs taken during the survey of the spawning grounds (Figs. 4 and 5) indicate that active transport of sand is taking place in that region of Georges Bank. Figure 4 shows a sand megaripple migrating over a gravelly bottom. The speed of drift of the submersible during the survey suggests that bottom currents are of the order of 0.5 to 1 m/sec. Figure 5 shows details of the sedimentary structures and the local phenomena of currents progressing in different directions as indicated by the smaller ripples superimposed across the larger ones. Sand waves were observed in the survey area particularly during dives 4, 5, and 7. These sedimentary structures were apparent on echograms of the ocean floor taken along dive tracks, such as the one for dive 7 reproduced in Fig. 8. With regard to the nature of the sediments covering the sea floor, Caddy *et al.* (1971) have reviewed all the data gathered during the survey and demonstrated that herring lay their eggs preferentially over the area covered with gravel.

Dynamics of Sedimentation on Herring Spawning Grounds

The environment in which herring spawning is taking place on Georges Bank is one of high energy as indicated by the sea bottom photographs and the sand waves recorded by the ship's echosounder in the spawning area. Sand waves are widespread on Georges Bank as shown in Fig. 7 which shows a compilation of sand waves based on soundings from the U.S. Coast and Geodetic Survey (Uchupi, 1968). Jordan (1962) and Stewart and Jordan (1964) studied these sand waves in detail. They report that in depths less than 20 m the sand waves are streamlined in the direction of maximum currents but, that in deeper water, the crestlines of sand waves are at 45° to 90° to the direction of maximum currents. These authors indicate that sand waves on Georges Bank occur at approximately 700-m intervals and average 10 m in height. Some large sand ridges were observed, one being 30 m high. Stewart and Jordan also report that comparison between surveys made in the 1930's and 1950's show a net westward movement of sand waves on Georges Shoal of the order of 300 m.

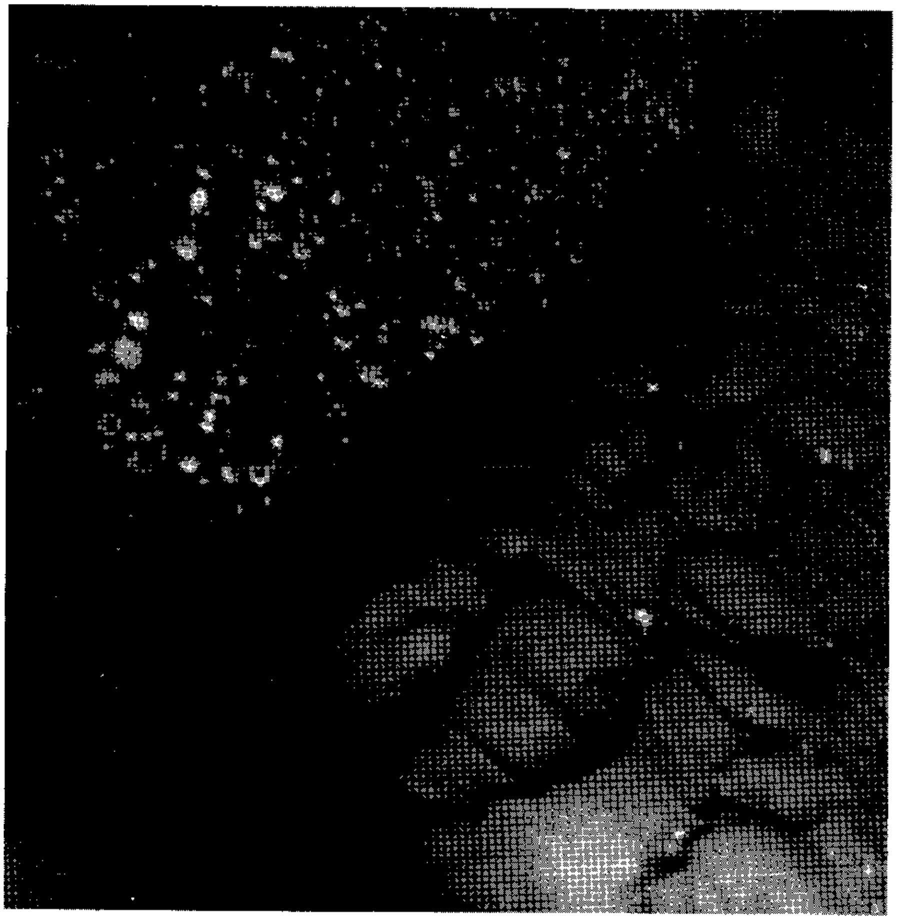

Fig. 4. (Dive 1) Megaripple on which are superimposed 30 cm long current ripples. The structure of the ripples witnesses strong bottom currents flowing towards the upper left corner of the photograph. The sand megaripple is transgressing over a gravelly substratum composed of medium size pebbles (10 mm) and sea urchin tests (40 mm).

