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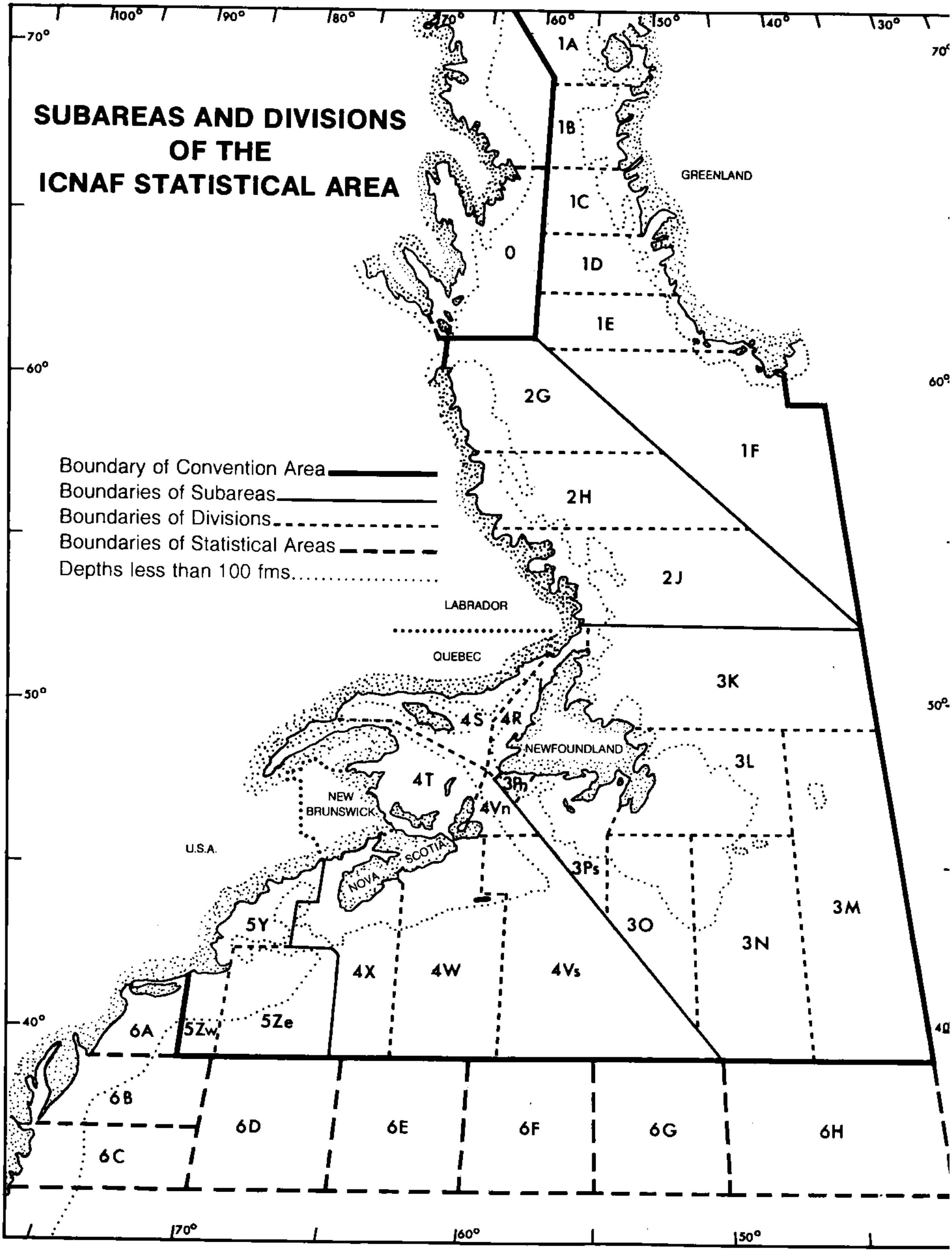
Foreword

This issue of Selected Papers is the third in the new series published annually or more frequently, depending on the number of contributions. During the period from 1958 to 1973, selected papers from ICNAF Meetings were published in the Redbook series.

Papers for publication in this new series are selected, subject to the approval of the authors, by the Steering and Publications Subcommittee of STACRES (Standing Committee on Research and Statistics) from papers presented to scientific meetings of ICNAF. In general, the papers selected contain information which is considered worthy of wider circulation than is normal for meeting documents but not of the standard required for publication in the Research Bulletin series. Each author is supplied with 50 reprints of his or her contribution.

The last paper in this volume contains a list of ICNAF standard oceanographic sections and stations, adopted by STACRES at the 1976 Annual Meeting and distributed earlier to scientists and institutes involved in the Commission's work. Reprints of this paper are now available and may be obtained from the ICNAF Secretariat upon request.



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Depths less than 100 fms
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4Vn
4Vs
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Contents

Dynamics and Yield Assessment of the Northeastern Gulf of St. Lawrence Cod Stock[1]

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Abstract

The area occupied by the northeastern Gulf of St. Lawrence cod stock extends from Subdivision 3Pn (January-April) along the west coast of Newfoundland (Division 4R) to the Quebec coast (Div. 4S). Annual catches ranged from 60,000 to 80,000 (metric) tons during 1965-69, reached a maximum of 103,000 tons in 1970 and averaged 60,000 tons during 1972-75. From data collected during 1973-76 with research and commercial trawls, the basic biological parameters for the stock were determined and used in the Beverton and Holt (1957) yield-per-recruit model. Length and age composition data indicated relatively good recruitment with strong year-classes appearing every two or three years. Growth parameters and the mean length and age at maturity were very similar to values reported by Wiles and May (1968) for the 1947-66 period, indicating the relative stability of the stock. Mean length at recruitment to the fishery was 44.2 cm at 5.25 years of age. Total mortality was fairly constant during 1973-76, averaging Z = 0.57 on fully recruited age-groups. For natural mortality values of 0.18 and 0.20, the yield-per-recruit analysis indicates that the stock has been exploited at a level close to that giving the maximum yield-per-recruit. The model predicts that no economic benefit could be obtained with a fishing mortality greater than 0.40. However, an increase in the mean length and age at first capture by increasing the trawl mesh size to 155 mm would provide a long-term increase in yield-per-recruit. Such an increase in mesh size would also heve the advantage of favouring better recruitment by avoiding the capture of immature fish.

Introduction

The Northeast Gulf of St. Lawrence cod stock is migratory, as indicated by results from various tagging experiments (Templeman, 1974; Minet, MS 1977). It inhabits the northern part of the Gulf (Div. 4S and the northern part of Div. 4R) during the summer, migrating to overwinter along the southwest coast of Newfoundland (Subdiv. 3Pn and the southern part of Div. 4R). From nominal catch statistics recorded in the ICNAF Statistical Bulletin for the years 1965-75 (ICNAF, 1967-77), the monthly evolution of cod catches in each division corresponds with the seasonal movement of the stock within the geographical boundaries of the stock area. From January to April (maximum in March), most of the catches are made in Subdiv. 3Pn and Div. 4R. Following a general decline in May, catches increase again during June-October (maximum in July) in Div. 4R and 4S. Therefore, the catches made in Div. 4R and 4S during the entire year and those made in Subdiv. 3Pn during January to April inclusive are considered to be from this stock (Table 1).

Total catches ranged approximately from 60,000 to 80,000 tons annually during the 1965-69 period, reached a

TABLE 1. Nominal catches (metric tons) of cod from the Northeast Gulf of St. Lawrence cod stock (Subdiv. 3Pn + Div. 4RS), 1965-75. (The 3Pn catches pertain to the fishery during the Jenuary-April period only.)

Year	Canada	France	Others[a]	Total	4R	4S	3Pn
1965	35,431	15,634	15,631	66,696	43,839	8,355	14,502
1966	35,065	13,708	13,062	61,835	44,208	7,253	10,374
1967	35,346	17,105	18,433	70,884	49,941	8,943	12,000
1968	48,394	26,344	11,716	86,454	70,029	7,721	8,704
1969	48,507	16,536	4,167	69,210	56,632	9,591	2,987
1970	46,116	30,457	26,726	103,299	91,146	9,114	3,039
1971	33,038	24,458	24,010	81,506	66,362	9,604	5,540
1972	27,345	13,326	14,017	54,688	37,583	10,297	6,808
1973	26,862	17,642	17,794	62,298	43,094	11,411	7,793
1974	33,094	16,614	14,297	64,005	39,446	12,977	11,582
1975	27,461	17,154	14,477	59,092	41,569	12,431	5,092

[a] *Mainly Portuguese and Spanish catches.*

[1] Submitted to the June 1977 Annual Meeting as ICNAF Res.Doc. 77/VI/24.

maximum of 103,000 tons in 1970 and averaged about 60,000 tons during 1973-75. Most of the catches (72%) were taken in Div. 4R, with 13% in Div. 4S and 15% in Subdiv. 3Pn (January-April). The Canadian catches, which declined slightly during the 1965-75 period, constituted about 50%, catches by France about 28% and those by other countries (mainly Portugal and Spain) about 22% of the total up to 1975. The catches in the offshore trawl fisheries, carried out mainly by Canada, France, Portugal and Spain, represented about 70% of the total for the period, with the remainder being taken in the Canadian inshore fisheries using various types of gear (longlines, handlines, gillnets, traps and jiggers).

A detailed study of this stock by Wiles and May (1968) for the 1953-66 period provided numerous data on the fishery (catches, fishing effort and the length and age compositions of the catches) and on the biology of cod (mortality, growth, maturity and spawning). The present study involves the analysis of complementary data on the dynamics of this stock (length and age compositions, mortality, growth, length and age at first maturity and at recruitment to the exploited phase) and on variations in yield-per-recruit in relation to fishing mortality and age at first capture from research surveys carried out by the ISTPM laboratory at St. Pierre and Miquelon during 1973-76.

Materials and Methods

The material used in this study was collected during five research surveys in Subdiv. 3Pn and Div. 4R and 4S with the research vessels *Thalassa* in July-August 1975 and *Cryos* during the winters (January-March) of 1973 to 1976. During the 1973 to 1975 surveys, the basic biological data were obtained from catches made with a polyamide research bottom trawl (Lofoten) with 31.2 m headrope, 17.7 m footrope, 140 mm mesh in the wings and body and 50 mm mesh in the codend. In the winter survey of 1976, the data were obtained from catches with two different trawls: the Lofoten research trawl, and a polyamide commercial bottom trawl used by the French (Metropolitan and St. Pierre) stern trawlers with 33.0 m headline, 12.0 m footrope, 140 mm mesh in the wings and body and also in the codend. The catches made with this latter trawl were similar to those made by the commercial trawlers fishing in the same area during the survey period.

Research trawl data

The length and age composition of the stock in each year were determined from 27,663 fish measured (total length) and 2,134 otoliths sampled at 312 trawling stations occupied during the 1973-76 period. Catch curves and the calculation of total mortality coefficients (Z) for fully recruited age-groups were obtained from numbers of each age-group caught per half-hour tow.

Estimates of natural mortality (M) were obtained in the first instance by applying the method of Ricker (1958) to 1976 data on tag recaptures following a cod tagging experiment in early 1976, and in the second instance by plotting the 1973, 1974 and 1975 values of Z against fishing effort (f) of the corresponding years, based on the standardized effort of tonnage class 6 (1000-2000 gross tons) trawlers.

Since no consistent trend in growth was observed during the 1973-76 period, the mean length-at-age data for all years were used to calculate the von Bertalanffy growth curve by the method of Walford (1946). The length-weight relationship based on the measurement of 757 specimens collected during the winter and summer surveys of 1975, was used to obtain the corresponding von Bertalanffy curve of growth by weight.

The mean length at 50% maturity (L_{50}) was calculated for both sexes by the method of Bliss (1935), using observations on the sexual stages of 3,379 males and 3,120 females from the winter survey of 1973.

Commercial trawl data

The length and age composition of the exploited portion of the stock were determined from 3,231 cod measured and 498 otoliths sampled from commercial trawl catches in the winter of 1976. During this survey, selectivity studies were carried out in Div. 4R with the research trawl (50 mm codend mesh) and the commercial trawl (140 mm codend mesh) using the alternate haul method (17 hauls of 30 min duration with each gear). From the length frequencies of cod caught per hour with each gear, the percentages retained at each length by the commercial trawl were determined using a conversion coefficient between the two gears. The selection curve for the commercial trawl was fitted by the probit method of Bliss (1935) and the mean length at entry to the catch (L_c) was determined from the 50% retention length.

Use of parameters

The values of the basic parameters, calculated as indicated above, were used in the Beverton and Holt (1957) yield-per-recruit model. Variations in yield-per-recruit were studied in relation to different values of the fishing mortality coefficient (F) and the mean age at recruitment to the exploited phase (t_c).

Results

Length and age composition

The length and age compositions of the northeastern Gulf of St. Lawrence cod stock in 1973-76 are shown in Fig. 1. The 1966 and 1968 year-classes were abundant in the 1973 and 1974 research catches. The 1968 year-class, still abundant in 1975, was followed by the strong 1971

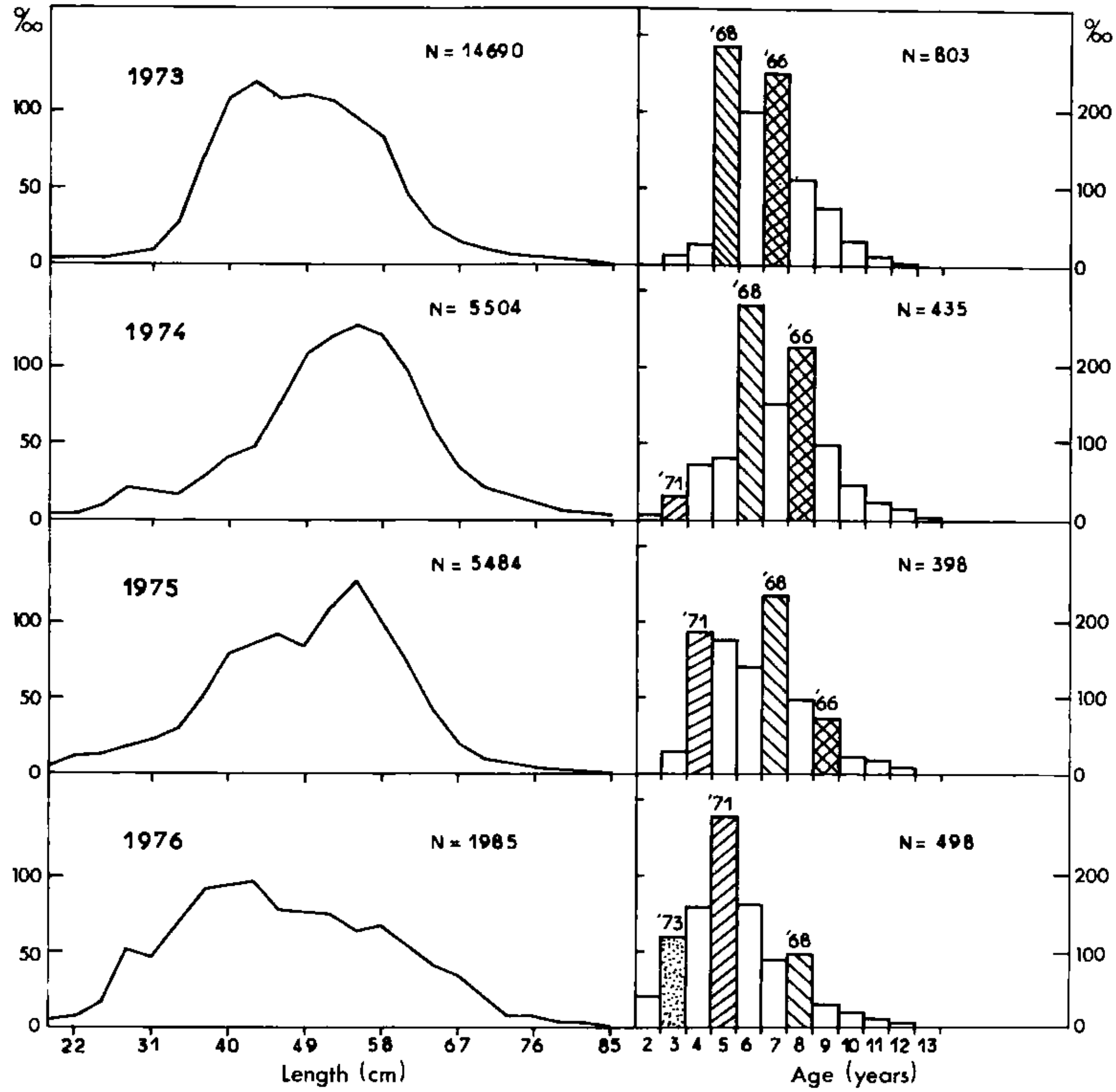

Fig. 1 Length and age compositions of cod from research trawl catches in Subdiv 3Pn + Div 4RS, 1973-76.

year-class which became the most important one in the research catches of 1976 when a good 1973 year-class appeared.

The length and age compositions of research and commercial trawl catches in 1976 are shown in Fig. 2. Age-groups 2 and 3 were not present in the commercial catches and age-groups 4 and 5 were only partly recruited to the fishery, with full recruitment at age 6.

Calculation of total mortality (Z)

The four catch curves based on data for the years 1973 to 1976 (Fig. 3) yielded values of Z (ages 6-11) of 0.67 0.50 0.50 and 0.57 respectively. Regression of the natural logarithms of the average number caught in each fully recruited age-group (6-11) during the period (Fig. 4) gives an average value of Z = 0.57 (r = 0.948). This estimate is slightly less than the value (Z = 0.65 for ages 7-15) obtained by Wiles and May (1968) for cod taken by small-meshed otter trawl in Div. 4R and 4S.

Estimation of natural mortality

From 1976 data on the number of cod recaptured during three 4-month intervals after tagging, the total mortality (F + M) for 1976 was estimated to be 0.48 and the fishing mortality (F) to be 0.28. The F-value is obviously underestimated due to incomplete reporting of tags mainly during the January-April period as indicated from comparing the return rate of tags with catches (Ricker's (1958) type A error). On the other hand, the M-value (0.20) may be slightly overestimated due to additional causes of mortality after tagging (traumatism, predation, etc.).

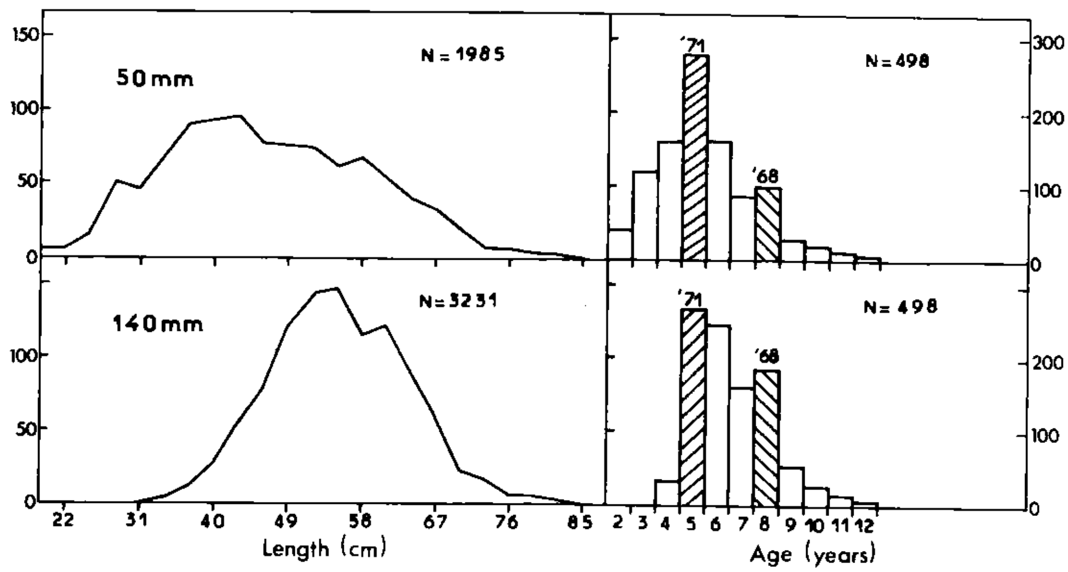

Fig. 2. Length and age compositions of cod from research trawl (50 mm codend mesh) and commercial trawl (140 mm) catches in Subdiv. 3Pn + Div. 4RS, 1976.

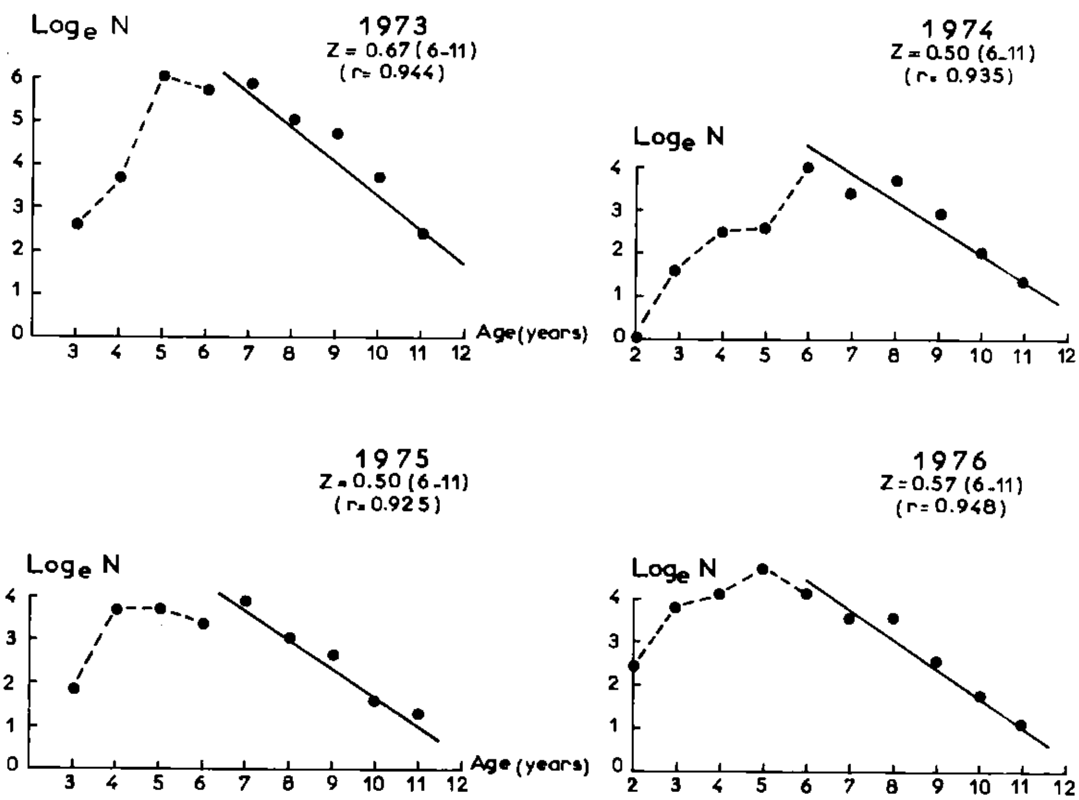

Fig. 3. Catch curves (logarithm of the age compositions) for cod from research trawl catches in Subdiv. 3Pn + Div. 4RS, 1973-76.

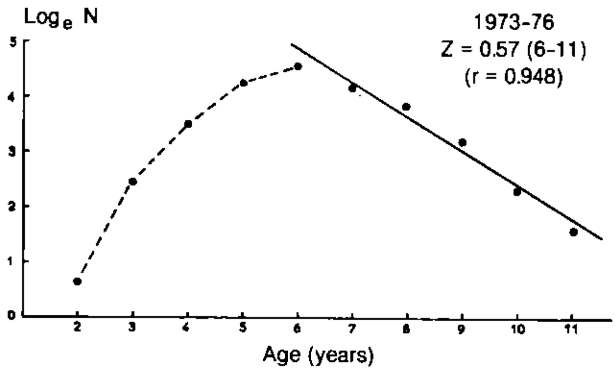

Fig. 4. The average catch curve for cod during the 1973-76 period based on the data shown in Fig. 3.

A further estimate of M was obtained by plotting the estimated values of Z for 1973 to 1976 against the fishing effort (f) calculated in days fished for the years 1972 to 1975. Regression of the Z-values on the corresponding f-values is expressed by the equation

$$Z = 0.000167\ f + 0.15$$

from which M = 0.15.

These two estimates of natural mortality are relatively close to the M-values found for other cod stocks in the Northwest Atlantic (Pinhorn, 1975). They can reasonably be taken as limit values for the northeast Gulf of St. Lawrence cod stock. If 0.57 is taken as the average value of Z during the 1973-76 period, the fishing mortality (F) was probably in the range of 0.37-0.42.

