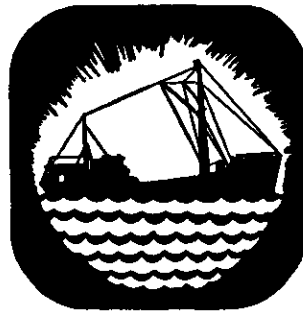


**INTERNATIONAL COMMISSION**  
**FOR THE**  
**NORTHWEST ATLANTIC FISHERIES**

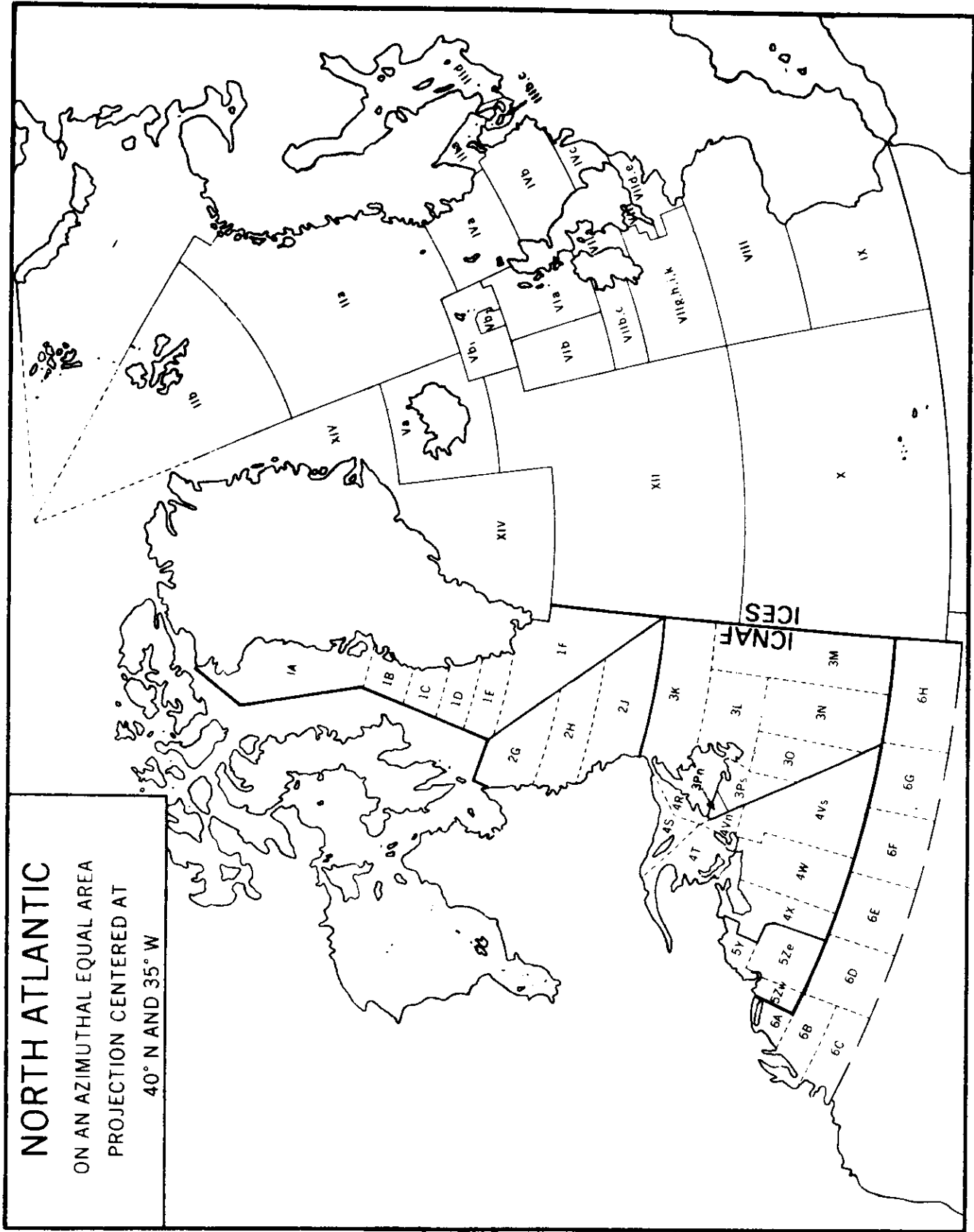


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NORTH ATLANTIC  
ON AN AZIMUTHAL EQUAL AREA  
PROJECTION CENTERED AT  
40° N AND 35° W



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# An Evaluation of the Status of ICNAF Divisions 3P, 3O and 3LN Redfish

L. S. Parsons<sup>1</sup> and D. G. Parsons<sup>1</sup>

## Abstract

The status of ICNAF Div. 3P, 3O and 3L-N redfish is evaluated, utilizing the Schaefer general production yield model. Estimates of maximum sustainable yields are 23,000 metric tons for Div. 3P redfish, 20,000 metric tons for Div. 3L-N redfish and approximately 15,000 metric tons for Div. 3O redfish. Recent levels of redfish catches from these stocks have been above the maximum sustainable yield level. Catch limitations are recommended to prevent an increase in fishing pressure on redfish in these areas until better knowledge of the effects of the fisheries on these redfish stocks becomes available. Levels of sampling of the commercial redfish catches in recent years have been inadequate.

## Introduction

The recent imposition of catch quotas for most important commercial fishes of the ICNAF area has precipitated concern that fishing pressure on redfish might increase substantially with the diversion of highly versatile mobile fleets to other species as national quotas for regulated species become filled. In view of this it was requested at the 1973 Special ICNAF Meeting that countries submit information on the status of the redfish stocks in Subareas 1-4.

Because of the lack of adequate recent information on the length and age compositions of redfish catches in Subareas 2 and 3, it has not been possible to conduct rigorous analyses of the fisheries in these areas utilizing catch-per-unit effort data or the virtual population method. In this paper the status of ICNAF Div. 3P, 3O and 3LN redfish is evaluated, utilizing a Schaefer yield model to examine commercial catch/effort data and provide approximate estimates of maximum sustainable yield.

Redfish, *Sebastes mentella* of ICNAF Div. 3P and 3O exhibit different growth rates (Sandeman, 1969) and hence are considered separately for assessment purposes. Redfish of the northern and eastern Grand Bank (Div. 3L and 3N) are considered to constitute a different stock from those of Div. 3P and 3O (Mead and Sindermann, 1961; Bainbridge and Cooper, 1971). In the absence of adequate evidence to indicate that redfish in Div. 3L and

3N constitute distinct stocks, data for Div. 3LN redfish have been combined for the purposes of this report.

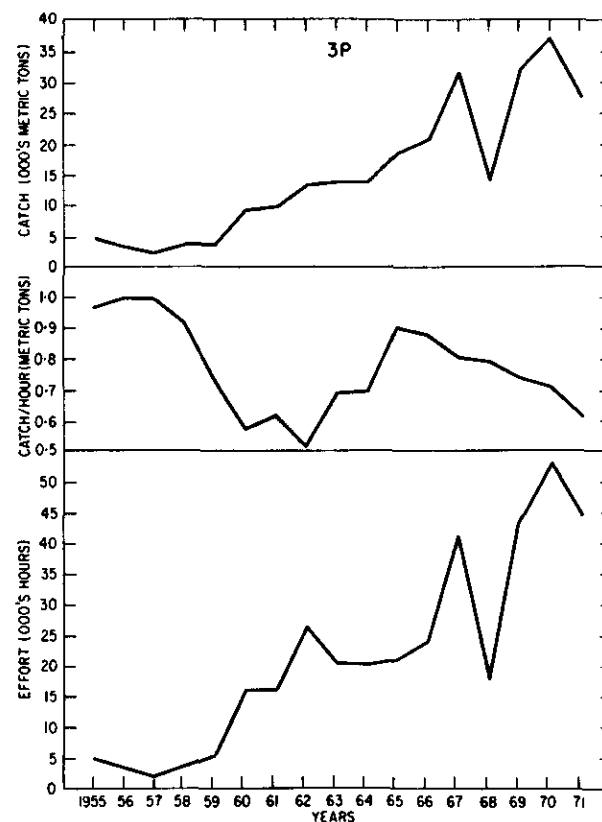


Fig. 1. Trends in nominal catches, effort and catches per unit effort in standard trawler units — Canada (Nfld) tonnage class 4 — for redfish in Div. 3P during 1955-71.

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## Trends in Landings

Redfish in ICNAF Subareas 2 and 3 were heavily exploited during the late 1950's with a peak catch of approximately 299,000 metric tons in 1959, the bulk of which was taken from the Northern Newfoundland Banks and Labrador (ICNAF Div. 3K and 2J). Catches in this northern region declined dramatically during the early 1960's and in recent years have averaged less than 30,000 metric tons annually. Landings from the south coast of Newfoundland (Div. 3Ps and 3Pn) increased gradually from less than 5,000 tons in 1959 to about 15,000 tons in 1964, with a substantial increase since 1965 reaching a peak of 37,000 tons in 1970 (Fig. 1; Table 1). Since 1960 redfish landings from the southwest slope of the Grand Bank (Div. 3O) have fluctuated between 6,000 and 20,000 tons per year (Fig. 2; Table 2) and landings from Div. 3LN between 8,000 and 35,000 tons per year (Fig. 3; Table 3).

During 1955-71 exploitation of redfish in these areas was almost exclusively by otter trawl. In Div. 3P Newfoundland tonnage class 4 trawlers (151-500 tons) were the main participants in the redfish fishery until

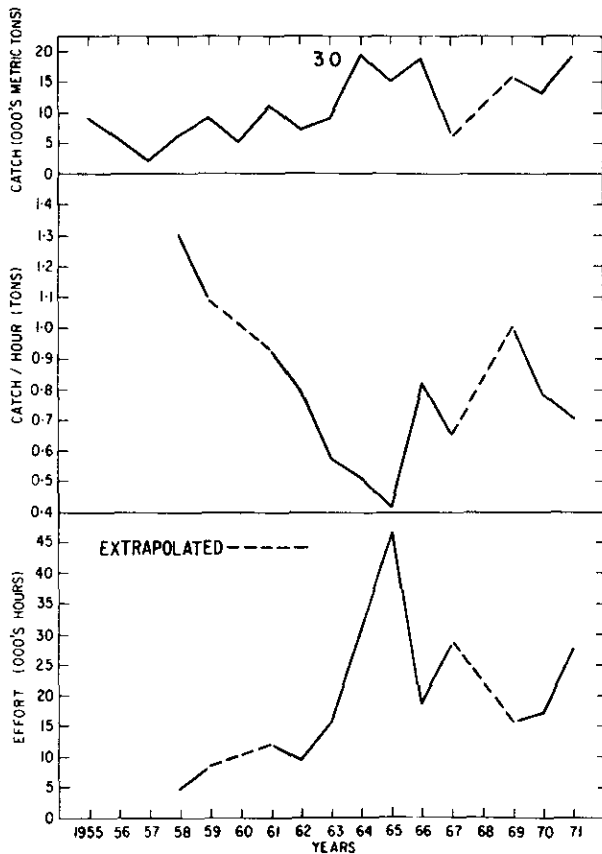


Fig. 2. Trends in nominal catches, effort and catches per unit effort in standard trawler units — Canada (Nfld) tonnage class 4 — for redfish in Div. 3O during 1955-71.

1966. In 1967 non-member countries caught slightly more than 50% of the redfish taken in 3P; during 1969-71 USSR vessels took approximately 65% of the total catch (Table 1). More than a dozen countries participated in the Grand Bank redfish fishery (Div. 3O and 3LN) during 1955-71 but USSR vessels were by far the largest contributors to the total catch (about 52% of the total during this period).

## Standardization of Effort

Entries for redfish catches and hours fished, where redfish represented more than 50% of the total fish

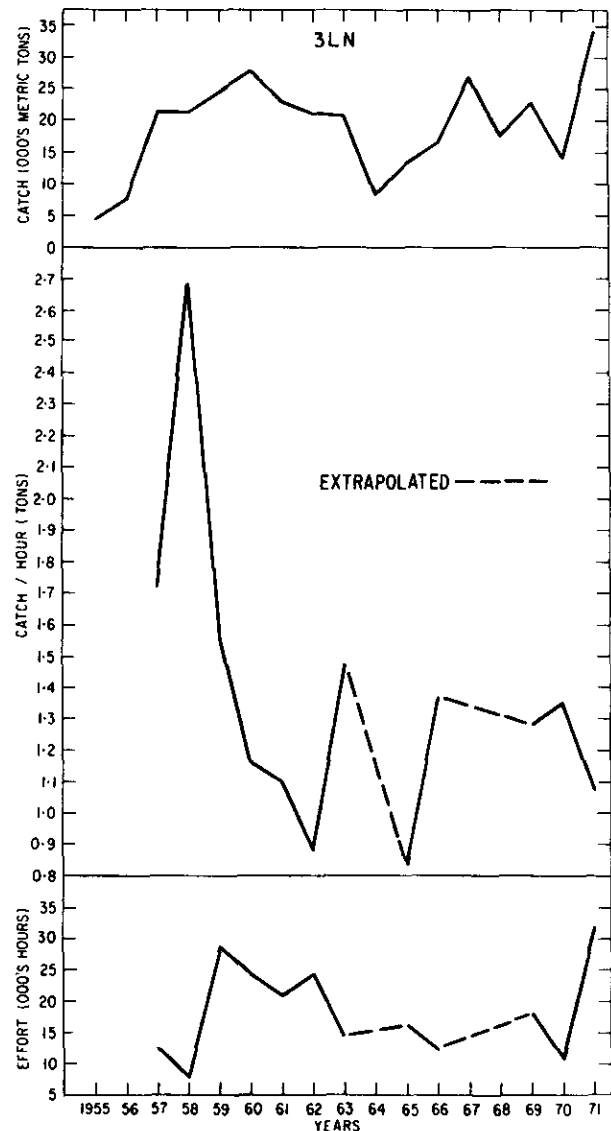


Fig. 3. Trends in nominal catches, effort and catches per unit effort in standard trawler units — USSR-Poland tonnage class 7 — for redfish in Div. 3LN during 1955-71.

TABLE 1. Nominal catches (metric tons) of redfish by country, from ICNAF Division 3P, 1955-71.

Year	Can (M&Q)	Can (N)	Fr (St. P&M)	Fr (M)	FRG	Japan	Poland	Spain	UK	USA	USSR	Non-mem	Total	Standard catch/hr (kg)	Standardized effort (hrs fished)
1955	393	2,975	—	—	—	—	—	—	—	1,323	—	—	4,691	996	4,856
1956	100	2,715	—	—	—	—	—	—	—	460	—	—	3,275	1,020	3,211
1957	147	2,023	—	—	2	—	—	—	—	215	—	—	2,387	998	2,392
1958	226	3,093	—	—	8	—	—	—	—	183	—	—	3,510	911	3,853
1959	235	2,571	—	—	—	—	—	—	2	883	83	—	3,774	733	5,149
1960	1,789	4,720	67	—	—	—	—	—	5	2,644	—	—	9,225	573	16,099
1961	1,256	7,877	266	—	—	—	—	—	1	376	—	—	9,776	611	16,000
1962	838	8,698	498	—	—	—	—	—	4	3,400	1	—	13,439	512	26,248
1963	349	12,019	323	—	—	—	2	—	5	1,048	1	—	13,747	682	20,157
1964	104	12,807	599	—	—	—	—	—	24	228	45	—	13,807	692	19,952
1965	329	17,122	779	6	12	—	—	—	11	474	—	—	18,733	905	20,699
1966	2,133	15,984	1,758	9	—	—	—	—	16	209	759	—	20,868	874	23,876
1967	548	12,038	1,583	—	—	—	117	—	7	125	1,216	16,357	31,991	804	41,034
1968	226	6,695	984	—	—	—	—	—	—	196	3,939	1,844	13,884	780	17,800
1969	387	8,214	638	—	—	—	780	—	—	23	22,009	—	32,051	736	43,548
1970	463	10,304	1,225	—	—	937	154	34	—	—	24,153	—	37,270	707	52,716
1971	242	5,284	1,404	—	—	2,466	58	—	—	—	18,046	—	27,500	619	44,426
Totals	9,765	135,139	10,124	15	22	3,403	1,111	34	75	11,787	70,252	18,201	259,928	—	—

TABLE 2. Nominal catches (metric tons) of redfish by country, from ICNAF Division 3O, 1955-71.

Year	Can (M&Q)	Can (N)	Fr (St. P&M)	Fr	GDR	Japan	Poland	Rom	UK	USA	USSR	Non-mem	Total	Standard catch/hr (kg)	Standardized effort (hrs fished)
1955	274	68	—	—	—	—	—	—	—	8,080	—	—	8,422	—	—
1956	401	50	—	—	—	—	—	—	—	5,564	—	—	6,015	—	—
1957	238	78	—	—	—	—	—	—	—	2,031	—	—	2,347	—	—
1958	246	1,786	—	—	2	—	—	—	—	4,037	—	—	6,071	1,303	4,659
1959	745	963	—	—	—	—	—	—	2	7,230	328	—	9,268	1,092	8,487
1960	93	97	30	—	—	—	—	—	1	4,609	200	—	5,030	—	—
1961	855	142	147	—	—	—	—	—	10	7,704	2,536	—	11,394	936	12,173
1962	380	666	285	—	—	—	—	—	—	325	5,901	—	7,557	793	9,530
1963	352	1,803	549	—	—	25	—	—	2	2,881	3,568	—	9,180	576	15,938
1964	316	1,004	260	—	—	—	—	—	3	1,675	12,786	—	16,044	514	31,214
1965	13	190	106	—	—	—	—	—	3	19,300	19,300	—	19,612	418	46,919
1966	9	98	41	—	—	452	—	—	5	14,667	14,667	26	15,305	825	18,552
1967	128	517	210	—	—	1	—	—	23	17,707	17,707	451	19,037	659	28,888
1968	—	52	6	—	—	—	—	—	—	6,364	6,364	—	6,424	—	—
1969	26	160	3	—	—	345	—	—	—	15,344	15,344	—	15,878	1,003	15,831
1970	190	98	—	—	—	51	—	58	—	12,795	12,795	—	13,192	787	16,762
1971	136	29	2	50	1,132	225	2	—	—	18,216	18,216	—	19,792	710	27,876
Totals	4,402	7,801	1,639	52	1,183	1,048	60	49	44,145	129,712	70,252	477	190,568	—	—

TABLE 3. Nominal catches (metric tons) of redfish by country, from ICNAF Divisions 3LN, 1955-71.

Year	Can		Fr	Fr (M)	FRG	GDR	Ice	Ita	Japan	Poland	Rom	Sp	UK	USA	USSR	Non-mem	Total	Standardized catch/hr (kg)	Standardized effort (hrs fished)
	(M&Q)	(N)																	
1955	96	263	—	—	—	—	—	—	—	—	—	—	—	4003	—	—	4,362	—	—
1956	102	176	—	—	—	—	—	—	—	—	—	—	3	7,226	—	—	7,507	—	—
1957	41	1,275	—	—	—	—	—	—	—	—	—	—	33	2,502	17,232	—	21,083	1,721	12,250
1958	300	1,863	—	—	—	—	—	—	—	—	—	—	—	5,959	12,947	—	21,069	2,686	7,844
1959	317	1,465	—	—	8,794	843	3,585	—	—	—	—	—	20	8,370	21,191	—	44,585	1,560	28,580
1960	384	1,994	156	—	4,837	—	853	2	—	—	—	—	526	7,978	9,832	1,448	28,010	1,160	24,147
1961	329	2,412	434	—	3,552	—	93	—	—	1,983	—	—	114	8,623	5,635	—	23,175	1,104	20,992
1962	889	5,973	152	—	134	—	—	—	—	2,229	—	—	107	10,530	1,420	—	21,434	886	24,192
1963	199	4,556	231	—	12	—	—	—	—	1,534	—	—	66	8,169	6,330	—	21,097	1,475	14,303
1964	139	1,224	86	—	199	—	3	—	—	704	—	—	73	2,791	2,885	—	8,104	—	—
1965	362	2,542	107	—	1,852	—	—	—	—	1,198	—	—	134	298	7,000	—	13,493	832	16,218
1966	106	1,352	191	6	143	—	292	—	—	2,710	—	—	57	131	6,133	5,853	16,974	1,368	12,408
1967	81	361	152	12	68	—	—	—	—	4,523	—	—	92	24	13,562	8,313	27,188	—	—
1968	116	546	100	22	—	—	—	—	—	241	—	—	10	—	14,795	1,783	17,613	—	—
1969	25	267	57	4	—	—	—	—	—	247	—	—	—	10	22,459	—	23,069	1,280	18,023
1970	80	332	7	—	—	—	—	—	—	67	220	—	—	—	13,111	—	14,388	1,352	10,642
1971	88	530	6	—	9	6,299	—	—	—	607	50	37	8	—	24,505	—	34,353	1,073	32,016
Totals	3,654	27,131	1,679	44	19,600	7,142	4,826	2	2,785	16,043	270	37	1,243	66,614	179,037	17,397	347,504	—	—

caught, were selected from the ICNAF Statistical Bulletins for the years 1955-71 and tabulated by country, vessel tonnage class and month for each year. Catches per hour fished were then calculated for each month.

### Division 3P

In Div. 3P Canada (Newfoundland) vessels of 151-500 tons fished most consistently and most heavily during 1955-68. Hence the Canada (Newfoundland) tonnage class 4 otter trawler hour was selected as the standard unit of effort for this period and total standard hours were estimated by dividing the catch per unit effort of Canada (Newfoundland) tonnage class 4 into the total catch of all countries. In more recent years (1969-71), USSR vessels of tonnage class 4 were most heavily involved in this fishery and for these years catch and effort data for USSR class 4 trawlers were used in conjunction with the Canada (Newfoundland) catch and effort data after conversion of USSR effort to the standard Canada (Newfoundland) otter trawler hour. This conversion factor was obtained by plotting catches per hour fished for USSR tonnage class 4 trawlers against catches per hour for Canada (Newfoundland) tonnage class 4 trawlers for each month for each area in which both fished at least 100 hr. A straight line drawn through the origin gave a conversion factor of 0.52 (Fig. 4). The average catch per hour (standard) in each year for 1969-71 was then obtained by dividing the redfish catches by these two vessel classes by the adjusted effort. The effort for redfish by all trawlers was estimated by dividing these values into the total yearly catches by all countries, resulting in estimates of total effort for the entire fleet in standard Canada (Newfoundland) tonnage class 4 trawler hours.

### Division 3O

Although Canada (Newfoundland) catches in most years represented only a small percentage of the total redfish catch in 3O, the Canada (Newfoundland) tonnage class 4 otter trawler was most consistently represented in the redfish effort data for 3O during 1955-71 and the catch per hour for this vessel class was used as the standard unit of effort for the whole period. USA vessels were heavily involved in the 3O redfish fishery during 1955-64 but they reported effort in days fished and no adequate conversion factor could be obtained to convert their catch per day to the catch per hour of Canada (Newfoundland) or USSR vessels. USSR tonnage class 4 and class 7 (> 1800 tons) otter trawlers did not fish concurrently in 3O to any large extent; in some years class 4 trawlers fished 3O and in other years class 7. In the absence of a conversion factor between these two vessel classes, it was not possible to use the USSR effort data as the standard.



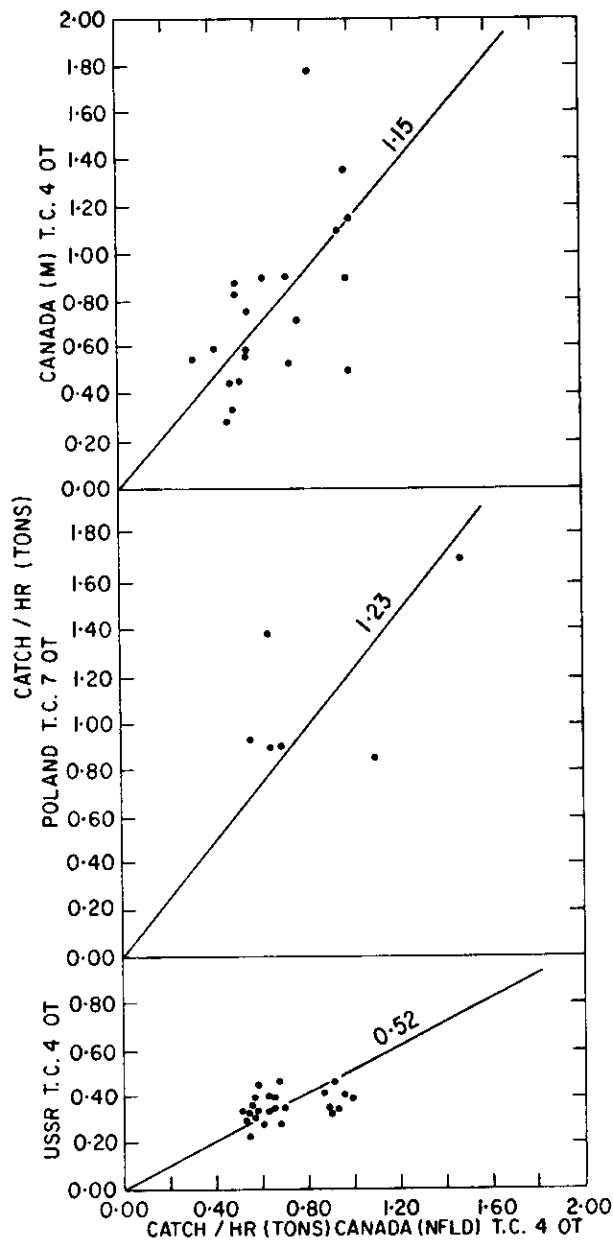


Fig. 4. Relation of redfish catches per hour fished by USSR tonnage class 4, Poland tonnage class 7, and Canada (Mainland) tonnage class 4 trawlers and the corresponding catches per hour of Canada (Nfld) tonnage class 4 trawlers.

For 1958, 1959, 1962 and 1963 the average catch per hour for Canada (Newfoundland) tonnage class 4 vessels was divided into the total yearly catches by all countries, resulting in estimates of total effort for the entire fleet in standard Canada (Newfoundland) class 4 trawler hours.

For the 2 years (1961 and 1967) in which Canada (Mainland) vessels were significantly represented in the

effort data, the effort was adjusted to that of Canada (Newfoundland) class 4 vessels by a conversion factor of 1.15 (Fig. 4). This was obtained by plotting catches per hour fished for Canada (Mainland) tonnage class 4 trawlers against catches per hour for similar Canada (Newfoundland) vessels for each month for each area in which both fished at least 100 hours and drawing a straight line through the origin. The standard catches per hour in 1961 and 1967 were then derived by dividing the redfish catches for both vessel classes by the adjusted effort. Total effort for these years was estimated by dividing these values into the total catches.

Effort for USSR tonnage class 4 trawlers in 1964 and 1965 was adjusted to that of Canada (Newfoundland) class 4 vessels by applying the conversion factor of 0.52 (Fig. 4) and the standard catch per hour was derived by dividing the annual catches by these vessels by the adjusted effort. During 1966 and 1969-71 USSR vessels of tonnage class 7 were represented most consistently in the effort data. However, there was insufficient comparative data to derive a factor for conversion to Canada (Newfoundland) tonnage class 4 vessels. In the absence of any evidence to the contrary it was assumed that USSR and Polish vessels of tonnage class 7 follow similar fishing practices and would have similar fishing efficiency. The redfish catches per hour fished for Polish tonnage class 7 trawlers were plotted against redfish catches per hour for Canada (Newfoundland) class 4 trawlers for each month for each area in which both fished at least 100 hr (Fig. 4). A straight line drawn through the origin gave a conversion factor of 1.23. The relatively low conversion factor is attributed to the different fishing practices of these vessels. Catches by the Canada (Newfoundland) vessels contained a very high percentage of redfish (about 90%) whereas the catches by the Polish (and USSR) vessels contained a significantly higher percentage of other groundfish species. A comparison of groundfish catches per hour would give a much higher conversion factor. For 1966 and 1969-71 redfish effort by tonnage class 7 USSR vessels was adjusted to that of Canada (Newfoundland) tonnage class 4 vessels by applying the conversion factor of 1.23. The standard catch per hour was derived by dividing the total redfish catches by these vessels by the adjusted effort.

The annual effort in 3O for redfish by all trawlers was estimated by dividing the yearly standard catches per hour into the total catches by all countries, resulting in estimates of total effort for redfish by the entire fleet in standard Canada (Newfoundland) tonnage class 4 trawler hours.

No effort could be estimated for 1955, 1956, 1957, 1960 and 1968 because of insufficient data.

### Division 3LN

USSR and Polish vessels of tonnage class 7 were most consistently represented in the effort data for 1957-71. In the absence of adequate data to provide a conversion factor, it was assumed that these vessels are similar in effective fishing intensity as indicated by the analyses of Brown *et al.* (1973) for Subarea 5 and Statistical Area 6. The standard unit of effort selected was the USSR-Polish tonnage class 7 otter trawler hour. The effort for redfish by all trawlers was estimated by dividing the standard catch per hour by all countries, resulting in estimates of total effort for redfish in standard USSR-Polish tonnage class 7 otter trawler hours. No effort could be estimated for 1955, 1956, 1964, 1967 and 1968 because of insufficient data.

### Trends in Effort and Catches Per Unit Effort

#### Division 3P

Total effort was less than 5,000 standardized hours (Newfoundland tonnage class 4) during 1955-58, increased fairly sharply from about 5,000 hr in 1959 to

more than 25,000 hr in 1962, remained relatively steady (about 20,000 hr) from 1963 to 1965 but increased rather sharply from 1966 to 1970, with the exception of 1968 when effort decreased to less than 20,000 hr (Fig. 1). Catch per hour was relatively high during 1955-58 (.91 to 1.0 tons), decreased from .74 tons in 1959 to about .5 tons in 1962, increased sharply to .9 tons in 1965 and then declined gradually to .62 tons in 1971.

#### Division 3O

Effort was low from 1958 to 1962 (between 4,000 and 12,000 hr), increased sharply to 47,000 hr in 1965, decreased to about 18,000 hr in 1966 and subsequently fluctuated between 15,000 and 30,000 hr (Fig. 2). Standard catch per hour values declined sharply from 1.3 tons in 1958 to about .4 tons in 1965, then increased to 1.0 tons in 1969 and subsequently declined to about .7 tons in 1971.

#### Divisions 3LN

Effort was relatively low in 1957 and 1958 (approximately 12,000 and 8,000 hr), increased sharply to 28,500 hr in 1959 (standardized to USSR-Polish tonnage class 7 vessels), subsequently decreased to less than

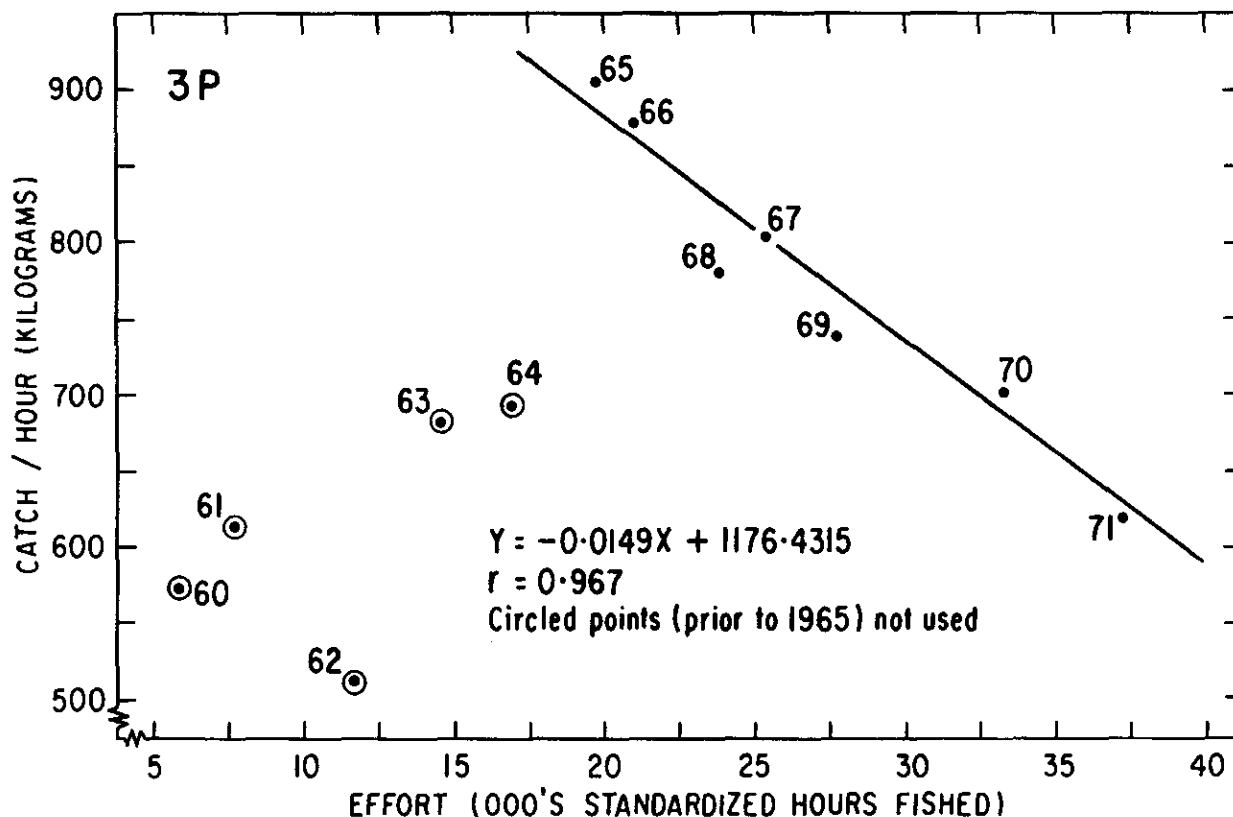


Fig. 5. Relation between standardized catch per hour and mean effort (6-year running average) for Div. 3P redfish.

15,000 hr in 1963, apparently fluctuated between 12,000 and 18,000 hr from 1963 to 1970, then increased sharply to a high of 32,000 hr in 1971 (Fig. 3). Catch per hour fluctuated irregularly during 1957-71.

### Yield-Effort Relationship

The Schaefer yield model (Schaefer, 1954) was used to derive estimates of maximum sustainable yield (MSY) from these catch and fishing effort data. The Schaefer model assumes logistic population growth and symmetric yield curves with the maximum sustainable yield value occurring at 50% of the maximum stock size. Curves fitted in this manner supposedly represent the equilibrium or long-term average expected yields. Gulland (1961) and Brown *et al.* (1973) have pointed out that, when there are large and consistent changes in fishing effort, a direct plot of catch per unit effort against effort will not give the relation to be expected under stable conditions. In such situations the catch per unit effort in any year will depend not only on the effort in that year but on the effort in as many preceding years as the oldest fish in the stock has been vulnerable to fishing (Gulland, 1961). Gulland suggested a method of averaging effort over the mean number of years that a year-class contributes significantly to the catch.

A given year-class of redfish contributes significantly to commercial catches over many years, the duration of its contribution being dependent upon the intensity of commercial fishing and variations in recruitment. However, the catch per unit effort in any year depends mainly upon the effort in most recent years, to which most of the fish in the stock have been exposed (Gulland, 1961). To take account of this effect, running averages of total effort were made over 6-year periods (the previous 5 years and year *i*) and the catch per unit effort values for each year were plotted against the 6-year running averages of effort (Fig. 5-7).

Least squares linear regressions relating catch per hour to mean effort were computed for Div. 3P and 3LN redfish. The standardized catch per unit effort values for 3P indicate an increase in redfish abundance in that area during the mid-1960's while effort was relatively steady. It is possible that a number of good year-classes recruited to the fishery during this period. Because of this dramatic change in catch per unit effort values, only the 1965 to 1971 data were used for fitting the 3P regression line.

The parameters of the linear regressions of catch per unit effort against mean effort for Div. 3P and 3LN were converted to those of the equilibrium yield versus effort parabolas which are depicted in Fig. 8-9. The estimates of maximum sustainable yields from the Schaefer model are approximately 23,000 metric tons for Div. 3P redfish and approximately 20,000 tons for Div. 3LN redfish. Catches

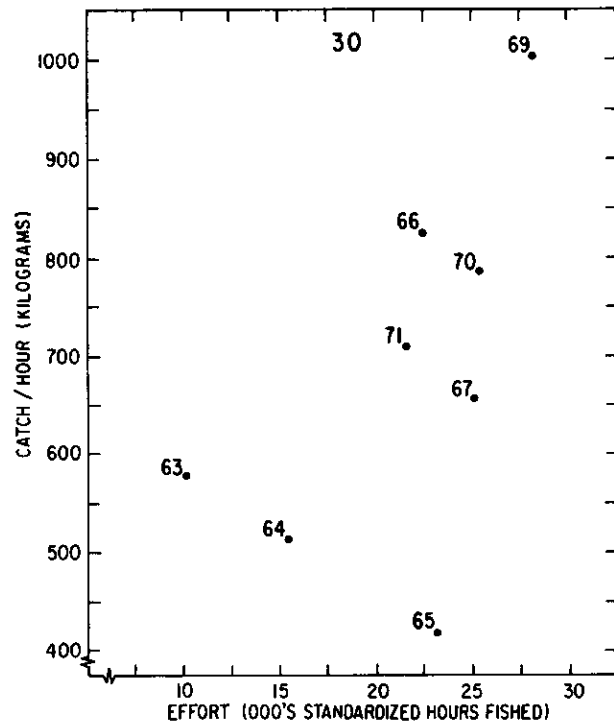


Fig. 6. Relation between standardized catch per hour and mean effort (6-year running average) for Div. 3O redfish.

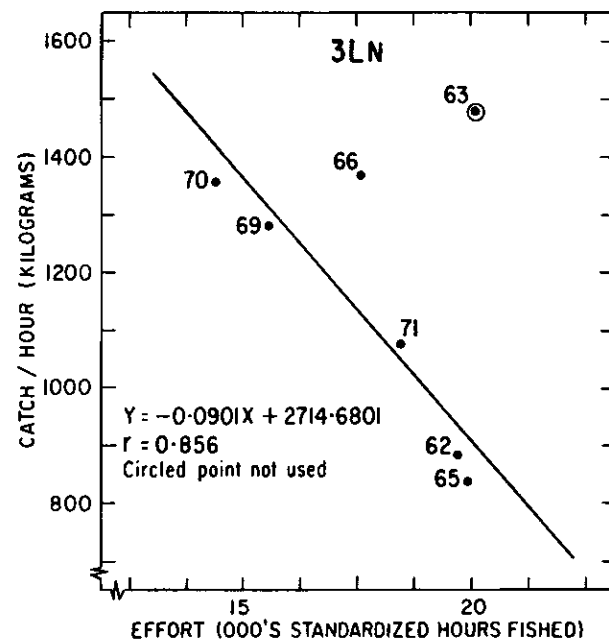


Fig. 7. Relation between standardized catch per hour and mean effort (6-year running average) for Div. 3LN redfish.

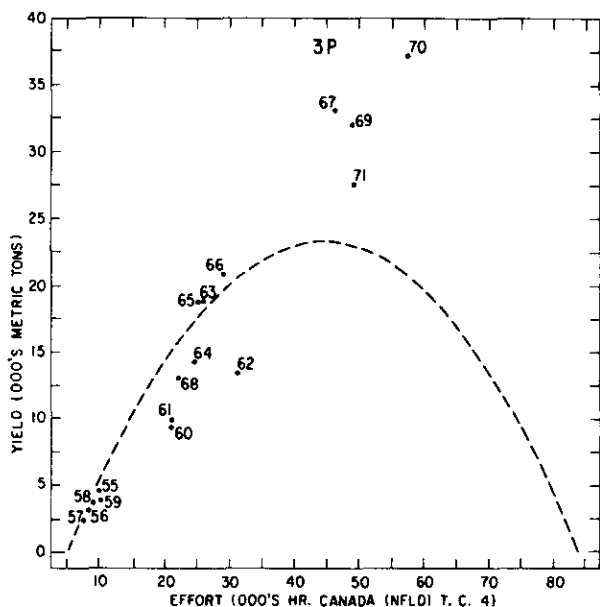


Fig. 8. Yield curve derived from the catch per unit effort/effort relation for Div. 3P redfish.

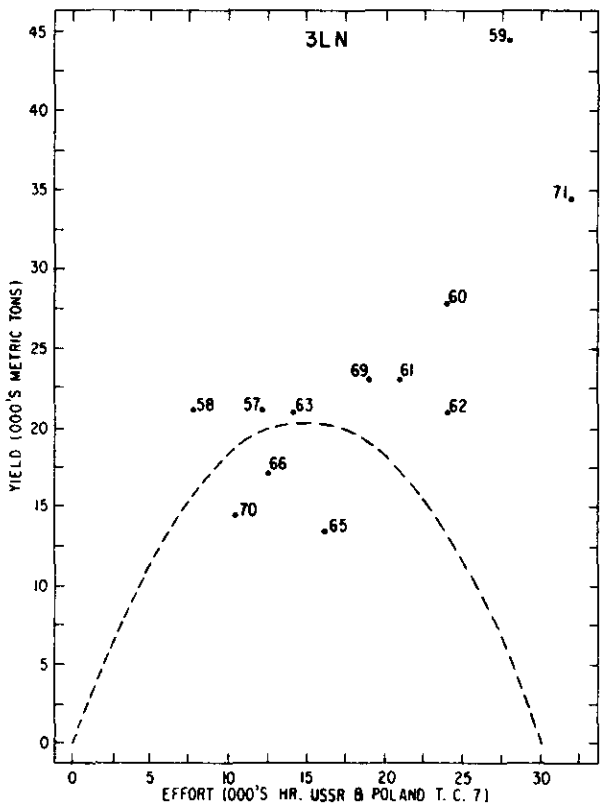


Fig. 9. Yield curve derived from the catch per unit effort/effort relation for Div. 3LN redfish.

of redfish in 3P exceeded the MSY level in 1967 and during 1969-71. Catches of redfish in 3LN were above the MSY level during 1959-62 and in 1969 and 1971.

There was no consistent pattern to the catch per unit effort-mean effort relation for Div. 3O (Fig. 6). Estimated standard catches per hour were relatively high during recent years despite increased mean effort. An estimate of the maximum sustainable yield for the redfish stock in Div. 3O was obtained by a simplified application of the Schaefer model. An equilibrium relationship between fishing effort in each year and catch per unit effort was determined by fitting a regression line by the least squares method to the catch per hour versus standardized hours fished for the years 1959-71 (Fig. 10). The equilibrium catch-effort relationship is depicted in Fig. 11. A maximum sustainable yield of approximately 19,000 tons for Div. 3O redfish was derived by this method but this is considered to be an over-estimate since this simplified application of the Schaefer model does not adjust for rapid changes in fishing effort and marked fluctuations in year-class strength.

## Discussion

The estimates of maximum sustainable yield presented here must be regarded as preliminary. The catch and effort data from which the estimates were derived are far from satisfactory. Furthermore, yield is greatly affected by recruitment and we have no real measures of recruitment for any of the areas considered here. A cursory examination of commercial length frequencies obtained from ICNAF Sampling Yearbooks for the period under consideration (Fig. 12-14) indicates that recruitment has been variable in these areas, more so in Div. 3P than on the Grand Bank. Recruitment in Div. 3P is assumed to be higher during 1965-71 than during the 1959-64 period. For this reason only the 1965-71 data have been considered when deriving the equilibrium yield curve for 3P redfish. A recent research cruise to Div. 3P in February of 1973, utilizing a lined otter trawl, revealed a predominance of 20-24 cm redfish (Fig. 15). Although we have no quantitative measures of recruitment, it appears that another relatively good year-class (possibly 1966) will soon recruit to the commercial fishery in 3P.

Another source of error in the maximum sustainable yield estimates derived in this analysis is the occurrence of diurnal variation in availability of redfish to the otter-trawl gear, a phenomenon well documented by Steele (1957), Konstantinov and Scherbino (1958), Templeman (1959), Beamish (1966) and Sandeman (1969b). The degree to which this pronounced diurnal vertical migration of redfish will bias attempts to use catch per unit effort by otter trawl as indices of abundance is not known. The recent switch to exploitation by midwater trawlers in the Gulf of

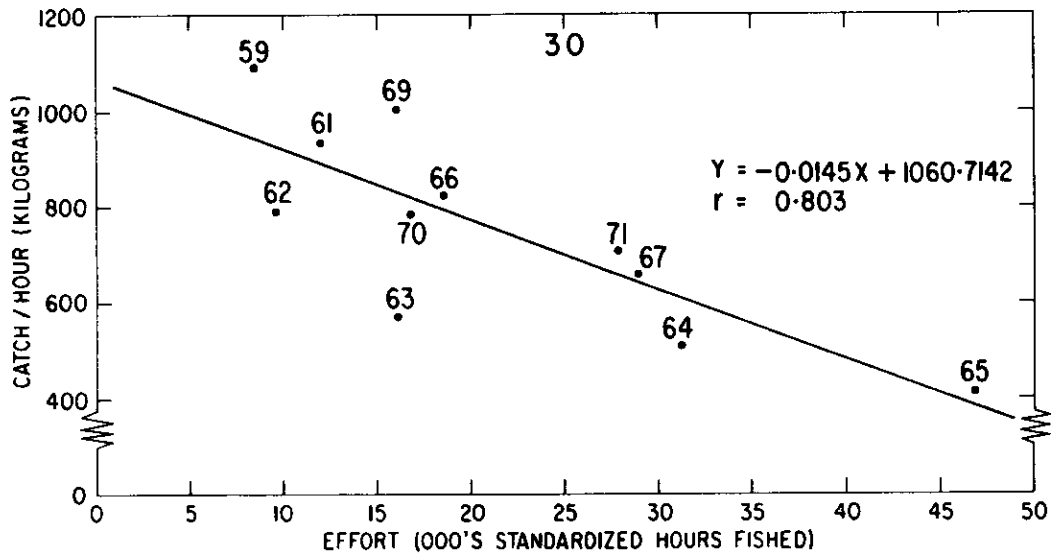


Fig. 10. Relation between standardized catch per hour and standardized hours fished in each year for Div. 3O redfish.

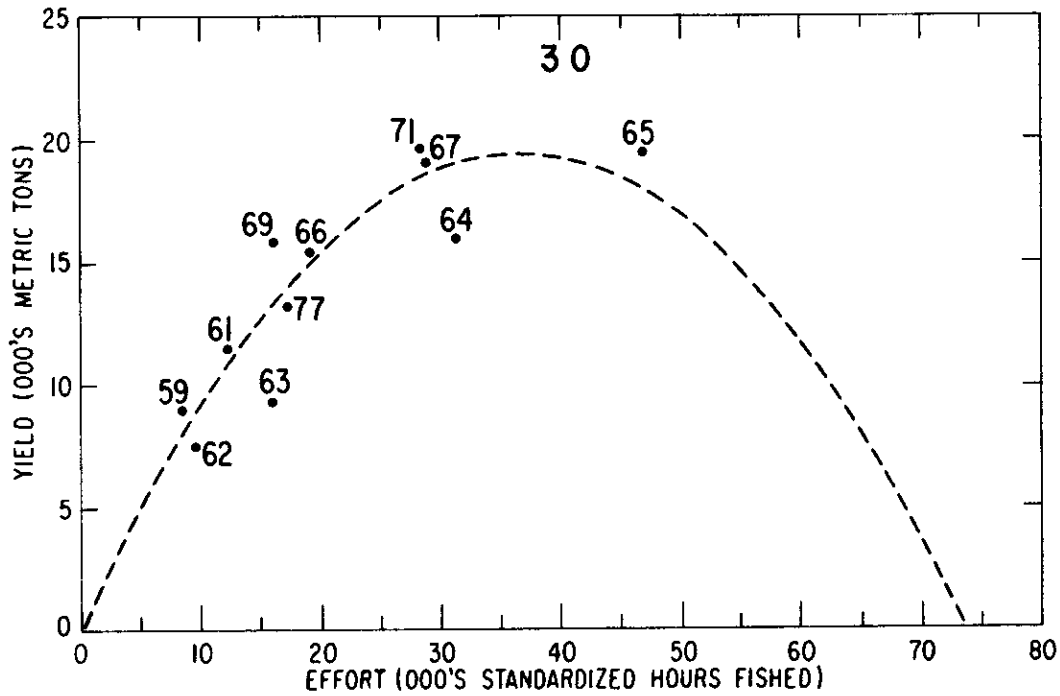


Fig. 11. Yield curve derived from the catch per unit effort/effort relation (Fig. 10) for Div. 3O redfish.

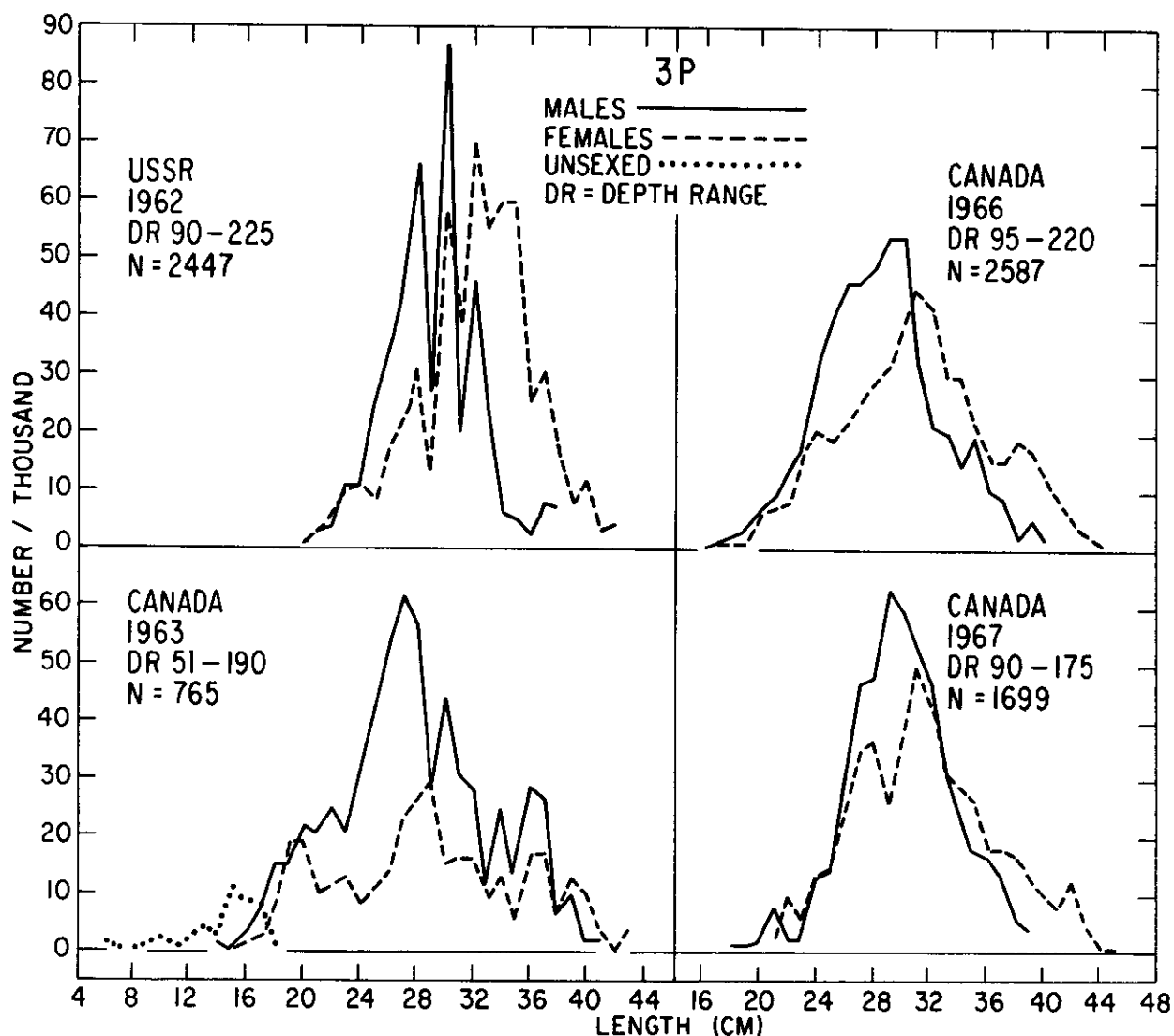


Fig. 12. Commercial otter trawl length frequencies for Div. 3P redfish.

St. Lawrence has resulted in greatly increased catches per unit of effort. In order to utilize otter trawl catch per unit of effort data to estimate maximum sustainable yields, it is necessary to assume that all redfish in a stock, although exhibiting diurnal variation in availability, have, on the average, an equal probability of capture by the bottom gear.

Despite these important qualifications it appears that the recent levels of redfish catches in Div. 3P and 3LN and

possibly 3O are above the maximum sustainable yield level. An increase in fishing pressure on redfish in these areas, as a result of diversion of the mobile fleets when quotas for regulated species become filled, would seem inadvisable. Catch limitations are required to prevent such an expansion until better knowledge of the effects of the fisheries on these redfish stocks becomes available. Previous experience has indicated that redfish stocks are very slow in rebuilding after a period of intense exploitation, e.g. Gulf of Maine (Kelly *et al.*, 1973).

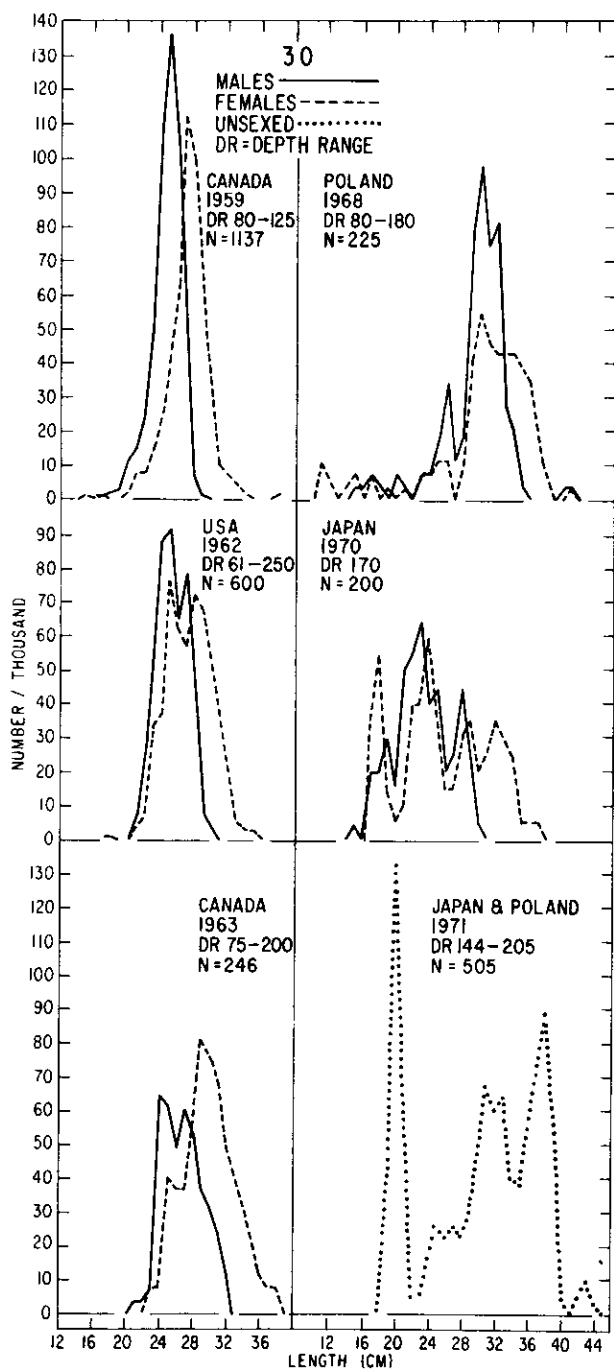


Fig. 13. Commercial otter trawl length frequencies for Div. 3O redfish.

It should be noted that levels of sampling of the commercial redfish catches in recent years have been inadequate. In order for meaningful assessments to be performed, more adequate length and age sampling of the commercial catches must be implemented.

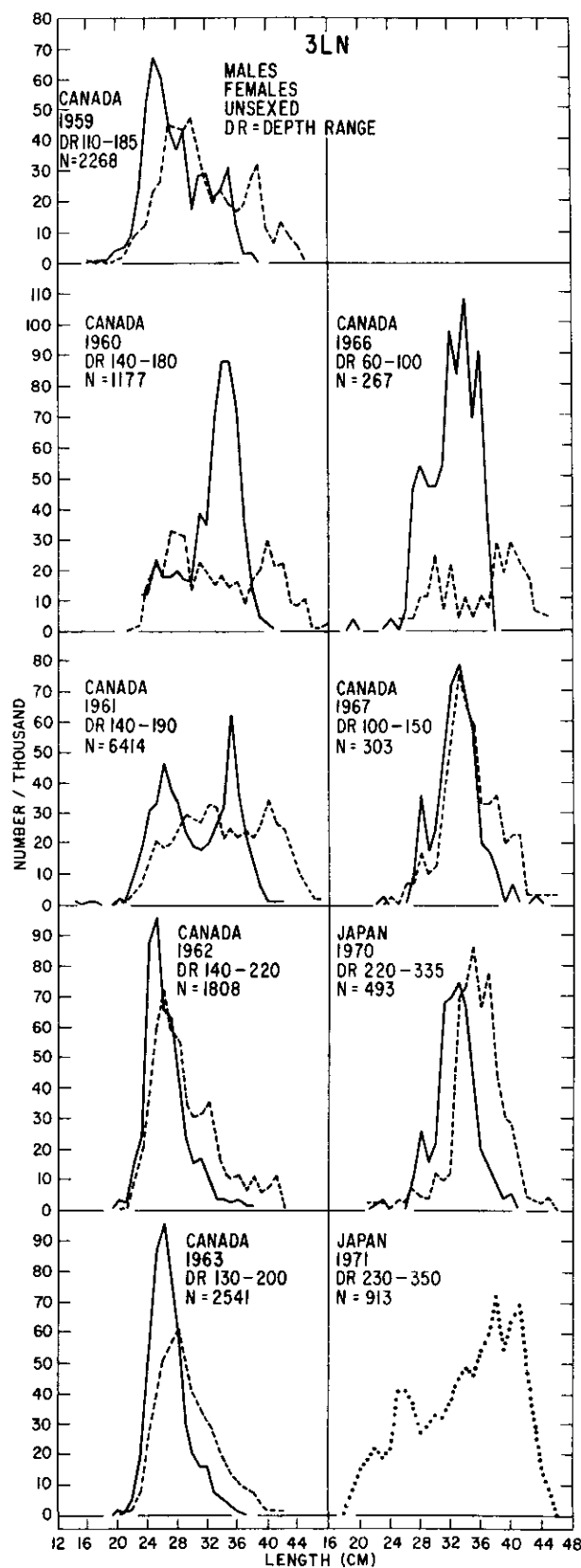


Fig. 14. Commercial otter trawl length frequencies for Div. 3LN redfish.

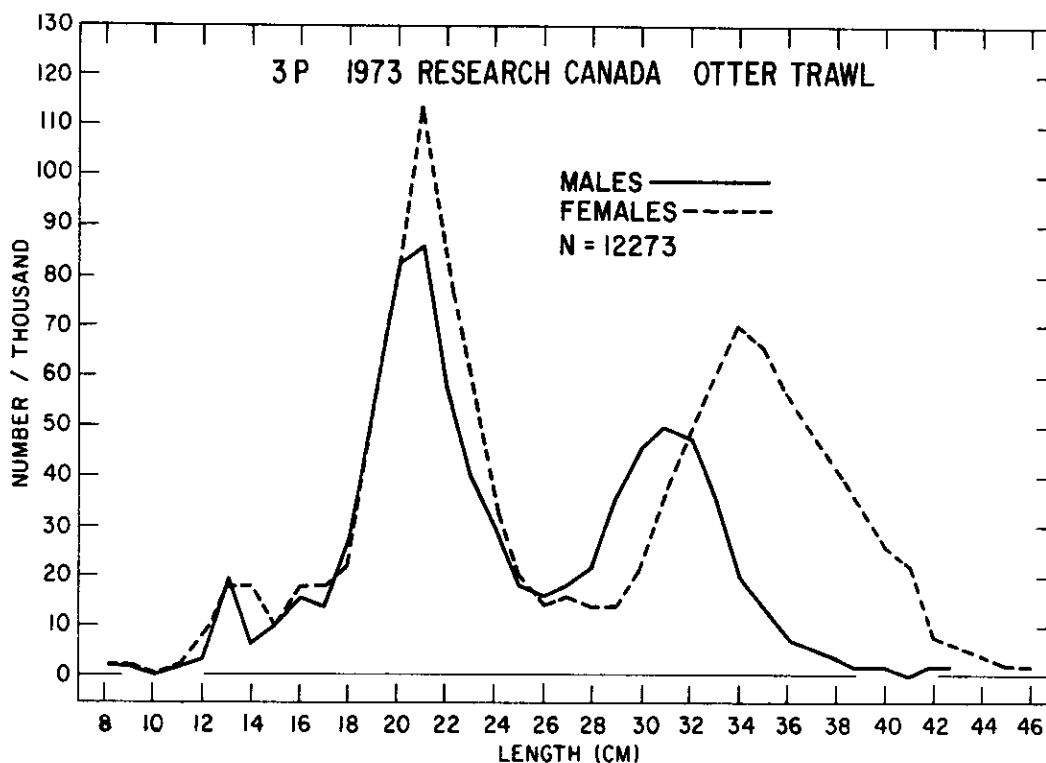


Fig. 15. Canada (Nfld) 1973 research length frequency for Div. 3P redfish.

### Acknowledgments

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# Sources of Error in Catch and Effort Quota Regulations with Particular Reference to Variations in the Catchability Coefficient

J. G. Pope<sup>1</sup> and D. J. Garrod<sup>1</sup>

## Introduction

Fishery management regimes have a number of possible objectives but whichever is chosen it involves the control of fishing mortality on all or part of the stock(s) in question. At the present time the International Commission for the Northwest Atlantic Fisheries (ICNAF) is attempting to control fishing mortality on a large number of resources in its area by a system of catch quotas and, in respect of particular problems of regulating mixed fisheries, it has been further suggested that a fishing effort regulation might also be applied.

The management scheme appropriate to these aims will be guided by scientific assessments of the resources but these are necessarily subject to error and, in deciding whether to regulate fishing mortality by effort control, or catch control, or both together, it is desirable to know the relative importance of the errors involved in one or the other system. Assessments of many of the stocks concerned are as yet incomplete and the variability of parameters contributing to the effect of fishing effort, catch and population size is virtually unknown. Necessarily, therefore, this paper cannot examine the effect of errors in an actual management scheme but it seeks to provide a general framework to investigate their effects. It will be seen, from the theoretical considerations of the following two sections, that scientific errors in the catch quota regulations devolve entirely from inaccuracies in the estimation of the present stock size and, owing to recruitment, the increment to stock size in the immediate future. Once established, however, the catch will represent a specified fishing mortality. Regulation of fishing mortality by the control of fishing effort introduces an error component dependent on the

variation in the relationship between fishing effort and the mortality it generates, i.e. the catchability coefficient, the variation in which is examined for selected fisheries by selected fleets. This variation may also have an implication to the efficiency of a regulation, depending on the size of individual national allocations, and, if a fishing effort regulation is used in conjunction with a catch quota, it has implications to the probability of fulfilling simultaneously the two quotas under which a fleet or vessel is operating.

The considerations dealt with in this paper are not exhaustive, but rather they serve as an introduction to a complex subject and to indicate the scale of errors that might be involved in this aspect of the management schemes currently being implemented.

## Sources of Inaccuracy

Errors in assessments may be classified into two types. The first type are biases in sampling techniques and parameters, which tend to give results which deviate systematically from the desired objectives. The second type are random errors in sampling and estimates of parameters. These, while less often resulting in the choice of incorrect objectives, tend to make it impossible to achieve precisely a stated objective in a given year.

### Causes and effect of biases

Biases in sampling schemes and estimates of stock parameters are caused mostly by improper sampling but

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they can also arise as a result of once-only assessment of particular parameters. Thus, for example, the natural mortality of a fish stock is often estimated by forming a regression of the yearly estimates of the total mortality acting on the stock against the yearly estimates of fishing effort deployed on the species. An extrapolation of the regression line to the point that corresponds to zero fishing effort gives a value of total mortality that is an estimate of the natural mortality ( $M$ ) from the available data. In practice, however, this may well be too high or too low. Indeed Ricker (1973) suggests that  $M$  estimated in this way has a bias upwards. Since an error in the estimate of the natural mortality of a stock will lead to an error in the estimated form of the yield curve it may well result in schemes of management which are designed to achieve an objective which is in fact incorrect. This can be illustrated very simply. Halliday (1972) developed three possible yield curves for the Eastern Scotian Shelf cod stock complex. These three yield curves were calculated under the alternative assumptions that  $M$  was 0.1, 0.2 and 0.3, with the corresponding fishing mortalities associated with the maximum sustainable yield (MSY) of 0.3, 0.4 and 0.6 respectively. If it was assumed that  $M$  was 0.2 and, if the aim of management was to achieve the MSY, then the management objective would be to achieve a fishing mortality ( $F$ ) of about 0.4. If in fact the true value of  $M$  was 0.1, management action to generate  $F$  of 0.4 would produce an actual  $F$  of 0.5 which (because when  $M = 0.1$ ,  $F_{MSY} = 0.3$ ) would be 67% higher than the desired objective. If, alternatively, the true value of  $M$  was 0.3, then the level of fishing which would produce an apparent fishing mortality of 0.4 relative to the assumption that  $M$  was 0.2 would in fact produce a true fishing mortality of approximately 0.3; this true fishing mortality would be about 50% too small to achieve the MSY, which for an  $M$  of 0.3 occurs at a fishing mortality of approximately 0.6 (a bias in  $M$  produces an approximately equal but opposite bias in fishing mortality as calculated by Virtual Population Analysis; see Agger *et al.* 1971). Thus erroneous assumptions about natural mortality can generate errors in the ends of fisheries management (i.e. erroneous values of MSY).

Similar errors might well be introduced by biases in sampling schemes. The non-reporting of catches, assigning the catches to the wrong areas and the absence of length and age sampling for some groups of fish or the measuring and ageing of fish in some biased fashion might all lead to assessments of fisheries for which suggested management objectives differ substantially from the true optimum management scheme. The effects of biases in sampling schemes cannot be overcome without drastic improvement in the data base of assessment work and they underline the necessity for countries to substantially improve the quality and quantity of their sampling data.

### **Causes of random errors and their effects on management objectives**

Random errors in sampling methods and estimates of stock parameters are created by the process of sampling populations and catches for characteristics of length and age. This inevitably leads to random errors in estimates of these characteristics. Gulland (1955) examines the errors inherent in estimating age distribution from samples of catches. In addition to errors introduced as a result of sampling, some parameters may vary about their mean value from year to year in an apparently random fashion. An example of the random variation of a parameter may often be observed in the catchability coefficient ( $q$ ) which relates fishing effort ( $f$ ) to fishing mortality ( $F$ ), in a particular stock (i.e.  $F = qf$ ). In these circumstances a given level of fishing effort would produce a fishing mortality that varied from year to year. Therefore, a level of fishing effort designed to be compatible with the maximum sustainable yield might in fact produce a series of fishing mortalities which varied to a greater or lesser extent about the optimum level. While it has been shown by Pope (1972) and by Garrod (1973) that fluctuations about an optimum do not inevitably lead to a smaller average yield, large fluctuations might be embarrassing in that they could lead to periodic shortages and could conceivably do permanent damage to stocks by impairing their ability to produce adequate numbers of recruits. This might conceivably be the case for a stock with a steeply parabolic stock-recruitment relationship, as, for example, the curve developed by Herrington (1948) for the Georges Bank haddock stock. Thus, random variations are caused in estimates of parameters and estimates of stock by both the lack of precision of sampling regimes and by the natural variability of some parameters.

### **Errors in Catch Quotas and Effort Quotas**

Biases are by their nature difficult to establish since they are often the result of incomplete data. To some extent they may be studied by considering alternative possibilities and choosing courses of action that minimize the risks involved.

Random errors are more amenable to analysis but the error components depend on the frequency of adjustment of the management regime. Catch quotas, as currently envisaged, necessitate annual adjustment with reference to an estimate of the existing stock level. Effort quotas may be adjusted annually, in which case they will be influenced by errors in estimates of the reference stock. Alternatively, effort quotas may be set to approximate MSY over a longer period.

Basically, errors in catch quotas result from errors in estimates of the population size at the beginning of the

year in question. Incorrect estimates of weight at age and selection at age may also cause random errors but these effects are usually smaller than the effect of errors in population estimates.

If  $C_a$  is the weight of catch of fish aged  $a$  from a stock with  $P_a$  fish of that age, whose selection to the fishery is defined by  $S_a$ , and whose weight is  $W_a$ , then

$$C_a = P_a \frac{S_a \cdot F}{M + S_a \cdot F} \left( 1 - \exp\{-(S_a \cdot F + M)\} \right) W_a. \quad (1)$$

This may be simplified if  $S_a$  can be regarded as the proportion of the population ( $P_a$ ) available to capture as opposed to the proportion of the (fully recruited fish) fishing mortality ( $F$ ) that acts on the age-group. Thus,

$$C_a = A_a \cdot \frac{F}{Z} \left( 1 - \exp(-Z) \right), \quad (2)$$

where  $A_a = P_a \cdot S_a \cdot W_a$  is the exploitable biomass of fish aged  $a$ .

The catch quota ( $Q$ ) that will cause a certain fishing mortality ( $\hat{F}$ ) on the stock is given approximately by

$$Q \cong A \cdot \frac{\hat{F}}{Z} \left( 1 - \exp(-Z) \right), \quad (3)$$

where  $A = \sum_{1}^n A_a$  is the sum over all age-groups.

In practice the  $A_a$  can be separated into three components. If  $r$  is the age of first capture, fish for which  $a < r$  are young unexploited fish for which  $A_a = 0$ . Fish for which  $a = r$  are the recruits of the year, and the value of  $A_r$  cannot be determined from the results of previous years' catch and effort data. Fish for which  $a > r$  are fish exploited in previous years.

$A_r$  may be estimated in some cases by young fish surveys. In other cases, it may not be known and, for the purpose of setting catch quotas, the average value of  $A_r$  may have to be used or the value of  $A_r$  predicted by a stock-recruitment relationship. Clearly this can lead to large errors in the catch quota, if  $A_r$  is a large proportion of  $A$  and if the year-to-year variation in recruitment to the stock is large.

Where  $a > r$  the  $A_r$ 's may be estimated in two main ways. The first of these is to use estimates of the catch at

age in the previous year together with the estimates of the fishing mortality (obtained from a knowledge of fishing effort), selectivity and natural mortality. The second method is to use the estimates of relative biomass obtained from yearly groundfish surveys to estimate the absolute abundance in the current year. Using the first method random errors occur in the total available biomass ( $A$ ) as a result of errors in the estimates of the numbers caught at each age in the previous year and the selectivity in the previous year. The error in selectivity is often small compared to errors in the other estimates and will be ignored for the purposes of this investigation in the interests of simplicity. If it can be assumed that the numbers caught at age have a fairly constant coefficient of variation (this is often the objective of sampling schemes), the errors in the estimate of fishing mortality and catch will induce errors in  $\sum_{a > r} A_a$  (the biomass of fish aged greater than the age of first capture, i.e.  $A - A_r$ ) such that,

$$\begin{aligned} \text{Var}(A - A_r) = & \left[ (A - A_r)^2 \left( \frac{\text{Var}(F)}{F^2} \right) \right] \\ & + \left[ \frac{(A - A_r)^2}{\theta} \left( \frac{\text{Var}(C)}{C^2} \right) \right] \end{aligned} \quad (4)$$

where  $\frac{\text{Var}(C)}{C^2}$  is the average value of this ratio for all ages,

and  $\theta$  is a factor which depends on the growth and mortality of the stock and the variability of its recruitment. The derivation of (4) is given in Annex A, where  $\theta$  is also explained.

Since  $A_r$  and  $A - A_r$  are statistically independent, then

$$\begin{aligned} \text{Var}(A) = & \left[ (A - A_r)^2 \left( \frac{\text{Var}(F)}{F^2} \right) \right] \\ & + \left[ \frac{(A - A_r)^2}{\theta} \left( \frac{\text{Var}(C)}{C^2} \right) \right] + \text{Var} A_r. \end{aligned} \quad (5)$$

From equation (3)

$$\text{Var}(Q) = \text{Var}(A) \left[ \frac{\hat{F}}{Z} \{1 - \exp(-Z)\} \right]^2. \quad (6)$$

which may be simplified to

$$\text{Var}(Q) = \text{Var}(A) (1 - \exp(-F))^2 \cdot \exp(-M), \quad (7)$$

using the basic assumption of cohort analysis (Pope 1972).