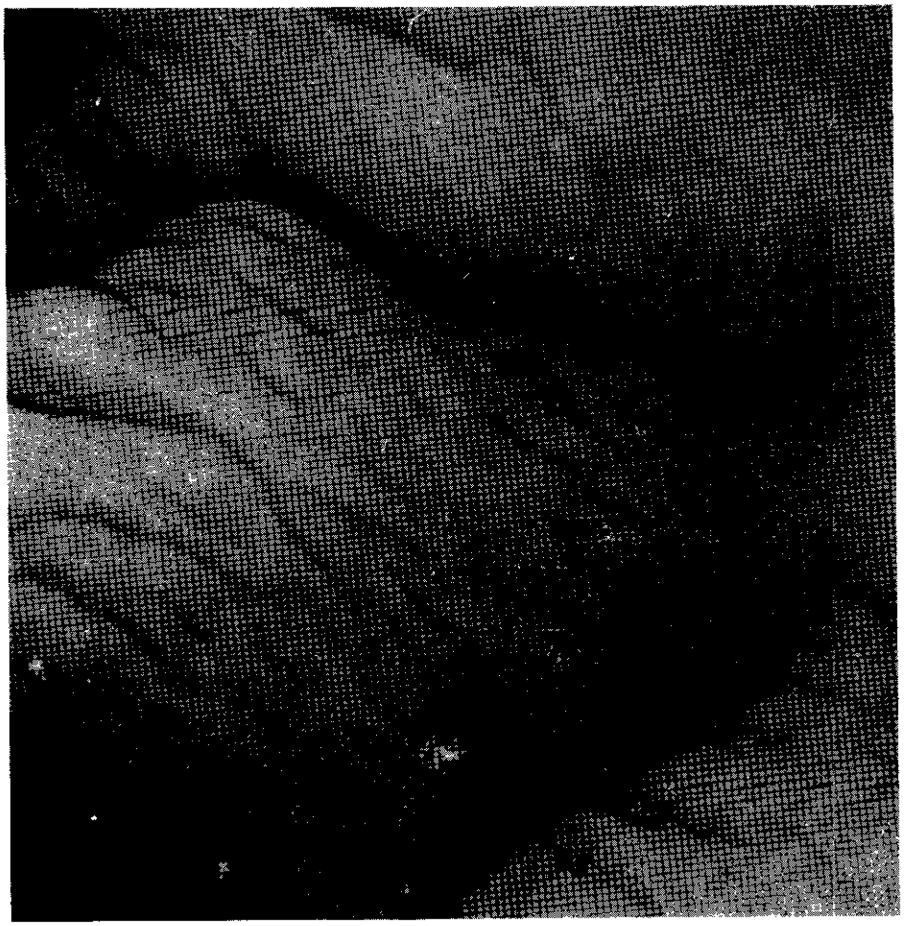

Fig. 5. (Dive 6) Ripples on a sand wave. A pattern of smaller ripples is superimposed on coarser ones. This indicates that the currents were originally flowing towards the upper left corner of the photograph and flowed subsequently towards the upper right corner. The hermit crab in the lower centre of the photograph is approximately 6 cm long.

Fig. 6. (Dive 8) Poorly sorted (5 mm to 15 cm) gravel bottom. The poor sorting as well as the mixed nature of the pebbles indicates that this material is of glacial origin. It is also noticeable that the pebbles show different stages of rounding from angular to fairly well rounded.

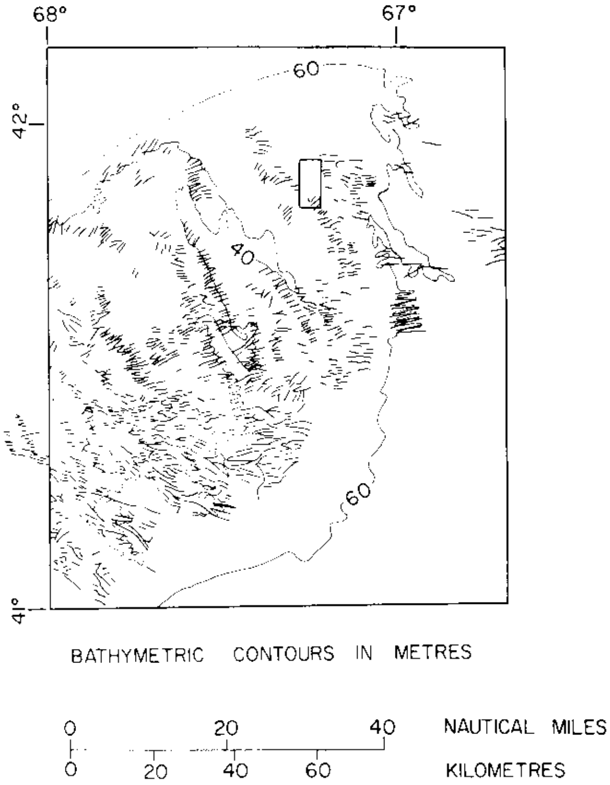

Fig. 7. Compilation of sand waves on Georges Bank based on detailed charting from U.S. Coast and Geodetic Survey. (From Uchupi, 1968.)

Stewart and Jordan (1964) suggest that sand waves on Georges Bank are formed by the superimposed effect of sea waves and tidal currents. Stride (1963) came to the same conclusion in his study of the expanses of sand waves in the English Channel. Stride points out that the areas investigated are subjected to strong winds and heavy seas which are estimated to produce bottom oscillatory currents reaching a velocity of 103 cm/sec at a depth of 91 m. A similar approach to the study of sand waves on Browns Bank, 60 km northeast of Georges Bank, showed that sand waves in that area are formed by tidal currents of the order of 1 m/sec, combined with oscillatory currents in excess of 20 cm/sec (Drapeau, 1970). Thus evidence exists from many areas that the formation of sand waves on continental shelves is associated with the combined action of tidal currents and storm waves.

As the spawning grounds surveyed on Georges Bank are closely associated with sand waves, they are subjected to the same conjugated action of tidal currents and storm waves which are the predominant sources of energy in that environment. In the case of Georges Bank, data of different nature are available to assess the intensity of the bottom currents over the spawning grounds. The tidal currents on Georges Bank were surveyed by the U.S. Coast and Geodetic Survey and are outlined in Fig. 9. These are rotary tidal currents for which the roses in Fig. 9 represent average values. The intensity of tidal currents varies through the lunar month and exceeds the average value by as much as 40%