Growth

From analysis of mean length-at-age data (ages 3-12) for the 1973-76 period, the von Bertalanffy growth curve (Fig. 5) is expressed by the equation

$$L_t = 91.9\left\{1 - e^{-0.13(t-0.20)}\right\}$$

The length-weight relationship (Fig. 6), as determined from the log-log regression of mean weight (grams) on total length (cm), is expressed by the equation

$$\log W = 2.96 \log L - 1.98$$

or after conversion

$$W = 0.01047\ L^{2.96}$$

This relationship, when applied to the growth-in-length equation, leads to the following equation for the growth-in-weight curve (Fig. 7):

$$W_t = 6783\left\{1 - e^{-0.13(\ -0.20)}\right\}^{2.96}$$

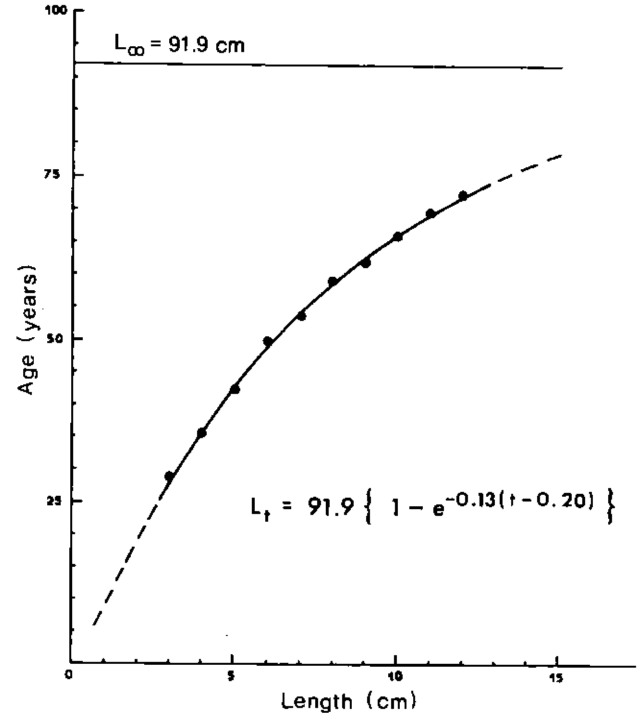

Fig. 5. Von Bertalanffy growth-in-length curve for the cod stock in Subdiv. 3Pn + Div. 4RS, 1973-76. (Dots are actual mean length-at-age values.)

The growth parameters calculated above for cod in Subdiv. 3Pn + Div. 4RS during 1973-76 are very similar to the results obtained by Wiles and May (1968) for cod in Div. 4RS during the 1953-64 period:

$$L_t = 91\left\{1 - e^{-0.14(t-0.30)}\right\}$$

and

$$\log W = 3.01 \log L - 4.68$$

The values of L_∞ (91 cm fork length) and K (0.14) given by these authors are very close to the respective values (91.9 cm total length, and 0.13) found in the present study, and the length-weight coefficients are likewise similar (3.01 *vs* 2.96). Also, our value (-1.98) for the intercept of the length-weight relationship, when converted from grams to pounds, becomes -4.64, which is essentially the same as that (-4.68) given by Wiles and May (1968).

Length and age at sexual maturity

The sigmoid curves, fitted by the method of Bliss (1935) to the proportions of mature males and females at each length in 1973 samples are shown in Fig. 8. The mean length and the corresponding mean age at which 50% of the male and female cod become mature are as follows:

Parameter	Male	Female	Combined
L_{50} (total length, cm)	45.7	51.9	48.8
t_{50} (years)	5.5	6.6	6.0

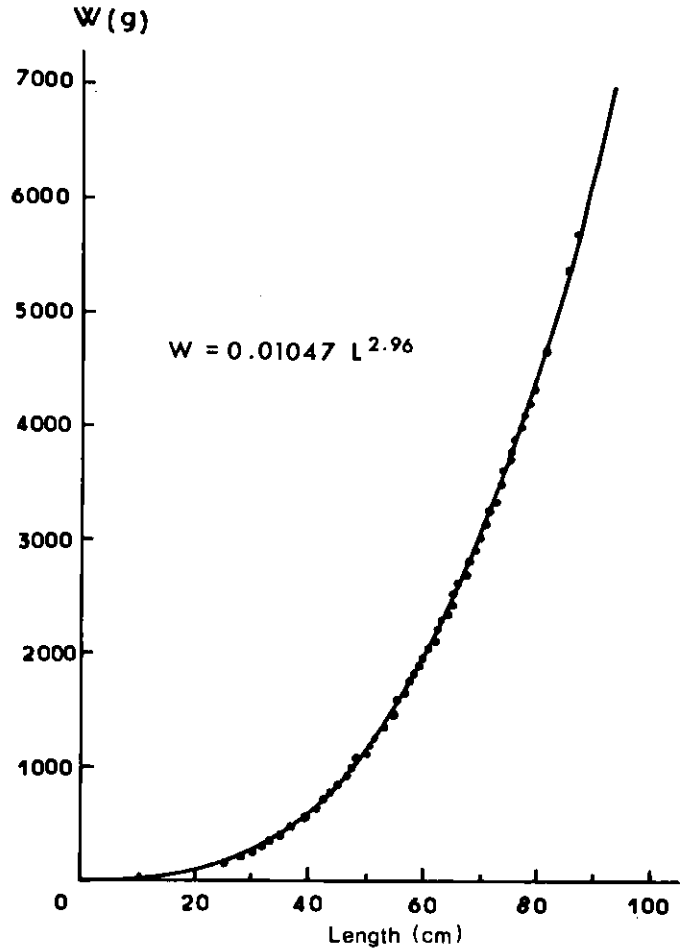

Fig. 6. Length-weight relationship for the cod stock in Subdiv. 3Pn + Div. 4RS, 1975.

Here again, these 1973 values are very close to those provided by Wiles and May (1968) for the 1947-66 period: 45.5 cm and age 5.1 for males, 49.7 cm and age 6.1 for females, and 47.5 cm and age 5.6 for sexes combined.

Length and age at entry to the fishery

The selection curve (Fig. 9) was derived from 1976 studies on selectivity of the French commercial polyamide trawl with a codend mesh size of 140 mm. The mean length (L_c) at which 50% of the fish are retained (calculated by the method of Bliss (1935)) is 44.2 cm total length, and the corresponding mean age at entry to the fishery (t_c) is 5.25 years. The selection factor for cod taken with the polyamide trawl is therefore 3.16. The application of this selection factor to the mean length at 50% maturity for both sexes (L_{50} = 48.8 cm) indicates that a minimum mesh size of 155 mm would be necessary to avoid the capture of many immature cod.

Yield per recruit

In order to simulate the effects of changes in natural mortality and mesh size, the following parameters were used in the Beverton and Holt (1957) yield-per-recruit model:

$Z = 0.57$	$t_o = 0.20$ yr
$K = 0.13$	$t_r = 2.00$ yr
$L_\infty = 91.9$ cm	$t_c = 5.25$ yr
$W_\infty = 6783$ g	$b = 3.16$

where t_r is the age at recruitment to the fishing area and b is the selection factor.

Effects of change in fishing mortality. Natural mortality (M) values of 0.15, 0.18 and 0.20, in the range of estimates previously calculated, were used in the yield equation, giving the results shown in Fig. 10. If M is taken to be 0.15 (F = 0.42), the maximum yield-per-recruit for the stock is obtained at F = 0.20, indicating that the stock is considerably over-exploited. For M = 0.18 (F = 0.39), the

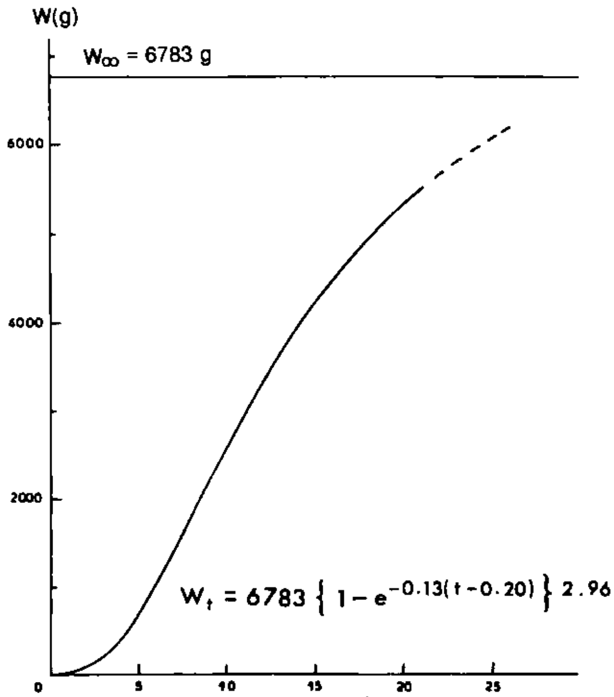

Fig. 7 Von Bertalanffy growth-in-weight curve for the cod stock in Subdiv. 3Pn + Div. 4RS, 1973-76.

maximum yield is obtained at F = 0.35, still slightly below the fishing mortality for the 1973-76 period. If, however, M is taken to be 0.20 (F = 0.37), the maximum yield-per-recruit is obtained at F = 0.45, indicating that the stock is slightly under-exploited (present yield = 96% of the maximum).

Effects of change in mesh size. The theoretical mean weight of cod in the catch ($\bar{W}$ = 1.40 kg), calculated for M = 0.18 and F = 0.39, is the closest value to the mean weight of cod ($\bar{W}$ = 1.45 kg) obtained in the catches of the commercial trawl (140 mm mesh). Consequently, variations in yield-per-recruit in relation to mesh size (m) and the corresponding values of mean length (L_c) and age (t_c) at first capture (Fig. 11) were examined for constant values of M = 0.18, F = 0.39 and b = 3.16. The maximum yield-per-recruit is obtained for a codend mesh size of m = 155 mm at L_c = 49.0 cm and t_c = 6.0 years, indicating an increase of 9.5% of the yield-per-recruit for an increase in mesh size from 140 to 155 mm.

Effects of simultaneous changes in fishing mortality and mesh size. Variations in yield-per-recruit in relation to fishing mortality and to mesh size (and consequently to t_c) are indicated in Table 2 and the yield-per-recruit curves are shown in Fig. 12. As the level of fishing mortality (F) is increased, the corresponding

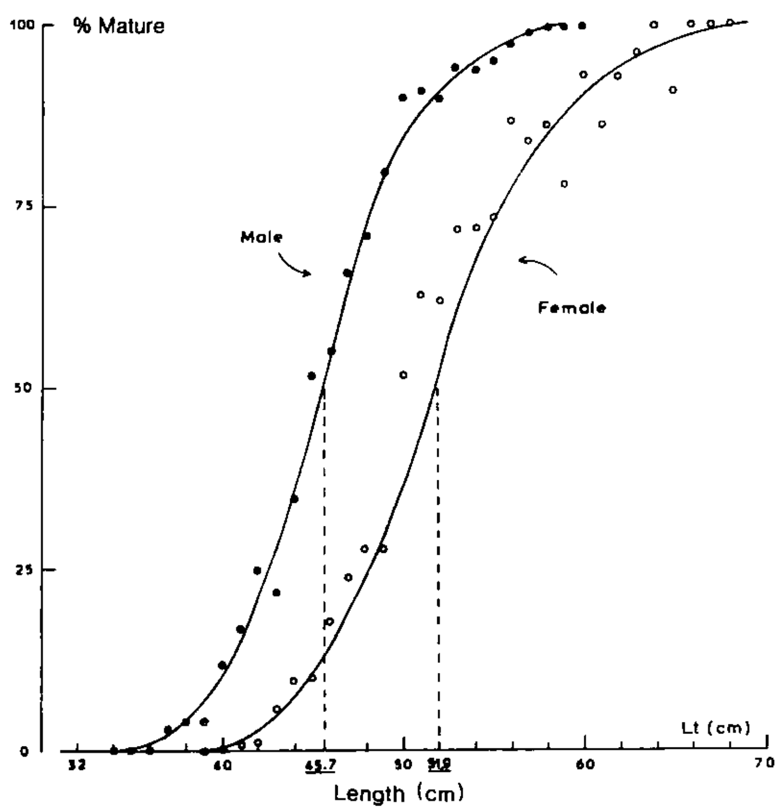

Fig. 8. Fitted sigmoid curves of length at sexual maturity for male and female cod in Subdiv. 3Pn + Div 4RS, 1973. (The observed values are represented by open and closed circles.)

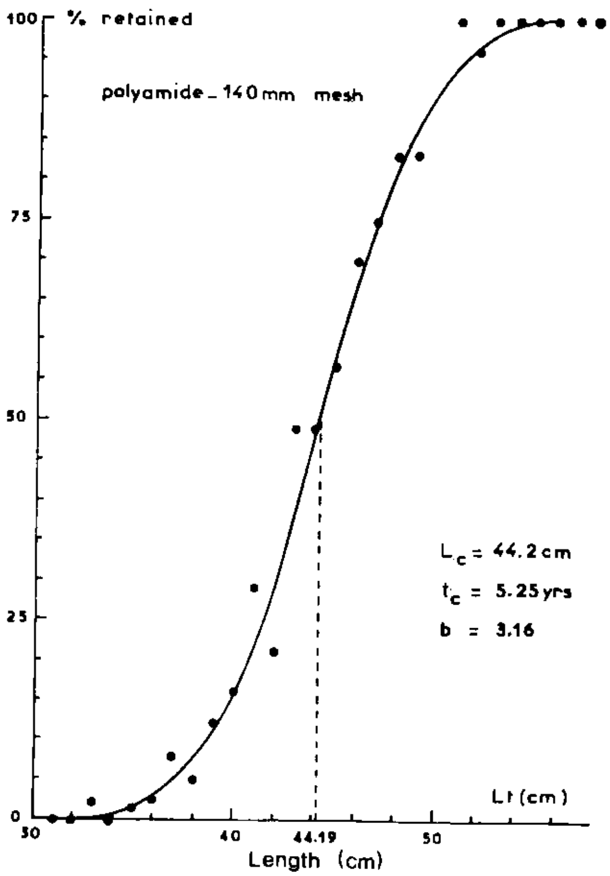

Fig. 9. Fitted selection curve for cod taken by commercial polyamide trawl (140 mm codend mesh) in Subdiv. 3Pn and Div. 4R, 1976. (Dots represent the observed values.)

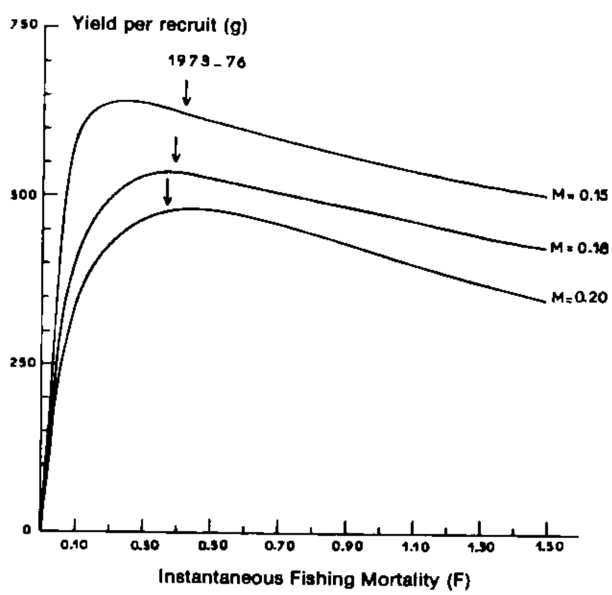

Fig. 10. Yield-per-recruit curves at 3 levels of natural mortality (M) for the cod stock in Subdiv. 3Pn + Div. 4RS. (Average 1973-76 positions are indicated by arrows.)

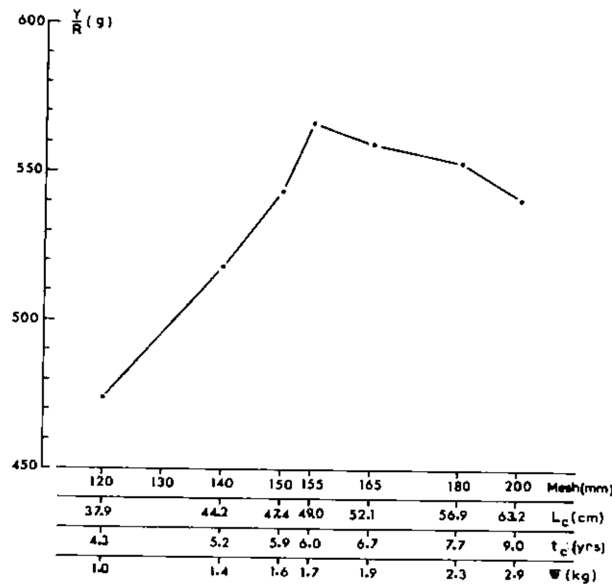

Fig. 11. Yield-per-recruit for the cod stock in Subdiv. 3Pn + Div. 4RS in relation to changes in mesh size and the corresponding mean lengths and ages at recruitment to the fishery.

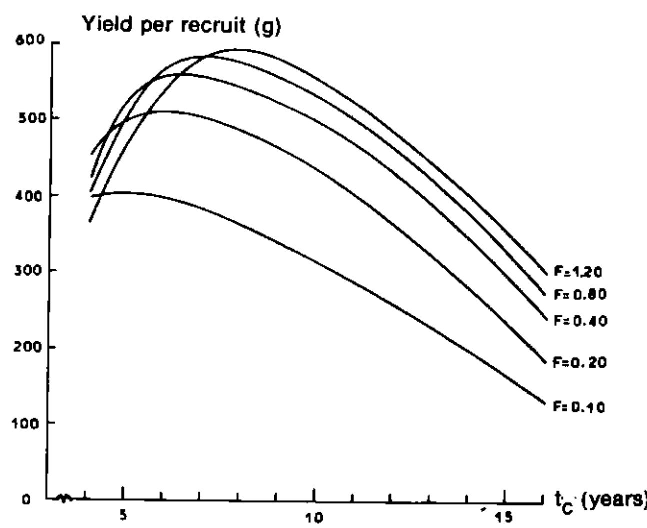

Fig. 12. Yield-per-recruit curves for the cod stock in Subdiv. 3Pn + Div. 4RS in relation to fishing mortality (F) and to age at recruitment to the fishery (t_c).

maximum yield-per-recruit increases with increasing mesh size (and in t_c) for F-values to 1.20; for example, at F = 0.40, the maximum is obtained with a mesh size of 155 mm (t_c = 6.0 years). The maximum yield-per-recruit tends to an asymptotic level with increasing F (Fig. 13). The increases in maximum yield are 27%, 11%, 3% and 0.3% for increasing F from 0.10 to 0.20, from 0.20 to 0.40, from 0.40 to 0.80 and from 0.80 to 1.20 respectively. It is therefore obvious that no significant advantage would be achieved by an increase in fishing intensity beyond the

TABLE 2. The effects of simultaneous changes in mesh size and fishing mortality (F) on yield-per-recruit for the cod stock in Subdiv. 3Pn + Div. 4RS. (Maximum yield-per-recruit values are in **bold**.)

Mesh size (mm)	L_c (cm)	t_c (years)	Yield-per-recruit for F = 0.10	F = 0.20	F = 0.40	F = 0.80	F = 1.20
120	37.9	4.3	396	476	474	468	378
140	44.2	5.2	**403**	501	518	486	456
150	47.4	5.9	400	**510**	544	544	532
155	49.0	6.0	396	509	**567**	555	554
165	52.1	6.7	387	498	560	**586**	563
180	56.9	7.7	367	485	554	568	**588**
200	63.2	9.2	337	459	542	552	578
250	79.0	15.3	164	234	294	336	355

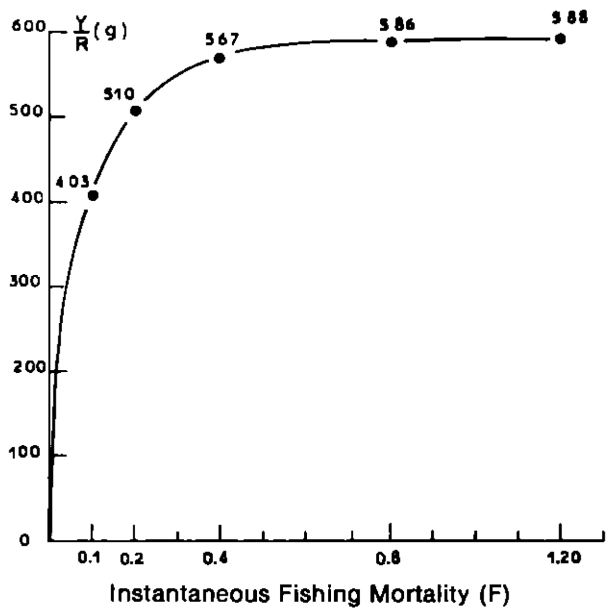

Fig. 13. Eumetric yield curve for the cod stock in Subdiv. 3Pn + Div. 4RS.

level of F = 0.40. The yield isopleth diagram for this cod stock is shown in Fig. 14, on which is plotted the point corresponding to the level of exploitation during the 1973-76 period for M = 0.18, F = 0.39 and t_c = 5.25 years.

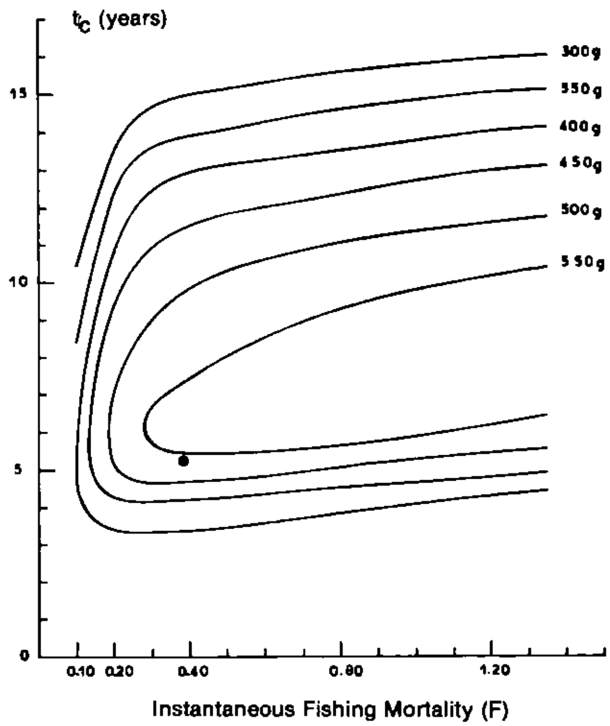

Fig. 14. Yield isopleth diagram for the cod stock in Subdiv. 3Pn + Div. 4RS. (The average 1973-76 position is indicated by a dot.)

Conclusions

The results presented here indicate that the Gulf of St. Lawrence cod stock in Subdiv. 3Pn + Div. 4RS has probably been at a relatively stable level during the past 20 years, as the values of the biological parameters found for the 1973-76 period are in fact very similar to those reported by Wiles and May (1968) for the 1947-66 period. This stability is mainly evident from estimates of total mortality, growth in length and weight, and length and age at sexual maturity.

Although recruitment may be somewhat irregular at times, some strong year-classes were evident during the period of investigation and young cod were particularly well represented in the 1976 catches.

In spite of uncertainties about the exact value for natural mortality, the yield-per-recruit analysis indicates that the stock was exploited during the 1973-76 period at a level very close to that giving the maximum yield-per-recruit. If the natural mortality (M) is assumed to be 0.20, the fishing intensity exerted on the stock (F = 0.37) was below the F_{max} level (0.45), but, if M is taken to be 0.18, the fishing mortality on the stock (F = 0.39) was slightly higher than the corresponding F_{max} level (0.35). In any case, the results obtained by applying the Beverton and Holt (1957) model indicates that no biological and economic benefits could be obtained from this stock by increasing the fishing mortality over F = 0.40.

The results indicate that long-term increases in yield-per-recruit could be achieved by increases in the mesh sizes of trawls (thus increasing the length and age at first capture). A mesh size of 155 mm was found to be the optimum size for giving the maximum yield from the stock, the corresponding values for length and age at recruitment to the fishery being 49.0 cm and 6.0 years. An increase in mesh size from 140 to 155 mm would bring a long-term increase in yield-per-recruit of 9.5%, with an immediate loss of 8%. A change in the mesh size from 130 to 155 mm could give a long-term increase in yield of 15% with an immediate loss of 11%. In addition, the increase in mesh size to 155 mm would avoid the capture of immature fish and thus favour an improvement in recruitment.

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Characteristics of the Beaked Redfish, *Sebastes mentella* Travin, in Bottom and Midwater Trawl Catches on Flemish Cap[1]

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Abstract

Fishing for the beaked redfish, *Sebastes mentella* Travin, has been carried out in the Flemish Cap area since 1972 by large USSR trawlers with midwater trawls. During the period of larval extrusion in the spring (March-June), mature females concentrate in the pelagic zone where midwater trawling is more effective than bottom trawling, and differences in such biological characteristics as length composition, stages of sexual maturity and feeding are evident in redfish taken by the two types of gear. The mating of males and females occurs in the pelagic zone in October and November, and significant differences in the biological features of redfish in the bottom and midwater trawl catches are again evident. Such differences are not as apparent in fish taken in the near-bottom and pelagics zones during the winter. Diurnal and seasonal vertical migration between the near-bottom and pelagic zones is considered an important aspect of redfish distribution. Consequently, it is concluded that a single population of beaked redfish inhabits the Flemish Cap area, differing components of which are exploited by bottom and midwater trawls at various times of the year.

Introduction

Large trawlers of the USSR fleet have periodically fished for redfish on the eastern and southern slopes of the Grand Bank and in the Flemish Cap area with bottom and midwater trawls since 1972. Midwater trawls were used less frequently on the slopes of the Grand Bank than on Flemish Cap, where in 1974 more than 40% of the total redfish catch by the USSR fleet was taken by midwater trawl (Table 1). The average catch per hour fishing with midwater trawl by large vessels (>2000 tons) was consistently greater than that for bottom trawls over all months of the year (Table 2).