The error in the catch quota causes an error in the value of  $\hat{F}$  generated on the actual populations. This is given approximately by

$$\text{Var}(\hat{F}) \approx \frac{\text{Var}(Q)}{A^2} \left\{ \exp(2\hat{F} + M) \right\} \quad (8)$$

or using formulae (5) and (7) above

$$\begin{aligned} \text{Var}(\hat{F}) \approx & (1 - e^{-\hat{F}})^2 \cdot \frac{e^{2\hat{F}}}{A^2} \left[ \left\{ (A - A_r)^2 \cdot \frac{\text{Var}(F)}{F^2} \right\} \right. \\ & \left. + \left\{ \frac{(A - A_r)^2}{\theta} \cdot \frac{\text{Var}(C)}{C^2} \right\} + \text{Var}(A_r) \right]. \quad (9) \end{aligned}$$

If we let  $\frac{A - A_r}{A} = u$ , and  $\frac{A_r}{A} = v$ ,

$$\begin{aligned} \text{then } \frac{\text{Var}(\hat{F})}{F^2} \approx & e^{2\hat{F}} \left[ u^2 \left( \frac{\text{Var}(F)}{F^2} + \frac{\text{Var}(C)}{\theta \cdot C^2} \right) \right. \\ & \left. + v^2 \left( \frac{\text{Var}(A_r)}{A_r^2} \right) \right]. \quad (10) \end{aligned}$$

Thus, if  $\hat{F}$  is the level of fishing mortality associated with MSY, equation (10) gives the error associated with catch quota. By way of comparison the variance of fishing mortality ( $\hat{F}$ ), that would be achieved by an effort quota, is given by:

$$\frac{\text{Var}(\hat{F})}{F^2} = \frac{\text{Var}(q)}{q^2}, \quad (11)$$

where  $q$  is the catchability associated with the effort measure adopted in the quota. If this measure of effort is the same as that used to estimate the level of fishing mortality in the previous year in the estimation of the catch quota (presumably the best available measure), then:

$$\frac{\text{Var}(q)}{q^2} = \frac{\text{Var}(F)}{F^2}. \quad (12)$$

In this case it is likely that an effort quota would be more accurate than a catch quota. If however, the effort quota were based on some measure of effort which related less well to the fishing mortality of the stock in question, either through choice of unit or its generalization over a number of stocks, then the catch quota might well be the more accurate. For example, for a cod stock the best estimate of fishing effort might be Spanish trawler hours fishing specifically for cod, which might relate quite well to the fishing mortality, while overall days on ground for all species might hardly relate to the fishing mortality on cod at all. (See Annex B, Example 3.)

Equations (10) and (11) relate to the case where the object of stock management is to generate some specific level of  $\hat{F}$  (e.g. MSY). When the objective of management is the maintenance of some specific level of stock biomass ( $B$ ) in the following year, then, if a catch quota is used, a variance will be induced in  $B$  so that, where  $\hat{F}$  is the fishing mortality of the current year and  $F$  the fishing mortality in the previous year,

$$\begin{aligned} \frac{\text{Var}(B)}{B^2} \approx & e^{2\hat{F}} \left[ v^2 \left( \frac{\text{Var}(A_s)}{A_s^2} \right) \right. \\ & \left. + u^2 \left( \frac{\text{Var}(F)}{F^2} + \frac{\text{Var}(C)}{\theta \cdot C^2} \right) \right]. \quad (13) \end{aligned}$$

When an effort quota is used,

$$\begin{aligned} \frac{\text{Var}(B)}{B^2} = & v^2 \left( \frac{\text{Var}(A_s)}{A_s^2} \right) \\ & + u^2 \left( \frac{\text{Var}(F)}{F^2} + \frac{\text{Var}(C)}{\theta \cdot C^2} \right) + \left( \frac{\text{Var}(q)}{q^2} \right) \hat{F}^2. \quad (14) \end{aligned}$$

This tends to mean that in an annually adjusted regime, such as is necessary to maintain a specified stock size, effort quotas have a less variable effect than catch quotas, but the greater precision of effort quotas is wholly dependent on there being an adequate relationship between fishing effort and fishing mortality.

Equation (4) is the expression for the variance of  $A - A_r$  when it is estimated from the previous year's catch and effort data. If the estimate of  $A - A_r$  was based on groundfish surveys, the variance of this estimate should be substituted for (4). The likely precision of estimates of available biomass are given by Grosslein (1971) and by Jones and Pope (1972). Methods of estimating the various variances are shown in the examples of Appendix B.

TABLE 1. Estimates of the catchability coefficient in various cod fisheries (F and G under "effort unit" refer to "days fished" and "days on grounds" respectively).

Stock	Country	Gear and tonn. class	Effort unit	Period	q	Standard deviation	Coeff. of variation
Arcto-Norwegian (I + IIB) <sup>1</sup>	UK	OT Steam	10 <sup>6</sup> hours	1950-68	0.53	0.11	20.7
		OT Motor	10 <sup>6</sup> hours	1951-68	0.53	0.14	26.5
	USSR	OT	10 <sup>6</sup> hours	1950-68	0.49	0.14	27.8
		FRG	OT	10 <sup>6</sup> days (F)	1955-61	9.26	7.11
Arcto-Norwegian (IIA) <sup>1</sup>	UK	OT Steam	10 <sup>6</sup> hours	1950-68	0.40	0.11	27.3
		OT Motor	10 <sup>6</sup> hours	1951-68	0.42	0.15	36.0
	Norway	Lofoten fishery	10 <sup>6</sup> men	1950-68	9.77	6.10	62.4*
	FRG	OT	10 <sup>6</sup> days (F)	1954-68	2.86	1.02	35.7
Iceland	UK	OT Steam	10 <sup>6</sup> hours	1960-68	0.23	0.051	22.11
		OT Motor	10 <sup>6</sup> hours	1960-68	0.16	0.025	15.54
Greenland (1A-1D) <sup>2</sup>	FRG	OT 501-900	10 <sup>6</sup> days (F)	1956-68	28.66	18.14	63.27*
		OT >901	10 <sup>6</sup> days (F)	1960-68	40.47	21.14	52.24*
	Portugal	OT 501-900	10 <sup>6</sup> hours	1956-68	2.05	1.03	50.30
		DV 501-900	10 <sup>6</sup> hours	1956-68	0.089	0.045	49.94
		DV >901	10 <sup>6</sup> hours	1956-68	0.088	0.038	42.83
Labrador (2G-3L) <sup>2</sup>	FRG	OT > 501	10 <sup>6</sup> days (F)	1961-68	15.74	9.46	60.13
		USSR	OT 901-1800	10 <sup>6</sup> days (G)	1961-68	5.77	3.01
	OT > 1800		10 <sup>6</sup> days (F)	1961-68	6.38	4.23	66.27
			10 <sup>6</sup> days (G)	1961-68	20.26	6.38	31.51
	Spain		OT 901-1800	10 <sup>6</sup> hours	1961-68	1.95	0.44
		10 <sup>6</sup> days (G)		1961-68	14.02	2.01	14.36
		PT 151-500	10 <sup>6</sup> days (F)	1961-68	16.13	2.32	14.38
			10 <sup>6</sup> hours	1961-68	1.21	0.16	13.39
			10 <sup>6</sup> days (G)	1961-68	9.49	3.59	37.77
			10 <sup>6</sup> days (F)	1961-68	11.29	4.13	36.61
	Portugal	OT 901-1800	10 <sup>6</sup> hours	1961-68	1.14	0.37	32.15
			10 <sup>6</sup> hours	1961-68	1.42	0.23	16.36
		DV < 500	10 <sup>6</sup> hours	1961-68	0.046	0.0065	14.20
		DV 501-900	10 <sup>6</sup> hours	1961-68	0.036	0.0068	18.75
DV 901-1800		10 <sup>6</sup> hours	1961-68	0.039	0.0166	42.10	

\*Includes trend with time.

<sup>1</sup>Statistical areas of ICES.

<sup>2</sup>ICNAF Divisions.

## Variation in the Catchability Coefficient

The formulation of potential errors set out above defines the importance of variations in the catchability coefficient in relation to regulation of fishing effort, which arise from variation in the fishing performance of vessels and biological variation in the availability of the stock. This Section examines their combined effect.

Virtual population estimates of fishing mortality (F) on fully recruited age-groups were taken from International Council for the Exploration of the Sea (ICES) and ICNAF publications and each mortality allocated to

component fishing fleets according to the ratio of the fleet catch to the total international catch. The estimated fishing mortality per fleet was then related to the recorded fishing activity of that fleet to provide an estimate of the catchability coefficient ( $F/f = q$ ), where both F and f have been measured independently. Strictly, the partitioned values of fishing mortality are not instantaneous coefficients but they may be used as such in considering the effect of a national fleet in relation to an annual quota.

Table 1 sets out for various fisheries and fleets the mean values of q, their standard deviations and coefficients of variation. Plots of q for individual years

are illustrated in Fig. 1. The following observations may be made. (a) For the Arcto-Norwegian cod, the yearly values of  $q$  for both UK and USSR vessels is remarkably consistent, although some differences between the fleets over time are indicated in Fig. 1A. For UK vessels the variation with time is similar in both major fisheries on this stock and neither relate very well to the trend in tonnage of UK vessels (Fig. 1D), which for these vessels is usually taken as an indicator of fishing power; this lack of correlation with tonnage indicates additional sources of variation in  $q$ . Estimates of  $q$  for trawlers of the Federal Republic of Germany (FRG) fishing Arcto-Norwegian cod vary more widely than estimates for the UK and USSR because of a smaller amount of fishing, with timing and fishery objectives which are rather more variable. The estimated  $q$  per Norwegian fisherman at Lofoten has shown a steady increase over time (Fig. 1C), but it is not clear how far this might be caused by increased fishing power per man or biological change.

(b) For West Greenland (ICNAF Divisions 1A to 1D), all estimates of  $q$  show a coefficient of variation close to

50%, but this contains variation due to the increase in  $q$  in recent years (Fig. 2A) which has been reported to ICNAF previously (Schumacher, 1970). Hitherto, the increase in  $q$  has been attributed to improved efficiency of trawler fleets concentrating activity at the most advantageous season for fishing. It is therefore of considerable interest that estimates of  $q$  for Portuguese dory vessels show the same trend (Fig. 2B). Dory effort measurements exclude increases in fishing power of the mother ship, and the stability of  $q$  for these same dory vessels fishing at Newfoundland indicates that the trend in  $q$  at Greenland is not caused by a trend in fishing power. The identical trend in all sets of data could result from systematic overestimate of the total fishing mortality, but the four-fold increase in  $q$  during the decade is too great to be entirely accounted for in this way, and one can only conclude that there has been a real change in the biological availability of the cod stock at Greenland in recent years.

(c) For Labrador (Divisions 2G to 3L), the trawler fleets of FRG and USSR (Fig. 2C) are relatively recent

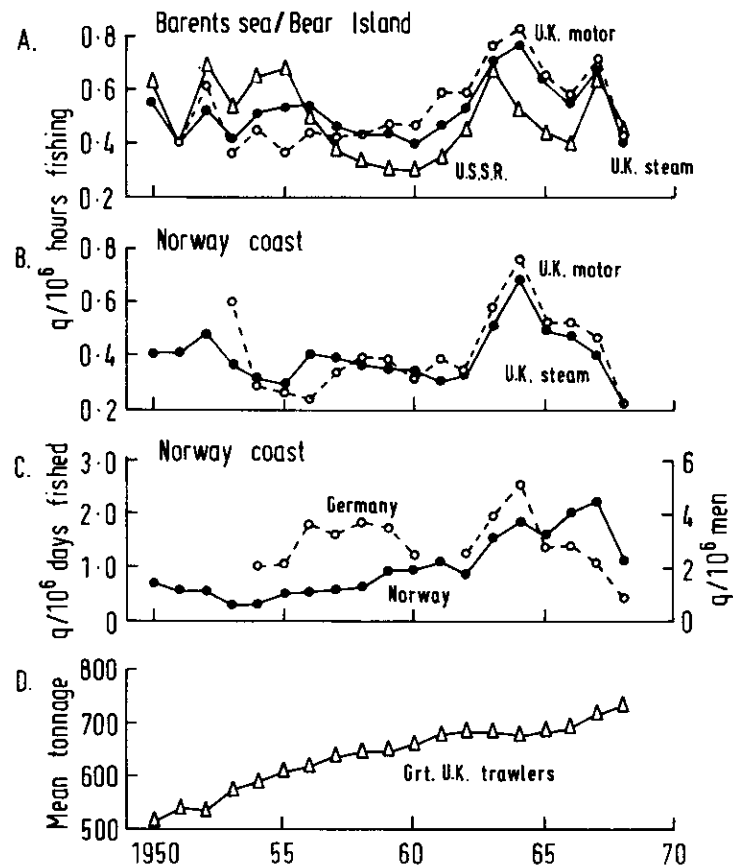


Fig. 1. Trends in the catchability coefficient with time for various national fleets fishing at the Northeast Arctic, together with the mean tonnage of UK trawlers.

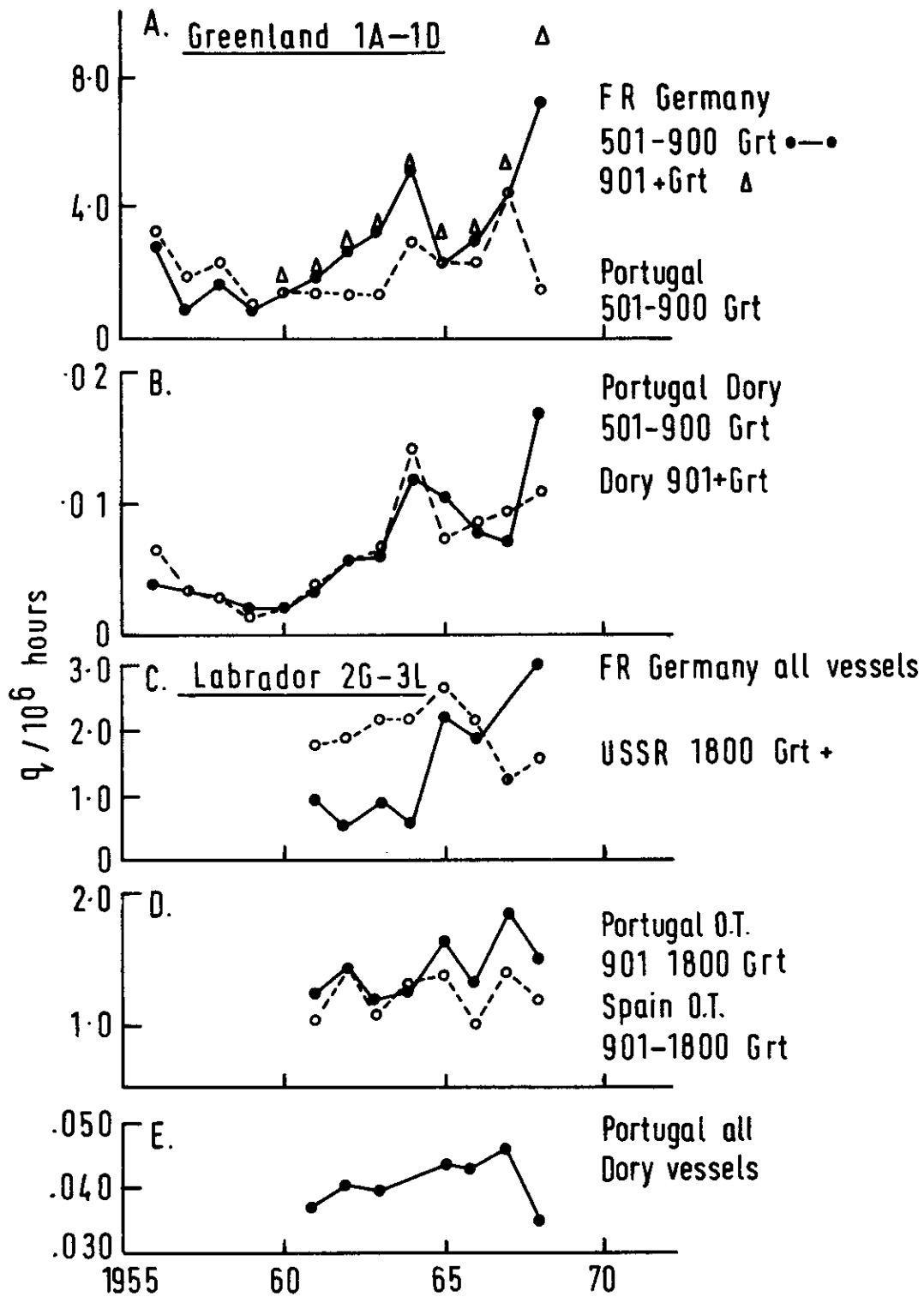


Fig. 2. Trends in the catchability coefficient with time for various national fleets fishing at West Greenland and at Labrador.

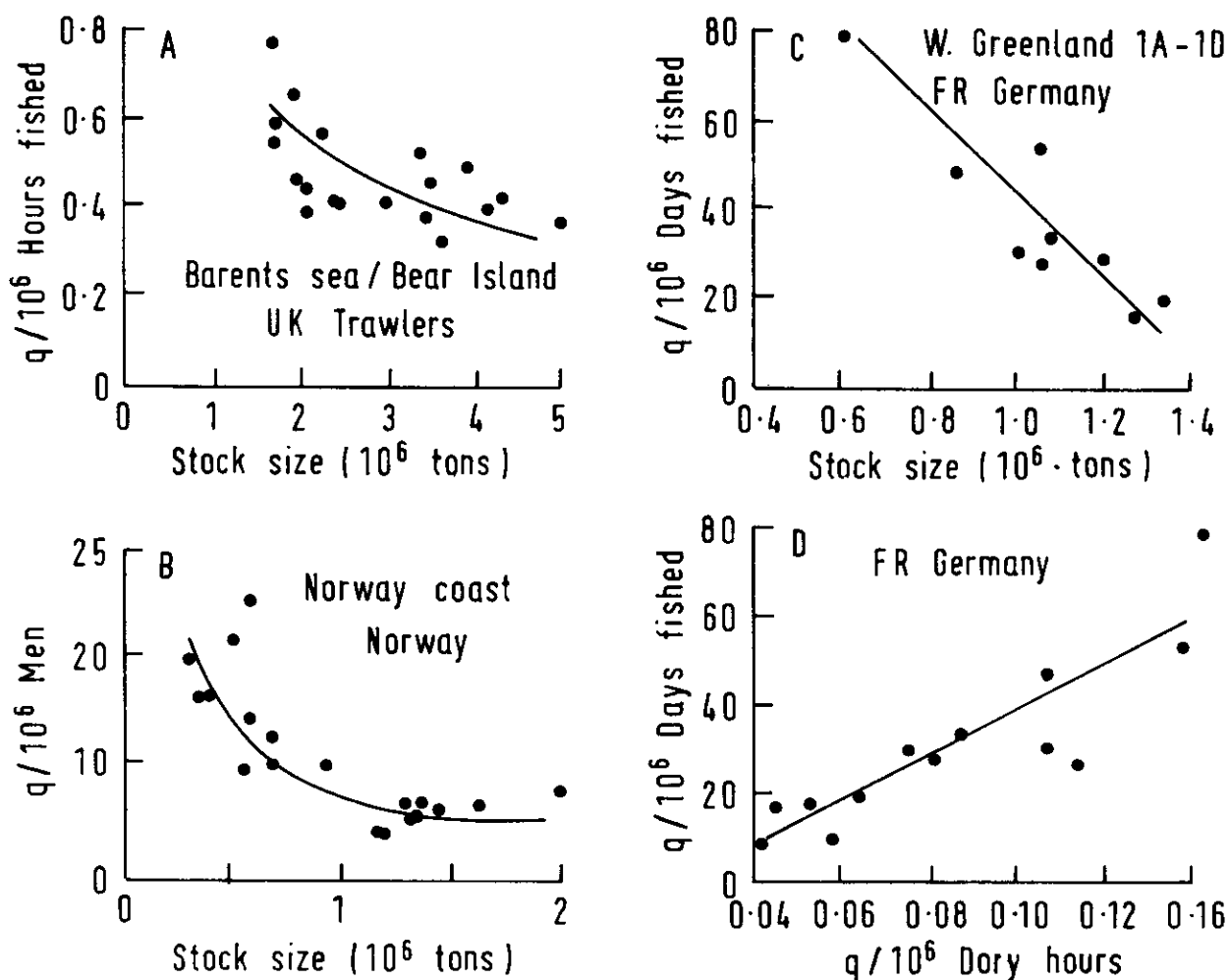


Fig. 3. A to C. The relationship between the catchability coefficient and the biomass of the stock at the Northeast Arctic and West Greenland. D. Correlation between catchability coefficient for otter trawlers of the Federal Republic of Germany and Portuguese dory vessels fishing at West Greenland.

entrants to this fishery compared to Spain and Portugal (Fig. 2D), and have other objectives besides cod. As a result, the coefficients of variation of the catchability for cod of the FRG and USSR fleets is considerably higher than that of Spain and Portugal. There is no clear trend in  $q$  with time for all fleets, and it is particularly interesting that there is no trend in  $q$  with respect to Portuguese dories which could parallel the increase at West Greenland referred to above.

The possibility of biological variation in  $q$  is taken further in Fig. 3 for those stocks which show evidence of trend in  $q$  with time. The estimates of catchability coefficient are plotted against estimated stock size. Trend lines have been fitted by eye only because too little is known to predict any form of relationship between the variables, but it is evident that the relationship is inverse, with catchability increasing as

stock decreases. In Fig. 3 the data for Arcto-Norwegian cod cover a period of decrease and recovery of stock size, so that the relationship cannot be an entirely spurious effect of increased fishing power coinciding with a time series of decreasing stock size. Likewise, for West Greenland cod the correlation between  $q$  for FRG trawlers and  $q$  for Portuguese dories shown in Fig. 3D would suggest that fishing power changes are not the source of trend in  $q$  with respect to FRG trawlers shown in Fig. 3C.

There is therefore evidence that the catchability of demersal resources is inversely proportional to stock size. This has been suspected to occur in species with strong shoaling characteristics, e.g. 'pelagic' species, and models have been described to show this must occur if behaviour causes fish to tend to an optimum density per unit area. The effect could be expected to be less



pronounced in demersal resources, but, if a smaller stock occupies a smaller geographical area, a given level of fishing effort must generate a higher fishing effort per unit area and catchability will appear to increase.

TABLE 2. Coefficient of variation of different units of effort, as measures of the same fishing mortality at Labrador.

Country	Gear and tonn. class	Days on grounds	Days fished	Hours fished
USSR	OT 901-1800	52.27	66.27	
	OT >1800	31.51		22.31
Spain	OT 901-1800	14.36	14.38	13.39
	PT 151-500	37.77	36.61	32.15

Table 2 compares the variability of  $q$  resulting from different possible measures of fishing effort used by fleets of the USSR and Spain fishing at Labrador. The results indicate that hours fished gives the best indication of the fishing mortality generated by the effort. It is interesting to note that the coefficient of variation of  $q$  associated with hours fishing is broadly similar to the

20% level that was associated with UK vessels fishing in the Northeast Arctic and at Iceland.

It is known that for some fisheries there are marked changes in catchability with season. Table 3 shows the results of a series of analyses of variance for various cod stocks and fleets. Each analysis shows a very significant change in catchability between quarters of the year. A knowledge of seasonal change in catchability could of course be used to reduce the coefficient of variation of catchability, but only at the expense of more complicated definitions of fishing effort and therefore of any resulting effort quota. Even if this adjustment was made, there would still be significant changes in catchability on a year-to-year basis as is indicated in the last column of Table 3.

Thus in brief it may be concluded that: (i) estimates of the catchability coefficient may contain a bias related to the size of the stock in question; and (ii) for fleets known to fish specifically for cod and catching a large proportion of the total catch, the coefficient of variation of the catchability coefficient is of the order 15-20% (95% confidence limits 40%); the coefficient of variation increases to the order 50% (95% confidence limits 100%) with respect to fleets taking smaller 'samples' on a more opportunistic basis.

TABLE 3. Analyses of quarterly and annual variation of catchability coefficient in selected fisheries (F under "effort unit" refers to days fished).

Stock area	Country	Gear and tonn. class	Effort unit	Mean square F ratio	
				Between quarters	Between years
Arcto-Norwegian (I + IIB) <sup>1</sup>	UK	OT Steam	10 <sup>6</sup> hours	33.54***	4.51***
		OT Motor	10 <sup>6</sup> hours	24.88***	8.68***
Greenland (1A-D) <sup>2</sup>	FRG	OT 501-900	10 <sup>6</sup> days (F)	11.49***	24.49***
Labrador (2G-3L) <sup>2</sup>	Spain	OT 901-1800	10 <sup>6</sup> days (F)	13.52***	2.21
		PT 151-500	10 <sup>6</sup> days (F)	6.12**	4.94**
	Portugal	OT 901-1800	10 <sup>6</sup> hours	27.28***	2.60*

\*P = ≤0.05; \*\* P = ≤0.01; \*\*\* P = ≤0.001.

<sup>1</sup>Statistical areas of ICES.

<sup>2</sup>ICNAF Divisions.

### The Variability of Fishing Vessel Performance in Relation to Catch and Effort Quotas

If effort quotas are set, either with or without catch quotas, the need to allocate the quota between countries will require a knowledge of the relative fishing power of

the fleets concerned. Similarly each country will need to assess the relative fishing power of the individual vessels it intends to utilize in taking up the national effort allocation, both to satisfy other participating nations and for internal administrative reasons. This relative fishing power of vessels can at present only be measured in terms of their relative fishing performance in some standardized fishing situation, but, in practice, given that an acceptable estimate can be achieved, the annual

average fishing power of an individual vessel (the presumed basis of an allocated share) will vary owing to the seasonal changes in fish abundance and variation in the performance of the trawler-skipper-gear combination. The fishing mortality exerted during a given effort quota allocation will then have a variance which will influence the efficiency of the regulation, and, where effort is regulated in conjunction with a catch quota, will influence the probability that both catch and effort quotas will be fulfilled coincidentally.

In order to gain some appreciation of the magnitude of these effects, an analysis has been carried out of the variability of the annual catch per unit effort of all UK vessels fishing at Iceland and in the Northeast Arctic in the years 1969-71. The analysis involved the between-ship variation of the catch per effort of individual vessels from their tonnage group mean for each year, and the within-ship variation in catch per effort between years.

Table 4 (A and B) summarize the relative catch per effort of trawlers in different tonnage categories fishing at Iceland and in the Northeast Arctic, the catch per effort being expressed as the deviation from the mean catch per effort of all vessels in each area. The catch per effort of trawlers in the 0-499 tonnage class is below the overall mean, owing to their smaller size and greater specialization in their fishery objectives. There is a considerable increase in catch per effort through the 500-900 GRT ranges, but this does not extend to the > 900 GRT class. Over the whole range of tonnage categories the variation attributable to tonnage only accounts for about half of the total variation. The standard deviation of catch per effort of all vessels fishing at Iceland is 25-30%; the dispersion is greater than in the Northeast Arctic because of the wider range of vessel operations there. Within each tonnage category the 'between-trawler' standard deviation is stable at  $\pm 20\%$ .

TABLE 4. Variations in vessel performance (S.D. = standard deviation).

	Tonnage category				All vessels
	0-499	500-699	700-899	900+	
Between vessel variation					
<b>A. Iceland</b>					
Group mean relative to overall mean	0.74	1.06	1.16	1.19	1.00
S. D. within years					
1969	0.18	0.20	0.32	0.62	0.34
1970	0.21	0.23	0.19	0.22	0.29
1971	0.19	0.14	0.21	0.16	0.23
Average S. D.	0.19	0.19	0.24	0.33	0.29
<b>B. Northeast Arctic</b>					
Group mean relative to overall mean	0.66	0.99	1.04	1.00	1.00
S. D. within years					
1969	0.18	0.16	0.20	0.10	0.23
1970	0.14	0.23	0.20	0.23	0.24
1971	0.18	0.22	0.22	0.19	0.23
Average S. D.	0.16	0.21	0.21	0.18	0.23
<b>C. Iceland only</b>					
Days on grounds					
Within vessel variation	0-50	51-100	101-150	151-200	
Group mean relative to overall mean	1.08	1.00	0.97	0.96	
S. D.	0.19	0.22	0.16	0.11	

The alternative analysis at Table 4C summarizes the within-ship variation over the 3 years (i.e. the deviation of a trawler catch per effort in 1 year from its own average relative catch per effort over the 3 years) in relation to the amount of time spent on the grounds. There is a weak trend of above-average performance with shorter periods, but this could easily be an artefact

of the statistics or a reflection of improvement due to fishing tactics which select for season, i.e. shorter periods. The period groupings show the standard deviation of individual vessel catch per effort decreasing from 20 to 10% as the period increases. The similarity between this figure and the between-trawler catch per effort suggests that the identity of the vessel has very

little connection with the annual catch per effort, and that each year's fishing might be considered as though it were carried out by a different boat.

A catch quota allocation would be determined by the projected application of a specified level of fishing mortality to an estimate of the available stock. Presuming that stock level is accurately determined, and ignoring natural year-to-year variations in the catchability of the fish. The variations recorded above give some measure of the degree to which the accuracy of an effort regulation would be influenced by variation in fishing power of the skipper/vessel combination. It also indicates the probability of fulfilling simultaneously catch and effort regulations applied to the same stock.

If, for example, a small national quota were allocated to a single vessel effort there would be a 95% probability that the exerted fishing mortality and hence the catch would be within 25% of the intended level. The accuracy with which the regulatory objective could be met would increase with the number of units to which it was allocated, but there would be a corresponding increase in variation between individual vessels, i.e. the match of effort to catch quota would deteriorate at the individual vessel level. These considerations would be relevant to nations with allocations that did not permit the use of large numbers of vessels.

## Discussion

Previous sections of this paper considered the sources of some assessment errors and the effects that these errors have on the objectives of fishery resource management by catch quota or by effort quota. Simplified formulae for the variance of fishing mortality and of stock biomass are developed. Simplifications of the mathematics have been deliberately made to make it possible to present these formulae in a readily comprehensible form. From these equations it is abundantly clear that the variance of catchability (see equations (10), (11) and (12)) plays a major role in causing errors in the objectives of management by both catch and effort quota. Although the variability of catchability acts on both forms of management, for an effort quota it acts directly and therefore causes the resulting fishing mortality to have a coefficient of variation equivalent to that of the catchability coefficient. Conversely, for a catch quota it acts indirectly through the estimate made of the stock size from the previous year's catch and effort statistics. This leads to an increase in the coefficient of variation of the resulting fishing mortality by a factor approximately equal to the exponential of the fishing mortality achieved. Rather similar results are obtained when the objective of

management is the achievement of some level of stock biomass rather than of a specific fishing mortality.

Because of these effects of the variance of the catchability coefficient, it follows that, if an effort quota could be based on the same measure of fishing effort that would be used to make assessments of stock size for a catch quota (presumably the best measure of effort), then the effort quota would achieve its objectives with less variability than a catch quota.

Because of the central importance of the catchability coefficient in these equations, its variance has been investigated in depth in the preceding sections. From the estimates of catchability for various North Atlantic cod fisheries, it may be concluded that catchability is associated with seasonal and longer-term variations. It can also be concluded that those fleets which fish on a more opportunistic basis the variation in catchability is large. Since total effort restrictions are likely to be based on total catch, and since fleets which catch the larger share of all species in any area are likely to have mixed objectives, it is likely that the catchability coefficient for any particular species associated with a total effort quota is likely to be rather variable. This point is illustrated by Example 3 of Annex B. Consequently it is likely in practice that a total effort quota would by itself lead to less-precisely attained management objectives than catch quotas.

If an effort quota were adopted, it would have to be allocated both internationally and nationally. Examination of the effect of variability of catchability on this problem at a national level indicates that for nations with small quotas the problem might be considerable.

In this paper the implications of adopting either a catch quota or an effort quota are considered. The question of the simultaneous application of both types has not been discussed, since it was felt that this problem would further obscure the central features of errors in the catch and effort quotas. However, the mathematical relationships should provide a useful base for an examination of this problem should this be needed.

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## ANNEX A — The Derivation of Equation 4 in Text

From Equation (2),

$$C_a = A_a \frac{F}{Z} (1 - \exp(-Z))$$

Using the cohort analysis approximation, this becomes

$$C_a = A_a \{1 - \exp(-F)\} \cdot \exp(-M/2) \quad (A.1)$$

If  $\Delta C_a$ ,  $\Delta A_a$  and  $\Delta F$  represent small differences in  $c_a$ ,  $A_a$  and  $F$  respectively, then from Taylor's theorem

$$\begin{aligned} \Delta C_a \approx & [\Delta A_a \{1 - \exp(-F)\} \cdot \exp(-M/2)] \\ & + [A_a \cdot \Delta F \cdot \exp(-F) \cdot \exp(-M/2)] \end{aligned} \quad (A.2)$$

Dividing (A.2) by (A.1) gives

$$\frac{\Delta C_a}{C_a} \approx \left( \frac{\Delta A_a}{A_a} \right) + \Delta F \left( \frac{\exp(-F)}{1 - \exp(-F)} \right) \quad (A.3)$$

For small  $F$  this is approximately equivalent to

$$\Delta A_a \approx A_a \left( \frac{\Delta C_a}{C_a} - \frac{\Delta F}{F} \right) \quad (A.4)$$

$$\text{Since Cov}(A_i, A_j) = \sum_i \sum_j \Delta A_i \cdot \Delta A_j, \text{ and} \quad (A.5)$$

$$\text{Since Var}(A - A_r) = \sum_{i>r} \sum_{j>r} \text{Cov}(A_i, A_j), \quad (A.6)$$

it follows that

$$\begin{aligned} \text{Var}(A - A_r) = & A^2 \left( \frac{\text{Var}(F)}{F^2} \right) \\ & + \sum_{a>r} A_a^2 \left( \frac{\text{Var}(C_a)}{C_a^2} \right) \end{aligned} \quad (A.7)$$

where  $\text{Cov}(F, C_j) = 0$  for all  $i$  and  $\text{Cov}(C_i, C_j) = 0$  for  $i \neq j$ . This latter condition is not strictly correct and in general  $\text{Cov}(C_i, C_j) < 0$  for  $i \neq j$ . Thus A.7 will tend to overestimate the variance of  $(A - A_r)$ , while

$$A^2 \left( \frac{\text{Var}(F)}{F^2} \right) \text{ would be an underestimate; A.7}$$

thus represent a pessimistic assumption.

Assuming that  $\frac{\text{Var}(C_a)}{C_a^2}$  has a similar value for each age (a frequent objective of sampling schemes), and letting  $\frac{\text{Var}(C)}{C^2}$  be the average value; it follows that

$$\frac{\text{Var}(A - A_r)}{(A - A_r)^2} \approx \frac{\text{Var}(F)}{F^2} + \frac{\text{Var}(C)}{\theta \cdot C^2} \quad (A.8)$$

$$\text{where } \theta = \frac{(A - A_r)^2}{\sum_{a>r} A_a^2} \quad (A.9)$$

## ANNEX B. Examples of the use of the Equations in the Section “Errors in Catch Quotas and Effort Quotas”.

### Example 1. Scotian Shelf Cod

Halliday's (1972) description of this stock gives cohort analysis estimates of the fishing mortality on each age. If, as an example, it had been intended to achieve a fishing mortality of 0.45 in 1970 (the appropriate level to achieve the MSY) using a catch quota, then this would have to be based on the catch at age data of 1969. Normally for this stock new recruits form a negligible proportion of the exploitable biomass. On the average, using equation (10)  $v = 0.006$  and  $u = 0.994$ . In 1969,  $\theta = 5.056$ , which was calculated using equation (A.9.).

$\frac{\text{Var}(C)}{C^2}$  can be estimated from the within-year coefficient of variation (28%) in fully recruited fishing mortality which gives the estimates  $100\sqrt{\frac{\text{Var}(C)}{C^2}}$  (see Pope 1972). Halliday considers there was little variation in  $F$  over the period analysed and thus the between-year coefficient of variation in the average fully recruited fishing mortality gives an estimator for 100

$$100\sqrt{\frac{\text{Var}(F)}{F^2}}$$

Thus  $\frac{\text{Var}(F)}{F^2} = 0.012$ , and  $\frac{\text{Var}(C)}{C^2} = 0.084$

Inserting the above values in equation (10) leads to an estimate of the coefficient of variation (of the fishing mortality achieved by the catch quota) of 27%.

Thus the fishing mortality ( $\hat{F}$ ) in fact achieved would most probably be in the range  $0.22 < \hat{F} < 0.67$  alternatively, if an effort quota had been applied, this would have a coefficient of variation of about 11% if the same effort measure was used, and in this case the fishing mortality achieved would most probably be in the range  $0.35 < \hat{F} < 0.55$ . However, for the measures of effort more likely to be adopted for effort regulations the coefficient of variation is likely to be far greater, since it is unlikely that these measures would bear any great relationship to cod fishing effort.

If it was the object of management to get a catch or effort quota on this stock (stock composition as at 1969) so that the biomass of fish ( $B$ ) available for capture (aged 4 and over) was  $144 \times 10^3$  metric tons, this would be

achieved by a catch quota of  $49 \times 10^3$  metric tons or an effort quota which produced a fishing mortality of 0.45.

From equations (12) and (13) the coefficient of variation of  $B$  would then be about 27% when a catch quota was used and about 18% when an effort quota was used.

### Example 2. Georges Bank Herring

Considerable doubts have been expressed about the level of recruitment to this stock in recent years and it is probable that the estimates of variance given here are on the conservative side.

Formally, 3 year-old recruits did not form a large proportion of the total stock, and there is some doubt as to whether the catch of 3 year-old fish adequately predicts the catch of 4 year-olds in the following year. Assuming that the prediction is valid, then  $\theta = 5.15$ .

$\frac{\text{Var}(C)}{C^2}$  is estimated as 0.193, i.e. coefficient of variation = 43%, and

$\frac{\text{Var}(F)}{F^2}$  is estimated as 0.011, i.e. coefficient of variation = 10%.

These values lead to a variance ratio of 35% for  $\hat{F} = 0.48$ , when a catch quota is applied. Therefore, the fishing mortality that would be achieved by the catch quota would be in the range  $0.14 < \hat{F} < 0.82$ . For an effort quota, the variance ratio would be 25%. If alternatively days fished with learning were used as the basis of an effort quota, then  $0.24 < \hat{F} < 0.72$ .

If the objective was to set a catch or effort quota on this stock (stock composition as at 1971) so that the biomass available to capture ( $B$ ) in the next year was  $277 \times 10^3$  metric tons excluding 3 year-old recruits, the variance ratio of  $B$  would be about 35% for a catch quota, and it would be 25% for an effort quota.

### Example 3. Cod — Divisions 2G-3L

Data for the following analysis were obtained mainly from the two sources given below.

Pinhorn and Wells (1972)<sup>a</sup> show that cod recruit to the fishery in significant numbers in their fourth year.

<sup>a</sup>PINHORN and WELLS. 1972. Combined Virtual Population Assessment for ICAF Divisions 2J, 3K and 3L Cod. *Int. Comm. Northw. Atlant. Fish., Redbook 1972*, Part III, p. 35-38.

From his work it is possible to ascertain that the coefficient of variation of  $q$  is of the order of 16%.

Hence  $\frac{\text{Var}(F)}{F^2}$  is estimated at about 0.026.

An estimate of  $\frac{\text{Var}(C)}{C^2}$  can be made using the method of Example 1 and this gives

$$\frac{\text{Var}(C)}{C^2} \approx 0.027.$$

Using the weight at age data of ICES (1973)<sup>b</sup> with the numbers at age and the selection at age given by Pinhorn and Wells (1972) leads to estimates of  $\theta = 5.8$ ,  $u = 0.9$ , and  $v = 0.1$ . The coefficient of variation of recruits (4

years-olds) from 1961 to 1969 is 29%, and hence the coefficient of variation of the fishing mortality achieved by a catch quota would be of the order of 25%. By comparison an effort quota for cod based on Spanish or Portuguese hours fished would have yielded a coefficient of variation for the  $F$  achieved of approximately 15% (see Fig. 2D and E). Thus a specific effort quota on cod might be expected to have a rather more predictable result than a catch quota. However, an effort quota on all species in these divisions would be likely to have a far more variable effect on individual stocks. For example, the coefficient of variation of the  $q$  for cod in these divisions for the USSR fleet of vessels  $> 1800$  GRT vessels is of the order of 45% (Fig. 2C). Since the USSR is one of the major catching nations in these divisions, an overall effort restriction would reflect this level of variation, and it is reasonable to suppose that the coefficient of variation of the  $F$  achieved by an overall effort quota on all species would be of the order 35-40%.

<sup>b</sup>ICES. 1973. *Cooper. Res. Rep. int. Coun. Explor. Sea*, No. 33.

# Estimates of Natural Mortality for the Cod Stock Complex in ICNAF Divisions 2J, 3K and 3L

By A. T. Pinhorn<sup>1</sup>

## Abstract

Estimates of natural mortality ( $M$ ) were determined for the cod stock complex inhabiting ICNAF Divisions 2J, 3K and 3L. Estimates based on catch and effort data for the Div. 2J portion of the stock ranged from 0.16 to 0.21 with a mean estimate of 0.18. Similar trends in fishing mortality in Div. 2J and Div. 2J-3L indicated that  $M$  estimates based on Division 2J data alone likely represent  $M$  for the entire stock complex.

## Introduction

In view of the importance of reliable estimates of natural mortality ( $M$ ) in virtual population analyses (Agger *et al.*, 1971), estimates of  $M$  have been derived for the cod stock complex occupying Div. 2J, 3K and 3L for which a virtual population assessment (VPA) was presented at the 1972 ICNAF Annual Meeting (Pinhorn and Wells, 1972). At that time  $M = 0.2$  was assumed as the level of natural mortality in this stock.

## Materials and Methods

Because of the greater reliability and ease of calculation of the effort measures for the Div. 2J fishery, estimates of  $M$  by the methods based on catch and effort data were derived for the portion of the stock in this division only, the estimate of  $M$  for this portion of the stock being considered to be representative of the entire stock.

The basic data used were catch and effort figures for the Div. 2J fishery during 1959-70. The catch figures were those reported by Pinhorn (1971) as number of cod caught per age-group updated to 1970. The effort figures were derived by standardizing the effort for various gears for each year to standard Spanish otter trawler units using the method developed by Hodder (1965) and used by Wiles and May (1968) and Pinhorn (1969, 1970). This consists of obtaining conversion factors from slopes of regressions of catch/hour fished of each country and/or gear on catch/hour fished of the standard gear.

These conversion factors are then used to convert the effort of each country/gear to that of the standard gear. Where necessary numbers per standard hour for each age-group were then calculated. Spanish otter hours were used as the standard unit of effort.

Five methods of arriving at estimates of  $M$  using catch and effort data were used, although it is realized that these are not independent but are only essentially five treatments of the same basic data. However, the different approaches should serve to indicate the range within which  $M$  likely lies and should produce an  $\bar{M}$  close to the true  $M$ .

## Results

The various estimates of  $M$  are shown in Table 1.

TABLE 1. Estimates of  $M$  by various methods, 2J cod.

	Method	$M$
1.	Catch curves of low effort period	0.20
2.	Silliman	0.16
3.	F of VPA versus fishing effort	0.16
4.	Z of year-class catch curves versus fishing effort	0.20
5.	Z of year-class from VPA versus fishing effort	0.21
	$\bar{M}$	0.18

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### Catch curves from period of low fishing effort

The average catch curve for 1960-61 produced a  $Z$  of 0.24 which would represent the upper limit of  $M$  assuming no fishing mortality ( $F$ ) (Fig. 1). The actual  $Z$  measured from this curve reflects the total mortality during some earlier period, in this case approximately 1954-59 (Ricker, 1958). The average effort in this period was about 22,000 standard hours. In 1959 an effort of 35000 hours resulted in an average  $F$  of 0.07 for the fully recruited age-groups. Therefore, assuming an  $F$  of 0.04 for the 1954-59 period results in an estimate of 0.20 for  $M$ .

### Silliman method

The rapid increase in fishing effort in 1960 and 1961 from a level of approximately 22,000 hours in 1954-59 to 133,000 hours in 1961-66 allows an estimate of  $M$  by the Method of Silliman (1943) (Fig. 1).

The level of  $Z$  during the 1954-59 period as determined from the average catch curve for 1960-61 was 0.24 with an effort level of 22,000 hours. During the 1961-66 period the  $Z$  as determined from the average catch curve of 1966-67 was 0.64 and the level of effort 133,000 hours. Substituting these variables in the

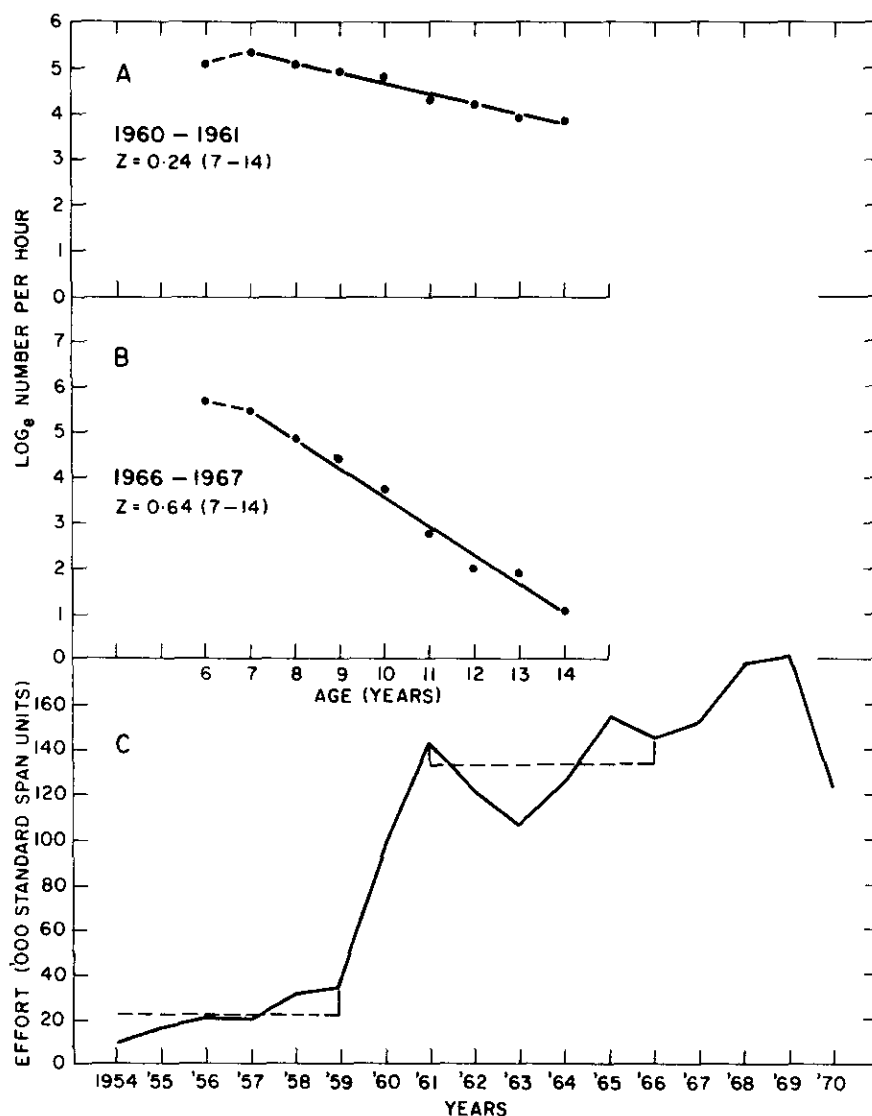


Fig. 1. A and B. Average catch curves for Div. 2J cod, 1960-61 and 1966-67. C. Trends in standard effort in Div. 2J, 1954-70.



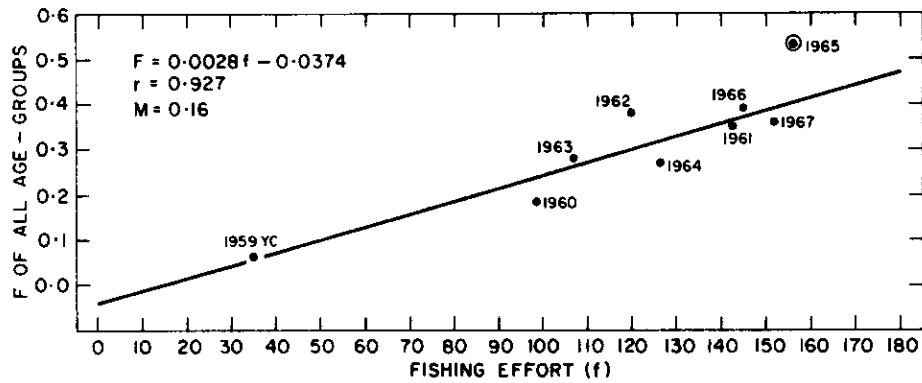


Fig. 2. Regression of  $\bar{F}$  of all age-groups from VPA on effective fishing effort ( $f$ ) for Div. 2J cod. Circled point for 1965 not used in fitting line.

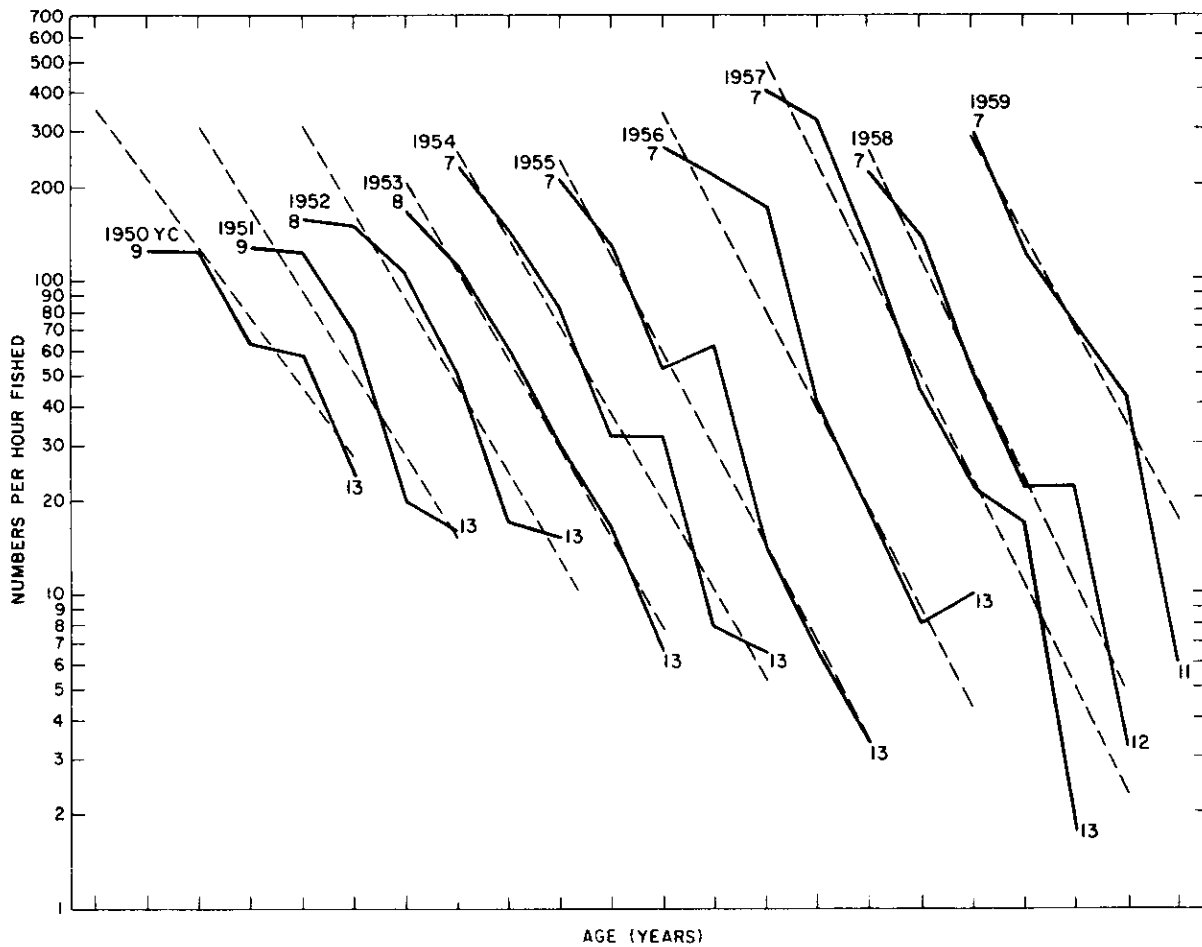


Fig. 3. Catch curves for 1950-59 year-classes (Broken lines are author's interpretation of slopes from age 8 onwards for 1950-53 year-classes and age 7 onwards from 1954-59 year-classes).

equation for the method ( $Z = F + M$ ) results in an estimate of 0.16 for  $M$ .

#### Regression of $\bar{F}$ from VPA on fishing effort ( $f$ )

In conducting the VPA on 2J cod, an estimate of  $M = 0.2$  was used. If this coincided with the true value of  $M$ , then the regression of  $\bar{F}$  on fishing effort ( $f$ ) should pass through the origin. Any intercept, therefore, gives some measure of the deviation of the assumed  $M$  from the true  $M$ . The regression from the VPA data produced an intercept of  $-0.04$ , indicating a value of  $M = 0.16$  (Fig. 2).

#### Regression of $Z$ from year-class catch curves on fishing effort ( $f$ )

From numbers caught at each age in each year and the effective fishing effort in each year, numbers caught per hour's fishing effort were calculated for each age. These were plotted as catch curves for the year-classes 1950-59 (Fig. 3). Total mortality estimates ( $Z$ ) were then determined from slopes of lines fitted to the  $\log_e$  of these values. These values of  $Z$  were then plotted against the average effective effort for each year-class by the method of Paloheimo (1961) and the regression (Fig. 4) yielded an estimate of 0.20 for  $M$ .

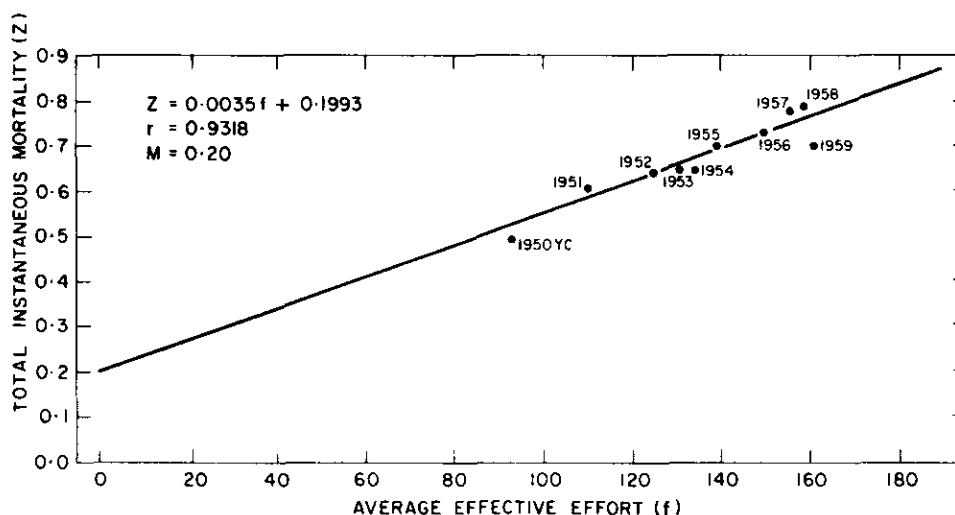


Fig. 4. Regression of  $\bar{Z}$  of fully recruited age-groups from year-class catch curves on average effective fishing effort ( $f$ ).

#### Regression of $\bar{Z}$ for each year-class from VPA estimates of $S$ on fishing effort ( $f$ )

VPA produce preliminary estimates of survival rates ( $S$ ) and hence  $Z$  for each age by year-class. The regression of  $\bar{Z}$  for fully recruited age-groups for each year-class on average effective fishing effort for that year-class produces an intercept which is an estimate of  $M$ . From the Div. 2J VPA data, an estimate of  $M = 0.21$  was obtained in this way (Fig. 5). In obtaining  $\bar{Z}$  by year-class the same range of ages was used for each year-class as in the previous method.

#### Discussion and Conclusions

In the method employing total mortality estimates ( $Z$ ) derived from year-class catch curves (Fig. 3), the straight lines fitted to the year-class catch curves are the author's interpretation of the slopes for age 8 onwards for the 1950-53 year-classes and age 7 onwards for the 1954-59 year-classes. For example, because of the inadequacy of samples in 1959, the slope for the 1950 year-class is fitted from age 10 onwards. Similarly for the 1954, 1955 and 1956 year-classes the points representing the 1965 catch are not included in fitting the

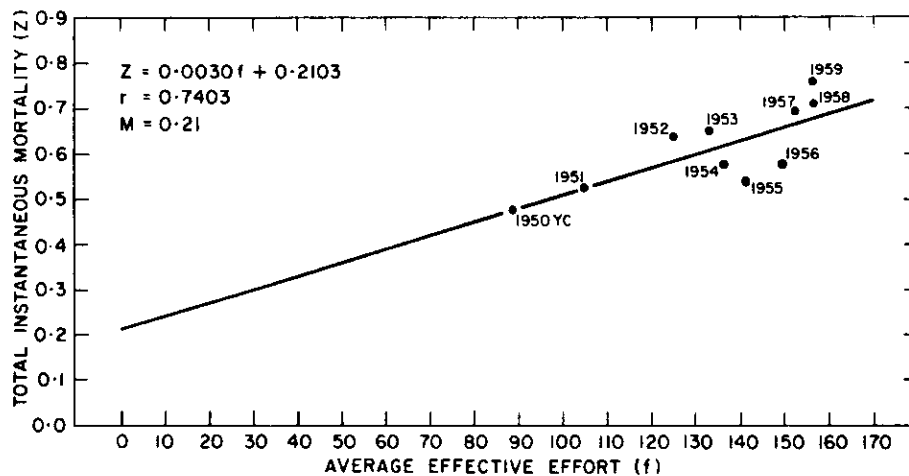


Fig. 5. Regression of  $\bar{Z}$  of fully recruited age-groups from VPA on average effective fishing effort ( $f$ ).

line because of doubt as to their validity. For the same reason, points representing the 1969 catch were not included for the 1956-59 year-classes. By editing the data in this manner it was possible in the author's opinion to obtain straight lines whose slopes reflected the true values of  $Z$  for their year-classes.

Since the methods based on catch and effort figures were only used for data from the fishery in Div. 2J, there is some question as to whether the estimate of  $M$  obtained for that portion of the stock complex is an unbiased estimate of  $M$  for the entire complex in Div. 2J, 3K and 3L. This is particularly so since there is a migration to spawning areas in Div. 2J during the early months of the year when the fishery is in fact heaviest. This may lead to underestimates of  $M$  if only the Div. 2J portion of the stock complex is considered unless trends in effort and hence  $F$  in Div. 2J were similar to those in the entire stock complex. Table 2 shows that generally the trend in fishing mortality in Div. 2J cod was similar to that for the entire stock complex in Div. 2J-3L. Hence it is reasonable to assume that the estimates for Div. 2J are representative of the whole stock complex.

Estimates of  $M$  obtained in this study ranged from 0.16 to 0.21 with  $M = 0.18$ . Thus, the value of  $M$  is not likely to be less than 0.16 or greater than 0.21. Even assuming  $M$  as low as 0.16, the assumed value of 0.20 used in the VPA would result in  $F$  being underestimated by less than 10%. If the true value of  $M$  is close to the  $M = 0.18$ , then the  $F$ -values estimated in the VPA for Div. 2J, 3K, and 3L would be little changed.

TABLE 2. Comparison of trends in fishing mortality estimates for the cod in Division 2J and for the cod stock complex in Divisions 2J-3L. Values are average fishing mortalities in fully recruited ages expressed as a percentage of the fishing mortality estimates in 1968.

Year	Percent	
	Division 2J	Divisions 2J-3L
1959	10	(24) <sup>a</sup>
1960	36	(49) <sup>a</sup>
1961	68	73
1962	78	75
1963	55	56
1964	52	82
1965	109	98
1966	68	69
1967	65	91
1968	100	100

<sup>a</sup>Not known for Division 3K. Estimated from  $F$  values in Divisions 2J and 3L.

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# Sexual Maturity and Reproductive Performance of Female Hooded Seals at Newfoundland

Torger Øritsland<sup>1</sup>

## Abstract

Ovaries and teeth for age determination were collected from 167 lactating female hooded seals off Newfoundland-Labrador in the hunting seasons from 1967 to 1972. From the distribution on age at first ovulation of 114 seals it was found that sexual maturity is attained at ages from 2 years (12%) to 9 years (2%) with 2.8 years as the median age of sexual maturity. Age-specific rates of presumed pregnancies were estimated from corpora missing in a regular size sequence between ovaries. The first pup is produced by 12% at an age of 3 years and 2% at an age of 11 years and the median age of reproductive maturity is 3.8 years. The average rate of presumed pregnancies was found to be 0.97 compared to 0.95 in the Northeast Atlantic. A rate of 0.95 is suggested as a conservative estimate of the average reproductive success of mature female hooded seals in the Northwest Atlantic.

## Introduction

The sexual maturity of hooded seals (*Cystophora cristata*) was studied by Soviet investigators in the Greenland Sea in 1956-58 (Popov 1960). Further information on the breeding biology of females is available from Norwegian investigations in the Denmark Strait and the Jan Mayen area of the Greenland Sea in 1956-60. A report on the gross anatomy and development of reproductive organs and on the reproductive cycle also contains data on sexual maturity and age-specific reproductive performance (Øritsland, 1964).

Data on the breeding biology of female hooded seals have now been obtained also from the Northwest Atlantic. This report presents information on sexual maturity and reproductive performance from samples collected off Newfoundland-Labrador as part of the Norwegian seal research program in that area in 1967-72.

## Material and Methods

Pairs of ovaries were collected together with canine teeth (lower jaws) for age determination from a total of 48 breeding females in the hunting seasons of 1967-71 and from 119 breeding females in the 1972 season. All these seals were captured during lactation, i.e. after parturition but before the new ovulation, so their age at the last ovulation was 1 year less than their age at capture.

Individually marked ovary pairs were fixed and stored in 4% formalin. At the laboratory the ovaries were cut in about 2 mm thick sections and examined for corpora lutea and albicantia which were also measured using the same method as in the previous study of hooded seals (Øritsland, 1964) and in a study of harp seals, *Pagophilus groenlandicus*, at Newfoundland (Øritsland, 1971). Recorded data on the size and weight of the ovaries and the number and size of Graafian follicles have not been analyzed for this report.

Age determinations which have also been included in analyses of age composition and mortality, were made from cementum growth layers as indicated in another report in this volume (Øritsland and Benjaminsen, 1975).

The age at sexual maturity (first ovulation) was determined for individual females by deduction from the age at last ovulation and the number of corpora in the ovaries. Accumulated maturity frequencies were then calculated from the distribution on age at maturity of all 3-13 years old females which had reached maturity within the three breeding seasons preceding the season they were captured by the method proposed by Fisher (1954) and modified by Øritsland (1964 and 1971).

Information on reproductive success was obtained by a method introduced for non-random samples of female harp seals at Newfoundland (Øritsland, 1971). The number of missing corpora in a regular size sequence between the two ovaries was determined through the three preceding breeding seasons for each

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TABLE 1. The distribution on age at sexual maturity (first ovulation) of female hooded seals in combined samples collected from breeding seals off Newfoundland-Labrador 1967-72.

Age		No. ovulating first time at age									
at capture	at last ov.	No.	2	3	4	5	6	7	8	9	10
2		0	—	—	—	—	—	—	—	—	—
3	2	2	2	—	—	—	—	—	—	—	—
4	3	35	5	30	—	—	—	—	—	—	—
5	4	26	7	12	7	—	—	—	—	—	—
6	5	23	2	10	7	4	—	—	—	—	—
7	6	19	—	7	5	4	3	—	—	—	—
8	7	21	1	3	4	5	8	0	—	—	—
9	8	8	—	3	0	2	2	1	0	—	—
10	9	4	—	1	1	1	1	0	0	0	—
11	10	5	—	1	0	1	1	2	0	0	0
12	11	6	—	—	—	1	0	3	0	2	0
13	12	6	—	—	1	0	1	2	1	1	0
Sum total		155	17	67	25	18	16	8	1	3	0
Sum 3 years		114	14	52	19	13	13	1	0	2	0
Per cent			12.3	45.6	16.7	11.4	11.4	0.9	0.0	1.8	0.0
Accum. per cent			12.3	57.9	74.6	86.0	97.4	98.3	98.3	100.1	

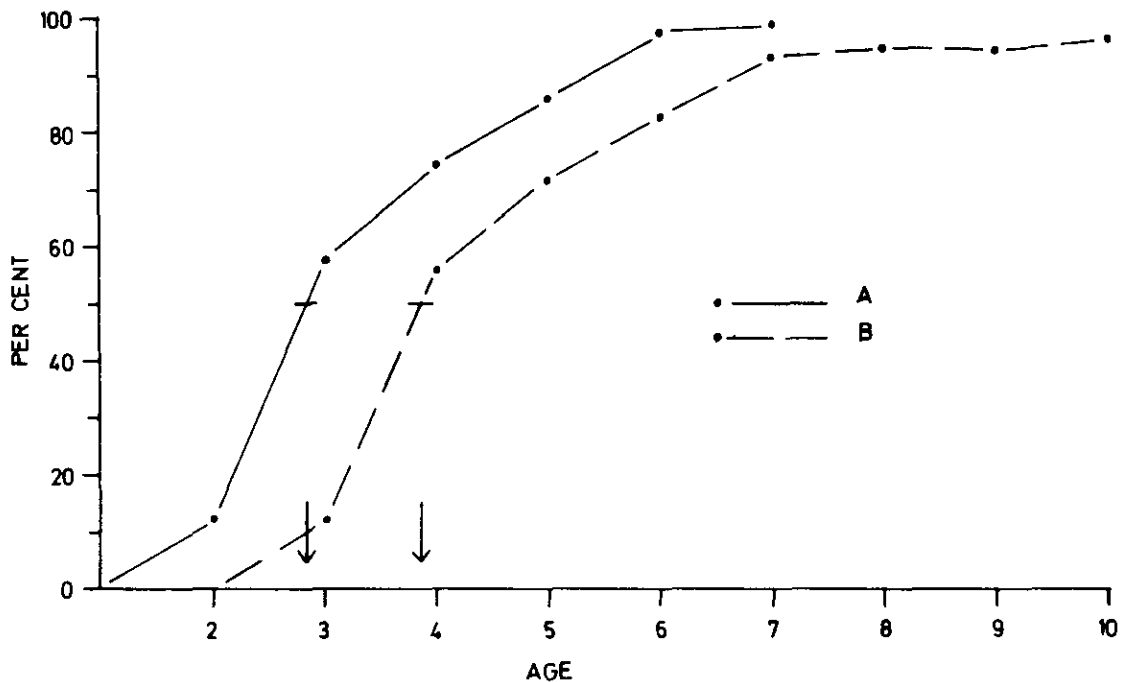


FIG. 1. Sexual maturity (age at first ovulation) and reproductive maturity (age at first parturition) of female hooded seals at Newfoundland. Accumulated frequencies are based on combined samples collected off Newfoundland-Labrador 1967-72.

female. These data were combined in estimates of maximum rates of presumed pregnancies for age-groups or series of age-groups in the combined samples.

## Results

The distribution on age at capture, age at sexual maturity or first ovulation and the calculated maturity frequencies for the maturing age-groups in the combined Newfoundland samples collected from 1967 to 1972 are presented in Table 1. In total the combined samples comprise data from 167 female seals with 155 seals being from 3 to 13 years old at capture (no seals 2 years old or younger were captured), and 114 of them having reached maturity in one of the last three breeding seasons.

The accumulated maturity frequencies in the bottom line of Table 1 are illustrated in Fig. 1 (graph A). This graph indicates that the median age of sexual maturity is about 2.8 years for female hooded seals breeding at Newfoundland.

The numbers of missing corpora in the combined samples give maximum rates of presumed pregnancies of 0.969 for age-groups 3-10 and 0.988 for 11 years old and older seals without any indication of a decreasing rate for the oldest females (Table 2).

TABLE 2. The reproductive performance of mature female hooded seals sampled off Newfoundland-Labrador 1967-1972. The rate of presumed pregnancies through the last three breeding seasons is estimated from corpora lutea or albicantia missing in a regular size sequence between the two ovaries for each animal. ('Total No.' include 'No. missing'.)

Age groups	Corpora lutea and albicantia			Pregnancy rate
	Total No.	No. missing	Per cent missing	
3-10	291	9	3.1	0.969
11-34	85	1	1.2	0.988
3-34	376	10	2.7	0.973

Taking 0.96 as a tentative estimate of the pregnancy rate for age-groups 3-10 and 0.98 as an estimate for the older seals, the following cumulative frequencies of reproductive maturity may be calculated from the sexual maturity frequencies in Table 1:

- 3 years — 11.8 %
- 4 years — 55.6%
- 5 years — 71.6%

- 6 years — 82.6%
- 7 years — 93.5%
- 8 years — 94.4%
- 9 years — 94.4%
- 10 years — 96.0%
- 11+ years — 98.0%

These estimates of age-specific production rates are illustrated in Fig. 1 (graph B). The graph indicates that 50% production is reached at an age of 3.8 years, which is therefore proposed as the median age of reproductive maturity for the female Newfoundland hooded seals.

## Discussion

The methods used for determination of age at sexual maturity and rate of presumed pregnancies are based on the assumptions that sexually mature female seals have a regular 1 year reproductive cycle producing one pup every year, that only one ovum is released and only one corpus luteum is formed at conception every year and that the two ovaries alternate so that each of them is active every second year. This actually is the common pattern in most pinnipeds (Harrison, 1969) included the hooded seal (Øritsland, 1964).

It is further assumed that corpora persist as recognizable scar tissue or corpora albicantia for at least three years after they are formed. Even if this is not true for all seals (Harrison, 1969), fairly strong evidence for such a hypothesis has been found in several species including the harp seal (Fisher, 1954; Yakovenko and Nazarenko, 1967; Øritsland, 1971), the ringed seal, *Pusa hispida*, (McLaren, 1958) and southern lobodontine seals (Mansfield, 1958; Øritsland, 1970).

For hooded seals it has been demonstrated that the number of corpora increases with age by about 0.7 per year through age-groups 2-7 and that 8 year-old and older females have an average of 3.74 corpora in their ovaries (Øritsland, 1964). The assumption therefore apparently is valid for this species.

In Fig. 2 sexual maturity frequencies are shown separately for the 1972 Newfoundland sample (graph C), the combined Newfoundland samples collected from 1967 to 1971 (graph B) and the presumably random combined samples of moulting seals collected in the Denmark Strait from 1956 to 1960 (graph A). It should be noted that the original frequencies reported from the Denmark Strait (Øritsland, 1964) were based on animals which had reached maturity in the two last breeding seasons before capture. These frequencies corresponded nearly too well with the 1972 data from Newfoundland. The Denmark Strait frequencies illustrated in Fig. 2 have

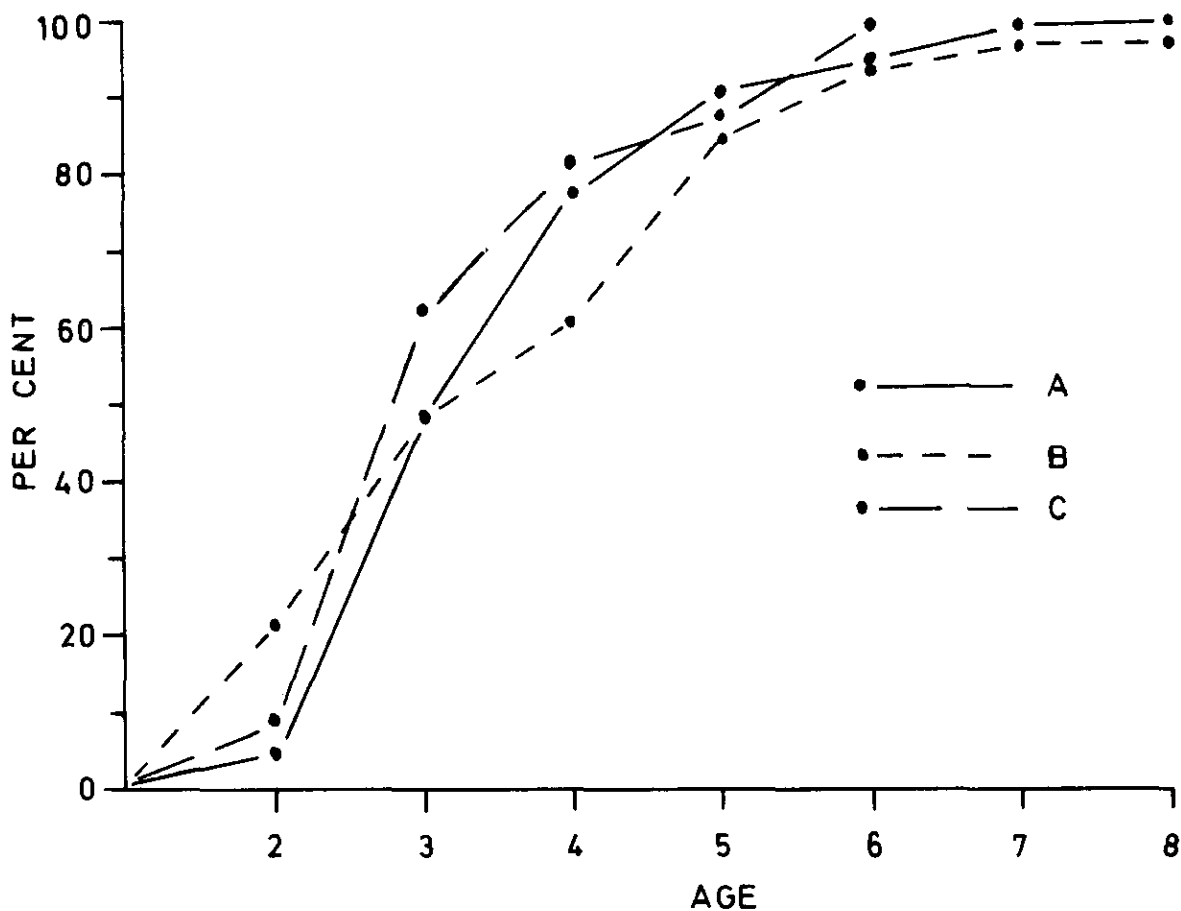


Fig. 2. The sexual maturity of female hooded seals. Accumulated frequencies in samples collected off Newfoundland-Labrador in 1967-71 (B) and in 1972 (C) are compared to data from the Denmark Strait (A).

been recalculated from the age distribution of animals matured within the three breeding seasons preceding capture and therefore are directly comparable to the frequencies from the breeding seals at Newfoundland.