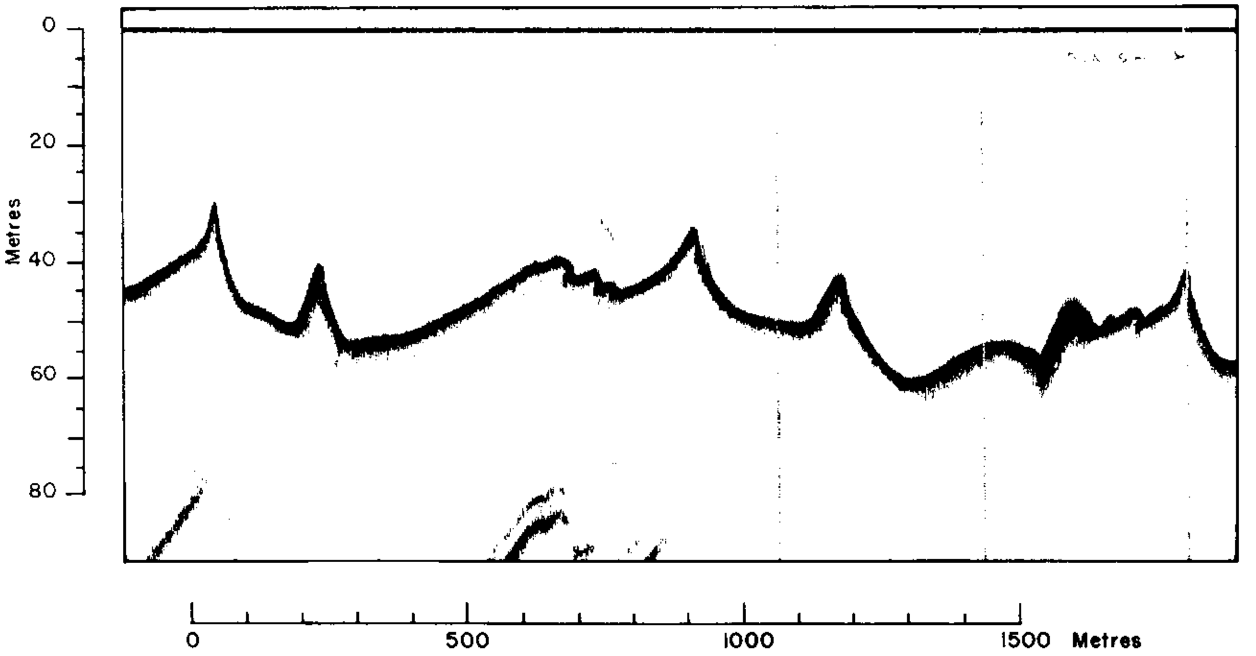

Fig. 8. Echogram showing the profile of the ocean floor along the submersible track no. 7. The sand waves seen on the echogram average 10 m in height and 135 m in length. They are somewhat smaller than those measured by Jordan (1962) farther west on Georges Bank.

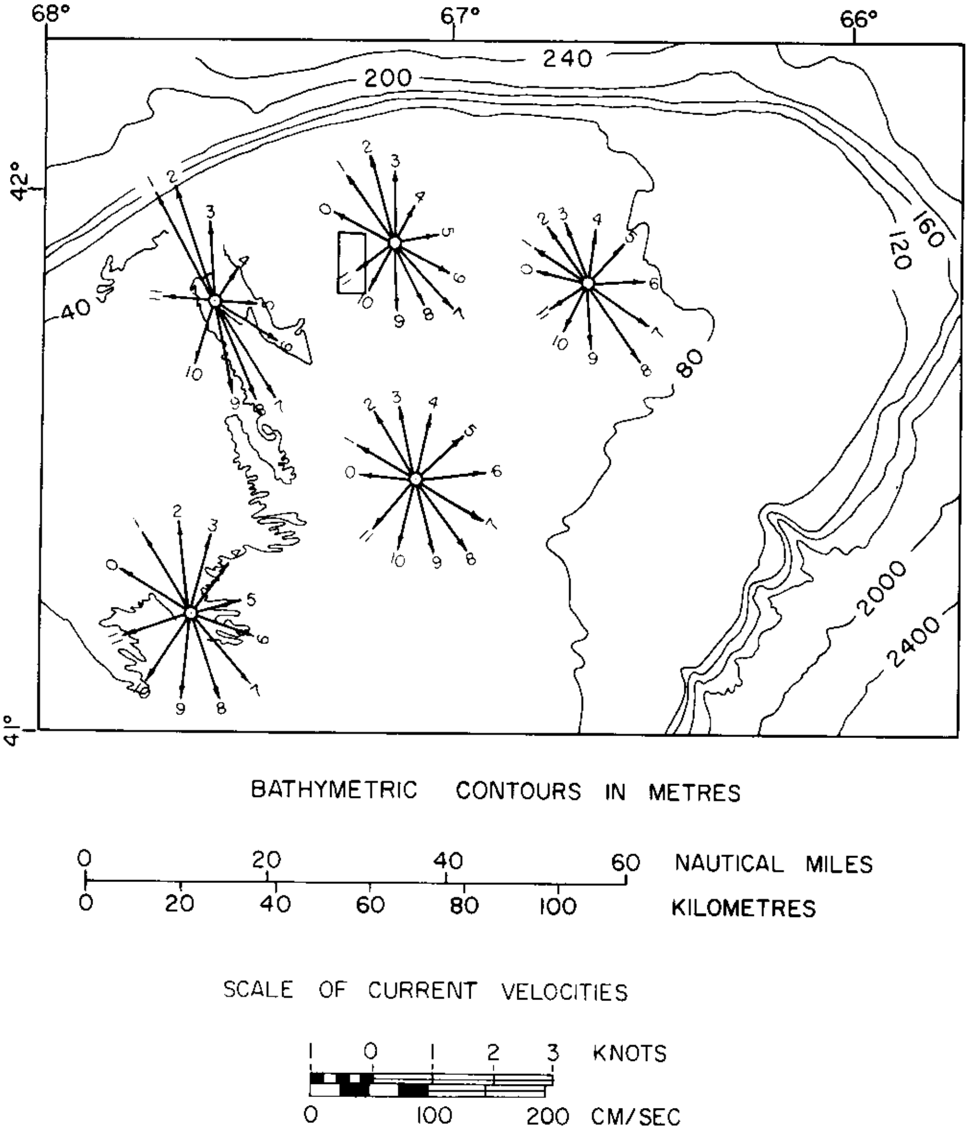

Fig. 9. Vector diagrams of tidal currents showing the hourly direction and intensity of tidal currents on Georges Bank. The velocities indicated by the arrows are averages. The moon at new, full, or perigee tends to increase the velocities by 15 to 20% above average and by 30 to 40% when new or full moon concurs with perigee. Quadrature and apogee tend to decrease the velocities below average by 15 to 20%. (Compiled from U.S. Department of Commerce, 1970, and Canadian Hydrographic Service Chart no. 8005.)