Conservation measures, through the implementation of catch quotas, have been in effect for most of the redfish stocks of the Northwest Atlantic since 1974. The recent rapid increase in midwater trawling for redfish, especially in

TABLE 1. Nominal catches of redfish (tons) taken by the USSR commercial fleet on the slopes of the Grand Bank (Div. 3L, 3N and 3O) and in the Flemish Cap area (Div. 3M), 1974. (OTB = bottom otter trawl; OTM = midwater trawl.)

	3L		3N		3O		3M	
Month	OTB	OTM	OTB	OTM	OTB	OTM	OTB	OTM
Jan	85	146	138	29	—	—	—	—
Feb	149	253	390	81	—	—	827	626
Mar	171	291	398	83	375	208	1,874	1,420
Apr	357	607	812	170	846	675	2,561	1,939
May	698	1,190	1,608	336	3,187	190	3,805	2,882
June	899	1,531	1,991	417	709	927	4,054	3,070
July	528	898	1,215	254	844	202	782	593
Aug	108	183	265	56	182	—	398	302
Sep	115	196	289	60	—	—	481	364
Oct	141	240	373	78	—	—	634	480
Nov	223	379	512	106	—	—	1,084	821
Dec	241	411	556	114	4,143	259	649	493
Total	3,715	6,325	8,547	1,784	10,286	2,461	17,149	12,990

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TABLE 2. Average catch per hour fishing by large trawlers (>2000 GRT) in the Flemish Cap area, 1974.

Gear	Catch per hour trawling (tons)										
	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Year
OTB	2.08	1.23	1.18	2.42	2.26	1.21	0.65	1.22	1.74	2.25	1.54	1.65
OTM	2.63	2.70	2.85	2.79	2.80	2.55	1.94	2.04	2.36	2.64	2.27	2.67

the Flemish Cap area, has posed the question as to whether the same stock of redfish is exploited by bottom and midwater trawls or whether a separate pelagic population of redfish exists in the area and is being exploited mainly by midwater trawl. The supposition about the presence of a separate pelagic stock in the area may not be unrealistic, as the existence of such pelagic populations of redfish have been reported in offshore waters off Iceland and Greenland (Zakharov, 1963, 1964; Henderson and Jones, 1964; Templeman, 1967; Konstantinov, 1969; Jones, 1969a, 1969b, 1970; Ernst, 1969). It is therefore reasonable to assume that Flemish Cap, which is situated at some considerable distance eastward of the continental shelf off Newfoundland, may be an area inhabited by a pelagic population of redfish. An attempt to elucidate this matter is made through the examination of data on redfish taken with bottom and midwater trawls.

Materials and Methods

The biological data, used as the basis for this study, were derived from samples of redfish catches taken by bottom and midwater trawls over several months during 1972-74. In order to minimize the effects of diurnal variability, the number of samples taken from day and night catches were approximately equal. Characteristics of redfish maturity are based on the scale of maturity stages devised by Sorokin (1958, 1960). Length frequency distributions are derived from total length measurements of specimens to the nearest centimeter. Data on feeding are based on the degree of fullness of the stomach in intervals from 0 (empty) to IV (full).

Results and Conclusions

The vertical distribution of redfish in the Flemish Cap area varies with the time of the year. In winter, the size composition of fish in the near-bottom and pelagic zones are quite similar, as evidenced by the length compositions of catches taken with bottom and midwater trawls in December and February (Fig. 1). However, specimens less than 30 cm in length were somewhat more numerous in the bottom trawl catches. The feeding and maturity conditions

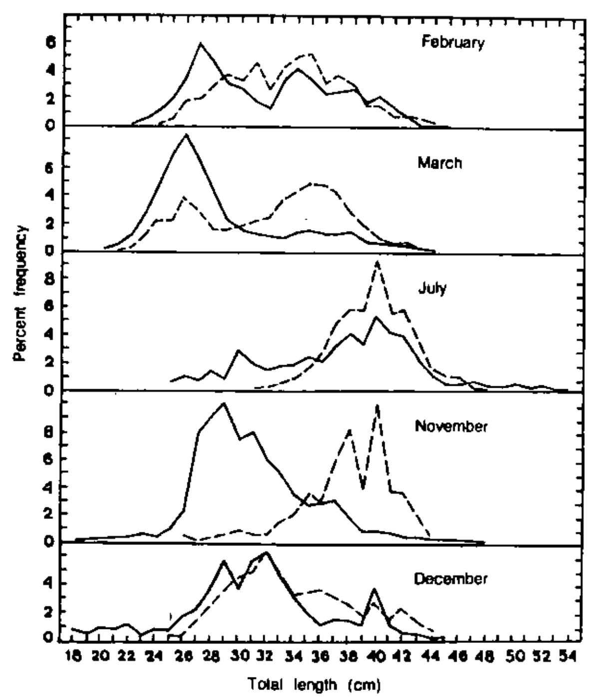

Fig. 1. Length composition of the beaked redfish taken with bottom trawls (solid line) and midwater trawls (broken line) on the Flemish Cap in 1972-74.

of redfish taken in both types of trawl were also rather similar (Fig. 2 and 3). The presence of females at maturity stages V, VI, VII and VIII in February is evidence of the approaching spawning (larval extrusion) period in the spring.

In March, the mature females migrate from the near-bottom to the pelagic zone, where effective fishing with midwater trawls occurs on the spawning concentrations. For this reason, the length and maturity composition of redfish taken by midwater trawl in March differs substantially from those taken by bottom trawl (Fig. 1 and 3). During this period the redfish in both the near-bottom and the pelagic zones have practically stopped feeding (Fig. 2).

By July, the mass extrustion of larvae is over, but some of the females remain in the pelagic zone, as indicated by the greater number of larger fish in the midwater than in the bottom trawl catches (Fig. 1). However, many of the females have by this time descended to the near-bottom zone, and females at maturity stages IX-II (post extrusion) (Fig. 3) were dominant in the catches of both the bottom and midwater trawls.

Redfish remaining in the pelagic zone in July feed intensively (Fig. 2). During August and September, redfish of all sizes and several maturity stages have been observed in the near-bottom zone, where intensive feeding also occurs. During October, the males and females migrate to the pelagic zone where they copulate. Mating is over by November, but most of the mature fish tend to remain in the pelagic zone, where considerably larger specimens are taken by midwater trawl in contrast to those taken by bottom trawl (Fig. 1).

It follows from the above observations that, during the seasons of larvae extrusion and mating, there are significant differences in the length and maturity compositions of redfish in the near-bottom and pelagic zones. However, during the winter, when redfish of all sizes and maturity stages occur at approximately the same depth along the slopes of the bank, the length compositions and other biological characteristics of redfish in bottom and midwater trawl catches are quite similar. This similarity supports the hypothesis that the Flemish Cap area contains a single population of redfish, separate components of which may be found during specific periods of the year with different biological features. Biochemical analysis of redfish taken with bottom and midwater trawls would be useful for confirmation or refutation of this conclusion.

Diurnal vertical migrations of redfish have been studied rather extensively (Konstantinov and Shcherbino, 1958; Templeman, 1959; Kelly and Barker, 1961, 1963; Chekhova, 1976). The volume of the catch and also the length composition and other biological characteristics of

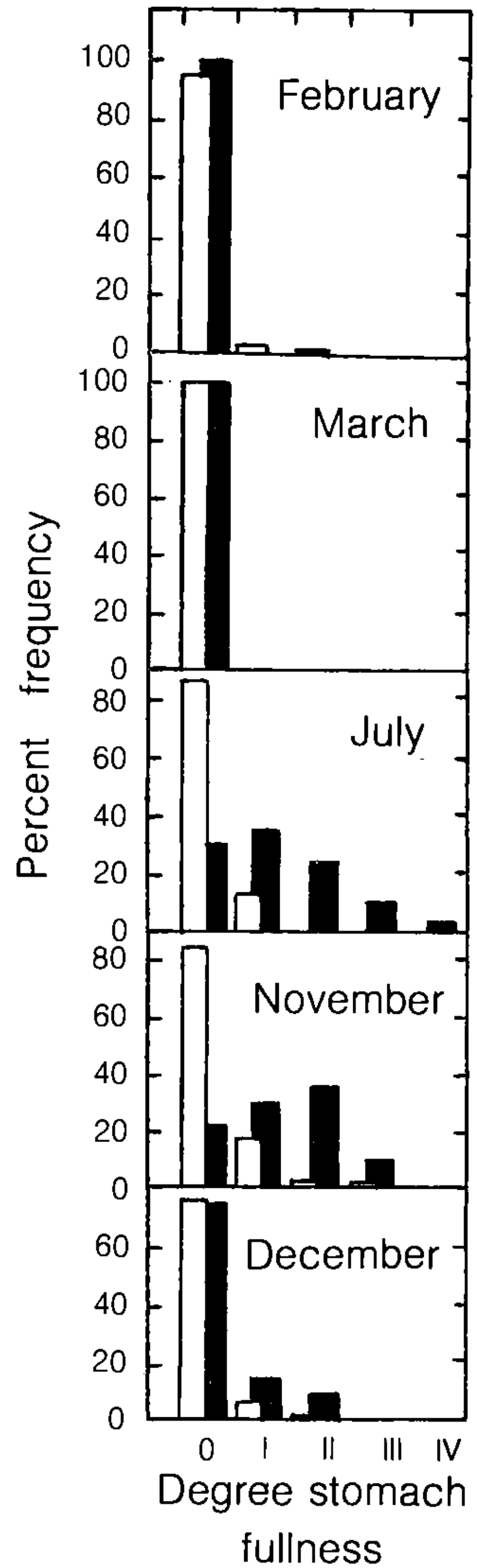

Fig. 2. Stomach contents of the beaked redfish taken with the bottom trawls (white columns) and midwater trawls (black columns) on the Flemish Cap in 1972-74.

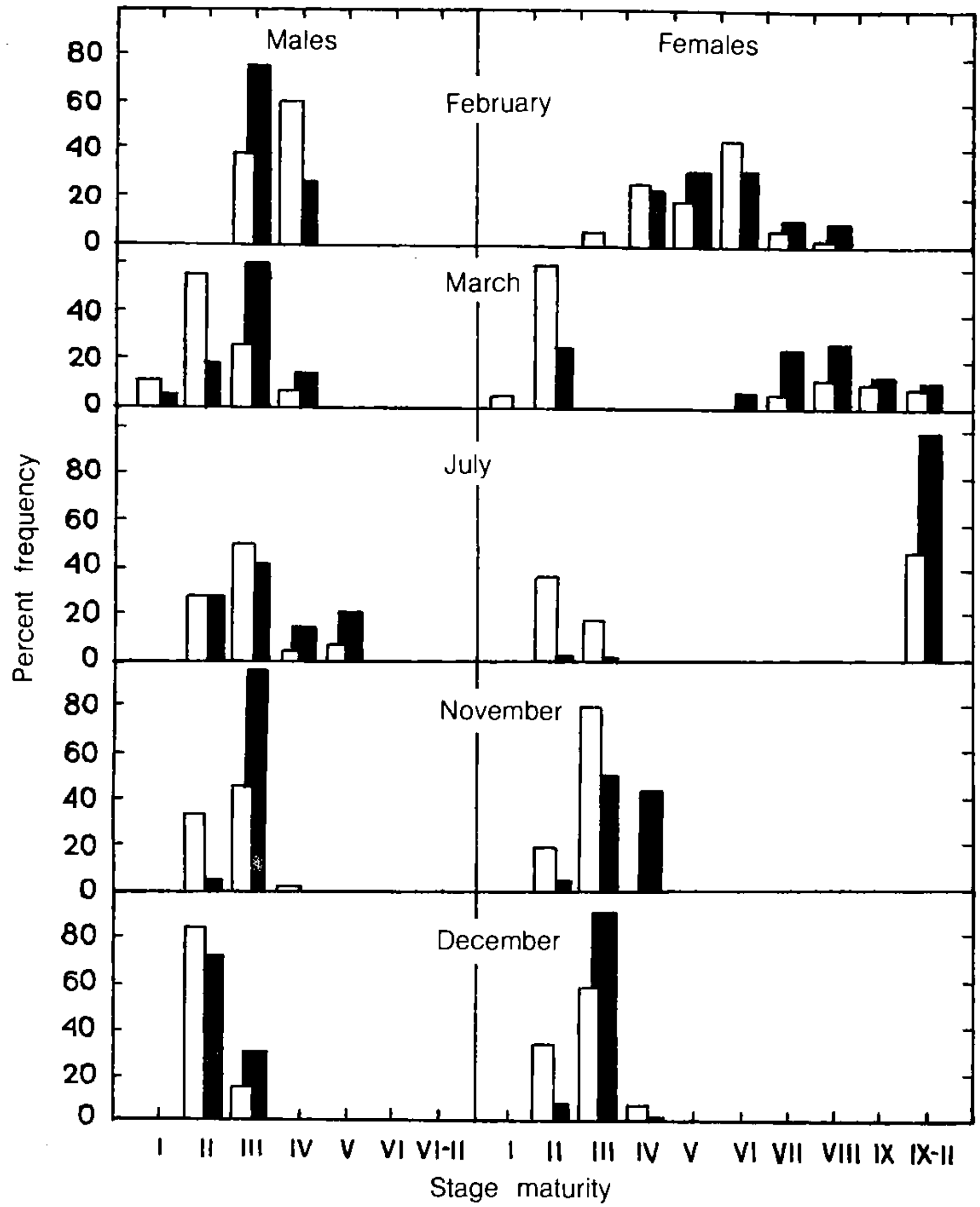

Fig. 3. Maturity stages of the beaked redfish taken with bottom trawls (white columns) and midwater trawls (black columns) on the Flemish Cap in 1972-74.

redfish may vary substantially during day and night fishing in the same area. For example, on the basis of a series of 356 trawl hauls on the north slope of Flemish Cap in March-April 1974, the average catch per hour fishing was greater with bottom trawl than with midwater trawl during the day-time when redfish were concentrated near the bottom, whereas during the early morning and evening hours, when redfish tended to migrate upward from the bottom, midwater trawl catches were greater than those with the bottom trawl (Fig. 4). It is therefore very important to take the time of the day into account when sampling is carried out for any kind of studies on redfish.

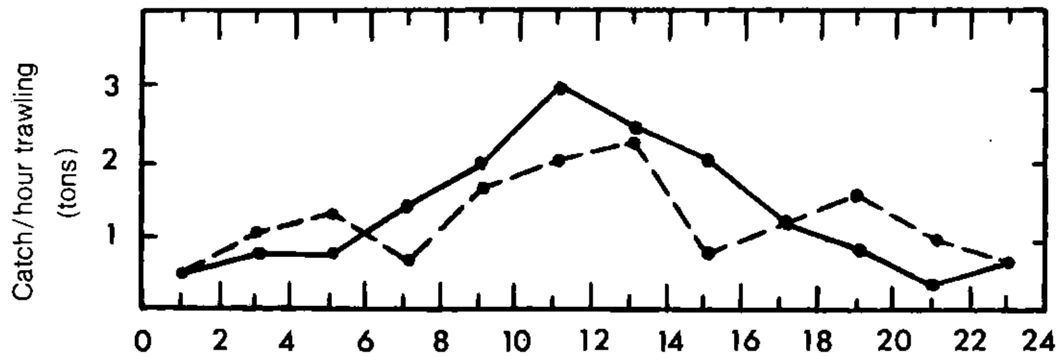

Fig. 4. Average catch of beaked redfish per hour trawling by the USSR large-capacity trawlers with bottom trawls (solid line) and midwater trawls (broken line) at different times of the day in the Flemish Cap area in March-April 1974.

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An Evaluation of the Status of Witch Flounder, *Glyptocephalus cynoglossus*, from ICNAF Divisions 2J, 3K and 3L[1]

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Abstract

The status of the witch flounder stock in ICNAF Divisions 2J, 3K and 3L is evaluated, using the Beverton and Holt (1957) yield-per-recruit model. The yield curves are essentially flat-topped with no definitive maximum. The fishing mortality values are averaged over the 1974-76 period and represent removals, averaging about 17,000 tons annually, from the stock during recent years.

Introduction

There was practically no fishery on this witch flounder stock before the early 1960's. In the early years of the fishery, catches were from the accumulated virgin stock and catch rates in the inshore Canadian fishery were relatively high. As catch rates declined, and the inshore populations became depleted, the inshore fishermen of Notre Dame, Bonavista and Trinity Bays moved progressively offshore. Also, during the late 1960's, USSR and Polish fleets exploited the offshore component of the stock in the area from Hamilton Inlet Bank (Div. 2J) southward to Funk Island (Div. 3K) (Table 1).

The fishery for various flatfish species has become of major importance to the inshore fishermen of the northeast coast of Newfoundland in recent years, especially since the recent decline in the traditional cod fishery in the area. Also, some fishing effort of the Canadian offshore fleet has recently moved to the area off northeast Newfoundland, following the decline of the redfish stock in the Gulf of St. Lawrence (Div. 4R) and of the flatfish stocks on the Grand Bank (Div. 3L, 3N and 3O). In the early months of 1977, witch flounder formed an important component of the catches of the Canadian offshore fleet from Div. 3K.

Nominal catches from Div. 2J, 3K and 3L increased from about 4,400 tons in 1965 to 23,000 tons in 1973 and then declined to 12,000 tons in 1975 and 1976 (Table 1), with Canada, Poland and USSR accounting for most of the total catch. This witch flounder stock has been regulated by catch quota since 1974 with an initial total allowable catch (TAC) of 22,000 tons. On the basis of an assessment in 1974 (Bowering and Pitt, MS 1974), the TAC was reduced to 17,000 tons for 1975 and has remained at that level for 1976 and 1977.

Materials and Methods

The assessment of this witch flounder stock was based on the assumption that Canadian inshore vessels and Canadian and European offshore fleets were exploiting the same population. Data used in the assessment were based on length and age samples from the Canadian gillnet fishery in Div. 3K for the years 1974-76, and from the Canadian offshore otter trawl fishery in Div. 3L for 1974-75 and in Div. 3K for 1976 (Fig. 1 and 2). Since the offshore samples were not representative of all segments of the stock for each year and quarter of year, and since sampling data were not available for the Polish and USSR fisheries, it was difficult to calculate realistic age compositions of the catches from the entire stock.

Estimates of total mortality (Z) were made from catch curves of age data from the 1974-76 gillnet and otter trawl samples separately. The numbers at age were then calculated from the landings by each gear and combined to give a weighted catch curve for both gears (Fig. 3). Gillnets used in the Canadian inshore fishery have a mesh size of 165-203 mm and the average mesh size of the otter trawl codend is about 130 mm.

Bowering and Pitt (MS 1974) indicated that the natural

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TABLE 1. Nominal catches (metric tons) of witch flounder from ICNAF Divisions 2J, 3K and 3L, 1965-76.

Year	Canada	Fed. Rep. of Germany	German Dem. Rep.	Poland	USSR	UK	Others	Total
1965	121	—	380	1,876	2,056	58	—	4,433
1966	187	—	1,045	559	1,868	29	—	3,688
1967	901	—	332	928	1,933	9	—	4,103
1968	446	—	358	1,990	7,834	33	—	10,661
1969	1,355	—	546	957	9,726	—	—	12,584
1970	4,020	—	508	3,566	9,934	—	—	18,028
1971	8,030	75	508	5,404	2,018	9	—	16,044
1972	5,520	7	645	4,013	7,016	225	—	17,426
1973	3,761	1,348	2,327	11,802	2,834	133	1,291	23,496
1974	1,868	1,082	272	5,302	6,917	29	485	15,955
1975	1,352	446	374	4,583	4,763	16	685	12,219
1976	2,085	1,321	110	4,029	4,597	2	—	12,144

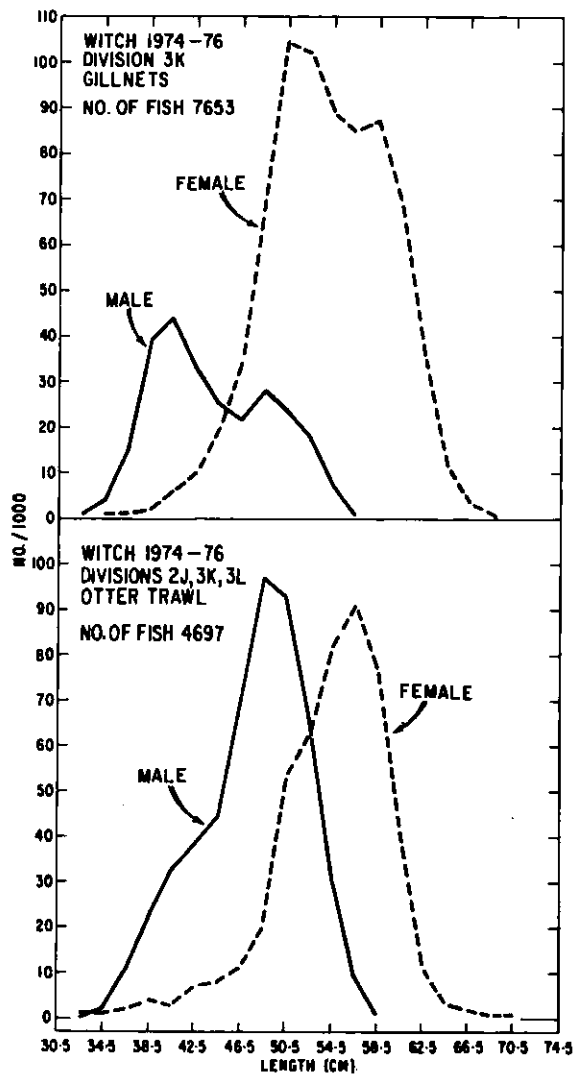

Fig. 1. Length composition of witch flounder by sex for commercial gillnet catches in Division 3K and otter trawl catches in Divisions 2J, 3K and 3L, 1974-76.

mortality coefficient (M) for males and females were probably maximal at 0.25 and 0.20 respectively. In an assessment of witch flounder on the Scotian Shelf, Halliday (1973) assumed values of M = 0.20 and M = 0.15 for males and females respectively. In view of the long life span of this species, M = 0.25 is probably too high, and consequently values of M = 0.10, 0.15 and 0.20 were used in computing the yield-per-recruit curves for the present assessment.

The mean selection lengths (l_c) for males and females were estimated from gillnet and otter trawl length frequency samples separately for each year of the 1974-76 period and then weighted by catch for each gear and year to produce average l_c values for the fishery during the period. The resultant l_c is 47.8 cm for males and 46.9 cm for females.

Von Bertalanffy growth equations were fitted for males and females separately, using the Ricker (1958) method (Fig. 4). The Beverton and Holt (1957) yield-per-recruit model was applied to the data for males and females separately (Fig. 5) for intervals of fishing mortality up to F = 2.5 on the basis of the following parameters:

Parameter	**Male**	**Female**
Asymptotic weight (W_∞)	2.148 kg	2.675 kg
Growth coefficient (K)	0.0679	0.0766
Arbitrary origin of growth curve (t_0)	-8.71 yr	-6.83 yr
Age at recruitment (t_ρ)	5 yr	5 yr
Age at mean selection length ($t_{\rho'}$)	11.52 yr	8.45 yr
Arbitrary maximum age (t_λ)	20 yr	23 yr

Results

The length and age range of witch flounder in the catches by offshore and inshore gears appear to be about the same. However, a much larger proportion of females than males are taken inshore, whereas approximately

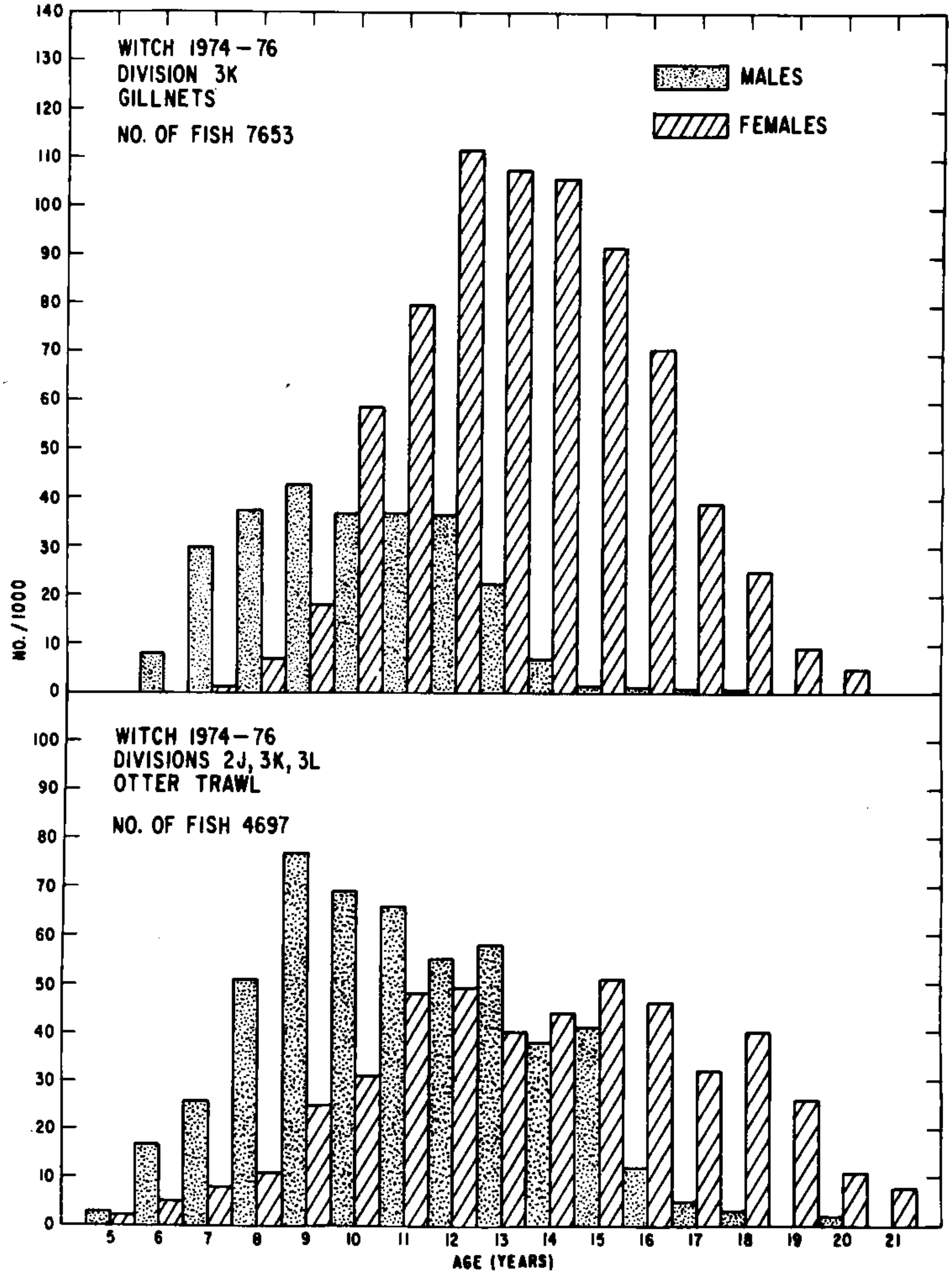

Fig. 2. Age composition of witch flounder by sex for commercial gillnet catches in Division 3K and otter trawl catches in Divisions 2J, 3K and 3L, 1974-76.