The fairly close fit of the three graphs in Fig. 2 suggests that the method used to calculate maturity frequencies in this report may be relied upon to give consistent results, even for quite small samples. The differences between the two Newfoundland samples (B and C in Fig. 2) and between each of them and the sample from the Denmark Strait (A in Fig. 2) are not significant at the 5% level ( $t_{BC} = -1.26$ ,  $t_{AB} = +0.50$  and  $t_{AC} = -0.55$ ).

Quite obviously it is impossible to decide whether newly matured animals in the older maturing age-groups with only one or two corpora in the ovaries have failed to conceive at the first possible opportunity. The recorded missing corpora therefore are minimum estimates and the rates of presumed pregnancies must be used as maximum estimates of reproductive success.

The present maximum estimates for hooded seals at Newfoundland with an average of about 97% are comparable to more direct estimates based on the incidence of corpora lutea from the last breeding season recorded in the Denmark Strait and at Jan Mayen. The pregnancy rates estimated from the combined samples from those areas increase from 0.778 at 3 years to 1.000 at 6 years with a mean rate of 0.982 for 6 year old and older seals and an overall average of 0.947 for all mature females.

By comparison it may be mentioned that data from migrating harp seals published by Sergeant (1966) indicate an average rate of 0.929 near term pregnancies among mature females in January. This is in close agreement with the average rate of 0.92 presumed pregnancies estimated for the Newfoundland harp seals from missing corpora in breeding females (Øritsland, 1971). Data on near term pregnancies have also been recorded for the southern crabeater seal (*Lobodon carcinophagus*). For this species which is virtually unexploited by man but probably is a frequent prey of



killer whales (*Orcinus orca*), a maximum pregnancy rate of 0.87 was estimated (Øritsland, 1970).

The high maximum rates found for the exploited and possibly increasing stock of hooded seals breeding at Newfoundland therefore may be accepted. An average rate of 0.95 is suggested as a conservative estimate of the rate of reproduction for mature females in the Northwest Atlantic.

### Acknowledgements

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# Analysis of the Southern Gulf of St. Lawrence Herring Stock and Implications Concerning its Future Management

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## Abstract

The purse-seine fisheries which developed in the southern Gulf of St. Lawrence and Southwest Newfoundland in the mid-1960's were based mainly on the southern Gulf of St. Lawrence stock complex of herring at different times and places along its seasonal migration route. Landings from this stock complex increased rapidly from 50,000 tons in 1964 to nearly 300,000 tons in 1969 and subsequently declined to 70,000 tons in 1972. Total stock size, estimated by cohort analyses, declined from 1,840,000 tons in 1965 to 506,000 tons in 1971, a reduction of 75%. Over the same period the decline was equally pronounced in the adult stock size which by 1972 had been reduced to only 12% of its original level in 1965. The very large 1958 year-class of autumn-spawners and the large 1959 year-class of spring-spawners accounted for nearly 60% of the exploitable stock size in 1965 and remained dominant until 1970. Recruitment to the southern Gulf of St. Lawrence herring stocks has been relatively poor since the late 1950's for both spring- and autumn-spawners, the strongest year-classes being the 1960 year-class of spring-spawners (about 1/5 of the 1959 strength) and the 1962 and 1963 year-classes of autumn-spawners (about 1/5 the strength of the 1958 year-class). Fishing mortality rates increased steadily from 0.04 in 1965 to 0.56 in 1970 and subsequently declined to probably less than 0.30 in 1972. Adjusted catch-per-unit-effort data adequately reflected the change in stock abundance estimated by cohort analyses.

The proportion of the southern Gulf of St. Lawrence herring stocks migrating to Southwest Newfoundland increases continuously with age, from less than 20% in the recruiting age-groups to 100% at age-group 10. Stock sizes in Southwest Newfoundland, estimated by several methods, declined from about 700,000 tons in 1966 to less than 50,000 tons in 1972.

It is shown that, excluding the effects of the fishery, the abundance of the southern Gulf of St. Lawrence herring stocks would have declined significantly from 1965 to 1971 due to inadequate recruitment. The effect of the purse-seine fishery was therefore to accelerate the rate and to increase the magnitude of the decline. It is also indicated that the low recruitment since the late 1950's is probably normal for this stock rather than the exception, large year-classes occurring only infrequently. In the future, therefore, average yields will probably be substantially less than those of the late 1960's. This will be particularly so for Southwest Newfoundland which is dependent mainly on large, old herring.

## Introduction

Prior to 1965 annual landings from the Newfoundland and Gulf of St. Lawrence herring fisheries tended to reflect the demand for the product rather than the abundance of the resource. These fisheries were traditionally carried on with fixed gears and were associated largely with the demand for herring as bait and food. With the exception of the periods during and just after World Wars I and II, when large quantities of pickled herring were required as food, landings were undoubtedly substantially lower than potential yields (Hodder, 1966 *a*; Tibbo, 1966). This situation rapidly changed after 1965 when large concentrations of herring were found to overwinter in the fjords along the western half of the south coast of Newfoundland (hereinafter referred to as Southwest Newfoundland or Area J; see Fig. 1). From a single vessel in the winter of 1964-65 the

seiner fleet increased rapidly to more than 50 vessels by 1968-69 (Hodder, 1969). The increased interest in the herring fishery also resulted in the expansion of fishing operations so that by 1967 the mobile purse-seine fleet had expanded their activities to include various areas of the southern Gulf of St. Lawrence (Fig. 1, Area T) and nearly all months of the year (Iles and Tibbo, 1970).

Coincident with the rapid development of the purse-seine fishery was the construction of several large reduction plants at various places in Areas J and T. There was thus a dramatic increase in the production of herring meal and oil which soon far exceeded the utilization of herring as food and bait (Hodder, 1969). This trend continued until 1970 when markets for food herring became available in Europe as a result of the drastic decline in the Northeast Atlantic herring stocks. Consequently since 1970 an increasing proportion of the

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herring caught in Areas J and T has been diverted to food and by 1972 more than 40% of the total herring landings were utilized in this manner.

Investigations into the herring stocks supporting the winter fishery in Southwest Newfoundland (Area J) were begun at the St. John's Biological Station in 1965, involving the intensive sampling of the mobile fleet catches, the collection of detailed catch and effort statistics, spawning and larval surveys, acoustic surveys and tagging (Hodder, 1966a; Hourston, 1968; Winters, 1970). Similar but less intensive investigations were conducted in the southern Gulf of St. Lawrence by the St. Andrews Biological Station, New Brunswick (Tibbo *et al.*, MS 1969). These studies soon revealed that the winter fishery in Area J was based almost entirely on mature adult herring consisting of a mixture of both spring and autumn spawning types (Hodder, 1971) which migrated to the area in November and remained until early April, and the fisheries in Area T were based

mainly on spring-spawners at Magdalen Islands and the Chaleur Bay area (Fig. 1) during April to June and on autumn-spawners in the Gaspé-Chaleur Bay area during July to October. The comparisons of various biological characteristics of herring from different areas (Hodder and Parsons, 1971a, 1971b; Parsons and Hodder, 1971b) together with the results of extensive tagging (Winters, 1970, MS 1971a; Beckett, MS 1971) have confirmed the hypothesis of Hodder (1969) that the herring which support the winter fishery in Area J represent the over-wintering phase of a stock complex of herring largely derived from spring and autumn spawnings in the southern part of the Gulf of St. Lawrence (hereinafter referred to as the southern Gulf of St. Lawrence stock). Thus the purse-seine fisheries which developed in Areas J and T during the mid-1960's were not based so much on completely different stocks but rather mainly on parts of the same stock complex at different times and places along its seasonal migration route. This has important implications in so far as conservation and management of the resource is concerned.

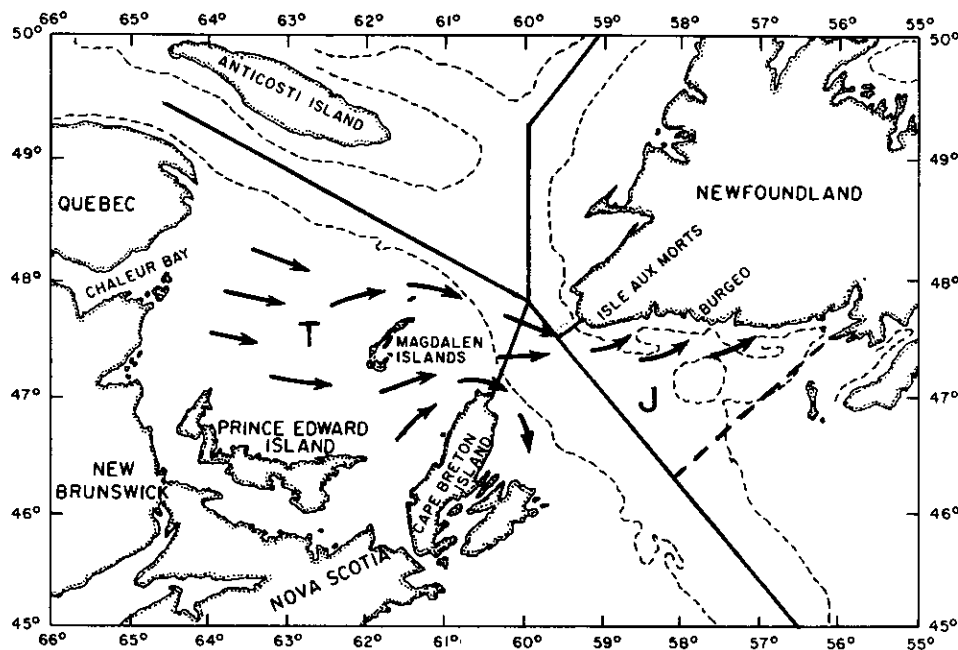


Fig. 1 Map of the southern Gulf of St. Lawrence and Newfoundland showing the autumn migration of herring.

The lack of significant recruitment to the fishable stocks (Hodder, 1971; Winters and Parsons, MS 1972) together with the dangerously high rates of exploitation (Winters, MS 1971b) has precipitated concern about the future of the fishery, and conservation measures have recently been imposed on the catches of herring in Areas

J and T by the Canadian Atlantic Herring Management Committee. In this paper we have attempted to assess the status of the southern Gulf of St. Lawrence stock complex in relation to the yields as the purse-seine fisheries in Areas J and T developed, employing the most recent virtual population techniques as well as

information from tagging experiments and catch/effect statistics, and to predict potential yields from the resource under rational management and the effect of such management on the fisheries in the various areas.

## Materials and Methods

### Compilation of length and age data

The basic data used to determine the length and age composition of the catches in the Area J winter fishery (November to early April) for the 1965-71 seasons were obtained from Hodder *et al.* (MS 1972) and for the 1971-72 season from Winters and Parsons (MS 1972). Since Area J represents only a part of ICNAF Div. 3P, the catch statistics for the fishery in this area were derived from detailed statistical records on file at the St. John's Biological Station rather than from ICNAF Statistical Bulletins. For the Area T spring and summer fisheries, catch statistics pertain to nominal catches for Div. 4T in ICNAF Statistical Bulletins, and the length compositions of catches are based on length frequencies given in Tibbo *et al.* (MS 1969) and in ICNAF Sampling Yearbooks. Although Tibbo *et al.* (MS 1969) provide age-length keys for samples taken up to 1968, for consistency in compiling the age compositions of the catches over the entire period under consideration (i.e. 1965-72), the age-length keys for the Area J fishery (Hodder *et al.*, MS 1972) were applied to the Area T length frequencies to obtain the age compositions of the Area T catches. In this context it should be noted that the techniques of age and year-class designation used at the St. John's Biological Station have been recommended for use by ICNAF Scientists in herring investigations of the Northwest Atlantic (Hunt *et al.*, MS 1973). In accordance with the recommended convention, age-groups have been used instead of ages. Thus a fish is placed in age-group 0 in the year of its birth, regardless of whether it was spawned in the spring or autumn, and both types enter the next age-group at the same time of the year. To maintain consistency of age-group designation throughout the fishery year, a cohort is considered to enter an age-group at the start of the fishery year, i.e. in April.

The assessment of the southern Gulf of St. Lawrence stock complex is complicated by the mixture of spring- and autumn-spawners in the catches and these have to be treated separately because of differences in growth and age composition. In the Area J winter fishery the separation of the two components is relatively simple because the maturity stages corresponding to each component are readily distinguishable in the samples and immature fish are relatively scarce. Consequently the age composition and relative contribution of spring and autumn spawners were readily obtainable from the

sampling data in order to determine the age compositions of these two components in the catches for Area J. No such separation of sampling data into spring- and autumn-spawners was available for the Area T summer fishery. However, Messieh and Tibbo (1971) have indicated that herring taken during April to June consisted mainly of spring-spawners, whereas those taken during July to October were mainly autumn-spawners. Consequently the age-length key for spring-spawners of the preceding winter fishery in Area J was applied to the length frequencies for the April-June period to obtain the age composition of the catch of spring-spawners for that period. Similarly all fish caught in Area T during July to October were assumed to be autumn-spawners, and the age-length key for autumn spawners in the subsequent winter fishery in Area J was applied to the Area T length frequencies to obtain the age composition of the catch of autumn-spawners for the summer-autumn period. The application of the age-length keys in this manner has the effect of minimizing differences in growth. For spring-spawners growth is negligible between the Area J over-wintering period and the period of the spring fishery in Area T, because feeding does not resume until mid-April and spawning occurs in May. For autumn-spawners most of the growth in length probably occurs during the pre-spawning period, as Hodder *et al.* (MS 1973) indicate that most of the post-spawning feeding is probably associated with the replenishment of fat reserves rather than growth in length.

All length and age composition data were initially compiled and weighted (using appropriate length-weight data) to monthly catches. These were then combined to represent the age compositions of the yearly catches for the two spawning components separately. In this context the yearly catches pertain to the 12-month period from April of one year to March of the next, and the stock sizes pertain to the beginning of the fishery year in April.

### Estimate of natural mortality used

Using age-composition data given by Day (1957) for herring stocks in the southern Gulf of St. Lawrence during the 1940's, Beverton (1963) calculated values of total mortality coefficients ( $Z$ ) ranging from 0.20 to 0.35. The relatively low level of the catches during this period (average about 35,000 tons) suggests that the fishing mortality ( $F$ ) was low, probably less than 0.10. Also the stock complex of herring in the southern Gulf of St. Lawrence (our Area T) has growth, maturity and life-span characteristics very similar to those for Atlanto-Scandian herring, for which natural mortality ( $M$ ) has been accurately estimated to range from 0.15 to 0.18 (Beverton, 1963). A value of  $M = 0.2$  has therefore been considered realistic for the southern Gulf of St. Lawrence stock complex.

## Results

### Trends in landings

Yearly landings from the southern Gulf of St. Lawrence stock complex are shown in Fig. 2. In the Area J winter fishery landings increased rapidly from less than 10,000 tons in 1964 to about 140,000 tons in 1968 and 1969 and declined to less than 17,000 tons in 1972. In the Area T summer fishery, purse-seining did not become a significant factor until 1967, after which landings increased to a peak level of 175,000 tons in 1970 and declined to about 50,000 tons in 1972. The continued increase in the Area T landings after the Area J landings had peaked is attributed to a significant diversion of effort from the Southwest Nova Scotia summer fishery in 1969 to Area T (Iles and Tibbo, 1970).

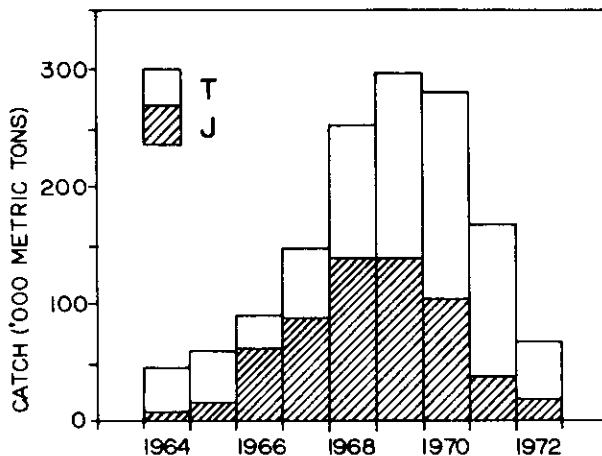


Fig. 2 Herring landings from the southern Gulf of St. Lawrence stock complex, 1964-72.

The trend in yearly landings from the stock complex as a whole (Fig. 2) indicates a rapid increase from about 50,000 tons in 1964 to a peak level of 300,000 tons in 1969 followed by a decline to about 70,000 tons in 1972. The rapid increase was associated with the expansion of purse-seining activities and reduction facilities. The equally rapid decline was due to reduced stock abundance, the reasons for which are discussed later.

### Length and age composition of catches

Although the southern Gulf of St. Lawrence stock complex is exploited at different times of the year in different areas, length and age-composition data (expressed as percentages), for both spring- and autumn-spawning components, reveal a remarkable degree of similarity for herring sampled in the Area J winter

fishery and in the Area T summer fisheries from 1965 to 1969 (Fig. 3). During this period the fisheries in both areas were based mainly on adult herring (age-group 6 and older). The Area J fishery in 1970 and 1971 continued to be based on adult fish, whereas the Area T fishery gradually shifted to the exploitation of smaller and younger fish which apparently did not migrate to Area J. The differences in the length frequencies for spring-spawners during 1965-68 are attributable to seasonal growth, the fishery in Area T being carried on in April-June whereas in Area J it occurs in the following November-March period.

For autumn-spawners in both areas the fisheries during 1965-69 were dominated largely by the very abundant 1958 year-class (Fig. 3) and this pattern continued into 1970 and 1971 in Area J, where the modal length of herring in the catches gradually increased from 32 cm in 1965 to 35-36 cm in 1971. The change in modal length for Area T after 1969 is reflected in the change in age composition due to the exploitation of smaller and younger fish.

For spring-spawners the dominant year-class was that of 1959, which contributed to the bulk of the catches during 1965-69 in both areas and during 1970-71 in Area J (Fig. 3), where the modal length gradually increased from 31 cm in 1965 to 33-34 cm in 1971. As for autumn-spawners, the catches of spring-spawners in Area T consisted mainly of smaller and younger fish in 1970 and 1971.

### Stock size estimates

For the Gulf of St. Lawrence stock, numbers of spring- and autumn-spawning herring in each year of the fishery were derived by sequential computation, using cohort analysis (Pope, 1972), from the numbers caught at each age-group (Table 1). An assumed value of  $M = 0.20$  and starting values for  $F_r$  (fishing mortality in the terminal year) increasing with age were used. To provide reliable estimates of stock size and fishing mortality rates in 1970 and 1971 age-group compositions of anticipated catches in 1972 and 1973 have been estimated and used in the cohort analyses.

There has been a continuous and pronounced decline in the stock sizes of both spring- and autumn-spawners since the development of a significant purse-seine fishery began in 1965 (Table 2). The spring-spawning stock declined from 2,782 million fish weighing 604,000 tons in 1965 to 679 million fish weighing 128,000 tons in 1971. Over the same period the autumn-spawning stock was reduced from 7,670 million fish with a biomass of 1,236,000 tons to 2,076 million fish with a biomass of 378,000 tons. Total stock size declined from 10,452 million fish weighing 1,840,000 tons in 1965 to

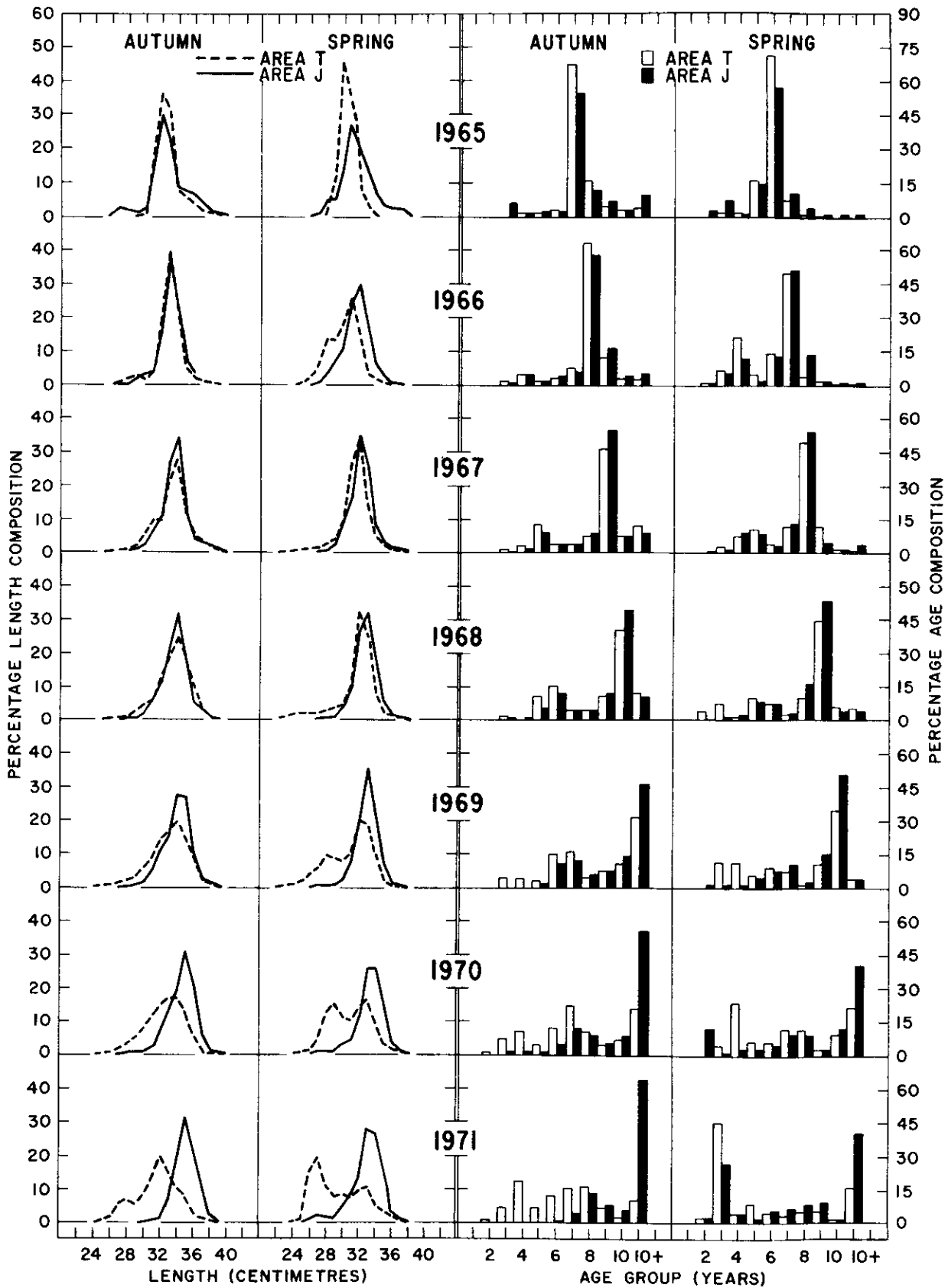


Fig. 3. Length and age composition of spring- and autumn-spawning herring in the southern Gulf of St. Lawrence and Southwest Newfoundland fisheries, 1965-71.

TABLE I. Numbers of spring- and autumn-spawning herring (millions) caught per year (April-March) and age-group in the southern Gulf of St. Lawrence (Area T) and along Southwest Newfoundland (Area J), 1965-71. (Weights caught (W<sub>c</sub>) are in metric tons.)

Area	Age-group	Spring-spawners										Autumn-spawners									
		1965	1966	1967	1968	1969	1970	1971	1965	1966	1967	1968	1969	1970	1971						
T	2	-	0.3	-	5.4	-	-	3.2	-	-	-	0.6	2.4	2.2	4.9						
	3	2.1	7.4	3.4	9.5	16.4	7.9	54.9	0.7	2.1	2.1	5.0	20.1	42.0	32.9						
	4	1.9	22.9	11.0	1.9	16.5	38.2	5.8	2.4	3.5	3.5	1.2	18.2	57.6	91.0						
	5	26.7	4.6	14.5	13.9	8.9	10.6	11.0	0.6	0.9	13.4	30.5	17.7	28.5	33.6						
	6	114.2	15.1	5.2	9.9	12.9	9.3	6.5	0.9	1.5	4.3	45.4	74.3	20.4	56.4						
	7	12.6	54.9	17.5	2.9	10.7	19.9	4.8	18.8	3.8	4.2	11.6	80.5	123.6	74.8						
	8	1.8	4.1	69.4	14.7	3.0	18.9	6.8	4.4	30.0	8.4	13.0	24.4	60.4	81.0						
	9	0.5	0.9	16.6	61.4	15.8	4.8	6.3	1.4	5.9	48.6	32.6	37.4	22.9	31.9						
	10	0.1	0.4	2.1	7.6	47.6	15.7	2.5	0.8	1.5	7.3	121.5	54.1	35.8	16.3						
	11	0.1	0.2	0.7	4.5	3.3	32.5	6.1	0.4	0.5	6.0	16.6	135.0	34.7	12.7						
	12	-	0.1	0.2	1.8	1.9	1.6	12.5	0.3	0.4	2.6	9.6	8.1	77.0	13.5						
	12+	-	0.1	0.2	1.0	0.5	1.1	0.6	0.3	0.4	3.6	8.8	7.0	4.0	25.4						
	N <sub>c</sub>		160.0	111.0	140.8	134.5	137.5	160.5	121.0	28.0	48.0	479.2	279.2	559.1	474.4						
W <sub>c</sub>		37,416	24,969	36,035	35,054	33,671	39,593	23,960	6,838	11,936	26,601	77,076	120,735	135,904	107,173						
J	2	0.4	0.1	0.4	0.8	0.5	11.1	1.1	-	-	-	1.8	0.2	0.2	0.2						
	3	1.2	2.2	0.9	1.9	2.5	1.0	11.5	2.8	0.1	0.5	1.8	1.4	1.9	0.2						
	4	0.3	4.5	8.5	4.0	2.1	2.6	2.1	0.8	7.8	3.8	1.8	1.7	2.0	0.5						
	5	2.3	0.6	7.5	16.4	7.3	3.1	1.1	1.1	3.3	21.3	16.8	5.0	3.6	0.4						
	6	9.1	4.9	2.7	14.4	12.7	4.3	2.6	2.6	6.3	10.4	39.2	36.8	14.0	1.2						
	7	1.6	19.6	12.6	5.5	16.7	8.5	2.8	24.5	9.1	8.7	14.0	42.8	34.8	4.4						
	8	0.6	5.2	48.4	32.8	5.4	8.7	3.8	5.4	96.0	20.6	13.1	20.0	26.7	12.8						
	9	0.2	0.8	4.3	107.8	23.6	3.1	4.1	3.1	27.6	128.6	39.9	26.0	15.2	7.9						
	10	0.1	0.2	1.4	8.0	80.2	10.9	0.9	1.6	7.6	19.2	156.5	49.5	23.1	5.1						
	11	0.1	0.1	1.0	2.5	3.7	37.2	2.8	1.4	3.3	10.0	15.0	145.2	45.9	12.3						
	12	0.1	0.1	0.8	1.8	1.0	0.3	9.5	1.1	2.5	4.3	8.8	8.7	101.9	17.0						
	12+	-	0.1	1.5	2.8	1.3	1.3	0.2	0.1	2.4	6.0	7.0	7.4	5.3	32.1						
	N <sub>c</sub>		16.0	38.4	90.0	198.7	157.0	91.0	42.4	45.5	166.0	233.4	315.7	344.7	274.6						
W <sub>c</sub>		3,929	9,834	24,764	56,706	46,222	25,443	11,250	10,827	42,268	61,035	82,900	93,361	77,635	26,250						
T+J	2	0.4	0.4	0.4	6.2	0.5	11.1	4.3	-	-	-	2.4	2.6	2.4	5.1						
	3	3.3	9.6	4.3	11.4	18.9	8.9	66.4	2.8	0.8	2.6	6.8	21.5	43.9	33.1						
	4	2.2	27.4	19.5	5.9	18.6	40.8	7.9	0.9	10.2	7.3	3.0	19.9	59.6	91.5						
	5	29.0	5.2	22.0	30.3	16.2	13.7	12.1	1.7	4.2	34.7	47.3	22.7	32.1	34.0						
	6	123.3	20.0	7.9	24.3	25.6	13.6	9.1	2.3	7.8	14.7	84.6	111.1	84.4	57.6						
	7	14.2	74.5	30.1	8.4	27.4	28.4	7.6	43.3	12.9	12.9	25.6	123.3	158.4	79.2						
	8	2.4	9.3	117.8	47.5	8.4	27.6	10.6	9.8	126.0	29.0	26.1	44.4	87.1	93.8						
	9	0.7	1.7	20.9	169.2	39.4	7.9	10.4	4.5	33.5	177.2	73.5	63.4	38.1	39.8						
	10	0.2	0.6	3.5	15.6	127.8	26.6	3.4	2.4	9.1	26.5	278.0	103.6	58.9	21.4						
	11	0.2	0.3	1.7	7.0	7.0	69.7	8.9	1.8	3.8	16.0	31.6	280.2	80.6	25.0						
	12	0.1	0.2	1.0	3.6	2.9	1.9	22.0	1.4	2.9	6.9	18.4	16.8	178.9	30.5						
	12+	-	0.2	1.7	3.8	1.8	1.3	0.7	0.7	2.8	9.6	15.8	14.4	9.3	57.5						
	N <sub>c</sub>		176.0	149.4	230.8	333.2	294.5	251.5	163.4	73.5	214.0	337.4	612.1	823.9	833.7						
W <sub>c</sub>		41,345	34,803	60,799	91,760	79,893	65,036	35,210	17,665	54,204	87,636	159,976	214,096	213,539	133,423						



TABLE 2. Stock size estimates (millions) at the start of each fishery year and corresponding fishing mortality coefficients during each fishery year for the southern Gulf of St. Lawrence stocks of spring-spawning and autumn-spawning herring, 1965-71.

Type	Age-group	Mean weight (gm)	Stock size at start of fishery year							F during fishery year							Percent recruitment	
			1965	1966	1967	1968	1969	1970	1971	1965	1966	1967	1968	1969	1970	1971		Weighted mean F
Spring	2	80	325	132	130	193	63	505	30	0.01	0.01	0.04	0.01	0.01	0.02	0.02	0.02	13
	3	150	335	265	108	106	152	51	403	0.01	0.04	0.06	0.04	0.14	0.23	0.18	0.06	40
	4	200	103	271	209	84	80	107	33	0.02	0.06	0.12	0.11	0.31	0.40	0.32	0.13	87
	5	230	426	82	210	153	60	46	59	0.08	0.07	0.24	0.19	0.33	0.43	0.27	0.15	100
	6	254	1409	323	63	142	98	38	24	0.10	0.07	0.15	0.21	0.34	0.45	0.36	0.14	100
	7	268	120	1042	246	44	94	57	20	0.14	0.08	0.14	0.23	0.39	0.56	0.42	0.14	100
	8	280	27	85	174	29	52	27	0.01	0.13	0.18	0.36	0.57	0.89	1.00	0.70	0.23	100
	9	291	15	22	61	31	100	16	22	0.05	0.08	0.47	0.43	0.57	0.70	0.60	0.43	100
	10	302	10	12	17	536	46	7	22	0.02	0.06	0.27	0.80	0.68	0.88	0.72	0.65	100
	11	312	6	8	9	10	11	16	7	0.02	0.05	0.22	1.37	1.13	0.99	0.75	0.92	100
	12	320	4	5	6	6	2	2	3	0.02	0.03	0.19	1.08	0.74	1.01	0.81	0.89	100
	12+	335	2	5	8	9	4	4	2	0.02	0.04	0.20	1.22	0.99	1.15	0.83	0.70	100
				2,782	2,252	1,852	1,488	979	1,042	679	0.08 <sup>1</sup>	0.08 <sup>1</sup>	0.18 <sup>1</sup>	0.37 <sup>1</sup>	0.53 <sup>1</sup>	0.70 <sup>1</sup>	0.52 <sup>1</sup>	F <sub>12-12</sub>
N <sub>s</sub> (× 10 <sup>6</sup> )			604	524	446	356	237	176	128	0.10 <sup>1</sup>	0.08 <sup>1</sup>	0.18 <sup>1</sup>	0.37 <sup>1</sup>	0.53 <sup>1</sup>	0.70 <sup>1</sup>	0.52 <sup>1</sup>	F <sub>12-12</sub>	
W <sub>s</sub> ('000 tons)																		
Autumn	2	40	1612	860	650	392	640	248	(250)	<0.01	0.01	<0.01	<0.01	<0.01	0.01	0.01	<0.01	3
	3	80	1129	1320	704	532	319	522	201	<0.01	0.01	0.01	0.01	0.02	0.07	0.17	0.02	18
	4	150	428	922	1080	574	429	255	398	<0.01	0.01	0.01	0.01	0.05	0.14	0.22	0.03	27
	5	193	562	349	746	877	468	333	182	<0.01	0.01	0.05	0.06	0.09	0.24	0.23	0.07	64
	6	214	885	458	282	579	676	349	214	<0.01	0.02	0.06	0.18	0.20	0.27	0.41	0.11	100
	7	232	2612	723	368	218	398	453	218	0.02	0.02	0.04	0.14	0.42	0.41	0.45	0.10	100
	8	247	234	2099	580	290	155	214	245	0.02	0.02	0.04	0.11	0.38	0.53	0.41	0.11	100
	9	257	109	183	1604	449	214	87	103	0.05	0.07	0.06	0.13	0.40	0.46	0.44	0.18	100
	10	268	47	85	119	1153	302	117	45	0.05	0.23	0.13	0.20	0.40	0.46	0.34	0.18	100
	11	279	30	36	61	74	693	153	50	0.06	0.13	0.28	0.31	0.48	0.65	0.45	0.34	100
	12	290	13	23	26	36	32	314	50	0.07	0.12	0.34	0.64	0.59	0.74	0.50	0.57	100
	12+	310	9	15	26	28	21	110	9	0.12	0.15	0.34	0.84	0.88	0.84	0.59	0.88	100
	N <sub>s</sub> (× 10 <sup>6</sup> )			7670	7073	6246	5202	4347	3060	2076	0.27	0.18	0.43	0.89	1.27	0.85	0.65	0.87
W <sub>s</sub> ('000 tons)			1,236	1,221	1,154	1,024	825	579	378	0.02 <sup>1</sup>	0.06 <sup>1</sup>	0.11 <sup>1</sup>	0.24 <sup>1</sup>	0.41 <sup>1</sup>	0.52 <sup>1</sup>	0.46 <sup>1</sup>	F <sub>12-12</sub>	
N <sub>s</sub> (× 10 <sup>4</sup> )			10,452	9,325	8,098	6,690	5,326	4,102	2,755	0.04	0.07	0.13	0.27	0.43	0.56	0.48	F <sub>12-12</sub>	
Autumn			1,840	1,745	1,600	1,377	1,062	755	506									

<sup>1</sup>Weighted mean for fully recruited age-groups.

about 2,750 million fish weighing 506,000 tons in 1971, a reduction of approximately 75% both in numbers and in biomass. The relative contributions of spring- and autumn-spawners to the total stock complex have remained almost constant throughout the entire period.

The large 1959 year-class accounted for over 50% by number of the spring-spawning stock in 1965 and remained the dominant year-class in that stock until 1970, when the 1968 year-class became partially recruited as 2-year-olds, but by 1971 the 1959 year-class constituted only about 5% of this stock. Similarly, the very large 1958 year-class comprised nearly 35% by number of the autumn-spawning stock in 1965 and remained dominant until the 1967 year-class was partially recruited as 3-year-olds in 1970, but by 1971 the 1958 year-class was reduced to less than 6% of the stock.

### Fishing mortality rates

Estimates of fishing mortality rates (Table 2), obtained from cohort analysis, indicate that recruitment to the fishery is essentially complete at age-group 5 for spring-spawners and at age-group 6 for autumn-spawners. Values of *F* for fully recruited age-groups of spring- and autumn-spawners combined increased from a very low level of 0.04 in 1965 to a high of 0.56 in 1970. Since there was a significant reduction in fishing effort during the 1971-72 winter fishery in Area J (Winters and Parsons, MS 1972) and no apparent increase in effort in Area T during the 1971 summer fishery, the overall fishing mortality rate declined to 0.48 in 1971. The relatively low level of stock abundance during 1972 resulted in poor fisheries in both Areas T and J, and undoubtedly the fishing mortality rate was substantially reduced, *F* in 1972 probably being less than 0.30.

The average values of *F* during 1965-71 for fully recruited spring-spawners are consistently higher than those for autumn-spawners. The reason for this is not clear, but it may be related to the greater vulnerability of spring-spawners to both purse seiners and fixed gears during their spawning period.

For both spring- and autumn-spawners, values of *F* increase with age, particularly after 1967 (Table 2). This coincides with the period of major increase in the Area J catches (Fig. 2). Since only the older mature herring migrate to Area J, the increase in *F* with age is probably due to the effects of the selective fishery in that area during the over-wintering period.

### Recruitment to the exploitable biomass

Recruitment rates (Table 2, last column) for the young age-groups were estimated as the ratio of the

weighted mean *F* values for these age-groups to the *F* corresponding to the age-group at which recruitment to the fishable stock is considered to be complete, i.e. at age-group 5 for spring-spawners and age-group 6 for autumn-spawners. Spring-spawners recruit fairly rapidly with 40% of the available population recruited by age-group 3 and nearly 90% by age-group 4. Autumn-spawners recruit more slowly with less than 30% recruited at age-group 4 and about 64% at age-group 5. The slower recruitment of autumn-spawners is probably related to their later age at reaching maturity compared to spring-spawners. The estimated ages at 50% recruitment are 3.5 years for spring-spawners and 4.7 years for autumn-spawners.

The population numbers of recruiting age-groups (2-6) were adjusted for partial recruitment and converted to weights to obtain the recruited biomass for each year as follows:

Year	Recruited biomass ('000 tons)		
	Spring Sp.	Autumn Sp.	Total
1965	41	105	146
1966	54	100	154
1967	44	147	191
1968	23	140	163
1969	24	81	105
1970	27	59	86
1971	30	40	70

The recruited biomass of both spring- and autumn-spawners was generally very low during the 1965-71 period, mainly because of the succession of a series of poor year-classes since the late 1950's (Table 2). The 1964-68 year-classes of autumn-spawners have been particularly poor as were also the 1963-67 year-classes of spring spawners. This explains the general decline in the recruited biomass of each spawning group in recent years. The 1968 year-class of spring-spawners was somewhat better than those of 1963-67 and the recruited biomass of spring-spawners will probably increase slightly in 1972. However, since this year-class is only about 1/8 as good as the abundant 1959 year-class of spring-spawners, its effect on the total recruited biomass will be insignificant. There is no evidence to date to indicate that year-classes of autumn-spawners since 1968 are large enough to significantly increase the recruited biomass in 1972 and 1973, if current levels of fishing intensity are maintained.

### Relationship between exploitable biomass, recruitment and catch

Mean weights for age-groups were applied to the adult population numbers given in Table 2 to obtain the

adult biomass for each spawning group at the start of each fishing year. These were combined and added to the total recruited biomass (see preceding section) for each year to obtain the biomass of the stock available to the fishery, i.e. the exploitable biomass. Although stock sizes of year-classes recruiting to the exploitable stock in 1972 and 1973 are not completely known, estimates for those year-classes which will contribute to the adult stock in those years are available (Table 2). Consequently, adult stock biomass has been estimated for 1972 and 1973, and these are shown in Fig. 4, together with exploitable biomass, adult biomass and recruited biomass for 1965-71 and the catch for 1965-72.

The adult biomass has constituted 80-90% of the exploitable biomass since the mobile fishery began in

1965, despite the fact that the adult biomass has been drastically reduced in recent years. This reflects the continued lack of good year-classes recruiting to the exploitable stock. With the current low level of the adult biomass, the entrance of a strong year-class to the exploitable stock would significantly change the ratio of adult biomass to exploitable biomass.

Although recruitment exceeded the catches during 1965-67 (Fig. 4), the differences were insufficient to maintain the exploitable stock at its initial level and by 1967 the latter had declined by 20%. The continued increase in the fishing effort (see Table 3) and the general decline in the recruited biomass after 1967 resulted in catches which greatly exceeded the recruited biomass. Consequently, by 1969 the exploitable biomass

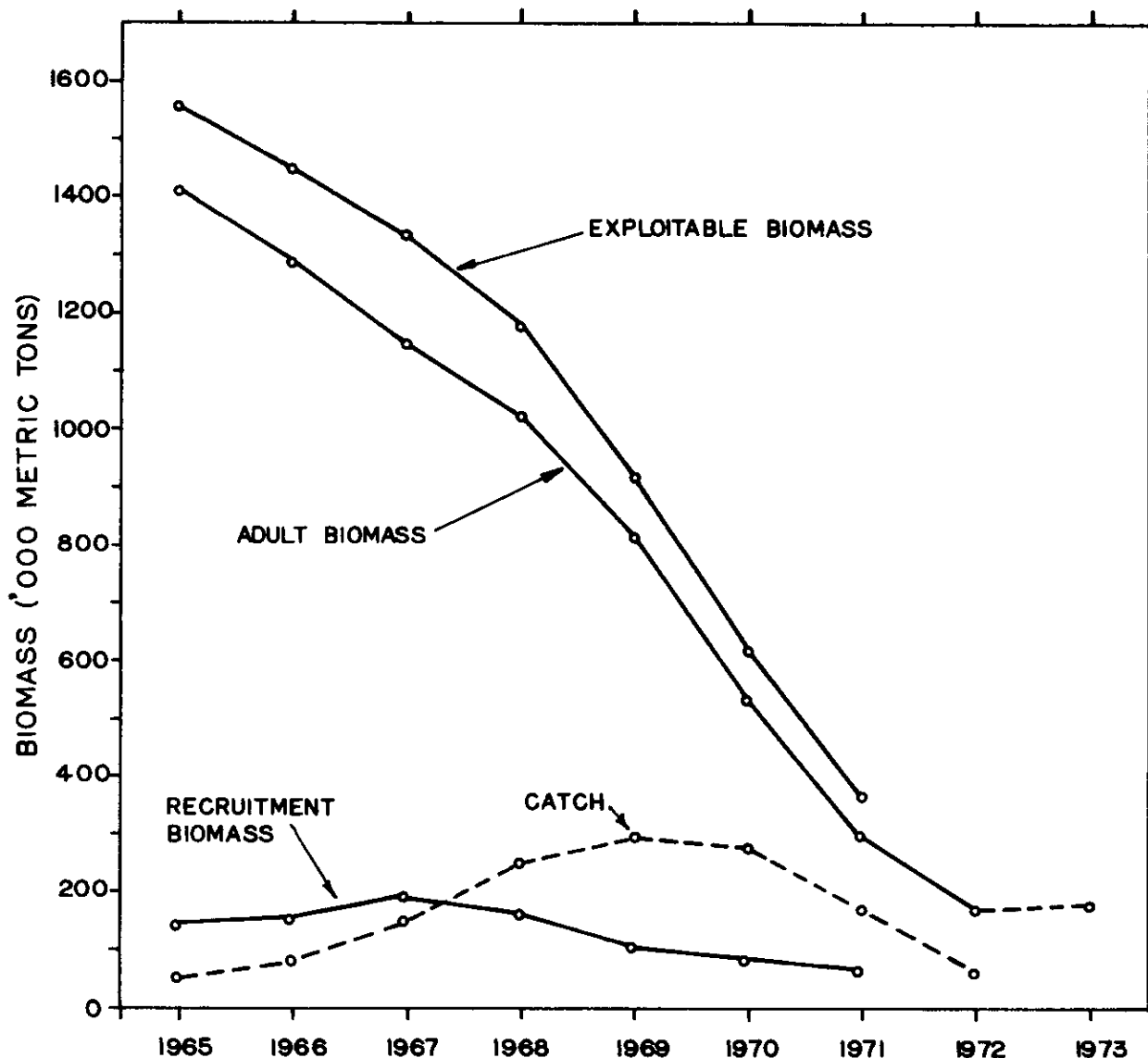


Fig. 4 Exploitable biomass, adult biomass, recruited biomass and catch for the southern Gulf of St. Lawrence herring stock, 1965-72.

was only about 60% of its initial 1965 level and by 1971 it had declined to less than 25%. The attrition in the adult biomass during this period was equally pronounced and by the start of the 1972 fishery year it had been reduced to only 12% of its initial level in 1965. The low level of the catch in 1972 (about 70,000 tons) should allow the adult biomass in 1973 to remain at approximately the same level as at the start of 1972 (i.e. 170,000-180,000 tons).

The total catch of the exploitable stock during 1965-70 was about 1,130,000 tons. Subtracting this value from the total stock biomass of 1,840,000 tons in 1965 (Table 2) gives a value of 710,000 tons which is an estimate of what the residual stock biomass would have been at the start of 1971 if recruitment to the exploitable stock and growth had balanced the losses in biomass due to natural mortality during the period. Since the estimated stock biomass at the start of 1971 was only about 474,000 tons (Table 2), the losses from the stock due to natural mortality was substantially greater than the production of biomass due to growth and recruitment.

#### Trends in catch-per-unit-effort and effort

Detailed catch and effort information has been collected for most of the individual vessels participating in the Area J purse-seine fishery since its development in 1965. The size of the seiners operating in the area have ranged from 40 to over 600 tons, but most of those which maintained a consistent association with the fishery were in the 150-325 ton range. The data from a selected group of these were compiled and analysed for trends in catch-per-unit-effort and effort.

The actual fishing operation involves searching, catching, delivery of loads to port, unloading and return to the fishing area. Analysis of the data available for

individual vessels revealed that the most appropriate effort measure was the total operating time in days. For some vessels the actual operating time (excluding such factors as bad weather, engine breakdowns, etc.) could be determined fairly precisely. For other vessels, when the non-operating time was not completely known, it was estimated using the criterion (based on information on the fishing behaviour of the vessels) that a vessel was out of operation if the time between the last landing date and the next catch date exceeded six days. The number of operating days for the standard fleet was accumulated on a monthly basis and applied to the total catch of these vessels to obtain the seasonal catch-per-unit-effort in terms of catch per operating day (Table 3, column 3).

In the early years of the fishery the fishing capability of the purse-seine fleet was restricted by the lack of sufficient processing facilities on shore. For example, in Area J the total processing capability was less than 500 tons per day in 1965; this subsequently increased to more than 2,000 tons per day in 1968, after which the normal fishing operations of the mobile fleet could be accommodated. A similar situation occurred in Area T. This is reflected in the ratio of the standard fleets catch to its total carrying capacity (Table 3, column 4). During 1966-68 this ratio (80-84%) was probably at or close to the saturation level for the fleet, but it declined to 50% by 1971, thus also reflecting the general decline in the availability of the resource. This implies that relative to the first 2-3 years of the fishery, seiners would have had to operate longer in subsequent years to attain the same saturation level. In order to take this factor into account, the standard catch-per-unit-effort values (column 3) were multiplied by the ratios (column 4) to provide adjusted catch-per-unit-effort values (column 5). These were then applied to the total catches (column 2) to obtain adjusted total effort estimates for the fishery as a whole (column 6).

TABLE 3. Trends in catch, catch-per-unit-effort and effort for the fishery on the southern Gulf of St. Lawrence herring stock, 1966-71.

1	2	3	4	5	6
Fishery year	Total catch in Areas T and J (m tons)	Catch/day of standard fleet (m tons)	Ratio of catch to capacity standard fleet	Adjusted catch/day of standard fleet (m tons) <sup>1</sup>	Adjusted total effort for Areas T and J (days) <sup>1</sup>
1966	89,007	44.2	0.83	36.7(74.0)	2,425(1,203)
1967	148,435	52.5	0.84	44.1(62.0)	3,365(2,394)
1968	251,736	62.9	0.80	50.3	5,005
1969	293,989	55.4	0.75	41.5	7,084
1970	278,575	41.7	0.59	24.6	11,324
1971	168,633	30.0	0.50	15.4	10,950

<sup>1</sup>Bracketed values for 1966 and 1967 are based on extrapolation in Fig. 3.

The information in Table 3 shows that while the adjusted catch-per-unit-effort decreased by 70% from 1968 to 1971 and the total adjusted effort more than doubled. The decrease in catch from 1970 to 1971 was nearly 40% while the adjusted effort barely decreased at all.

The increasing trend in catch-per-unit-effort for 1966-68 is not indicative of the trend in stock abundance as shown by cohort analysis (Table 2) but rather of increase in the catchability coefficient, due to such factors as increasing processing facilities, increasing familiarity of fishermen with the fishing grounds and fish distributions, etc. Assuming that catchability was relatively constant during 1968-71, an indication of what the 1966 and 1967 catch-per-unit-effort values might have been can be obtained by extrapolation from a straight line fitted to the values for 1968 to 1971 (Fig. 5). The extrapolated values (bracketed in Table 3) suggest that the purse-seine fleet operated at about 50% efficiency in 1966 and about 75% efficiency in 1967.

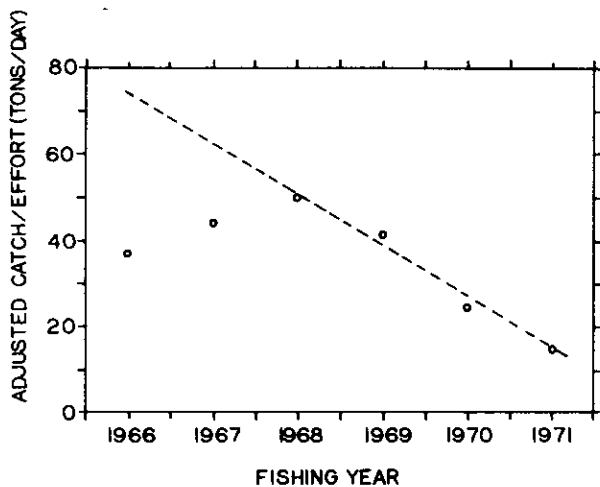


Fig. 5 Adjusted catch-per-unit-effort in the Southwest Newfoundland purse-seine fishery, 1966-71.

Adjusted catch-per-unit-effort values for 1968-71 and extrapolated values for 1966-67 plotted against mean exploitable stock abundance (Fig. 6) show a direct linear relationship between the two variables. The regression line has a y-intercept value very close to zero (+ 1.062), indicating that the catch-per-unit-effort values adequately reflect the changes in stock abundance. The slope of the line (catchability coefficient,  $q = 5.75 \times 10^{-5}$ ), when applied to the adjusted total effort values in column 6 of Table 3, provides fishing mortality coefficient values which are very similar to those obtained from cohort analysis in Table 2.

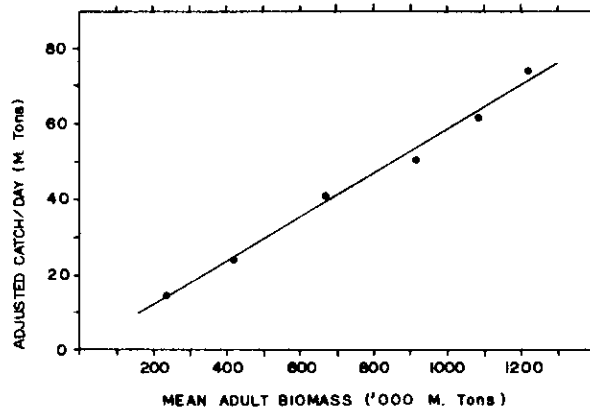


Fig. 6 Relationship between standardized catch-per-unit-effort and mean stock abundance, 1966-71.

### Estimates of stock size in Southwest Newfoundland

Length and age-composition data (Fig. 2) indicate that not all of the fish in southern Gulf of St. Lawrence herring stock complex migrate to overwinter in Southwest Newfoundland (Area J). If the proportions of the survivors of the Area T fishery migrating to Area J in the autumn were known for each age-group (hereinafter referred to as  $N_J/N_T$  ratios, where  $N_T$  is the residual stock size in numbers at the end of the Area T fishery in October, and  $N_J$  the initial stock size at the start of the Area J fishery in late November) for both spring- and autumn-spawners, estimates of the stock at the beginning of the Area J winter fishery can be obtained.

Reliable stock size estimates for the Area J fishery in 1969 and 1970 are available from tagging data (Winters, MS 1971b). The Area J age-composition data for 1969 and 1970 (Fig. 2) were applied to these stock size estimates, adjusted for natural mortality, to obtain the population numbers by age-group ( $N_J$ ) for spring- and autumn-spawners at the start of the Area J winter fishery in those years. Residual population numbers by age-group at the end of the Area T summer fishery ( $N_T$ ) were determined by applying survival rates (as calculated from partial mortality rates) to the initial stock size at the beginning of the fishery year. The  $N_J/N_T$  age-group ratios, averaged for 1969 and 1970, are shown in Fig. 7. For both spring- and autumn-spawners the proportion of the southern Gulf of St. Lawrence stock which migrates to Southwest Newfoundland continuously increases with age from less than 20% for the recruiting age-groups to 100% for fish older than age-group 10. Spring-spawners tend to migrate at an earlier age-group than autumn-spawners with 50% migration occurring at age-group 6 for the former and at age-group 8 for the latter. This difference in age at 50% migration is probably attributable to the earlier maturity of spring-spawners.

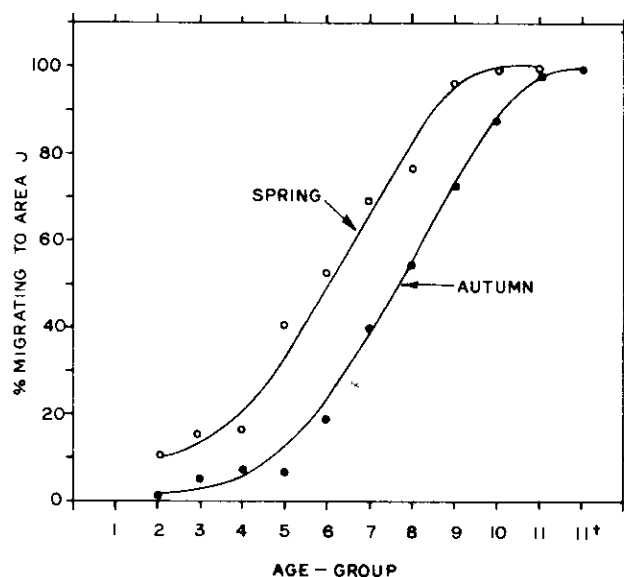


Fig. 7 Migration ogives for spring- and autumn-spawners as estimated for the autumn migration of herring from the southern Gulf of St. Lawrence to Southwest Newfoundland.

The  $N_J/N_T$  age-group ratios from the curves of Fig. 7 were applied to the residual population numbers at the end of the Area T fishery in the years 1966 to 1968 and 1971 to estimate the stock sizes (by weight) of spring-spawners and autumn-spawners at the start of the Area J fishery for those years (Table 4).

Using the more reliable of the tagging data estimates (the 1969 estimate was based on returns from 25,000 fish tagged and the 1970 estimate on returns from 10,000 tagged fish) as the base, i.e. 418,000 tons, independent estimates of stock size at the start of the Area J fishery in the years 1966-68 and 1970-71 were computed from the adjusted catch-per-unit-effort values given in column 7 of Table 3 (Table 4).

Both sets of estimates agree reasonably well (Table 4) and their averages indicate that the stock size available to the Area J fishery declined from about 700,000 tons in 1966 to about 130,000 tons in 1971.

Figure 8 shows the trends in the residual exploitable and adult portions of the southern Gulf of St. Lawrence stock together with trends in the exploitable stock available to the Area J fishery and the Area J catch. Comparison of the Area J and residual exploitable stock sizes indicate that during the 1966-71 period about 50-60% of the southern Gulf stock migrated to over-winter in Southwest Newfoundland. Relative to the residual adult stock in Area T, the proportion migrating to Area J increased from 60% in 1966 to about 75% in 1971, this being attributable in part to poor recruitment to the adult stock during the period and in part to the progression of the dominant 1958 and 1959 year-classes through the fisheries. Despite the maintenance of the 1972 residual adult stock at about the 1971 level due to the recent influx of younger age-groups, preliminary information from the Area J fishery indicates a further decline in stock size in that area in 1972 to probably less than 50,000 tons.

#### Yield-per-recruit considerations

The Beverton and Holt (1957) constant parameter yield-per-recruit curves were calculated for spring- and autumn-spawners separately using the following parameters (Parsons and Hodder, MS 1973):

	Spring	Autumn
M	0.20	0.20
K	0.282	0.260
$t_0$	-1.87 yr	-2.29 yr
$t_0' = t_0$	3.5 yr	3.7 yr
t	15 yr	15 yr

TABLE 4. Estimates of stock size available to the Southwest Newfoundland fishery (Area J) in November of each fishery year.

Stock size estimates ('000 m tons)					
Autumn of fishery year	Based on tagging data	Based on migration ratios	Based on catch-per-unit-effort	Range of stock size estimates	Mean stock size estimate
1966	—	655	744	655-744	700
1967	—	622	627	622-627	625
1968	—	553	506	506-553	530
1969	418 + 22	(418)	(418)	396-440	418
1970	277 + 18	(277)	247	247-295	262
1971	—	112	151	112-151	132

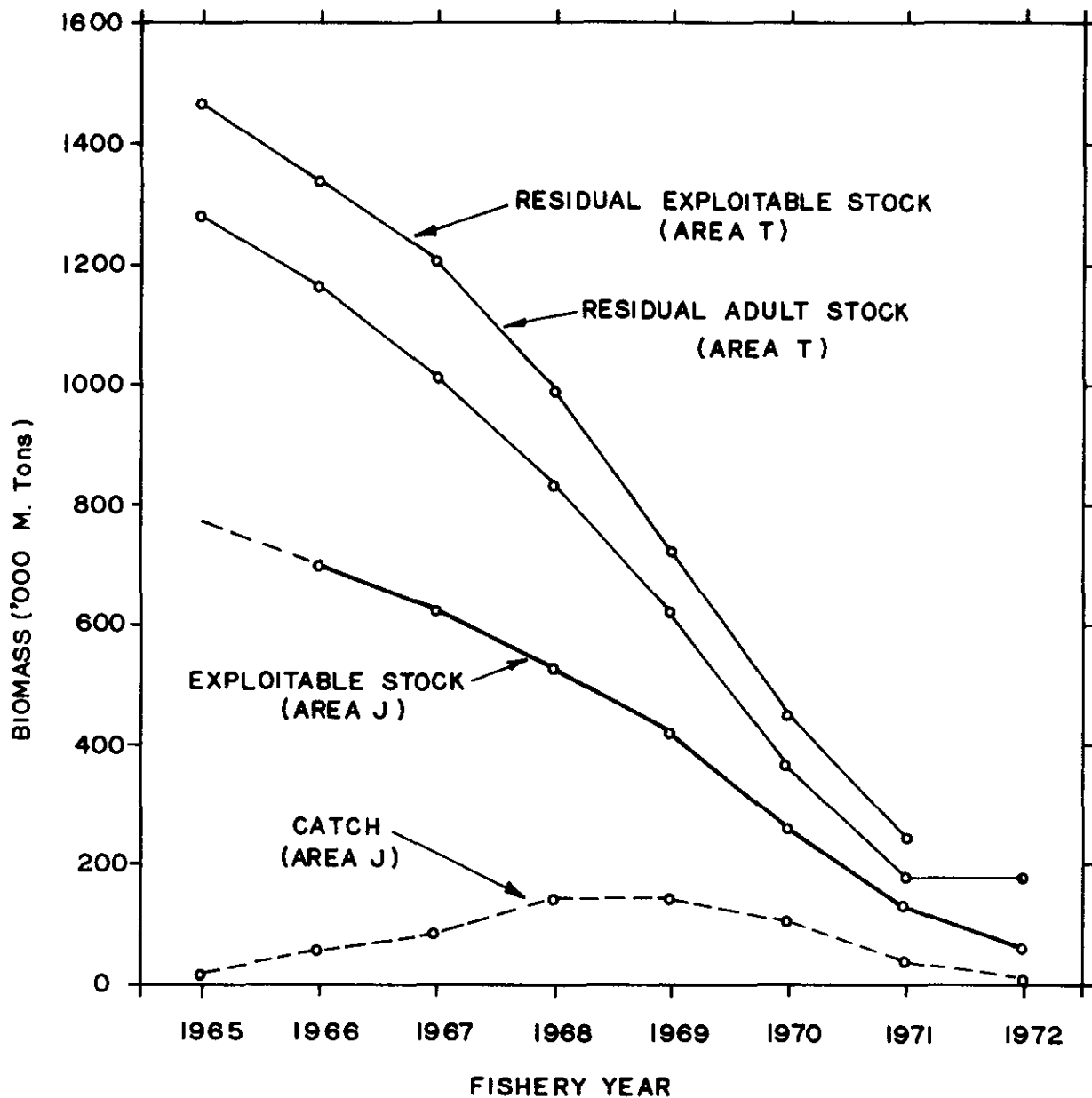


Fig. 8 Residual exploitable and adult stock biomass at the end of the Area T fishery, exploitable biomass at the start of the Area J fishery and the Area J catch, 1965-72.

The curves for spring- and autumn-spawners were essentially identical in curvature and elevation and a single curve for the southern Gulf of St. Lawrence stock complex of herring is shown in Fig. 9. The curve is flat-topped with the maximum yield-per-recruit occurring at a level of fishing mortality ( $F$ ) greater than 2.0. Consequently the fishing mortality corresponding to the maximum yield-per-recruit is unrealistic from a practical viewpoint. However, Gulland (MS 1972) defines the

optimum fishing mortality as close to the level of  $F$  at which the marginal yield-per-recruit is 10% of the yield-per-recruit per unit mortality in a very lightly exploited stock. This value, called  $F_{opt}$ , was estimated to be approximately 0.4 for both spring- and autumn-spawners. Thus the fishing mortality exerted on the southern Gulf of St. Lawrence stock complex was lower than  $F_{opt}$  during 1966-68, near the  $F_{opt}$  level in 1969 and higher than the optimum level in 1970 and 1971.

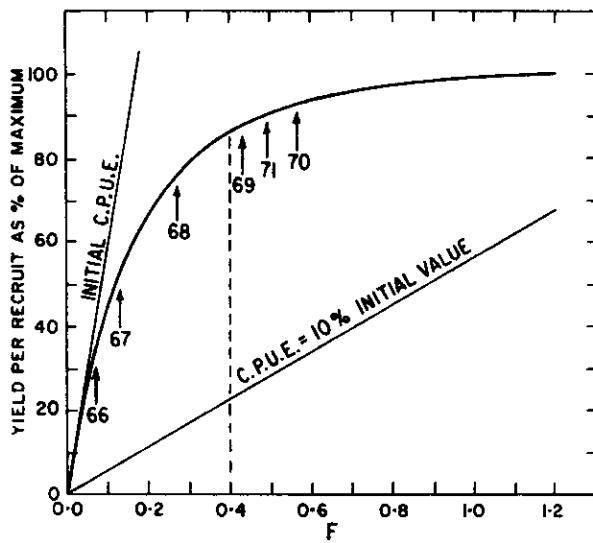


Fig. 9 Yield-per-recruit curve for southern Gulf of St. Lawrence herring. Arrows indicate levels of  $F$  in various years and the vertical (broken) line indicates the optimum of  $F$  as calculated from marginal yield-per-recruit.

### Estimation of natural mortality rate

The reliability of the value of  $M$  used in this paper can be checked by plotting the average total  $F$  (Table 2) obtained from cohort analyses against the adjusted total fishing effort (Table 3, Col. 6). The regression (Fig. 10) shows that there is only a very small intercept which indicates that the value of  $M = 0.2$  used in the analysis is the correct one.

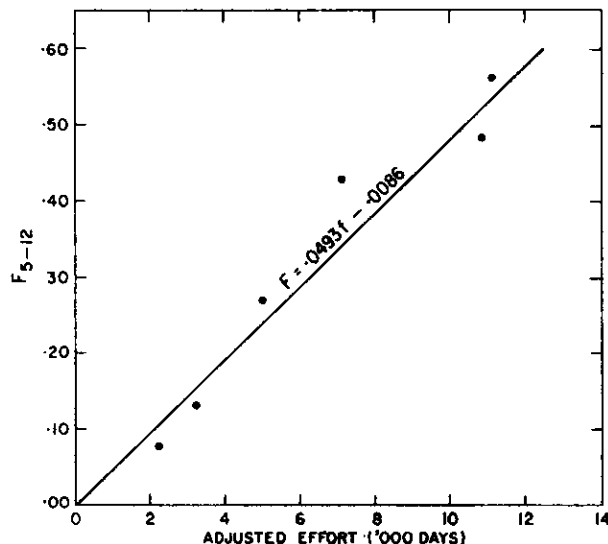


Fig. 10. The regression of fishing mortality ( $F$ ) for age-groups 5 to 12+ on fishing effort ( $f$ ).

## Discussion and Conclusions

The great abundance of herring in the southern Gulf of St. Lawrence and Southwest Newfoundland during the 1960's was due largely to the accumulation of biomass produced by two large year-classes spawned in the autumn of 1958 and in the spring of 1959. These year-classes had passed their age of maximum biomass before the purse-seine fishery developed in 1965, at which time the total stock size was estimated to be 1,840,000 tons. Therefore, at the age of maximum biomass in 1964 the stock size was undoubtedly of the order of 2,000,000 tons. During most of the 1965-72 period the purse-seine fishery was supported mainly by the 1958 and 1959 year-classes, and as the abundance of these year-classes declined so did the fishery.

Yield-per-recruit calculations show that the stocks have been overfished since 1969 at least in so far as the amount of optimal fishing effort is concerned. The rapid decline in stock abundance cannot however be attributed solely to the disproportionate removal of biomass due to fishing. Recruitment to the exploitable biomass has been relatively poor since the mobile fishery developed. For spring-spawners the large 1959 year-class was estimated to number about 4 billion fish at age-group 2; the next largest was the 1960 year-class which was  $1/5$  that of 1959 and the largest since then was the 1968 year-class which at age-group 2 was only  $1/8$  as large; and the others up to 1969 have ranged from  $1/10$  to  $1/60$  the size of the 1959 year-class. For autumn-spawners the 1962 and 1963 year-classes were about  $1/5$  the size of the 1958 year-class (about 7 billion fish at age-group 2) and the others up to 1968 were  $1/10$  to  $1/30$  as large. It therefore appears that the recruitment to the stocks has been at or below the replacement level since the purse-seine fishery began. In fact the application of the assumed natural mortality coefficient ( $M = 0.2$ ) to the stock sizes present at the beginning of 1965 and adding recruitment at age-group 2 for each subsequent year indicates that the total stock would have declined by nearly 50% up to 1971 even if the fishery had not existed. Thus the purse-seine fishery did not cause the decline in stock abundance but rather precipitated and increased the magnitude of the decline. On the assumption that there is no filial-parental relationship over the range of stock sizes estimated, overfishing in terms of biological yield has not occurred. In fact from 1965 to 1971 nearly 55% of the reduction in total stock size of the 1958 and 1959 year-classes was due to natural mortality. Under conditions of optimum fishing mortality the elimination of standing crop due to natural mortality would have been less than 35%.

At the start of 1972 the total adult biomass of spring- and autumn-spawners was only about 12% of that present at the beginning of 1965. Because landings



were relatively low in 1972 (Fig. 2) and because the 1968 year-class of spring-spawners will recruit to the adult stock in 1973, the adult stock size during 1973 will probably be maintained at about the 1972 level (Fig. 4). While the delineation of a critical spawning biomass remains a contentious and unresolved subject, the severe attrition in the size of the spawning stocks of the southern Gulf of St. Lawrence should be recognized as possibly detrimental to the recovery of the resource. Recent experiences in a number of heavily exploited fish stocks, such as the Grand Bank haddock (Hodder, 1966b), the Georges Bank haddock and the Arcto-Norwegian cod (Garrod, 1970) and the California sardine (Iles, 1970), have indicated that a small spawning stock can only produce large year-classes under exceptionally favourable circumstances and consequently a stock in this condition would be extremely vulnerable to unfavourable environmental conditions occurring in succession. Garrod (1970) also points out that for a number of stocks there seems to be a maximum rate of survival beyond which a further reduction in stock size cannot be intrinsically compensated for. Under such circumstances the rapid recovery of the stock cannot be assured even by the most stringent management measures. The biomass of the southern Gulf of St. Lawrence spawning stocks of herring is probably approaching the level at which compensatory survival cannot be expected to maintain sustainable recruitment. Immediate and effective conservation measures are therefore required to ensure the best possible chance of stock recovery. In this regard, the Canadian Atlantic Herring Management Committee has recently recommended conservation measures, such as the imposition of minimum size limits and catch quotas and closure of spawning grounds to mobile gears.

During the initial exploratory phase in the development of the purse-seine fishery along Southwest Newfoundland, Peuvion (1966), on the basis of acoustic surveys carried out over a 3-month period (January-March) in 1966, estimated that up to 1,000,000 tons of herring were present during that winter. Extrapolation of the Area J exploitable biomass curve (Fig. 8) to 1965 (i.e. to the start of the Area J fishery in November 1965) provides a stock size estimate of slightly less than 800,000 tons. Since the acoustic surveys extended over a 3-month period during which there is a gradual westward movement of herring along the coast (Hodder, 1971), some of the schools were probably included in the acoustic estimate more than once. Taking this into consideration would reduce the estimate based on acoustic surveys to a level in close agreement with the stock size estimate (800,000 tons) projected from the analysis of data presented in this paper.

The large stock size of herring present in the Southwest Newfoundland area during the 1960's and the

associated high yields from the fishery in that area were probably fortuitous in that they resulted from several unrelated factors acting concurrently. First of all, the very large 1958 and 1959 year-classes which supported the purse-seine fishery since its inception were produced under exceptional circumstances, occurring in succession shortly after a fungus disease (*Ichthyosporidium hoferi*) had caused widespread mortalities of herring in the southern Gulf of St. Lawrence during 1953-57 (Tibbo and Graham, 1963). The fact that in the decade following the production of the large 1958 and 1959 year-classes not a single large year-class was produced suggests that the occurrence of large year-classes, particularly in successive years, is not a regular feature of the biology of this stock complex; more likely, the much smaller year-classes which prevailed after 1959 represent the normal situation. Secondly, the two large year-classes were relatively old (age-groups 7 and 8) before they were subjected to significant exploitation, and consequently large numbers of them were able to survive to ages at which the migration ratios were high enough to allow significant quantities of them to migrate to Southwest Newfoundland. Also the slower development of the purse-seine fishery in the southern Gulf of St. Lawrence enabled a large residual biomass to be available to the Southwest Newfoundland fishery even up to 1969 (Fig. 8), as the dominant 1958 and 1959 year-classes migrated to the area in increasing proportions, and enabled Southwest Newfoundland catches to increase substantially to a peak level of 140,000 tons in 1968 and 1969. Finally, the decline and collapse of the British Columbia herring fishery occurred coincidentally with the discovery of the large over-wintering concentrations of herring in the fjords along Southwest Newfoundland in the mid-1960's, and this provided a ready surplus of purse seiners and experienced fishermen which enabled the resource to be exploited almost immediately upon its discovery.

The obvious implication of the above discussion is that the magnitude of the future herring fishery in Southwest Newfoundland will be considerably reduced and will be greatly dependent on the extent and intensity of the fishery in the southern Gulf of St. Lawrence. Some indication of the biomass available to, and the yield from the Southwest Newfoundland fishery relative to the fishing mortality in the southern Gulf of St. Lawrence can be obtained from a hypothetical model of the fisheries based on the data presented in this paper. In the model it has been assumed that the present migration pattern, migration ratios (averaged for spring- and autumn-spawners (Fig. 7)), growth rates and other biological characteristics of the southern Gulf of St. Lawrence herring stocks remain unchanged and that a fleet of purse-seine vessels exists which is capable of exploiting the resource at its optimum yield. An initial stock size at age-group 2, approximately equal to the

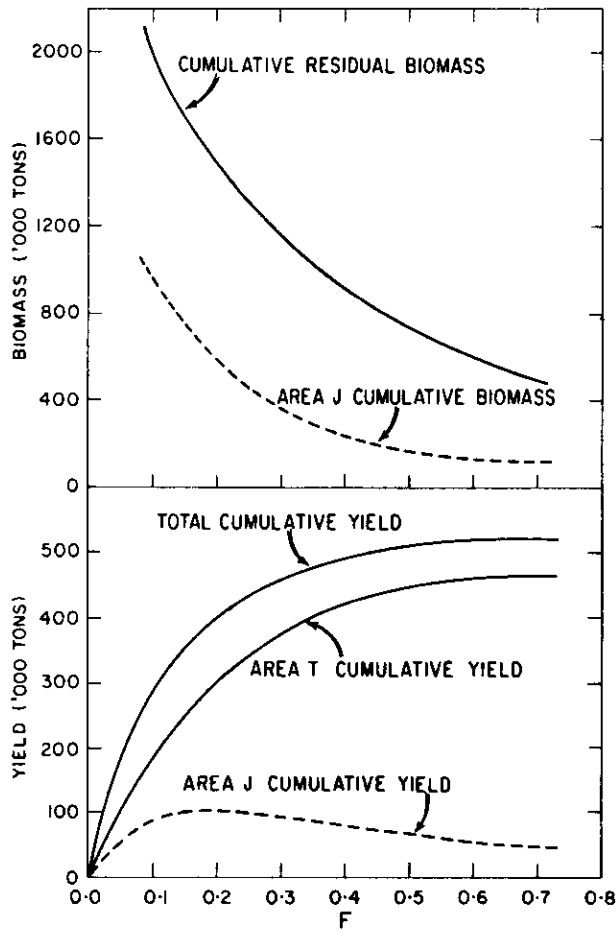


Fig. 11 Cumulative biomass and yield estimates of the southern Gulf of St. Lawrence herring stock complex from a hypothetical recruitment of 5,000 million fish subjected to a range of fishing mortality rates.  $F$  is the same in Areas T and J for each year.