when perigee concurs with full or new moon. Under these circumstances the tidal currents reach an intensity of 1 m/sec in the area of study. Based on the drifting of *Pisces I* during the survey of the spawning grounds, there is no perceptible change with depth in either direction or intensity of tidal currents. In the area of survey the tidal currents are essentially symmetrical which implies that the eventual progression of sediments on the bottom results from the combined effect of wind-driven currents and waves enhanced by tidal currents.

No direct measurements of waves are available for the area of study but data compiled by Hogben and Lumb (1967) can be used to assess the wave energy in the area under investigation. These data are generalized for a wide area (Marsden squares 149, 150, and 151), but since Georges Bank is far offshore in the open ocean, these data are good first order approximations. Figure 10 summarizes the data from Hogben and Lumb for the area including Georges Bank. The shaded portion of the table shown in Fig. 10 outlines the conditions under

HEIGHT Metres	Calm	1-5	6-7	8-9	10-11	12-13	14-15	16-17	18-19	20-21	21	TOTALS
				WAVE PERIOD IN SECONDS								
0.25	853	974	13	17	9	2	1	1	1	32	17	1920
0.50	101	2384	245	52	28	8	2	2	3	3	136	2964
1.00	223	4211	1527	402	102	40	14	8	4	5	56	6592
1.50	233	2213	3128	969	273	87	29	5	3	1	6	6947
2.00	195	650	2295	1387	389	99	34	7	4		1	5061
2.50	154	264	1366	1265	520	158	46	8	7	2		3790
3.00	123	107	640	976	485	186	48	12	4			2581
3.50	86	77	421	682	426	170	60	15	4	1	2	1944
4.00	48	37	227	416	344	138	49	25	3			1287
4.50	59	33	189	358	292	150	55	26	8			1170
5.00	15	3	27	71	50	15	10	1		1		193
5.50	10	5	28	48	52	27	9	4	2		1	186
6.00	12	8	41	102	96	49	16	6	1			331
6.50	5	8	34	86	88	52	22	8				303
7.00	2	2	10	39	39	28	6	4				130
7.50	2	1	15	45	42	26	14	3				148
8.00	7	1	8	33	29	30	3	3			2	116
8.50			5	21	18	20	6	2				72
9.00	1		4	10	11	15	4	6				51
9.50	7	3	4	16	28	17	11	4	3	1	1	95
11.00			1	2		1						4
TOTALS	2136	10981	10228	6997	3321	1318	439	150	47	46	222	35885

Fig. 10. Ocean waves statistics for Marsden Squares 149, 150, and 151 for waves from all directions and for all seasons. The shaded area of the table outlines the conditions under which the horizontal orbital velocity on the bottom due to wave motion is in excess of 20 cm/sec. (From Hogben and Lumb, 1967).

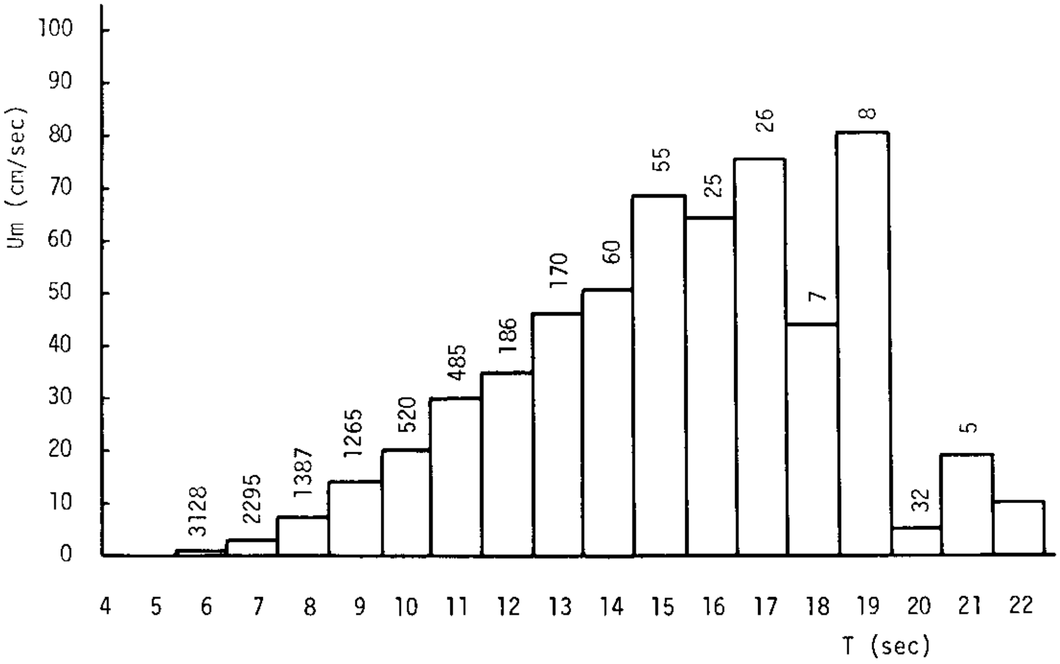

Fig. 11. Simplified wave energy spectrum for the data shown in Fig. 10. The horizontal orbital velocity on the bottom (Um) is recorded on the vertical axis and the wave period (T) on the horizontal axis. The figures on top of each column indicate the relative frequency of waves of different periods. The histogram indicates that the longer period waves release much more energy and that the orbital velocity on bottom can in certain circumstances reach 80 cm/sec.