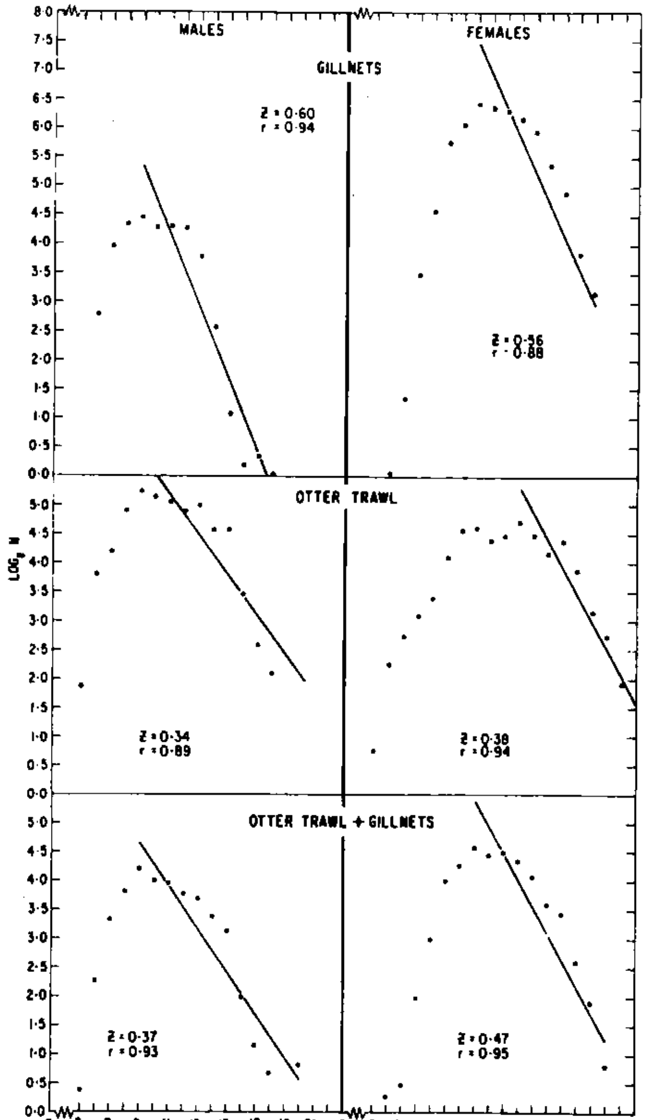

Fig. 3. Estimates of total mortality (Z) for witch flounder in Divisions 2J, 3K and 3L, based on the age composition data of Fig. 2.

equal numbers of males and females are taken offshore. Since the otter trawl used offshore is much less selective than gillnets and account for more than 80% of the total catch, the estimates of total mortality (Z) (Fig. 3) for the offshore fishery were considered to be more representative of that of the overall stock, and these are indicated on the yield-per-recruit curves as representing the average levels of fishing mortality for the 1974-76 period. Considering the possible differences in interpretation of ages and differences in areas sampled, the Canadian and Polish age compositions for 1976 offshore (Fig. 6) are not greatly different. However, since Polish age readings were grouped beyond age 15 for the males and age 17 for the females, these were not used in computing the catch curves (Fig. 3).

The yield-per-recruit curves are flat-topped with no definitive maximum for any of the M-values used up to F = 2.5. However, for F > 0.8 the increments of yield-per-recruit were extremely small. Estimated levels of $F_{0.1}$ (ICNAF, 1972) were 0.27, 0.38 and 0.43 for males and 0.21, 0.27 and 0.32 for females, based on M-values of 0.10, 0.15 and 0.20 respectively.

Estimates of total mortality (Z) for the offshore otter trawl fisheries were 0.34 for males and 0.38 for females. These values are all lower than $F_{0.1}$ at the assumed levels for M with the exception of that for females at M = 0.10. The estimates are probably representative of the fishery over the past 10 years when removals averaged about 14,000 tons annually. The average level of catch for the 1974-76 period was approximately 13,000 tons.

Discussion

The data necessary to do a more precise assessment of this stock, using more sophisticated analytical models, are presently lacking. Data on the location of juvenile fish are generally unavailable. While research surveys, both in the offshore and inshore areas, have yielded very small catches of juvenile witch flounder along the south and west coasts of Newfoundland (Div. 3P and 4R), none have been reported for the southern Labrador and eastern Newfoundland areas. It is possible that Div. 4R is the source of recruitment for the stock in Div. 2J, 3K and 3L, but no evidence is available to support this view.

For a proper assessment of this stock, it is important that data be collected in all three divisions of the stock area and from all components of the fishery. Bowering (1975) indicated that growth patterns vary considerably between localities. Witch flounder in the northern part of the stock area (Div. 2J and 3K) apparently have a faster growth rate and are larger at comparable ages than those from Div. 3L. Thus, offshore samples from Div. 3L are not entirely representative of catches from the stock as a whole. Data on catch and effort are also scanty. Some information on the Canadian gillnet fishery is available, but this represents only a small part of the total fishery. In any case, these data may not be indicative of stock abundance, since the gillnet fishery has moved progressively offshore as catch rates in the inshore areas declined.

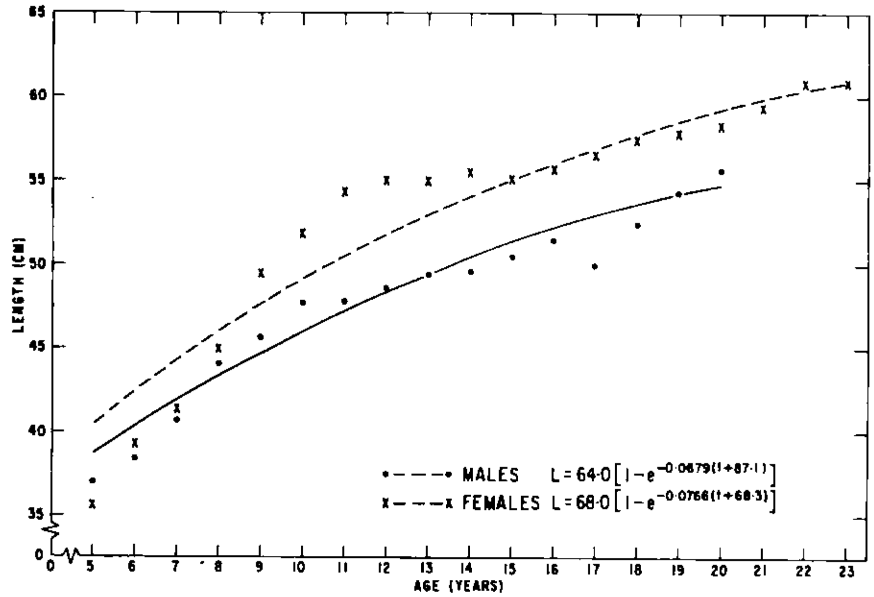

Fig. 4. Growth curves for male and female witch flounder in Divisions 2J, 3K and 3L, based on commercial data for 1974-76.

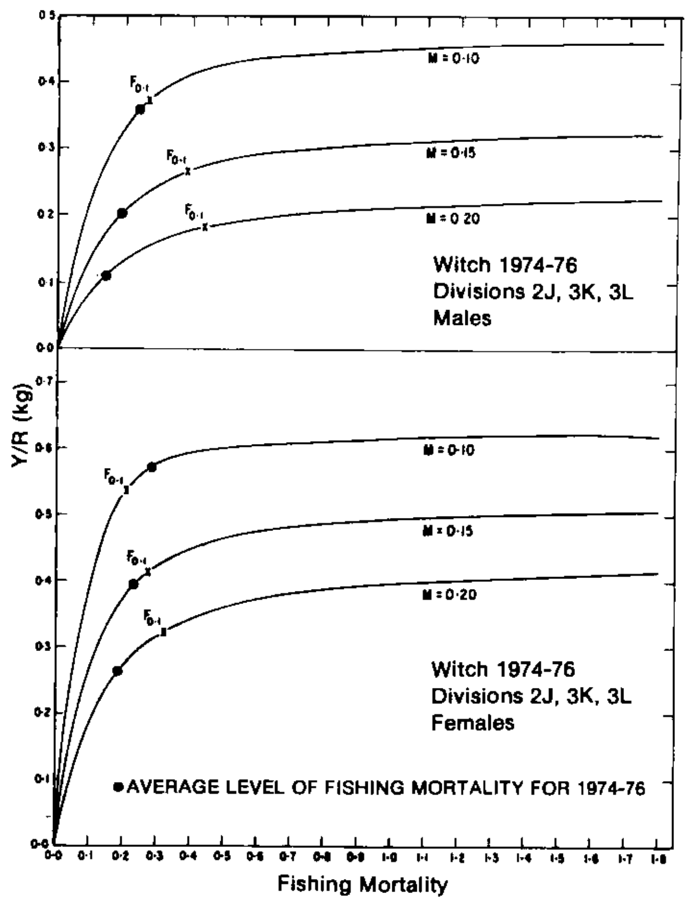

Fig. 5. Yield-per-recruit curves for male and female witch flounder in Divisions 2J, 3K and 3L, based on commercial data for 1974-76.

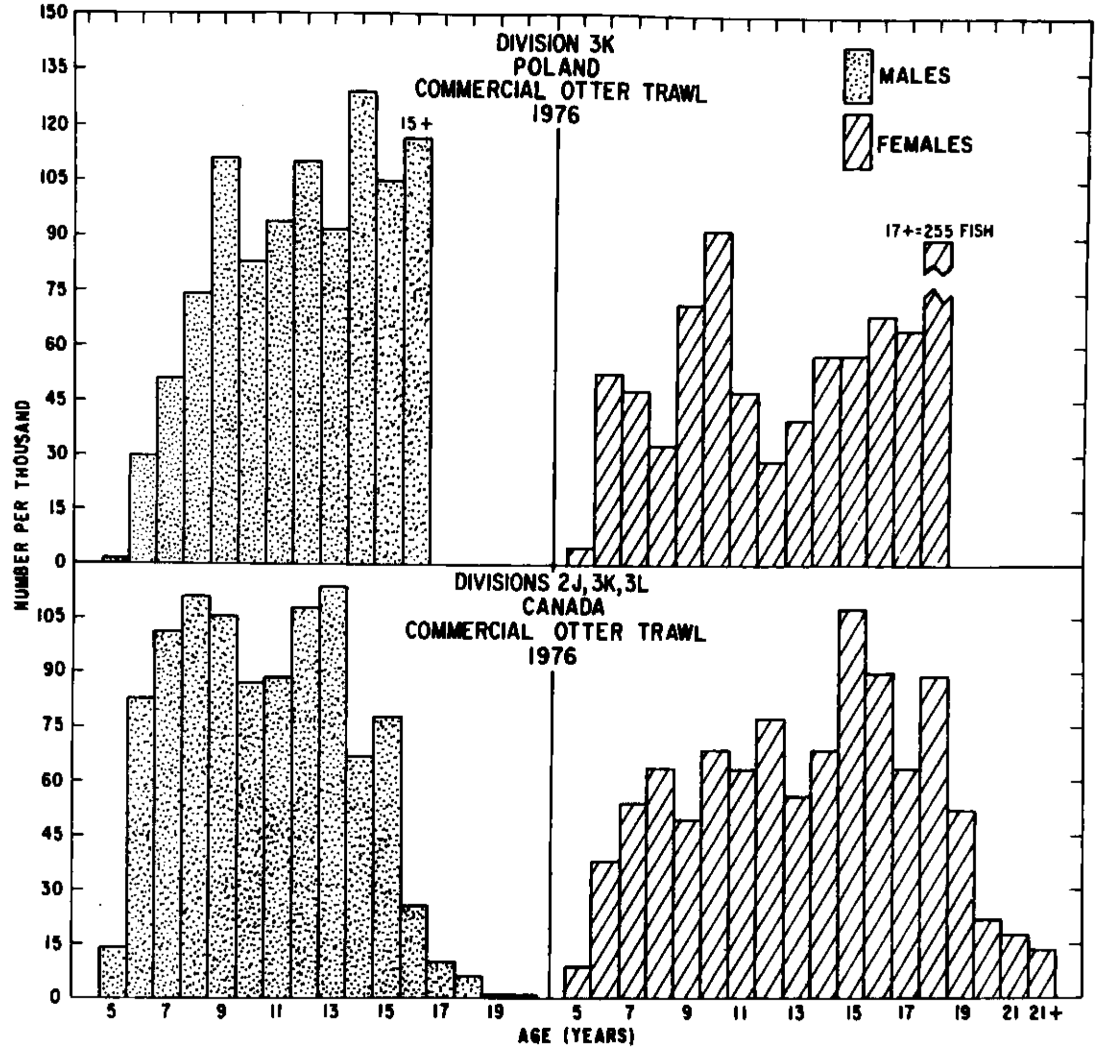

Fig. 6. Age compositions of witch flounder in Polish and Canadian otter trawl catches in Divisions 2J, 3K and 3L, 1976.

The level of fishing during the past 10 years, as reflected in the catch curves for 1974-76 (Fig. 3), is generally below the $F_{0.1}$ level for both sexes, except for females at M = 0.10. The annual catch during 1974-76 ranged from 12,000 to 16,000 tons, which have been below the TAC quota of 17,000 tons, established on the basis of an assessment by Bowering and Pitt (MS 1974).

The decline in the Canadian catch since 1971 (Table 1) is possibly more the result of weather and ice conditions and problems in the fishing industry rather than to declining abundance. In the absence of a more precise assessment of the fishery based on analytical methods, there appears to be no reason to change the TAC from the current level of 17,000 tons.

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Estimates of Natural Mortality for the Silver Hake Stock on the Scotian Shelf [1]

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Abstract

Estimates of natural mortality for silver hake, based on data of catch and population size (in numbers at age) and on fishing effort data, ranged from 0.34 to 0.55 with a mean estimate of 0.45. Omitting the less reliable estimate of 0.55, the average of the remaining estimates indicates that M = 0.40 is appropriate for use in assessment of the silver hake stock on the Scotian Shelf.

Introduction

The Virtual Population Analysis (VPA) technique requires that a known or assumed value of natural mortality (M) for all age-groups be used in the computations, and the reliability of the stock size estimates derived from the calculations depends critically on the reality of this parameter. The silver hake stock on the Scotian Shelf (ICNAF Divisions 4VWX) has recently been assessed by Noskov (MS 1976a, MS 1976b), Doubleday *et al.* (MS 1976), and Doubleday and Hunt (MS 1976), with values of M ranging from 0.4 to 0.8. The present study utilizes existing data on silver hake and various techniques of estimating natural mortality rates in an effort to determine the best estimate of M for use in stock assessment.

Materials and Methods

The primary source of data used in this study is the paper by Doubleday *et al.* (MS 1976), from which such material as fishing effort, in hours and days fished, catch in numbers at age and population size in numbers at age were derived. Due to the high variability of effort data in hours fished, these data were used in only one of the five methods of estimating natural mortality, fishing effort in days fished being used in the other cases.

The fishing effort for silver hake, as used in the present analysis, is based entirely on USSR data, which represented more than 97% of the total catches reported during the 1963-75 period for which data were analyzed.

The methods applied for computing the natural mortality estimates are not substantially different, but the analysis of data from various viewpoints provides estimates of M, the average of which would be expected to be close to the actual value.

Results and Discussion

The numbers-at-age of fish caught per hour fished was computed from the age composition of the catch in each year and the standardized fishing effort for USSR vessels. The natural logarithms of these values were plotted against age to obtain the catch curves of the 1963 to 1970 year-classes (Fig. 1). Total mortality estimates (Z) were derived from the slopes of these catch curves and the values for the 1966-70 year-classes were plotted against the average of the fishing effort values involved in the determination of each Z value (Fig. 2). The resulting regression gave an M-value of 0.34.

Doubleday *et al.* (MS 1976) used an assumed value of M of 0.40 in their virtual population analysis of silver hake on the Scotian Shelf. If this assumed value of M is close to the actual value, a regression of the average values of F from VPA on fishing effort should intercept the F-axis at F = 0 or be very close to it. The resulting regression of fishing mortality for fully-recruited age-groups for the VPA gave an intercept of 0.0016 for an M-value of 40.0016 (Fig. 3).

The VPA technique gives an estimate of the number of fish in each year-class at the beginning of each year. In following the different year-classes from year to year, these estimates represent the individuals which survive the effects of natural and fishing mortality and thus provide estimates of the survival rate(s). From these were obtained total mortality values for each age by year-class, and the

[1] Submitted to the June 1977 Annual Meeting as ICNAF Res.Doc. 77/VI/6.

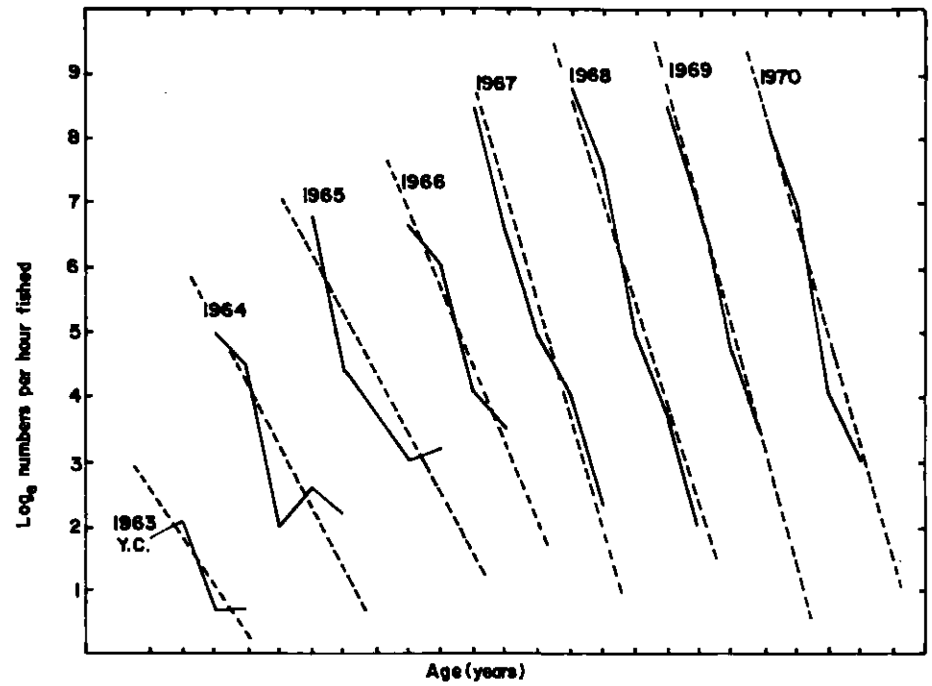

Fig. 1. Catch curves for the 1963-70 year-classes of silver hake on the Scotian Shelf.

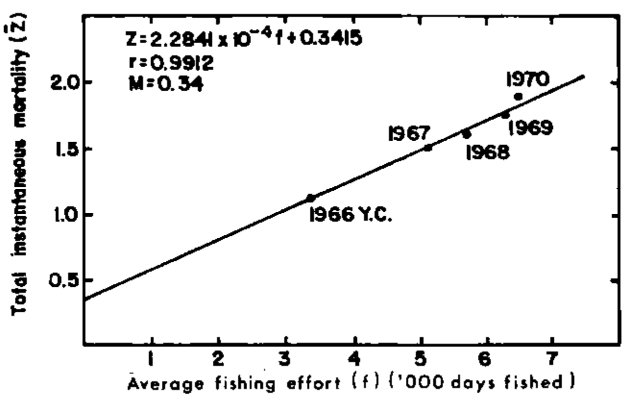

Fig. 2. Regression of total mortality ($\bar{Z}$) for fully recruited age-groups, from year-class catch curves, on average fishing effort for silver hake on the Scotian Shelf.

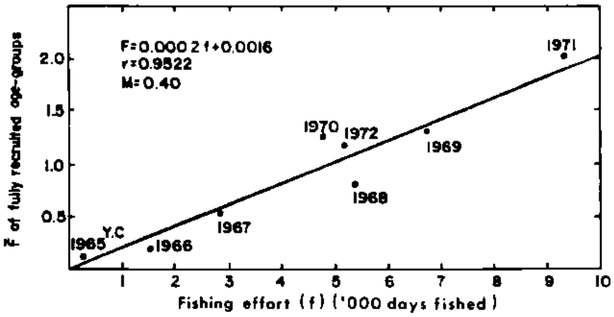

Fig. 3 Regression of fishing mortality ($\bar{F}$) for fully recruited age-groups from VPA on fishing effort for silver hake on the Scotian Shelf.

average Z-values were plotted against the average fishing effort for the years involved in each case. The resulting regression gave an estimate of M of 0.49 (Fig. 4).

The level of exploitation of silver hake has varied considerably during the 1963-75 period. The 1963 year-class had a low level of exploitation during 1966-68 with an average catch in these years of just over 5,000 tons, whereas the 1970 year-class had a period of high exploitation during 1972-75 with an average catch of 155,000 tons. The total mortality (Z) value estimated for the 1963 year-class during the period of low exploitation was 0.46, which can be considered a maximum value of M. If

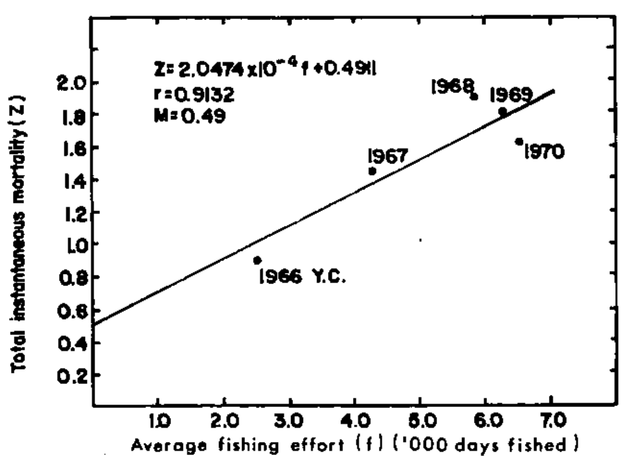

Fig. 4. Regression of total mortality ($\bar{Z}$) for fully recruited age-groups from VPA on average fishing effort for silver hake on the Scotian Shelf.