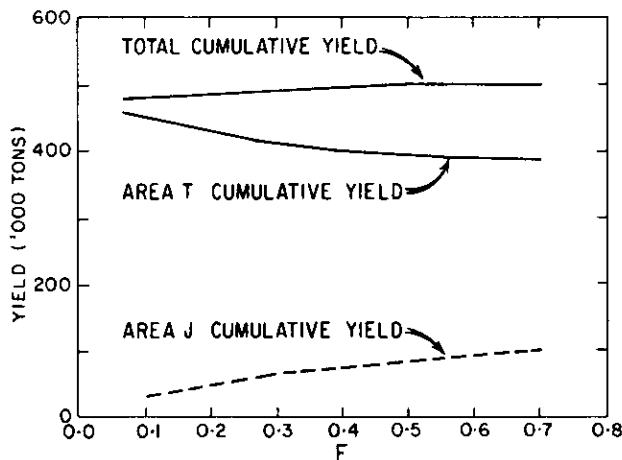


Fig. 12 Effect of increases in the fishing mortality rate in Southwest Newfoundland (Area J) on the cumulative yield of a fishery regulated at the optimum level ( $F = 0.40$ ) in the southern Gulf of St. Lawrence (Area T).

average size of the 1958 and 1959 year-classes at the same age-group (5 billion fish) is assumed and to this stock have been applied a range of fishing mortality rates which are the same for each year in the southern Gulf of St. Lawrence and in the Southwest Newfoundland areas. Estimates of yield and biomass thus obtained have been cumulated over the age-groups and plotted against fishing mortality (Fig. 11). As expected, there is a monotonic decline in both the cumulative residual biomass at the end of the southern Gulf of St. Lawrence fishery and that available to the Southwest Newfoundland fishery as fishing mortality increases. This decline amounts to over 70% in the latter area from the lightly exploited state ( $F = 0.10$ ) to the level of optimum fishing ( $F = 0.40$ ). In terms of cumulative yield, increases in the fishing mortality rate would increase both the total yield and the yield from the southern Gulf fishery but would cause a decrease in the yield from the Southwest Newfoundland fishery. If the fishery were regulated at the optimum level, the cumulative yield from the stock would be slightly over 400,000 tons in the southern Gulf of St. Lawrence and about 75,000 tons in Southwest Newfoundland. On an annual basis average yields for the three peak years would be about 100,000 tons for the southern Gulf fishery and about 20,000 tons for the Southwest Newfoundland fishery.

The effect of a varying fishing mortality rate in Southwest Newfoundland on the cumulative yield of a fishery regulated at the optimum level in the southern Gulf has also been examined (Fig. 12). An increase in the fishing mortality rate in Southwest Newfoundland will increase the cumulative yield from that area but will also result in a concomitant decrease in the cumulative yield from the southern Gulf fishery to the extent that the yield from the stock as a whole will increase only slightly. It would therefore appear that the yield from the total stock exploited at the optimum level is not substantially increased by a fishery in Southwest Newfoundland.

In summary the large purse-seine fisheries characteristic of the southern Gulf of St. Lawrence and Southwest Newfoundland during the 1960's were based mainly on the accumulation of biomass produced by two very large year-classes, and as such, yields from these fisheries are not representative of the average yield of the southern Gulf of St. Lawrence herring stocks. Since the expansion of the fisheries occurred during a period of declining stock abundance due to poor recruitment initial increases in catch were at the expense of substantial increases in fishing effort which eventually reduced the stocks to a very low level. Rational management is now required to ensure the recovery of the stocks to a viable level. Under optimum fishing rates and with large year-classes occurring only infrequently the average yield from the southern Gulf of St. Lawrence stocks of

herring will be considerably lower in the future, perhaps reaching 150,000 tons in peak years of strong year-classes. Since the southern Gulf herring are fairly old before they migrate to Southwest Newfoundland in significant proportions, a fishery regulated at the optimum level in the southern Gulf of St. Lawrence will considerably reduce potential yields from Southwest Newfoundland.

### Acknowledgements

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# The Continuous Plankton Recorder Survey: Plankton in the ICNAF Area, 1961-71, with Special Reference to 1971

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## Abstract

Results from the survey by the Continuous Plankton Recorder have been used to describe the variability in distribution of the plankton in the ICNAF area from 1959 to 1971. Details of the routine data processing of the results are provided.

Over the Grands Banks, the end of the spring outbreak of phytoplankton has occurred progressively earlier over the period 1965 to 1971 and numbers of cells have increased during the autumn from 1968 onwards. These changes may be related to the earlier outbreaks of copepods in spring from 1963 onwards and a decline in their abundance in the autumn. Copepods have shown a general decline in abundance in Subareas 2, 3 and 4 over the period of the survey.

There was a close relationship between the annual fluctuations in abundance of the plankton and the young stages of the fish (*Sebastes* spp., Ammodytidae, Clupeidae, *Mallotus villosus* and Scopolidae).

During 1971, copepods were abundant in the first half of the year in all Subareas; young stages of *Sebastes* spp. and Ammodytidae were scarce while *Mallotus villosus* and Clupeidae were more abundant than usual.

## Introduction

Material collected by the Continuous Plankton Recorder (Hardy, 1939 and Glover, 1967) has been used to study the variability in the distribution of the plankton in the ICNAF area from 1959 onwards. Accounts of variation in abundance in the northeastern Atlantic and North Sea have been presented for every year since 1946 for *Annales Biologiques* of ICES. In 1959, the survey was extended into the western North Atlantic and this paper attempts to show the kind of data presentation that could be offered, annually, for the ICNAF area. In particular, the distribution of the plankton in 1971 is discussed here with respect to the annual and seasonal fluctuations in abundance since 1961.

There have been several reports on Recorder collections in the ICNAF area; Henderson (1965, 1968) and Bainbridge and Cooper (1971) investigated the distribution of *Sebastes* larvae; Glover and Robinson (1968) and Robinson (1968) described the distribution of plankton in the western Atlantic at the time of the NORWESTLANT Survey in 1963; Colebrook (1971) has discussed the distribution and abundance of the plankton from Recorder results in the North Atlantic and Robinson (1970) has analysed the seasonal variability of phytoplankton in the same area.

## Methods

Continuous Plankton Recorders are towed at a depth of 10m by merchant ships, Ocean Weather Ships and Coast Guard Cutters of the United States Navy once in each month along a number of standard routes (Fig. 1). The rolls of silk are cut into sections representing 10 miles of tow and alternate sections, bearing the plankton from 3 cubic metres of water, are analysed. The methods of analysis have been described by Rae (1952) and Colebrook (1960). The present Recorder survey has been in operation since 1948 and since then plankton has been collected and the results have been processed in exactly the same way. Some clear patterns in distribution, abundance and time of occurrence have been established in the North Sea and the eastern Atlantic where there is a longer time series of results than in the ICNAF area.

The area of the survey has been subdivided into a grid of rectangles (each 1° of latitude by 2° of longitude) with diagonal subdivisions to follow the 100 fathom depth contour to differentiate between oceanic and shelf areas. These statistical rectangles can be grouped into larger areas; for the purpose of this paper each large area corresponds with ICNAF Subareas 1-5 (Fig. 1). The data are processed by computer according to the scheme outlined in the following paragraphs.

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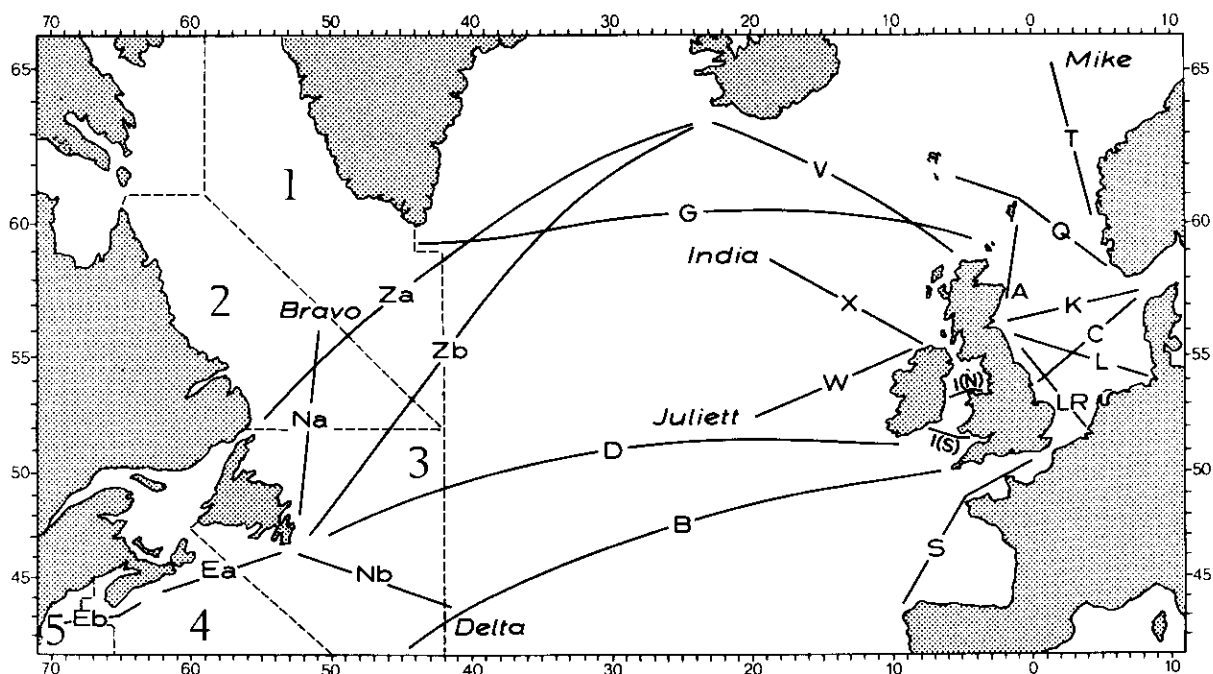


Fig. 1. The Continuous Plankton Recorder Survey during 1971. The routes are identified by code letters and the Ocean Weather Stations by their international names Za indicates the positions of tows along the Z route in summer and Zb in winter. The boundaries of ICNAF Subareas 1-5 are outlined.

### Monthly data processing

- A chart is drawn by the Calcomp Graph Plotter every month showing the routes samples during that month.
- Each 10-mile sample is allocated to a statistical rectangle and a chart produced showing the number of samples per statistical rectangle for each month.
- The mean number of each species is calculated for the statistical rectangle in which it occurred in every month and the results are output by the line printer in quasi chart form.
- The mean number of each species is calculated for each of the five main ICNAF Subareas.

Some species are more abundant in samples taken at night because of the diurnal vertical migration of some zooplankton; for these, the data processing system is repeated for samples taken at night only.

### Annual data processing

- For each species in each ICNAF Subareas, a matrix is produced by the computer showing the

mean number per month for the period 1961 onwards. Contoured representations of each standard area matrix are produced by means of line-printer graphic methods as well as the matrix of basic data (Fig. 2).

- For each species in each ICNAF Subarea in which it is sufficiently abundant, the annual fluctuations in abundance are calculated for the period 1961 onwards; the data are available as tables of log-transformed counts, as standardized deviates (from the long-term means) and as graphs drawn by the Calcomp Graph Plotter (Fig. 3).
- Long-term monthly means of abundance for the ICNAF Subareas are calculated and the results output by the line-printer in table form and also as graphs drawn by the Calcomp Plotter. These results can be used for comparison with area monthly means for a particular year (Fig. 8 to 11).
- Estimates of the "timing" of the seasonal cycle of abundance of each species in each standard area are calculated using the method described by Colebrook and Robinson (1965) and the results produced in table form and as graphs drawn by the Calcomp Plotter.

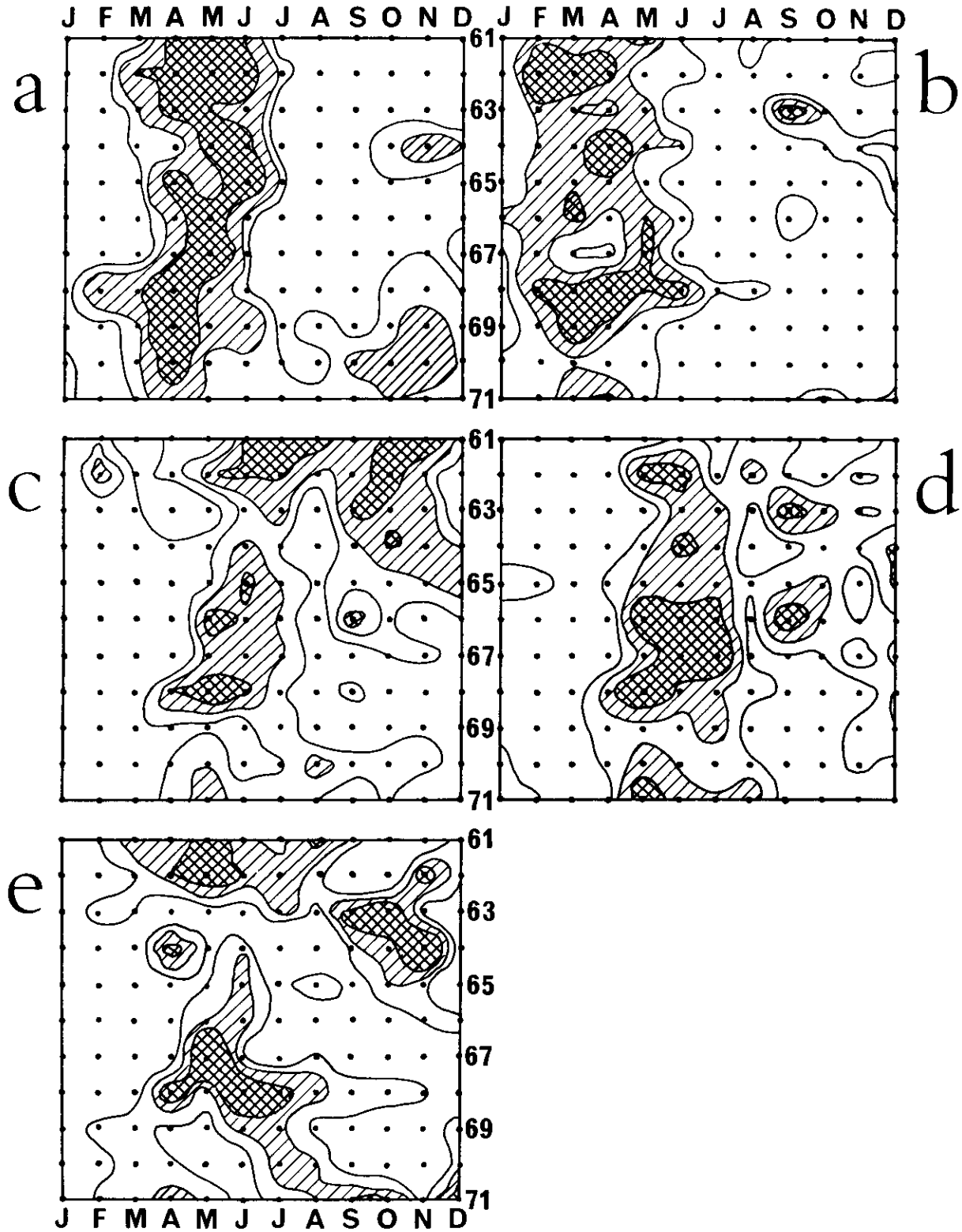


Fig. 2. Contour diagrams of the annual and seasonal fluctuations in abundance of (a) phytoplankton (b) copepodite stages V-VI of *Calanus finmarchicus* (c) total copepods (d) copepodite stages I-IV of *C. finmarchicus* and (e) Euphausiacea in ICNAF Subarea 3. Contour levels for phytoplankton are shown on an arbitrary scale at 2, 4, 6 and 12. Contour levels for the remaining diagrams are drawn at 6, 11, 19 and 30 per sample of 3m<sup>3</sup> for (b), 179, 272, 396 and 600 for (c), 23, 43, 83 and 155 for (d) and 2, 3, 4 and 6 for (e).

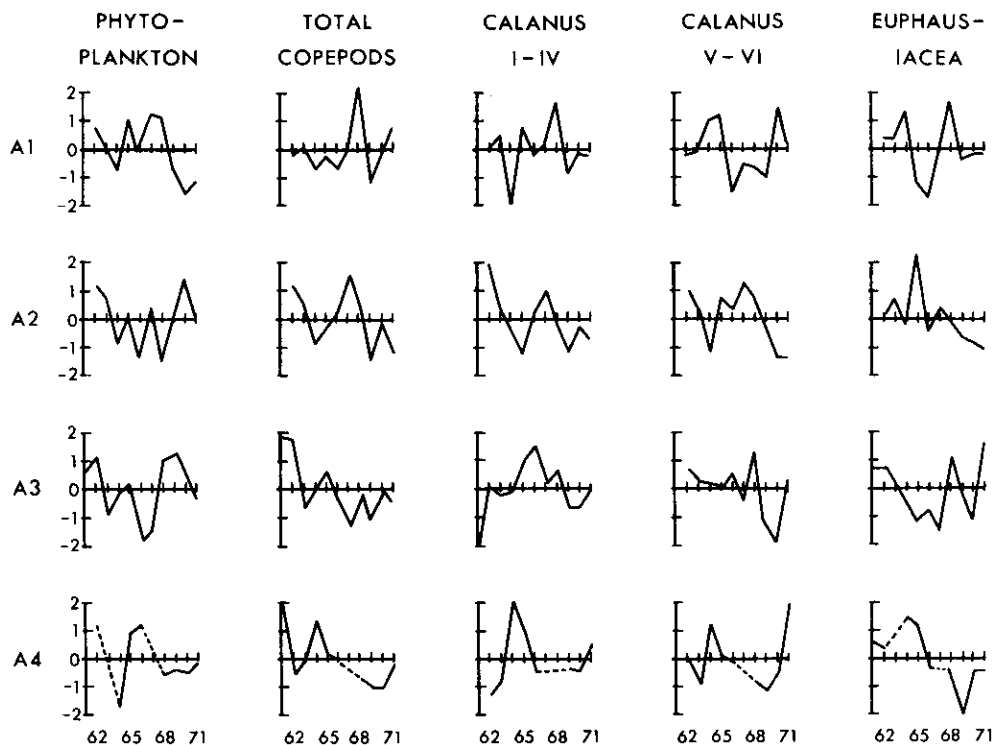


Fig. 3. Graphs of the annual fluctuations in abundance of total phytoplankton, total copepods, copepodite stages I-IV of *Calanus finmarchicus*, copepodite stages V and VI of *C. finmarchicus* and Euphausiacea in ICNAF areas 1-4 for the period 1961-71. Each graph is shown as a standardised variable about a mean of zero. The ICNAF Subareas are indicated by A1, A2 etc.

- e) A chart showing the annual distribution of each species for every year from 1959 onwards together with an anomaly chart showing its variation from the long-term mean chart (Fig. 7).
- f) Product moment correlations are calculated for (i) the annual fluctuations in abundance of species, (ii) the annual fluctuations in the "timing" of species between all possible pairs of ICNAF Subareas, and (iii) the annual fluctuations in abundance of the species within each subarea.
- g) The latent roots, vectors and principal components of all the correlation matrices are derived by Householder's method (Fig. 4).

The results from this routine data processing have been used to describe the distribution of the plankton in the ICNAF Subareas 1-5 in this report. During 1971, Recorders sampled 1,092 miles in Subarea 1; 2,315 miles in Subarea 2; 13,244 miles in Subarea 3; 3,345 miles in Subarea 4 and 1,258 miles in Subarea 5.

## Results

### Annual and seasonal fluctuations in abundance

Annual and seasonal distributions can be summarized conveniently by considering the distributions of the major components of the plankton in the ICNAF Subareas. Figure 2 gives the annual and seasonal fluctuations in abundance for phytoplankton, total copepods, Euphausiacea, copepodite stages V-VI and I-IV of *Calanus finmarchicus* for Subarea 3. This type of diagram is provided in computer printout for all species in all subareas in which they occur.

The estimate of phytoplankton was obtained from a visual assessment of the green coloration of the filtering silks. The main phytoplankton season occurs in the spring (Fig. 2a, April and May) and, although there was marked year-to-year variation in the timing and abundance of its start, there was no consistent trend within the eleven-year period. However, there is some evidence that the spring outbreak declined at a



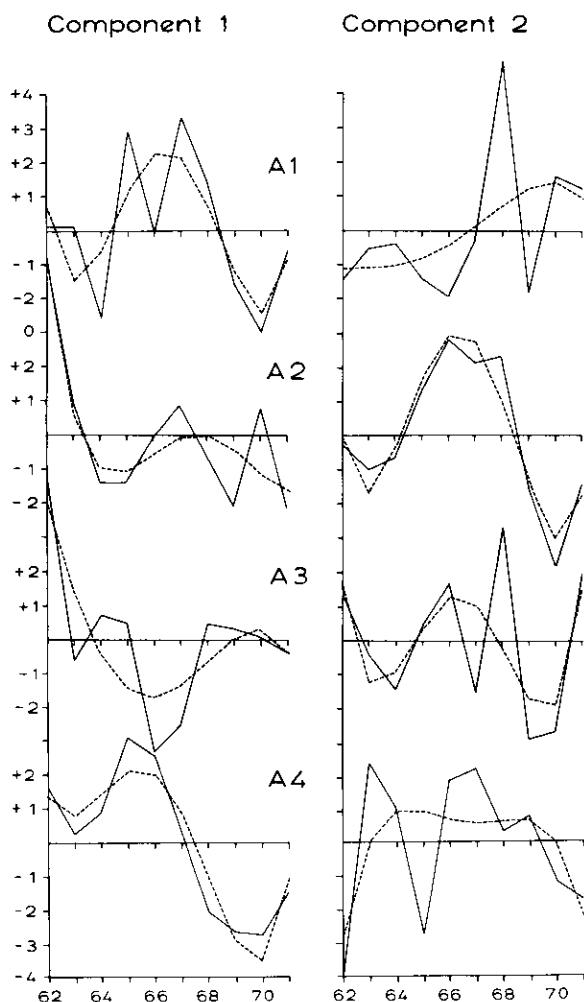


Fig. 4. Graphs of first and second components of the annual fluctuations in abundance of the species occurring in the ICNAF areas 1-4. Each graph is shown as a standardised variable about a mean of zero. The ICNAF Subareas are indicated by A1, A2 etc.

progressively earlier date from 1965 onwards. Dominant spring species were *Thalassiosira* spp., *Chaetoceros* spp. and *Thalassiothrix longissima*. From 1968 onwards, there has been an autumnal peak which was not apparent in previous years, except 1964. This may be related to changes in the abundance of copepods (Fig. 2c) which, from 1967 onwards, became much less numerous from August to December than in the preceding years. Also, there was a spring outbreak in copepod production which indicated a trend of earlier production from 1963 onwards.

The diagrams for copepodite stages V-VI and I-IV of *Calanus finmarchicus* should be compared. The overwintering adult stages appeared at 10m in February

and disappeared in May or June. The timing of their occurrence has been stable but there have been considerable fluctuations in their abundance and length of season. In 1968 they occurred early and were abundant until June but were extremely scarce in 1970. There was considerable variation in the time of production of copepodite stages I-IV with a trend of earlier production from June 1961 to May 1971.

The abundance of the Euphausiacea was more variable than that of other organisms illustrated in Fig. 2. The adults usually appear in samples taken at 10m in February or March and disappear in June (Jones, 1969); thereafter, they are replaced by young stages which will appear as adults the following spring. Adults were particularly numerous in 1961, 1962, 1967 and 1968 in spring, while young stages were abundant in 1963 and 1964 in the autumn.

Figure 3 shows the annual fluctuations in abundance of the same five organisms in Subareas 1-4 for 1961 to 1971. Eleven years may be too short a period to detect trends in the fluctuations in abundance such as have been identified in northeastern Atlantic and the North Sea over a period of 25 years (Colebrook, 1971; Glover, Robinson and Colebrook, 1972). An attempt to analyse these patterns of annual fluctuations in abundance has been made by calculating the Principal Components of the array of data formed from annual fluctuations in abundance of all the species occurring in each subarea (Williamson, 1961). The first components (Fig. 4) for Subareas 1-4 express 30, 37, 46 and 50% and the second components 20, 26, 20 and 27% respectively of the total variation in the annual fluctuations in abundance. Fourth order polynomials have been fitted to the graphs to indicate trends in annual fluctuations in abundance.

The trend lines of the first components for Subareas 2 and 3 are similar indicating a downward trend in the abundance of the plankton. The first component for Subarea 1 and the second component of Subarea 2 are similar with a peak from 1965 to 1967 and troughs on either side in 1963 and 1970 while the trend lines for the first component of Subareas 4 and the second component for Subarea 3 differ from these two with the peak 2 years earlier in 1964 and 1965. The annual fluctuations in abundance of young fish (*Sebastes* spp., Clupeidae, Ammodytidae, *Mallotus villosus* and Scopelidae) are shown in Fig. 5 and 6. Fourth order polynomials have been fitted to the graphs so that the fluctuations in abundance may be compared with the principal components of the annual fluctuations in abundance of the plankton given in Fig. 4. There are close relationships between these two parameters in the following instances; *Sebastes* spp. and the first components for Subareas 1, 2 and 4; Clupeidae and the first component for Subarea 4;

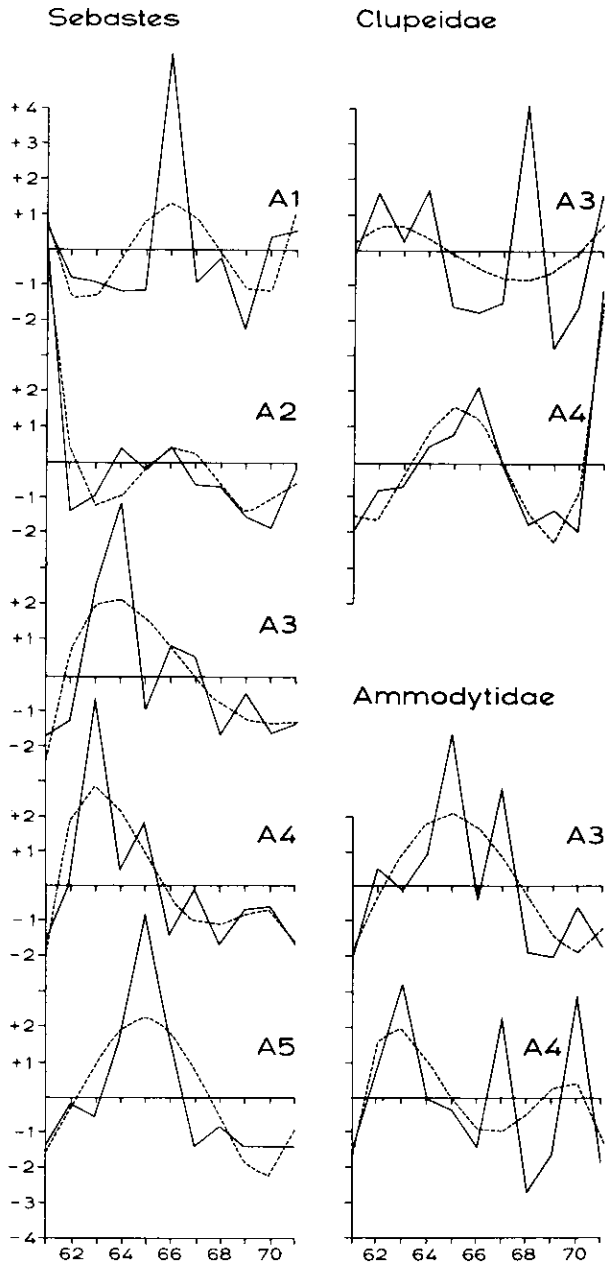


Fig. 5. Graphs of the annual fluctuations in abundance of *Sebastes* spp. in Subareas 1-5, Clupeidae and Ammodytidae in Subareas 3 and 4 for the period 1961-71. Each graph is shown as a standardised variable about a mean of zero. Fitted trend lines are shown by the dashed lines. The ICNAF Subareas are indicated by A1, A2 etc.

Ammodytidae and the second components for Subareas 3 and 4; *Mallotus villosus* and the first component for Subarea 3 and Scopelidae and the second component for Subarea 3. Thus eight out of ten trend lines fitted to the graphs of the annual fluctuations in abundance of young

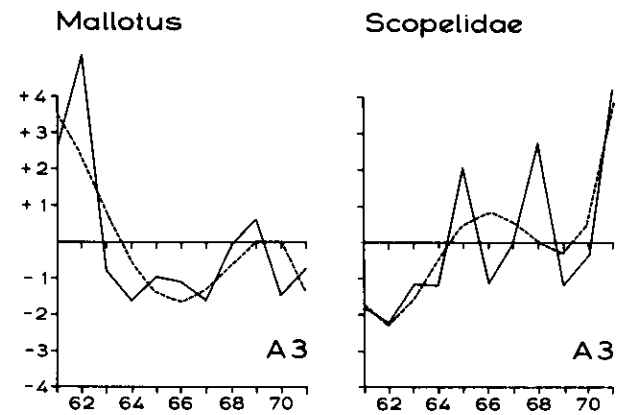


Fig. 6. Graphs of the annual fluctuations in abundance of *Mallotus villosus* and Scopelidae in ICNAF Subarea 3 for the period 1961-1971. Fitted trend lines are shown by the dashed lines.

fish in ICNAF Subareas 1-4 show similar annual fluctuations in abundance to the first or second components of the annual fluctuations in abundance of the plankton in the same subareas.

#### Geographical distributions in 1971

The charts in Fig. 7 (top) give the distributions in the ICNAF area of the phytoplankton and the two major components of the zooplankton (Copepoda and Euphausiacea) for 1971. The distribution of individual species, or groups of species, are available on request in the form of quasi-synoptic charts produced by the line-printer. Phytoplankton and copepods were both found in greatest abundance over the Grand Banks and other coastal areas. Euphausiacea, however, were numerous in the Labrador Sea as well as in the coastal areas south of Newfoundland and Nova Scotia.

The anomaly charts (Fig. 7, bottom) compare the distribution in 1971 with the long-term mean distribution (1959-70); the average number per sample for each statistical rectangle is expressed as a percentage of the 12 year mean for that rectangle. For the phytoplankton, numbers were higher than usual to the east and south of the Grand Banks with an area of low numbers to the north and also south of Greenland. Copepods tended to show the reverse distribution with numbers lower than usual to the east and south of the Grand Banks; they were also below average in the Labrador Current but abundant in the Labrador Sea. Euphausiids were abundant in the coastal waters south of Newfoundland, but below average in most other areas.

#### Plankton in ICNAF Subareas 1-5 in 1971

The results are presented in the same way as those published annually in *Annls. biol. Copenh.*, (Glover,

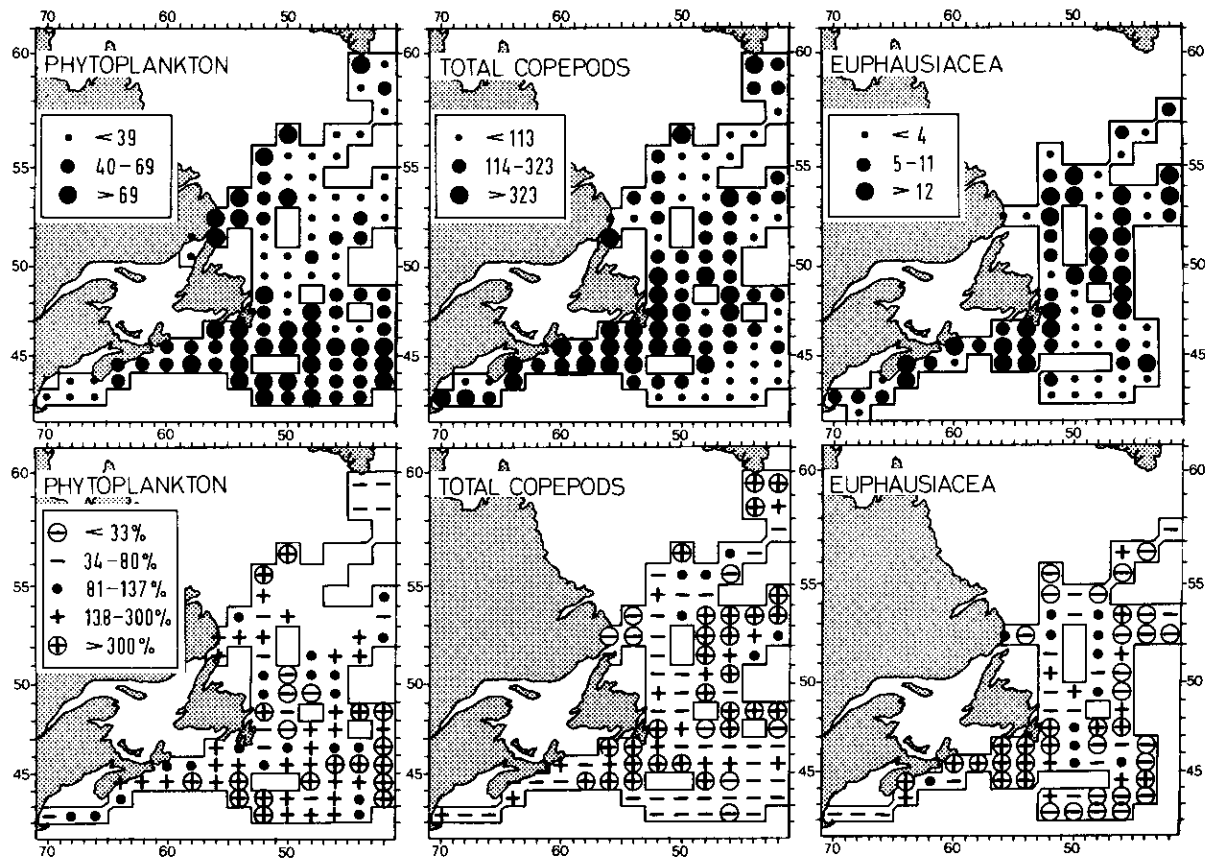


Fig. 7. **Top**, charts showing the geographical distributions of total phytoplankton, total copepods and Euphausiacea in the ICNAF area in 1971. The symbols show the average numbers of organisms per sample for each statistical rectangle for total copepods and Euphausiacea (see key at top left of each chart); the phytoplankton scale is an arbitrary measure of the coloration of the samples. The distribution chart for Euphausiacea was constructed from samples taken at night only. **Bottom**, anomaly charts of the distribution of total phytoplankton, total copepods and Euphausiacea in 1971. The symbols represent the average numbers per sample for each rectangle expressed as a percentage of the 13-year mean.

Colebrook and Robinson, 1962). For each month, for ICNAF Subareas 1-5, the mean number per Recorder sample (of  $3\text{m}^3$ ) has been calculated for the dominant members of the plankton and young fish. The results are shown in Fig. 8-11 in which the data for 1971 are presented as histograms (gaps in the baseline indicate there was no sampling during that month). A measure of the normal seasonal cycle is provided by line graphs of the average number per sample during the period 1959 to 1970 or 1971). Both the monthly means for 1971 as well as the long-term means for the plankton were calculated from logarithmic transformations of the original counts; the means for the young fish are calculated from the untransformed data.

Figure 8 shows the results for phytoplankton and total copepods. The spring outbreak of phytoplankton in Subarea 1 occurred in June and July, about a month later

than usual. Numbers were high in April in Subareas 2, 3 and 4 suggesting that the spring outbreak was slightly earlier than usual in these areas; also it was unusually abundant in Subarea 1 in October, Subarea 2 in July and November, Subarea 4 in October and Subarea 5 in November and December. Numbers of copepods were above average in the early months of the year in all areas; in particular April to September in Subarea 1, May and June in Subarea 2, January, March, April and June in Subarea 3, January and April in Subarea 4 and January and March in Subarea 5. (There was no sampling for 4 months in Subarea 4 and five months in Subarea 5). Numbers were lower than usual at the end of the year in Subareas 1, 2 and 3, but high in Subarea 5.

Adult *Calanus finmarchicus* (Fig. 9, left) was more numerous than usual in Subarea 1 with two major peaks (April/May and August/September). It was below

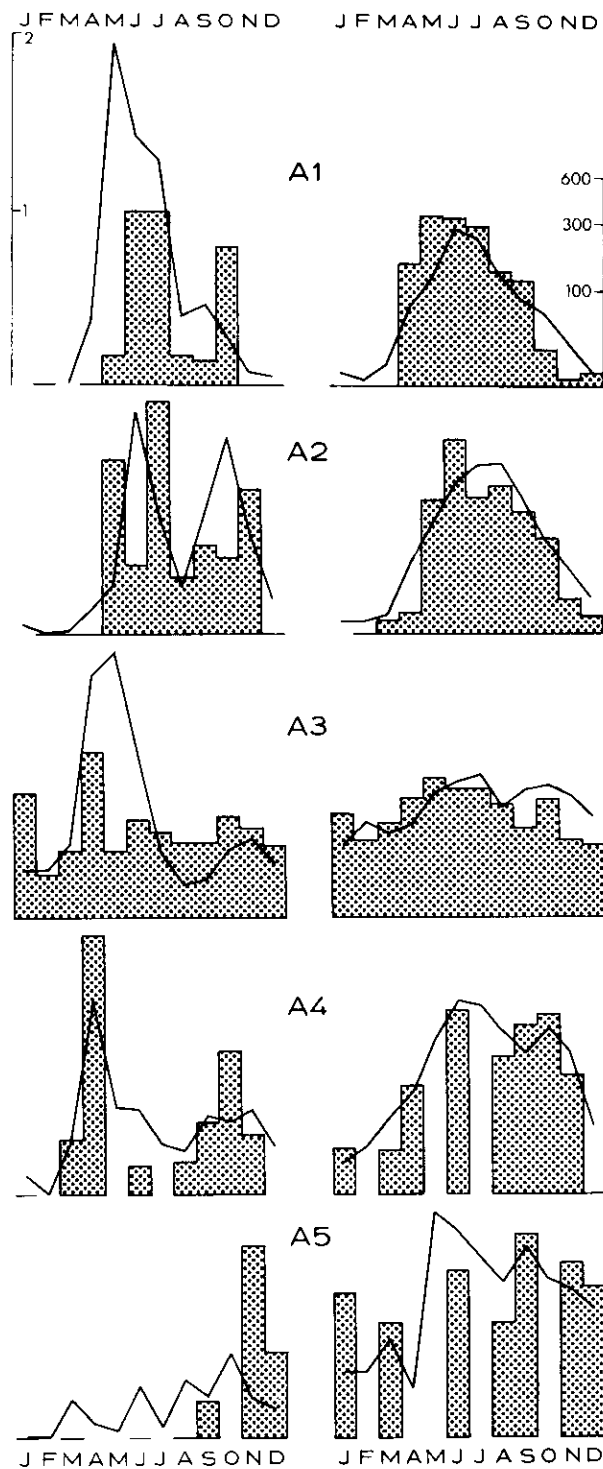


Fig. 8. Histograms showing average numbers per Recorder sample of phytoplankton (left) and total copepods (right) in ICNAF areas 1-5 in 1971. The line graphs show the mean value for the period 1959-71.

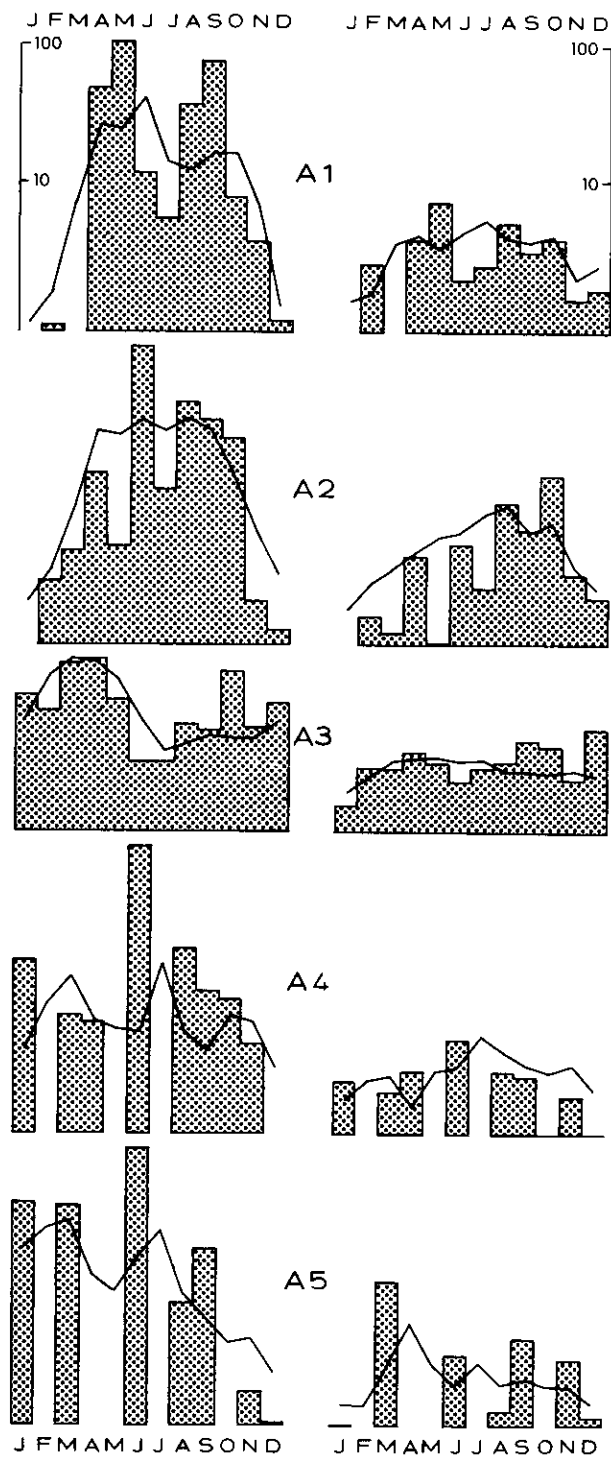


Fig. 9. Histograms showing average numbers per Recorder sample of copepodite stages V-VI of *Calanus finmarchicus* (left) and Euphausiacea (right) in ICNAF areas 1-5 in 1971. The line graphs show the mean values for the period 1959-71.

average in most months until May in Subareas 2, 3 and 4 but was generally more abundant in these areas in the second half of the year (June and August to September in Subarea 2; August to December in Subarea 3; June to October in Subarea 4). It was abundant in the months sampled until September in Subarea 5.

Euphausiids (Fig. 9, right) were generally below average or close to the long-term mean except in Subarea 1 in May, Subarea 2 in October, Subarea 3 from August to October and in December and Subarea 4 in April and June. However, they were more abundant than usual in most months sampled in Subarea 5.

Copepodite stages I-IV of *Calanus finmarchicus* (Fig. 10, left) were abundant in spring in all areas sampled (June and July in Subarea 1, May and June in Subarea 2, January, February and May in Subarea 3 and April in Subarea 4). However, they were below average in most months in all subareas from July onwards except July in Subarea 1 and August in Subareas 3 and 4. Numbers were low in all months when samples were taken in Subarea 5.

Young stages of *Sebastes* spp. (Fig. 10, right) were scarce in all areas. High numbers occurred for a short period in Subarea 1 (in May, a month earlier than usual) and in June in Subarea 2. Young stages of Ammodytidae, Clupeidae and *Mallotus villosus* (Fig. 11) are only found in appreciable numbers in Subareas 3, 4 or 5. Ammodytidae were present for 1 month only in Subareas 3 and 4; Clupeidae were abundant in January, March, July, November and December in Subarea 3, in January and April in Subarea 4, and in November and December in Subarea 5.

## Conclusions

The main results of the sampling in the ICNAF area from 1961 to 1971 may be summarized as follows:

- in Subarea 3 the end of the spring outbreak of the phytoplankton has occurred progressively earlier over the period 1965-71. This may be correlated with the earlier outbreak of copepods, and copepodite stages I-IV of *Calanus finmarchicus* from 1963 onwards;
- the autumnal peak of the phytoplankton production has increased since 1968 while there has been a decline in the abundance of copepods over the same period;
- there has been a decline in the abundance of copepods in Subareas 2, 3 and 4;

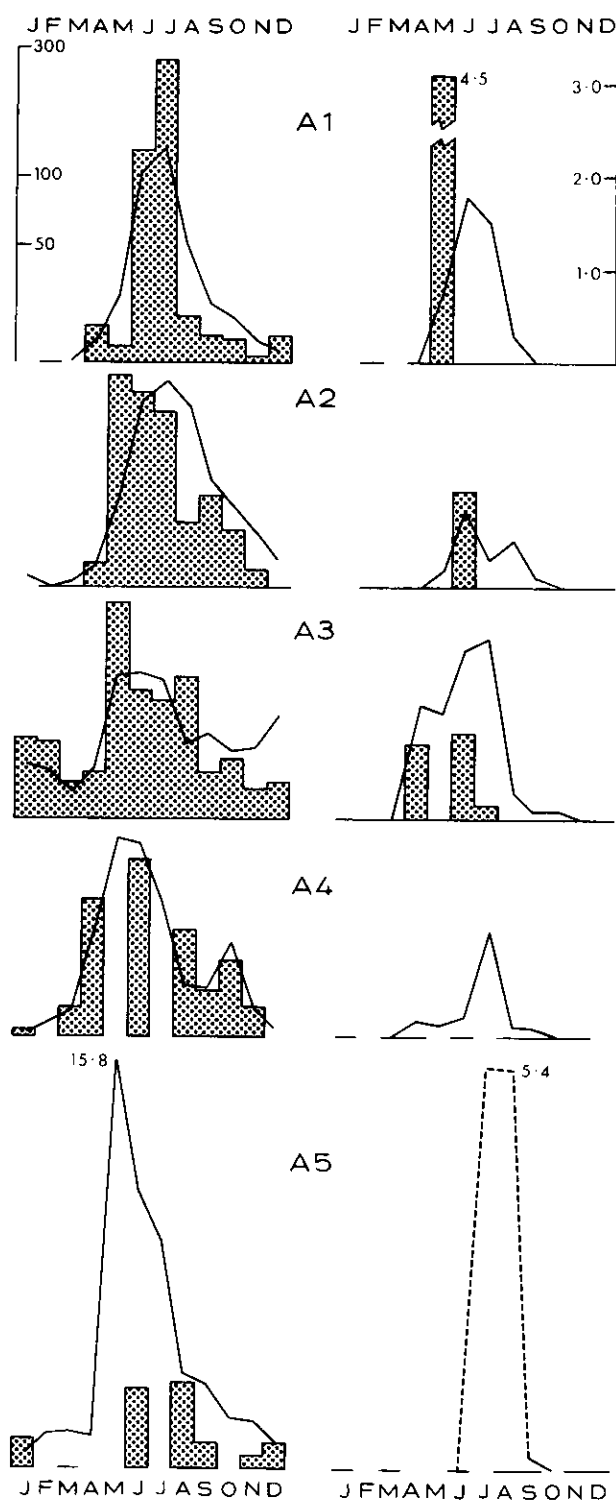


Fig. 10. Histograms showing average numbers per Recorder sample of copepodite stages I-IV of *C. finmarchicus* (left) and young stages of *Sebastes* spp. (right) in the ICNAF areas 1-5 in 1971. The line graphs show the mean values for the period 1959-71.

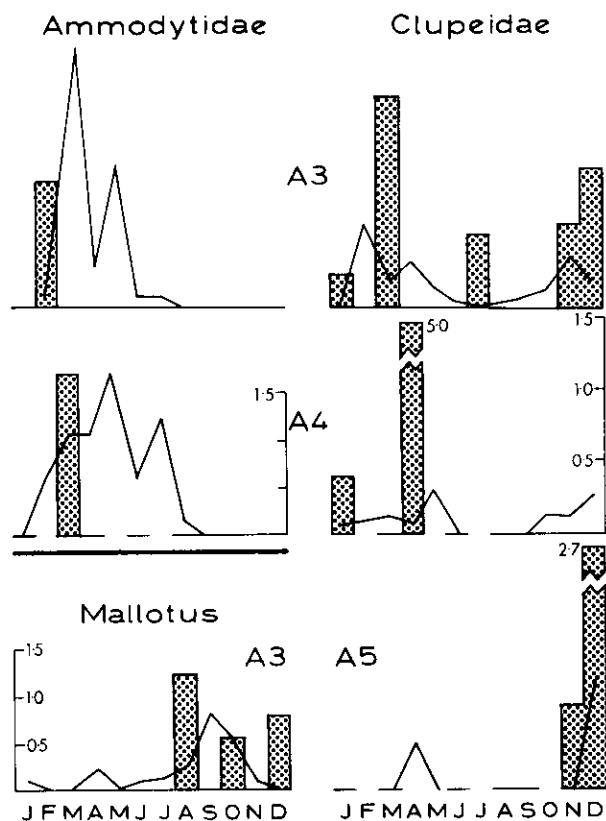


Fig. 11. Histograms showing average numbers per Recorder sample of young stages of Ammodytidae in Subareas 3 and 4, Clupeidae in Subareas 3, 4 and 5 and *Mallotus villosus* in Subarea 3 in 1971. The line graphs show the mean value for the period 1959-70.

- d) the annual fluctuations in the young stages of *Sebastes* spp., Ammodytidae, Clupeidae, *Mallotus villosus* and Scopelidae all show strong correlations with the first or second components of the annual fluctuation in abundance of the permanent plankton. Bainbridge and Cooper (1971) suggested that there were four independent populations of *Sebastes* in the North Atlantic, three of which occurred in the ICNAF area; these were distinguished by their spawning times which appeared to be related to the seasonal cycle of copepods. Three different patterns of annual fluctuation of abundance of *Sebastes* can be identified (Fig. 5) in Subareas 1-2, Subareas 3 and 4 and Subarea 5; this is further evidence in support of the conclusions of Bainbridge and Cooper;
- e) young stages of *Sebastes* spp. and Ammodytidae were scarce in 1971, while *Mallotus villosus* and Clupeidae were more abundant than usual. Copepods were abundant in the first half of the

year in all areas; numbers remained high throughout the year in Subareas 4 and 5 but were below average in Subareas 2 and 3 from June onwards.

This paper does no more than provide examples of descriptive data presentation from the Continuous Plankton Recorder survey which could be made available as a routine. The paper does not attempt to deal with the analysis and interpretation of variability in the plankton.

### Acknowledgement

We acknowledge gratefully the assistance of the captains and crews of many vessels which have towed Continuous Plankton Recorders; the survey would be impossible to operate without their willing co-operation. The plankton samples have been analysed by the staff of the Oceanographic Laboratory, and the young fish have been identified by G. T. D. Henderson and G. A. Cooper.

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# Morphometric Variation in Atlantic Herring from Newfoundland and Adjacent Waters

By L. S. Parsons<sup>1</sup>

## Abstract

The relative sizes of various body parts (orbit diameter, head, snout, postorbital and predorsal length) of herring from Newfoundland and adjacent waters were examined to ascertain the value of these characters for the differentiation of herring stocks in the Newfoundland area. In most areas autumn spawners have relatively larger heads, snouts, orbit diameters, postorbital and predorsal lengths than spring spawners. Sexual dimorphism in morphometric characteristics is negligible. Covariance comparisons of the log-log regressions of body parts on standard length revealed considerable heterogeneity in morphometric characteristics. Between-area differences were evident for all characters and all pairs of areas compared. Significant differences were found even between closely related stocks. It is concluded that morphometric characters are of limited value for stock differentiation.

## Introduction

Although morphometric characters have been frequently used in population studies of scombroid fishes, particularly the tunas (Godsil, 1948; Schaefer, 1948; Schaefer and Walford, 1950; Roedel, 1952; Royce, 1953, 1964; Yang, Nose and Hiyama, 1969), there have been very few attempts to characterize different biological groups of herring on the basis of the relative dimensions of various body parts. Apart from a few scattered observations by early European investigators, Popiel (1955), who examined the head lengths of certain groups of Baltic herring, was one of the first to utilize morphometric characters in European herring racial investigations. Muzinic and Parrish (1960) compared the head length-total length relationships among herring spawning in the northern and southern regions of the North Sea and found a significant difference between the body proportions of the two spawning groups studied. More recently, Burd (MS 1969) applied principal component or cluster analysis to eight morphometric characters — preorbital, postorbital, caput, pectoral, predorsal, pelvic, preanal and cranial lengths. He reported that multiple morphometric measurements did not satisfactorily discriminate between three samples of spawning herring from the Dogger, Sandettie and Flamborough fisheries. However, Pope and Hall (MS 1970) concluded from a preliminary discriminant function analysis that these same characters, although of little value singly, were useful when combined to construct a linear discriminant function for separating the Buchan and Kobbergrund herring stocks.

Jean (1967) compared herring from different regions in the Gulf of St. Lawrence on the basis of four morphometric characters — head length, snout length, orbit diameter and postorbital length. He reported that herring from the relatively cold waters of Ile Verte had a slower growth rate and smaller snouts and heads than those from the warmer waters of Anse au Gascon.

The present study was undertaken to examine the variation in morphometric characters of herring inhabiting Newfoundland and adjacent waters and to ascertain the value of such characters for stock delineation.

## 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 during the period from January 1969 to June 1970. Herring samples, usually of 50 specimens but sometimes in multiples of 50, were collected from catches of purse seines, midwater trawls, gillnets and codtraps.

The numbers of herring in each area from which body measurements were obtained are listed in Table 1.

Various body measurements were made on thawed specimens using a measuring board similar to that described and illustrated by Rounsefell (1930) and employed by Tester (1937) and Jean (1967). All

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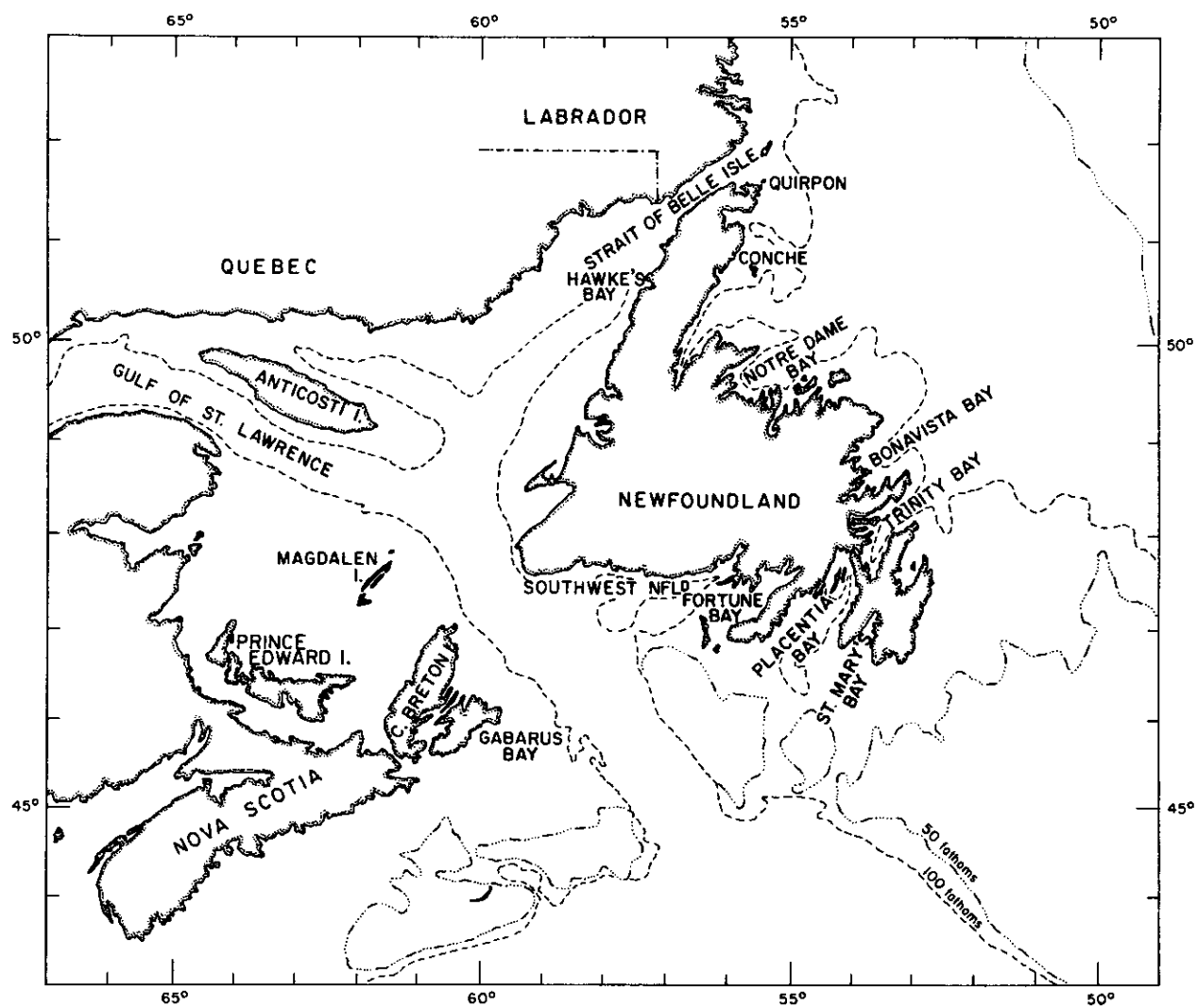


Fig. 1. Area map showing the localities and place names mentioned in the text.

TABLE 1. Numbers of herring in each area from which body measurements were obtained (S = Spring spawners; A = Autumn spawners).

Area Code	Locality and spawning group	No. of specimens
1	Gabarus Bay, N.S. (A)	146
2	Magdalen Islands (S)	107
	Magdalen Islands (A)	373
3	Southwest Nfld. (S)	141
	Southwest Nfld. (A)	348
4	Fortune Bay (S)	219
5	Placentia Bay (S)	76
	Placentia Bay (A)	49
6	St. Mary's Bay (S)	244
	St. Mary's Bay (A)	—
7	Trinity Bay (S)	322
	Trinity Bay (A)	105
8	Bonavista Bay (S)	334
	Bonavista Bay (A)	150
9	Notre Dame Bay (S)	431
10	Conche (S)	73
	Conche (A)	74
11	Quirpon (S)	82
	Quirpon (A)	133
12	Strait of Belle Isle (A)	195
13	Hawke's Bay (S)	243
	Hawke's Bay (A)	141
		3,986

distances were measured in millimetres from the tip of the closed lower jaw to the various end points. These measurements were not of actual distances but rather of distances as projected on the millimetre scale of the board. All measurements were made by the author to eliminate between-individuals variation in methods of measuring. No corrections were made for shrinkage due to freezing.

The following body measurements were taken (Fig. 2):

*Total Length:* distance from the tip of the closed lower jaw to the end of the longest lobe of the caudal fin

with the lobe extending posteriorly in line with the body (greatest total length).

*Standard length:* distance from the tip of the closed lower jaw to the end of the silvery area on the caudal peduncle after the scales have been removed from that region.

*Head length:* distance from the tip of the closed lower jaw to the posterior margin of the operculum.

*Snout length:* distance from the tip of the closed lower jaw to the anterior margin of the orbit.

*Orbit diameter:* horizontal distance from the anterior to the posterior margin of the orbit.

*Postorbital length:* distance from the posterior margin of the orbit to the posterior margin of the operculum.

*Predorsal length:* distance from the tip of the closed lower jaw to the base of the most anterior ray of the dorsal fin.

Individual adult fish were assigned to spawning groups on the basis of gonad development in relation to time of capture, as described by Parsons (1973).

The relative growth method of analysis described by Huxley (1924, 1932) was utilized for analyses of the morphometric data.

Graphical plots of the raw data indicated straight line relationships between standard length and all body parts examined; there were no obvious departures from linearity. It has been demonstrated for many species that the major growth inflection is related to the onset of sexual maturity after which the rate of relative growth is relatively constant (Desbrosse, 1936; Mottley, 1936; Hamai, 1941; Wilder, 1952; Martin, 1949). Therefore, to avoid difficulties introduced by allometric growth, immature specimens were excluded from the data analyses. To ensure linearity and homogeneity of variance the data were converted to common logarithms and log-log regressions of the various body parts on standard length were calculated. Differences in the regression coefficient (slopes) and adjusted means of the regression lines were compared by analysis of covariance as described by Snedecor (1961). If the differences in slopes are significant, in which case the regression lines are not parallel, differences in adjusted means have little meaning. Because of the relatively small size and irregular length distribution of the samples, a significance level of 0.01 was used.

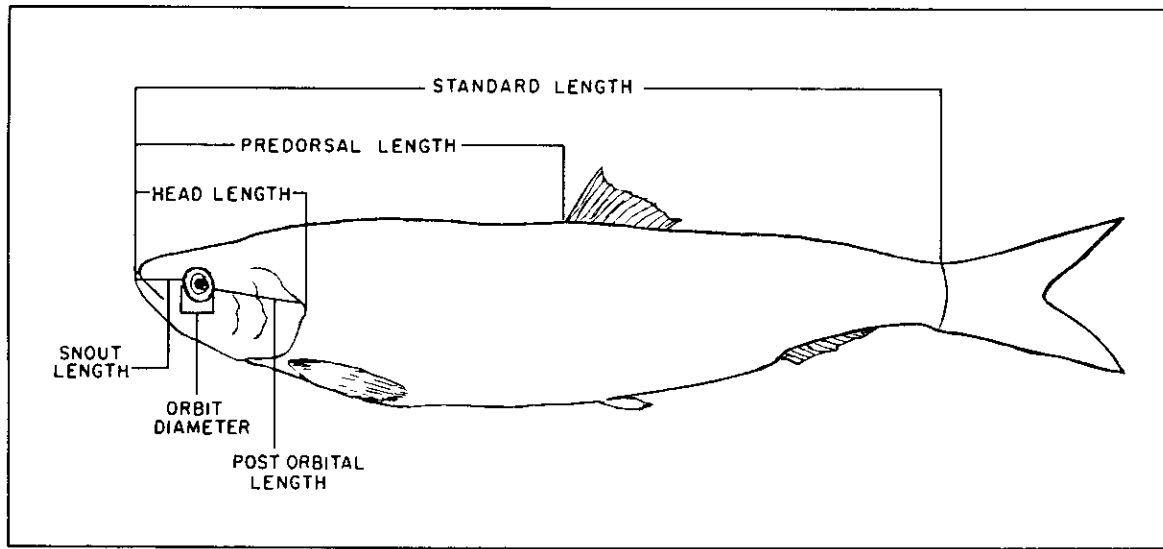


Fig. 2. Sketch of a herring showing the body measurements taken.

TABLE 2. Covariance comparisons of the log-log regressions of various body parts on standard length between samples within each area for spring and autumn spawners separately. (\*\* indicates significance at the 1% level.)

Area	D.F.		Head length		Snout length		Orbit diameter		Postorbital length		Predorsal length	
	Slopes F	Adj. Means F	Slopes F	Adj. Means F	Slopes F	Adj. Means F	Slopes F	Adj. Means F	Slopes F	Adj. Means F	Slopes F	Adj. Means F
<b>Spring spawners</b>												
Magdalen Islands	8,89	8,97	0.57	0.38	0.49	1.79	0.78	1.40	0.91	0.74	0.64	1.69
Southwest Nfld	9,121	9,130	1.54	1.63	0.30	3.70**	1.32	1.60	1.07	1.38	0.72	1.19
Fortune Bay	3,207	3,211	0.70	20.47**	3.19	21.91**	0.95	4.24**	1.92	8.72**	1.75	1.01
Placentia Bay	1,72	1,73	0.00	0.40	0.11	2.68	0.01	0.00	0.11	4.18	0.00	0.10
St. Mary's Bay	2,240	2,241	3.92	0.84	0.25	1.18	0.02	4.18	4.68	8.81	6.72**	13.54**
Trinity Bay	6,303	6,309	0.90	3.99**	1.05	5.21**	1.12	1.42	0.45	4.59**	1.14	4.52**
Bonavista Bay	9,310	9,319	1.01	6.76**	0.70	10.41**	0.55	2.51	1.48	10.76**	0.98	1.63
Notre Dame Bay	4,421	4,425	0.63	5.51**	0.87	4.40**	1.93	4.78**	1.57	9.59**	0.95	3.78**
Conche	3,65	3,68	1.10	1.24	0.41	0.17	0.62	3.39	1.00	2.89	2.76	0.14
Quirpon	3,71	3,74	4.67**	1.58	0.80	24.43**	1.55	2.26	2.87	15.88**	1.96	2.54
Hawke's Bay	8,225	8,233	1.47	5.77**	2.39	2.66**	0.60	3.28**	0.63	2.54	1.01	3.36**
<b>Autumn spawners</b>												
Gabarus Bay, N.S.	1,142	1,143	1.00	0.06	0.93	0.08	0.00	1.17	0.33	0.65	1.22	0.29
Magdalen Islands	8,355	8,363	0.60	3.67**	0.61	9.53**	0.20	2.73**	0.50	1.03	0.64	1.26
Southwest Nfld.	9,328	9,337	0.94	4.67**	1.07	3.59**	1.34	2.59	1.23	3.63**	0.93	1.16
Placentia Bay	1,45	1,46	0.48	0.01	2.42	0.98	0.11	2.40	0.05	2.27	0.88	0.32
Trinity Bay	4,90	4,94	0.57	0.16	2.91	0.62	1.48	0.76	2.41	0.76	1.00	0.56
Bonavista Bay	7,132	7,139	2.31	3.25**	0.48	7.97**	1.57	3.52**	1.56	0.93	0.95	0.83
Conche	4,64	4,68	2.32	2.17	0.49	4.87**	2.90	0.67	1.19	1.21	1.79	2.00
Quirpon	5,121	5,126	2.38	1.75	0.67	21.55**	1.16	5.74**	1.99	7.00**	0.92	3.92**
Strait of Belle Isle	3,187	3,190	1.70	2.15	4.36**	6.15**	0.19	1.68	0.39	0.22	0.15	3.03
Hawke's Bay	8,123	8,131	0.80	0.95	0.28	1.91	1.66	1.57	0.70	0.58	1.72	0.66

## Results

### Variation among samples

Log-log regressions of body parts on standard length were calculated separately for each sample for both spawning groups within each area. Between-sample differences were tested by analysis of covariance (Table

2). Differences in slopes were generally not significant (only 2 instances out of a possible 105). However, there were numerous instances of between-sample differences in adjusted means for all morphometric characters examined. Despite between-sample differences within areas valid area comparisons can be made if the mean square difference among the samples is smaller than that between areas. Therefore, the variation between samples

within areas was used to test the differences between the areas. For both spawning groups and all morphometric characters the mean square difference between areas exceeded the mean square difference between samples and in each instance the F value thus derived was statistically significant. Therefore, all samples within each area were pooled and regression lines computed for both spawning groups and both sexes within each area.

### Variation between spawning groups

Log-log regressions of body parts on standard length were calculated for spring and autumn spawners within each of the eight areas where both spawning

groups were represented (Tables 3-7). In seven of the eight areas autumn spawners had relatively larger heads at any particular standard length than spring spawners (Fig. 3). However, Conche spring spawners had relatively larger heads than autumn spawners. Covariance analysis to test the hypothesis that a common line can be utilized to express the head length-standard length relationship yielded significant F values for six of the eight areas (Table 3). Differences in slopes of the regression lines were significant between spring and autumn spawners from southwestern Newfoundland and Hawke's Bay. Adjusted means accounted for the significant differences between spring and autumn spawners from Magdalen Islands, Trinity Bay, Bonavista Bay and Conche.

TABLE 3. Covariance statistics comparing the log-log regressions of head length on standard length for spring and autumn spawners within each area. (\*\*indicates significance at the 1% level.)

Area and spawning group		No. of specimens	Regression coef., n	Intercept log k	Correlation coef., r	Std. error of estimate	Covariance analysis	
							Slopes F	Adjusted means F
Magdalen Islands	(S)	107	0.9847	-0.6458	0.850	0.013	0.15	107.70**
Magdalen Islands	(A)	373	0.9593	-0.5688	0.832	0.012		
Southwest Nfld.	(S)	141	0.8479	-0.3159	0.698	0.012	7.79**	143.66**
Southwest Nfld.	(A)	348	1.0764	-0.8591	0.832	0.012		
Placentia Bay	(S)	76	0.8583	-0.3297	0.956	0.013	0.07	2.70
Placentia Bay	(A)	49	0.8393	-0.2779	0.870	0.015		
Trinity Bay	(S)	322	0.8503	-0.3132	0.933	0.012	0.32	10.05**
Trinity Bay	(A)	105	0.8131	-0.2162	0.844	0.009		
Bonavista Bay	(S)	330	0.8316	-0.2656	0.892	0.013	1.46	34.84**
Bonavista Bay	(A)	150	0.9058	-0.4394	0.789	0.013		
Conche	(S)	73	0.9026	-0.4435	0.933	0.013	0.51	14.39**
Conche	(A)	74	0.9421	-0.5487	0.949	0.012		
Quirpon	(S)	82	0.8607	-0.3425	0.903	0.012	0.01	2.96
Quirpon	(A)	133	0.8671	-0.3547	0.843	0.014		
Hawke's Bay	(S)	243	0.9275	-0.5184	0.920	0.014	7.29**	39.01**
Hawke's Bay	(A)	141	1.0377	-0.7786	0.943	0.013		
Fortune Bay	(S)	217	0.7806	-0.1484	0.921	0.015		
St. Mary's Bay	(S)	244	0.8139	-0.2308	0.934	0.010		
Notre Dame Bay	(S)	431	0.7914	-0.1730	0.896	0.010		
Gabarus Bay, N.S.	(A)	146	0.8719	-0.3600	0.940	0.010		
Strait of Belle Isle	(A)	195	0.9962	-0.6860	0.868	0.011		

A = Autumn; S = Spring.

TABLE 4. Covariance statistics comparing the log-log regressions of snout length on standard length for spring and autumn spawners within each area. (\*\*indicates significance at the 1% level.)

Area and spawning group		No. of specimens	Regression coef., n	Intercept log k	Correlation coef., r	Std. error of estimate	Covariance analysis	
							Slopes F	Adjusted means F
Magdalen Islands	(S)	107	0.8148	-0.7769	0.532	0.027	1.14	43.52
Magdalen Islands	(A)	373	0.9576	-1.1064	0.607	0.024		
Southwest Nfld.	(S)	141	0.7155	-0.5277	0.370	0.026	3.29	34.53
Southwest Nfld.	(A)	348	1.0094	-1.2312	0.587	0.023		
Placentia Bay	(S)	76	0.7632	-0.6181	0.868	0.022	0.63	1.70
Placentia Bay	(A)	49	0.8547	-0.8356	0.765	0.022		
Trinity Bay	(S)	321	0.7711	-0.6433	0.785	0.023	0.18	5.79
Trinity Bay	(A)	105	0.7183	-0.5054	0.546	0.020		
Bonavista Bay	(S)	332	0.7000	-0.4629	0.653	0.025	3.88	3.50
Bonavista Bay	(A)	150	0.9314	-1.0296	0.570	0.025		
Conche	(S)	73	0.8481	-0.8463	0.781	0.025	2.02	5.69
Conche	(A)	74	1.0101	-1.2550	0.828	0.026		
Quirpon	(S)	82	1.3238	-1.9956	0.806	0.028	0.87	11.60**
Quirpon	(A)	133	1.1809	-1.6280	0.698	0.030		
Hawke's Bay	(S)	243	0.7999	-0.7458	0.698	0.028	1.59	5.51
Hawke's Bay	(A)	141	0.9080	-1.0026	0.759	0.027		
Fortune Bay	(S)	217	0.6503	-0.3643	0.668	0.033		
St. Mary's Bay	(S)	243	0.6416	-0.3327	0.736	0.020		
Notre Dame Bay	(S)	431	0.6416	-0.3327	0.736	0.017		
Gabarus Bay, N.S.	(A)	146	0.7830	-0.6740	0.777	0.021		
Strait of Belle Isle	(A)	195	0.9272	-1.0432	0.653	0.022		

A = Autumn; S = Spring.

TABLE 5. Covariance statistics comparing the log-log regressions of orbit diameter on standard length for spring and autumn spawners within each area. (\*\*indicates significance at the 1% level.)

Area and spawning group		No. of specimens	Regression coef., n	Intercept log k	Correlation coef., r	Std. error of estimate	Covariance analysis	
							Slopes F	Adjusted means F
Magdalen Islands	(S)	107	0.9436	-1.1772	0.597	0.027	0.23	7.39**
Magdalen Islands	(A)	373	0.8762	-1.0044	0.544	0.026		
Southwest Nfld.	(S)	141	0.9341	-1.1520	0.454	0.026	0.43	2.10
Southwest Nfld.	(A)	348	1.0412	-1.4102	0.597	0.024		
Placentia Bay	(S)	76	0.7609	-0.7489	0.821	0.026	0.80	3.16
Placentia Bay	(A)	49	0.8917	-1.0579	0.679	0.030		
Trinity Bay	(S)	321	0.8248	-0.8963	0.796	0.024	0.40	10.11**
Trinity Bay	(A)	105	0.9055	-1.0880	0.635	0.020		
Bonavista Bay	(S)	332	0.8052	-0.8466	0.690	0.026	0.88	7.76**
Bonavista Bay	(A)	150	0.6890	-0.5496	0.426	0.028		
Conche	(S)	73	0.8231	-0.8885	0.752	0.027	0.80	5.68
Conche	(A)	74	0.9338	-1.1720	0.778	0.029		
Quirpon	(S)	82	0.6533	-0.4796	0.574	0.027	0.06	2.16
Quirpon	(A)	133	0.6172	-0.3971	0.452	0.030		
Hawke's Bay	(S)	243	1.0285	-1.3898	0.798	0.027	0.04	1.72
Hawke's Bay	(A)	141	1.0116	-1.3445	0.783	0.028		
Fortune Bay	(S)	217	0.7540	-0.7235	0.799	0.025		
St. Mary's Bay	(S)	243	0.8845	-1.0342	0.852	0.018		
Notre Dame Bay	(S)	431	0.7747	-0.7584	0.691	0.021		
Gabarus Bay, N.S.	(A)	146	0.6306	-0.4084	0.675	0.022		
Strait of Belle Isle	(A)	195	0.7424	-0.6816	0.565	0.022		

A = Autumn; S = Spring.