which the horizontal component of the orbital velocity on the bottom at a depth of 50 m is in excess of 20 cm/sec. This indicates the lower threshold at which sand particles are moved on the bottom due to wave action. The orbital velocity on the bottom is a function of both wave height and wave length. This is shown in Fig. 10 which also shows that the wave height needed to produce equivalent horizontal orbital velocities on the bottom decreases with the wave period. According to the statistics of Hogben and Lumb (1967) 16% of the time throughout the year the horizontal orbital velocity exceeds 20 cm/sec on the bottom of Georges Bank. The range of orbital velocities on the bottom is shown by means of a histogram (Fig. 11) which outlines the fact that long-period waves are much more energetic and can induce velocities on the bottom exceeding 70 cm/sec.

Conclusions

The present survey confirmed that Georges Bank herring preferentially spawn on gravelly sea floors, and it also inferred from the hydrodynamic characteristics of the surficial sediments that spawning takes place in a high energy environment.

The choice of gravel for spawning ground on Georges Bank and other areas, except for the case reported by McKenzie (1964), may be explained by the fact that hatching is more successful if the eggs remain undisturbed during the period of incubation (Burd and Wallace, 1971). In a high energy environment it would be difficult for herring eggs, although they are covered with an adhesive mucus, to adhere to a sandy bottom because the weight of sand grains adhering to the eggs would not be sufficient to prevent them from being carried away by bottom currents. On the other hand, gravel-size particles are heavy enough to remain in place and provide a stable surface to which herring eggs can adhere firmly. The necessity for herring to attach its eggs securely to the substratum has been observed by Tibbo, Scarratt, and McMullon (1963) during *Scuba* dives in a subtidal environment. The finding of a gravel substratum by herring stocks at the time of spawning is not difficult on the continental shelves of the North Atlantic because the distribution of herring on both sides of the Atlantic coincides roughly with areas of the sea floor that were modified directly or indirectly by the glaciations of the Pleistocene. Continental glaciers transported huge quantities of gravel which were either left in place when the glaciers melted or carried farther than the glaciers themselves either by means of glacier outwash or by ice rafting at sea. For that reason, large expanses of gravel now cover the continental shelves of the North Atlantic within the latitudes where herring are found.

Spawning in a high energy environment probably serves a double purpose. Strong currents prevent siltation of fine particles that could impede the eggs from adhering to rocky surfaces at the time of spawning and could also smother the eggs during the period of incubation (Hildebrand, 1963). Furthermore, active circulation of sea water over the spawn removes the metabolites and supplies the oxygen necessary for successful hatching (Hempel, 1971). The sea floor of the banks and coastal waters, where herring are normally spawning, is generally swept by tides, longshore currents, and waves that maintain the circulation of oxygenated water on the bottom.

On the basis of the information presently available, the grounds most favorable for herring spawning on eastern Georges Bank would be included within a 50 X 100 km area between the lat. 41°34′N and 42°08′N, and the long. 66°30′W and 67°45′W. Obviously, this outline of potential spawning grounds does not imply that herring spawn could not be found outside that area; it means rather, on the basis of the observations made in this survey, the data available concerning the bathymetry, the geology, and the oceanography of the area, that the region defined above outlines the environment that seems most suitable for herring spawning on Georges Bank.

Acknowledgements

The participation to the international venture on survey of spawning grounds of Georges Bank with AtlantNIRO, the U.S. Bureau of Commercial Fisheries, and the Fisheries Research Board of Canada has been a most rewarding experience from a personal as well as from a scientific point of view, and the author is thankful to the Bedford Institute for the opportunity which was given to him to participate on that mission. The author is particularly appreciative of the close co-operation received from Dr J. F. Caddy and T. D. Iles, Fisheries Research Board of Canada, St. Andrews, New Brunswick who also reviewed the manuscript with Drs B. R. Pelletier and K. H. Mann, Bedford Institute, Dartmouth, Nova Scotia and to J. J. Graham, National Marine Fisheries Service, West Boothbay Harbour, Maine, USA. The crews of *Albatross IV* and *Pisces I* are acknowledged for their seamanship and their cooperation.

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Notes

Gutted Weight Versus Total Length of Atlantic Salmon at West Greenland

By A. W. May[1],[2] and W. H. Lear[1]

Data on the relationship between gutted weight and total length of Atlantic salmon taken at West Greenland are provided in response to a request from the Planning Group for the 1972 international tagging experiment, contained in the report of its meeting of 18-20 January 1972 (ICNAF Research Document No. 32, Serial No. 2785).

Material was collected in 1968 (20-25 September) from salmon taken by shore nets and delivered to the fish factory at Godthaab, and in 1969-71 during the course of drift net fishing by the Canadian research vessel *A. T. Cameron.* Dates of collections were in 1969 6 Sept. - 2 Oct., in 1970 3 Sept. - 4 Oct., and in 1971 6-23 Sept. Most of the material is from the northern part of the West Greenland fishing area.

Weighted average values of gutted weight at each cm total length were used to fit regressions to each data series, as well as to combined material for 1968-71 (Fig. 1). The regression constants are given for each series.