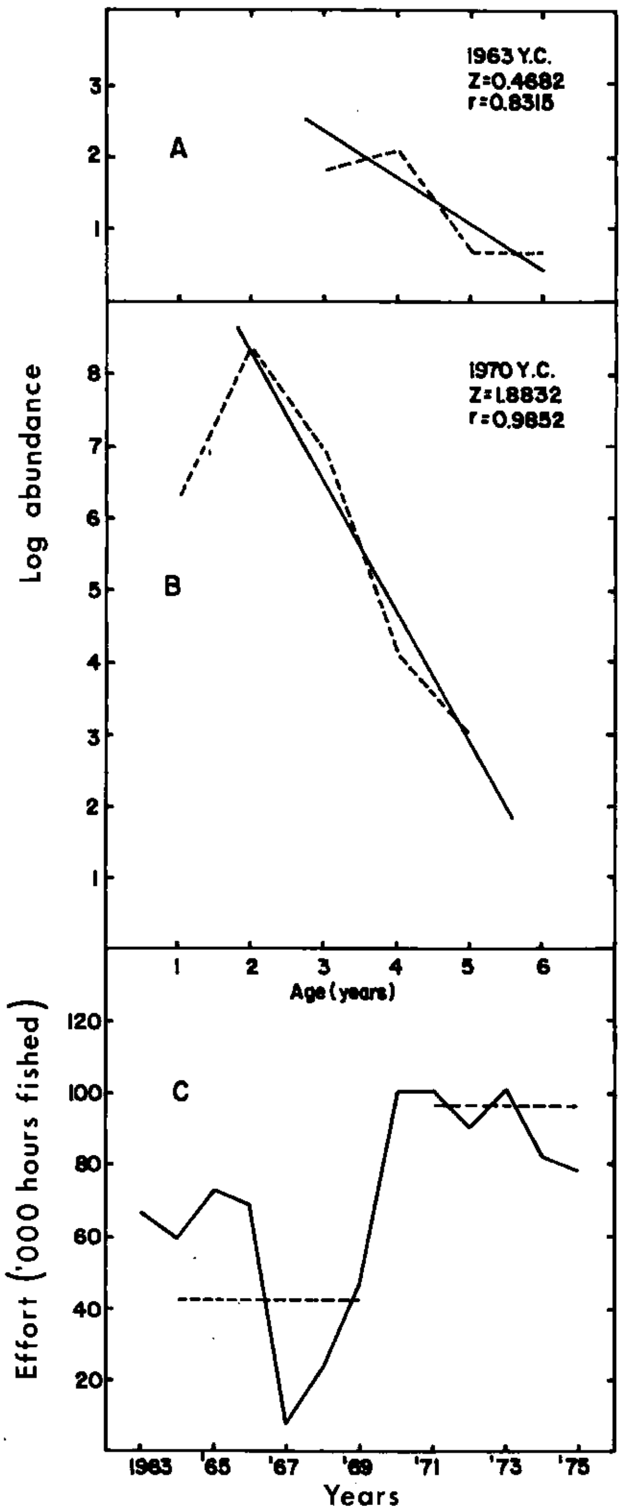

Fig. 5. Catch curves for the 1963 (A) and 1970 year-classes (B), and trends in fishing effort (C) for silver hake on the Scotian Shelf.

the fishing mortality is assumed to be very small (say, about 0.06), the natural mortality is therefore estimated at 0.40 (Fig. 5).

A total mortality estimate of Z = 0.7288 was obtained from the catch curve for the 1964 year-class, whereas Z = 1.8832 was estimated for the 1970 year-class (Fig. 1). Average fishing effort values for the two periods in which these year-classes were exploited were 2,937 and 6,494 days fished respectively. Applying the method of Silliman (1943), a value of M = 0.55 is obtained.

The estimates of M, obtained by the various methods, for silver hake on the Scotian Shelf are as follows:

	Method	M
1.	Z of year-class catch curves versus fishing effort	0.34
2.	F of VPA versus fishing effort	0.40
3.	Z of year-classes from VPA versus fishing effort	0.49
4.	Catch curve for low effort period	0.40
5.	Silliman (1943) method	0.55
	Average	0.44

The estimates of natural mortality range from 0.34 to 0.55 with an average value of 0.44. In computing the natural mortality by the Silliman method, data on fishing effort in days fished (days fished = 0.0641 × hours fished; r = 0.9233) were used for the years 1963-66 only, and the estimate for M may be less reliable than the values obtained by the other methods. If this estimate of M is omitted, the average of the remaining four estimates is 0.41. It seems therefore that an M-value of 0.40 is more appropriate for use in assessment of the silver hake stock on the Scotian Shelf than values ranging up to 0.8.

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Age, Growth and Distribution of Silver Hake, *Merluccius bilinearis*, on the Scotian Shelf[1]

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Abstract

Modal analysis of silver hake length frequencies indicate well-defined modes for both sexes in the 10-35 cm range which are consistent from year-to-year within limits of anticipated year-class variations. Von Bertalanffy growth parameters fitted to calculated mean length-at-age data appear to adequately describe growth of silver hake in the first 5 years. Ages determined from otoliths are in close agreement with those calculated from modal analysis. Size-segregated and seasonal differences in silver hake distributions of the Scotian Shelf stock complex are indicated.

Introduction

Recent controversy over the ageing of silver hake, *Merluccius bilinearis*, from otoliths has given rise to variation in technique and attempts to resolve differences through international discussion and workshops (Anderson and Nichy, MS 1975; Hunt, MS 1976, MS 1977). Results of otolith exchanges, workshops and other research have identified the problem as differing opinions on adult growth rates for this species which are unlikely to be resolved without some form of indirect evidence of age and growth. While hyaline (translucent) and opaque zones are evident in the otolith, separation of annuli, spawning checks, and other zones of slow growth cannot be accomplished without some prior index of growth in relation to probable size-at-age. To date, however, a mutually accepted age-length key and definition of associated growth parameters for Northwest Atlantic silver hake have not been resolved.

In an attempt to provide evidence of growth and length-at-age and to bypass the otolith controversy, an indirect method of ageing by length frequency modal analysis has been developed. This report uses a technique suggested by Buchanan-Wollaston and Hodgson (1929) and adapted to a desk-top calculator and plotter (Doubleday and Halliday, MS 1975) to analyze silver hake length frequencies into modal components as evidence of length-at-age and growth characteristics.

Materials and Methods

Trawl surveys conducted by Canada using a No. 36 Yankee otter trawl and by the USSR have provided length frequencies of silver hake caught on the Scotian Shelf and adjacent areas from 1970 to 1976 (Doubleday, *et al.*, MS 1976; Noskov, 1976) and these data were used throughout the analyses (Table 1). Separate length frequencies by sex were available in each of the years for Canadian data, while all USSR data were combined by sex for October. Length frequencies of commercial catches were not considered because of a two centimeter (cm) length interval as opposed to the 1 cm interval for trawl surveys and the resultant reduction in resolution.

A sample of 742 silver hake otoliths collected in July of 1976 in ICNAF Divisions 4WX were examined for age following guidelines and recommendations suggested at a recent ageing workshop (Hunt, MS 1977). These otoliths had been stored in glycerine and were examined whole in alcohol using reflected light. Hyaline zones were counted and age defined as the number of completed zones. Separate age-length keys by sex were then generated from these data. Otoliths examined by Hunt (MS 1977) from the same area and time and for which agreed ages were obtained were included in the age-length key for comparison.

To assess the accuracy of modal analysis, the catch length frequency of the same cruise as that from which otoliths were examined was resolved into age-groups and a calculated age-length key derived. This length frequency was then proportioned on the basis of the otolith age-length key and the two independent keys examined for differences.

Modal analysis of length frequencies assumes a normal distribution of length-at-age for each group and

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TABLE 1. Length frequencies of silver hake from research cruises on the Scotian Shelf during 1970–76.

Length	1970			1971		1972			1973				1974						1975			1976	
(cm)	Mar 4WX	June 4W	July 4WX	Mar 4WX	July 4WX	Mar 4WX	July 4WX	Oct[a] 4W	July 4WX	Oct[a] 4W	Oct 4WX	Dec 4WX	Mar 4WX	Mar 4WX	June 4W	July 4V	July 4WX	Oct[a] 4W	Mar 4WX	July 4WX	Oct[a] 4WX	Mar 4WX	July 4WX
5	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	1	1	—	—	—	—	—	4	—	—	—	2	—	—	—	—	—	3	—	—	—	—	—
7	1	—	—	—	—	—	—	13	—	3	—	—	—	—	—	—	—	8	—	—	—	—	—
8	—	—	—	—	1	—	—	13	—	3	—	2	—	—	—	—	—	10	—	—	—	—	—
9	—	—	—	1	—	1	—	22	—	1	—	4	—	—	—	—	—	5	3	—	—	—	—
10	8	8	1	1	3	1	—	22	—	—	—	4	—	—	—	—	—	3	8	—	—	—	—
11	10	12	—	—	—	7	1	18	1	—	—	3	—	2	3	—	2	1	6	—	—	—	—
12	8	43	1	6	1	10	—	5	1	—	—	2	—	1	5	—	—	2	21	—	—	—	—
13	11	46	—	2	—	13	3	1	5	—	—	—	—	5	16	—	1	1	27	—	—	3	—
14	12	65	4	8	10	10	7	—	12	—	—	—	—	2	35	—	4	—	7	1	—	4	1
15	4	51	10	1	20	9	16	—	23	—	1	—	—	2	67	1	10	1	8	3	—	1	2
16	3	33	30	5	24	8	23	—	31	—	2	—	—	—	127	5	15	—	6	9	1	3	3
17	4	11	34	4	37	10	42	2	60	—	5	1	—	—	141	11	40	—	8	16	3	—	14
18	—	1	74	2	83	7	55	1	93	3	8	2	—	—	81	27	80	7	1	22	8	1	21
19	1	1	83	—	64	2	68	4	152	11	12	2	—	—	74	35	117	4	—	28	15	—	34
20	2	—	125	—	45	2	75	21	153	25	68	5	—	3	28	47	153	7	1	62	20	3	86
21	12	—	150	6	33	4	45	64	154	49	118	13	—	5	18	41	116	18	4	70	48	2	95
22	22	—	169	8	14	15	40	112	130	83	136	21	3	31	11	16	98	37	11	66	72	5	93
23	59	—	111	21	11	25	31	113	61	107	110	22	—	69	15	6	46	69	18	49	95	6	46
24	86	—	68	72	5	59	22	163	35	79	61	35	5	107	48	8	48	76	43	26	164	13	32
25	97	—	75	114	14	69	26	90	58	65	23	15	9	86	131	27	106	85	64	14	147	9	30
26	101	1	191	173	27	51	42	59	255	47	14	12	1	44	259	86	274	94	53	13	124	1	79
27	28	—	362	146	95	24	72	50	503	34	22	8	4	21	403	124	504	69	56	22	69	5	184
28	39	—	494	107	153	2	77	40	738	54	52	3	4	15	373	123	563	52	36	47	35	5	267
29	31	—	428	131	142	3	45	30	551	89	69	7	2	13	357	82	469	60	13	99	38	1	263
30	29	—	298	172	110	—	50	38	362	103	69	3	7	14	356	43	391	97	8	77	24	1	206
31	18	—	198	128	90	—	33	30	179	84	55	3	4	9	400	20	305	92	1	86	41	—	151
32	12	—	103	67	68	2	36	33	88	63	32	—	4	7	536	13	201	86	5	53	28	—	110
33	3	—	79	41	47	—	35	16	79	24	16	1	5	1	519	7	158	43	5	55	26	1	80
34	1	—	58	12	27	—	30	11	45	16	14	—	1	6	469	8	101	26	1	27	20	—	47
35	2	—	31	4	9	—	21	5	47	13	6	—	1	3	352	7	57	13	1	17	7	—	35
36	—	—	30	4	7	—	13	5	40	11	—	—	1	2	230	3	47	6	4	14	5	—	44
37	1	—	27	3	9	—	8	5	36	3	7	2	1	1	155	1	37	5	4	6	3	—	36

[a] Data from Noskov (MS 1976) reduced to per mille.

requires a minimal overlap between adjacent ages. Accuracy of this method depends on sufficient observations at relatively small length intervals over the entire length range of a species and, for silver hake, this implies a length frequency from 0 to 50+ cm at intervals of 1 cm or less. Both the Canadian and USSR trawl survey data conform to these conditions. In general, the technique of modal analysis used here consists of plotting the natural logarithm (*ln*) of the frequency at each length interval and fitting parabolas to apparent modes by the method of least squares using a Hewlett-Packard 9821A calculator and plotter[2]. The natural logarithm of a normal distribution

$$ln\,(Y) = ln \left\{ \frac{k}{\sigma\sqrt{2\pi}} \right\} - 0.5 \left\{ \frac{X-\mu}{\sigma} \right\}^2$$

where k is the total number, μ is the mean length and σ is the standard deviation, can be reduced to a parabola of the form

$$ln\,(Y) = a_0 + a_1X + a_2X^2$$

where $\mu = \frac{-a_1}{2a_2}$

$$\sigma = \sqrt{\frac{-1}{2a_2}}$$

and $k = \sqrt{\frac{-\pi}{a_2}} \cdot \text{EXP} \left\{ a_0 - \frac{a_1^2}{4a_2} \right\}$

A parabola was fitted to the left-most part of the frequency distribution (i.e. smallest lengths) and the contribution of this component subtracted from the total frequency and the residual treated as a new length frequency. This process was repeated until all modes had been resolved or until the degree of overlap in adjacent modes made futher resolution impossible.

Canadian survey results were analyzed in this way by sex to ascertain if significant differences existed in mean

[2] Program listing available from author.

length-at-age for males and females. Length frequencies by sex from the same cruise were examined and, if differences in modal length were present for the same relative age group, these were attributed to differing growth rates between males and females.

To assign a specific age to modal lengths, it was necessary to establish a time interval required to reach that length. This was accomplished by selecting January 1970 as an arbitrary starting date and then plotting all modal lengths from available length frequencies against elapsed time from this date. For example, modal lengths of 20 and 29 cm from a length frequency of silver hake caught in March 1974 (mean date of a cruise) were plotted as 20 cm and 50 months and 29 cm and 50 months. All resolved modes were plotted in this way and obviously different groups of fish within the same length frequency were plotted with a different symbol. Data points were then joined to give a series of growth curves under the following conditions: (a) modal length of a group of fish would not be appreciably less in successive months; and (b) a mode of fish would not "disappear" from the length frequency at the next time interval except through the effect of mortality.

Lacking sufficient length frequencies of fish less than 10 cm, an average length in October was calculated from the USSR data and this point used in successive years (i.e. 9, 21, 33 months). In addition, 1 July was accepted as a mean date of spawning (Doubleday and Halliday, MS 1975) to give an intercept for zero length in successive years.

From the ensuing curves, lengths at 6, 12, 18... months were calculated and the mean of these values assumed to be the best representation of length-at-age for silver hake. Von Bertalanffy growth curves were then fitted to these values for both males and females by the method of Beverton (1954).

To show distribution and relative abundance of silver hake catches from Canadian trawl surveys, the total catch per tow (in numbers) and the proportion of the total less than 25 cm in length were plotted on maps of the Scotian Shelf. Open and solid squares were used, respectively, to indicate catches $\leq$10, $\leq$50, $\leq$100, $\leq$200 and >200 fish per 30-minute tow over the Scotian Shelf.

Results

A length frequency generated by summing known normal distributions over the total length range is shown in Fig. 1 and parameters of normal components derived from modal analysis are indicated. These indicate very good agreement with actual values and validate this technique for resolution of Gaussian components from frequency distributions.

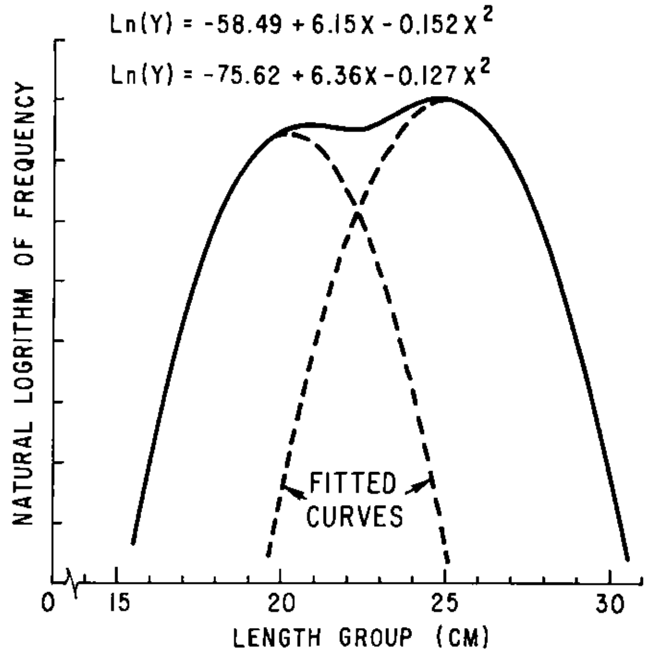

Fig. 1. Resolution of normal components by modal analysis from a silver hake length frequency generated by summing known normal distributions.

Modal lengths derived from length frequencies are shown in Table 2. A total of 21 frequencies were analyzed to obtain mean length-at-age for relative age groups, in most cases, by sex. Examination of modal lengths for males and females from the same cruise show little variation up to about 25 cm but indicate a consistent trend towards larger lengths for females over this length compared to males at the same relative age. Consequently, modal lengths for males and females were treated separately, although modal lengths from combined frequencies up to 24 cm were accepted on the basis of minimal difference between sexes. Modal lengths from Table 2 plotted against time elapsed from 1 January 1970, are shown in Fig. 2(A) and 2(B). The smallest observed modal lengths are at 9.0 and 8.4 cm in October 1972 and 1974, and the next series of modes are at about 20 cm in July-August. Assuming fish with a modal length near 9 cm in October to be a recruiting year-class and that this year-class would be well represented in the following July-August period, it follows that growth in this time period must be 10-12 cm. An average October length of 8.73 cm was calculated and used for successive October lengths. Accepting July as a probable spawning month (Noskov, MS 1976), a length of zero was entered for successive July

TABLE 2. Modal lengths of silver hake from research vessel cruises on the Scotian Shelf during 1970-76.

Year	Month	Div.	Sex	A		B		C		D	
				Mean	σ	Mean	σ	Mean	σ	Mean	σ
1970	Mar	4WX	M+F	—	—	12.68	2.11	24.90	1.94	29.94	1.95
	June	4W	M+F	—	—	13.83	1.67	—	—	—	—
	July	4WX	M	—	—	18.72	1.76	27.53	1.67	—	—
			F	—	—	19.94	1.97	28.87	1.44	—	—
1971	Mar	4WX	M	—	—	—	—	26.51	1.83	29.67	0.78
			F	—	—	—	—	26.62	1.78	31.38	1.13
	July	4WX	M	—	—	18.62	1.90	27.90	1.57	—	—
			F	—	—	19.19	2.63	29.37	1.66	33.13	1.64
1972	Mar	4WX	M+F	—	—	14.69	2.55	24.72	1.66	—	—
	July	4WX	M	—	—	19.28	2.29	26.81	1.53	30.98	1.54
			F	—	—	19.95	2.56	28.07	1.54	33.14	2.20
	Oct	4W	M+F	9.04	1.67	23.83	1.80	29.98	2.89	—	—
1973	July	4WX	M	—	—	20.42	1.92	27.73	1.11	32.40	1.12
			F	—	—	20.05	2.02	28.85	1.42	—	—
	Oct	4W	M+F	—	—	23.08	1.88	30.17	1.93	35.86	1.70
	Oct	4WX	M	—	—	21.88	1.66	28.60	1.52	—	—
			F	—	—	22.06	1.68	30.49	1.77	34.69	1.45
	Dec	4WX	M+F	—	—	23.44	2.09	—	—	—	—
1974	Mar	4WX	M	—	—	24.04	1.19	28.38	0.93	—	—
			F	—	—	24.41	1.71	30.55	1.31	34.69	1.45
	June	4W	M+F	—	—	16.95	2.15	28.05	2.10	33.24	1.80
	July	4Vs	M	—	—	19.77	1.86	26.94	1.42	—	—
			F	—	—	19.77	1.86	28.18	1.57	34.39	1.28
	July	4WX	M	—	—	19.91	2.20	27.88	1.72	31.52	1.58
			F	—	—	20.35	1.86	28.57	1.77	32.70	1.79
	Oct	4W	M+F	8.41	2.81	25.40	2.56	31.70	1.60	—	—
1975	Mar	4WX	M	12.73	1.56	25.61	2.09	—	—	—	—
			F	12.73	1.56	25.96	2.02	—	—	—	—
	July	4WX	M	—	—	21.26	2.17	29.41	1.60	—	—
			F	—	—	21.38	2.05	—	—	—	—
	Oct	4W	M+F	17.67	1.05	24.46	2.39	31.80	2.00	—	—
1976	July	4WX	M	—	—	21.18	1.93	28.11	1.71	32.98	1.27
			F	—	—	21.14	1.99	29.87	1.97	—	—

observations. By joining observed lengths and extrapolating through estimated values, a series of probable growth curves was generated as shown in Fig. 2(A) and (B) for males and females. These curves appear to be smooth and show a tendency towards a typical Von Bertalanffy growth curve. Comparison of curves for males and females confirms a different growth rate between sexes with length-at-age diverging at about 0.5 cm per year above 24 cm in length.

Mean length-at-age at six month intervals were obtained by determining lengths in January, 1970-76, and July, 1970-76, from the curves (Fig. 2) and assigning respective ages to the calculated length and results are shown in Table 3. Von Bertalanffy parameters were derived for these mean length-at-age and the resultant curves are shown in Fig. 3(A) and 3(B) and appear to adequately describe growth of silver hake, at least over the initial 4 years of life.

The asymptotic length calculated for females (37.88 cm) may be lower than the actual value based on observed lengths (Table 1) because of few resolved modes above 30 cm. However, inclusion of fish from a closely related species (*Merluccius albidus*) in length frequencies may incorrectly indicate the presence of fish above 40 cm in length. This species has been encountered on Canadian research cruises, generally at lengths above 40 cm and requires careful examination to separate it from *M. bilinearis* (personal observation).

Examination of derived growth curves (Fig. 2(A) and 2(B)) indicate some variation in growth rate between the 1968 and 1975 year-classes.

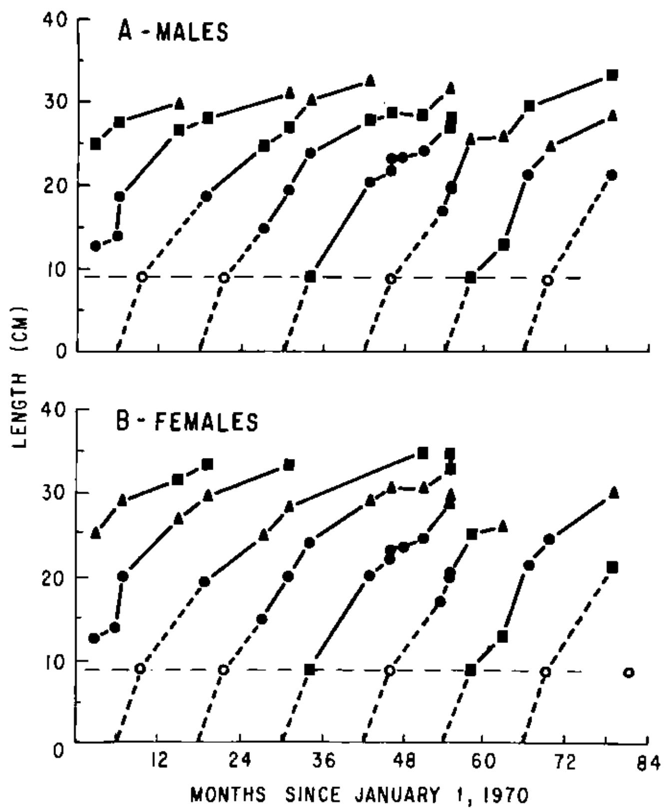

Fig. 2. Modal lengths of silver hake from research cruises (from Table 2) plotted against time elapsed since 1 January 1970.

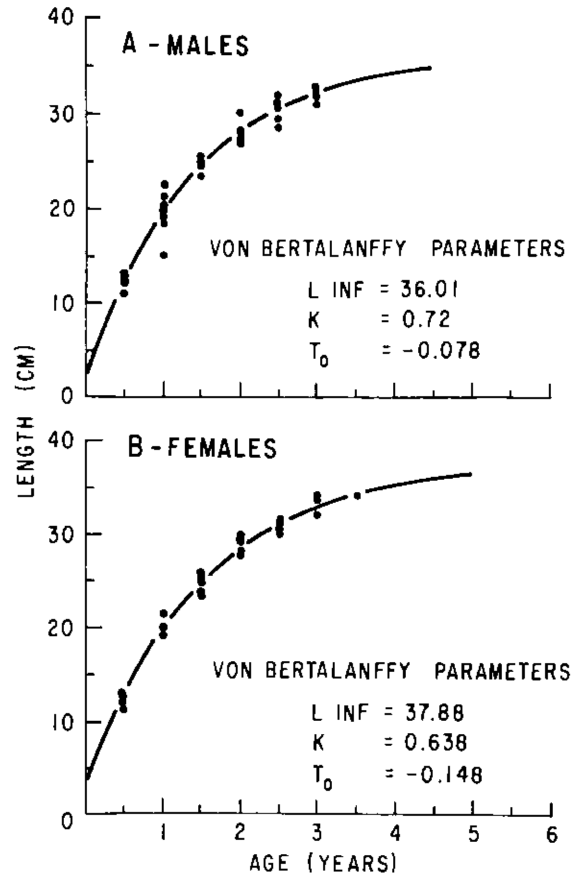

Fig. 3. Mean lengths-at-age at six-month intervals (January and June) from the curves in Fig. 2, and fitted von Bertalanffy growth curves.