TABLE 6. Covariance statistics comparing the log-log regressions of postorbital length on standard length for spring and autumn spawners within each area. (\*\*indicates significance at the 1% level.)

Area and spawning group		No. of specimens	Regression coef., n	Intercept log k	Correlation coef., r	Std. error of estimate	Covariance analysis	
							Slopes F	Adjusted means F
Magdalen Islands	(S)	107	1.1041	-1.2549	0.789	0.018 } 0.018 }	1.22	60.36**
Magdalen Islands	(A)	373	1.0000	-0.9848	0.741			
Southwest Nfld.	(S)	141	0.9421	-0.8724	0.578	0.019 } 0.017 }	2.78	128.23**
Southwest Nfld.	(A)	348	1.1368	-1.3274	0.754			
Placentia Bay	(S)	76	0.9653	-0.9119	0.924	0.020 } 0.022 }	2.28	0.10
Placentia Bay	(A)	49	0.8017	-0.5096	0.752			
Trinity Bay	(S)	321	0.9134	-0.7921	0.872	0.019 } 0.015 }	0.59	0.34
Trinity Bay	(A)	105	0.8346	-0.5948	0.710			
Bonavista Bay	(S)	329	0.9310	-0.8361	0.802	0.021 } 0.019 }	0.40	21.53**
Bonavista Bay	(A)	150	0.9924	-0.9757	0.699			
Conche	(S)	73	1.0023	-1.0062	0.905	0.018 } 0.015 }	1.60	5.09
Conche	(A)	74	0.9114	-0.7895	0.920			
Quirpon	(S)	82	0.6458	-0.1448	0.647	0.022 } 0.025 }	1.14	0.00
Quirpon	(A)	133	0.7792	-0.4735	0.611			
Hawke's Bay	(S)	243	0.9578	-0.9181	0.859	0.020 } 0.021 }	7.67**	33.92**
Hawke's Bay	(A)	141	1.1282	-1.3214	0.885			
Fortune Bay	(S)	215	0.8666	-0.6801	0.883	0.021		
St. Mary's Bay	(S)	243	0.8875	-0.7429	0.852	0.018		
Notre Dame Bay	(S)	431	0.9363	-0.8610	0.824	0.017		
Gabarus Bay, N.S.	(A)	146	1.0506	-1.1204	0.899	0.017		
Strait of Belle Isle	(A)	195	1.1684	-1.4444	0.831	0.016		

A = Autumn; S = Spring.



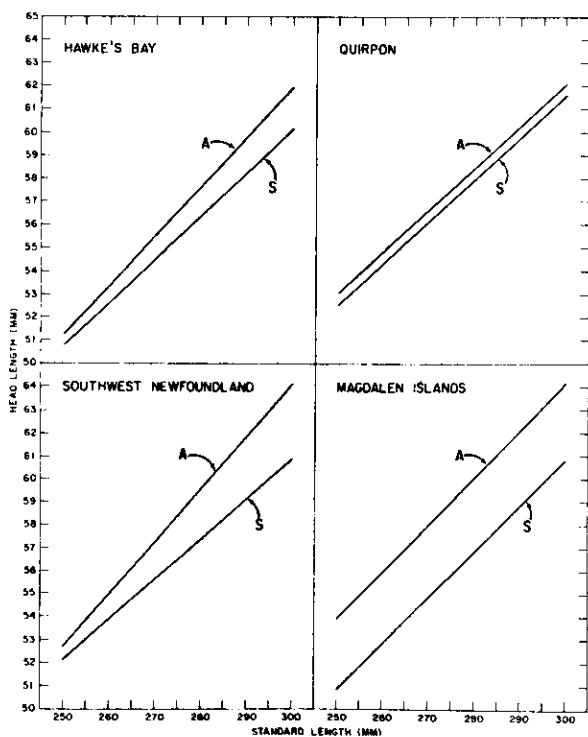
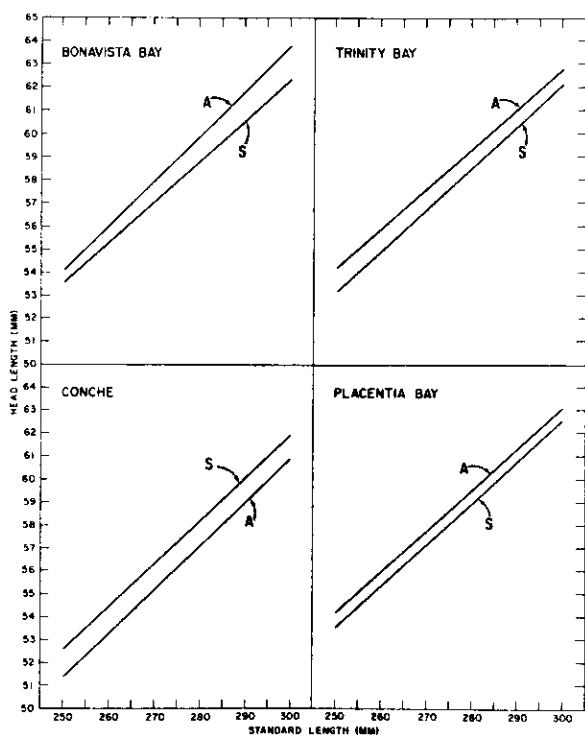


Fig. 3. Relation of head length to standard length for spring and autumn spawners in each area.

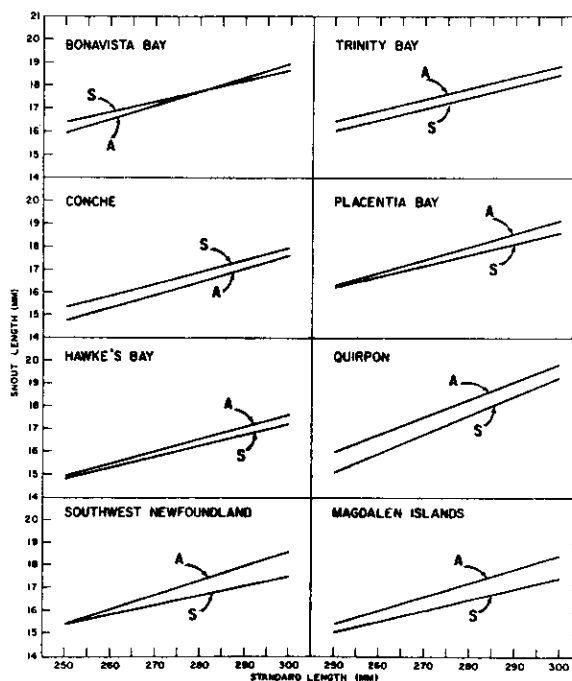


Fig. 4. Relation of snout length to standard length for spring and autumn spawners in each area.

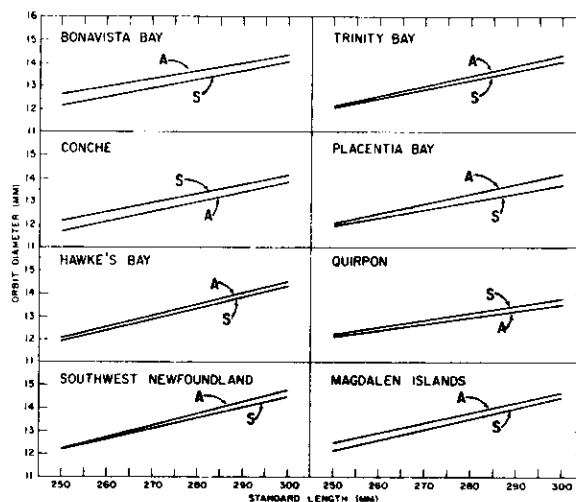


Fig. 5. Relation of orbit diameter to standard length for spring and autumn spawners in each area.

TABLE 7. Covariance statistics comparing the log-log regressions of predorsal length on standard length for spring and autumn spawners within each area. (\*\*indicates significance at the 1% level.)

Area and spawning group		No. of specimens	Regression coef., n	Intercept log k	Correlation coef., r	Std. error of estimate	Covariance analysis	
							Slopes F	Adjusted means F
Magdalen Islands	(S)	107	1.0879	-0.5116	0.947	0.008	1.16	16.93**
Magdalen Islands	(A)	373	1.0418	-0.3951	0.928	0.008		
Southwest Nfld.	(S)	141	1.0757	-0.4808	0.890	0.008	0.46	7.63**
Southwest Nfld.	(A)	348	1.1099	-0.5621	0.932	0.007		
Placentia Bay	(S)	76	1.0179	-0.3405	0.986	0.009	1.34	1.33
Placentia Bay	(A)	49	0.9661	-0.2112	0.964	0.008		
Trinity Bay	(S)	322	1.0498	-0.4169	0.977	0.009	1.20	6.78
Trinity Bay	(A)	105	1.1017	-0.5432	0.926	0.008		
Bonavista Bay	(S)	334	1.0227	-0.3504	0.970	0.008	0.43	3.89
Bonavista Bay	(A)	149	0.9984	-0.2883	0.925	0.008		
Conche	(S)	73	1.0234	-0.3494	0.980	0.008	0.10	1.31
Conche	(A)	74	1.0347	-0.3787	0.979	0.008		
Quirpon	(S)	82	0.9618	-0.1998	0.969	0.007	5.76	0.72
Quirpon	(A)	133	1.0652	-0.4534	0.948	0.009		
Hawke's Bay	(S)	243	1.0336	-0.3765	0.974	0.008	1.81	4.69
Hawke's Bay	(A)	141	1.0674	-0.4614	0.978	0.008		
Fortune Bay	(S)	219	1.0427	-0.4023	0.986	0.008		
St. Mary's Bay	(S)	244	0.9807	-0.2441	0.977	0.007		
Notre Dame Bay	(S)	431	1.0230	-0.3467	0.970	0.007		
Gabarus Bay, N.S.	(A)	146	1.0085	-0.3087	0.975	0.007		
Strait of Belle Isle	(A)	195	1.0084	-0.3114	0.936	0.008		

A = Autumn; S = Spring.

Snout length-standard length regression lines for spring and autumn spawners in each area are illustrated in Fig. 4. In six of the eight areas autumn spawners had relatively larger snouts than spring spawners but Conche spring spawners had relatively larger snouts than autumn spawners. The regression lines for Bonavista Bay spring- and autumn-spawning herring overlap. F values comparing spring and autumn spawners were significant for three areas (Table 4). Differences in adjusted means were significant between spring and autumn spawners from Magdalen Islands, Southwest Newfoundland and Quirpon. In all three instances autumn spawners had relatively larger snouts than spring spawners.

In six areas autumn spawners had relatively larger orbit diameters than spring spawners (Fig. 5) but F values were significant (in adjusted means) for only three areas (Table 5). Spring spawners at Conche and Quirpon had relatively larger orbit diameters than autumn spawners but the differences were not statistically significant.

Autumn spawners had relatively larger postorbital lengths than spring spawners in five areas (Fig. 6). F values were significant in four of the five instances. Adjusted means accounted for the differences between spawning groups at Magdalen Islands, along Southwest

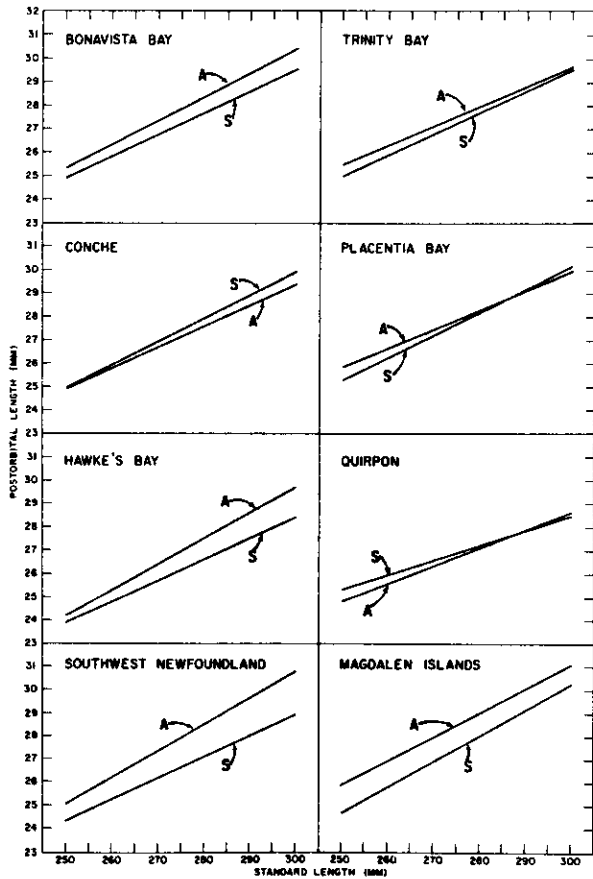


Fig. 6. Relation of postorbital length to standard length for spring and autumn spawners in each area.

Newfoundland and in Bonavista Bay. Hawke's Bay spring and autumn spawners differed significantly in slope. Conche spring spawners had relatively larger postorbital lengths than autumn spawners but the difference was not significant. The regression lines for spring and autumn spawners from Quirpon and Placentia Bay overlap.

In four areas autumn spawners had relatively larger predorsal lengths than spring spawners throughout the adult size range (Fig. 7). Spring spawners from Hawke's Bay appeared to have slightly larger predorsal lengths than autumn spawners. The regression lines for spring and autumn spawners in the other three areas overlap. In these instances the predorsal lengths of spring spawners were relatively larger than those of autumn spawners in smaller fish and relatively smaller in larger fish. F values were significant for only two of the eight areas (Table 7).

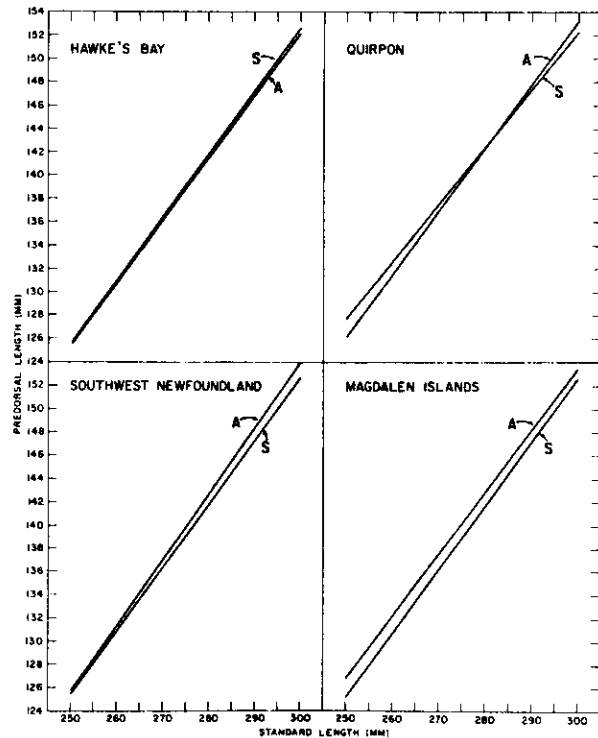
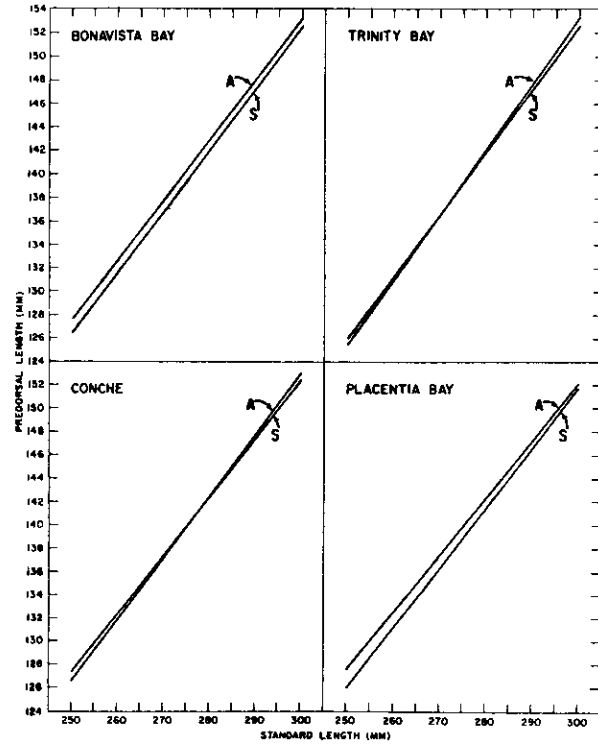


Fig. 7. Relation of predorsal length to standard length for spring and autumn spawners in each area.

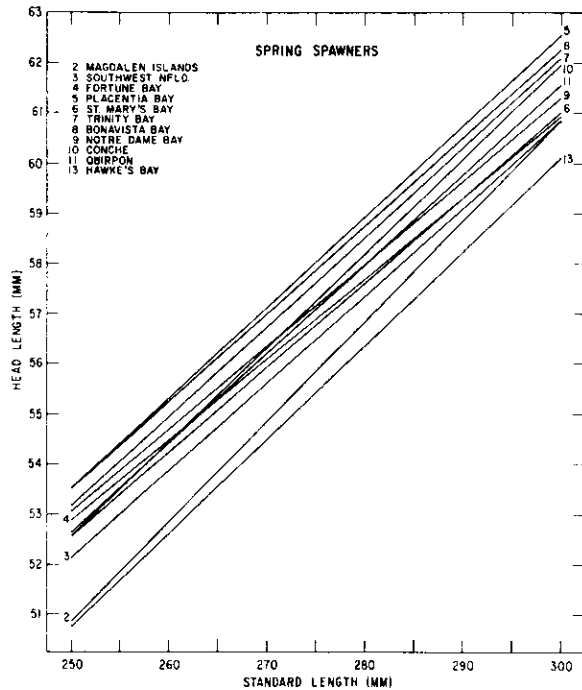


Fig. 8. Relation of head length to standard length for spring spawners in all areas.

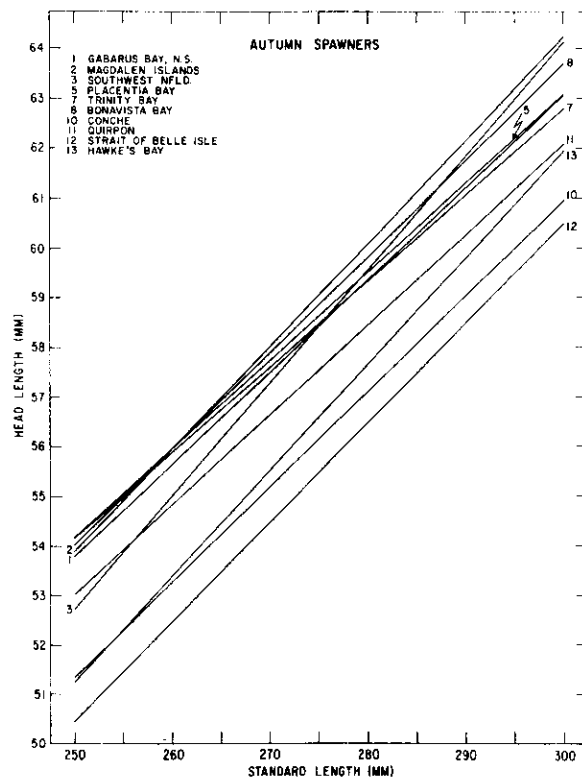


Fig. 9. Relation of head length to standard length for autumn spawners in all areas.

In general there was a tendency for autumn spawners to possess relatively larger body parts (in relation to standard length) than spring spawners.

#### Variation between sexes

Log-log regressions of body parts on standard length were computed for the sexes within each spawning group for each area (Table 6). There was no evidence of sexual dimorphism in snout length and orbit diameter. Significant sex differences were evident in only 1 of 21 possibilities for each of head length, postorbital length and predorsal length. It was concluded that sexual dimorphism is negligible.

#### Variation among areas

Head length-standard length regression lines for all areas are shown in Fig. 8 and 9 for spring and autumn spawners respectively. Spring-spawning herring from Placentia, Bonavista and Trinity bays have the largest heads. Hawke's Bay spring spawners have the smallest heads followed in order of increasing size by Magdalen Islands and Southwest Newfoundland spring spawners. Regression lines for spring spawners from the other areas overlap considerably. Among autumn spawners Strait of Belle Isle herring have the smallest heads followed in order of increasing size by Conche, Hawke's Bay and Quirpon herring. Autumn spawners from Magdalen Islands, Bonavista Bay, Placentia Bay, Gabarus Bay and Southwest Newfoundland have relatively larger heads. Regression lines for these latter areas exhibit considerable overlap but there is a fair amount of spread between the lines for Strait of Belle Isle, Conche, Hawke's Bay and Quirpon.

Spring-spawning herring from Bonavista and Placentia bays have the largest snouts and Hawke's Bay spring spawners the smallest followed in order of increasing size by Magdalen Islands and Southwest Newfoundland spring spawners (Fig. 10 and 11). Among autumn spawners herring from Quirpon, Placentia Bay, Trinity Bay and Bonavista Bay have the largest snouts. Conche autumn spawners have the smallest snouts followed in order of increasing size by Hawke's Bay and Strait of Belle Isle autumn spawners. Snout length is intermediate in autumn spawners from Gabarus Bay, Southwest Newfoundland and Magdalen Islands.

There is considerable overlap of the orbit diameter-standard length regression lines for both spring and autumn spawners and no clearcut geographic trends are evident (Fig. 12 and 13). Notre Dame Bay herring have the largest orbit diameters among spring spawners and Placentia Bay herring the smallest. Spring spawners from Southwest Newfoundland and Magdalen Islands appear to have similar relatively large orbit diameters

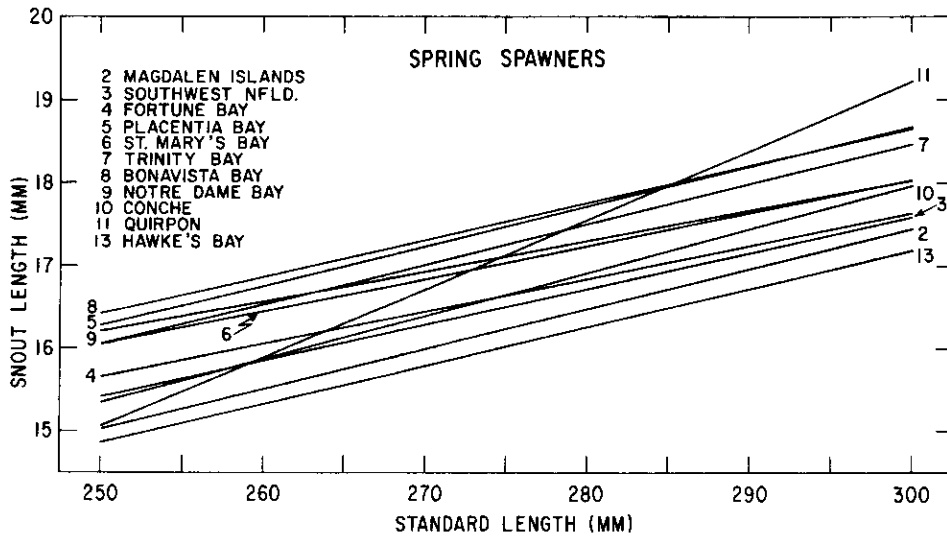


Fig. 10. Relation of snout length to standard length for spring spawners in all areas.

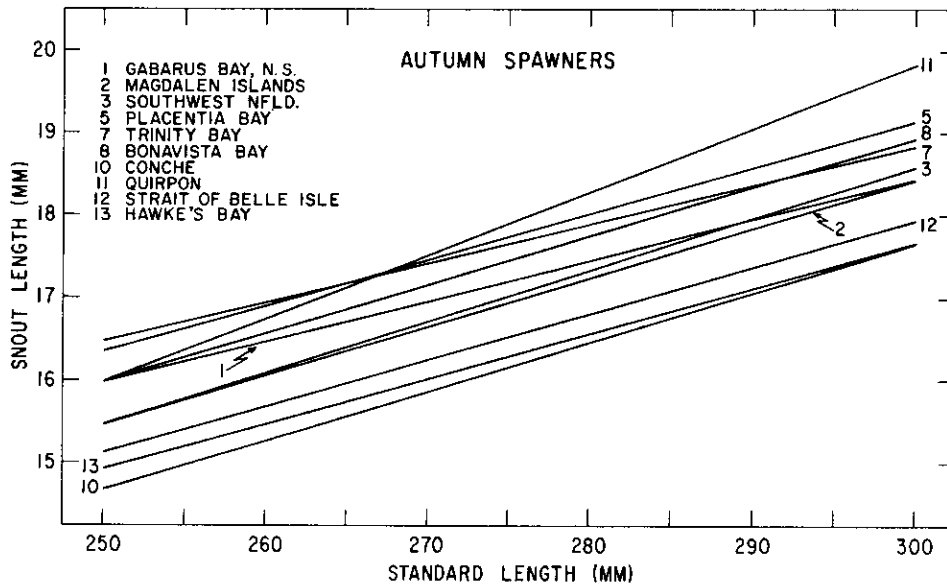


Fig. 11. Relation of snout length to standard length for autumn spawners in all areas.

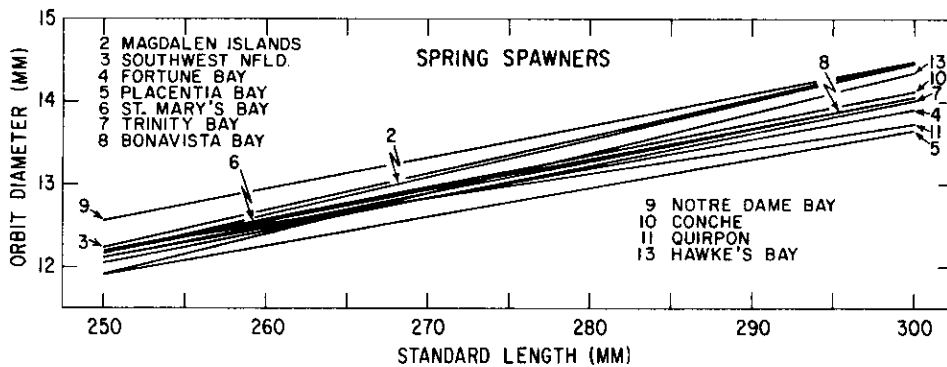


Fig. 12. Relation of orbit diameter to standard length for spring spawners in all areas.

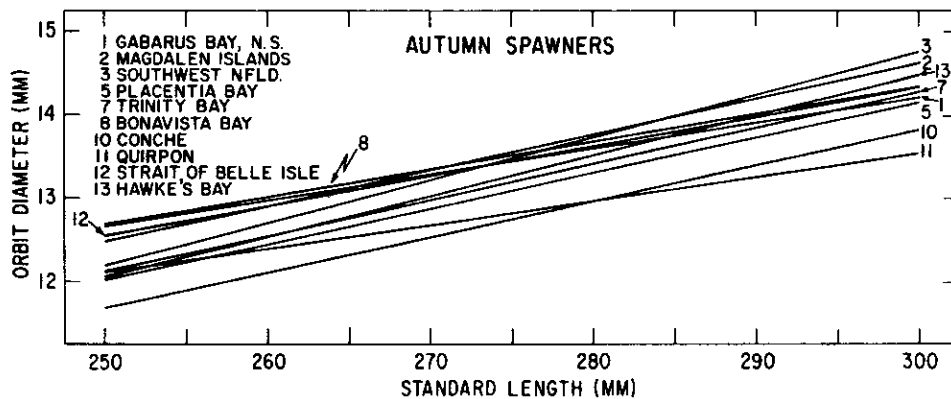


Fig. 13. Relation of orbit diameter to standard length for autumn spawners in all areas.

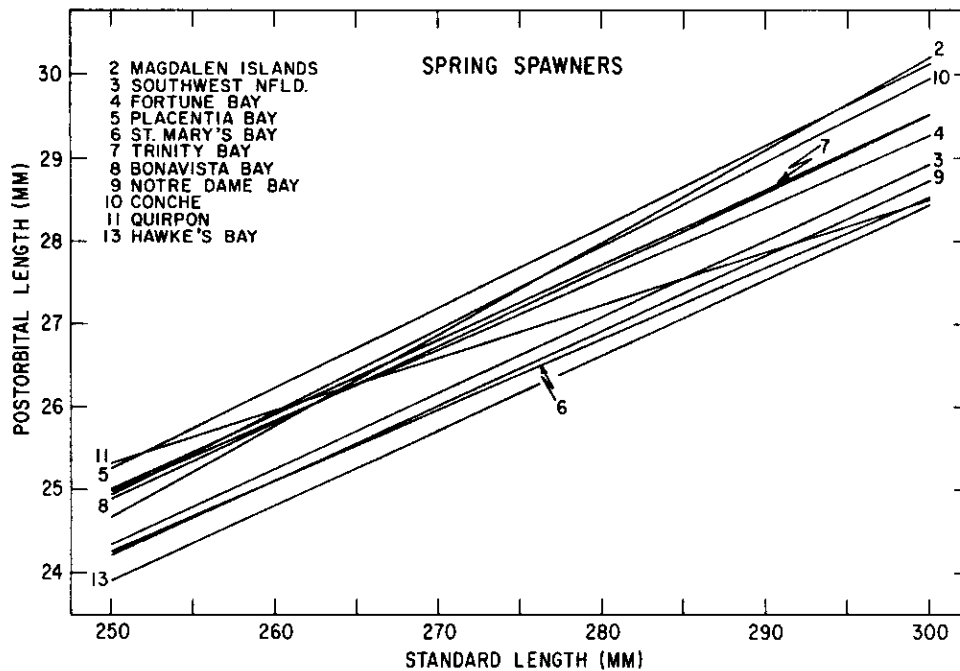


Fig. 14. Relation of postorbital length to standard length for spring spawners in all areas.

exceeded only by Notre Dame Bay spring spawners. Herring from Quirpon and Conche have the smallest orbit diameters among autumn spawners. Regression lines for several areas including Southwest Newfoundland and Magdalen Islands overlap near the top of the scale for autumn spawners.

No geographic trend in postorbital length is evident among spring spawners (Fig. 14). Throughout most of the adult size range Placentia Bay spring spawners have the largest postorbital lengths and Hawke's Bay spring spawners the smallest. St. Mary's Bay, Notre Dame Bay

and Southwest Newfoundland spring spawners have relatively small postorbital lengths. Regression lines for spring spawners from other areas overlap considerably. Among autumn spawners there appears to be a tendency for herring from the more northerly areas to possess relatively small postorbital lengths (Fig. 15). Strait of Belle Isle autumn spawners have the smallest postorbital lengths followed in order of increasing size by autumn spawners from Quirpon, Conche and Hawke's Bay which exhibit considerable overlap. Magdalen Islands autumn spawners have the largest postorbital lengths and autumn spawners from Southwest Newfoundland also

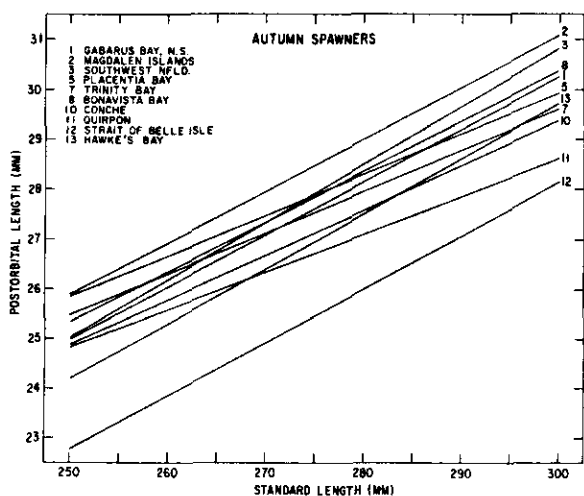


Fig. 15. Relation of postorbital length to standard length for autumn spawners in all areas.

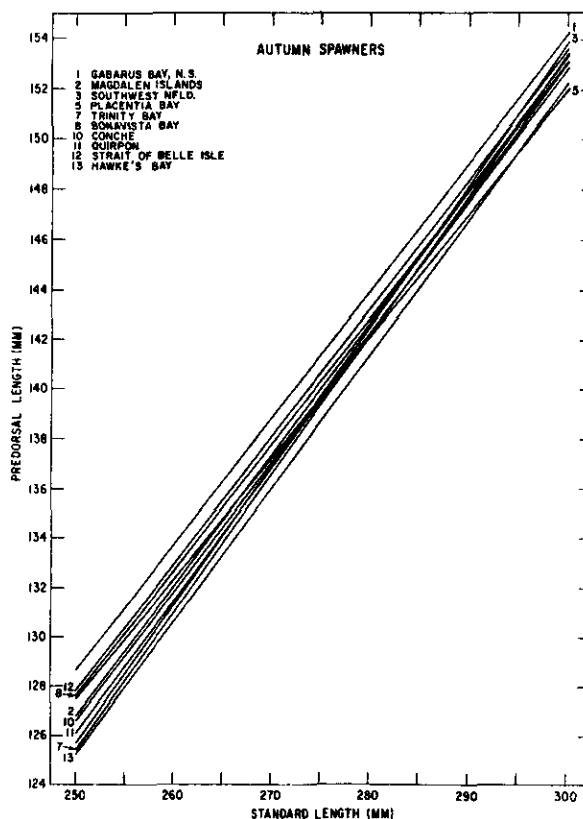


Fig. 17. Relation of predorsal length to standard length for autumn spawners in all areas.

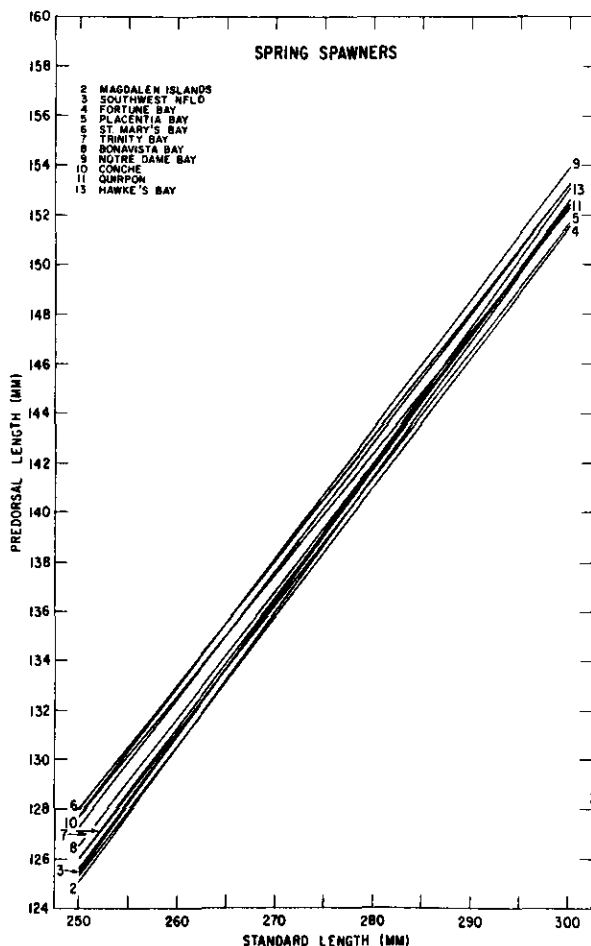


Fig. 16. Relation of predorsal length to standard length for spring spawners in all areas.

possess relatively large postorbital lengths. Autumn spawners from Gabarus Bay, the most southerly area, possess intermediate postorbital lengths.

No geographic trend in predorsal length is evident among either spawning group (Fig. 16 and 17). Notre Dame Bay and Conche herring have the largest predorsal lengths among spring spawners and Fortune Bay herring the smallest over most of the adult size range. Placentia Bay and Southwest Newfoundland spring spawners also have relatively small predorsal lengths. Gabarus Bay herring have the largest predorsal lengths among autumn spawners and Hawke's Bay herring the smallest. Autumn spawners from the Strait of Belle Isle have relatively large predorsal lengths exceeded only by those from Gabarus Bay.

There were highly significant differences among areas for both spring and autumn spawners in both slopes and adjusted means (Table 8) for all characters examined in this study. To test the significance of apparent differences between areas, regression lines for pairs of geographically adjacent areas were compared for spring and autumn spawners separately (Tables 9 and 10). The results of these area comparisons are summarized below.

TABLE 8. Covariance comparisons of the log-log regressions of head length on standard length among all areas for spring and autumn spawners separately. (\*\* indicates significance at the 1% level.)

Test	Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Among areas spring spawners	Within Samples	2244	$3.4448 \times 10^{-1}$	$1.5351 \times 10^{-4}$	4.03**
	Reg. Coefficients	10	$6.1829 \times 10^{-3}$	$6.1829 \times 10^{-4}$	
	Common Regression	2254	$3.5067 \times 10^{-1}$	$1.5557 \times 10^{-4}$	46.11**
	Adjusted Means	10	$7.1728 \times 10^{-2}$	$7.1728 \times 10^{-3}$	
	Total	2264	$4.2239 \times 10^{-1}$		
At df 10 and $\infty$ : F(.01) = 2.32					
Among areas autumn spawners	Within Samples	1694	$2.5208 \times 10^{-1}$	$1.4881 \times 10^{-4}$	4.37**
	Reg. Coefficients	9	$5.8523 \times 10^{-3}$	$6.5025 \times 10^{-4}$	
	Common Regression	1703	$2.5793 \times 10^{-1}$	$1.5146 \times 10^{-4}$	82.86**
	Adjusted Means	9	$1.1295 \times 10^{-1}$	$1.2549 \times 10^{-2}$	
	Total	1712	$3.7088 \times 10^{-1}$		
At df 9 and $\infty$ : F(.01) = 2.41					

### Spring spawners

Spring spawners from Trinity Bay differed only in snout length from Bonavista Bay spring spawners but differed significantly in orbit diameter, head, postorbital and predorsal length from St. Mary's Bay spring spawners, in head, snout and postorbital length from Placentia Bay spring spawners and in head, snout and predorsal length from Fortune Bay spring spawners. Bonavista Bay spring spawners differed significantly in head, snout and predorsal length from both Fortune Bay and Conche spring spawners and in head, snout, postorbital and predorsal length from St. Mary's Bay spring spawners. Spring spawners from Notre Dame Bay differed in all five characters from both Bonavista Bay and Trinity Bay spring spawners; they also differed in orbit diameter, head, snout and postorbital length from Conche spring spawners and in orbit diameter, snout, postorbital and predorsal length from Quirpon spring spawners. Conche and Quirpon spring spawners differed only in snout and postorbital length but Conche spring spawners differed in head, snout and postorbital length from Hawke's Bay spring spawners while Quirpon and Hawke's Bay spring spawners differed in orbit diameter, head, snout and postorbital length. Spring spawners from Hawke's Bay also differed in head, postorbital and

predorsal length from Magdalen Islands spring spawners and in head, snout and postorbital length from Southwest Newfoundland spring spawners. The latter differed only in postorbital length from Magdalen Islands and in orbit diameter and postorbital length from Fortune Bay spring spawners. Spring spawners from Fortune Bay in turn differed in head, snout, postorbital and predorsal length from Placentia Bay spring spawners and in snout, postorbital and predorsal length from St. Mary's Bay spring spawners. Placentia Bay and St. Mary's Bay spring spawners differed in all five characters.

### Autumn spawners

Autumn-spawning herring from Trinity Bay differed only in predorsal length from Placentia Bay and in head and postorbital length from Bonavista Bay autumn spawners. They also differed in orbit diameter, head and snout length from Conche and in orbit diameter, head and postorbital length from Southwest Newfoundland autumn spawners. Bonavista Bay autumn spawners differed only in orbit diameter and predorsal length from Placentia Bay autumn spawners but differed in orbit diameter, head, snout and postorbital length from both Conche and Quirpon autumn spawners. They also differed in head, snout and postorbital length from Strait



TABLE 9. Covariance comparisons of the log-log regressions of various body parts on standard length between pairs of areas for spring spawners. (\*\* indicates significance at the 1% level.)

Area comparisons (spring spawners)	Head length		Snout length		Orbit diameter		Postorbital		Predorsal length	
	Slopes F	Adj Means F	Slopes F	Adj Means F	Slopes F	Adj Means F	Slopes F	Adj Means F	Slopes F	Adj Means F
Bonavista Bay vs Trinity Bay	0.40	3.76	1.63	12.12**	0.11	1.09	0.14	0.48	1.99	0.47
Bonavista Bay vs Notre Dame Bay	1.84	39.33**	4.66	36.57**	0.26	66.57**	0.01	76.24	0.00	73.61**
Bonavista Bay vs St. Mary's Bay	0.32	60.43**	0.94	31.01**	1.73	4.91	0.68	48.61**	4.42	48.19**
Bonavista Bay vs Conche	2.24	7.60**	2.63	45.81**	0.04	0.26	0.88	2.00	0.00	8.06**
Bonavista Bay vs Fortune Bay	2.49	26.56**	0.56	71.29**	0.72	0.23	1.68	0.00	1.18	21.99**
Notre Dame Bay vs Conche	7.92**	0.42	14.67**	23.92**	0.35	17.90**	1.11	52.74**	0.00	3.52
Notre Dame Bay vs Quirpon	2.38	0.03	79.62**	4.35	1.64	42.19**	14.73**	5.30	4.55	11.25**
Notre Dame Bay vs Trinity Bay	4.93	16.49**	15.86**	4.22	0.90	84.56**	0.29	91.04**	2.25	74.76**
Conche vs Quirpon	0.46	0.67	12.53**	11.03**	1.59	2.34	12.57**	10.76**	2.77	1.04
Conche vs Hawke's Bay	0.25	61.77**	0.22	20.51**	4.27	0.02	0.39	61.35**	0.11	4.97
Quirpon vs Hawke's Bay	1.40	49.42**	18.87**	68.92**	10.76**	4.78	12.96**	12.24**	4.33	1.15
Hawke's Bay vs Magdalen Islands	0.74	59.52**	0.01	2.47	0.40	3.49	2.33	74.15**	1.78	7.46**
Hawke's Bay vs Southwest Nfld.	0.94	33.54**	0.25	16.31**	0.33	6.68	0.02	12.14**	0.69	2.22
Magdalen Islands vs Southwest Nfld.	2.08	5.87	0.25	4.00	0.00	0.35	1.33	27.48**	0.04	1.02
Southwest Nfld. vs Fortune Bay	0.62	3.50	0.13	1.40	1.31	13.18**	0.38	11.41**	0.47	5.05
Fortune Bay vs Placentia Bay	10.13	25.29**	6.63	42.90**	2.65	1.77	2.60	7.35**	1.53	6.96**
Fortune Bay vs St. Mary's Bay	1.15	2.76	0.02	18.36**	5.92	4.17	0.19	46.48**	11.49**	149.63**
Fortune Bay vs Trinity Bay	5.99	12.31**	4.37	29.72**	1.87	0.12	1.23	0.82	0.16	9.58**
Placentia Bay vs St. Mary's Bay	5.58	63.59**	11.54**	24.67**	0.38	12.86**	1.25	79.61**	4.21	49.13**
Placentia Bay vs Trinity Bay	1.40	14.28**	0.88	15.25**	0.21	0.41	0.41	7.13**	2.41	0.33
St. Mary's Bay vs Trinity Bay	1.68	30.33**	6.11	3.59	1.32	12.45**	0.32	60.36**	12.69**	46.63**

of Belle Isle autumn spawners and in orbit diameter, snout and predorsal length from Southwest Newfoundland autumn spawners. Conche autumn spawners differed from Strait of Belle Isle autumn spawners only in orbit diameter and postorbital length but differed from Quirpon autumn spawners in head, snout and postorbital length. Autumn spawners from Quirpon differed from both Strait of Belle Isle and Hawke's Bay autumn spawners in orbit diameter, head, snout and postorbital length. Strait of Belle Isle autumn spawners differed in head, postorbital and predorsal length from Hawke's Bay autumn spawners, in orbit diameter, head, snout and

postorbital length from Magdalen Islands autumn spawners, in head, snout and postorbital length from Gabarus Bay autumn spawners and in all five characters from Southwest Newfoundland autumn spawners. Hawke's Bay autumn spawners differed from Magdalen Islands, Southwest Newfoundland and Gabarus Bay autumn spawners in all five characters. Magdalen Islands autumn spawners differed only in head and postorbital length from Southwest Newfoundland autumn spawners but differed in orbit diameter, head, postorbital and predorsal length from Gabarus Bay autumn spawners. The latter differed in orbit diameter,

TABLE 10. Covariance comparisons of the log-log regressions of various body parts on standard length between pairs of areas for autumn spawners. (\*\* indicates significance at the 1% level.)

Area comparisons (autumn spawners)	Head length		Snout length		Orbit diameter		Postorbital length		Predorsal length	
	Slopes F	Adj Means F	Slopes F	Adj Means F	Slopes F	Adj Means F	Slopes F	Adj Means F	Slopes F	Adj Means F
Bonavista Bay vs. Trinity Bay	1.26	21.55**	1.73	3.11	1.58	0.01	1.67	24.25**	3.50	3.10
Bonavista Bay vs Conche	0.28	107.92**	0.33	66.50**	2.68	14.97**	0.72	30.81**	0.73	0.08
Bonavista Bay vs Quirpon	0.26	49.25**	2.59	36.73**	0.20	54.79**	2.95	96.97**	2.06	0.45
Bonavista Bay vs Strait of Belle Isle	1.70	250.47**	0.00	85.29**	0.15	0.07	3.26	256.55**	0.05	4.11
Bonavista Bay vs Placentia Bay	0.12	4.76	1.04	0.14	1.55	7.50**	0.30	2.53	0.34	6.75**
Bonavista Bay vs Southwest Nfld.	6.44	2.07	0.36	9.50**	6.91**	11.93**	2.35	6.41	7.73**	4.38
Conche vs Trinity Bay	3.86	52.71**	4.22	46.25**	0.04	12.93**	0.68	2.74	1.70	1.76
Conche vs Quirpon	1.49	18.91**	1.61	136.20**	5.19	3.70	1.66	11.50**	0.57	0.35
Conche vs Strait of Belle Isle	0.99	2.80	0.59	3.16	2.87	19.00**	12.43**	53.96**	0.51	2.71
Quirpon vs Strait of Belle Isle	4.28	48.85**	3.96	226.78**	0.95	77.87**	14.95**	2.72	1.93	0.60
Quirpon vs Hawke's Bay	9.10**	1.86	4.97	169.05**	10.07**	48.84**	12.72**	21.11**	0.00	5.33
Strait of Belle Isle vs Hawke's Bay	0.64	41.75**	0.03	4.78	6.39	2.00	0.27	95.16**	3.09	11.36**
Strait of Belle Isle vs Magdalen Islands	0.47	316.02**	0.08	19.09**	1.45	8.78**	4.93	426.61**	0.89	0.93
Strait of Belle Isle vs Southwest Nfld.	1.99	298.55**	0.56	30.06**	7.37**	15.30**	0.16	364.02**	8.17**	0.37
Strait of Belle Isle vs Gabarus Bay, N.S.	6.62	110.22**	2.39	14.17**	1.32	0.89	2.75	164.07**	0.00	5.82
Hawke's Bay vs Magdalen Islands	3.01	198.79**	0.30	52.83**	1.96	9.01**	3.69	143.98**	0.78	17.20**
Hawke's Bay vs Southwest Nfld.	0.62	141.06**	1.06	68.97**	0.09	8.19**	0.01	71.00**	2.00	21.32**
Hawke's Bay vs Gabarus Bay N.S.	16.47**	79.51**	2.16	60.69**	18.14**	1.99	1.37	24.51**	4.72	78.98**
Magdalen Islands vs Gabarus Bay, N.S.	3.97	18.30**	4.07	4.85	6.91**	3.26	0.62	43.63**	1.30	36.10**
Magdalen Islands vs Southwest Nfld.	5.27	9.96**	0.27	1.52	2.51	0.17	3.67	28.64**	4.50	0.06
Gabarus Bay, N.S. vs Southwest Nfld.	18.62**	2.06	5.97	1.54	18.66**	1.96	1.60	4.79	11.48**	42.72**
Southwest Nfld. vs Placentia Bay	11.26**	1.49	1.36	17.03**	1.16	17.61**	11.54**	6.40	11.73**	7.20**
Southwest Nfld. vs Trinity Bay	13.34**	35.50**	4.19	1.68	0.90	19.32**	8.76**	49.89**	0.03	1.75
Placentia Bay vs Trinity Bay	1.08	1.15	0.70	2.07	0.16	5.08	1.07	3.23	2.95	10.21**

head and predorsal length from Southwest Newfoundland autumn spawners which in turn differed in orbit diameter, head and postorbital length from Trinity Bay autumn spawners and in all five characters from Placentia Bay autumn spawners.

### Discussion and Conclusions

The present study provides evidence that spring- and autumn-spawning herring from the same area differ

in morphometric as well as meristic characteristics as described by Parsons (1973). In most areas autumn spawners have relatively larger heads and snouts and relatively larger orbit diameters and postorbital and predorsal lengths in relation to standard length than spring spawners.

Martin (1949) demonstrated that early development is important in the determination of the relative size of the body parts of fish and that temperature and diet during the early growth period result in differences in

body form. Since data on the influence of these environmental factors on body form in herring are lacking, it is not possible to relate these factors to the observed morphometric differences between spring- and autumn-spawning herring. However, it is possible that these differences are due to differences in the size at which these herring attain sexual maturity and spawn for the first time. If spring spawners mature earlier than autumn spawners, as is suggested by available data, differences in the size at growth inflection would account for the tendency for adult autumn spawners to possess relatively larger body parts than adult spring spawners.

In view of the significant morphometric differences between spawning groups within areas, it is necessary to consider spring and autumn spawners separately for between-area comparisons of all morphometric characters. Herring from Newfoundland and adjacent waters exhibit considerable heterogeneity in morphometric as well as meristic characteristics. Between-area differences are evident for all morphometric characters and all pairs of areas compared for at least one character. Some areas differ in all morphometric characters but for other paired area comparisons the results are much more complex.

Mayr, Linsley and Usinger (1953), Royce (1953, 1957, 1964) and Ahlstrom (1957) have shown that statistically significant morphometric differences can be found commonly even between closely related natural populations. Such statistical differences have been found so consistently that Royce (1953) concluded that, even with samples from closely related stocks, highly significant statistical differences could always be found by increasing the size of the sample or by considering enough characters. Groups considered to be distinct on the basis of morphometric studies have been found to exhibit considerable intermixture when tagging experiments were performed.

In this study differences in two morphometric characters — head length and postorbital length — were found between autumn-spawning herring from the Magdalen Islands and Southwest Newfoundland and spring spawners from these areas also differ in postorbital length. However, tagging results have demonstrated that herring which overwinter along Southwest Newfoundland merely represent the overwintering phase of a stock complex which spawns and feeds in the southern Gulf of St. Lawrence (Winters, MS 1971; Beckett, MS 1971). Therefore, it is apparent that statistically significant differences in head length and postorbital length cannot be considered valid indicators of stock discreteness. Although the highly significant morphometric differences between herring stocks in Newfoundland and adjacent waters confirm that the herring from these various areas do not belong to a single

completely mixed population, it is difficult to determine from these differences which stocks are distinct and which intermingle freely. The author has not yet attempted to apply cluster analysis using the technique of principal components to these morphometric data but it appears unlikely that further analyses along these lines will shed much additional light on the degree of intermixture between stocks.

Fish inhabiting colder waters tend to have relatively smaller heads and other body parts than fish from warmer waters (Rounsefell, 1930; Hubbs, 1940; Martin, 1949). These smaller body parts are usually correlated with higher meristic counts for these populations. Jean (1967) from investigations in 1943-44 found that herring from the relatively cold waters of Ile Verte in the Estuary of the Gulf of St. Lawrence had a slower growth rate and smaller snouts and heads than those from the warmer waters of Anse au Gascon. In the present study no clearcut geographic trend in either of the morphometric characters is evident among spring spawners. No geographic trend in snout or predorsal length is evident among autumn spawners, but autumn spawners from more northerly areas, e.g. Strait of Belle Isle, Quirpon, Conche, and Hawke's Bay, tend to have smaller heads, orbit diameters and postorbital lengths than those from more southerly areas, e.g. Magdalen Islands and Southwest Newfoundland. Herring in these northern regions inhabit generally colder water than those along Southwest Newfoundland and in the southern Gulf of St. Lawrence.

### Acknowledgements

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# Age Analyses and Catch of the Harp Seal in Northwest Greenland, 1953-72

Finn O. Kapel<sup>1</sup>

## Abstract

A declining tendency in the catch of harp seals in Greenland, fluctuations in catches and the annual distribution of the catch are described on the basis of hunting statistics from 1953 to 1972.

Age analyses of material collected in Northwest Greenland in 1953 and 1972 show, that differences exist in age composition between various localities and between different years.

The relation between catches in the breeding areas and catches in Greenland and the possibility of an increased mortality rate during the period in question are discussed.

## Introduction

Although the ringed seal in recent times is by far the most important hunting object in Greenland, the catch of harp seal is of some importance in many parts of the country. Harp seal hunting takes place especially in summer and autumn and the northern part of West Greenland has apparently for centuries been the centre of this activity.

General descriptions of the occurrence and hunting of harp seals in Greenland have been presented in earlier publications, e.g. Sergeant (1965) and Hansen (1966).

In this paper a more detailed description of the development of the harp seal hunt in Northwest Greenland during the last 20 years and a presentation of some age analyses is given.

## Materials and Methods

Data for estimating the catch of the harp seals in Greenland and its seasonal variations comes from the "Hunters Lists of Game" issued by the Ministry for Greenland (Anon. 1954-69). This statistical material is not exact to the last detail, but is considered good enough to give a reliable picture of the distribution and variation of the catch. A presentation of the history of these hunting statistics and its value has been given by Rosendahl (1961), and a few comments of this subject

are included in a paper, which will appear in the near future (Kapel, unpublished manuscript).

Another source of evidence used as the basis for this paper are samples of harp seal jaws collected in Greenland in 1953 and 1972. The former collection was made by Dr Paul Hansen and Mr Ph. Rosendahl, head of office in the Ministry for Greenland, by arranging the purchase of jaws of harp and hood seals from hunters. The result was about 800 jaws from more than 40 localities. In this paper only some of the samples are dealt with, namely about 500 jaws from the localities in Northwest and Central West Greenland listed at the top of Table 1 and shown on Fig. 1.

Little material was obtained after 1953, until sampling was rearranged by the Greenland Fisheries Investigations in 1970. The results were rather poor until 1972, when 670 jaws were collected in the above-mentioned areas.

The jaws were cleaned and preserved in salt, and after arrival at the laboratory they were boiled and the canines extracted. Transverse sections of the canines were prepared by a method similar to that described by Fisher and Mackenzie (1954), but it was found unnecessary to polish the sections after cutting.

The 1953 material was aged by the staff of Greenland Fisheries Investigations in the mid-1950's, and the results were presented and used by Sergeant and

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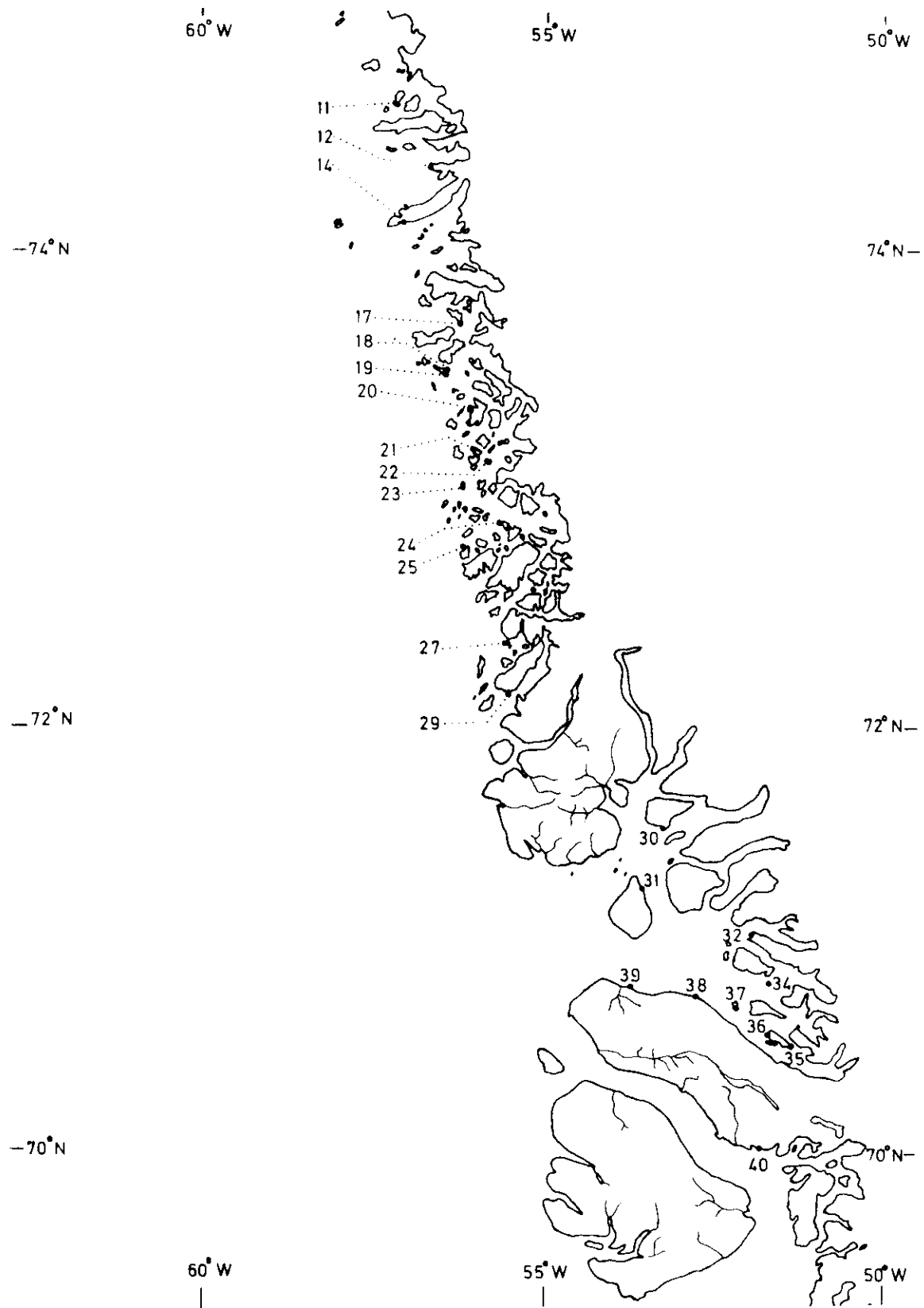


Fig. 1. Sampling localities in Northwest and Central West Greenland.

TABLE 1. Age samples of harp seal from Greenland.

Loc. No.	Locality	1953	1954	1955	1956	1957	1962 <sup>a</sup>	1970	1971	1972
(12-) 14	Kraulshavn	25	1	—	—	—	—	—	—	3
17-20	Tasiussaq	26	31	—	—	4	91	—	19	70
21-23	Tugssaq	30	—	—	—	—	—	—	—	115
24	Augpilagtoq	30	—	—	—	—	—	4	23	44
25	Upernavik	42	—	—	—	—	—	—	—	—
27	Proven	30	—	—	—	—	—	1	—	85 <sup>a</sup>
District:	Upernavik	183	32	—	—	4	91	5	42	317
30	Nugatsiaq	74	—	—	—	—	—	—	—	—
31	Igdlorssuit	30	1	—	—	—	—	—	25	73 <sup>c</sup>
32	Uvkusigssat	19	26	—	—	—	—	—	—	—
34	Satut	30	—	—	—	—	—	—	—	—
35-36	Ikerasak	37	3	—	8	2	—	—	—	—
37	Umanak	34	33	13	—	4	—	—	—	—
38	Qaersut	32	—	—	—	—	—	77	98	115
District:	Umanak	256	63	13	8	6	—	77	123	188
40	Sarqaq	54	—	—	—	—	256	45	10	164
	other	29	40	52	—	—	—	—	—	1
District:	Vaigat-Jak.	83	40	52	—	—	256	45	10	165
Subtotal	NW + CWn	522	135	65	8	10	347	127	175	670
District:	Christiansh�b	73	10	17	—	—	—	—	—	—
District:	Godhavn	64	—	—	8	—	6	—	—	—
District:	Egedesminde	29	—	6	—	—	—	—	—	—
District:	Kangatsiaq	78	—	—	—	—	—	—	4	—
District:	Holsteinsborg	20	—	—	—	—	—	—	—	—
District:	Sukkertoppen	10	28	—	—	—	—	—	—	—
District:	Godth�b	—	—	—	—	—	—	—	—	—
District:	Frederiksh�b	13	—	—	—	—	—	—	—	—
District:	Julianeh�b + Nanortalik	40	—	—	—	—	—	—	—	—
Total West Greenland		849	173	88	16	10	353	127	179	670
Total East Greenland		10	20	—	—	—	—	—	1	—

<sup>a</sup>Collected by Fisheries Research Board of Canada.

<sup>b</sup>Of these only 56 animals have been aged.

<sup>c</sup>Only two animals have been aged. The rest of the material received recently.

Fisher (1960), but these previous age determinations has shown not reliable, and the material was therefore revised by the present author.

## Results

### Catch of harp seals in West Greenland, 1953-1972.

In the last 20 years, the catch of harp seals in West Greenland has shown great fluctuations with a generally decreasing tendency (Fig. 2). In the early 1950's the total catch was of the order 15,000-20,000 seals per

year, in the period 1956-1965 the catch fluctuated between 16,000 and 18,000 animals, but in the last years it has been at the level 4,000-7,000 seals. (Final data for 1972 are not yet available, but provisional data indicate a slight increase over the level of the preceding years.)

The recent decline can be traced in all parts of West Greenland, but it is more pronounced in the northern regions. The catch in Upernavik and Umanak districts (Region NW) was at a level of 3,000-5,000 seals in the period 1953-61, about 2,500 for some years thereafter and ranged between 1,000 and 2,000 seals since 1966.

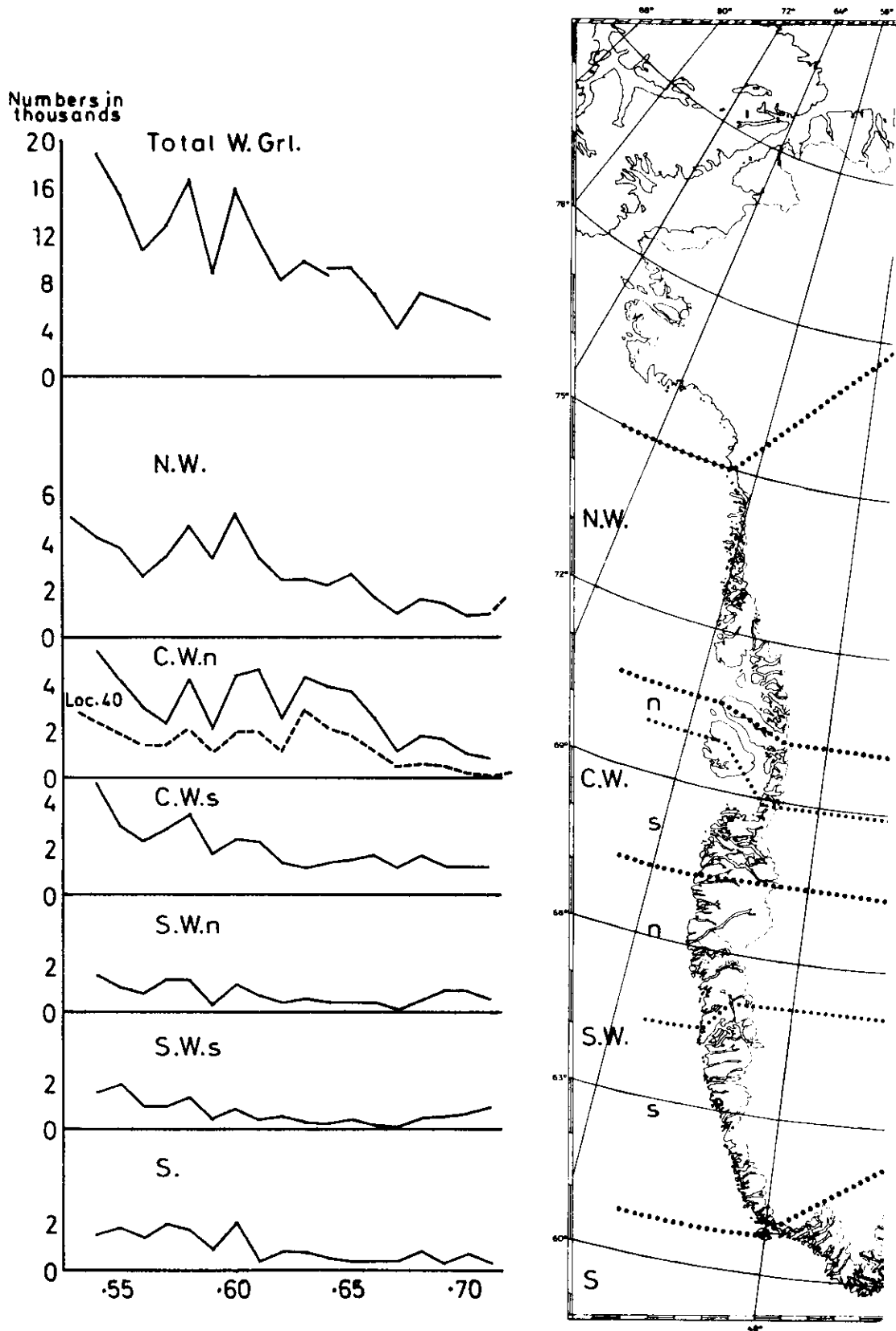


Fig. 2. Catch of harp seals in West Greenland.



In the Vaigat-Jakobshavn area (CWn) the catch fluctuated between 2,000 and more than 5,000 seals until 1966, but since 1967 it has ranged between 1,000 and 2,000 animals.

Except for 1 year, the two regions (NW and CWn) accounted for 50-70% of the total catch in West Greenland up to 1966 and might thus be considered the most important areas for hunting of harp seals, but in the last 5 years the share of the two regions has been no more than 35-50% of the total catch. The percentage of total catch accounted for by different regions is as follows:

Mean for	NW	CWn	CWs	SWn	SWs	S
1954-59	27.1	24.8	21.3	7.3	8.3	11.1
1960-64	28.1	37.0	16.9	4.9	4.0	7.9
1965-69	23.3	32.0	21.8	7.5	5.0	7.2
1970-71	19.1	17.5	23.9	13.9	15.8	9.8

Besides the general decline in the catch of harp seals in West Greenland, a shift in the relative importance of various hunting districts seems to have occurred. Whereas the catch of the northern regions in the years up to 1966 was much more important than in the southern regions, in recent years the catch has been more evenly distributed along the coast of West Greenland, although the main areas for harp seal hunting are still the regions from Disko Bay and northwards.

### Catch and samples in Northwest Greenland

Figure 3 shows fluctuations in catch of harp seals during 1953-72 at various localities in Regions NW and CWs, the monthly break-down of the catch in 1953 and 1972, and the number of jaws collected in these 2 years. On the basis of correspondence in catching period, the catches for some closely situated localities are combined.

In 1953 the hunting in Vaigat (Loc. 40) started in May, was significant in June and reached its maximum in July and August, but the catch was considerable throughout the autumn months and did not cease until January of the following year.

In the Umanak district (Loc. 30-39) catching was negligible until the end of June, somewhat larger in July especially in the northern parts of the district, but did not reach its maximum until August. In some localities the activity continued into September and then declined during the autumn; at the innermost (eastern) localities the catch was negligible in October, whereas in the outermost (western) localities the catch continued to be of some importance in the last 2 months of the year.

In the Upernavik district (Loc. 11-29) catching began almost at the same time as in the Umanak area, and in most localities the maximum was reached at the end of July or first half of August. The succeeding development seems to be different in various localities, but generally speaking a decreasing catch in September was followed by a new maximum in October. At the end of November catching had finished.

The above picture of catching activity in 1953 correlates well with current descriptions of the occurrence of harp seals in Northwest Greenland (Rosendahl, 1961 and Sergeant, 1965), according to which a northward migration reaches the Disko area in June and continues to Umanak and Upernavik districts, where the seals show up a little later — maybe latest in Umanak where winter ice as a rule disappears later than in the southern parts of the Upernavik area. The two peaks on the curves for the Upernavik area might support the theory of a southward migration along the coast of Northwest Greenland in autumn, but the curves for the Umanak and Vaigat areas indicate that some herds of harp seals did not make this double migration but remained in the area to which they arrived in early summer.

In 1972 the catch in the Vaigat area was negligible until the beginning of July. The catch curve shows a peak in August followed by a rather smooth decrease towards the end of the year.

Preliminary 1972 hunting statistics for the Umanak area indicate that a few harp seals were caught in June-July and that the catching maximum occurred in the last half of August and the beginning of September. Very few seals were caught later than the end of September.

In the middle part of Upernavik district some harp seals were caught already in the last days of June and catches were rather good in July. In most parts of the district catching activity peaked in August, but in the northernmost part (Loc. 14) not until September; in other localities catches were low in September, and only in the southernmost localities (Loc. 27 and 29) the catch was of some importance in October to December.

The occurrence of harp seals in Northwest Greenland in 1972 thus seems to differ from the occurrence in 1953 (apart from a considerably lower number) in two respects: firstly, the seals appeared a month later in the Vaigat, and, secondly, they apparently left the northern parts of West Greenland a little earlier. A possible explanation of the first circumstance might be that the early "waves" of harp seals, faced by the ice, followed migration routes in the open sea west of Disko Island and did not show up in the hunting areas until they reached the Upernavik district.

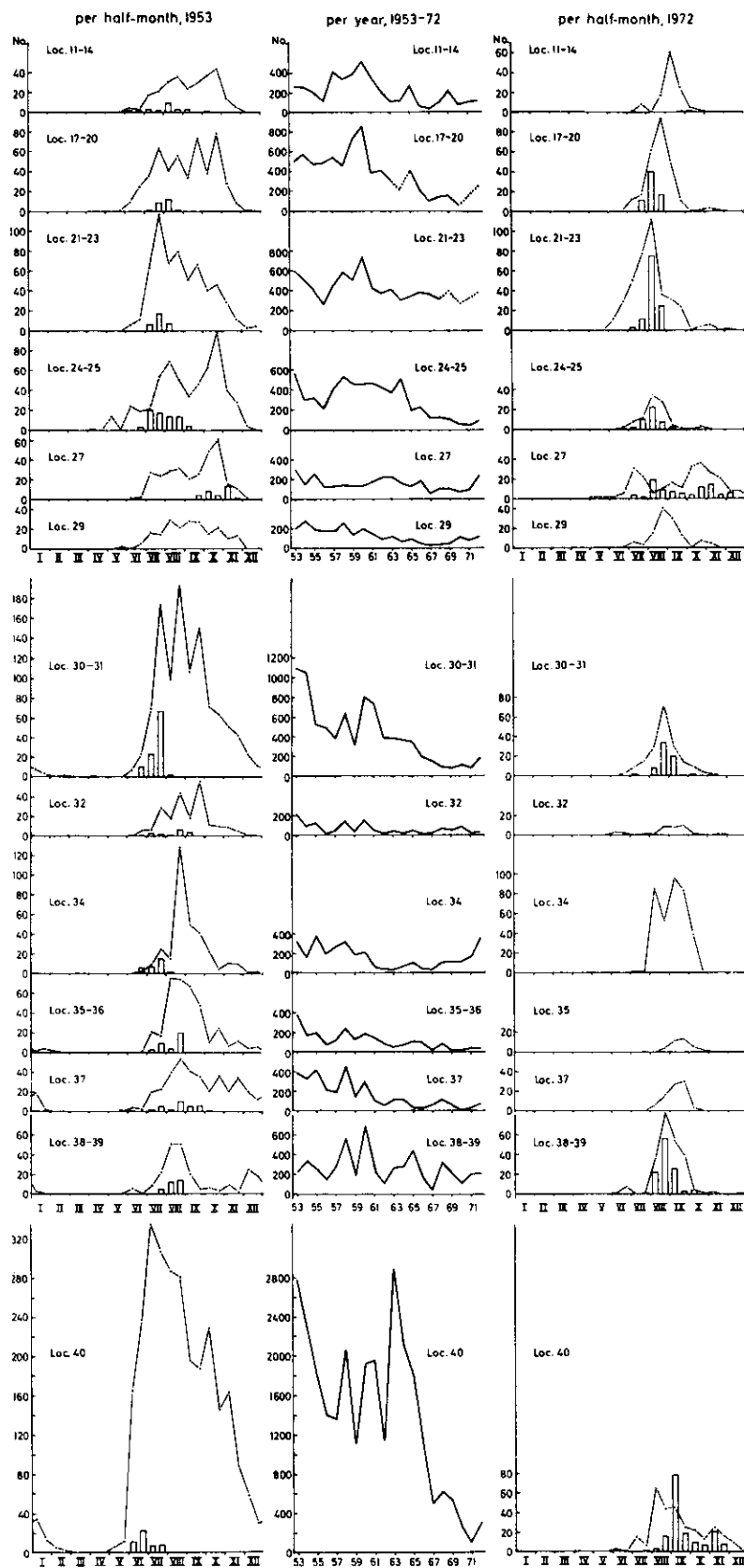


Fig. 3. Catch of harp seals on different localities in Northwest Greenland.