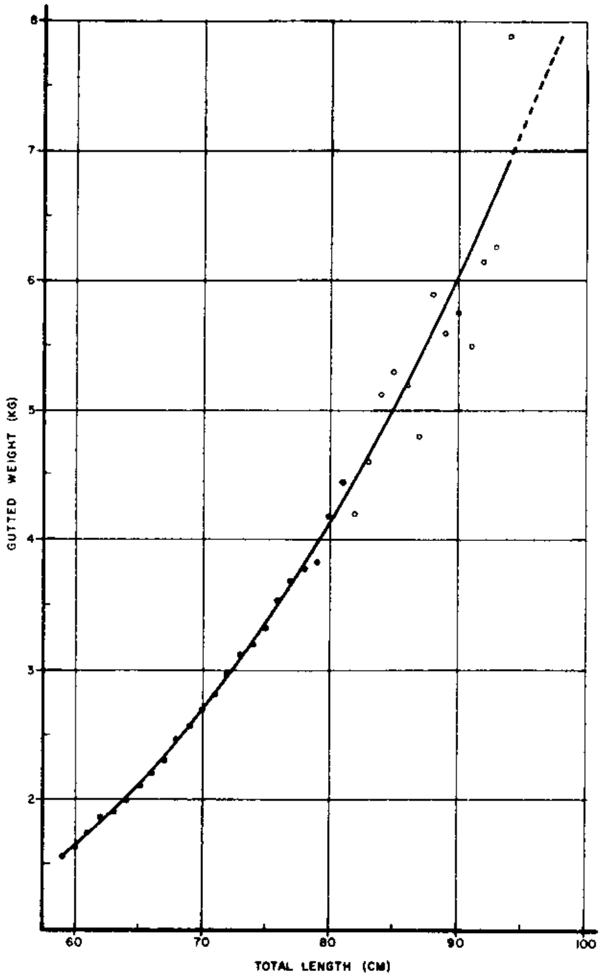

Fig. 1. Relationship of gutted weight to total length for Atlantic salmon at West Greenland, 1968-71. Open circles represent average weights based on less than five fish.

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TABLE 1. West Greenland 1968-71. Gutted weight (kg) versus total length (cm).

Total length (cm)	Average gutted weight (kg)	N	Range (kg)	Calculated weight (kg)
59	1.557	7	1.4 – 1.8	1.552
60	1.630	10	1.5 – 1.8	1.638
61	1.735	20	1.5 – 2.0	1.726
62	1.873	15	1.6 – 2.1	1.820
63	1.896	25	1.6 – 2.1	1.914
64	1.976	46	1.7 – 2.2	2.015
65	2.110	50	1.8 – 2.6	2.117
66	2.214	50	1.8 – 2.6	2.223
67	2.298	65	1.9 – 2.7	2.334
68	2.474	54	2.1 – 3.1	2.447
69	2.557	72	2.2 – 3.2	2.565
70	2.696	96	2.3 – 3.5	2.687
71	2.826	72	2.3 – 3.4	2.814
72	2.974	77	2.4 – 3.6	2.942
73	3.123	93	2.5 – 4.3	3.075
74	3.191	65	2.4 – 3.8	3.212
75	3.329	56	2.9 – 4.2	3.356
76	3.530	54	3.0 – 4.1	3.500
77	3.683	29	3.1 – 4.2	3.652
78	3.776	25	3.3 – 4.7	3.806
79	3.821	14	3.3 – 4.4	3.964
80	4.231	13	3.3 – 5.3	4.129
81	4.460	5	3.5 – 4.9	4.297
82	4.200	3	3.8 – 4.9	4.469
83	4.600	1	–	4.648
84	5.125	4	4.7 – 5.4	4.831
85	5.300	2	4.8 – 5.8	5.017
86	5.200	1	–	5.210
87	4.800	4	3.8 – 5.4	5.406
88	5.900	1	–	5.610
89	5.600	2	4.8 – 6.4	5.817
90	5.750	2	5.2 – 6.3	6.027
91	5.500	1	–	6.246
92	6.150	2	5.2 – 7.1	6.471
93	6.267	3	5.5 – 6.8	6.701
94	7.900	1	–	6.933
		1,040		

Log-log Regression
Slope = 3.2154
Intercept = -5.5034

TABLE 2. Godthaab, 1968. Gutted weight (kg) versus total length (cm).

Total length (cm)	Average gutted weight (kg)	N	Range (kg)	Calculated weight (kg)
59	1.560	5	1.4 – 1.8	1.574
60	1.671	7	1.5 – 1.8	1.661
61	1.763	16	1.5 – 2.0	1.749
62	1.911	9	1.6 – 2.1	1.842
63	1.923	13	1.6 – 2.1	1.937
64	2.005	20	1.8 – 2.2	2.037
65	2.150	26	1.9 – 2.5	2.140
66	2.200	22	1.9 – 2.4	2.246
67	2.324	25	2.0 – 2.6	2.357
68	2.527	26	2.1 – 3.1	2.469
69	2.559	29	2.2 – 3.1	2.586
70	2.764	25	2.3 – 3.4	2.708
71	2.839	18	2.5 – 3.4	2.833
72	2.962	13	2.7 – 3.3	2.961
73	3.125	20	2.7 – 3.7	3.093
74	3.133	12	2.6 – 3.7	3.229
75	3.143	7	2.9 – 3.4	3.372
76	3.409	11	3.1 – 3.6	3.516
77	4.000	4	3.8 – 4.2	3.665
78	3.550	2	3.5 – 3.6	3.819
79	3.700	1	–	3.975
80	4.300	1	–	4.138
81	4.700	3	4.6 – 4.9	4.305
82	4.700	1	–	4.475
84	5.050	2	4.7 – 5.4	4.832
85	5.800	1	–	5.016
86	5.200	1	–	5.206
87	5.300	2	5.2 – 5.4	5.400
92	6.150	2	5.2 – 7.1	6.451
93	6.800	1	–	6.676
94	7.900	1	–	6.904
		326		

Log-log regression
Slope = 3.1754
Intercept = -5.4263

TABLE 3. *A. T. Cameron* Cruise 164, 1969. Gutted weight (kg) versus total length (cm).