The age-length key by sex derived from otoliths is presented in Table 4. These data indicate well defined age-groups at 1 and 2 years for both males and females, and some divergence in the mean length-at-age by sex is evident at age 2 and older. Age 3 and older males were poorly represented in the sample but age 3+ females accounted for 22% of the total. Females at age 3 show a wide range in length (28–44 cm) which might be attributed to the proportion mature at age 3. Doubleday and Hunt (MS 1976) found considerable variation in the percent mature at age 2 which could influence the size at age 3 (i.e.,

TABLE 3. Calculated mean lengths-at-age from the curves of Fig. 2 for silver hake on the Scotian Shelf.

Age (months)	Mean lengths-at-age (cm)							Average
				Males				
6	12.4	12.5	12.8	11.8	12.6	11.0	—	12.18
12	18.2	18.6	19.2	20.4	21.2	19.9	22.5	19.61
18	23.6	23.5	25.2	23.5	24.8	25.5	—	24.35
24	27.5	27.8	26.9	27.8	28.2	27.5	30.0	27.96
30	31.8	29.5	30.8	28.6	31.2	—	—	30.38
36	31.0	32.5	33.0	31.8	—	—	—	32.08
				Females				
6	11.3	12.5	12.5	13.0	12.0	—	—	12.26
12	21.4	20.0	19.2	19.9	20.0	20.0	—	20.08
18	24.8	25.0	23.5	25.6	23.8	—	—	24.54
24	27.6	29.2	28.1	28.5	28.5	—	—	28.38
30	30.8	31.5	30.0	30.5	—	—	—	30.70
36	33.5	33.7	32.0	33.5	—	—	—	33.18
42	34.0	—	—	—	—	—	—	34.00

TABLE 4. Age-length key for silver hake for Div. 4W and 4X for July 1976 from otolith samples. Data in parentheses from Hunt (MS 1977).

Length	Age 1		Age 2		Age 3		Age 4		Age 5		Age 6		Age 7		Age 8		Age 9		Total		
(cm)	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M+F.
14	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	1
	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	2
16	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	2
	7	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	7	2	9
18	6	8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6	8	14
	9(1)	13	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	9	13	22
20	27	25(3)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	27	25	52
	26	38(2)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	26	38	64
22	29(1)	35	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	30	36	66
	17	17(1)	1	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	18	19	37
24	5	8(1)	4	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	9	11	20
	2	3	7	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	9	6	15
26	2	1	10	10	—	—	—	—	—	—	—	—	—	—	—	—	—	—	12	11	23
	—	1	24(1)	34(2)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	24	35	59
28	—	—	24	29(1)	—	1	—	—	—	—	—	—	—	—	—	—	—	—	24	30	54
	—	—	16(1)	50(1)	—	2	—	—	—	—	—	—	—	—	—	—	—	—	16	52	70
30	—	—	13	39(1)	—	6	—	—	—	—	—	—	—	—	—	—	—	—	13	45	58
	—	—	8	24(1)	2	7	—	—	—	—	—	—	—	—	—	—	—	—	10	31	41
32	—	—	1	18(4)	1	6	—	—	—	—	—	—	—	—	—	—	—	—	2	24	26
	—	—	2	9(1)	3	13	—	—(1)	—	—	—	—	—	—	—	—	—	—	5	22	27
34	—	—	—	3	—	6	1	—	—	—	—	—	—	—	—	—	—	—	1	9	10
	—	—	—	1	1(1)	7	—	—	—	—	—	—	—	—	—	—	—	—	1	8	9
36	—	—	—	—	1	10(1)	—	2	—	—	—	—	—	—	—	—	—	—	1	12	13
	—	—	—	—	—	10	—	—	—	—	—	—	—	—	—	—	—	—	—	10	10
38	—	—	—	—	—	3	—	2(1)	—	—	—	—	—	—	—	—	—	—	—	5	5
	—	—	—	—	—	6	—	1(2)	—	—	—	—	—	—	—	—	—	—	—	7	7
40	—	—	—	—	—	3	—	3	—	—	—	—	—	—	—	—	—	—	—	6	6
	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	2	2
42	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1
	—	—	—	—	—	1	—	1	—	—	—	—	—	—	—	—	—	—	—	2	2
44	—	—	—	—	—	2	—	1	—	—	—	—	—	—	—	—	—	—	—	3	3
	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	1	1
46	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	1	1
	—	—	—	—	—	—	—	—	—	1(1)	—	1	—	—	—	—	—	—	—	2	2
48	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	1	1
	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	1	1
50	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
52	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
54	—	—	—	—	—	—	—	—	—	1	—	1	—	—	—	—	—	—	—	2	2
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	1	1
56	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	1	1
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
58	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	1	—	2	2
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
60	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Total	133	153	113	226	8	66	1	11	—	5	—	3	—	1	—	—	—	2	255	487	742
Mean	20.9	21.1	27.9	29.1	33.0	34.7	34.0	39.9	—	48.8	—	53.0	—	56.0	—	—	—	56.0			
%	52.2	31.4	44.3	46.4	3.1	17.7	0.4	2.3	—	1.0	—	0.6	—	0.2	—	—	—	0.4	34.4	65.6	

immature fish should be smaller when compared to mature fish at the same age). Comparison of otolith ages from this sample with those aged by Hunt (MS 1977) indicate a good agreement and imply conformity with accepted criteria for ageing silver hake.

It is interesting to note that about 5% of the otoliths were identified as offshore hake (*M. albidus*) and were excluded from analysis. Otoliths from this species are easily recognized by a very broad anterior end, particularly in larger specimens (30+ cm).

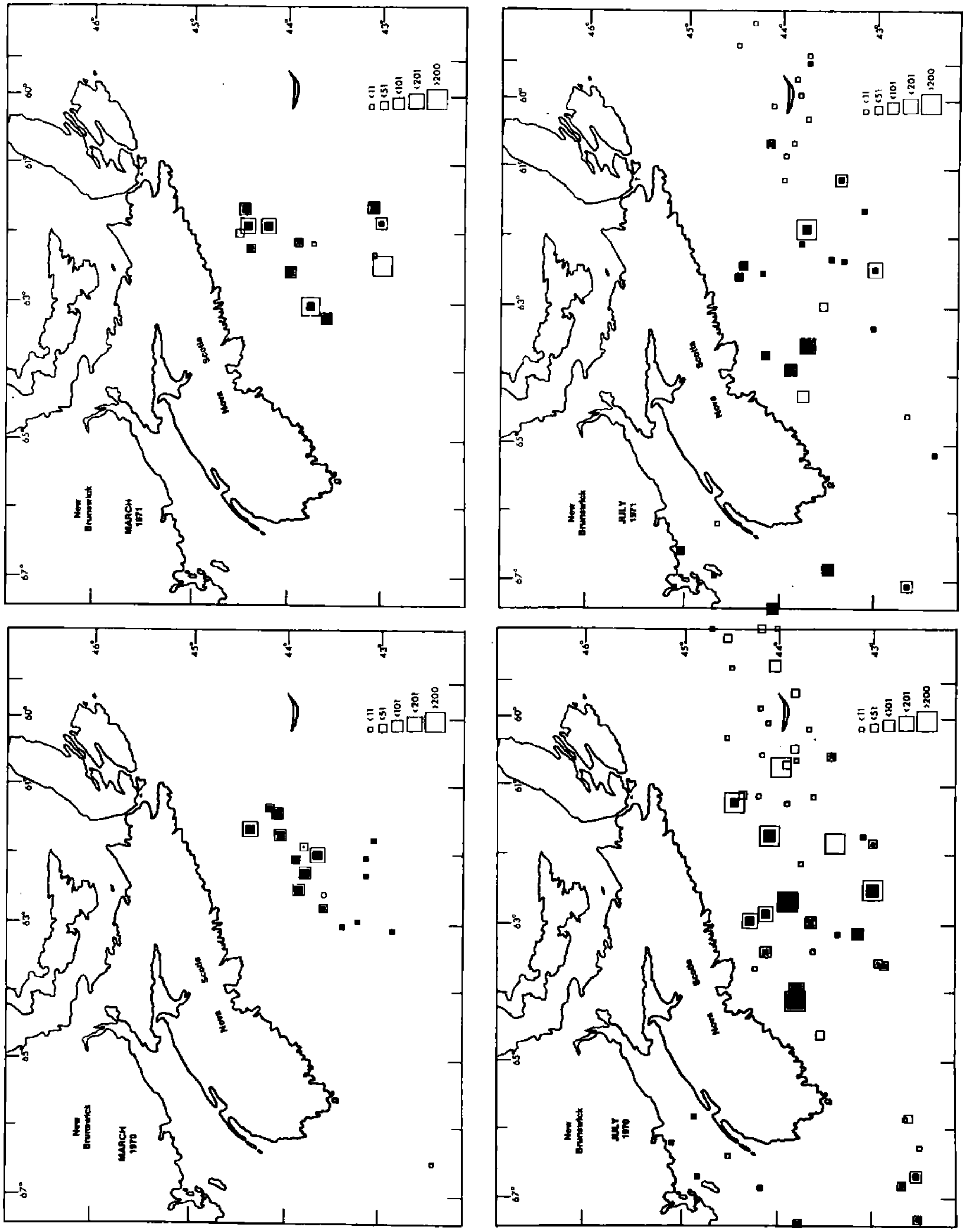

Fig. 4. Distribution of silver hake from Canadian research cruises, 1970–76. Total number per tow (open square) and number per tow less than 25 cm in length (closed square).

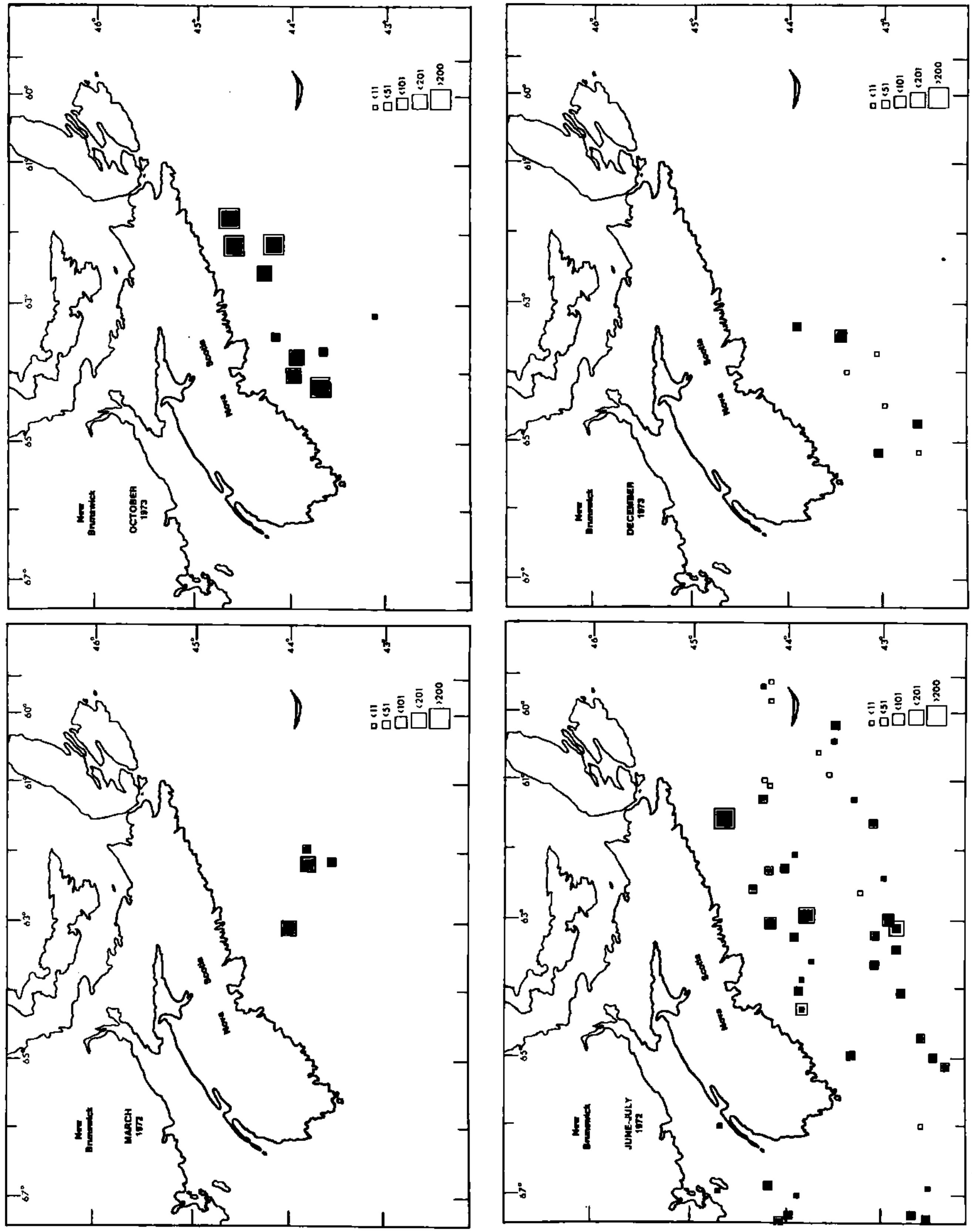

Fig. 4. (continued)

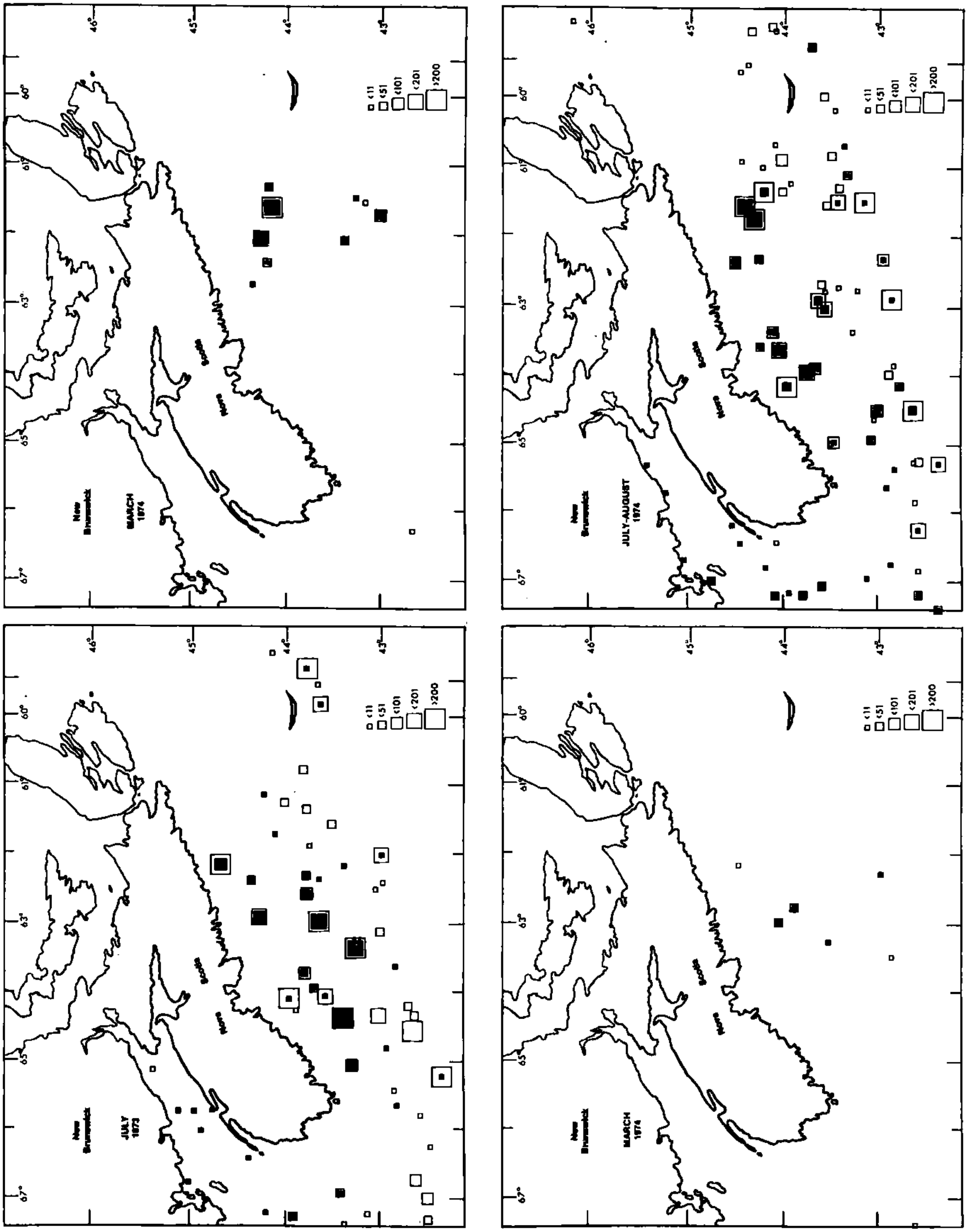

Fig. 4. (continued)

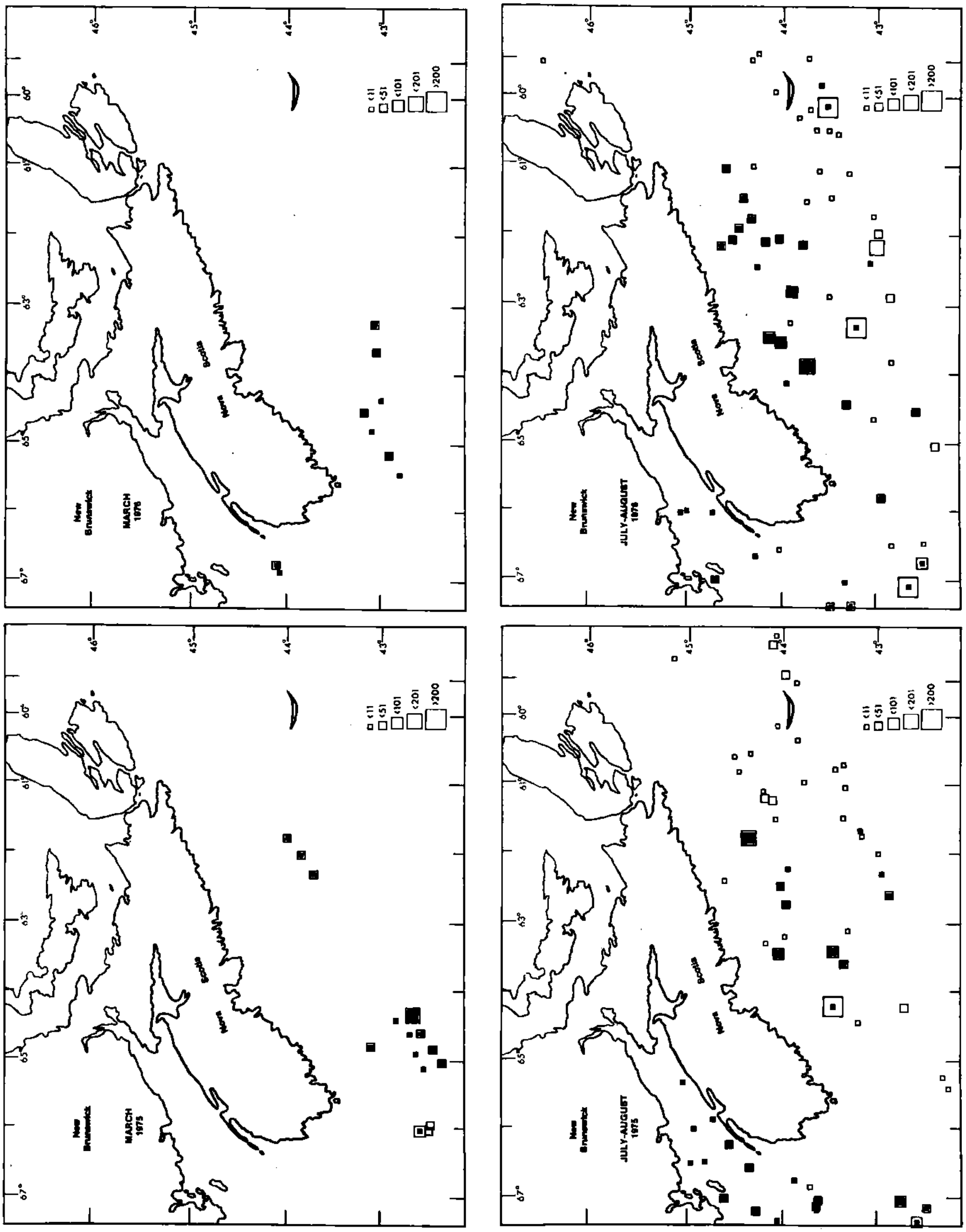

Fig. 4 (continued)

Numbers at age, derived from modal analysis, and the age-length key are shown in Table 5 for males and females. These data indicate very good agreement in the two methods for ages 1 and 2 but become less comparable at age 3. Percent composition of the three age-groups examined and mean length-at-ages 1 and 2 for two keys are within limits of accuracy imposed by the relatively small sample size.

Distribution and abundance of silver hake from cruise surveys are shown in Fig. 4 where open squares have been used to show total catch per 30-minute tow and black squares to indicate the proportion less than 25 cm in length. Winter (March) and summer (July-August) distributions are shown for each of the years 1970-76 with additional surveys in October and December, 1973. Winter surveys, because of inclement weather and restricted vessel operation, do not adequately survey the entire Scotian Shelf and consequently may miss part of the overwintering distribution.

Summer distributions show a widespread abundance over the Shelf area with highest concentrations in the Emerald Bank-Sable Island Bank area. Abundance is limited to an area west of 60° latitude and is discontinuous at about 66° latitude, suggesting a possible stock boundary between Sable Island Bank "stock" and Brown's Bank-Georges Bank "stock". In general, small fish are found closer to shore than the larger (>24 cm) adult fish. Concentrations of adult fish were found on the West Sable Island Bank area, which was described by Sarnits and Sauskan (1967) as a major spawning area with above average densities in 1970 and 1974.

Conclusions

Modal analysis of silver hake length frequencies indicate well-defined modes for both males and females in the 10-35 cm length range. Lengths at which these modes occur are consistent within narrow limits of year-class variation from year to year. Derived growth rates for males and females show some divergence at lengths above 25 cm with females reaching a larger calculated asymptotic length (37.88 cm *versus* 36.01 cm for males). Von Bertalanffy growth parameters derived from calculated

TABLE 5. Comparison of number-at-age distributions based on modal analysis and age-length key. (O = observed, C = calculated, and ALK = age-length key.)

Length	Male								Female							
	Frequency		Age 1		Age 2		Age 3		Frequency		Age 1		Age 2		Age 3	
(cm)	O	C	ALK	C	ALK	C	ALK	C	O	C	ALK	C	ALK	C	ALK	C
14	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	1	0.9	0.9	0.9	—	—	—	—	1	—	—	—	—	—	—	—
16	1	2.6	2.6	2.6	—	—	—	—	2	0.8	0.8	0.8	—	—	—	—
	9	6.4	6.4	6.4	—	—	—	—	5	3.4	3.4	3.4	—	—	—	—
18	9	13.1	13.1	13.1	—	—	—	—	12	10.7	10.7	10.7	—	—	—	—
	15	22.0	22.0	22.0	—	—	—	—	19	24.6	24.6	24.6	—	—	—	—
20	41	30.6	30.6	30.6	—	—	—	—	45	41.2	41.2	41.2	—	—	—	—
	39	35.1	35.1	35.1	—	—	—	—	56	50.7	50.7	50.7	—	—	—	—
22	42	33.3	32.2	33.3	1.1	—	—	—	51	45.8	44.5	45.8	1.3	—	—	—
	22	26.0	24.6	26.0	1.4	—	—	—	24	30.3	27.1	30.3	3.2	—	—	—
24	16	18.1	10.1	16.7	8.0	1.4	—	—	16	15.1	11.0	14.7	4.1	0.4	—	—
	20	20.9	4.6	8.9	16.3	12.0	—	—	10	7.9	4.0	5.2	3.9	2.7	—	—
26	67	58.4	9.7	3.9	48.7	54.5	—	—	12	13.8	1.3	1.4	12.5	12.4	—	—
	129	135.4	—	1.4	134.0	134.0	—	—	55	39.9	1.1	—	38.8	39.9	—	—
28	182	177.9	—	0.4	177.5	177.5	—	—	76	90.4	—	—	87.4	90.4	3.0	—
	114	127.1	—	—	126.8	126.8	—	0.3	149	143.5	—	—	138.0	143.4	5.4	0.1
30	52	52.6	—	—	48.9	48.9	—	3.7	154	160.3	—	—	138.9	159.7	21.4	0.6
	33	27.4	—	—	21.9	10.2	5.5	17.2	118	126.7	—	—	98.1	124.6	28.6	2.1
32	38	35.0	—	—	14.0	1.1	21.0	33.9	72	74.5	—	—	55.9	68.2	18.6	6.3
	19	28.3	—	—	—	—	28.3	28.3	61	40.6	—	—	16.6	26.2	24.0	14.4
34	12	10.0	—	—	—	—	10.0	10.0	35	32.5	—	—	10.8	7.0	21.7	25.5
	5	4.5	—	—	—	—	1.5	1.5	30	36.3	—	—	4.5	1.3	31.8	35.0
36	5	5.0	—	—	—	—	0.1	0.1	39	37.3	—	—	—	0.2	37.1	37.1
	1	1	—	—	—	—	—	—	35	30.5	—	—	—	—	30.5	30.5
38	1	1	—	—	—	—	—	—	16	19.4	—	—	—	—	19.4	19.4
	2	2	—	—	—	—	—	—	18	9.6	—	—	—	—	9.6	9.6
40	—	—	—	—	—	—	—	—	—	3.7	—	—	—	—	3.7	3.7
Total	876	866.5	191.9	201.8	598.6	566.5	66.4	94.1	1113	1089.5	220.4	228.8	614.0	676.4	254.8	184.3
Mean	—	—	21.11	21.21	28.03	28.00	32.72	32.29	—	—	21.09	21.17	29.62	29.80	34.27	35.73
%	—	—	22.4	23.4	69.9	65.7	7.8	10.9	—	—	20.23	21.01	56.36	61.97	23.39	17.02

mean length-at-age data show a good fit to data and indicate an approximate mean length of 30 cm at 36 months of age. Results of the present analysis are in good agreement with length-at-age estimates made by Doubleday and Halliday (MS 1975) using commercial catch length frequencies. The growth curve derived from this independent data is similar to those obtained here and supports the conclusion that growth of silver hake can be adequately derived from length frequency modal analysis. Ages and year-class composition derived from otoliths were in close agreement with those calculated from length frequency modal analysis.