TABLE 2. Age samples of harp seals in Northwest Greenland, 1953. (Age 0.4, 1.4, etc. indicates that most animals were caught 3-6 months after breeding period.)

Loc. No.:	District													
	Upernavik						Umanak							Vaigat
	14	20	23	24	25	27	30	31	32	34	35+36	37	38	40
Age/Nos.														
0.4	13	8	5	6	8	—	23	9	5	7	16	19	19	6
1.4	4	11	14	6	14	5	19	6	5	9	9	8	8	10
2.4	—	1	1	4	2	3	3	2	1	1	1	2	1	4
3.4	1	1	1	4	2	7	6	5	1	3	1	3	—	8
4.4	—	1	1	1	3	4	2	2	—	1	3	—	—	5
5.4	—	—	—	1	1	—	9	1	1	3	1	—	1	2
6.4	1	1	1	1	2	2	3	1	1	—	3	—	1	4
7.4	1	—	1	4	—	1	1	—	—	—	1	1	1	1
8.4	—	—	1	1	—	1	2	1	1	1	1	—	—	2
9.4	2	—	—	—	1	1	2	—	—	1	—	—	—	3
10.4	—	—	1	—	—	—	—	—	1	—	—	—	—	1
11.4	1	—	—	—	—	—	—	1	—	—	—	—	—	2
12.4	—	—	—	—	1	—	—	—	—	—	—	—	—	2
13.4	—	—	—	1	1	—	1	—	—	1	—	—	—	2
14.4	—	—	1	—	1	2	—	—	—	—	—	—	—	—
15.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—
16.4	1	—	1	1	1	—	—	—	—	—	1	—	1	—
17.4	—	—	—	—	—	1	—	1	—	1	—	—	—	—
18.4	—	1	—	—	1	1	1	1	1	—	—	—	—	—
19.4	—	—	—	—	—	—	1	—	—	—	—	—	—	—
20.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—
21.4	—	—	—	—	1	1	—	—	—	—	—	—	—	—
22.4	—	2	—	—	2	1	—	—	—	—	—	—	—	—
23.4	—	—	2	—	—	—	—	—	—	1	—	—	—	—
24.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—
25.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—
26.4	—	—	—	—	—	—	—	—	—	—	—	—	—	1
27.4	1	—	—	—	—	—	1	—	—	—	—	1	—	—
28.4	—	—	—	—	—	—	—	—	—	1	—	—	—	1
29.4	—	—	—	—	1	—	—	—	1	—	—	—	—	—
30.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—
+30.	—	—	—	—	—	—	—	—	1	—	—	—	—	—
Total	25	26	30	30	42	30	74	30	19	30	37	34	32	54

In addition to the above description of hunting activities, Fig. 3 gives an impression of how representative the samples in 1953 and 1972 are of the catches of these years.

In 1953 samples do not amount to more than 10% of the catch in the localities concerned (not even 2% for Loc. 40). Further, it is characteristic that the samples are chiefly derived from the initial phases of the hunting periods, thus only giving an impression of composition of catches in June to August and not of the final phases of the hunting activity. An exception is seen for the samples from Loc. 27 (and to some degree from Loc. 37), which were collected during September to

November, but on the other hand there is no material from the catch in early summer.

The 1972 material, although not much larger in respect to absolute number of jaws, gives an essentially better coverage. Firstly, the samples account for 25-88% of the catches in the sampling localities, except in the northernmost localities of Upernavik district, where only 2% of the catch were sampled. Secondly, in respect to distribution of sampling activity throughout the hunting period, the 1972 material is much better than that of 1953. For Loc. 17-20 in Upernavik district, however, samples cover only the initial phases of catching activity, but in the southern localities of Upernavik district the

TABLE 3. Age samples of harp seals in Northwest Greenland, 1970-72. (Age 0.4, 1.4, etc. indicates that most animals were caught 4-6 months after breeding period.)

District:	Year														
	1970		1971						1972						
	Umk	Vai	Upv		Umk		Vai	Upernavik				Umk		Vai	
Loc. No.	38	40	20	24	31	38	40	14	17- 20	21+ 23	24	27	31	38	40
Age/Nos															
0.4	63	3	4	3	18	83	2	2	28	50	14	7	—	95	126
1.4	6	3	3	2	4	8	—	—	16	15	10	17	1	8	8
2.4	2	2	—	4	—	4	—	1	11	15	3	11	—	1	7
3.4	1	6	3	4	2	1	2	—	2	7	5	6	—	1	—
4.4	2	1	2	2	—	—	—	—	3	8	7	5	—	1	3
5.4	—	5	—	—	1	—	1	—	2	5	—	1	—	2	2
6.4	—	4	1	1	—	—	—	—	1	3	1	—	1	—	4
7.4	—	3	1	—	—	—	—	—	1	3	1	3	—	1	2
8.4	—	2	—	1	—	—	—	—	—	3	—	—	—	—	—
9.4	1	2	1	2	—	—	—	—	—	—	—	—	—	—	—
10.4	1	1	—	—	—	—	1	—	—	1	—	2	—	—	—
11.4	1	2	2	—	—	—	1	—	—	—	1	1	—	—	—
12.4	—	1	1	—	—	1	—	—	1	—	—	—	—	—	2
13.4	—	1	—	—	—	—	—	—	—	—	—	1	—	—	—
14.4	—	1	1	1	—	—	1	—	—	—	—	—	—	—	—
15.4	—	—	—	—	—	—	1	—	1	1	—	—	—	—	1
16.4	—	—	—	—	—	—	—	—	—	—	1	—	—	—	1
17.4	—	—	—	—	—	1	—	—	—	1	—	—	—	—	—
18.4	—	—	—	1	—	—	—	—	—	—	1	—	—	—	1
19.4	—	—	—	—	—	—	—	—	—	—	1	1	—	1	—
20.4	—	2	—	—	—	—	—	—	—	1	—	—	—	—	1
21.4	—	1	—	1	—	—	—	—	—	—	—	—	—	—	2
22.4	—	2	—	—	—	—	1	—	—	—	—	—	—	—	—
23.4	—	—	—	—	—	—	—	—	1	—	—	—	—	1	1
24.4	—	—	—	—	—	—	—	—	1	—	—	—	—	—	1
25.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
26.4	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—
27.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
28.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
29.4	—	—	—	—	—	—	—	—	—	1	—	—	—	—	1
30.4	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—
+30.	—	2	—	—	—	—	—	—	1	1	—	—	—	—	—
Total	77	45	19	23	25	98	10	3	70	115	44	56	2	112	165
?														3	

maximum and the final phases of hunting are represented.

The material from Loc. 31 in the northern part of Umanak district has recently arrived at the laboratory and accounts for about 75% of the catch in this locality, but the material has not yet been accurately aged. The sample from Loc. 38 constitutes 85% of the catch and is considered to give a good picture of the catch in the

southern part of the district. The sample from Loc. 40 in the Vaigat area gives (as opposed to the 1953 material) a good representation of the catch, except for the rather negligible catch in July and December.

The above evaluation of the two sets of samples (1953 and 1972) should be borne in mind, when both series of age composition are described and compared below.

## Age analyses of 1953 and 1972 samples

Tables 2 and 3 present the age determination of the material from all sampling localities in 1953 and 1970-72. The 1953 material from some localities is so scanty that some pooling was desirable. The pooling of data was carried out for closely situated localities, where (a) hunting activities are similar, (b) samples represent same phase of catching, and (c) age determinations show a reasonable degree of mutual agreement. The results are presented in Table 4 and Fig. 4.

In 1953 the young-of-the-year form 20-25% and one-year-olds 35-45% of the samples in most localities in Upernavik district (Loc. 20-25). In the sample from Loc. 12-14 in the northern part of the district young-of-the-year seem to dominate, but this difference may be accidental, taking into account the small size of the samples. It is striking, however, that young-of-the-year are totally absent in the sample from Loc. 27. The explanation might be that this sample covers only the end of the hunting period, and that young-of-the-year form a smaller proportion of the catch at this time (at least in

TABLE 4. Age composition of harp seals caught in Northwest Greenland, 1953 and 1972. (Age 0.4, 1.4, etc. indicates that most animals were caught 3-6 months after breeding period.)

District: Loc. No.:	Year												
	1953								1972				
	Upernavik				Umanak			Vaig.	Upernavik			Umn.	Vai.
	14	20-23	24-25	27	30-31	32-34	35-38	40	17-23	24	27	38	40
	%	%	%	%	%	%	%	%	%	%	%	%	%
Age													
0.4	52.0	23.2	19.4	—	30.8	24.5	52.4	11.1	42.2	31.8	12.5	84.8	76.4
1.4	16.0	44.6	27.8	16.7	24.0	28.6	24.3	18.5	16.8	22.7	30.4	7.1	4.9
2.4	—	3.6	8.3	10.0	4.8	4.1	3.9	7.4	14.1	6.8	19.6	0.9	4.2
3.4	4.0	3.6	8.3	23.3	10.6	8.2	3.9	14.8	4.9	11.4	10.7	0.9	—
4.4	—	3.6	5.6	13.3	3.8	2.0	2.9	9.3	5.9	15.9	8.9	0.9	1.8
5.4	—	—	2.8	—	9.6	8.2	1.9	3.7	3.8	—	1.8	1.8	1.2
6.4	4.0	3.6	4.2	6.7	3.8	2.0	3.9	7.4	2.2	2.3	—	—	2.4
7.4	4.0	1.8	5.6	3.3	1.0	—	2.9	1.9	2.2	2.3	5.4	0.9	1.2
8.4	—	1.8	1.4	3.3	2.9	4.1	1.0	3.7	1.6	—	—	—	—
9.4	8.0	—	1.4	3.3	1.9	2.0	—	5.6	—	—	—	—	—
10.4	—	1.8	—	—	—	2.0	—	1.9	0.5	—	3.6	—	—
11.4	4.0	—	—	—	1.0	—	—	3.7	—	2.3	1.8	—	—
12.4	—	—	1.4	—	—	—	—	3.7	0.5	—	—	—	1.2
13.4	—	—	2.8	—	1.0	2.0	—	3.7	—	—	1.8	—	—
14.4	—	1.8	1.4	6.7	—	—	—	—	—	—	—	—	—
15.4	—	—	—	—	—	—	—	—	1.1	—	—	—	0.6
16.4	4.0	1.8	2.8	—	—	—	1.9	—	—	—	1.8	—	0.6
17.4	—	—	—	3.3	1.0	2.0	—	—	0.5	—	—	—	—
18.4	—	1.8	1.4	3.3	1.9	2.0	—	—	—	2.3	—	—	0.6
19.4	—	—	—	—	1.0	—	—	—	—	2.3	1.8	0.9	—
20.4	—	—	—	—	—	—	—	—	0.5	—	—	—	0.6
21.4	—	—	1.4	3.3	—	—	—	—	—	—	—	—	1.2
22.4	—	3.6	2.8	3.3	—	—	—	—	—	—	—	—	—
23.4	—	3.6	—	—	—	2.0	—	—	0.5	—	—	0.9	0.6
24.4	—	—	—	—	—	—	—	—	0.5	—	—	—	0.6
25.4	—	—	—	—	—	—	—	—	—	—	—	—	0.6
26.4	—	—	—	—	—	—	—	1.9	0.5	—	—	—	—
27.4	4.0	—	—	—	1.0	—	1.0	—	—	—	—	—	—
28.4	—	—	—	—	—	2.0	—	1.9	—	—	—	—	0.6
29.4	—	—	1.4	—	—	2.0	—	—	0.5	—	—	—	0.6
30.4	—	—	—	—	—	—	—	—	—	—	—	—	—
+30.0	—	—	—	—	—	2.0	—	—	1.1	—	—	0.9	—
Total	100	100	100	100	100	100	100	100	100	100	100	100	100
No.	25	56	72	30	104	49	103	54	185	44	56	112	165

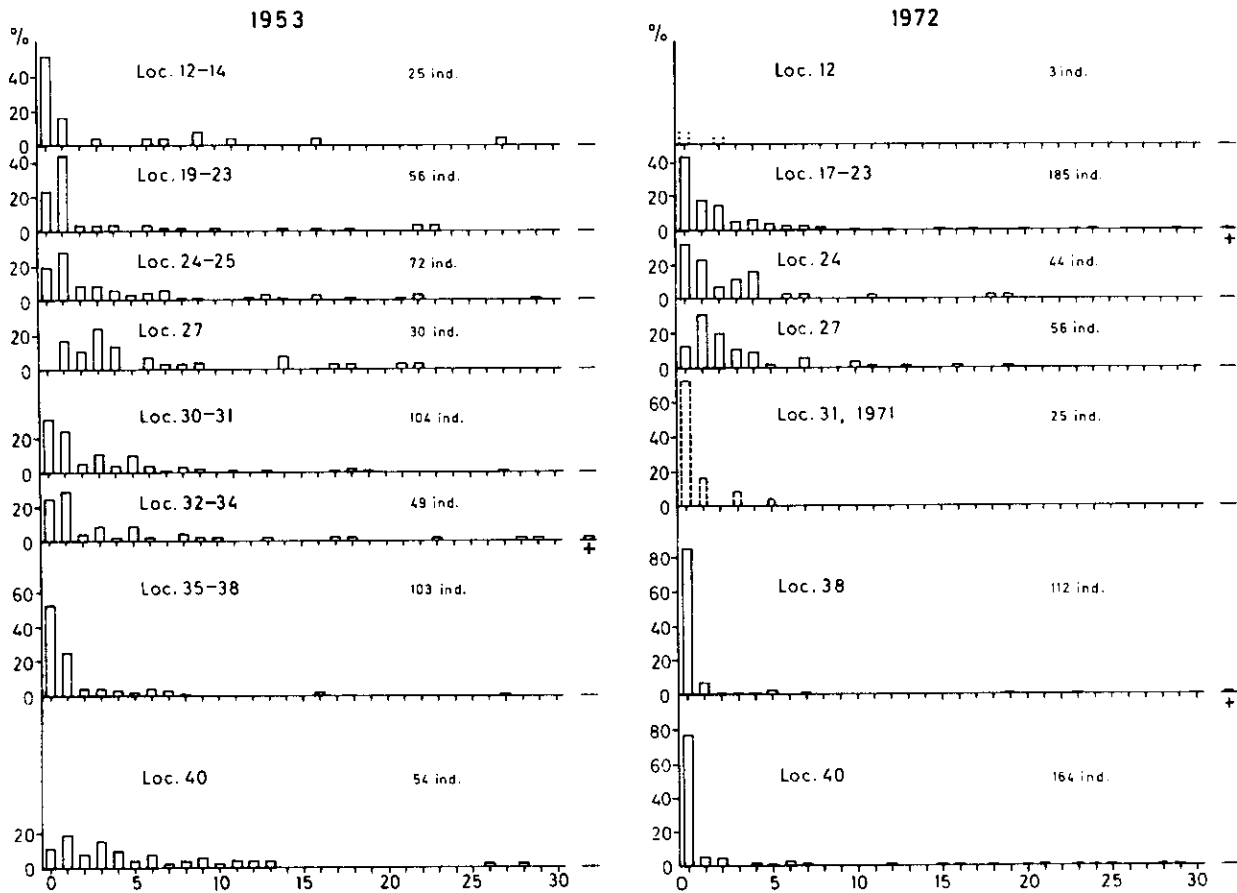


Fig. 4. Age composition of harp seals caught in Northwest Greenland.

Loc. 27). Other age-groups of young seals (2-4) are weakly represented in the northern part, stronger in the southern part of the district. The percentage of mature animals (5 years and more) is rather identical in all localities or slowly increasing from north to south.

In the material from the northern and middle part of Umanak district young-of-the-year account for 20-30% of the sample and a similar proportion is represented by the one-year-olds. Other young animals (age-groups 2-4) and mature animals (age-group 5 and older) are represented with the same percentages as in the northern and middle parts of Upernavik district.

The composition of the material from the southern part of Umanak district differ to some degree from the northern part. Here the young-of-the-year account for more than 50% and 1-year-olds about 25% of the

sample, whereas 2- to 4-year-olds and mature animals are weakly represented.

The sample from Loc. 40 in the Vaigat area is characterized by a very weak representation of young-of-the-year and rather few 1-year-olds, whereas 2- to 4 year-old seals and especially mature animals are well represented. This picture is not very representative of the figures in the game lists and other statements, according to which young harp seals are extremely important to the hunting in the Vaigat area (cf. also the 1972 sample and a Canadian sample from Loc. 40, 1962). An age composition like that in 1953 is found in one or two samples from 1970 to 1971, but it is known that younger harp seals were not sampled in 1970-71 as a consequence of interpretative misunderstanding of the sampling instructions. This may also have been the case in 1953 and the sample is probably biased by selection of older

animals. The sample, which represents only 2% of the local catch, should thus be categorized as not typical of the catch in the Vaigat area.

Sampling in 1972 was carried out in fewer localities than in 1953, but is considered to be more representative of the catch, since the sample accounts for a considerably higher percentage (25-88%) of the catch in the sampling areas.

The samples from Loc. 40 and 38 are dominated by young-of-the-year (75 and 85% respectively), whereas 1- to 4-year-olds and younger age-groups of mature animals are very weakly represented in both samples. In Loc. 38 older age-groups of mature animals are equally badly represented, whereas they occur in greater number in the sample from Loc. 40. The sample from Loc. 31 has not yet been aged, but a rough estimate indicates that 70-90% of the sample are young-of-the-year.

The age composition of the material from Upernavik is quite different. In the samples from Loc. 19-23 young-of-the-year account for well 40%, 1-year-olds for almost 20%, age-groups 2-4 about 25% and mature animals about 15%. In the sample from Loc. 24 the corresponding percentages are 32, 23, 34 and 11 respectively. It is possible, that a selection of older animals (especially females) has occurred here, but on the other hand it is striking that the 1953 sample from this locality also differed in the same way from those of other localities in the district. There is, however, no indication of the sample representing only the final phase of the hunting period as in 1953, although the catching activity at Loc. 27 as a whole did fall a little later than in the other localities. The evidence thus indicates that young-of-the-year is of minor importance to the hunting in the vicinity of Loc. 27.

Altogether the samples in 1972 seem to represent the catch of the localities in question rather well, although a better representation of the final phases might be desirable. However, there is the tendency that older animals account for an increasing percentage of the catch in the autumn.

It is evident that some differences in age composition exist between catches of harp seals in various parts of Northwest Greenland. Young-of-the-year seem to dominate catches in the Vaigat and Umanak areas, whereas 1- to 4-year-old animals account for the major part of catches in Upernavik district. Older animals occur in all areas but with varying percentages. Thus samples from one area are not sufficient to give a picture of composition of the catch in Northwest Greenland as a whole. Thus it is necessary to weight the various samples in relation to the size of the catch in the area in question. An attempt in this direction is shown in Fig. 5, omitting

the Vaigat samples which for 1953 were biased as mentioned above.

The general feature seems to be that the curve for 1972 shows a steeper decline than that for 1953, probably as a result of heavy exploitation of the stock in the 1950's and 1960's. In the 1953 samples age-groups 1, 3 and 7 (year-classes 1952, 1950 and 1947) seem to be rather strongly and age-group 2 (1951) rather weakly represented. In the 1972 sample age-group 7 (1965) and maybe age-group 4 (1968) show values a little higher and age-group 3 (1969) a little lower than would be expected by a steady production and a constant mortality rate.

### Sex ratio

For the 1953 material sex was not reported, but the information is available for most of the animals in the 1972 samples. As a whole, females accounted for only 42%, and the same percentage is found when young-of-the-year are considered separately. For the 1-4 year-old animals the percentage is slightly lower (35.3%), but of the older animals females constitute more than 50% of the samples. This fact may be due to the circumstance that samples of mature females were specially asked for.

Some differences in sex ratio occur between samples from different localities. In Upernavik district females account for less than 25% in the northernmost locality and more than 50% in the southernmost. In the samples from Umanak and Vaigat they constitute 42.6 and 48.5% respectively.

Especially as regards mature animals the difference between localities is evident. In the northern localities of Upernavik district and in Umanak district most mature animals were males, but in Loc. 27 in the southern part of Upernavik district and in Loc. 40 of the Vaigat almost all old animals were females. It is thus possible, that mature females concentrate in some areas, but the material is too sparse to draw any definite conclusion, and, furthermore, the differences may reflect differences in sampling activity.

### Discussion

It has been mentioned above, that the collection of material from 1972 seems to represent the catch on the localities in question rather well, and it is further indicated that these localities give a sufficient coverage of the catch in Northwest Greenland as a whole. The 1953 material is less satisfactory, but may, however, serve to characterize the catch at that time and to compare with the recent samples.

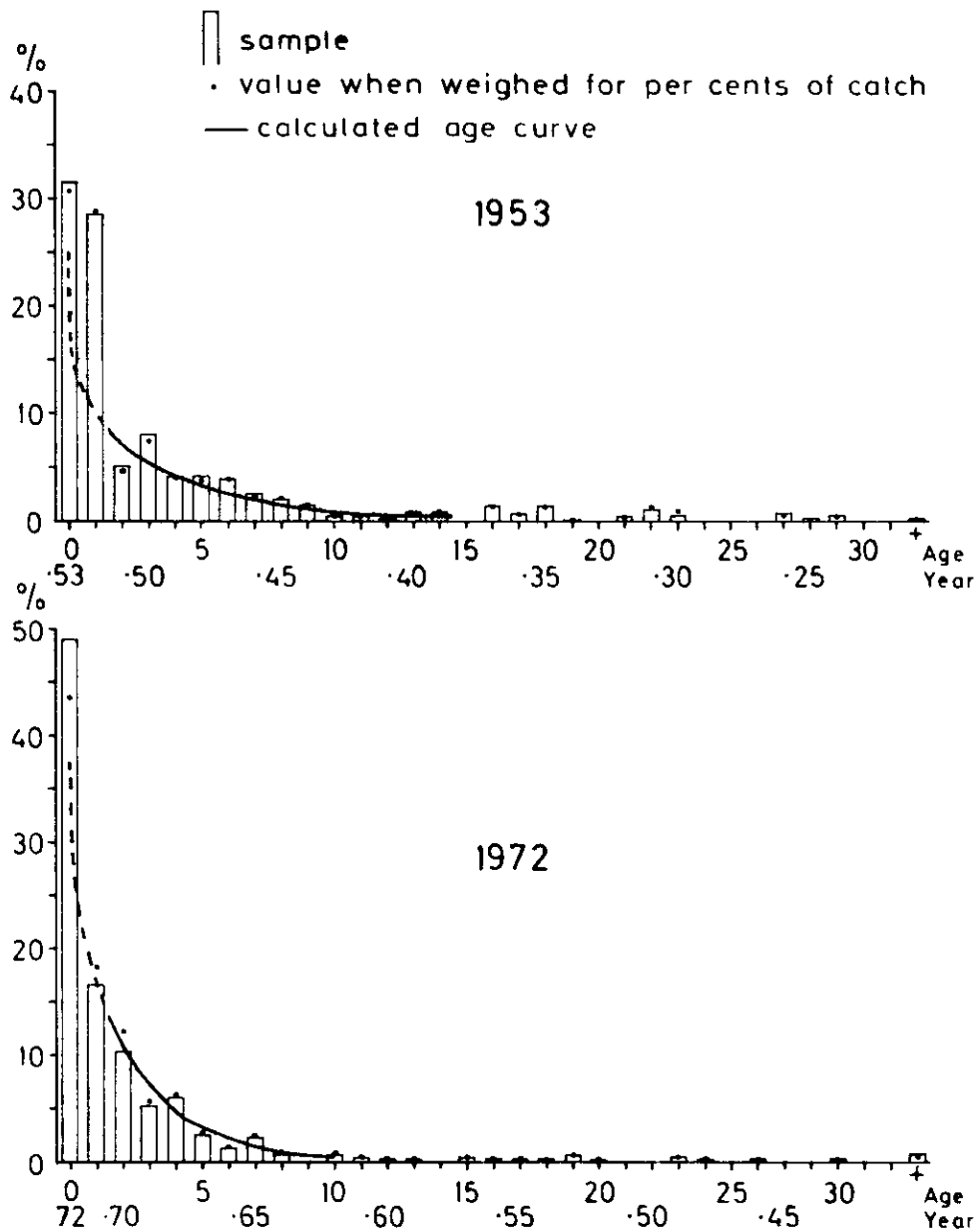


Fig. 5. Age composition of harp seals in Upernavik and Umanak districts.

Whether the catch in other regions of Greenland is composed as in Northwest Greenland is not known. It has been shown above that age composition differs from area to area within Northwest Greenland, and the same may be the case in other regions. Data from the Lists of Game on the relation between "blaasider" and "sortsider" (young and mature animals respectively) might point in this direction. Further, the previous age determinations tended to show higher percentages of mature animals in samples from some areas in Southwest

Greenland, but, as the age determinations are not fully reliable and as the samples from these parts of Greenland are considered less representative of the catch, further discussion is not possible until new age analysis of material from other regions has demonstrated the variation in age composition more clearly. At present, it is assumed that the age composition described above for Northwest Greenland catches is rather typical for Greenland as a whole, although older animals may occur in some other regions in high percentages.



Another question is whether the composition of the catch is sufficient to illustrate the composition of the herds of harp seals in the hunting areas, i.e. whether a selection of some age-groups occurs by catching. It is generally assumed among hunters that young seals are easier to catch than old ones. This assertion is probably more valid for young ringed seals, which are known to show markedly inquisitive behaviour, but may also apply to young harp seals. If so, some degree of selection of young animals will take place during the hunting, and especially young-of-the-year may be overrepresented in the catches.

Furthermore, it might be discussed whether composition of the herds of harp seals in the hunting areas of Greenland are the same as of the stock as a whole. It is suggested that various age-groups may arrive to different areas at different times and may concentrate in different regions. It is also possible that some age-groups may stay away to a certain degree from the hunting areas of Greenland and thus may be underrepresented in the catches. Samples from Baffin Island indicate that mature animals are relatively better represented than immatures, and this may be the case in other parts of the Canadian Arctic. However, until more evidence in this direction is available, it is assumed here that harp seals occur in the hunting areas of Greenland in the proportions by which they are represented in the stock.

If these assumptions are valid, the size and composition of the catches in Greenland would be expected to reflect fluctuations of the stock of harp seals in the Northwest Atlantic, especially those caused by exploitation at the breeding areas near Newfoundland. The intensive exploitation, which has occurred here during the 1950's and 1960's, is probably the most important cause of the general decline in catch of harp seals in Greenland (Fig. 2), although climatic influence and changes of hunting activities in Greenland may also have played a role.

In addition to the evidence on the status of the harp seal stock in the 1953-72 period, the material presented may give some information on the relation between catches at the breeding places and in Greenland for each particular year. As young-of-the-year contribute to the Greenland catches by a significant proportion, it should be expected that years of particularly large catches (high mortality) of young in the Front and the Gulf areas would result in rather low catches in Greenland, and vice versa. From Fig. 2 it appears that catches in Greenland were comparatively low in 1956, 1959, 1967 and, for region CWn, also in 1962. In the breeding areas 1956 was the year with the largest catch of young in the period, and catches were larger than usual in 1959 and 1967. In 1962, however, the catch was only slightly higher than

in the preceding year and much lower than in the two following years.

Catches in Greenland were comparatively high in 1952-54, 1958 and 1960. In the two last mentioned years catches of young in the breeding areas were unusually low, and the results were rather poor also in the 1952-54 period. The comparatively low catches of young in the breeding areas in 1957, 1961, 1965 and 1968, however, do not seem to have resulted in particularly high catches in Greenland during the following summer.

Although exceptions are found for a number of years, a correlation between catches of harp seals in the breeding areas and in Greenland seems to exist. This fact is in good agreement with the statement by Sergeant and Fisher (1960) that large catches can be traced in age samples as poorly represented year-classes, and it is also supported by the age analyses presented in this paper. As mentioned above, the year-classes of 1947, 1965 and 1968 (and to some degree 1950 and 1952) are rather well represented in the samples, corresponding to low catches of young in the breeding areas in each of these years. On the other hand only 1 year of unusually high catch of young in the breeding areas, namely 1951, seems to have resulted in an especially weak representation in the age samples. The lack of correspondence between catches in the breeding areas and in Greenland, found for some years, may be explained by fluctuations in production and natural survival or by differences in weather conditions and other factors affecting hunting activity in Greenland.

The fact that the age curve for the 1972 samples shows a steeper fall than that of the 1953 samples is an indication of increasing mortality rates in the intervening years, in all probability caused by heavy exploitation. An attempt to calculate mortality rates on the basis of the samples from Northwest Greenland gave values far too high to be real ( $Z = 0.3-0.5$ ). This applies to both the 1953 and the 1972 samples. The explanation may be that medium-aged animals are under-represented in catches of Northwest Greenland.

Sergeant and Fisher (1960) used the 1953 samples from West Greenland as a whole for calculating mortality rates and found a total mortality coefficient of  $Z = 0.22$  for ages 0-4 and  $Z = 0.11$  for ages 5-10. Consideration of the part of the sample, for which ages have been redetermined, suggests slightly higher the mortality coefficients for the new age determinations. However, re-examination of the samples from regions CWs, SWn, SWs and S has not yet been done, and it is difficult to say whether the changes will be significant.

It is thus evident that further revision of the previous samples is needed. It is also obvious that new

samples from Northwest Greenland are necessary to show whether the age composition found for the 1972 samples is valid for other years. Finally, it would be of interest to obtain samples from other regions of Greenland to illustrate the composition of the catches of harp seals at Greenland as a whole.

### Summary

Hunting statistics for the last 20 years show a declining catch of harp seals in Greenland, more particularly in the northwestern regions.

According to hunting statistics for Northwest Greenland, harp seals appeared later and left the area earlier in 1972 than in 1953.

Samples of jaws seem to represent fairly well the initial phases of the 1953 catch and to provide good representation of the 1972 catch.

Age analyses show that young-of-the-year seem to dominate catches in the Vaigat and Umanak districts, whereas 1-4 year-old harp seals are more numerous in the Upernavik district, but differences exist between localities within a district and between samples from different years.

Female harp seals tend to account for about 35-45% of the catches in Northwest Greenland, but the material is too sparse to draw any definite conclusions.

Indications are found of a relation between catches in the breeding areas and the catches in Greenland, so

that large catches of a year-class in the breeding areas generally result in low catches of the year-class at Greenland during the following summer.

The samples from 1953 and 1972 give evidence of an increase in mortality rate, indicating heavy exploitation of the stock in the intervening period, but calculation of mortality rates is not attempted on the data presented.

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# Virtual Population Assessment of the Southern Grand Bank Cod Stock (ICNAF Divisions 3N and 3O)

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## Abstract

Assessment of the Southern Grand Bank (ICNAF Divisions 3N and 3O) cod stock using the "virtual population analysis" technique, indicated fishing mortalities 1.5 - 3 times  $F_{max}$  in 1959-64 but 3.5 times and 4.5 times  $F_{max}$  during 1965-66 and 1967-68, respectively. Estimates for 1969-71 indicate a lower  $F$  but still 2 - 3 times  $F_{max}$ . During the 1959-66 period cod were fully recruited at age 6 and 50% recruited at 4.4 years; while during 1967-68 cod were fully recruited at age 5 and 50% recruited at 3.8 years, representing a shift in fishing pattern toward the earlier ages. Stock size of fully recruited fish declined from about 20 - 30 million in 1959-66 to 15 million in 1969 in response to heavy exploitation after 1966. A reduction in fishing effort well below the level in the 1960's is suggested.

## Introduction

At previous mid-term and annual ICNAF meetings, virtual population assessments have been presented for cod stocks in ICNAF Divisions 2J + 3K + 3L (Pinhorn and Wells, 1972) and Subdivisions 3Ps (Pinhorn, 1972). The present paper presents a similar assessment for cod in Div. 3N and 3O.

## Materials and Methods

The method of treating the Sampling Yearbook data (ICNAF publications) on lengths and ages was similar to that described by Pinhorn (1971, 1972) and consisted of adjusting length frequencies by month and quarter to the numbers landed in each month and quarter and applying quarterly age-length keys to these quarterly length frequencies to produce quarterly age-distributions of the numbers landed. These were then combined into annual numbers caught at each age. Because of lack of data on discards and of adequate length samples before discard, no attempt was made to adjust numbers landed to numbers caught. In addition to Sampling Yearbook data, age-length keys from Canada (Newfoundland) research vessel surveys were used to supplement or even replace commercial age-length keys in some years.

Jones' (1967) modification of Gulland's (1965) virtual population technique was used. Natural mortality of 0.20 was assumed and  $E = 0.8$  and  $E(1-e^{-z}) = 0.506$

was used for the oldest age-groups. Average weight-at-age data were derived from growth curves and length-weight curves for the most recent period available.

## Results

### Estimates of fishing mortality

Numbers of cod caught per year and age-group are shown in Table 1 and Fig. 1. From the data in Table 1, estimates of instantaneous fishing mortalities ( $F$ ) for each age were derived for the 1959-68 period (Table 2). Estimates of  $F$  of fully recruited age-groups fluctuated between 0.3 and 0.6 during 1959-64 but increased to 0.72 and 0.77 in 1965 and 1966, respectively, and to 0.9 in 1967 and 1968.

During the 1959-66 period cod were fully recruited at age 6 and 50% recruited at 4.4 years, while very few 3-year-olds were taken. However, during 1967-68 cod were fully recruited at age 5 and were 50% recruited at age 3.8 while an average of 15% recruitment occurred at age 3.

### Yield per recruit

Yield-per-recruit calculations incorporating the partial recruitment estimates shown in Table 2 produced a curve almost identical to that shown by Pinhorn and Wells (1970) with the point of maximum sustainable

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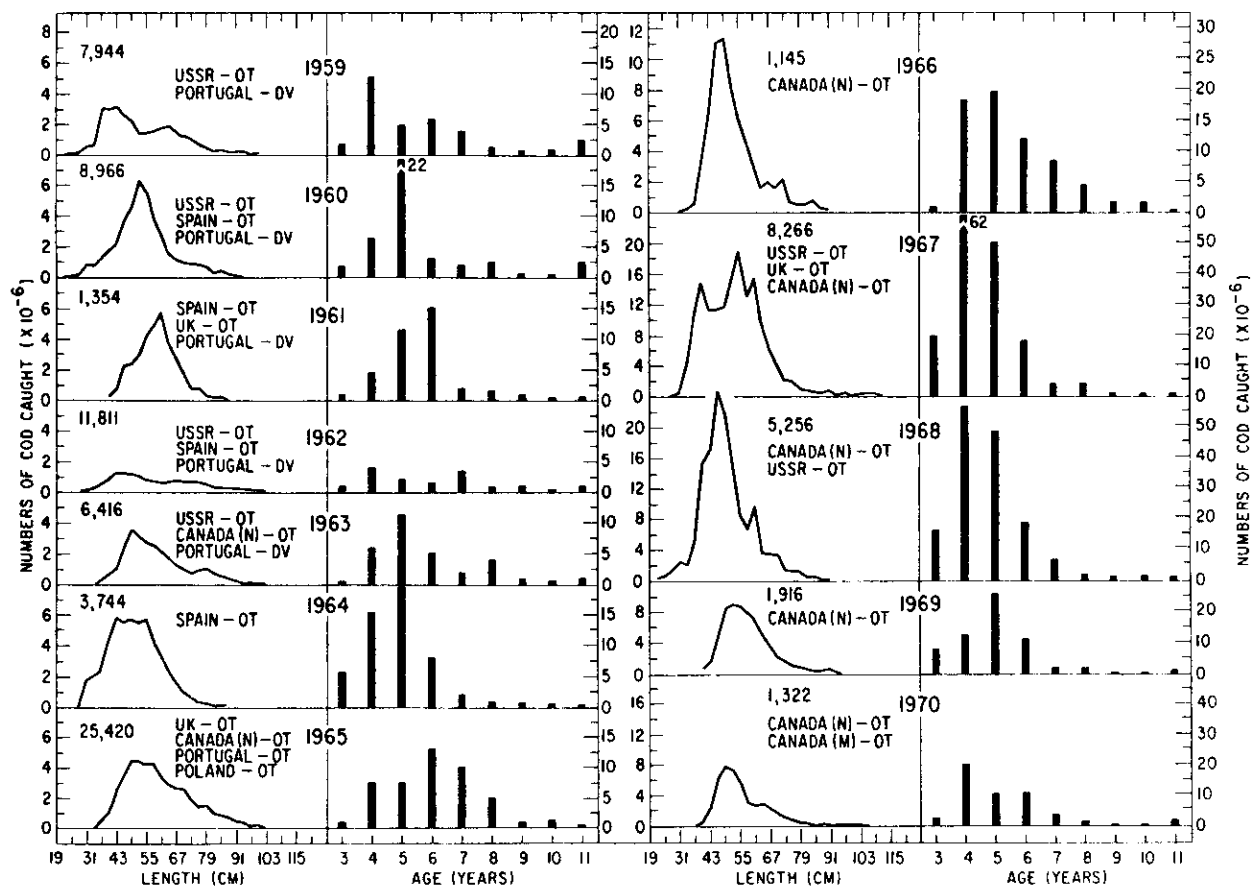


Fig. 1. Age and length distributions of cod catches used in assessment of Divisions 3N and 3O cod stock, 1959-70. Numbers for each year are total numbers of length measurements. Countries for which measurements were available in each year are also shown.

TABLE 1. Numbers of cod caught per year and age-group, ICNAF Div. 3N and 3O, 1959-70 ( $\times 10^3$ ).

Age	Year											
	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
2	417	230	—	21	6	—	9	—	179	853	81	25
3	1711	1846	812	1,026	313	6,202	1,013	753	20,086	16,359	8,154	2,105
4	13,036	6,503	4,400	3,882	5,757	15,555	7,611	18,413	62,442	56,775	12,924	19,703
5	5,068	22,050	11,696	2,206	11,210	19,496	7,619	19,681	50,317	48,608	26,949	10,799
6	6,025	3,095	15,258	1,581	4,849	7,919	13,258	11,795	18,517	18,485	11,191	9,481
7	3,935	2,377	2,014	3,594	1,935	2,273	9,861	8,486	4,774	6,337	2,089	3,646
8	1,392	2,504	1,672	773	3,840	1,109	4,827	4,467	4,651	1,592	1,393	1,635
9	757	583	847	668	1,165	788	1,081	1,829	236	505	518	541
10	926	387	196	433	608	328	1,248	1,694	180	178	292	149
11	1,220	898	25	226	322	37	163	122	71	90	134	227
12	103	242	245	216	208	112	141	57	45	45	202	90
12+	1,128	1,409	392	746	473	56	276	183	335	35	574	1,472
Total	35,718	42,124	37,557	15,372	30,686	53,875	47,107	67,480	161,833	149,862	64,553	49,873

TABLE 2. Estimates of instantaneous fishing mortality for cod in ICNAF Div. 3N and 3O, 1959-68.

Age	Year										Average F			% Recruited		
	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1959-66	1967-68	1959-68	1959-66	1967-68	1959-68
3	0.036	0.041	0.012	0.010	0.004	0.068	0.008	0.004	0.12	0.17	0.02	0.15	0.05	4	15	9
4	0.17	0.19	0.13	0.070	0.076	0.31	0.11	0.17	0.52	0.62	0.15	0.57	0.24	31	57	43
5	0.34	0.47	0.61	0.093	0.29	0.39	0.25	0.41	0.93	0.96	0.36	0.95	0.47	75	100	84
6	0.51	0.35	0.70	0.15	0.30	0.35	0.51	0.79	0.88	1.15	0.45	1.01	0.57	100	100	100
7	0.47	0.38	0.41	0.35	0.27	0.22	0.96	0.74	0.91	0.89	0.47	0.90	0.56	100	100	100
8	0.51	0.63	0.50	0.27	0.78	0.24	1.03	(1.60)	1.30	0.93	0.57	1.11	0.69	100	100	100
9	0.41	0.42	0.46	0.38	0.84	0.36	0.40	(1.80)	0.67	0.42	0.47	0.54	0.48	100	100	100
10	0.38	0.38	0.24	0.45	0.72	0.61	(1.75)	(2.40)	0.65	?	0.46	0.65	0.49	100	100	100
Ages 3-10	0.35	0.36	0.38	0.22	0.41	0.32	0.47	0.43	0.75	0.73						
Fully recruited ages	0.46	0.43	0.46	0.32	0.58	0.36	0.72	0.77	0.89	0.87						
Catch ('000 tons)	62.4	77.7	71.5	34.4	67.7	62.0	95.6	105.9	220.1	158.9						

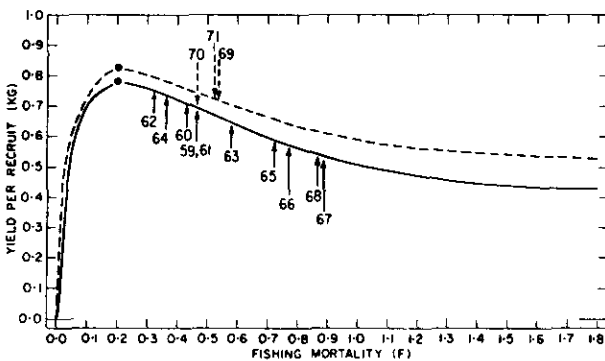


Fig. 2. Yield per recruit for Divisions 3N and 3O cod stock. Solid line represents curve using 1967-68 recruitment pattern. Broken line represents curve using 1959-66 recruitment pattern.

yield per recruit at about  $F = 0.2$  (Fig. 2). The level of  $F$  in fully recruited age-groups during 1959-64 fluctuated about a level of 1.5 - 3 times the level of  $F_{max}$  but in 1965-66 the  $F$  was about 3.5 times  $F_{max}$  and in 1967 and 1968 about 4.5 times  $F_{max}$ .

**Stock size**

Numbers present in the stock at the beginning of the year (Table 3) indicated that total stock size of fish age 4 and older decreased from about 156 million fish in 1959 to 120-125 million in 1961-62 and then increased to 185 million during 1964-65 and to 300 million in 1967. There was a subsequent decline to 180 million in 1969. The adult portion of the stock (age 7+) fluctuated around

20 - 30 million fish in 1959-66 and then decreased to 15 million in 1969. The adult proportion of the commercially-exploited stock decreased from 12-19% in 1959-66 to 6-8% in 1967-69.

**Discussion and Conclusions**

Fishing mortality estimates for the cod stock in Div. 3N and 3O were relatively stable during 1959-64 but were almost double the 1959-64 average in 1965-66 and were even higher in 1967-68. This increased fishing mortality is a reflection of the increased fishing effort attracted to the area by the abundant 1963 and 1964 year-classes (Table 3 and Pinhorn, 1970).

Age at 50% recruitment was less in 1967-68 than in 1959-64. The observed increase in growth rate between the two periods (Table 4) was not sufficient to account for this difference in age at recruitment. The length at 50% selection corresponding to the age at 50% recruitment for 1959-66 was 48.6 cm and for 1967-68 was 45.3 cm. Thus, there appears to have been a shift in fishing pattern toward the earlier ages as the fleets concentrated on the abundant 1963 and 1964 year-classes as 3 and 4 year-old-fish.

The general conclusion from the assessment is that a general reduction in fishing effort well below the level in the 1960's is necessary to achieve maximum yield-per-recruit. Estimates of  $F$  obtained from projected stock sizes and catches in 1969-71 indicate that  $F$  was probably lower than in 1967-68, in the vicinity of 0.5 - 0.6, but still 2 to 3 times the estimate of  $F_{max}$ .

TABLE 3. Numbers of cod present in the stock at the beginning of the year, ICNAF Div. 3N and 3O, 1959-69 ( $\times 10^3$ ).

Age	Year										
	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
3	53302	51854	75185	115280	86944	103367	140694	209167	195010	115204	153849
4	91803	41737	40199	62232	91030	67436	83633	121957	169389	137899	78967
5	19270	63861	28011	28392	48754	66656	37519	64843	89969	83772	59340
6	16507	11370	32970	12451	20851	29724	35937	23329	34614	29237	26780
7	11472	8187	6600	13402	8889	12550	17174	17338	8719	11697	7578
8	3814	5862	4633	3479	7718	5671	8219	5728	6912	2861	3932
9	2416	1870	2532	2314	2240	2876	3636	2406	1012	1577	950
10	3215	1342	1006	1304	1295	787	1646	1967	388	631	868
10+	8286	6787	3457	3189	2632	1207	1155	778	618	387	1492
4-10+	156783	141016	119408	126763	183409	186907	188919	238346	311621	268061	179907
7-10+	29203	24048	18228	23688	22774	23091	31830	28217	17649	17153	14820
7-10+ as % of 4-10+	19	17	15	19	12	12	17	12	6	6	8

TABLE 4. Average lengths at each age for recruiting age groups, 1959-66 and 1967-70, Div. 3N 3O cod stock.

Age	Average length	
	1959-66	1967-70
	cm	cm
3	37.5	40.2
4	46.1	46.5
5	52.4	54.5
6	60.8	62.7
50% selection length	48.6	45.3

As with the assessment of the cod stock in Subdivision 3Ps (Pinhorn, 1972), the present assessment was greatly hampered by lack of adequate sampling data from the offshore fishery. Unlike the stock in Subdivision 3Ps, which has an inshore fishery component for which adequate samples were available, the fishery on Div. 3N and 3O cod is solely offshore by otter trawlers, pair trawlers and dory vessels and no samples from the inshore area can be used to estimate offshore numbers. Figure 1 shows that the numbers of commercial length measurements in recent years have been few and have been available in some cases for only one quarter. In fact in 1971, no commercial sampling data existed at all for

Div. 3N and 3O cod. If an assessment of the effectiveness of recent quota regulations in this and other stocks is to be made in future, more sampling data covering all fisheries and all seasons will have to be provided.

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# Spawning and Development of Witch Flounder, *Glyptocephalus cynoglossus* L., in the Northwest Atlantic

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## Abstract

The development of witch flounder in the Northwest Atlantic from the egg stage to metamorphosis is described. The eggs are pelagic, spherical, without oil globule, and from 1.10 to 1.45 mm in diameter. Scattered pigment cells appearing on the embryo body at the end of developmental Stage II become grouped into three distinct postanal bands at Stage IV. Before hatching the eyes of the embryo are not pigmented. Metamorphosis occurs when the larvae are about 20 mm long. Eggs of witch flounder are found from May to September, in the area from the northern slopes of the Grand Bank to the southwestern part of Georges Bank. Larvae are found mainly in the areas of egg distribution. Spawning of witch flounder occurs from March to September. Spawning grounds are located off southern Labrador and eastern Newfoundland, on the Grand Bank, off Nova Scotia and on Georges Bank. Spawning appears to be most intensive in March-April in the northern areas and in July-August in the south. The main drift of eggs and larvae of witch flounder is southward from the northern spawning grounds. The young may remain pelagic for up to 1 year.

## Introduction

Witch flounder, *Glyptocephalus cynoglossus*, has recently become one of the important commercial species for trawl fisheries in the Northwest Atlantic, particularly in the Newfoundland area and on the Nova Scotia Banks. In 1970 and 1971 the annual catches of witch flounder off the Atlantic coast of Canada amounted to 40,000 metric tons and 60,000 metric tons respectively. However, information on the biology of witch flounder is sparse, especially information on spawning and early development. There are no papers on reproduction and development of this species in the Northwest Atlantic, but some scattered information on this subject can be found in Canadian and American literature (Powles and Kennedy, 1967; Powles and Kohler, 1970). Instances of the occurrence of witch flounder eggs and larvae in the waters of the Northwest Atlantic have been mentioned by Bigelow (1914, 1917) for the Gulf of Maine; Dannevig (1919) for Gulf of St. Lawrence; Fish and Johnson (1937) for Gulf of Maine and Bay of Fundy; Frost (1938) for Newfoundland; Bigelow and Schroeder (1953) for Gulf of Maine and Bay of Fundy; Alvarino (1956) for Nova Scotia; Legare and Maclellan (1960) for Passamaquoddy Bay; Marak *et al.* (1962a, 1962b) for Gulf of Maine; Bergeron and Lacroix (1963), Lacroix and Bergeron (1964) and Lacroix (1966) for Gulf of St. Lawrence; Graham and Boyar (1965) for Gulf of Maine; Serebryakov (1962,

1965) for Newfoundland and Nova Scotia areas. Most of the publications mentioned are related mainly to witch flounder of the coastal waters and bays of Canada and USA, and the authors have given very little information on witch flounder reproduction and on the development and the distribution of its early stages.

This paper presents the results of studies on material collected by USSR research and scouting vessels from Labrador to the Georges Banks during 1959-70.

## Material and Methods

The material on development and distribution of eggs and larvae of the witch flounder, was collected by research vessels of the Polar Institute of Marine Fisheries and Oceanography (PINRO) during the spring and summer seasons of 1959-1970. A total of 3,127 ichthyoplankton stations have been made in the area from the northern regions of Labrador to Georges Bank and 3,400 samples taken. The material was collected according to the methods of Rass and Kasanova (1966) at the stations used for standard hydrological observations and for trawling operations. The fishing gear used was a cone-shaped plankton net with an opening of 0.5 m<sup>2</sup> (the number of eggs and larvae is given per one haul

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of the net). Information on gonad maturity stages of the adults was obtained in 1960-1972 on the basis of field analyses of trawl catches made by PINRO research vessels and scouting vessels. In the field analysis, the 6-point maturity scale was used to determine the stages of maturity (Sorokin, 1957). The descriptions and drawings of fish eggs and larvae were made from preserved material. The drawings were made with a "Promar" projection microscope. For the identification of egg and larva development stages the periodicity of development after Rass (1949) was used.

### Description of Witch Flounder Eggs and Larvae

Information on the development of witch flounder from the coast of North America is rather scarce (Bigelow and Schroeder, 1953; Dannevig, 1919).

Eggs are pelagic, spherical, with a narrow perivitelline space and without oil globule. The diameter of eggs is 1.10-1.45 mm with the average of 1.27 mm. Yolk

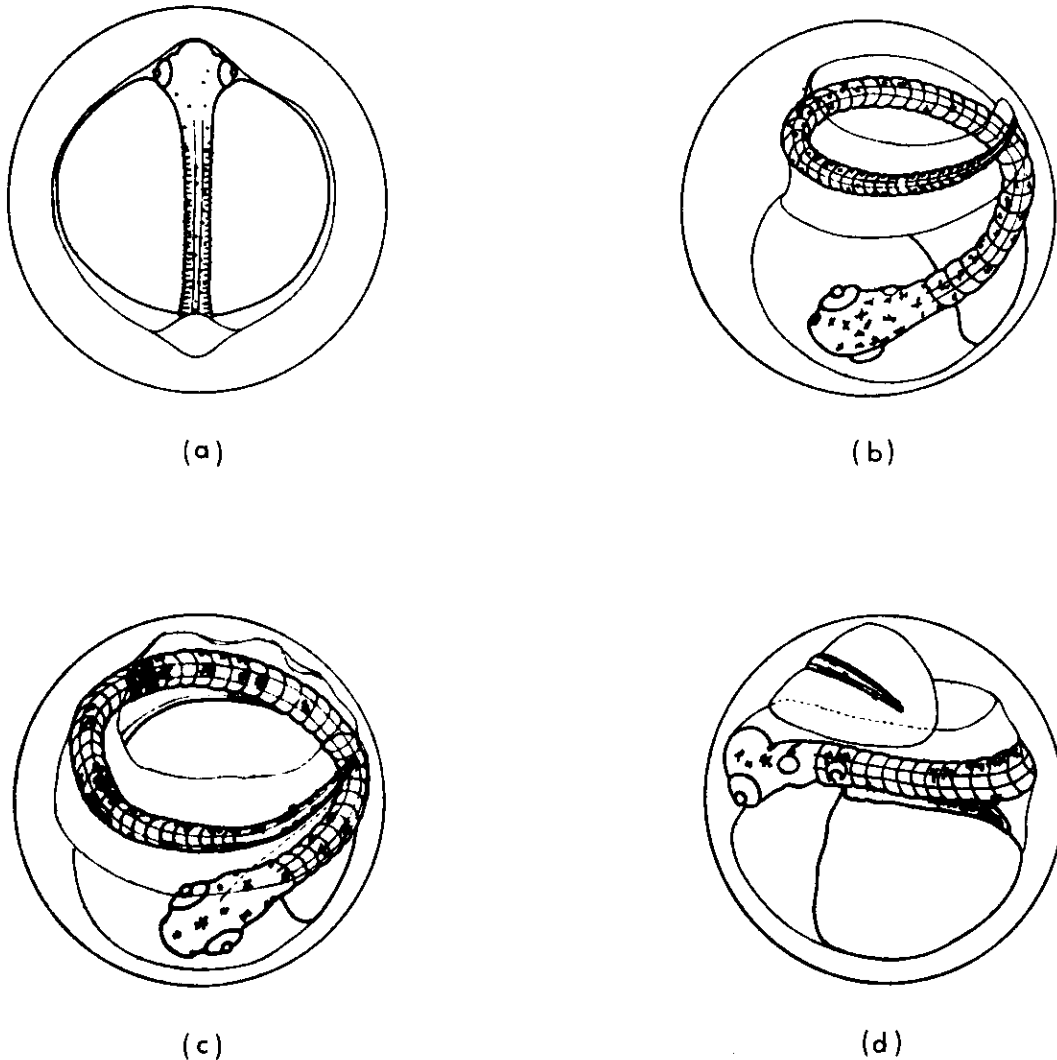


Fig. 1. Eggs of witch flounder:  
 (a) stage II of development;  
 (b) the beginning of stage IV of development;  
 (c) continuation of stage IV of development;  
 (d) the end of stage IV of development.



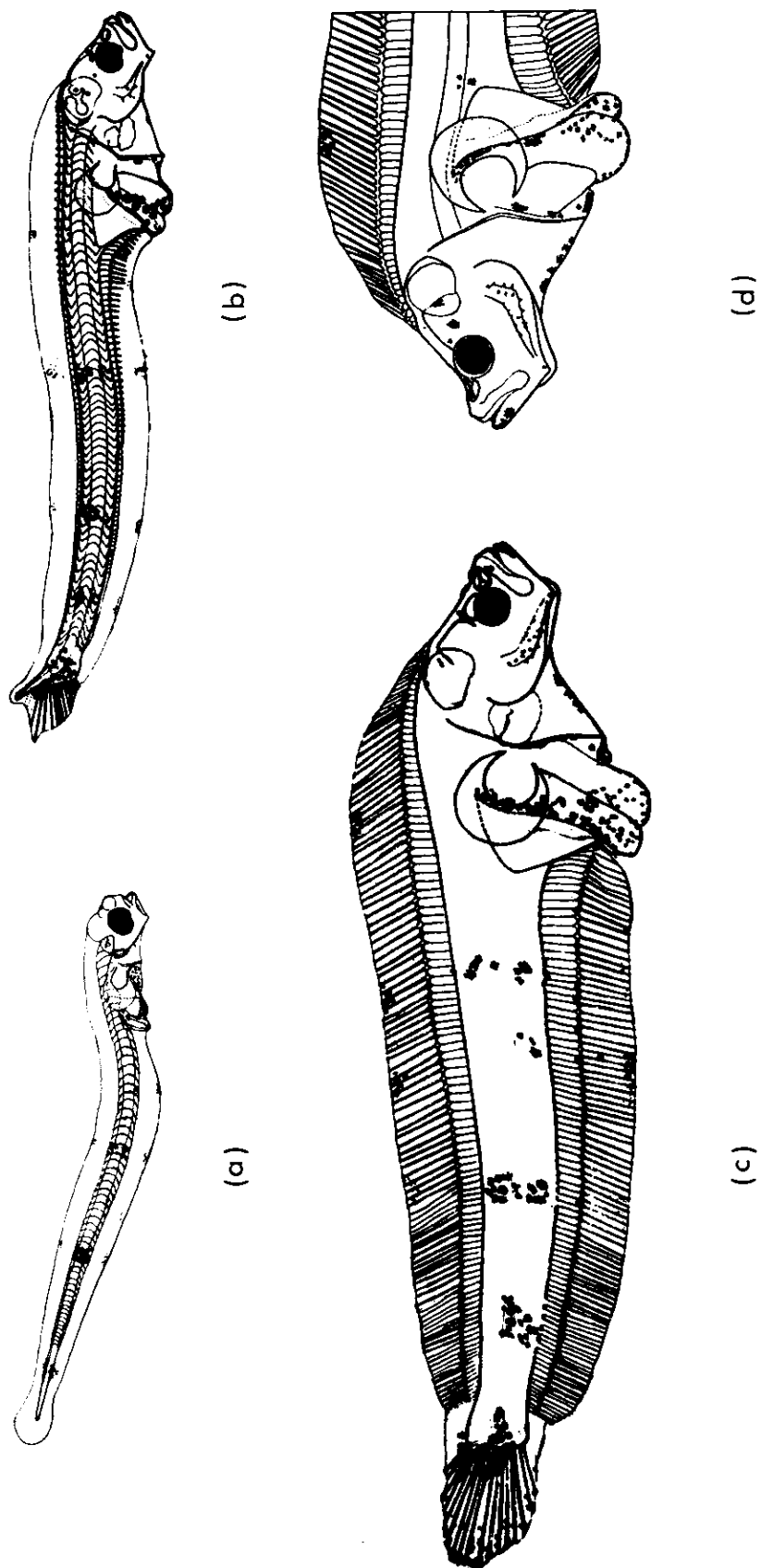


Fig. 2. Larvae of witch flounder :  
(a) length — 5.8 mm;  
(b) length — 16.7 mm;  
(c) length — 22.5 mm right side;  
(d) length — 22.5 mm left side.

diameter is 0.95-1.05 mm. Egg sheath is rather thick, grooved, with many folds.

*An egg of Stage II (Fig. 1a).* In the embryo body there are 34 myotomes. Pigmentation is rather weak, with melanophores having the form of scattered points which are located mainly on the back part of the embryo body and on the head.

*An egg of Stage IV (Fig. 1b).* In the embryo body there are 47 myotomes. The olfactory capsule can be seen. Pigment cells are still scattered over the whole body of the embryo, but two rows of melanogores on the sides of the body become rather distinct. The embryonic fin fold and yolk sac are non-pigmented.

*An egg of Stage IV (Fig. 1c).* In the embryo body there are 47 myotomes (12 + 35). Alimentary canal has the shape of a straight pipe. On the sides of the body at the border of myotomes 1 and 2, there are rudiments of pectoral fins. One mass of melanophores is in the anal area, and three belt-shaped masses are seen in the post-anal part of the body (Fig. 1d). The newly hatched larvae are about 4.9 mm in length (Bigelow and Schroeder, 1953).

*Pre-larva of 5.8 mm in length (Fig. 2a).* The body is thread-like, with the distance from the snout to the anal aperture being 25.9% of the body length. The anus is located at the edge of the embryonic fin fold. The gut forms a loop in the middle part of the cavity and ends in the intestine which bends ventrally to discharge from the posterior part of the body cavity. Fragments of yolk sac can be seen near the cleithrum. The brain is differentiated into its main parts. The pectoral fins are fan-like. Pigmentation is belt-like. In the area of the anus a concentration of branched melanophores are seen. Pigment cells are of similar shape and form three post-anal belts. Spot-like melanophores also form small concentrations between myomeres 17-18, 32-33 and 48-51 in the ventral part. At the edges of the post anal part of the embryonic finfold above and under the pigment masses (except the 3rd belt), concentrations of very small spot-like melanophores can be seen.

*Larva of 16.7 mm in length (Fig. 2b).* The body is symmetric and thin and is encircled with an embryonic fin fold. Pre-anal distance is 29.3% of the body length. The number of myomeres is 57 (12 + 45). Behind the intestines fragments of the large urinary bladder can be seen, with free space of triangular shape behind it, where the gonads develop at later stages. The cleithrum can be clearly seen with a double-chambered heart anterior to it. The upper and lower jaws are formed. On the posterior edge of the pre-operculum three large spines can be seen, while on the anterior edge there are five small spines directed forward. Between the anterior and posterior

edges of the pre-operculum there is also one spine. In the place of dorsal and anal fins there can be seen rudiments of pterigiophores, dorsal 85 and anal 68; from the pterigiophores rudiments of fin rays extend, 31 dorsal and 41 anal. The urostyle is bent, and below it are rudiments of 18 rays. The character of pigmentation is mainly the same as before while the intensity is higher.

*Larva of 22.5 mm in length (Fig. 2c) — the right side of the body.* Metamorphosis has begun. The left eye has started its migration towards the right side. The caudal part of the body is still long, but the pre-anal distance is now 35.1% of the total body length. The number of myomeres is 54-55 (11 + 43-44). Three teeth can be seen on each side of the upper and lower jaw. Pectoral fins are still of larva character. On the anterior edge of the pre-operculum there are four spines pointing anteriorly, while on the posterior edge there are seven spines of larger size. Between the anterior and posterior edges of the pre-operculum eight spines point in different directions. There are 111 rays in the dorsal fin, 95 in the anal and 20 in the caudal fin. A rudiment of pelvic fin with 4-5 rays can be seen posterior to the ventral part of the cleithrum. The character of pigmentation has not changed, but the contours of the post-anal belts are rather well-developed when compared with earlier stages.

*Larva of 22.5 mm in length (Fig. 2d) — the left side of the body.* The olfactory capsule is located almost on the head profile but it cannot be seen from the right side. The number of spines on the pre-operculum (17 left side) differs from that on the right side of the body (19). Very interesting changes in the character of pigmentation have been observed on the left side of the body as compared to the right side; there are many less pigment cells on the intestinal loops and these are mainly located on the ventral parts; above the left side of the mesencephalon there are two pigment cells.

## Distribution of Eggs and Larvae of Witch Flounder

### Egg distribution

Bigelow (1917) was the first to report the eggs of witch flounder off the Atlantic coast of North America, when he indicated their occurrence in the Gulf of Maine. Bigelow and Schroeder (1953) and Marak and Colton (1962a, 1962b) described the distribution of witch flounder eggs in the Gulf of Maine, Bay of Fundy and on Georges Bank. Alvarino (1956) and Serebryakov (1965) described the distribution of eggs in the region of Newfoundland and Nova Scotia. The PINRO information on witch eggs and larvae for 1959-70 are summarized and presented in the form of charts of egg and larvae distribution (Fig. 3-6).

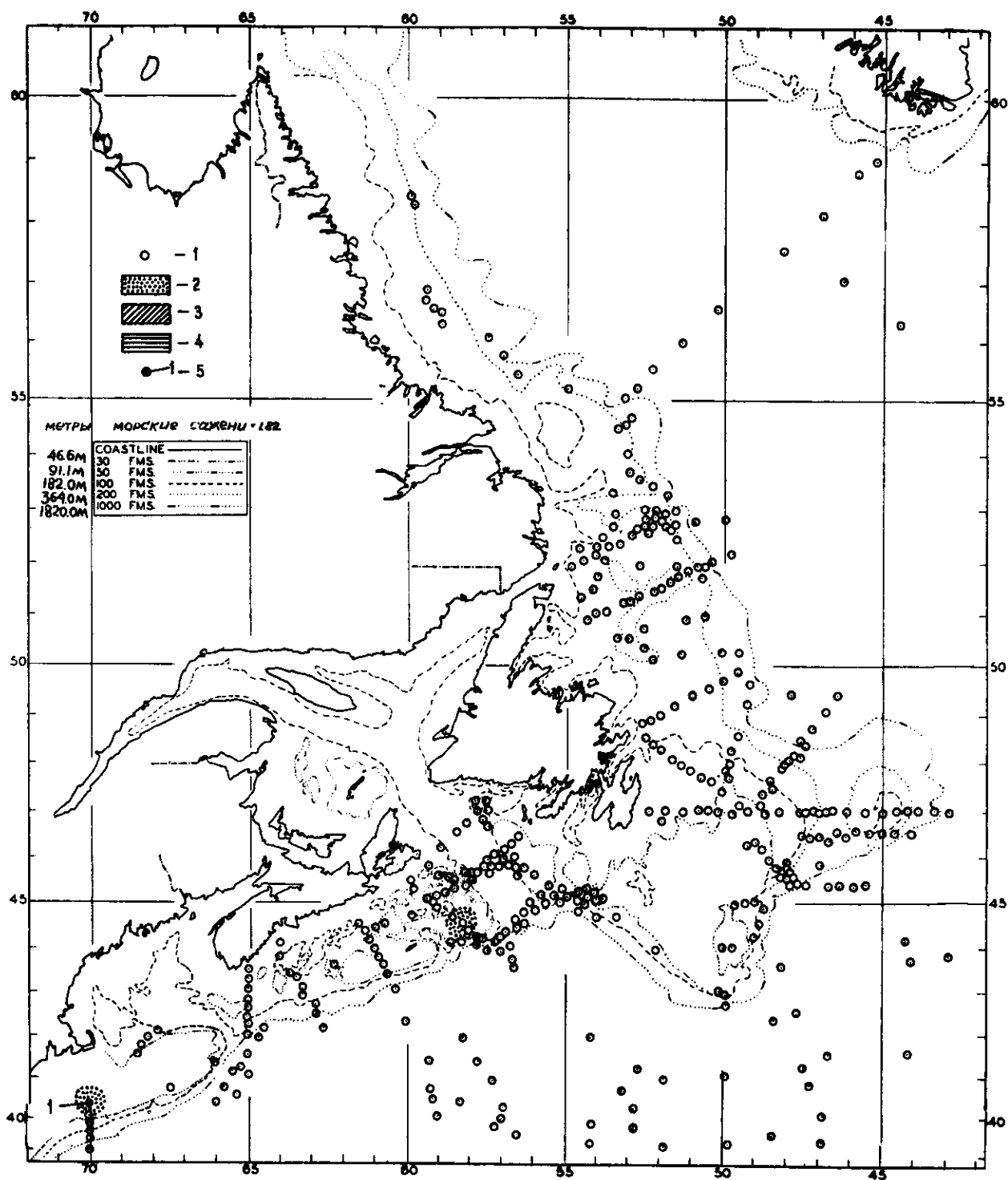


Fig. 3. Distribution of eggs and larvae of witch flounder in May:

- Legend:
- 1 — station;
  - 2 — 1-10 eggs per catch;
  - 3 — 11-100 eggs per catch;
  - 4 — 101-500 eggs per catch;
  - 5 — number of larvae at the station.

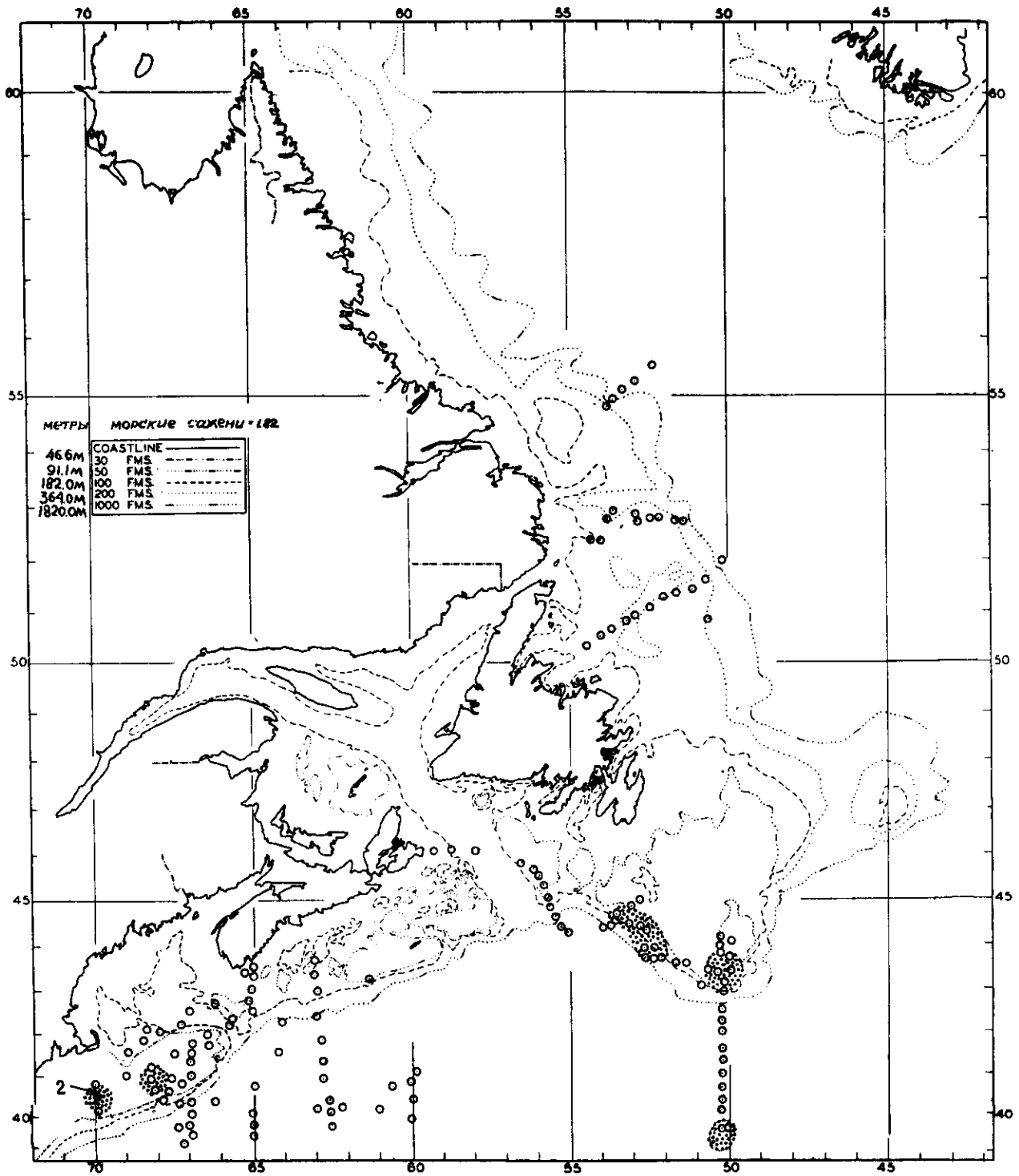


Fig. 4. Distribution of eggs and larvae of witch flounder in June (see Fig. 3 for legends).

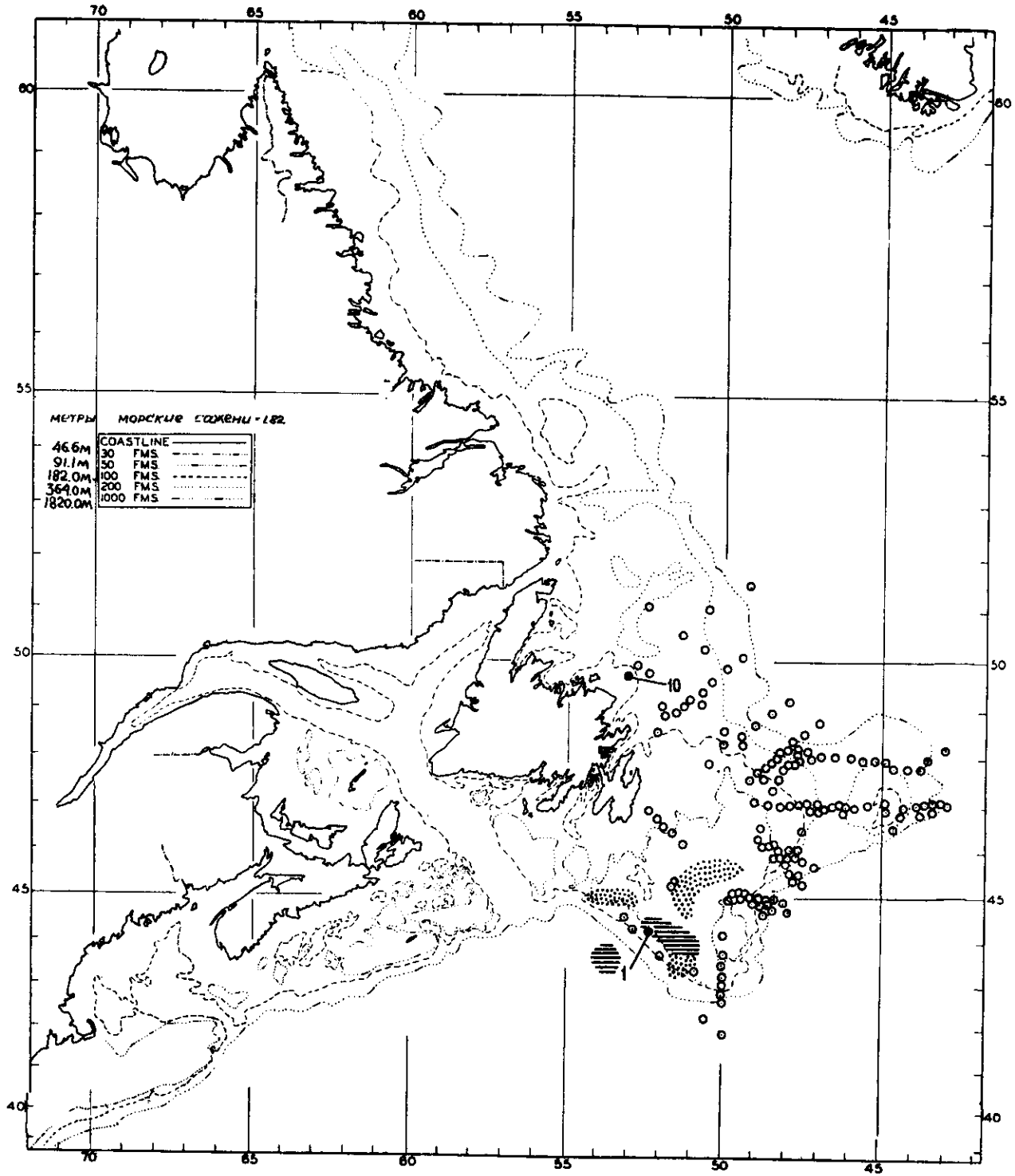


Fig. 5. Distribution of eggs and larvae of witch flounder in July (see Fig. 3 for legends).