Total length (cm)	Average gutted weight (kg)	N	Range (kg)	Calculated weight (kg)
60	1.500	1	–	1.664
62	1.867	3	1.8 – 2.0	1.858
63	2.100	1	–	1.960
64	1.967	3	1.9 – 2.0	2.067
65	2.129	7	1.9 – 2.6	2.178
66	2.382	11	2.1 – 2.6	2.293
67	2.371	17	2.1 – 2.7	2.413
68	2.486	7	2.1 – 2.9	2.536
69	2.619	16	2.3 – 3.2	2.663
70	2.727	30	2.4 – 3.5	2.796
71	2.912	17	2.5 – 3.2	2.933
72	3.165	23	2.7 – 3.6	3.073
73	3.324	25	2.9 – 4.3	3.219
74	3.416	19	3.2 – 3.7	3.370
75	3.585	13	3.2 – 4.2	3.527
76	3.714	21	3.3 – 4.1	3.686
77	3.940	5	3.6 – 4.2	3.853
78	4.043	7	3.8 – 4.7	4.024
79	3.917	6	3.4 – 4.4	4.200
80	4.200	6	3.3 – 5.3	4.382
81	4.700	1	–	4.568
84	5.000	1	–	5.164
88	5.900	1	–	6.039
89	6.400	1	–	6.273
93	6.500	1	–	7.274
		243		

Log-log regression
Slope = 3.3656
Intercept = -5.7634

TABLE 4. *A. T. Cameron*, Cruise 177, 1970. Gutted weight (kg) versus total length (cm).

Total length (cm)	Average gutted weight (kg)	N	Range (kg)	Calculated weight (kg)
61	1.700	1	–	1.770
62	1.700	1	–	1.856
63	1.900	2	–	1.942
64	1.900	5	1.7 – 2.0	2.032
65	2.100	4	1.9 – 2.5	2.124
66	2.267	3	2.2 – 2.3	2.220
67	2.288	8	2.1 – 2.5	2.319
68	2.467	9	2.2 – 2.7	2.419
69	2.529	7	2.2 – 2.9	2.523
70	2.615	13	2.4 – 2.9	2.629
71	2.836	11	2.3 – 3.4	2.740
72	2.750	14	2.6 – 2.9	2.851
73	2.978	23	2.6 – 3.4	2.967
74	3.108	13	2.5 – 3.5	3.085
75	3.222	18	2.9 – 3.8	3.207
76	3.470	10	3.1 – 3.7	3.332
77	3.475	8	3.1 – 4.0	3.459
78	3.763	8	3.3 – 4.4	3.590
79	3.720	5	3.3 – 4.0	3.724
80	4.100	3	3.8 – 4.5	3.862
81	3.500	1	–	4.002
82	3.800	1	–	4.146
85	4.800	1	–	4.596
87	4.300	2	3.8 – 4.8	4.915
89	4.800	1	–	5.248
90	5.200	1	–	5.418
91	5.500	1	–	5.593
93	5.500	1	–	5.955
		175		

Log-log regression
Slope = 2.8764
Intercept = -4.8873

TABLE 5. *A. T. Cameron*, Cruise 190, 1971. Gutted weight (kg) versus total length (cm).

Total length (cm)	Average gutted weight (kg)	N	Range (kg)	Calculated weight (kg)
59	1.550	2	1.5 – 1.6	1.479
60	1.550	2	1.5 – 1.6	1.564
61	1.600	3	1.5 – 1.7	1.652
62	1.800	2	1.7 – 1.9	1.745
63	1.833	9	1.6 – 2.0	1.840
64	1.967	18	1.7 – 2.2	1.940
65	2.023	13	1.8 – 2.2	2.043
66	2.093	14	1.8 – 2.3	2.149
67	2.180	15	1.9 – 2.5	2.260
68	2.358	12	2.2 – 2.6	2.374
69	2.515	20	2.3 – 2.8	2.492
70	2.639	28	2.4 – 3.0	2.616
71	2.758	26	2.5 – 3.2	2.744
72	2.933	27	2.4 – 3.4	2.873
73	3.052	25	2.5 – 3.6	3.008
74	3.071	21	2.4 – 3.8	3.148
75	3.322	18	3.0 – 3.8	3.294
76	3.367	12	3.0 – 3.8	3.442
77	3.608	12	3.2 – 3.9	3.596
78	3.613	8	3.3 – 3.9	3.753
79	3.850	2	3.8 – 3.9	3.915
80	4.400	3	4.3 – 4.6	4.085
82	4.100	1	–	4.435
83	4.600	1	–	4.618
84	5.400	1	–	4.807
90	6.300	1	–	6.049
		296		

Log-log regression
Slope = 3.3369
Intercept = -5.7393

International Commission for the Northwest Atlantic Fisheries

The Commission in Brief

Under the terms of a Convention signed in 1949, the International Commission for the Northwest Atlantic Fisheries (ICNAF) is responsible for promoting and co-ordinating scientific studies on the stocks of the species of fish which support international fisheries in the Northwest Atlantic. Based on these researches, the Commission recommends measures to keep these stocks at a level permitting the maximum sustained catch.

The governments sharing these conservation interests are Bulgaria, Canada, Denmark, France, Federal Republic of Germany, Iceland, Italy, Japan, Norway, Poland, Portugal, Romania, Spain, Union of Soviet Socialist Republics, United Kingdom, and United States of America.

Research Bulletin of ICNAF

The International Commission for the Northwest Atlantic Fisheries invites contributions to its serial publication, "The Research Bulletin of ICNAF".

There will be one or more issues each year depending on the number of papers received and accepted for publication.

Purpose. The main purpose of the Research Bulletin is to publish the results of research carried out in the ICNAF area. It is expected that most papers published in the Research Bulletin will be selected from papers presented at Annual Meetings of the Commission, but other papers, either concerning the ICNAF area or outside it, will be accepted if their contents are of importance to the work of the Commission.