Distribution and abundance of silver hake obtained from research vessel cruises indicate some segregation of size groups and a possible stock boundary. In summer, juvenile fish appear to concentrate inshore of the larger adult fish, but both size groups are found over the entire Shelf area with localized areas of high density. Distribution appears to be discontinuous at about 66° longitude. Winter distributions suggest more dense aggregations in several areas.

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Comparison of USA Spring Bottom Trawl Survey Abundance Indices for Atlantic Mackerel Based on Day, Night and Total Catches[1]

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Abstract

Differences between day and night mackerel catches during USA spring bottom trawl surveys were examined. Day catches over all years averaged about four times greater than night catches. The stratified mean catch-per-tow indices based on day tows exhibited a close relationship to the indices based on total tows, whereas the indices based on night tows showed a weaker correspondence.

Introduction

Atlantic mackerel, *Scomber scombrus*, appear to exhibit a pattern of diel vertical periodicity in the water column. They are generally found near bottom during the day but move upward in the water column at night apparently to feed (Isakov, MS 1976; Olla *et al.*, MS 1976). Their movement off bottom at night would presumably render them less susceptible to capture by bottom trawls. Isakov (MS 1976) reported that bottom trawling during daylight hours resulted in significantly larger catches of mackerel than that done at night.

Since the USA bottom trawl surveys are conducted 24 hours per day, data exist to compare possible differences between day and night mackerel catches. The purpose of this paper is to examine the day and night catches and determine the difference between abundance indices based on day tows, night tows, and total number of tows.

Materials and Methods

Data examined were from the USA spring bottom trawl surveys conducted in 1968-76 from Cape Hatteras through Georges Bank (strata 1-25 and 61-76) (Fig. 1).

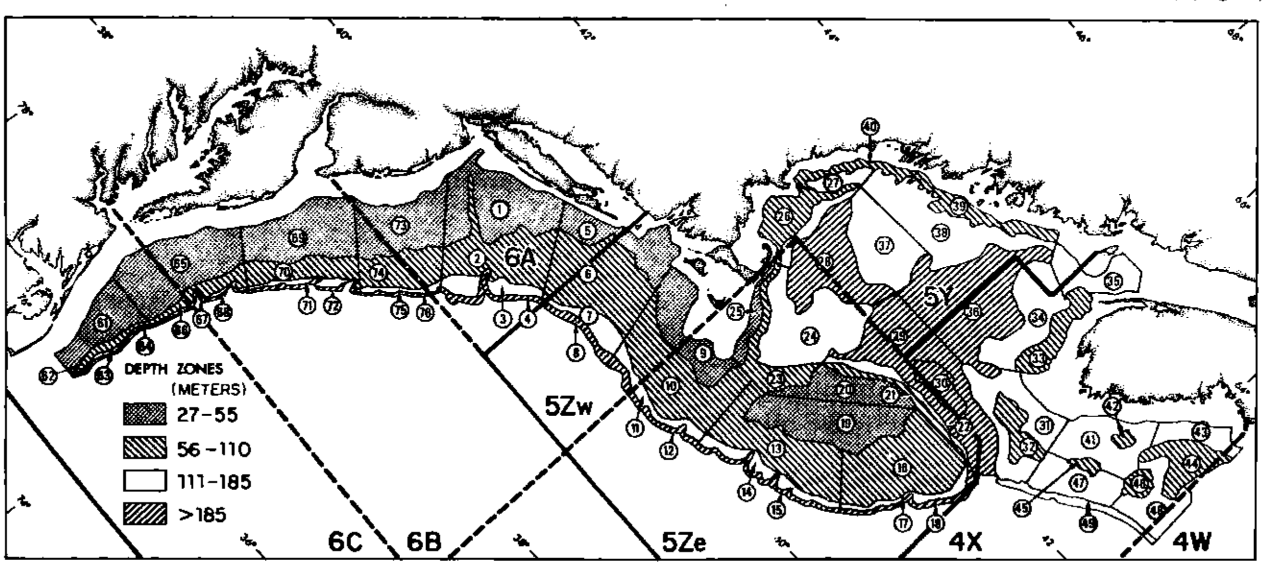

Fig. 1. USA bottom trawl survey sampling strata in ICNAF Subarea 5 and Statistical Area 6.

[1] Submitted to the December 1976 Special Meeting as ICNAF Res.Doc. 76/XII/138.

These were the same data used to calculate the mean catch-per-tow indices reported by Anderson *et al.* (MS 1976). Since the 1968-72 surveys were conducted using a No. 36 Yankee trawl and the 1973-76 surveys used a No. 41 trawl, the 1968-72 individual catches (both in weight and number) were adjusted upwards by a 3.25:1 ratio (Anderson, 1976) to be equivalent to No. 41 trawl catches.

USA survey catches are grouped into six 4-hour daily time-periods for analysis. These periods include 2400-0400, 0400-0800, 0800-1200, 1200-1600, 1600-2000, and 2000-2400. Although these periods cannot be grouped precisely into day and night periods (e.g., the 0400-0800 and 1600-2000 periods include both daylight and darkness), it was felt that the time periods from 0400-2000 (16 hours) and 2000-0400 (8 hours) would adequately define day and night, respectively, for the purpose of this paper.

Stratified mean catch-per-tow (kg, $\log_e$ scale) indices were calculated for strata 1-25 and 61-76, using all tows, day tows, and night tows. During a survey, all tows in a particular stratum are occasionally made either during the day or during the night. In the analyses involving only day tows and only night tows, it was necessary to maintain the same number of strata as in the analysis involving all tows, so that all three stratified mean catch-per-tow indices would be based on the same total area (43,155 square miles or 111,771 km² for strata 1-25 and 61-76). Therefore, for the day and night analyses, any stratum without tows was still weighted into the final stratified mean.

Results and Discussion

During 1968-76, about 67% of the tows were made during daylight hours and 33% during the hours of darkness (Table 1). This corresponds with the assignment of 16 hours to the day period and 8 hours to the night period. Approximately 190 tows were made per year in the strata set examined. The percentage of tows in which at least one mackerel was caught averaged 25% during the day and 23% at night. The yearly mean number of mackerel caught per tow ranged from 1.1 to 121.2 during the day and from 0.5 to 121.4 at night. Ratios between the yearly day and night mean numbers per tow ranged from 0.16 to 30.60 and averaged 6.68 for the 9-year period. The exclusion of a single extraordinarily large catch in 1973 from the analysis reduced the 9-year mean day/night ratio to 3.55.

Stratified mean catch-per-tow (kg, $\log_e$ scale) indices are given in Table 2 and plotted in Fig. 2. The indices

TABLE 1. Comparison of day and night tows for mackerel in USA spring bottom trawl surveys in ICNAF Subarea 5 and Statistical Area 6 (strata 1-25, 61-76) in 1968-76.

	Day					Night					Day/Night
Year	Number of tows	Percentage of total	Percentage of tows catching mackerel	Number of mackerel caught	Number per tow	Number of tows	Percentage of total	Percentage of tows catching mackerel	Number of mackerel caught	Number per tow	Number per tow
1968	120	67	19	2,403	20.03	60	33	25	7,288	121.43	0.16
1969	122	66	10	130	1.07	62	34	6	31	0.50	2.14
1970	124	64	35	1,884	15.19	70	36	23	414	5.91	2.57
1971	126	66	29	2,070	16.43	64	34	13	62	0.97	16.94
1972	134	68	26	1,398	10.43	62	32	26	200	3.23	3.23
1973	140	65	27	16,963	121.16	76	35	36	301	3.96	30.60
1974	105	66	37	817	7.78	54	34	35	189	3.50	2.22
1975	134	67	19	1,362	10.16	65	33	25	507	7.80	1.30
1976	133	70	23	1,036	7.79	58	30	14	465	8.02	0.97
Mean	126.4	67	25			63.4	33	23			6.68 3.55[1]

[1] A single day tow in 1973 contained 15,619 fish and excluding that catch from the calculations gives a number/tow of 9.67 instead of 121.16, a day/night catch/tow of 2.44 instead of 30.60 and an overall day/night mean ratio of 3.55 instead of 6.68

TABLE 2. Stratified mean catch-per-tow (kg, $\log_e$ scale) indices of mackerel from USA spring bottom trawl surveys (strata 1-25, 61-76) based on all catches, day catches, and night catches.

	All catches		Day catches		Night catches	
Year	Index	Mean length (cm)	Index	Mean length (cm)	Index	Mean length (cm)
1968	0.58	20.0	0.40	18.5	0.81	20.4
1969	0.03	24.2	0.04	23.7	0.02	24.1
1970	0.47	29.6	0.62	30.2	0.18	21.4
1971	0.43	28.9	0.49	29.5	0.13	26.1
1972	0.35	26.6	0.40	26.2	0.24	20.9
1973	0.23	26.5	0.24	32.0	0.16	18.6
1974	0.28	27.3	0.31	27.3	0.16	31.5
1975	0.12	21.4	0.14	19.1	0.12	17.3
1976	0.14	25.1	0.20	25.1	0.05	26.3

calculated from day tows exhibited a close relationship to the indices based on total tows. A strong correlation (r = 0.88, p = 0.01) existed between these two sets of indices (Fig. 3A). The indices calculated from night tows exhibited a weaker correspondence to the indices calculated from both day and total tows, although the 1972-76 night indices demonstrated the same downward trend in abundance as did the other two indices. The correlation coefficient (r) between night and total indices (Fig. 3B) was 0.74 (p = 0.05).

The day indices were larger than the night and total indices in all years except 1968. The night catches of mackerel in that year were much larger than the day catches (Table 1). The ratios between the day and night indices in 1969-76 averaged 2.4, reflecting the larger day catches.

Mean lengths of mackerel caught during day and night were compared. Mackerel caught during the day in 5 of the 9 years were larger than those caught at night; and, in the remaining 4 years, the mackerel caught at night were larger. These results were insufficient to suggest any overall differences.

Results of the analyses presented in this paper support Isakov's (MS 1976) conclusion that daylight trawling achieves much higher catches of mackerel than night trawling. Mackerel were, however, caught by survey tows made at night, and in some cases (1968) the night catches were greater than the day catches. Since the use of daylight tows resulted in a time-series of abundance indices differing only slightly from and showing the same trend in mackerel abundance as indices using both day and night catch data, it is concluded that the survey indices

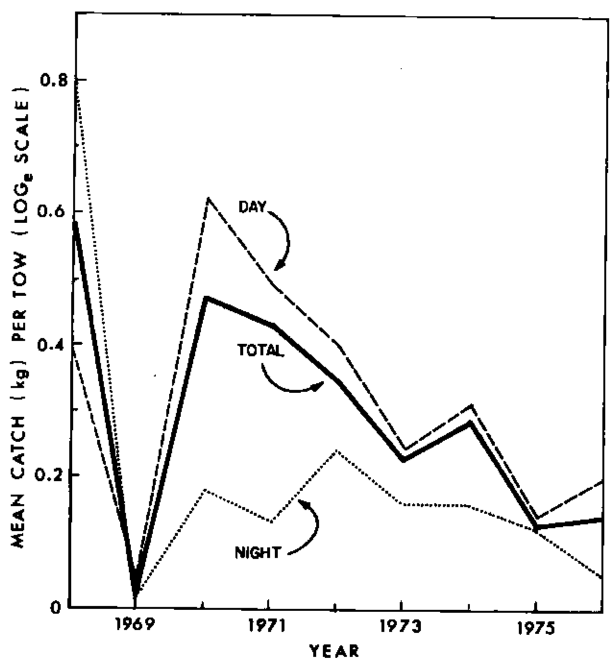

Fig. 2. Stratified mean catch-per-tow of mackerel (kg. $\log_e$ scale) from USA spring bottom trawl surveys calculated using the total number of tows, day tows, and night tows.

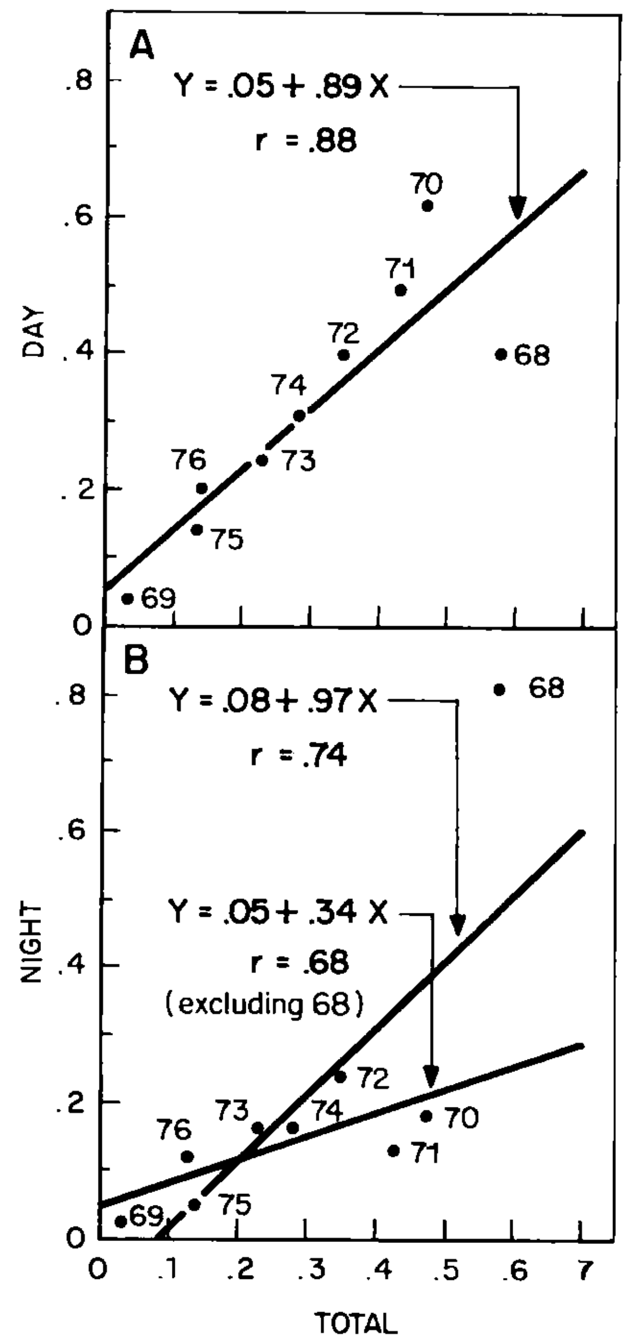

Fig. 3. Correlation between stratified mean catch-per-tow of mackerel (kg. $\log_e$ scale) from USA spring bottom trawl surveys using (A) day tows compared to the total number of tows, and (B) night tows compared to the total number of tows.

used in the assessment of the mackerel stock (Anderson *et al.*, MS 1976) are not unduly biased downwards by the inclusion of night tows.

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Using the USA Research Vessel Spring Bottom Trawl Survey as an Index of Atlantic Mackerel Abundance[1]

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Abstract

Catch frequency distributions of mackerel in USA research vessel spring bottom trawl surveys were examined and found to be highly skewed. A linear relationship (on a log-log scale), with a slope of approximately 2, between the mean and variance of a series of samples from the survey indicates that a log transform is appropriate in order to normalize the distribution of survey catches. The log transformation was tested by simulating sampling from hypothetical cumulative distribution functions which were based on observed survey frequency distributions. These simulations indicate that the mean of log transformed catches has a symmetric distribution with a strong central tendency.

Introduction

The use of USA research vessel spring bottom trawl survey as an index of Atlantic mackerel, *Scomber scombrus*, abundance was recently proposed by Anderson (1976). Because mackerel is a pelagic schooling species, catches of mackerel in the survey have been more sporadic (usually small catches but occasionally very large) than catches of most common demersal species. Therefore, special consideration of the frequency distribution of catches from the survey and of the distributional characteristics of indices based on survey data is warranted. In this paper, catch frequency distributions from the survey are presented, an appropriate transformation is derived and the distributional properties of several indices are investigated by Monte Carlo simulation.

Method

USA research vessel bottom trawl surveys have been conducted between Cape Hatteras and Nova Scotia in the spring of each year since 1968. Each survey has a stratified random sampling design where strata are selected on the bases of depth and area (Fig. 1). A No. 36 Yankee otter trawl was used prior to 1973 and is still used in autumn surveys. Since 1973, spring surveys have used a modified No. 41 high-opening Yankee bottom trawl. More details of the surveys are given by Grosslein (1969).

Mackerel abundance is best reflected by tows from strata 1-25 and 61-76. Spring bottom trawl survey catches of mackerel in the Gulf of Maine and further north are rare. About 200 tows are made in these strata during each spring survey. The population mean ($\overline{X}$) and variance (S^2) of the catch per tow of mackerel is estimated by:

$$\overline{X} = \frac{1}{A}\sum_h A_h \overline{X}_h \tag{1}$$

$$S^2 = \frac{1}{A}\sum_h A_h(\overline{X}_h)^2 - A(\overline{X})^2 + \frac{1}{A}\sum_h (A_h - 1) + \left(\frac{A_h - A}{A}\right)\left(\frac{A_h - n_h}{n_h}\right)S_h^2 \tag{2}$$

where A is the area of all strata considered, A_h is the area of strata h, $\overline{X}_h$ and $S_h{}^2$ are strata means and variances and n_h is the strata sample size. Equation (2) was derived by J.A. Brennan (personal communication). The population variance cannot be estimated by using the standard formula for the sample variance (Snedecor and Cochran, 1967) because data is from a stratified random sampling design (not simple random sampling), therefore the more complicated method of estimation is necessary.

Taylor (1961) empirically derived the "Power Law".

[1] Submitted to the December 1976 Special Meeting as ICNAF Res.Doc. 76/XII/144.

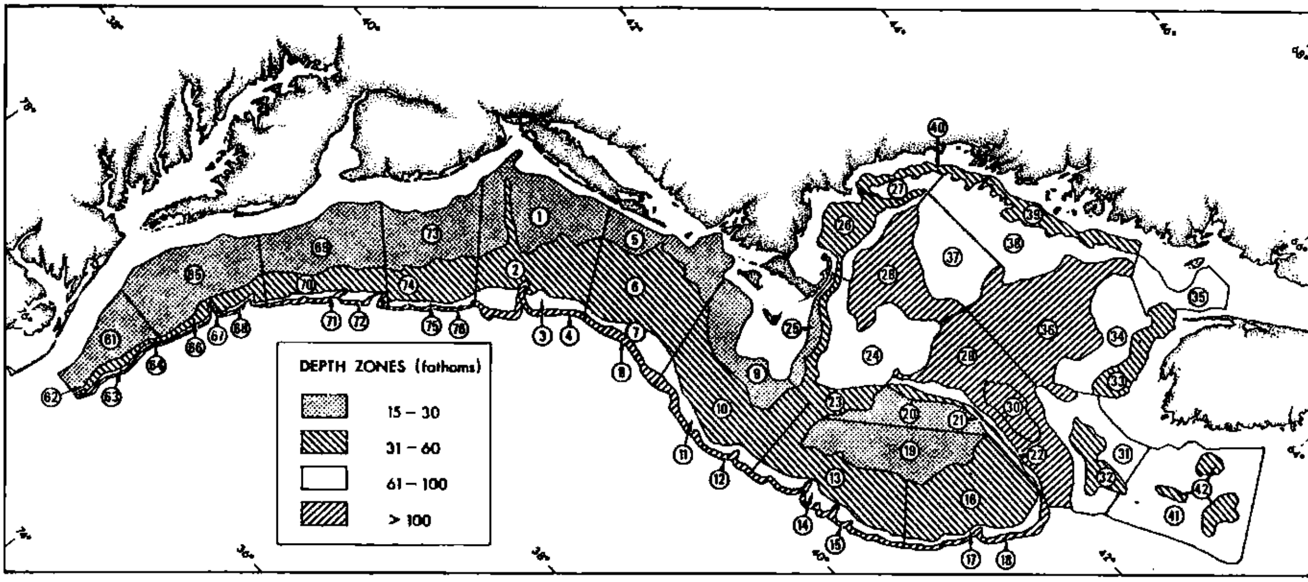

Fig. 1. USA research vessel bottom trawl survey strata.

Taylor's power law states that the variance of a population is proportional to a fractional power of its mean:

$$S^2 = a\overline{X}^b \qquad (3)$$

$$\log S^2 = \log a + b \log \overline{X} \qquad (4)$$

The parameter a depends chiefly upon the size of the sampling unit. Parameter b is an index of dispersion and varies from 0 for a regular distribution to 1 for a random distribution with values greater than 1 indicating a contiguous distribution. The slope of the linear relationship between the log S^2 and log $\overline{X}$ for a series of samples is an estimate b. Once b is estimated, a common transformation can be applied to the catch from each tow thus stabilizing the sample variance and allowing the application of normal statistics. The appropriate transformation is to replace the catch from each tow (X) by X^p where $p = 1 - b/2$. When $p = 0$, a log transformation should be used (Elliott, 1971). The slope of the relationship between the $\log_e S^2$ and $\log_e \overline{X}$ for the series of spring surveys between 1968–76 was used to estimate b. Sample strata means and variances for strata in which at least four tows were made in a specific spring survey were also used to estimate b.

Once an appropriate transformation was derived, the distributional properties of the sample mean of transformed data were investigated using a Monte Carlo simulation. Monte Carlo simulation was recently used by Barrett and Goldsmith (1976) in a similar manner to investigate the distribution of sample means drawn from non-normal distributions. For a brief but general discussion of the method of Monte Carlo simulation, see Gordon (1969). The specific application used in this work is discussed below.

The cumulative distribution function [F(X)] of a population defines the probability of an observed value from that population being less than X. Therefore, F(X) is non-decreasing and ranges from 0 to 1 for all populations.

$$F(X) = \int_{-\infty}^{X} f(X)dx \qquad (5)$$

where f(X) is a probability density function. Then if u is a uniformly distributed random variable between 0 and 1 and the equation u = F(X) is solved for X, this value of X will have f(X) as its probability density function. Therefore, random numbers with a desired distribution can be generated from uniformly distributed random numbers based on a cumulative distribution function. For an empirically determined cumulative distribution function, the transformation is most easily accomplished graphically. If F(X) is plotted on the vertical axis and X on the horizontal axis, then, for a random value of u, the corresponding value of X is determined by projecting the point on the curve with level u on the vertical axis to the horizontal axis. When a series of points from a cumulative distribution function is known, the transformation is easily accomplished by linearly interpolating between points. Uniform random numbers between 0 and 1 can be generated by a subroutine written by IBM (1970).

A program was written to generate random numbers distributed according to a specified cumulative distribution.

TABLE 1. Catch (kg) frequency of mackerel in spring bottom trawl surveys in strata 1-25 and 61-76 for 1968-76.