In May, only one egg at Stage II of development was found in the shallow water on Banquereau Bank (65 m depth) at a surface temperature of 4.38°C, and two eggs of Stages I and II on the southwestern part of Georges Bank above a depth of 85 m (Fig. 3).

In June, separate eggs of witch flounder (1-8 eggs per haul) were found on the southern and southwestern slopes of the Grand Bank above depths of 65 to 350 m (water temperature at the surface being 6.12° to 7.14°C), in shallow water of Georges Bank over 50-65 m depth, as well as above ocean depths of more than 5,000 m to

the south of the Grand Bank (Fig. 4). The eggs caught in these regions were mainly at Stages I and II and only two of them at Stages III and IV of development.

In July, eggs were found on the southern part of the Grand Bank and above ocean depths in the region of the southwestern slope (Fig. 5). The largest numbers of eggs (130-290 eggs per haul) were caught over the southwestern slope of the Grand Bank, with the maximum catch (290 per haul) at 44°13'N, 52°20'W. In the Grand Bank area the eggs were mostly in Stages I and II of development, while 35% of the eggs caught above the ocean depths were in Stage III (Table 1).

TABLE 1. Witch flounder eggs in the Grand Bank area in July and August.

Month	Area	Depth (m)	Surface temp. (°)	Development stages (%)				No. of eggs
				I	II	III	IV	
July	S. Grand Bank	58-200	10.6-14.4	62.7	25.6	8.4	3.3	302
	S. Grand Bank	>3000	11.8	30.6	30.1	34.6	4.7	107
August	N. Grand Bank	65-540	9.0-12.0	58.0	36.1	5.0	0.9	219
	Avalon Peninsula	70-160	12.1-13.2	25.2	14.0	28.4	32.4	194
	S. Grand Bank	60-250	14.1-17.5	45.7	35.7	13.5	5.1	62

In August, witch flounder eggs (1-100 eggs per haul) on the Grand Bank were distributed over the whole aquatic zone from shallow water to the depths of the shelf slope (Fig. 6). The maximum number of eggs (100 per haul) was off the Avalon Peninsula at 46°35'N, 53°00'W. Eggs of Stages I to IV were variously caught in most areas of the Bank (Table 1). Eggs of Stage III and IV prevailed only in the region of the Avalon Peninsula, while Stages I and II eggs over most areas of the Bank.

Small quantities of witch flounder eggs (1-11 eggs per haul) were found in the shallow-water areas of St. Pierre Bank and the Scotian Shelf (Fig. 6). On St. Pierre Bank several eggs of Stage I and II and one of Stage III were caught above depths of 45-65 m where the surface temperatures were 12.9° to 15.12°C. In the waters off Nova Scotia scattered eggs in all stages of development were caught on Banquereau Bank, near Sable Island, and on Scattery Bank above depths of 30-100 m.

In September, there were only nine witch flounder eggs of all stages caught off the Avalon Peninsula above depths of 70-165 m and on the southeastern slope of the Grand Bank (50-70 m depth) (Fig. 6). Surface water temperature, where the eggs were found, ranged from 10.86° to 14.34°C.

### Larval distribution

Instances of witch flounder larvae catches in the Atlantic waters of North America were described by Bigelow (1914), Dannevig (1919), Fish and Johnson (1937), Frost (1938), Bigelow and Schroeder (1953), Legare and Maclellan (1960), Marak *et al* (1962a, 1962b), Serebryakov (1962, 1965), Bergeron and Lacroix (1963), Graham and Boyar (1965), and Lacroix (1966).

In the PINRO collections, witch flounder larvae were found in the survey areas from May to September, mainly in the areas where eggs occurred (Fig. 3-6). In May-June (Fig. 3, 4) three larvae (4.9, 6.0 and 7.0 mm long) were found on the southwestern part of Georges Bank above depths of 48-85 m. During the July survey, larvae were found off the middle part of the east coast of Newfoundland and on the southwestern slope of the Grand Bank (Fig. 5). The size and number of larvae caught in the Northwest Atlantic are given in Table 2.

In August, witch flounder larvae were caught off the south coast of Labrador in the area of Hamilton Bank, on the Grand Bank, near the Avalon Peninsula, on St. Pierre Bank and over the Nova Scotia Shelf (Fig. 6). The largest number of larvae was found on the

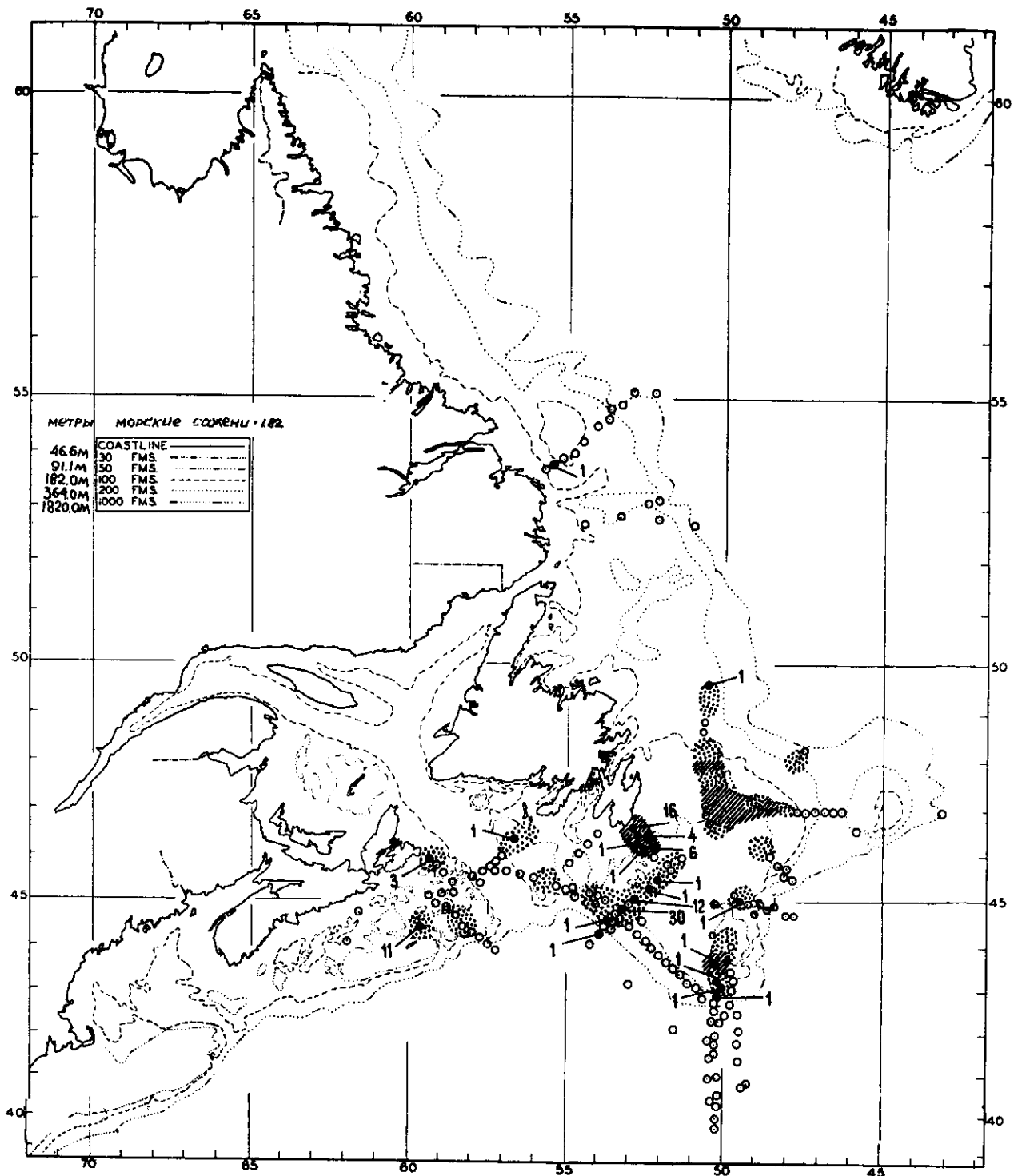


Fig. 6. Distribution of eggs and larvae of witch flounder in August-September (see Fig. 3 for legends).

southwestern slope of the Grand Bank and near the Avalon Peninsula (Table 2). Single specimens were taken at stations over the deep water (above 1,000 m) of the southwestern slope of the Grand Bank. Several larvae were caught in September near the Avalon Peninsula and on the southeastern slope of the Grand Bank (Fig. 6).

Witch flounder larvae were mainly caught in the upper warm layers of water. As a rule, the smaller larvae were more abundant over the deep water areas.

### Witch Flounder Spawning

Witch flounder are distributed from Newfoundland and Gulf of St. Lawrence to Cape Hatteras (Bigelow and Schroeder, 1953). The season of its reproduction is extensive; spawning takes place late in spring and summer at rather high temperature (Bigelow and Schroeder, 1953). The main spawning grounds are likely to be located in deep waters of the southern parts of its area of distribution (Pertseva-Ostroumova, 1961). Canadian scientists (Powles and Kohler, 1970), who studied witch flounder distribution in the Gulf of St. Lawrence and along the coast of Nova Scotia, indicated that mature fish were found in large numbers at depths of 92-162 m in summer (May-October) and at 218-325 m in winter (November-April).

According to our knowledge of the Labrador-Newfoundland fishing area, mature spawning fish are

found in trawl catches during most of the year from shallow water (50-80 m) to a depth of 1,000 m, and, according to some authors (Pechenik and Troyanovsky, 1970), down to 1,500 m. Based on the information available on the distribution of eggs in different stages of development and on the occurrence of mature spawning fish, it is possible to make a supposition that the spawning of witch flounder in the surveyed areas of the Northwest Atlantic is extended from March to September, the periods of witch flounder spawning being dependent on the geographical position of the spawning grounds.

The spawning of witch flounder is less extensive in the northern than in the southern areas. The spawning period in the southern Labrador and Northeast Newfoundland Shelf areas continues from March to July. However, a newly-hatched larvae was caught near the coast of southern Labrador in the middle of August. By analysing the distribution of spawning fish, it is possible to conclude that the most intensive spawning of witch flounder in the above-mentioned regions takes place mainly in March-May. Pechenik and Troyanovsky (1970) indicate that, in the southern Labrador and Northeast Newfoundland Shelf areas, mass spawning of witch flounder takes place in March-April at depths of 570-700 m and that it stops in May. However, eggs of witch flounder in these areas have not been found, and the assumption based on the distribution of spawning fish only is not always true, since only the presence of eggs at early stages of development can verify the location of spawning grounds.

TABLE 2. Witch flounder larval distribution in the Northwest Atlantic during July-September.

Area	Month	No. of larvae	Length range (mean)	Depth (m)	Surface temp. (°)
S. Labrador	Aug	1	4.9	185	—
N Grand Bank	Jul	10	4.7-10.3 (6.4)	160	—
	Aug	1	5.0	320	9.0
NE Grand Bank	Aug	8	5.0-7.5 (6.2)	110-250	9.7-11.8
Avalon Peninsula	Aug	26	4.7-18.3 (6.7)	70-160	12.1-13.2
	Sep	2	4.8-6.5	160-166	12.2-12.4
SE Grand Bank	Aug	1	6.5	190	15.4
	Sep	4	5.8-26.5	50-70	11.3-14.3
SW Grand Bank	Jul	1	5.0	90	13.4
	Aug	46	4.9-25.6 (10.9)	76-106	14.5-15.5
St. Pierre Bank	Aug	1	6.9	45	14.0
Banquereau	Aug	14	6.5-13.4 (9.0)	28-96	17.7-18.8



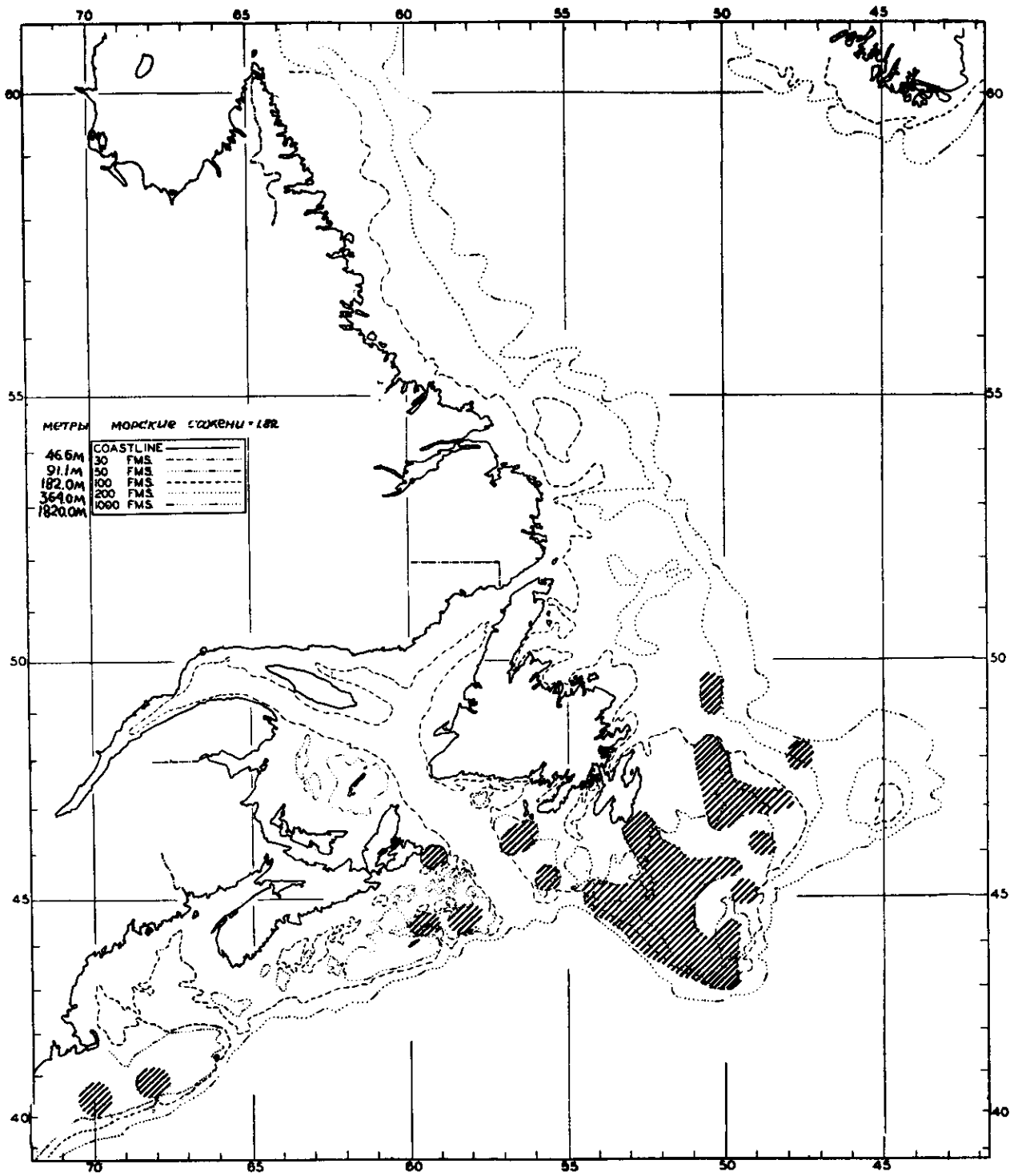


Fig. 7. Spawning grounds for witch flounder.

In the Grand Bank area, judging by the occurrence of early-stage eggs and the distribution of spawning fish (Table 3), the spawning of witch flounder continues up to September. The most intensive spawning evidently occurs in July-August, although an earlier peak in April is also possible. Spawning evidently occurs over the whole area of the bank in shallow water (50-100 m) and on the slopes (500 m and deeper) (Fig. 7). The most

intensive spawning seems to occur on the slopes, as indicated earlier by the accumulations of earlier stage eggs and newly hatched larvae.

On St. Pierre Bank, witch flounder eggs were found over the shallow water zone to 100 m, where the adults probably spawn.

TABLE 3. Monthly distribution (%) of spawning witch flounder in trawl catches in the Labrador and Newfoundland areas, 1960-72.

Area	Mar	Apr	May	Jun	Jul	Aug	Sep	No. of fish
S. Labrador and NE Nfld Shelf	19.0	3.3	40.1	3.8	14.0	—	—	1607
Grand Bank and St. Pierre Bank	18.4	37.7	8.9	16.3	—	6.2	4.3	626

Egg occurrence in the waters of the Nova Scotia Shelf and on Georges Bank at the end of May indicates that spawning starts in these areas in May and probably even earlier. American scientists (Bigelow and Schroeder, 1953), who reported on witch flounder of the Gulf of Maine, indicated that spawning occurs there in late spring and summer. Judging by the occurrence of small larvae, spawning may occur up to the middle of October. The spawning peak is observed in July and August. There are probably no distinct differences in time of witch flounder spawning in the Gulf of Maine, on Georges Bank and in the area off Nova Scotia.

An extensive spawning season is characteristic of witch flounder of the Northwest Atlantic. Significant fluctuation in size of larvae (Table 2), especially in August-September, also attests to that fact. In different years, depending on hydrological conditions, the periods and places of witch flounder spawning may vary slightly.

### Eggs and Larvae Drift

By a comparison of egg and larval distribution diagrams, current charts and spawning ground charts, it is possible to trace the main routes of witch flounder egg and larval drift. The general pattern of the drift of earlier stages in the Northwest Atlantic is similar to that of egg and larval drift of some other commercial species in this area (cod, haddock, American plaice).

From the northern spawning grounds, witch flounder eggs and larvae drift southward to the areas off Newfoundland and the Grand Bank, where hydrological conditions are more favourable for both larvae and juveniles. Taking into account the rather high velocities of the current (0.5-2.0 knots) off Labrador and Newfoundland, the eggs and larvae from the northern spawning ground must drift great distances. In the Grand Bank area, witch flounder eggs and larvae may not drift far from the spawning grounds because of the anti-cyclonic movement of the water over the southern part of the bank and the slow speed of the currents (0.1-0.2 knots). However, in certain seasons small numbers of eggs are carried beyond the boundaries of the bank to areas over oceanic depths.

The pelagic stage of witch flounder is the longest among the species of the family *Pleuronectidae*. According to Bigelow and Schroeder (1953), it may continue for 4-6 months and, according to recent information obtained by Powles and Kohler (1970), possibly up to a year.

Canadian scientists (Powles and Kohler, 1970), who studied the distribution of larvae, juveniles and adult fish near Nova Scotia and in the Gulf of St. Lawrence, indicated their ecological isolation. It was found that juvenile and adult fish in these areas concentrated at quite different depths, namely 180-290 m and 35-430 m respectively. Deep-water distribution of the juveniles, according to these authors, eliminates direct food competition with the juveniles of the more numerous species of cod and American plaice.

## Summary

1. The development of witch flounder from egg to metamorphosis is described.
2. Witch flounder eggs occur in the Northwest Atlantic in a vast area from the northern slopes of the Grand Bank to the southwestern part of Georges Bank.
3. Witch flounder larvae were mainly found in the places of egg distribution, the smaller larvae occurring more frequently above the deeper water than the larger ones.
4. Witch flounder spawning in the Northwest Atlantic is rather wide-spread in time, continuing from March to September. Spawning grounds are located in the areas off southern Labrador (Div. 2J), off eastern Newfoundland (Div. 3L), on the Grand Bank (Div. 3NO), on the Nova Scotia Shelf (Div. 4VWX), and on Georges Bank (Div. 5Z). In the northern regions more intensive spawning takes place, evidently, in March-April, and in the southern regions in July-August.
5. The main direction of witch flounder egg and larval drift from the northern spawning grounds is southward. On the Grand Bank the drift is probably less extensive due to the anti-cyclonic movement of the currents. The pelagic larval stage is extensive and may continue up to a year.

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# Status of the Yellowtail Flounder Fishery in ICNAF Divisions 3L, 3N and 3O

T. K. Pitt<sup>1</sup>

## Abstract

The number of yellowtail 6 years and older for ICNAF Divisions 3L and 3N increased from 14.7 million fish in 1965 to 170.6 million in 1970 and 18.1 million in 1972. Fishing mortality (F) ranged from 1.20 in 1967 to 0.77 in 1970 and 0.88 in 1972 ( $M = 0.30$ ). A long term sustainable yield of 35,000 tons for Div. 3L and 3N and 5,000 for Div. 3O appears to be appropriate if recruitment remains at the present level.

## Introduction

This paper presents the first major assessment of the yellowtail flounder, *Limanda ferruginea*, fishery on the Grand Bank. From a previous analysis of both research and commercial catches (Pitt, 1970) it was apparent that there was a rather rapid increase in abundance of this species on the Grand Bank since the early 1960's. This apparent increase in abundance began on the southern half of the Bank (ICNAF Div. 3N and 3O) and gradually spread to most of the shallow localities (< 91 m).

Significant commercial landings were first reported in 1965 (Table 1) when slightly more than 3,000 tons were reported; however, landings increased rapidly to over 37,000 tons in 1971 and 39,000 tons in 1972. The increase in abundance was tentatively attributed to a very slight upward trend in bottom temperatures and to the drastic decline in haddock abundance (Pitt, 1970).

With the demise of the Grand Bank haddock fishery and a decline in the catch per hour for American plaice (Pitt, 1973) the Canadian fleet in particular have become increasingly dependent on yellowtail flounder. At the 1972 annual meeting of ICNAF a preliminary quota of 50,000 tons was adopted for 1973. The only available data at that time were some estimates of total mortality and indications that the stock was probably expanding (Pitt, 1972).

## Materials and Methods

In the absence of evidence to the contrary, Grand Bank yellowtail were considered as belonging to a single

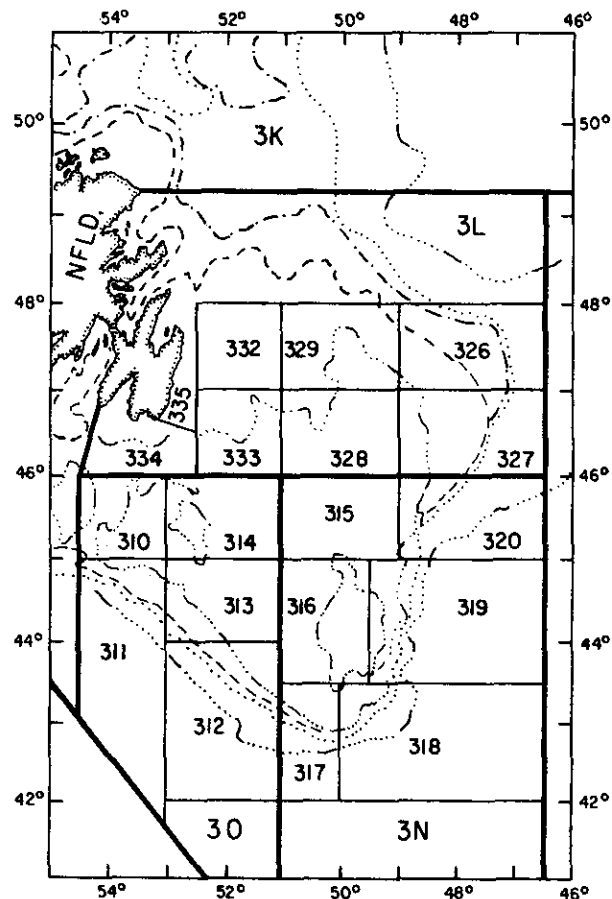


Fig. 1. Map of the Grand Bank showing the statistical units used in calculating catch per unit fishing intensity.

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TABLE 1. Nominal catches of yellowtail flounder in ICNAF Div. 3L, 3N and 3O (metric tons). "Other" landings up to 1970 based on USSR 1970 breakdown of unspecified flounder.

Year	Country	Div. 3L	Div. 3N	Total 3L and 3N	Div. 3O
1965	Canada (M)	115	951	1,066	6
	Canada (N)		2,001	2,001	
	Other		19	19	
	<b>Total</b>	<b>115</b>	<b>2,971</b>	<b>3,086</b>	
1966	Canada (M)	57	1,737	1,794	300
	Canada (N)	5	1,948	1,953	138
	Other		2,035	2,035	
	<b>Total</b>	<b>62</b>	<b>5,720</b>	<b>5,782</b>	<b>438</b>
1967	Canada (M)	118	429	547	81
	Canada (N)	334	1,081	1,415	78
	Other		3,451	3,451	
	<b>Total</b>	<b>452</b>	<b>4,961</b>	<b>5,413</b>	<b>159</b>
1968	Canada (M)	632	149	781	107
	Canada (N)	2,164	1,081	3,245	
	Other	63	5,143	5,206	
	<b>Total</b>	<b>2,859</b>	<b>6,373</b>	<b>9,232</b>	
1969	Canada (M)	3,217	1,048	4,665	273
	Canada (N)	2,033	3,840	5,873	53
	Other	19	1,867	1,886	
	<b>Total</b>	<b>5,269</b>	<b>6,755</b>	<b>12,424</b>	<b>326</b>
1970	Canada (M)	718	2,069	2,787	156
	Canada (N)	6,657	13,003	19,660	183
	Other	16	3,426	3,442	
	<b>Total</b>	<b>7,391</b>	<b>18,498</b>	<b>25,889</b>	<b>339</b>
1971	Canada (M)	874	3,150	4,024	196
	Canada (N)	5,741	13,851	19,592	392
	Other	16	8,172	8,178	4,948
	<b>Total</b>	<b>6,631</b>	<b>25,173</b>	<b>31,794</b>	<b>5,536</b>
1972	Canada (M)	799	1,263	2,062	392
	Canada (N)	7,388	16,552	23,940	545
	Other	1,143	7,976	9,119	3,245
	<b>Total</b>	<b>9,330</b>	<b>25,791</b>	<b>35,121</b>	<b>4,182</b>

stock. A tagging program by the St. John's Biological Station in the autumn of 1972 has not yet yielded sufficient data to draw any conclusions but preliminary information seems to support this.

Although the males usually spawn about 1 year earlier (Pitt, 1970) and grow at a slightly slower rate (Fig. 2) than the females, the differences were not considered to be great enough to warrant treatment of the sexes separately.

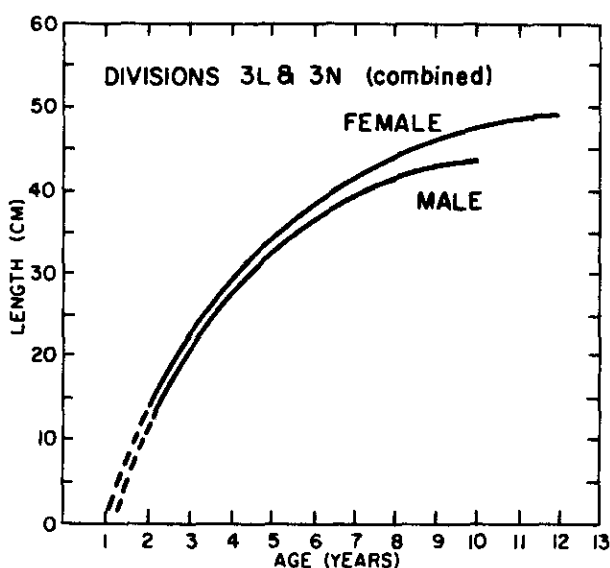


Fig. 2. Growth curves of male and female yellowtail flounder from the Grand Bank (ICNAF Divisions 3L and 3N).

Schumacher (1970) for West Greenland cod, Pinhorn (1971) for ICNAF Div. 2J cod and Pitt (1973) for Grand Bank American plaice utilized modifications of the "virtual population" method by Gulland (1965) and Jones (1961, 1968) to assess fish stocks and the method was used here following the procedure outlined by Schumacher (1970).

The method requires estimates of the total annual number of fish caught at each age, an estimate of natural mortality ( $M$ ) and the exploitation rate at the older age-groups  $E(1-e^{-Z})$ . For the latter an examination of catch curves and a few trial values at the older age-groups suggested an exploitation rate of 0.524.

### Calculation of numbers caught

The numbers caught at each age for Div. 3L and 3N (Table 2) since the fishery began were calculated from the total landings and the age distribution from sampling of the commercial catches of Canada (N) trawlers by the St. John's Biological Station.

The estimation of total yellowtail landings prior to 1970 presented difficulties since the USSR which, besides Canada, caught a major share of the yellowtail on the Grand Bank reported their flatfish as "unspecified flounder". In 1971 the USSR indicated that the breakdown of flatfish in catches prepared for the ICNAF Statistical Bulletin for 1970 was similar to the breakdown for previous years. However, 1970 no yellowtail were reported from ICNAF Div. 3O by the USSR; thus, because of doubt about total landings from this division and also because no samples were available from there, this assessment is actually for Div. 3L and 3N only with appropriate amounts added to arrive at the total allowable catch for the whole Grand Bank.

### Estimates of natural mortality ( $M$ )

Although there was no directed fishing for yellowtail on the Grand Bank prior to 1965, the intensive haddock fishery probably removed substantial quantities from what was then a relatively small population. This produced comparatively high total mortality values ( $Z$ ) (average male and female 0.73) from research catch curves for 1951-52 and 1961 (Fig. 3). Lux (1969) suggested a natural mortality rate of about 20% ( $M = 0.22$ ) for New England yellowtail flounder.

TABLE 2. Number of yellowtail flounder caught, ICNAF Div. 3L and 3N ( $\times 10^3$ ).

Age	Year							
	1965	1966	1967	1968	1969	1970	1971	1972
5	524	3,341	3,097	3,854	2,784	2,537	3,920	3,707
6	1,006	2,711	3,041	7,755	7,254	17,850	27,928	10,096
7	1,201	3,128	1,662	5,670	8,949	18,817	16,176	26,372
8	1,064	922	769	873	2,708	4,221	3,478	12,700
9	766	110	227	30	126	398	1,400	2,490
10	247	116	85		37	67	301	537
11	60		28					113
12	24							

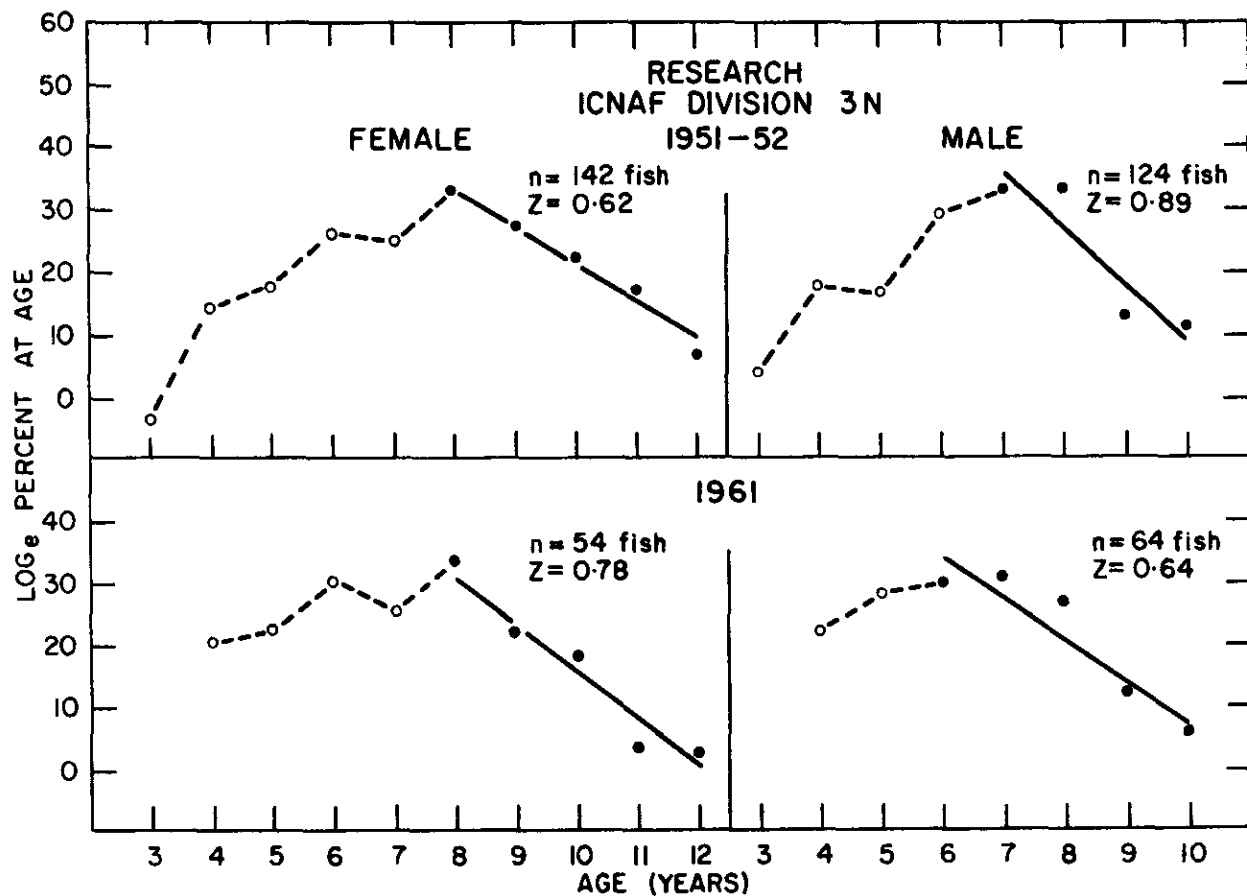


Fig. 3. Research vessel catch curves for 1951-52 and for 1961, ICNAF Division 3N.

Beverton and Holt's (1959) review of the relationship between the life span of fish, natural mortality and growth rate, etc., suggests a value of  $M$  probably higher than 0.22 for yellowtail with a maximum recorded age of 12 years. Dickie and McCracken (1955) for winter flounder which probably has a  $T_{max}$  less than 18 years calculated  $M$  at 0.3 and for American plaice in the Northwest Atlantic with a  $T_{max}$  in excess of 20 years  $M$  has been estimated to range between 0.13 and 0.25 (Powles, 1969; Pitt, 1973). Thus, a value of 0.30 was used in this assessment as an appropriate level of natural mortality.

#### Estimates of fishing effort and intensity

Total annual fishing effort was calculated by dividing total catch of all countries by the catch per hour of Canada (N) Tonnage Class 5 otter trawlers. Fishing intensity was calculated by weighting the effort of the Canada (N) fleet in each statistical unit (Fig. 1) by the

total area fished (in square nautical miles) in each unit and summing across units. The area of the individual statistical units or the proportion 90 m (50 fathoms) or less were used to calculate the total area fished.

#### Calculation of stock size and yield curves

Stock size at the beginning of the year was estimated from the catches and the estimates of  $F$  for the various age groups. Because of the possibility of inaccuracies in estimating the number of 5-year-old fish, the total numbers were summed for fish 6 years and older only. The estimation of 6-year-olds for 1972 was based on recruitment of 135 million 5-year-olds in 1971, which was the average level of 5-year-olds in 1969 and 1970.

Yield curves were calculated using partial recruitment values of  $F$  on the basis of one million recruits entering the fishery at age 4.



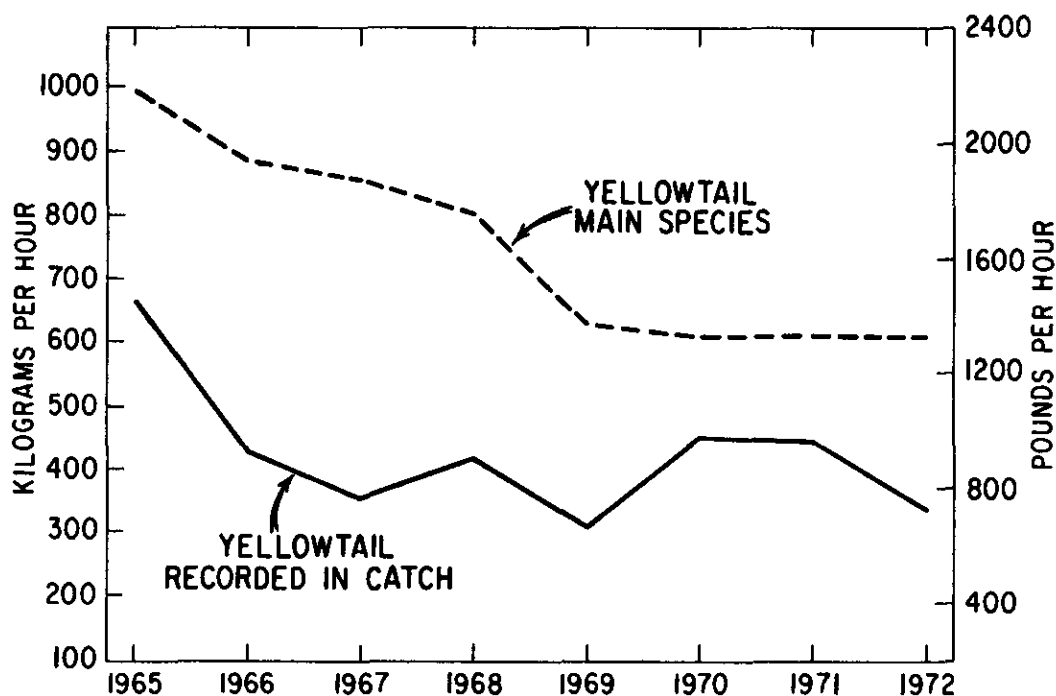


Fig. 4. Catch per hour of yellowtail flounder by Canada (N) stern trawlers. Broken lines, main species and solid lines, some yellowtail recorded in the catch.

## Results

Catch per unit effort for total effort and catch in ICNAF Div. 3L, 3N and 3O for Canada (N) (Fig. 4) indicated an initial decline in 1966 and 1967. However, the catch per hour with yellowtail as the main species suggested a gradual decline from 1965 to 1969 at which point it stabilized at about 600 kg (1,300 lb.) per hour. Total effort for yellowtail increased from 3,000 hr. in 1965 to 43,500 in 1970, and was in excess of 66,000 in 1972.

Catch per unit effort, however, may not be a good index of abundance since it is probable that with the gradual spread of yellowtail to most shallow localities, small catches in the peripheral localities have tended to reduce the overall catch per hour for Div. 3L, 3N and 3O combined. Catch per unit fishing intensity is, therefore, a better index of abundance.

For the three divisions combined there was a general overall upward trend in the catch per unit fishing intensity (Fig. 5). The peak in 1968 was apparently

caused by a few exceptionally high catches in two particular statistical areas (Fig. 1, Areas 314 and 328) during September. After a peak in 1970 a slight decline appears to have occurred in 1971 and 1972. This decline can probably be attributed mainly to Div. 3L. Division 3O normally produces small catches and has shown a gradual increase after declining sharply from a peak in 1968.

The estimates of stock size (Table 3) for Div. 3L and 3N indicated a rapid increase in numbers for fish 6 years and older from 14.7 and 15.7 million fish in 1965 and 1966 to 141.3 million in 1970 at which point the rate of increase was reduced considerably.

Estimates of  $F$  for 1965 to 1970 indicated yellowtail flounder to be fully recruited at age 7 (Table 4). A similar conclusion was derived from survival rates for catch per unit fishing intensity (Table 5 and Fig. 6). Mean estimates of  $F$  from the latter for 1965-71 for fully recruited fish was 1.0 ( $Z = 1.30$  and  $M = 0.30$ ); while, from the "virtual population" method (Table 4), the mean value of  $F$  was 0.98 for 1965-70 and for 1967-70 it

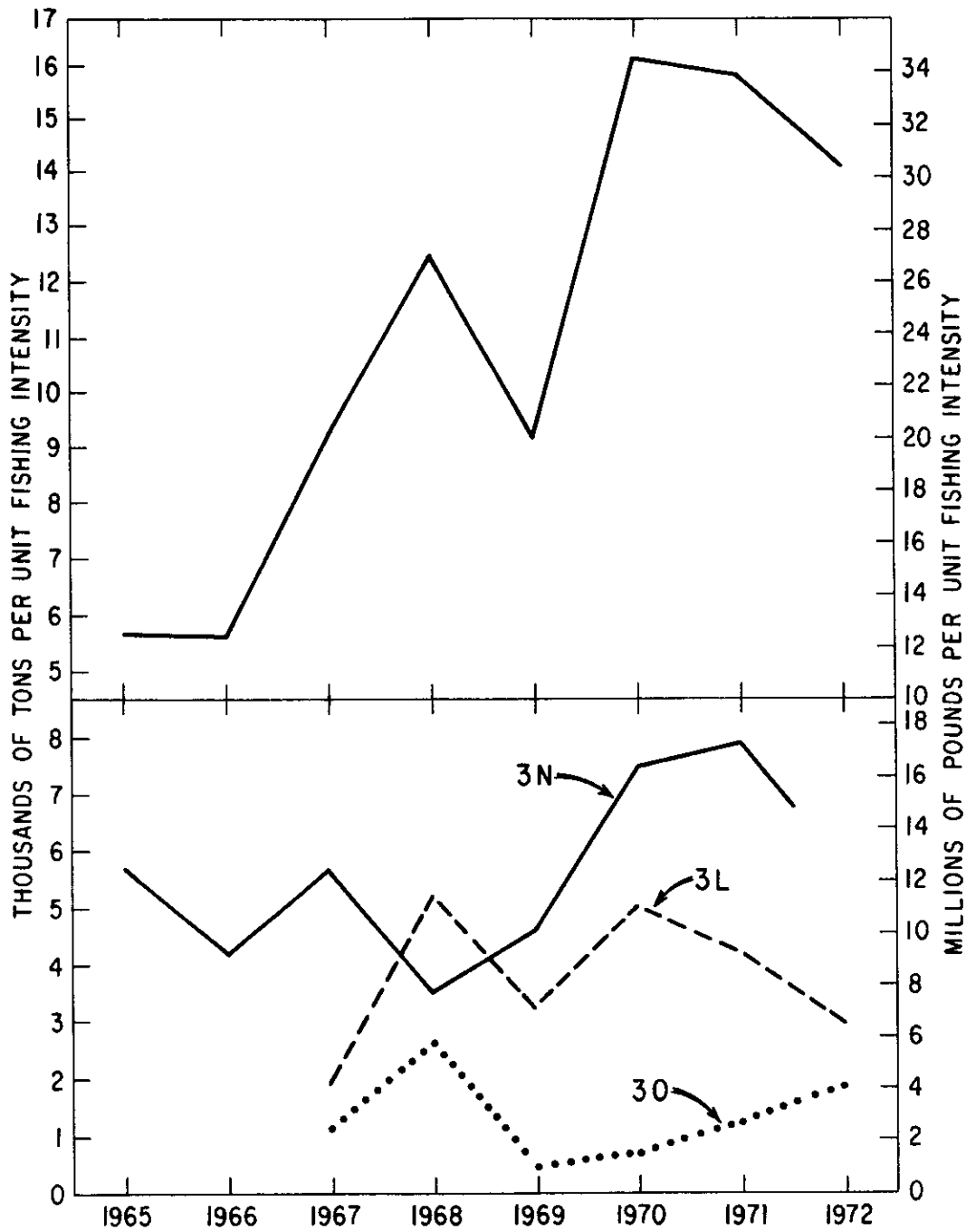


Fig. 5. Catch per unit fishing intensity of yellowtail for ICNAF Divisions 3L, 3N and 30 combined and for the separate Divisions (Canada (N) stern trawlers).

was 0.80. Annual values of F estimated by the virtual population method ranged from 1.20 in 1967 to 0.71 in 1970; however, most of these averages were based on two age-groups only. The average fishing mortality rate

calculated from the estimated stock size at the beginning of 1971 and the catch in 1971 was 0.65 but a similar projection for 1972 gave an annual rate for F of 0.89 for the fully recruited age-groups.

TABLE 3. Estimates of stock size of yellowtail flounder from ICNAF Div. 3L and 3N ( $\times 10^3$ ).

Age	Year							
	1965	1966	1967	1968	1969	1970	1971	1972
5	12,417	31,608	52,940	76,468	130,704	138,363	(135,000)	
6	7,847	8,512	20,922	37,766	54,979	95,765	107,711	96,660 <sup>a</sup>
7	3,545	4,928	3,812	13,122	22,160	35,202	49,259	56,225
8	1,654	1,619	1,026	1,408	4,902	8,792	9,958	22,807
9	1,130	261	399	90	286	1,359	2,948	4,431
10	426	197	90	81	46	118	666	1,011
11	103	109	46	30		25	54	
12	41	27						
6+ years	14,746	15,653	26,295	52,497	82,373	141,261	170,596	181,134

<sup>a</sup>Calculated from the estimated recruitment of 135 million 5-year-olds in 1971.

TABLE 4. Estimates of fishing mortality of yellowtail flounder from ICNAF Div. 3L and 3N.

Age	Year							Mean 1967-70	% from fully recruited age-group
	1965	1966	1967	1968	1969	1970			
5	0.05	0.13	0.07	0.06	0.02	0.02	0.04	5.0	
6	0.16	0.47	0.18	0.26	0.16	0.27	0.22	28.0	
7	0.49	1.26	0.69	0.68	0.62	0.95	0.74	100	
8	1.28	1.02	1.80	1.20	0.98	0.79	1.19	100	
9	1.42					0.41	0.41	100	
Mean F									
Age 7+	1.06	1.14	1.20	0.94	0.80	0.71			

TABLE 5. Survival rates and total mortality (Z) based on catch per unit fishing intensity.

Age	Year						Mean = 1.31
	1965-66	1966-67	1967-68	1968-69	1969-70	1970-71	
5/4	9.952	10.073	8.480	1.105	5.087	9.235	
6/5	2.611	1.556	1.716	1.037	22.227	8.771	
7/6	1.544	1.404	1.358	0.583	2.279	0.756	
8/7	0.385	0.607	0.280	0.255	0.455	0.153	
9/8	0.087	0.503	0.254	0.154	0.133	0.222	
10/9	0.124	0.663			0.345	0.567	
G.M. 8/7 to 10/9	0.161	0.587	0.267	0.198	0.275	0.268	
Z	1.83	0.53	1.32	1.62	1.21	1.32	Mean = 1.31
$\Sigma$ 8-10	0.224	0.587	0.251	0.228	0.376	0.151	
$\Sigma$ 7-9							
Z	1.50	0.53	1.38	1.48	0.98	1.89	Mean = 1.29

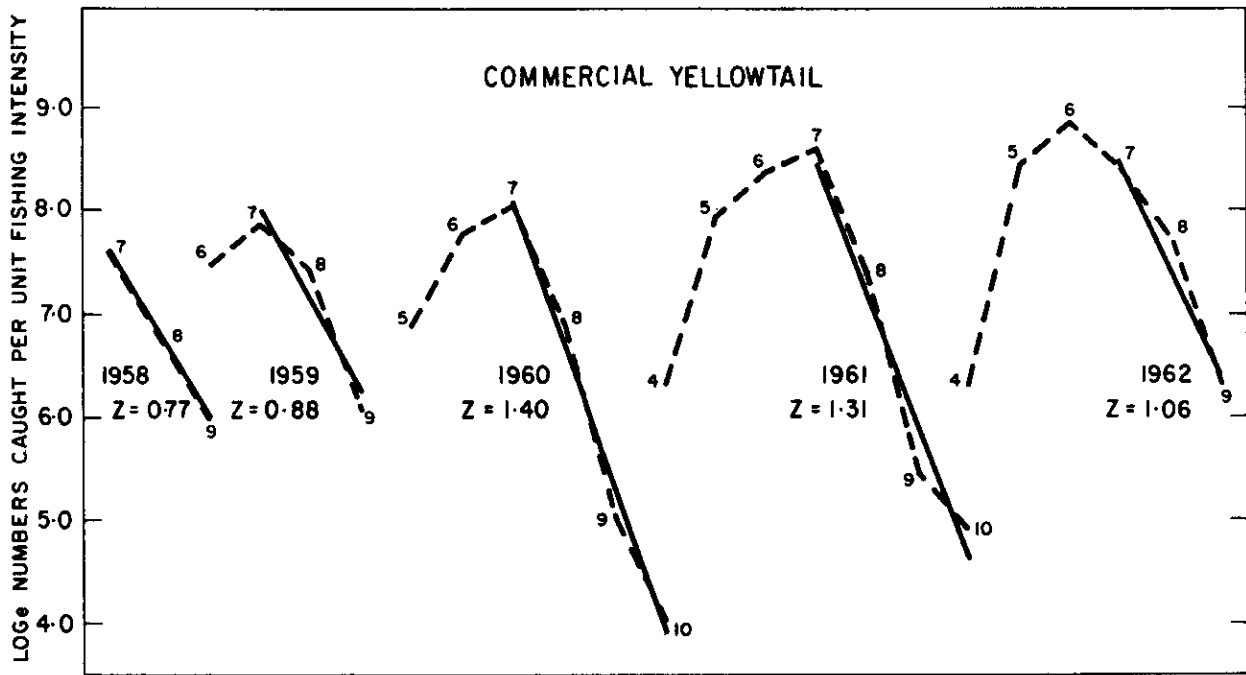


Fig. 6. Catch curves of individual year-classes for commercial yellowtail based on the catch per unit fishing intensity of Canada (N) stern trawlers.

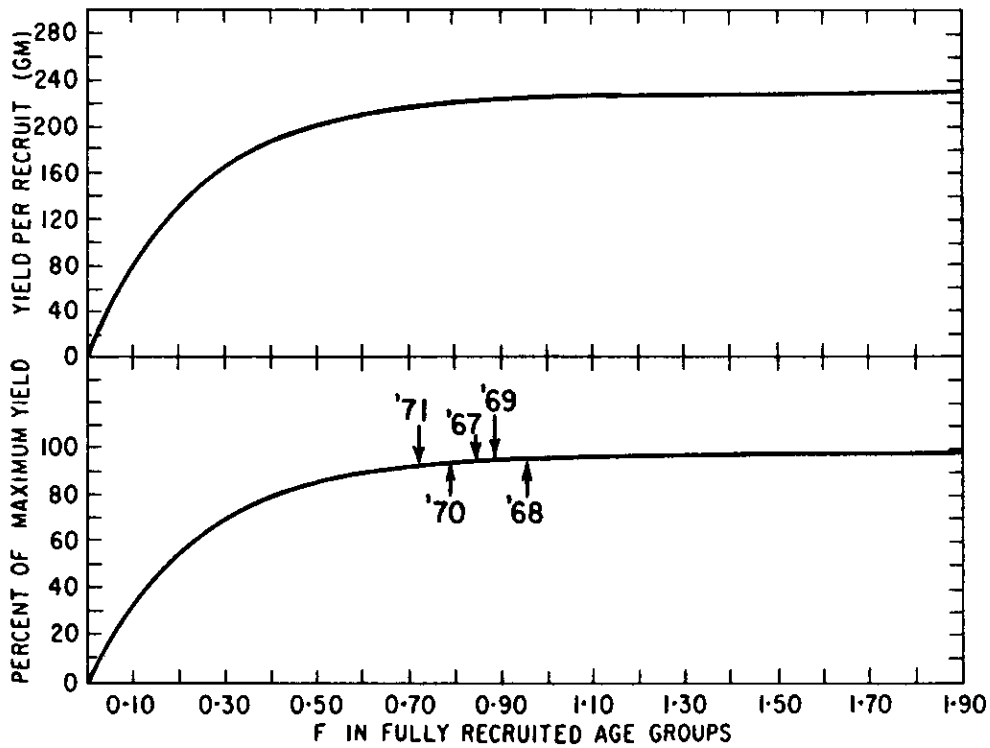


Fig. 7. Yield per recruit and percent of maximum yield for values of F in the fully recruited age groups. Amount at the bottom indicates  $F_{0.1}$ .

TABLE 6. Estimate of probable catches in 1973 and 1974 in ICNAF Div. 3L and 3N based on 1972 nominal catches and total stock estimations projected from ( ) = age, N = stock size at the beginning of the year, F = fishing mortality and C = catch (N and C  $\times 10^{-3}$ ).

	1972	1973	1974
1961	(11)		
N	240		
F	0.77		
C	113		
1962	(10)	(11)	
N	1,011	298	
F	0.92	0.90	
C	537	156	
1963	(9)	(10)	(11)
N	4,431	1,210	364
F	1.00	0.90	0.70
C	2,490	634	164
1964	(8)	(9)	(10)
N	22,807	6,271	1,187
F	0.99	0.90	0.70
C	12,700	3,286	851
1965	(7)	(8)	(9)
N	56,225	19,454	4,468
F	0.76	0.90	0.70
C	26,372	10,193	2,015
1966	(6)	(7)	(8)
N	96,660	62,925	18,940
F	0.13	0.90	0.70
C	10,096	32,972	8,541
1967	(5)	(6)	(7)
N	(135,000)	97,065	56,007
F	0.03	0.25	0.70
C	3,707	18,636	25,259
1968		(5)	(6)
N		(135,000)	95,580
F		0.045	0.20
C		5,143	15,006
1969			(5)
N			(135,000)
F			0.035
C			4,009
Total catch 3L and 3N (tons)	39,303	44,015	34,526

Yield curves (Fig. 7) indicated  $F_{0.1}^a$  to be at 0.68 or at approximately 92% of the maximum yield per recruit. As with American plaice in the same locality (Pitt, 1973), the curves were flat topped without a definite maximum yield per recruit. With an average recruitment of 135 million fish at age 5 (the average of 1969 and 1970 stock size at age 5), an annual yield of 35,000-37,000 tons for Div. 3L and 3N should be produced as a long term sustainable yield. Estimates of probable catches in 1973 and 1974 (Table 6) based on projected stock size and the recorded catch in 1972 show that to take the quota of 45,000 tons for 3L and 3N (5,000 tons additional for 3O) will require a level of fishing of about 0.90 and then fishing near the optimal level at 0.70 in 1974 should produce approximately 35,000 tons in Div. 3L and 3N.

### Discussion

In setting the level of removals for 1974 at 35,000 tons for Div. 3L and 3N (with an additional 5,000 tons estimated for Div. 3O), the assumption was made that yellowtail were not increasing in abundance as in the previous 3 or 4 years and the recruitment of 5-year-olds for 1971-74 was assumed to be at the average rate for 1969 and 1970. The obvious importance of the size of the new year-class entering the fishery is illustrated in Table 6. Thus 5-year-olds recruited in 1972 will account for 45% of the total numbers caught in 1974 as 7-year-old fish. In fact, the quota calculated for 1974 is based on the assumption of 135 million fish recruited.

The probability of a leveling off in the rate of increase seems to be supported by the catch per unit effort and catch per unit fishing intensity of the Canada (N) fleet. The latter declined in 1971 and 1972 from a peak in 1970 (Fig. 5) and the rate of increase in the size of the stock 6 years and older also declined from 1970. The possible increase in abundance of yellowtail in Div. 3O should be noted. Landings from this division by the Canadian fleet were relatively small (Table 1) with catch per hour and catch per unit fishing intensity at a low level but showing a slight increase since 1969.

One of the problems in assessing yellowtail on the Grand Bank is getting a true estimate of the actual numbers caught since, besides countries reporting yellowtail catches, there could be quantities taken as by-catches and either discarded or put to industrial use

and not reported as yellowtail flounder. However, boats involved here would be fishing almost exclusively for cod and may use a type of net that might not catch large quantities of fish associated with the benthic habitat.

### Acknowledgements

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<sup>a</sup>See ICNAF Redbook, Part I, 1972, p. 41.

# Sex Ratio, Age Composition and Mortality of Hooded Seals at Newfoundland

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## Abstract

Material and data have been collected from Norwegian catches of breeding hooded seals off Newfoundland-Labrador from 1964 to 1974. Sex ratios are given for 1,309 pups (51.4% males) and 3,069 adult breeding hooded seals (38.4% males). Age frequencies are presented for a total of 670 male, 1,153 female and 306 unspecified hooded seals sampled from 1964 to 1972. Mortality rates have been calculated and it is concluded that the total annual mortality rates of hooded seals in the Northwest Atlantic are about 0.16 for breeding females older than 6 years and about 0.23 for breeding males older than 10 years.

## Introduction

Information on age and sex composition and mortality of hooded seals, *Cystophora cristata*, has been collected in the Northeast Atlantic since 1954. Data from breeding and moulting hooded seals in the Jan Mayen area and the Denmark Strait were first published by Rasmussen (1957 and 1960). In a later paper, Rasmussen (1962) reviewed data from the Denmark Strait and estimated a total mortality of 22.8% for adult hooded seals (5-15 years) in the years 1957-60. Recent samples (1962-64, 1966-67, 1970, 1972 and 1974 from this area where all adult age-groups of both sexes are fairly well represented in the catches, have suggested a decreasing adult mortality rate from the early 1960's up to 1974 (Øritsland and Benjaminsen, unpublished), a development probably due to the protection of moulting seals in the Denmark Strait since 1960. Sex composition data from pups at Jan Mayen and adults in the Denmark Strait were published by Øritsland (1964). Age and sex compositions of hooded seals from Soviet studies in the Jan Mayen area, 1960-65, were published by Khuzin and Yakovenko (1963), Khuzin and Potelov (1963), Potelov (1964), Khuzin (1967) and Beloborodov and Potelov (1967). Data for 1966 were reported by Popov (MS 1966).

Until recent years very few age data had been recorded from the Northwest Atlantic. Samples were collected from Canadian catches at Newfoundland in 1953 and 1966. Age frequencies have not been reported, but mortality estimates from these samples were

compared with estimates from Jan Mayen samples by Sergeant (MS 1967), who concluded that different mortality rates suggest distinct stocks of hooded seals in the two areas. Revised mortality estimates from these samples and one Norwegian sample collected at Newfoundland in 1971 were presented by Sergeant (MS 1972) who found that mortality of females at Newfoundland had increased from 1966 to 1971.

In Greenland, age samples have been collected each year from 1970 to 1973. Age-group frequencies for 1970, 1971 and a small sample collected in 1953 were reported by Kapel (MS 1972) who gave mortality estimates for a 1971 sample from South Greenland. Age-groups frequencies and mortality estimates for the 1972 and 1973 samples from South Greenland have also been reported (Kapel, MS 1974).

The emphasis of Norwegian research on seals at Newfoundland was changed somewhat from harp seals to hooded seals in 1971. Age samples collected from Norwegian catches of hooded seals off Newfoundland-Labrador in 1971 and 1972 have been analyzed, and the results are presented and discussed in this paper together with data from occasional Norwegian sampling in the area in earlier years and information on sex ratios collected through the years from 1964 to 1974.

## Material and Methods

All age samples collected from Norwegian catches of hooded seals off Newfoundland from 1964 to 1972

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and included in this report are listed in Table 1. One sample (1967b) was collected for the specific purpose of studying the age composition of breeding females. In 1968, when the Institute of Marine Research did no research at Newfoundland, a small sample without information on sex was obtained from a sealing vessel. The rest of the material collected from 1964 to 1970 was from animals dissected for general biological studies and sampled without any selection as to age or sex.

As many animals as possible were sampled for age and sex analysis in 1971 and 1972. Samples 1971a and 1972a (Table 1), collected by Institute personnel, include seals dissected for studies of general biology and reproductive performance of females. Additional age samples were collected by sealing inspectors assisted by sealers (sample 1971b and sample 1972c) and by a sealing crew which had been instructed in previous seasons (sample 1972b).

TABLE 1. Age samples collected from catches of hooded seals off Newfoundland-Labrador 1964-72.

Year	Dates	Ship	Number of specimens			
			Male	Female	Not sexed	Total
1964	21-31 March	<i>Polarhav</i>	21	28		49
1965	24 March-2 April	<i>Polarhav</i>	2	3		5
1967a	24 March	<i>Polarhav</i>	6	15		21
1967b	28-29 March	<i>Polarhav</i>		122		122
1967c <sup>1</sup>	26 March-13 April	<i>Theron</i>	15	12		27
1968	?	<i>Polarstar</i>			29	29
1969	23 March-3 April	<i>Norvarg</i>	7	15		22
1970	29 March	<i>Polarbjørn</i>	1	7		8
1971a	20 March-6 April	<i>Norvarg</i>	212	368		580
1971b	20-27 March	<i>Kvitungen</i>			278	278
1972a	17 March-2 April	<i>Polaris</i>	115	133		248
1972b	20-24 March	<i>Norvarg</i>	88	166		254
1972c	27 March-4 April	<i>Polarstar</i>	203	284		487
1964-72	Total		670	1,153	307	2,130

<sup>1</sup>Supplied by Arctic Biological Station, Fisheries and Marine Service, Dept. of the Environment, Canada.

Age samples, containing 362 and 923 hooded seals, were collected at Newfoundland in 1973 and 1974, but these have not been processed yet and are not reported here. However, counts by sex of pups and adults in 1973 and 1974 are included in the data on sex composition.

Lower jaws were cut off near the middle of the jawbone with a cable-cutter or an axe. They were marked individually or in batches for each sex and day of capture and stored in salt for shipment. At the laboratory jaws were boiled in water without any additive for about 1 hr to allow the canine teeth to be easily extracted. Transverse sections, about 0.2 mm thick, were cut from the middle of one tooth for each animal, using a modification of the double-bladed cutting machines described by Khuzin (1972).

Cementum growth layers (Laws, 1953; Rasmussen, 1960; Khuzin, 1967) were counted in transmitted light, using a binocular dissecting microscope or a microprojector. For most of the material, age determinations were made independently by two persons, who later re-examined together the specimens with differing age determinations. However, age determinations for the 1972 samples were made by one person, and all doubtful determinations, together with a random sample of the others, were checked by a second person.

Mortality estimates were made by two methods, using both the regressions of catch curves (Ricker, 1958; Chapman and Robson, 1960) and the mean ages of fully recruited age-groups (Chapman and Robson, 1960; Robson and Chapman, 1961).



## Sex Composition

Sex ratios of pup and adult hooded seals in Norwegian catches at Newfoundland are shown in Table 2. Pup sex ratios in the rather small samples vary around 1:1, and the totals for 1964-74 give a slightly higher proportion of males than females, as found in the harp seal at Newfoundland (Øritsland, 1971). This postnatal sex ratio differs a little from the ratio of 49.2% male in 1,125 hooded seal pups counted at Jan Mayen in 1958-60 (Øritsland, 1964), but the difference is not significant at the 5% level (Student's  $t = 1.1$ ).

TABLE 2. Sex ratios of pup and adult hooded seals in Norwegian catches off Newfoundland-Labrador, 1964-74.

Year	Male		Female		Total
	No.	%	No.	%	
<b>Pups</b>					
1964	11	—	8	—	19
1967	195	48.6	206	51.4	401
1969-72	68	53.5	59	46.5	127
1973	261	51.8	243	48.2	504
1974	138	53.5	120	46.5	258
Total	673	51.4	636	48.6	1,309
<b>Adults</b>					
1964-70	52	39.4	80	60.6	132
1971	212	36.6	368	63.4	580
1972	406	41.1	583	58.9	989
1973	163	45.0	199	55.0	362
1974	347	37.6	576	62.4	923
Total	1,180	39.5	1,806	60.5	2,986

The adult sex ratio with 60.5% females for the 1964-74 samples off Newfoundland differs from the ratio with 53.6% females found in a Norwegian sample of 237 hooded seals at Newfoundland in 1951 (Rasmussen, 1952). This difference is significant at the 5% level ( $t = 2.1$ ). The adult sex composition in Table 2 also differs from the composition with 72.2% females found in a Canadian sample of 209 hoods from Newfoundland in 1966 (Sergeant, MS 1967). The difference here is significant at the 1% level ( $t = 3.4$ ). However, in a total sample of 626 hooded seals collected in South (southwestern) Greenland from 1970 to 1973 (Kapel, MS 1972 and MS 1974) only 33.7% are females. Even if the females may be underrepresented because they avoid the hunters (Kapel, MS 1974), this

indicates that males are more numerous than females in the Northwest Atlantic stock. The South Greenland sex ratio therefore confirms the adult Newfoundland ratios cited above which all show that more females than males are taken during the breeding season.

All recorded adult sex ratios from Newfoundland differ from the ratios in samples of breeding seals in the Greenland Sea. In a total of nearly 3,000 seals counted in the Jan Mayen area by Norwegian workers in 1954 and 1958 (Rasmussen, 1960) and by Soviet investigators in 1962, 1963, 1964 and 1966 (Potelov, 1964; Popov, MS 1966; Khuzin, 1967), no more than 47.7% were females. This value differs from the 60.5% females at Newfoundland at the 1% level of significance ( $t = 9.9$ ). Finally the Newfoundland ratio may be compared with the sex composition of 598 moulting seals with 53.2% females counted in the Denmark Strait in 1958-60 (Øritsland, 1964).

## Age Composition

The small male samples collected from 1964 to 1970 add up to only 52 animals, so they have been combined in column 1 of Table 3. The 1971 *Norvarg* sample and the combined 1972 samples are both large enough to be given separately in columns 2 and 3. However, knowing that the 1971 *Norvarg* sample and the 1972 *Polaris* sample (1971a and 1972a, Table 1) were collected at the edges of the areas where breeding hooded seals were found, these samples were compared with the combined *Norvarg* and *Polarstar* male samples of 1972 (1972b and 1972c, Table 1), which were collected from catches in the middle of the breeding area. As shown in Fig. 1, the three graphs follow the same general pattern, although they do suggest that the newly recruited males in age-groups 4 to 8 are relatively more numerous at the edges than in the middle of the breeding area.

Age-group frequencies of females are shown in Fig. 2. The graphs for the combined female 1967 samples (1967a+b+c, Table 1; column 6, Table 3) and the combined *Norvarg* and *Polarstar* female samples of 1972 (1972b+c, Table 1; column 9 of Table 3) follow the same pattern, even if primiparous 4-year-olds are more numerous in 1972 than in 1967. By comparison the 1971 *Norvarg* sample (1971a, Table 1; column 7, Table 3), and the 1972 *Polaris* sample (1972a, Table 1; column 8, Table 3) both have a surplus of newly recruited young females (age-groups 6 and 7 in 1971 and age-group 4 in 1972). This over-representation of the younger animals, which is also reflected in the low mean ages found in the two samples (8.4 and 7.3 years respectively), strongly suggests some segregation between age-groups of breeding female hooded seals. It seems clear from these

TABLE 3. Age-group frequencies (numbers) of hooded seals taken off Newfoundland-Labrador, 1964-72.

Age-group	Male				Female					Not sexed		
	1964 -70	1971a	1972	1964 -72	1964 -70 <sup>1</sup>	1967	1971a	1972a	1972 b+c	1964 -72	1968	1971b
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
2	—	—	—	—	—	—	—	—	—	—	—	—
3	—	—	1	1	—	—	5	1	2	8	—	1
4	—	1	5	6	3	14	48	35	71	171	3	21
5	1	6	4	11	4	20	34	17	62	137	3	23
6	5	15	5	25	5	17	61	17	36	136	1	35
7	4	20	29	53	4	8	57	13	39	121	3	32
8	1	29	42	72	6	12	33	16	33	100	2	34
9	2	24	49	75	1	11	30	6	41	89	2	27
10	5	18	58	81	6	9	21	6	28	70	3	17
11	4	31	45	80	3	8	19	3	24	57	—	16
12	3	9	47	59	3	6	12	7	11	39	2	16
13	3	10	26	39	2	9	10	3	13	37	—	8
14	3	13	24	40	2	7	9	1	13	32	1	16
15	2	13	15	30	3	3	5	2	10	23	2	7
16	3	10	15	28	3	5	3	2	10	23	—	5
17	2	4	8	14	—	3	2	1	9	15	1	5
18	2	1	6	9	1	3	—	—	9	13	1	2
19	2	1	6	9	1	1	4	1	2	9	—	1
20	—	2	6	8	1	1	3	1	8	14	1	—
21	—	1	1	2	1	3	—	—	7	11	1	2
22	—	—	5	5	2	1	2	1	4	10	1	1
23	1	—	2	3	1	1	1	—	3	6	—	3
24	3	1	—	4	—	3	3	—	2	8	1	—
25	2	—	2	4	—	1	1	—	—	2	—	1
26	—	1	1	2	1	1	1	—	4	7	—	2
27+	4	2	4	10	—	2	4	—	9	15	1	3
Total	52	212	406	670	53	149	368	133	450	1153	29	278
Max. age	31	29	34	34	26	35+	34	22	33	35+	31	36
Mean age	14.4	10.8	11.5	11.5	11.2	10.3	8.4	7.3	9.6	9.1	11.7	9.6

<sup>1</sup>1967 not included.

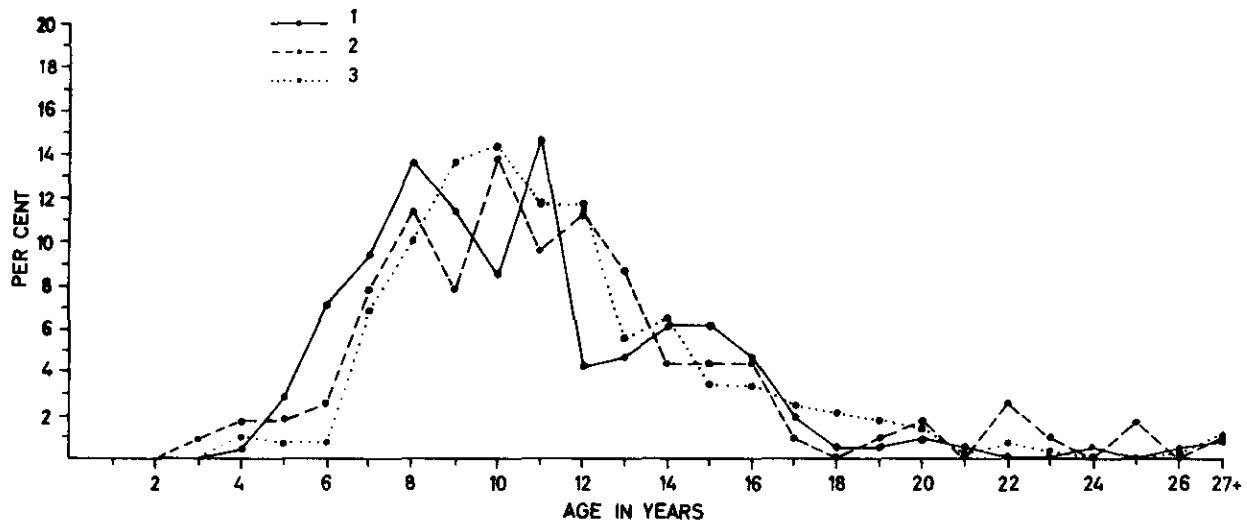


Fig. 1. Age-group frequencies of male hooded seals collected off Newfoundland-Labrador in 1971 and 1972. (1 — 1971a; 2 — 1972a; 3 — 1972b+c represent samples listed in Table 1.)

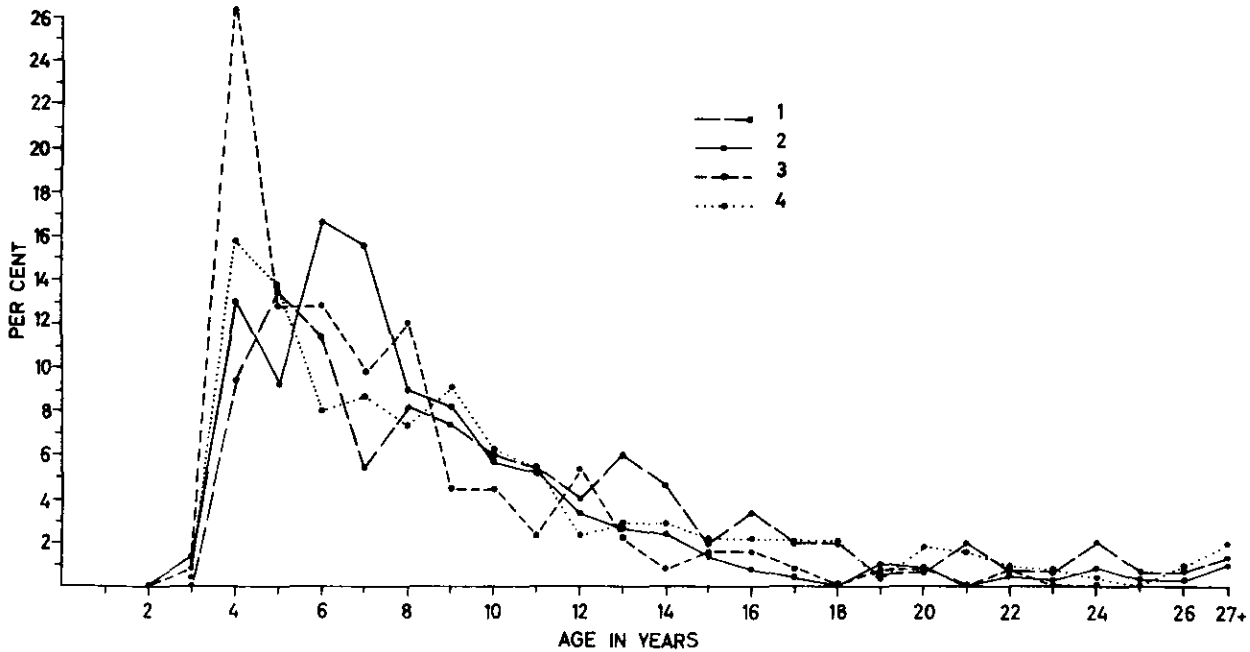


Fig. 2. Age-group frequencies of female hooded seals collected off Newfoundland-Labrador in 1967, 1971 and 1972. (1 — 1967a+b+c; 2 — 1971a; 3 — 1972a; 4 — 1972b+c; represent samples listed in Table 1.)

age samples that the newly recruited and perhaps primiparous females do not mix completely with the older multiparous seals but remain at the fringes of the breeding areas. The segregation seems to be more pronounced in females than in males, perhaps because most females bear young in their first year after sexual maturity, whereas males do not reach breeding status

until they are physically able to compete with their elders.