Submission of Manuscripts. Manuscripts for publication should be submitted to the Commission's Secretariat on or before 1 October each year. This provides authors with sufficient time to revise or extend papers submitted or solicited at the previous Annual Meeting of the Commission which is held in early June each year. The arrangement also provides the possibility that the Bulletin can be issued before the next Annual Meeting of the Commission.

Editing. The Editor of the Research Bulletin will be the Executive Secretary of the Commission. He will be assisted on matters of editorial policy by the Chairman of the Commission's Standing Committee on Research and Statistics and the members of the Steering and Publications Subcommittee.

Refereeing. To maintain a high standard of publication each contribution will be submitted by the Editor to one or more referees from a panel of experts appointed for that purpose. On the advice of the referee(s), the Editor will request the author to make such amendments to his manuscript as will help to avoid error or misunderstanding and add strength to his presentation or will reject the manuscript. Referees will remain anonymous and will treat all manuscripts as confidential.

Preparation of Manuscripts. To achieve maximum conformity of presentation by authors and to minimize typing and other editorial work, the Commission's Secretariat has prepared the following aid.

Instructions to Authors for the Preparation of Manuscripts Intended for Publication in the Research Bulletin of ICNAF

Text

a) Manuscript should be type-written, *double-spaced,* and on one side only of good quality white bond quarto paper, size 8½ × 11 inches (220 × 280 mm).

b) Leave all margins 1 inch (25 mm) to 1½ inches (38 mm) for editorial marks and queries.

c) Prepare and submit the original and two carbon copies of the text and at least two sets of illustrations.

d) Number all pages of the manuscript consecutively with Arabic numerals in the centre of the top margin space.

e) Start a new page for each of the following sections with appropriate headings and sub-headings: (1) title, name and address of author, list of contents (if applicable); (2) abstract of the paper; (3) text; (4) references to literature; (5) tables; (6) legends for figures and (7) figures.

f) Please *double-space everything* – Text, quotations, footnotes, tables and table headings, legends, references to literature, and use even greater spacing where helpful (particularly around equations and formulate).

g) Wherever practical the text should be subheaded into Introduction, Materials and Methods, Results, and Discussion. Authors must provide a Summary which lists one by one the principal facts and conclusions of the paper. Acknowledgements should be placed immediately after the Summary.

h) All measurements, linear, weight, and time, should be given in numerals (not words) in the metric system. The Celsius scale should be used as a standard. When other units of measure are preferred, authors should include equivalents in metric units.

i) Footnotes should be avoided as far as possible, but if necessary they must be numbered consecutively in the text and type under a horizontal line at the foot of the page concerned.

j) Only those words to be printed in italics should be underlined.

(This page is perforated. TEAR OUT and file for future use)

Abstract

Each manuscript should have an abstract not to exceed 3% of the length of the text or 200 words whichever is the smaller. For position of the abstract in the manuscript see (e) above. The abstract should summarize the contents and conclusions of the paper, point to new information in the paper and indicate the relevance of the work.

Tables

a) Tables should be carefully constructed so that the data presented may be easily understood.

b) Tables should be set out on separate sheets following the references.

c) Position of the tables in the text should be indicated clearly.

d) Each table should be provided with a descriptive heading which, together with the column headings, makes the table intelligible without reference to the text.

e) Tables should be numbered consecutively with Arabic numerals, e.g. Table 1, 2, 3, etc.

Figures

a) All illustrations, whether black-and-white drawings, graphs, photographs, or tone drawings, are to be considered as figures.

b) Each figure should be mentioned and described in the text.

c) A legend should be provided for each figure; the legends should all be typed together on a separate sheet or sheets attached to the manuscript following the tables.

d) Figures should be numbered consecutively with Arabic numerals, as Fig. 1, 2, 3, etc.

e) Figures should be set out on sheets preferably the same size as the text pages and in any case should not require a printer's reduction to less than one-third. Small figures can be arranged in groups on sheets the same size as the text pages.

f) For guidance in preparing figures, the size of the printed area of the *Research Bulletin* page is 21 X 17 cm. The *Bulletin* will have a two-column format, each column 8 cm wide.

g) Photographs presented as figures should be high contrast, glossy prints, about 5 X 7 inches (125 X 175 mm) in size and should be shipped flat protected by stout cardboard.

h) Each illustration should be identified by marking on the back lightly in soft pencil on the margin the figure number and the author's name.

Bibliographic Style

a) References to literature in the text should be by the author-date system, for example

> It was reported that (Collins, 1960) the . . .;
> In examining the situation, Rossini (1959) felt that . . .

Where more than one paper by the same author(s) have appeared in one year, reference should be given as follows:

> Osborne and Mendel (1914*a*); Osborne and Mendel (1914*b*)
> or Oxborne and Mendel (1914*a* and *b*); (Barnet and Robinson, 1942; King and Pierce 1943*a*, 1954)

Reference to material not yet submitted for publication should be written into the text e.g. "Harvey, in an unpublished manuscript, . . ." or "Harvey, in a letter, . . ."

b) All references cited by the author-name system in the text should be listed alphabetically by the surname of the first ***author*** at the end of the paper. ***Year*** of publication follows the authorship. Then give the full ***title*** of the paper. This should be followed by the abbreviated name of the ***periodical*** with the ***volume*** and ***pages*** in Arabic numbers (e.g. :2 : 120 - 136). For abbreviations of periodicals follow the "Word List of Scientific Periodicals". An issue, number supplement or other part within a volume is shown in parentheses only when paged independently (e.g.: 2(4) :1 - 56; 34 (Suppl.2) :1 - 26). Any special Series (Ser 3, III, cr C) precedes the volume number. In ***book citations*** after the title, there appears the edition, the publisher's name, place of publication, and the number of pages if one volume, but the number of volumes if more. Reference to material submitted but not yet published should be referred to in the list of references as "in press" or "Submitted for publication" followed by the date of submission.

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