The combined male age samples and the combined female age samples (columns 4 and 10 of Table 3) are compared in Fig. 3. The difference between sexes in age of recruitment to the breeding stock is quite evident.

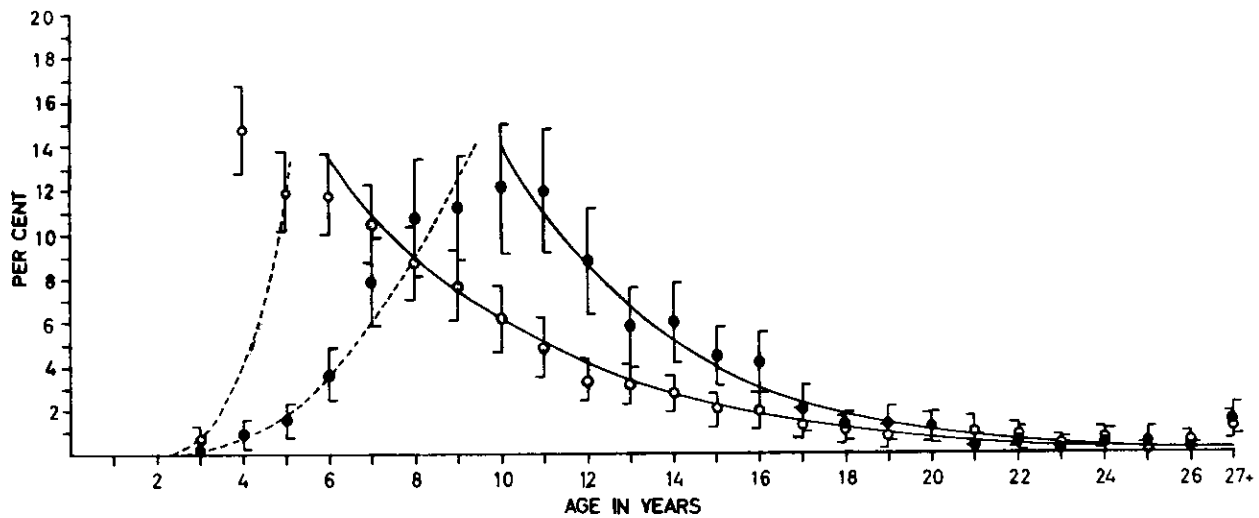


Fig. 3. Age-group frequencies of total male and total female hooded seals sampled off Newfoundland-Labrador in 1964-72. O = females, • = males and vertical lines indicate 95% confidence intervals. The solid curves represent the calculated logarithmic regressions.

TABLE 4. Estimates of total annual mortality (A in per cent) of hooded seals from age samples collected off Newfoundland-Labrador, 1964-72. Mortalities with 95% confidence intervals (B) have been calculated both from the regression of catch curves and from the mean ages of the fully recruited age-groups.

Sample	Number of animals	From catch curve				From mean age			
		A	B	Age-groups	No.	A	B	Age-groups	No.
<b>Male</b>									
1971	212	10.6	±14.3	10-16	104	23.0	±3.7	10-29	117
1972	406	22.7	± 2.9	10-20	256	22.8	±2.4	10-34	271
1964-72	670	22.6	± 2.9	10-20	397	21.2	±1.8	10-34	427
<b>Female</b>									
1967	149	6.7	± 7.3	6-14	87	14.9	±2.6	6-35	115
1964-70	202	9.4	± 3.7	6-16	133	14.0	±2.0	6-35	161
1971	368	23.1	± 2.5	6-15	257	21.3	±2.2	6-34	281
1972a	133	24.8	±24.8	6-10	58	23.0	±4.6	6-22	80
1972b+c	450	13.7	± 3.1	6-18	276	14.9	±1.6	6-33	317
1972	583	15.6	± 1.9	6-18	353	15.9	±1.5	6-33	395
1964-72	1134	15.7	± 1.3	6-24	804	17.0	±1.1	6-35	837

Females may be fully recruited at an age of about 6 years whereas males are not fully represented among the breeding seals until they are about 10 years old. It also appears that, among the fully recruited age-groups of breeding seals, males have an appreciably higher mortality rate than females.

Age-group frequencies in the unspecified samples (1968 and 1971b, Table 1) are given in columns 11 and 12 of Table 3.

### Mortality Estimates

Two sets of total annual mortalities (A in per cent) of adult seals, calculated for most of the age-group frequencies in Table 3, are listed in Table 4. The age-group frequencies indicate full recruitment to the catchable stock of breeding seals at 10 years for males (total 1964-72 samples) and at age 4 (1972 samples and total 1964-72 samples), age 5 (1967 sample) or age 6 (1971 sample) for females. Soviet investigations in the

Greenland Sea indicate that male hooded seals attain sexual maturity at 4-6 years of age and that they are all mature at 7 years and older (Popov, 1960). However, observations on breeding seals suggest that males are not successful in defending a position as head of a family until they have grown bigger and older than the 7-year-old adolescents. For females, Norwegian data from Newfoundland show that a few seals produce their first pup at 3 years, that the age of 50% natality is about 3.8 years, and that about 70% and 80+% produce pups at 5 and 6 years respectively (Øritsland, 1975). On the basis of this information, the youngest age-groups to be included in the mortality estimates were selected as 10 years for males and 6 years for females. In accordance with Chapman and Robson (1960), the old age-group represented by fewer than five animals in the samples were omitted from the catch curve regression estimates. The age-groups included and the number of animals in these age-groups are shown for each estimate in Table 4. The 95% confidence intervals for the catch curve estimates (Goldstein, 1964) are also given.

As indicated by some very wide confidence intervals, the usefulness of the catch curve estimates is limited for the smaller samples. In order to make better use of these samples, mortalities were also calculated from the mean age of all fully recruited age-groups, with 95% confidence intervals calculated according to Robson and Chapman (1961) (Table 4). Differences in mortality between the catch curve and mean age estimates are less than 2% for all samples which contain more than a total of 250 specimens.

The age-group frequencies for males in 1971 and 1972 did suggest some segregation between the old and the younger animals. However, this apparently does not change the slope of the catch curve for the fully recruited age-groups, and 23% is considered a fairly good estimate of total annual mortality of male hooded seals which have obtained breeding status or reached reproductive maturity at Newfoundland.

The segregation between old and young breeders (probably between multiparous and primiparous seals) is far more pronounced for females than for males, and, consequently, sampling error is more likely to occur for females. The 1971 *Norvarg* and the 1972 *Polaris* samples (columns 7 and 8, Table 3), which were collected at the edges of the breeding areas, give mortality estimates as high as those for males, and are not considered representative for the stock of breeding females. The 1972 *Norvarg* and *Polarstar* samples (Table 3, column 9) with a catch curve mortality estimate of 13.7% may, on the other hand, be somewhat biased towards the older animals. It is, therefore, considered that the catch curve estimate of 16% from the combined 1964-72 samples is the best estimate of total

annual mortality of adult breeding females at Newfoundland.

Hewer (1964) found similar differences between male and female mortality rates in the polygynous grey seal, *Halichoerus grypus*, and he suggested that the higher total mortality for breeding males could be explained by the stress and strain involved in holding breeding territories over periods of several weeks. The strain on male hooded seals in defending their claims to single females through the short lactation period of 8-12 days can hardly be so severe as to explain the differences between adult male and female mortalities at Newfoundland. However, challenging males, which compete to replace the established heads of families, gather around the family groups and haul out at the edges of icefloes where the families have settled. When shot during the hunt, these challengers frequently slip into the sea and are lost. Also, the established males tend to move towards the edge of the floe when disturbed and are more frequently lost than the females which remain to defend their pups through lactation. Whether dead or wounded, the males slipping into the sea add up to an appreciable number which is not recorded in the catch statistics. The difference between male and female total mortality rates might be accounted for by this hidden hunting mortality of males and the fact that the breeding stock contains fewer and older age-groups of males than of females.

It should be mentioned that Sergeant (MS 1972) found no significant difference between male and female mortalities in his Newfoundland samples of 1953 and 1966. However, his calculations included males down to an age of 5 years, which according to our data is too low. Possibly for the same reason he also found a male mortality rate as low as 0.160 for the (nearly complete) Norwegian sample from 1971, whereas our estimate based on age 10 years and older males in this sample is 0.230.

Kapel (MS 1974) found total annual mortalities ranging from 10.8 to 18.2% for males and from 13.0 to 17.5% for females in his samples from South Greenland collected in 1971, 1972 and 1973. In order to make his data directly comparable to ours, we have calculated the annual mortalities for each sex from his total age frequencies (Table 5). The mean age estimates are very similar (about 19%), suggesting a better mixing of sex and age-groups and in particular a better representation of the younger age-groups of males at South Greenland than at Newfoundland.

The basic assumptions made for estimates of mortality are listed by Ricker (1958) and Chapman and Robson (1960). Having remarked upon the danger of selective sampling of females caused by a possible segregation between old and young, we can only

TABLE 5. Mortality estimates (A in per cent) of hooded seals from age samples collected in South Greenland 1971-73 (Kapel, MS 1974). Mortalities with 95% confidence intervals (B) have been calculated both from the regression of catch curves and from the mean ages of fully recruited age-groups.

Sex	Number of animals	From catch curves				From mean ages			
		A	B	Age-groups	No.	A	B	Age-groups	No.
Male	380	15.3	+3.9	4-16	269	18.9	+2.0	4-23	280
Female	192	17.0	+3.6	4-12	115	19.0	+2.9	4-21	136

presume that the larger samples are nearly random. We are satisfied that no change with time has yet been demonstrated in the mortality of hooded seals of either sex. In spite of the variation between age-groups found in individual samples, the close fit of the observed combined frequencies for each sex to the calculated regression lines (Fig. 3) also suggests that mortality does not change appreciably with increasing age after the age of recruitment.

However, we are less confident that recruitment to the breeding stock at Newfoundland has not changed over the past decade. The catch statistics show increasing catches per ship since the early 1960's, even if allowance is made for the increasing efficiency of the ships. The recent recovery at Angmagssalik, East Greenland (Norwegian tag No. B464) of a marked seal from Newfoundland, has strengthened the theory of a connection between the breeders at Newfoundland and the moulting animals in the Denmark Strait where hooded seals have been under nearly complete protection since 1960. Norwegian catches in the Denmark Strait averaged nearly 16,000 hooded seals per year from 1951 to 1960, and the protection of these seals since 1960 may have contributed to an increase of the breeding stock at Newfoundland. Also the rediscovered breeding herd in the Davis Strait may have recruited the Newfoundland stock (Sergeant, 1974).

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# Biological Characteristics of Southwest Newfoundland Herring, 1965-71

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## Abstract

The Southwest Newfoundland herring fishery during 1965-71 exploited overwintering schools of nonfeeding spring- and autumn-type spawners, with the latter being generally more than twice as abundant as spring spawners. The average size and age of both spawning groups gradually increased during this period; the fishery was based largely on two dominant year-classes, the 1958 year-class of autumn spawners and the 1959 year-class of spring spawners. Recruitment has been poor in recent years.

Spring and autumn spawners exhibit growth differences, autumn spawners having slightly higher length-at-age values. Growth rate of both types decreases rapidly after they attain sexual maturity at ages 4 and 5. Overwintering mature spring spawners are heavier than autumn spawners of the same length by an amount approximately equal to the difference between the weight of gonads of spring and autumn spawners. During December to April spring spawners have a consistently higher fat content than autumn spawners. The average fat content of both spawning groups increased during 1966-71, probably as a result of more favourable feeding conditions in recent years due to reduced competition for food.

## Introduction

Since its inception during the winter of 1965 the Newfoundland purse seine fishery for herring has been primarily concentrated along Southwest Newfoundland in areas J1 and J2 (Fig. 1) with lesser quantities being caught in Fortune, Placentia and St. Mary's bays and along western Newfoundland (Hodder, 1971). In Southwest Newfoundland coastal waters the seasonal catches increased from less than 5,000 tons in 1964-65 to nearly 140,000 tons in 1968-69 and 1969-70, accompanied by a rapid increase in the seiner fleet to more than 50 vessels during the 1969-70 and 1970-71 fishing seasons (July-June). Recently there has been a substantial decrease in Southwest Newfoundland herring catches to 103,000 tons in 1970-71 and less than 40,000 tons in 1971-72 (Winters and Parsons, MS, 1972). Information on the fishery and distribution of catches is given by Hodder (1969, 1970, 1971).

The herring concentrations which appear in Southwest Newfoundland fjords in late November — early December have recently been shown by meristic studies (Hodder and Parsons, 1971a, b; Parsons, 1973) and tagging recaptures (Winters, 1970; MS 1971a, b) to migrate there from the southwestern Gulf of St. Lawrence where a substantial fishery occurs during June to September. The eastward migration apparently com-

mences in October and, for a brief period in November just prior to the start of the Southwest Newfoundland fishery, the herring schools are exploited as they move eastward past the Magdalen Islands. In late April, as the westward migration of herring into the Gulf of St. Lawrence is in progress, a brief fishery occurs in the area between St. Paul Island and the Magdalen Islands.

This paper presents data on the size and year-class compositions, growth and selected biological characteristics of herring from the Southwest Newfoundland area during the recent period of increased exploitation (1965-71) and analyzes these in relation to recent changes in the fishery.

## Materials and Methods

Random samples of 50 fish each were obtained from the catches of seiners as they were being discharged at the processing plants. Information on the time and place of capture was obtained from logbook records or from port interviews with officers of the fishing vessels. Emphasis was placed on sampling the southwest Newfoundland fishery but catches from other areas were sampled when opportunities arose. The sampling program was designed to obtain as broad a coverage of the fleet as possible during each fishing season. In

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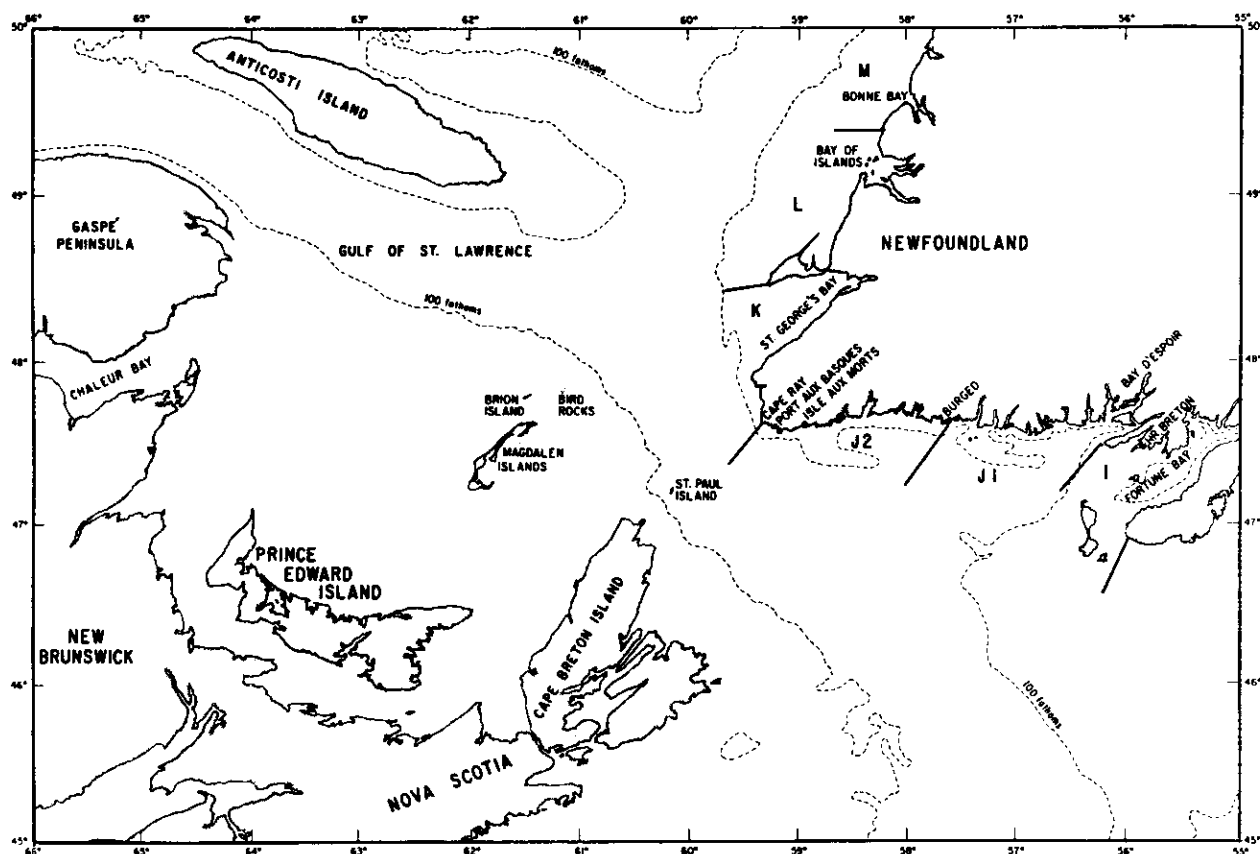


Fig. 1. Map of Gulf of St. Lawrence and Newfoundland showing the location of place names and statistical areas mentioned in the text.

TABLE 1. Numbers of herring specimens sampled (A) for age and growth studies and (B) for fat and moisture analyses, from Southwest Newfoundland and the southern Gulf of St. Lawrence during the 1965-66 to 1970-71 seasons.

Area	Month	1965-66	1966-67	1967-68	1968-69	1969-70	1970-71
A. Southwest Newfoundland	Nov	—	250	500	250	250	250
	Dec	300	500	1000	1000	1000	1000
	Jan	400	500	1000	1000	1000	1000
	Feb	150	500	1000	1000	1000	1000
	Mar	—	500	1000	1000	1000	1000
	Apr	—	500	500	—	550	450
	May	—	—	—	—	—	300
South Gulf of St. Lawrence	Nov	—	—	—	—	500	—
	Apr	—	—	—	—	500	250
B. Southwest Newfoundland	Dec	—	10	—	—	—	48
	Jan	32	—	—	40	—	60
	Feb	30	—	—	60	72	60
	Mar	—	—	—	42	60	72
	Apr	—	—	—	—	40	—

addition to the samples collected for age and growth studies, special collections of herring for fat and water analyses were begun in 1966 and continued during 1969-71 (Table 1). Details of sample collection and processing are given by Hodder *et al.* (MS, 1972; MS, 1973).

Some of the samples were examined in the fresh condition immediately after capture but many were examined after being kept in frozen storage for several weeks. Routine examination for each specimen involved the recording of total length, whole weight, gonad weight, maturity condition of gonads, estimation of the degree of stomach fullness, and the removal of otoliths for subsequent age determination. 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). In tables and figures where length measurements are given in cm, the cm-interval is given such that 30 cm = 300 to 309 mm. Whole weights of fish and weights of gonads 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 numerical scale of gonadal development stages adopted by ICNAF (ICNAF, 1964). The absence of stages V to VII in the samples facilitated the classification of the adult specimens as spring- or autumn-type spawners; those classed as stages III and IV (mostly IV) were designated as spring spawners and stage VIII as autumn spawners. Immature herring were generally scarce in the samples but those present were assigned as spring- or autumn-type on the basis of otolith characteristics. The necessity of treating autumn- and spring-spawning types separately was demonstrated by Parsons and Hodder (1971) and Parsons (1972) who showed that they differed significantly in mean numbers of fin rays and gill rakers and suggested that these spawning components constitute distinct breeding populations.

Feeding intensity was estimated by the degree of fullness of the stomachs based on the following scale: 0 = empty, 1 =  $\frac{1}{4}$  full, 2 =  $\frac{1}{2}$  full, 3 =  $\frac{3}{4}$  full, 4 = full.

Age determinations were made from whole otoliths premounted in small circular depressions of otolith trays of black plexiglass according to the technique developed by Watson (1965). The otoliths were immersed in ethyl alcohol and viewed under reflected light. Age estimates were initially made independently by two experienced

readers with about 60-80% agreement on a sample-by-sample basis. Disagreements were resolved either mutually after further checking or by majority decision after the disputed otoliths were examined by a third reader.

The age was recorded as the number of completed summer (opaque) growth zones on the otolith. A fish is considered to be age 1 following completion of the first summer's growth. Ages were recorded individually for specimens up to 10 years and those obviously greater than 10 years old were grouped into a 11+ category. The age compositions reported in this paper are based upon monthly data for the six seasons from 1965-66 to 1970-71 presented by Hodder *et al.* (MS, 1972).

In nearly all cases specimens for fat and moisture analyses were measured and weighed while in the fresh condition, placed in individual polyethylene bags and frozen for subsequent sampling at the laboratory, where the entire fish was chopped into small pieces and blended into a paste. For determination of moisture content the paste samples were mixed, 10-15 g of the paste weighed to the nearest mg and then dried to a constant weight at 100°C in an oven. Loss in weight was reported as percent moisture. Fat content was determined by ethyl-ether extraction in a Soxhlet apparatus, and the fat content was calculated as the percent of the wet weight of the whole fish. All analyses were performed in duplicate with a precision of  $\pm 0.5\%$  for moisture and  $\pm 0.1$  for fat.

## Results

### Size, maturity and age composition

#### a) Southwest Newfoundland

There has been a gradual increase in the average size of herring taken along southwest Newfoundland since the purse seine fishery began in 1965 (Fig. 2). The modal size increased from 32 cm during the 1965-66 season to 35 cm during 1970-71 and the average length from 32.7 to 34.5 cm. The increase in size over the six seasons was steady at a rate of about 0.4 cm per year. The relatively narrow size range with more than 95% of the herring between 30 and 36 cm and the gradual increase in size suggests that a narrow range of year-classes was represented in the fishery.

The composition of the samples by maturity stages indicates a mixture of two spawning groups — spring and autumn, with the latter type comprising about 70% of the specimens in the samples. The relative abundance of the two types fluctuated from month to month within a season (Fig. 3) but no consistent trend is evident.

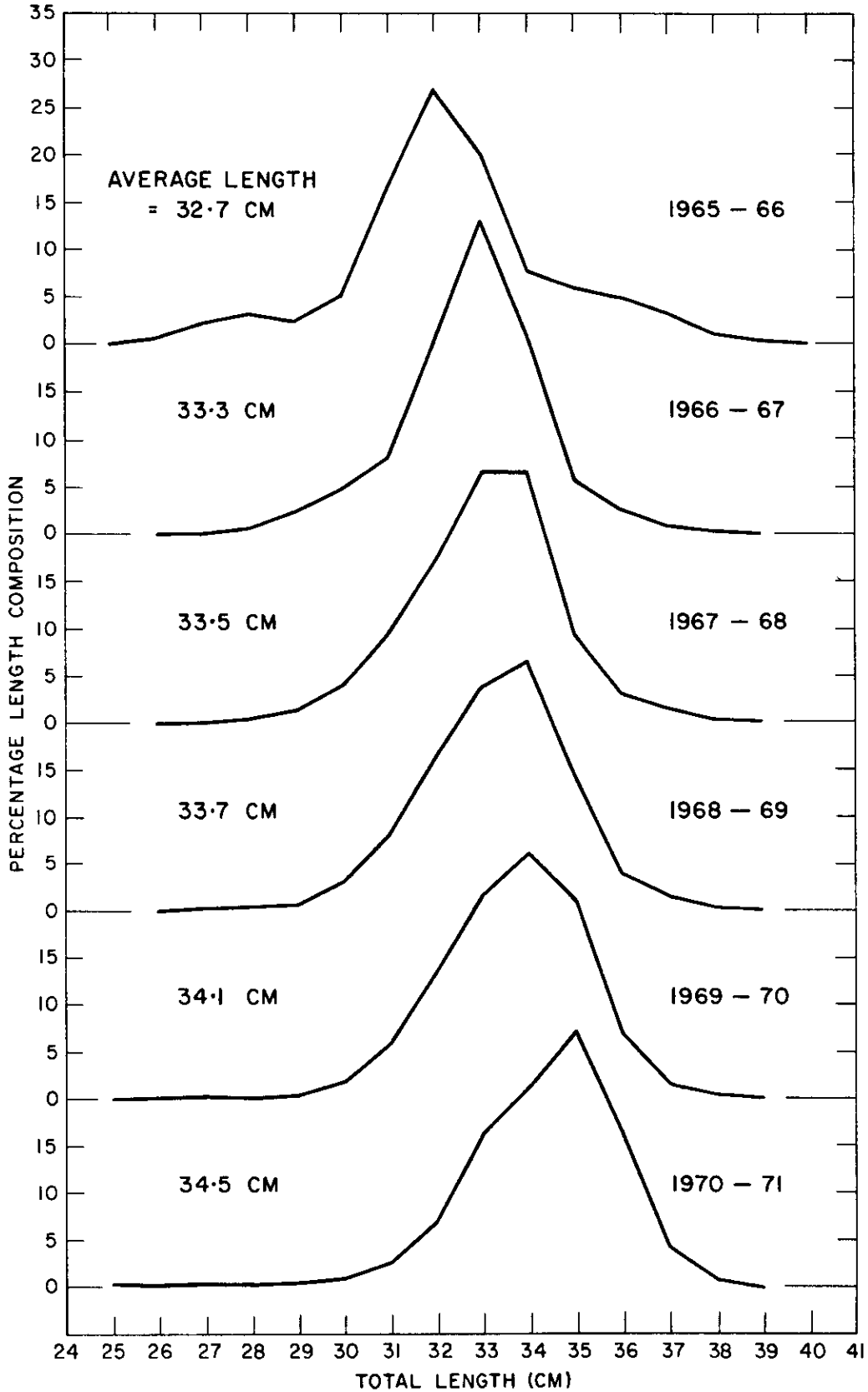


Fig. 2 Length composition of herring from seiner catches in Southwest Newfoundland coastal waters during the 1965-66 to 1970-71 seasons.

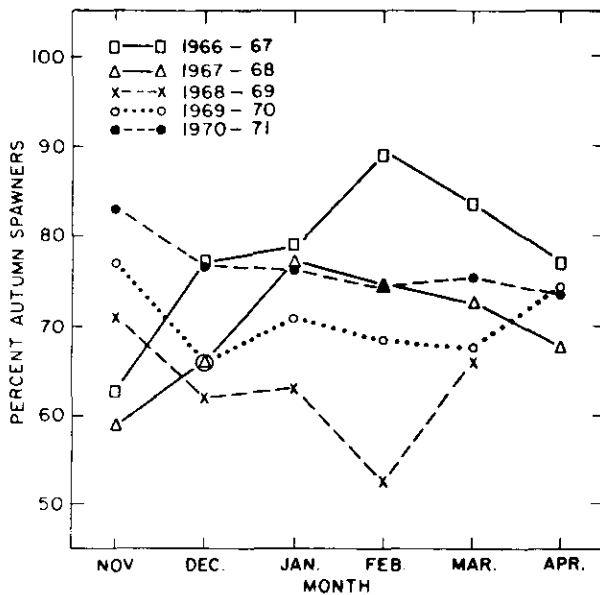


Fig. 3. Percentage of autumn spawners by month along Southwest Newfoundland during the 1966-67 to 1970-71 seasons.

The high degree of similarity among the monthly length frequency distributions within each spawning type and season (Fig. 4) indicates that very little change in the stock structure occurred on a month by month basis during each of the six seasons, the only exception being

for spring spawners in April 1971, when 3 of the 15 samples examined consisted almost entirely of juveniles taken after the adults had disappeared from the area. These juveniles are probably the progeny of "local" spring-spawning stocks which frequent the coastal waters of western Newfoundland. The length distributions in Fig. 4 also show the consistency of the difference in modal size between spring- and autumn-type spawners over the six seasons during which each type gradually increased in size at about the same rate, as indicated by the vertical lines through the modes. The obvious difference in average size of spring and autumn spawners necessitated separate treatment of the two types in analyses of the data.

The seasonal length and age compositions of the two types in the seiner catches during the 1965-66 to 1970-71 seasons are shown in Fig. 5. The trend in length composition of both types is indicative of the progression of one or two good year-classes through the fishery, and this is confirmed by the age composition data. Since its inception this winter fishery has been largely dependent on the very abundant 1958 year-class of autumn-spawned herring, exploited in the 1965-66 season as 7-year-olds and just as dominant during the 1970-71 season (over 40% by number) as 12-year-olds. Spring spawners, which on the average constituted about 30% of the herring sampled, were dominated by a reasonably good 1959 year-class which persisted as the most

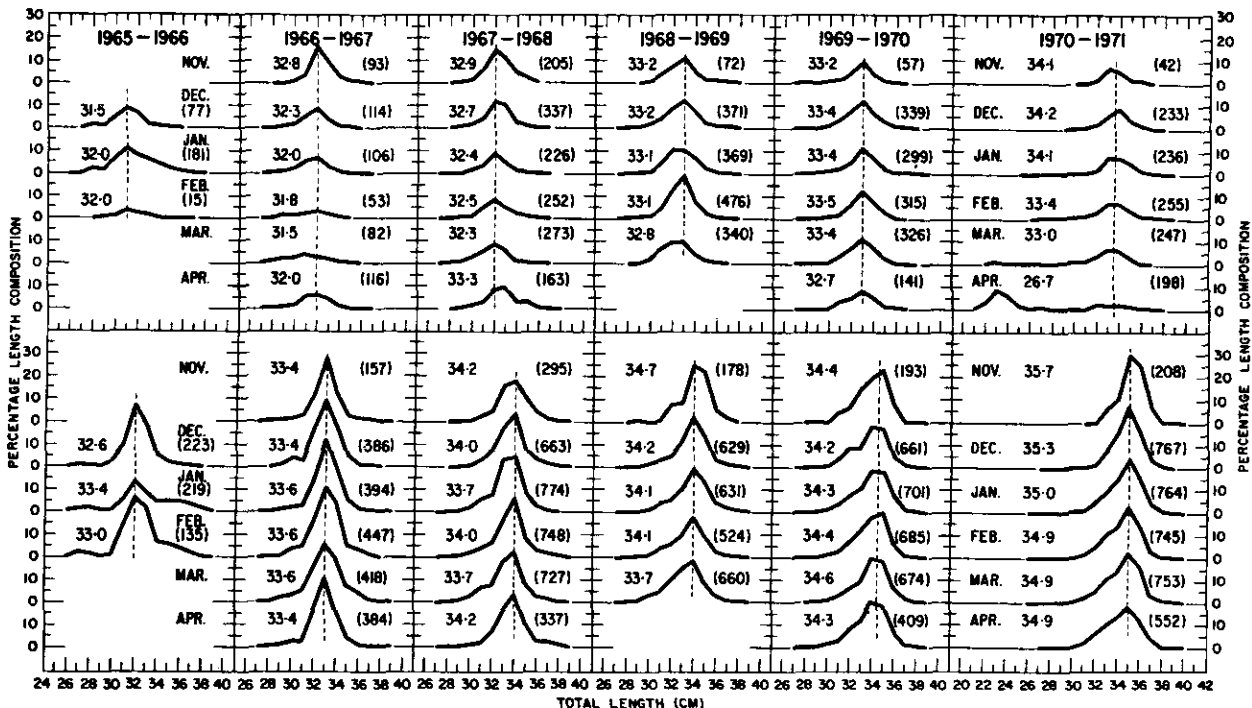


Fig. 4. Length composition and average length (cm) of Southwest Newfoundland herring by month for spring spawners (upper) and autumn spawners (lower) during the 1965-66 to 1970-71 seasons.

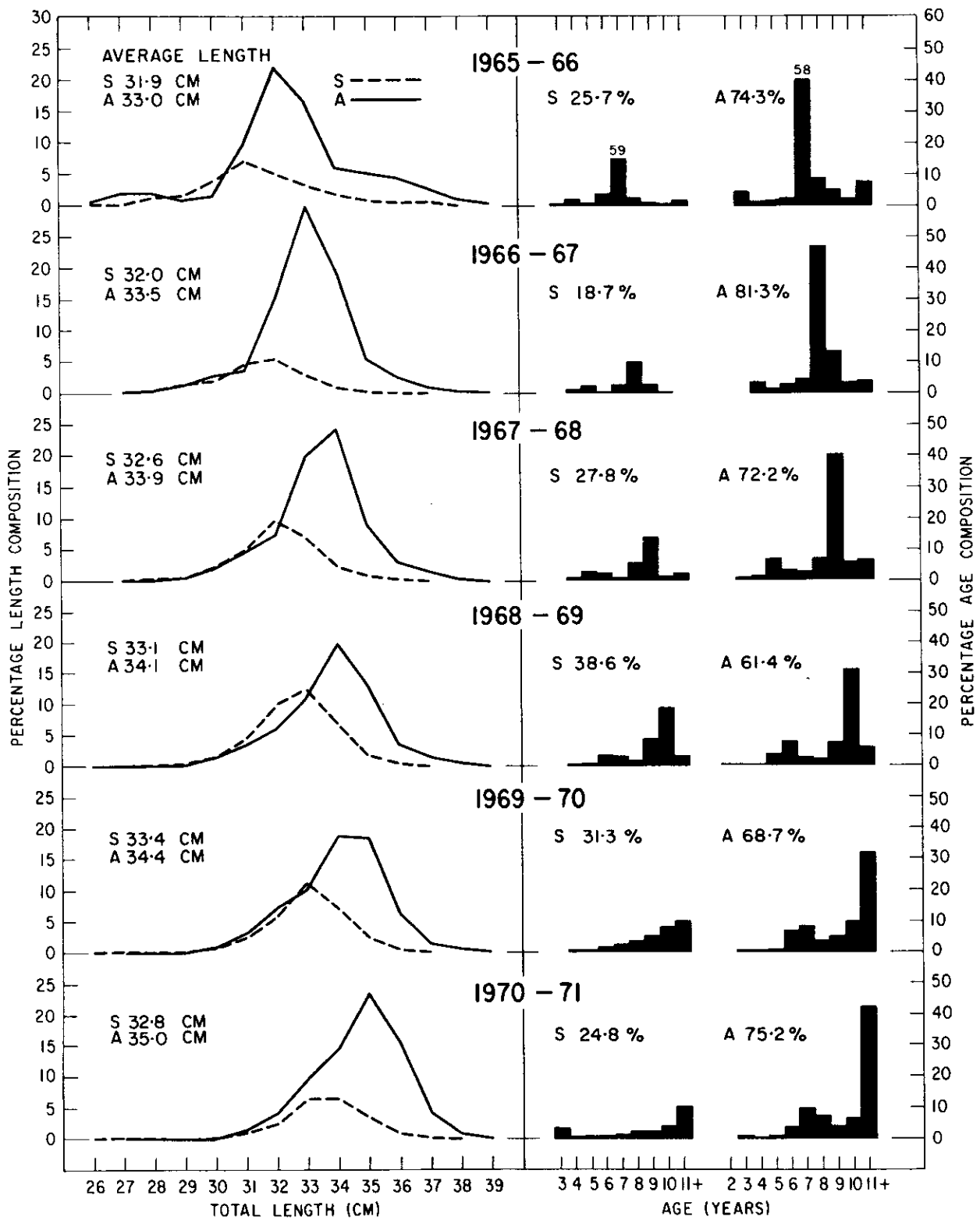


Fig. 5. Length and age composition of spring (S) and autumn (A) spawners in the Southwest Newfoundland herring fishery during the 1965-66 to 1970-71 seasons.

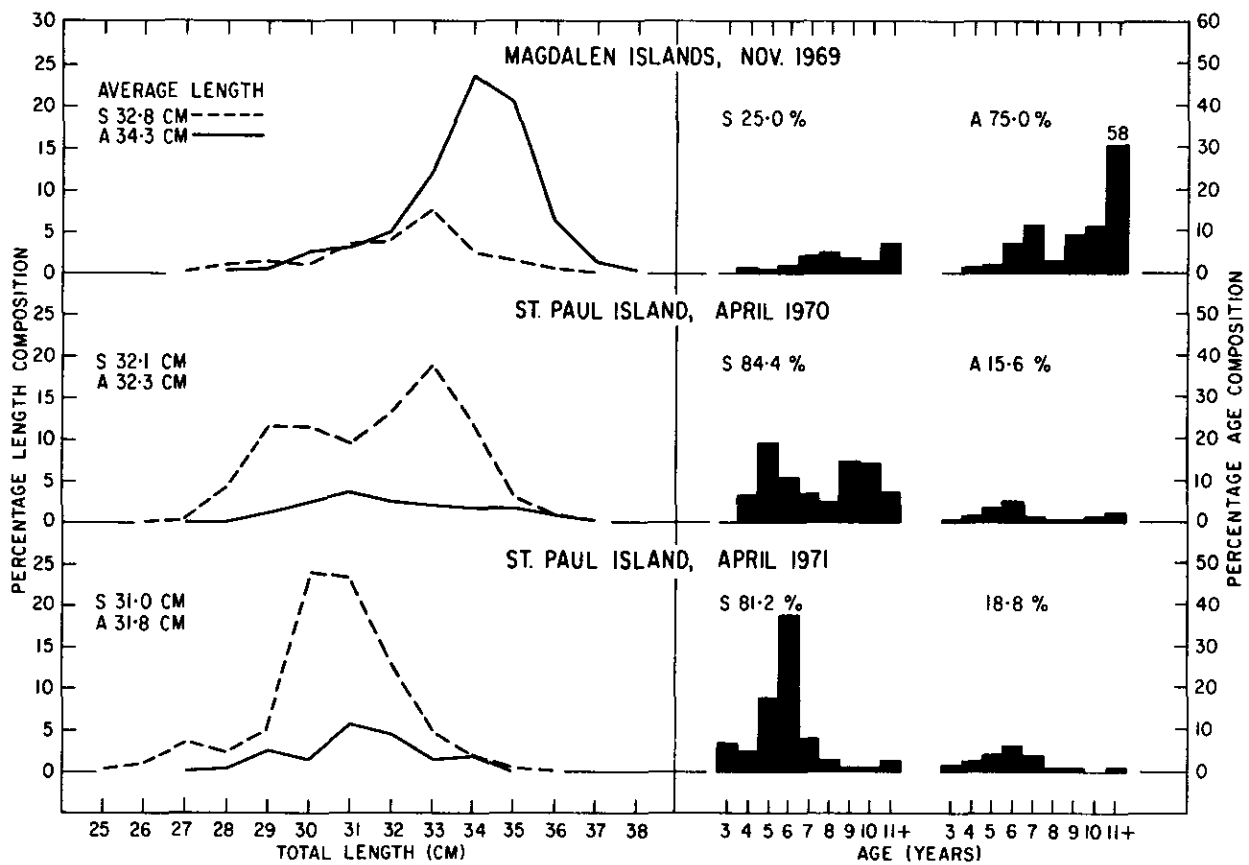


Fig. 6. Length and age composition of spring (S) and autumn (A) spawners from Magdalen Islands in November 1969 and St. Paul Island in April 1970 and 1971.

TABLE 2. Mean length at age by spawning type and season for Southwest Newfoundland herring.

Type	Age	Average length (cm)						Unweighted mean (cm)
		1965-66	1966-67	1967-68	1968-69	1969-70	1970-71	
Spring	2	—	—	—	—	21.5	—	21.5
	3	25.7	27.5	28.2	26.8	27.3	24.6	26.7
	4	28.8	29.4	29.8	29.3	29.2	29.7	29.4
	5	30.1	29.9	30.8	30.3	30.6	31.3	30.5
	6	31.5	31.4	31.2	31.4	31.6	32.0	31.5
	7	31.8	31.8	32.2	32.0	32.2	32.7	32.1
	8	33.2	32.3	32.5	32.6	32.7	33.3	32.8
	9	34.3	33.3	33.0	32.8	33.2	33.6	33.4
	10	34.8	34.5	34.1	33.5	33.7	34.0	34.1
	11+	36.1	35.7	35.1	35.2	34.5	34.9	35.2
	Autumn	2	—	—	—	21.5	23.2	23.8
3		27.6	25.7	28.2	27.1	27.1	27.4	27.2
4		29.8	30.2	30.0	29.6	29.8	30.9	30.1
5		31.5	31.3	31.6	31.1	31.3	32.0	31.5
6		32.1	32.1	32.5	32.5	32.2	32.9	32.4
7		32.6	32.7	33.0	33.1	33.1	33.6	33.0
8		33.5	33.4	33.5	33.6	33.8	34.3	33.7
9		35.1	34.2	34.1	33.9	34.1	34.6	34.3
10		35.8	35.3	35.0	34.8	34.5	35.0	35.0
11+		37.0	36.8	36.4	36.5	35.5	36.0	36.4

TABLE 3. Mean length at age by spawning type for herring samples from Magdalen Islands and St. Paul Island.

Type	Age	Average length (cm)			Unweighted mean (cm)
		Nov 1969	Apr 1970	Apr 1971	
Spring	3	—	—	27.4	27.4
	4	28.9	28.8	29.5	29.1
	5	29.4	30.0	30.7	30.0
	6	31.1	31.2	31.3	31.2
	7	32.2	32.4	32.6	32.4
	8	32.9	32.9	32.4	32.7
	9	33.1	33.4	33.6	33.4
	10	33.7	33.8	34.4	34.0
11+	34.4	34.9	33.9	34.4	
Autumn	3	—	26.8	29.3	28.0
	4	29.7	30.2	30.3	30.1
	5	31.1	30.9	31.4	31.1
	6	32.1	31.9	32.0	32.0
	7	33.4	32.9	33.2	33.2
	8	33.9	33.0	32.8	33.3
	9	34.3	34.7	34.8	34.6
	10	34.7	34.7	—	34.7
11+	35.5	35.5	34.7	35.2	

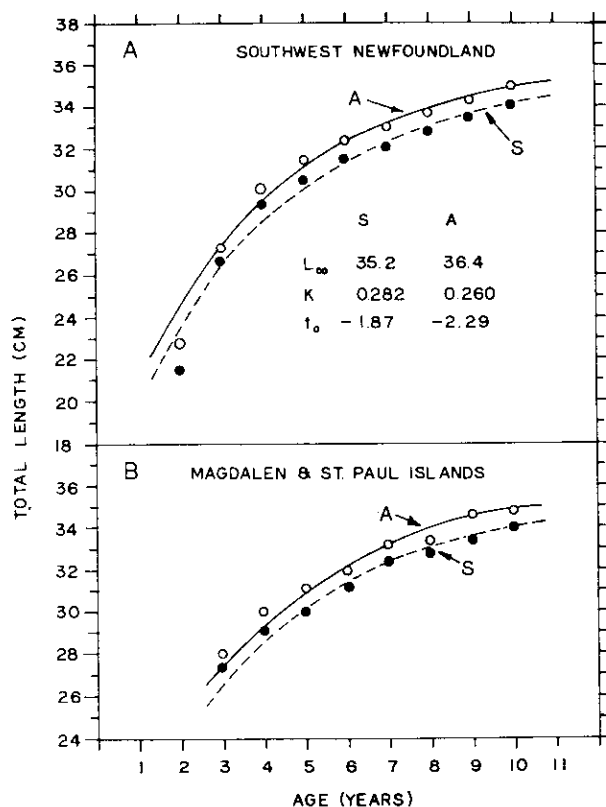


Fig. 7. A. Bertalanffy growth curves fitted to age-at-length data for Southwest Newfoundland herring. B. Age-at-length data for herring from Magdalen and St. Paul Islands with the growth curves for Southwest Newfoundland herring superimposed.

important one throughout the six seasons of sampling. Clearly evident is the absence of any significant recruitment of recent good year-classes to the exploited stock.

#### b) Southern Gulf of St. Lawrence

Herring taken at Magdalen Islands in November 1969, just before the start of the southwest Newfoundland winter fishery, and those taken near St. Paul Island in April of the years 1970 and 1971, after the cessation of the winter fishery, were very different in both length and age composition (Fig. 6). However, those from Magdalen Islands are very similar to herring from southwest Newfoundland for the 1969-70 season in both length and age composition and the relative proportions of spring- and autumn-spawning types. The April samples, on the other hand, consisted largely of spring spawners whose year-class compositions bear little resemblance either to those from Magdalen Islands or to those from southwest Newfoundland. Reports from seiner captains indicate that the herring concentrations found in the vicinity of St. Paul Island in April gradually move towards the Magdalen Islands where they spawn in early May.

#### Age-length relationships

The length-at-age data, given on a monthly basis by Hodder *et al.* (MS, 1972), are summarized by spawning type and season in Table 2 for the Southwest Newfoundland data and in Table 3 for the data available



from the southern Gulf of St. Lawrence. Except for age group 2 whose average lengths are based on very small numbers of specimens, the seasonal variability in the length-at-age values is very small for both areas.

The unweighted mean values, given in the last column of Tables 2 and 3, are shown separately for spring and autumn spawners in Fig. 7. In the upper part of the figure are shown the Bertalanffy growth curves for Southwest Newfoundland herring based on the parameters given under S and A for ages 3-10. These same curves are superimposed on the plotted length-at-age values for the Magdalen and St. Paul Islands area in the lower part of the figure.

The difference in growth between spring and autumn spawners, the latter having slightly higher length-at-age values, is probably due to the fact that in the first full year of growth after metamorphosis the progeny of autumn spawners have a longer growing period than those of spring spawners. At age 2 the values on the curves are higher than the data points and probably do not realistically reflect the growth pattern for this age. For some fish species the rather rapid rate of

growth for juveniles followed by the inhibition of growth with the onset of sexual maturity usually produces length-at-age values to which the fit of the Bertalanffy growth equation is not strictly applicable. This may be to a certain degree true for herring, whose growth rate seems to decrease rapidly after they reach sexual maturity at about ages 4 and 5.

### Length-weight relationships

Length-weight data for Southwest Newfoundland herring during the 1966-67 to 1970-71 seasons are summarized in Table 4. On the average the mean weight values over the 28-37 cm range decreased between November and April by about 6% for spring spawners and 4% for autumn spawners. A similar decrease in weight-at-length is also evident in the limited data from the southern Gulf of St. Lawrence (Hodder *et al.*, MS, 1972).

Length-weight curves (Fig. 8) for spring and autumn spawners separately were derived from the least squares regression  $\log_e W = b \cdot \log_e L + C$ , where  $W$  = whole weight,  $L$  = total length and  $C$  = constant. The

TABLE 4. Length-weight relationships for Southwest Newfoundland herring by spawning type and month for the 1966-67 to 1970-71 seasons combined.

Total length (cm)	Average weight (grams)													
	Spring type							Autumn type						
	Nov	Dec	Jan	Feb	Mar	Apr	Average	Nov	Dec	Jan	Feb	Mar	Apr	Average
19	—	—	—	—	—	43	43	—	—	—	—	—	—	—
20	—	—	—	—	—	56	56	—	—	59	—	—	—	59
21	—	—	—	—	—	68	68	—	—	62	—	—	—	62
22	—	—	—	—	71	75	73	—	—	66	77	—	—	71
23	—	—	—	—	84	84	84	—	—	77	79	72	86	79
24	—	—	95	—	97	94	95	—	118	—	100	89	100	102
25	—	—	—	—	—	106	106	—	—	136	98	107	114	114
26	—	—	150	132	109	133	131	—	127	137	138	124	—	132
27	—	157	151	151	149	150	152	—	150	155	152	152	134	149
28	178	174	182	163	169	175	174	172	180	167	160	159	160	166
29	222	215	205	196	195	204	206	183	186	182	175	178	169	179
30	235	234	224	216	219	214	224	197	199	195	191	190	192	194
31	258	258	249	245	242	241	249	214	218	212	209	210	216	213
32	280	283	275	270	267	262	273	233	238	231	229	232	234	233
33	301	301	295	290	287	281	292	253	257	252	249	249	251	252
34	323	327	318	312	308	306	316	274	275	270	268	269	269	271
35	352	347	334	335	327	325	337	298	295	290	286	288	290	291
36	384	362	375	364	357	360	367	317	315	312	310	307	316	313
37	399	390	416	398	390	406	400	334	335	343	335	331	337	336
38	—	—	440	440	429	—	436	365	371	374	370	349	371	367
39	532	—	493	—	—	—	512	404	403	429	389	378	401	400
40	—	—	—	—	—	—	—	—	383	—	390	422	424	405
41	—	—	—	—	—	—	—	—	—	506	472	486	—	488
43	—	—	—	—	—	—	—	520	—	—	—	—	—	520

curves begin to diverge at about 26-27 cm, the size at which spring spawners reach sexual maturity. At each 1-cm length group spring spawners are heavier than autumn spawners by an amount approximately equal to the difference between the weight of gonads of spring and autumn spawners.

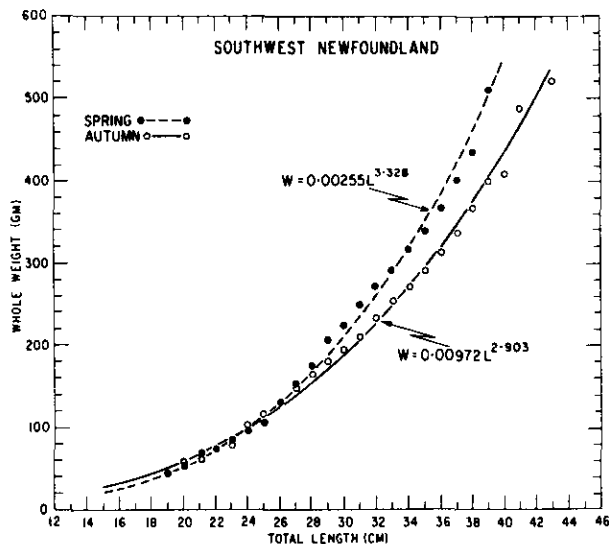


Fig. 8. Length-weight relationships for Southwest Newfoundland herring based on data for the 1966-67 to 1970-71 seasons.

### Relationship between gonad weight and maturity condition

Almost from the start of the most recent period of herring investigations at the St. John's Biological Station, the maturity condition of the gonads was used for separating adult spring- and autumn-spawning herring in the samples. Adult herring taken in autumn and winter were classed mostly as maturity stages IV and VIII. The absence of intermediate stages (the observations are based largely on the examination of fresh herring) indicate that spawning is restricted to the spring and autumn periods.

The percentage composition of the monthly samples by maturity stage during the 1970-71 season was as follows:

Area	Month	I, II	VIII	III	IV
Southwest Nfld	Nov 1970	—	82.8	4.4	12.8
Southwest Nfld	Dec 1970	0.3	76.3	2.4	21.0
Southwest Nfld	Jan 1971	1.2	75.5	1.1	22.2
Southwest Nfld	Feb 1971	1.7	73.6	1.2	23.5
Southwest Nfld	Mar 1971	2.3	74.3	1.7	21.7
Southwest Nfld	Apr 1971	30.2	57.7	3.4	8.7
St. Paul Island	Apr 1971	4.0	15.6	2.8	77.6

Herring of maturity stage VIII (autumn spawners) constituted about 75% of the fish in the November-March samples; gonads of practically all of these were in the weight interval 0-9 g, with females weighing slightly more than males (Fig. 9). The gonads of spring spawners (stage IV), on the other hand, were generally greater than 20 g in weight. During November-March juveniles (stages I and II) and adults classed as stage III were infrequent. The latter type, whose gonad development was intermediate between that of autumn spawners (stage VIII) and spring spawners (stage IV), may have been summer spawners which had a somewhat longer period for growth and gonad development than autumn spawners prior to the onset of winter. The April samples from southwest Newfoundland, taken at a time when the adults are moving westward into the Gulf of St. Lawrence, contained an unusually large proportion of juveniles in 1971. The St. Paul Island samples were taken at a time when herring were migrating towards Magdalen Islands for spawning in early May, and a high proportion of spring spawners (stage IV) would be expected.

Plots of average gonad weight against fish length separately by sex for the various maturity stages for December 1970 to March 1971 (Fig. 9) revealed an obvious increase in gonad weight with fish size for maturity stages III and IV but little or no increase during this period for maturity stage VIII. This relationship was more pronounced for males of maturity stages III and IV than for females. Stage III-IV female herring exhibited a definite increase in average gonad weight during the December-March period but there was no discernible weight increase for males of the same maturity category. Stage III-IV male gonads were, on the average, 24 g heavier than females of the same maturity stage in December but by March male and female gonads were equivalent in weight. The average weight of stage III-IV female gonads increased from 29.9 g in December to 45.2 g in March whereas the male gonads were almost fully developed in December.

### Feeding intensity

During the overwintering period from late November to early April virtually all of the herring examined had empty stomachs (Fig. 10). By early May 1971, however, approximately 90% of the stomachs examined contained food, indicating that the feeding intensity was very high at that time. These stomach samples were taken from catches off St. George's Bay which consisted almost entirely of autumn-type spawners. Apparently the autumn-spawning component of the herring concentrations which overwinter along Southwest Newfoundland resumes feeding during its westward migration into the Gulf of St. Lawrence in the spring. A cursory examination of the stomach contents of these

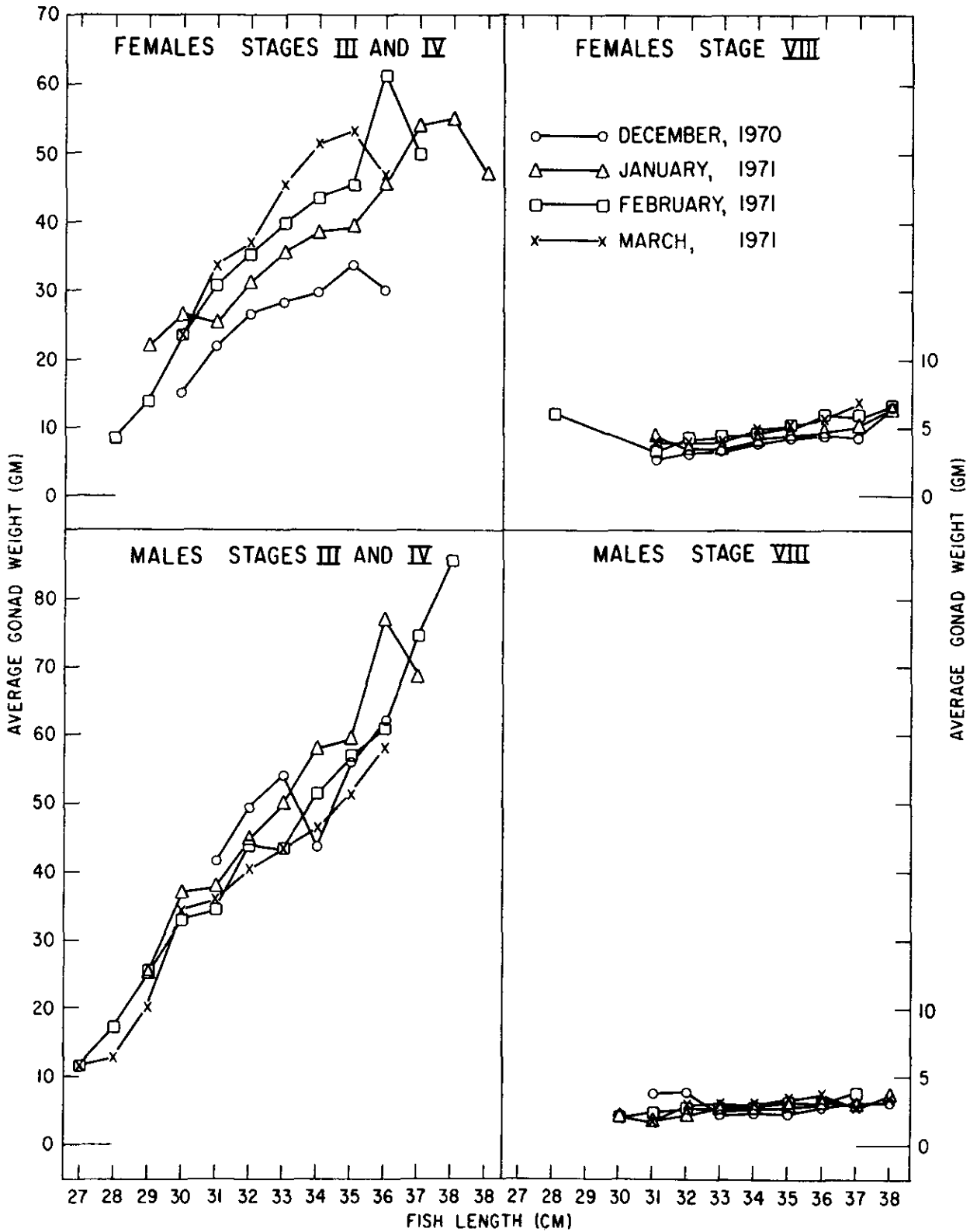


Fig. 9. Average gonad weight (gm) against fish length (cm) by sex and maturity stage from December 1970 to March 1971.

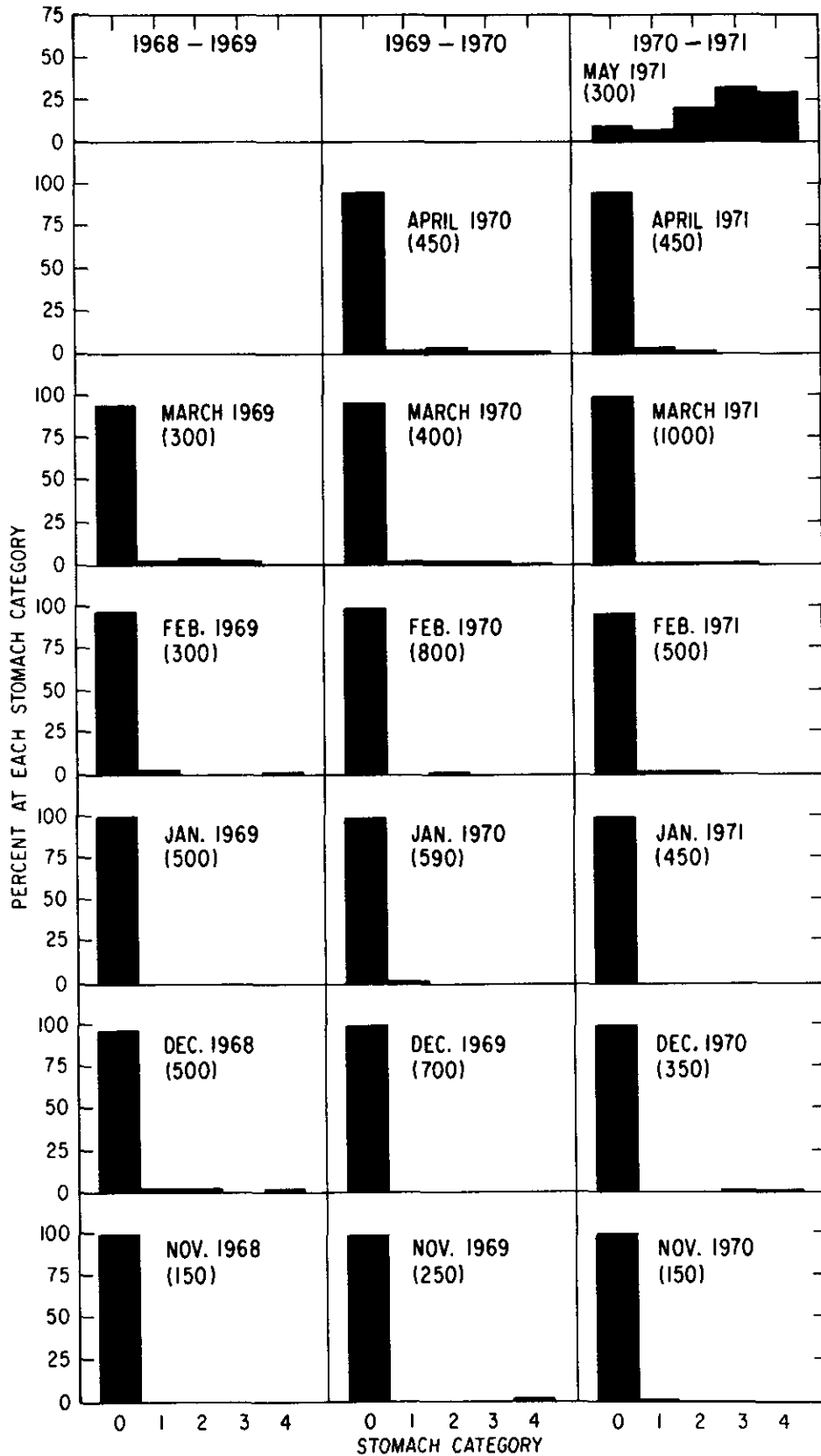


Fig. 10. Feeding intensity of Southwest Newfoundland herring by month during the 1968-69 to 1970-71 seasons.

herring revealed that euphausiids were by far the predominant food item (J. A. Moores, personal communication).

### Fat and water content

A summary of the fat content analyses by months (Table 5) indicates that during December to April spring spawners have a consistently higher fat content than autumn spawners, the average of the differences being nearly 5% in absolute terms. Also some evidence of an increasing trend in the fat content of both spring and autumn spawners is indicated in the data, with the values for 1970 and 1971 being generally higher than those in 1966 and 1969. Although there has been a gradual increase in the average size and age of herring sampled between 1965 and 1971 (Fig. 5), an analysis of the fat content data by length of fish for each spawning type separately and for each month and year revealed no consistent trend in fat content with length. Consequently the apparent trend from 1966 to 1971 cannot be attributed to variation in the length and age composition of the samples over that period.

In Fig. 11 the average fat content values of the individual samples for spring and autumn spawners separately (for details, see Hodder *et al.*, MS, 1973) are plotted against the dates when the samples were collected. For spring spawners the fat content decreases rapidly from about 15% in December and January to a low of 10% in April. Autumn spawners, which have an average of about 12% fat in December, exhibit a similar rapid decrease to a low level of about 6% in April. The variation about an imaginary trend line through the

points is associated with the annual variation mentioned in the preceding paragraph.

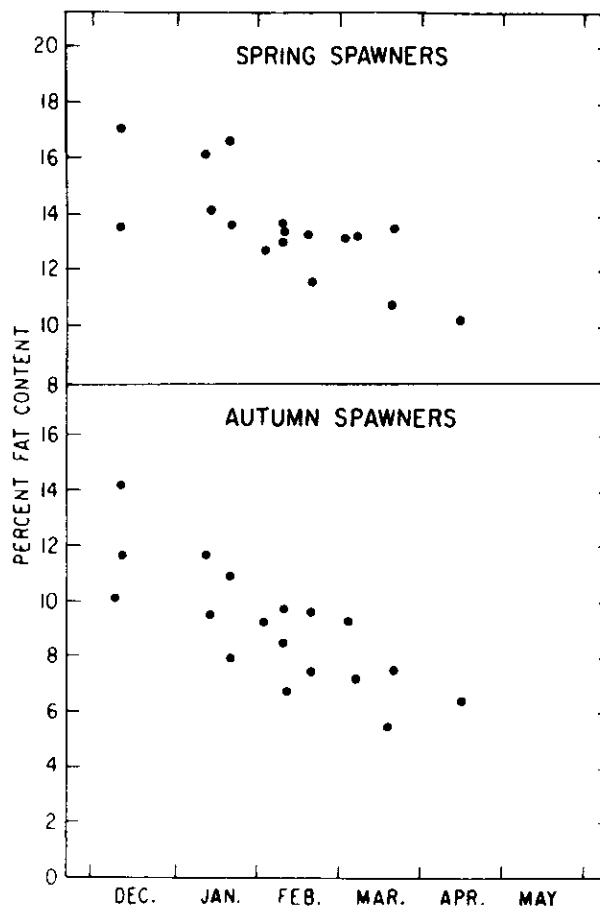


Fig. 11. Seasonal variation in fat content for spring and autumn spawners from Southwest Newfoundland.

TABLE 5. Average fat content by month and year for spring-and autumn-type herring taken in Southwest Newfoundland waters, 1966-71.

Month	Year	Spring			Autumn			Difference in fat content
		No. of fish	Percent fat	Range	No. of fish	Percent fat	Range	
Dec	1966	—	—	—	10	10.08	(5.3-14.3)	—
	1970	20	15.56	(6.3-21.1)	27	12.80	(8.2-17.2)	2.76
Jan	1966	14	13.85	(11.6-16.2)	12	8.18	(3.9-12.0)	5.67
	1969	11	14.08	(11.8-16.8)	29	9.67	(4.9-14.6)	4.41
Feb	1971	23	16.33	(12.5-22.8)	37	11.34	(5.7-17.0)	4.99
	1966	12	13.67	(9.9-16.5)	13	9.81	(6.3-12.3)	3.86
Mar	1969	36	12.57	(4.9-16.7)	24	6.98	(1.3-12.6)	5.59
	1970	36	13.52	(9.0-18.1)	36	8.55	(2.5-12.8)	4.97
Apr	1971	16	13.35	(7.2-17.1)	39	9.52	(5.1-17.3)	3.83
	1969	20	10.77	(8.1-16.6)	22	5.52	(2.1-11.9)	5.25
May	1970	30	13.37	(9.0-18.8)	21	7.24	(2.0-11.2)	6.13
	1971	25	13.47	(7.5-18.5)	43	8.50	(2.5-14.5)	4.97
Apr	1970	11	10.36	(6.3-15.8)	17	6.43	(3.3-11.2)	3.93

Perusal of the percentage fat and water values for individual fish suggest that fat and water together make up a constant percentage of about 80% of the wet weight of the fish, indicating that as the fat is utilized as a source of energy the fish takes in water in the same proportion, and vice versa. This aspect was examined by analyzing the trend in total fat plus water content with increasing fat content values grouped in 5% intervals (Table 6). There appears to be a gradual increase in the total fat plus water content with increasing fat content; fish with fat content values less than 5% have on the average a total fat plus water content of just under 80%, and those with more than 20% fat have a total fat plus water content of about 81.5%. The fat/water relationship is, therefore, not strictly linear.

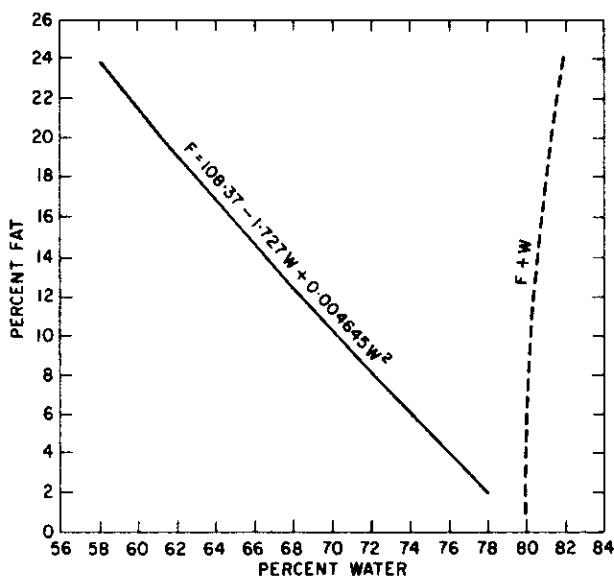


Fig. 12. The fat-water relationship in Southwest Newfoundland herring.

plus water content plotted against the water content. The very high degree of correlation (0.98) between the percent fat and percent water values indicates that a reliable estimate of the percent fat may be computed from the equation, given an estimate of the percent water content.

## Discussion and Conclusions

The rapid upsurge in the Newfoundland herring fishery during the mid- to late-1960's was due almost entirely to the development of a substantial late autumn and winter purse seine fishery in the fjords along the western part of the south coast on herring concentrations which migrate there from the southern part of the Gulf of St. Lawrence in November and move westward into the Gulf in late April. Whether or not the migratory pattern of these herring has been a traditional one is uncertain, for prior to the initial explorations in the fjords of Southwest Newfoundland by a large purse seiner in 1964-65, there are no records of a significant inshore fishery along that part of the coast in winter.

Past periods of intensive herring fisheries in Newfoundland waters have occurred in areas where the local stocks being fished were known to move inshore for spawning in May and June (Tibbo, 1956; 1957), whereas the stocks exploited along Southwest Newfoundland disappear from the fjords in April. During the overwintering period the fjord schools of herring consist of a mixture of nonfeeding spring- and autumn-type spawners, with the latter being generally more than twice as abundant as spring spawners. Just before the herring leave the fjords in the spring some separation of spring- and autumn-spawning herring is evident from samples of seiner catches near the end of the season in April. Catches during the short fishery in the area between St.

TABLE 6. Comparison of average fat, water and total fat plus water content by 5% fat content intervals for Southwest Newfoundland herring.

Range of fat (%)	Number of fish	Percentage		
		Fat	Water	Fat + Water
0.0-4.9	48	3.70	76.00	79.70
5.0-9.9	220	7.88	72.24	80.12
10.0-14.9	266	12.30	68.13	80.43
15.0-19.9	88	16.56	64.34	80.90
20.0-24.9	4	21.07	60.43	81.50

Polynomial regression, with percent water as the dependent variable, was used to determine the fat/water relationship. The resulting curve and quadratic equation are shown in Fig. 12, together with the curve for total fat

Paul Island and Magdalen Islands in late April consist mostly of spring spawners heading for shallow water at Magdalen Islands to spawn. Catches made at this time off the Southwest tip of Newfoundland and off St.

George's Bay consist almost entirely of autumn-type spawners. These latter schools ultimately move westward to the southwestern part of the Gulf of St. Lawrence where they feed during the summer and spawn in late summer and early autumn. While the movement of spring spawners toward the Magdalen Islands area and autumn spawners to the Gaspé area has been confirmed by tagging experiments (Winters, 1971a), this does not preclude the possibility of some spring spawners moving westward past the Magdalen Islands to spawn in the Chaleur Bay — Gaspé area in May.

The average size and age of the two spawning groups of herring which overwinter in Southwest Newfoundland fjords gradually increased during the 6-year-period from 1965-66 to 1970-71. The Southwest Newfoundland purse seine fishery has, since its inception, been based largely on two dominant year-classes of herring, the 1958 year-class of autumn spawners and the 1959 year-class of spring spawners. The scarcity of immature herring suggests that juveniles do not migrate with the adults, and the general scarcity of adult herring in the younger age groups indicates that recruitment has been very poor since the appearance of the 1958 and 1959 year-classes.

It has been traditional for most herring fisheries to fluctuate greatly according to great variations in year-class strength, with the consequence that stock recruitment relationships are unpredictable. This is especially true for the southern Gulf of St. Lawrence — Southwest Newfoundland spring- and autumn-spawning stocks, which, despite the great abundance of sexually mature adults of the 1958 and 1959 year-classes from about 1962 or 1963 until recently, has exhibited relatively poor recruitment to the exploited stocks in recent years. There is no evidence to show that the series of poor year-classes has been caused by consistently unfavourable environmental conditions. The extremely high yields from these stocks in recent years may be somewhat anomalous for the fishery has been based almost entirely on two very large year-classes of herring which are now passing out of the fishery leading to a dramatic decline in landings to less than 40,000 tons in 1971-72 and an even further decrease in 1972-73. There has been no significant recruitment of young fish to replace these dominant year-classes. It is likely that the fishery along Southwest Newfoundland in the future will be very sporadic.

In the past the Gulf of St. Lawrence herring stocks have periodically been stricken by epidemics of fungus disease (*Ichthyosporidium hoferi*), particularly during periods when the demand for herring was low and the fishery practically nonexistent. The most recent period of widespread natural mortality occurred during an epidemic of fungus disease in 1953-57 (Leim, 1955;

Sindermann, 1958). It has been estimated that at least half of the mature herring in the western Gulf of St. Lawrence were destroyed by this disease, with the spring-spawning stocks reduced to a greater extent than the autumn-spawning stocks (Tibbo and Graham, 1963). The resulting reduction in predation and in competition for food undoubtedly provided conditions favourable to the production of good year-classes during the late 1950's. It is our opinion that the abundant 1958 and 1959 year-classes thus experienced favourable conditions for survival, and that their consequent great abundance both as juveniles during 1959-62 and subsequently as adults inhibited opportunities for the good survival of young for several years.

The difference in percentage fat content between spring and autumn spawners in the late autumn when they migrate to southwest Newfoundland, i.e. 15% and 12% respectively, is undoubtedly due to the fact that the accumulation of fat in body tissues of autumn spawners is interrupted in the middle of the main feeding and growing period (September, when spawning occurs). A consequence of this is that during the winter nonfeeding period, when fat is utilized by the fish as a source of energy, autumn spawners have an average fat content consistently lower than that of spring spawners by a factor of about one-third. The seasonal trend in fat content between December and April is in general agreement with observations on herring taken in western and southern Newfoundland waters during 1945-50, for which data the maximum values were recorded in November and December and the lowest values in April and May (Leim, 1957). Also the apparent decrease in mean weight-at-length between December and April (Table 4) is probably associated with the rapid decline in fat content during the same period.

The evidence of an increasing trend in fat content between 1966 and 1971 may be indicative of the operation of a density-dependent factor, e.g. food supply during the feeding season in the southern Gulf of St. Lawrence. Information obtained from acoustic surveys, tagging experiments, trends in catch per unit effort and quantitative estimates of stock sizes (Winters and Hodder, 1975) indicates that the herring stocks in 1971 were less than one-fifth the size of the stocks present in 1966. A consequence of this would be more favourable feeding conditions in the most recent years due to reduced competition for food.

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## 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, German Democratic Republic, 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.

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### 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 × 280mm).
- b) Leave all margins 1 inch (25mm) 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 formulae).
- 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.

**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 × 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 × 7 inches (125 × 175 mm) in size and should be shipped flat protected by stout cardboard.
- h) Each illustration should be identified by markings 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 (1914a); Osborne and Mendel (1914b)  
or Osborne and Mendel (1914a and b); (Barnet and Robinson, 1942; King and Pierce 1943a, 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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