Year	Weight range (kg)	No. of tows	% of tows	Cumulative %
1968	0	142	78.9	78.9
	0-0.5	10	5.6	84.5
	0.5-1	4	2.2	86.7
	1-2	2	1.1	87.8
	2-3	5	2.8	90.6
	3-4	2	1.1	91.7
	4-5	2	1.1	92.8
	5-10	5	2.8	95.6
	10-100	6	3.2	98.8
	175-176	1	0.6	99.4
	228-229	1	0.6	100.0
1969	0	168	91.5	91.5
	0-0.5	10	5.5	92.0
	0.5-1	2	1.0	98.0
	1-2	1	0.5	98.5
	2-3	2	1.0	99.5
	14-15	1	0.5	100.0
1970	0	135	69.6	69.6
	0-0.5	12	6.2	75.8
	0.5-1	18	9.3	85.1
	1-2	6	3.1	88.2
	2-3	4	2.1	90.3
	3-10	6	3.1	93.4
	10-30	8	4.2	97.6
	30-100	4	2.1	99.7
	120-121	1	0.3	100.0
1971	0	146	76.8	76.8
	0-0.5	9	4.7	81.5
	0.5-1	13	6.8	88.3
	1-2	6	3.2	91.5
	2-5	7	3.7	95.2
	5-10	2	1.1	96.3
	10-20	2	1.1	97.4
	40-70	4	2.1	99.5
	214-215	1	0.5	100.0
1972	0	145	74.0	74.0
	0-0.5	17	8.7	82.7
	0.5-1	14	7.1	89.8
	1-5	9	4.6	94.4
	5-10	3	1.6	96.0
	10-20	4	2.0	98.0
	20-100	4	2.0	100.0
1973	0	149	69.0	69.0
	0-0.5	25	11.6	80.6
	0.5-1	20	9.3	89.9
	1-2	8	3.6	93.5
	2-5	5	2.3	95.8
	5-10	2	0.9	96.7
	10-50	4	1.8	98.5
	72-73	1	0.5	99.0
	194-195	1	0.5	99.5
	5162-5183	1	0.5	100.0
1974	0	101	63.5	63.5
	0-0.5	26	16.4	79.9
	0.5-1	15	9.4	89.3
	1-2	5	3.1	92.4
	2-3	3	1.9	94.3
	3-5	2	1.3	95.6
	5-6	3	1.9	97.5
	6-10	1	0.6	98.1
	50-100	3	1.9	100.0
1975	0	158	79.3	79.3
	0-0.5	15	7.6	86.9
	0.5-1	13	6.6	93.5
	1-2	5	2.5	96.0
	2-10	3	1.5	97.5
	15-16	1	0.5	98.0
	25-35	4	2.0	100.0
1976	0	152	79.7	79.7
	0-0.5	2	1.0	80.7
	0.5-1	23	12.0	92.7
	1-2	7	3.7	96.4
	2-10	3	1.6	98.0
	15-16	1	0.5	98.5
	29-30	1	0.5	99.0
	69-70	1	0.5	99.5
	78-79	1	0.5	100.0

Several cumulative distributions were considered, some of which corresponded to observed catch frequencies of mackerel from the spring bottom trawl surveys. Samples of 25, 100 and 200 values were generated and 100 samples of each sample size were considered for each distribution. Frequency diagrams of sample means of transformed and untransformed data were prepared in order to compare their distribution characteristics under various circumstances.

Results and Discussion

The catch frequencies in weight of mackerel in spring surveys during 1968-76 are given in Table 1. The weight of mackerel caught is considered instead of the number of mackerel because Anderson's (1976) index is based on weight. Weight intervals in which there were no occurrences are omitted from the table. Catch frequency diagrams for three typical years are given in Fig. 2, 3 and 4. The skewness of sample distributions is obvious. From 63 to 92% of the tows in each year had no mackerel. The highest catch was greater than 5,000 kg (occurring in 1973), more than 20 times the catch in any other tow. This catch approached a physical limit (on catch in any single tow) thus indicating that the catch distribution is finite with a finite variance.

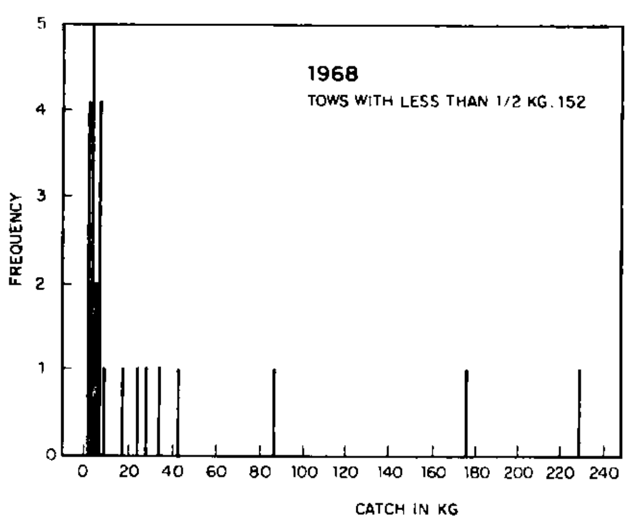

Fig. 2. Catch frequency from 1968 spring bottom trawl survey.

The $\log_e(\bar{X})$ and $\log_e(S^2)$ for each year (1968-76) are plotted in Fig. 5. These variables are also plotted for each strata in which four or more tows were made in a single year (Fig. 6). The points in Fig. 6 from surveys prior to 1973 were adjusted to values equivalent to expected catches using a No. 41 net as described by Anderson (1976). The points marked by +'s in Fig. 5 were adjusted upward to

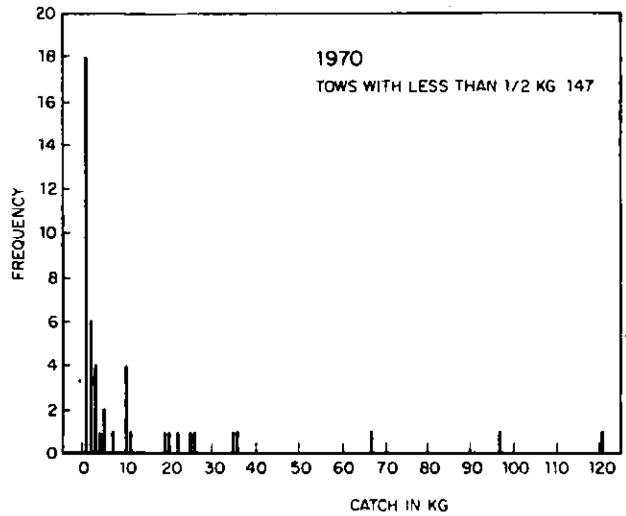

Fig. 3. Catch frequency from 1970 spring bottom trawl survey.

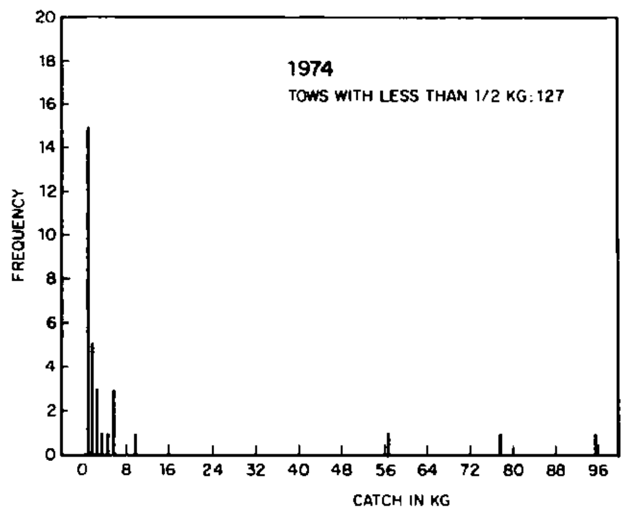

Fig. 4. Catch frequency from 1974 spring bottom trawl survey.

correspond to the No. 41 net, but these were not considered in fitting the regression line. It is obvious that the line fits the points based on actual catches and adjusted catches equally well. The slope of both regression lines is approximately 2 (1.96 and 1.91 for Fig. 5 and 6 respectively) and therefore p approaches 0 indicating a log transformation. If the slopes are interpreted exactly, the appropriate transforms would be $X^{0.02}$ or $X^{0.04}$. Both the log transform ($\log_e(X + 1.0)$) and an exponential transform ($X^{0.02}$) were considered in the simulations described below.

Two hypothetical cumulative distribution functions are shown in Fig. 7. These distributions are smoothed versions

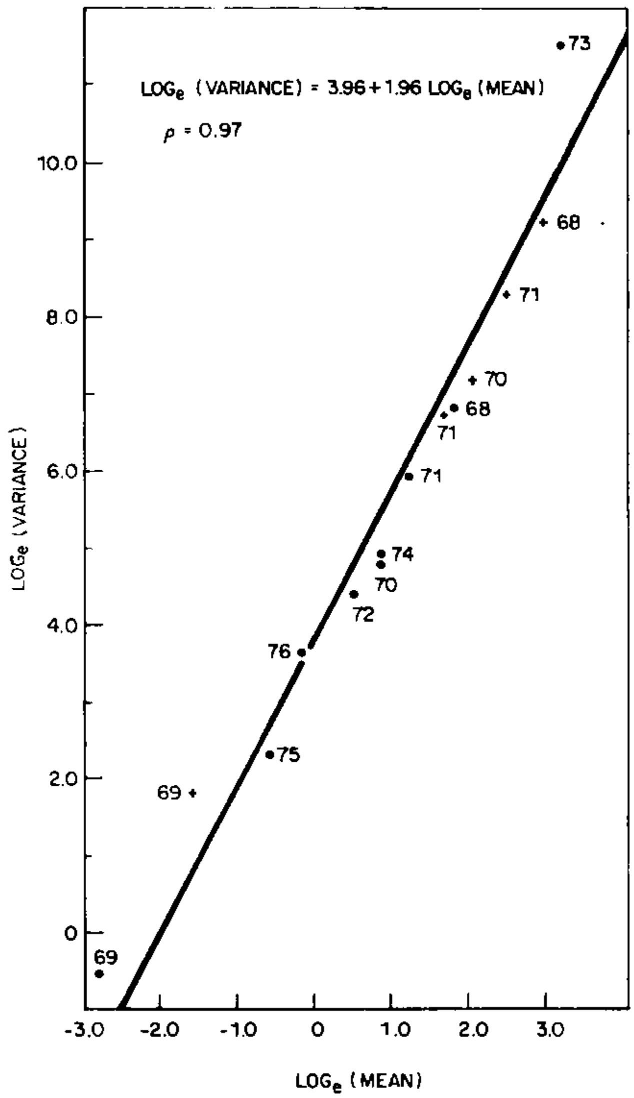

Fig. 5. The relationship between annual survey sample means and variances. Dots are actual sample statistics while +'s are adjusted to expected values of catch using the No. 41 net.

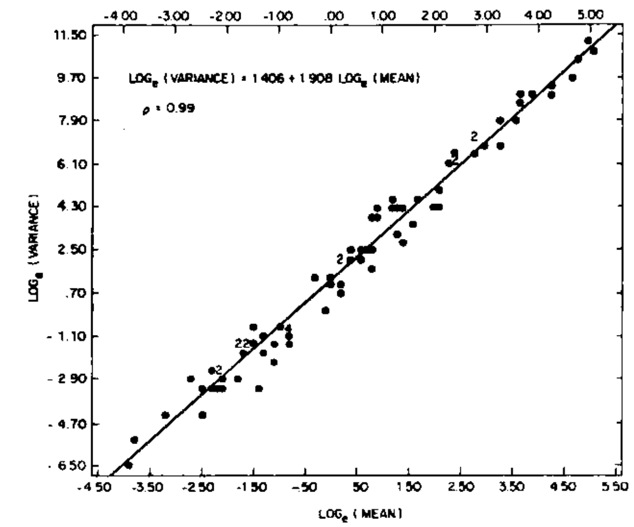

Fig. 6. The relationship between strata means and variances.

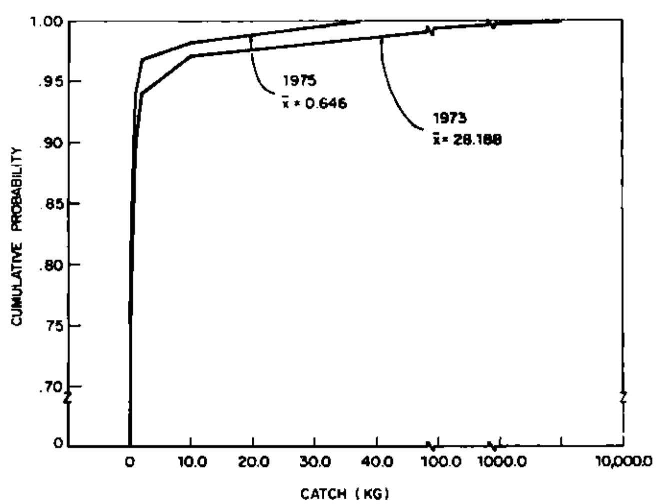

Fig. 7. Hypothetical cumulative distribution functions based on 1973 and 1975 catches of mackerel in USA spring bottom trawl surveys.

of the 1973 and 1975 survey samples, which are representative of high and low levels of mackerel abundance in the survey respectively. The means of these distributions are 26.2 and 0.65. Simulated samples of 25, 100 and 200 were drawn from each population. The means of the untransformed and transformed samples were calculated and the procedure was repeated 100 times. Frequency distributions of sample means are plotted in Fig. 8, 9, 10 and 11. The means of exponentially transformed samples are not shown, but their frequency distributions are similar in shape to log transformed means. Therefore, there is no benefit in using the less common exponential transformation.

According to the central limit theory, the probability density function of the sample mean converges to a normal distribution as sample size increases, when the population from which the sample is drawn has a finite variance. Usually, a sample size of 30-60 is assumed adequate for a sample mean to approach a normal distribution, but this may not be true for samples from a highly skewed population. The symmetry and central tendency of the normal distribution are highly desirable characteristics for an abundance index based on random sampling.

For both empirical distributions, the arithmetic means are highly variable and asymmetric for a sample size of 25

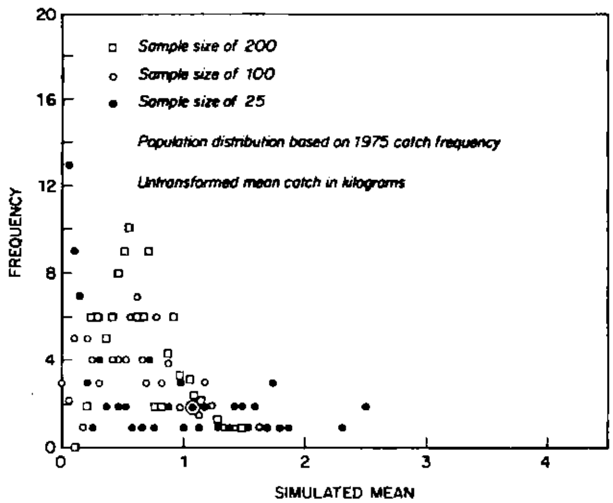

Fig. 8. Frequency distribution of simulated untransformed means.

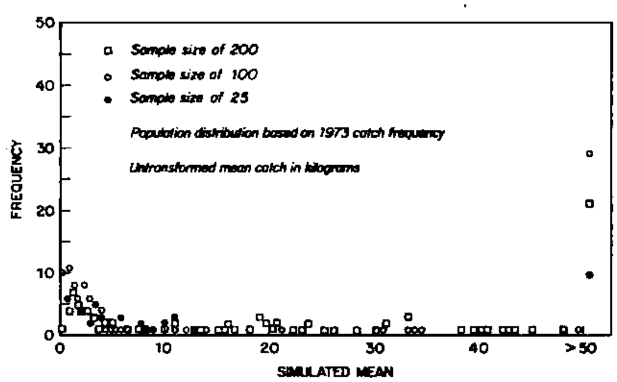

Fig. 9. Frequency distribution of simulated untransformed means.

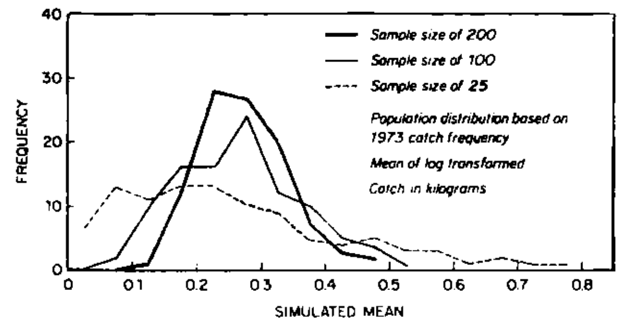

Fig. 10. Frequency distribution of simulated log transformed means.

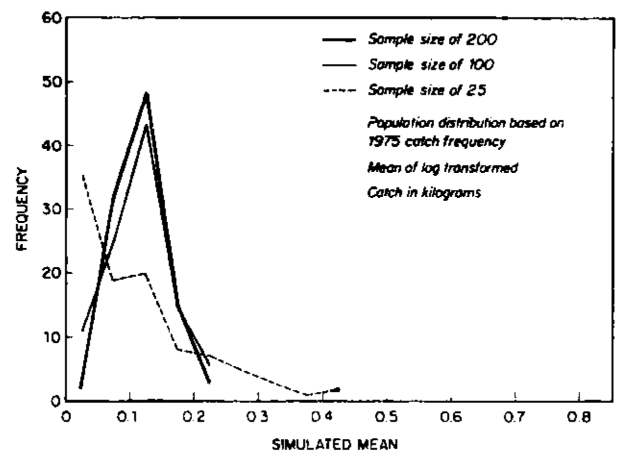

Fig. 11. Frequency distribution of simulated log transformed means.

and 100. For the low abundance (1975) distribution and a sample size of 200, the arithmetic means appear more symmetric and exhibit some central tendency. This does not occur for the high abundance (1973) distribution even with a sample size of 200.

Log transformed means are less variable and more symmetric than untransformed means for all three sample sizes and both distributions. The log transformation appears adequate to allow the application of normal statistics to means for sample sizes of 100-200.

Some words of caution on the use of means of log transformed catches from trawl surveys are necessary. Firstly, while the work reported in this paper does indicate that the means of log transformed catches have desirable characteristics (as described above), the use of this statistic as an index of abundance depends on the assumption that the survey randomly samples the population. For mobile populations with oriented movements, sampling should be random in both time and space. In fact, it is virtually impossible to randomize the order in which randomly selected stations are sampled. Secondly, it is important to note that catch frequency distributions with vastly different means might have the same log transformed means. Therefore, it may not always be possible to distinguish between populations with different means when using a log transformed index even with an extremely large sample size. In conclusion, the log transformation does tend to normalize the sample means of mackerel catches from spring research vessel bottom trawl surveys. The significance of non-random temporal sampling and of the relationship between transformed and untransformed means of a population should be considered further.

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On the Correlation Between Water Temperature and the Spawning Times for Georges Bank Herring[1]

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Abstract

Correlations between the times of peak herring spawning on Georges Bank and three water temperature indices indicate that knowledge of the near-bottom water temperature conditions on the spawning grounds in August is suitable for predicting the time of peak spawning in September.

Introduction

Research vessels of the Atlantic Research Institute of Marine Fisheries (AtlantNIRO) have conducted surveys of the herring spawning grounds on Georges Bank since 1963 in order to study the dynamics of the spawning population. On the basis of available data on herring spawning and fluctuations in water temperature during the spawning and pre-spawning periods, correlation analyses were undertaken in an attempt to develop a method for predicting the time of peak spawning.

Materials and Methods

Surveys of the herring spawning grounds on Georges Bank have been carried out annually during 1963-73, in order to estimate the size of the spawning population on the basis of the number of eggs laid. During the course of the surveys, the position and area of the main spawning grounds, as well as the approximate dates of the beginning, peak and end of massive spawning, were determined, and observations were made on the thermal regime during the pre-spawning, spawning and post-spawning periods (Noskov and Zinkevich, MS 1967; Pancratov and Sigaev, 1970). Although herring spawning takes place during September and October, the time of peak spawning usually occurs in September. Biological material collected during the spawning season facilitated the determination of the date of peak spawning in each year, based on the ratio of maturity stages in the samples. The data on the thermal regime are based on two sources of information: near-bottom temperatures recorded on the spawning grounds in August, and summer temperature anomalies at depths of 50 and 75 m as given by Karaulovsky and Sigaev (MS 1976).

The dates of peak spawning and the thermal regime indices are given in Table 1, where T_a is the near-bottom temperature in the spawning area in August, and ΔT_{50} and ΔT_{75} are temperature anomalies during the summer (including September) at depths of 50 and 75 m respectively. Values of T_a for 1964 and 1972 were not available, but these were estimated by a regression of T_a on ΔT_{50}. The good correlation of 0.85 between T_a and ΔT_{50} not only allowed the calculation of reasonable estimates for the missing T_a values but also confirmed the representative character of these thermal regime indices.

TABLE 1. Relationship between the time of peak herring spawning and the summer thermal regime on Georges Bank, 1963-73. (Values in parentheses are estimated.)

Year	Date of peak spawning in September	Summer temperature anomalies at 50 m and 75 m (°C)		Temperature near bottom in August (°C)
	D	ΔT_{50}	ΔT_{75}	T_a
1963	12	0.8	1.0	13.6
1964	29	-1.2	-1.2	(10.8)
1965	22	0.1	-0.7	12.0
1966	25	-0.4	-1.5	11.1
1967	27	-0.9	-0.9	10.3
1968	19	0.4	0.5	11.0
1969	17	0.8	0.4	13.3
1970	18	-0.5	-0.5	11.5
1971	11	0.9	1.1	13.3
1972	22	0.7	1.1	(12.9)
1973	26	-	—	12.6

[1] Submitted to the June 1977 Annual Meeting as ICNAF Res.Doc. 77/VI/42.

The August temperatures evidently make a significant contribution to the formation of the summer anomalies in the Georges Bank area, where highly developed dynamic processes exclude thermal inertia.

Results and Discussion

A good correlation between the peak spawning time for herring and the summer thermal regime indices on Georges Bank is indicated (Table 2), in spite of the relatively short time series of observations. Plots of the correlations between the thermal indices and the peak spawning times for herring (Fig. 1) indicate that peak spawning occurs earlier in September, if the heat content of the water prior to spawning is relatively high, and later in the month if the water temperatures before spawning are relatively low. If the correlations between the summer anomalies (ΔT_{50} and ΔT_{75}) and the times of peak spawning are not considered suitable for prognosis, since they usually include data for September, the correlation between the August near-bottom temperatures (T_a) and peak spawning times may be considered as the basis for predicting the latter.

TABLE 2. Correlation analyses of the thermal regime and time of peak herring spawning (D) on Georges Bank, 1963-73. (T_a^1 includes the estimated values given in Table 1.)

Index	Number of years (n)	Correlation coefficient (r)	Confidence level	Regression equation
ΔT_{50}	10	-0.81	0.01	$D = 20.6 - 6.50\ T_{50}$
ΔT_{75}	9	-0.83	0.01	$D = 20.5 - 4.95\ T_{75}$
T_a	9	-0.75	0.05	$D = 67.1 - 3.89\ T_a$
T_a^1	11	-0.71	0.05	$D = 64.1 - 3.62\ T_a^1$

The development of the gonads in Georges Bank herring during the pre-spawning and spawning period coincides with the increase in near-bottom temperature on the spawning grounds, the highest values of which are usually observed in September (Fig. 2). This has been shown to be characteristic of Sakhalin-Hokkaido herring (Probatov and Shelegova, 1952), Baltic herring in Vistula Bay and the Gulf of Riga (Berenbeim, 1971), Azov anchovy (Berenbeim, 1973), and Okhotsk herring (Zavernin, 1972). All of these species, like the Georges Bank herring, spawn during the period when water temperatures are at their peak, with spawning occurring earlier when water temperatures are higher during the pre-spawning period and later if the temperatures are lower.

The foregoing analysis for Georges Bank herring indicates that knowledge of near-bottom temperature conditions on the spawning grounds in August may be used to estimate the time of peak spawning in September, which in turn is related to the period during which spawning occurs, and which determines the period of egg incubation and the approximate time of hatching. Such information is

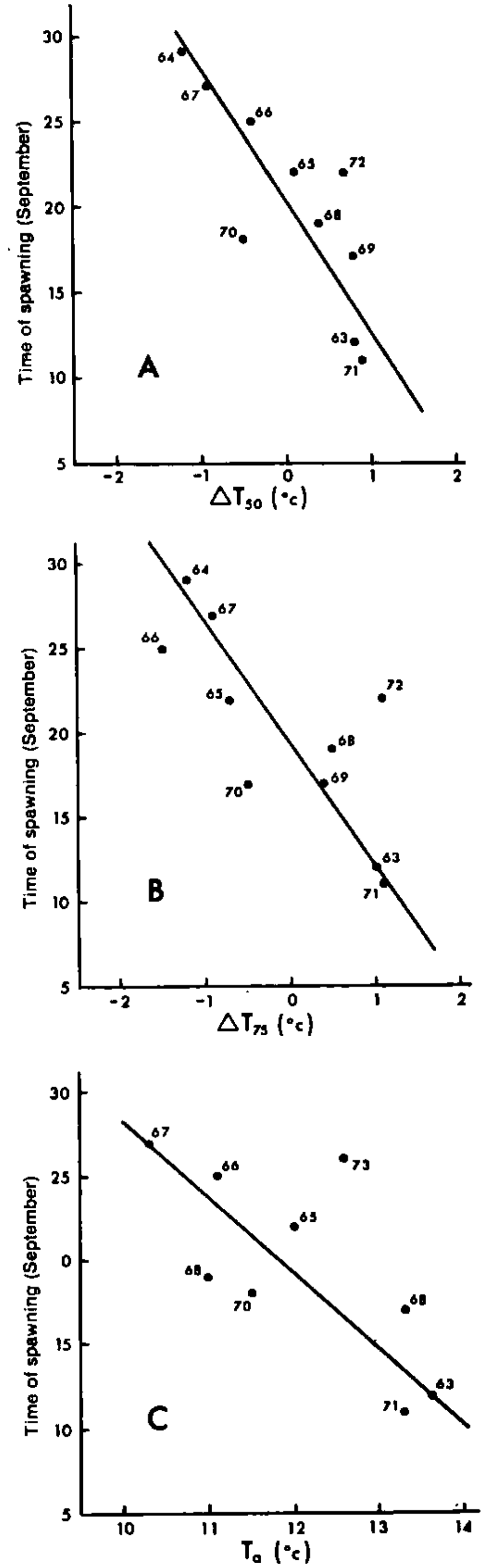

Fig. 1. Plots of correlation between peak spawning times and thermal regime indices for Georges Bank herring, 1963-73.

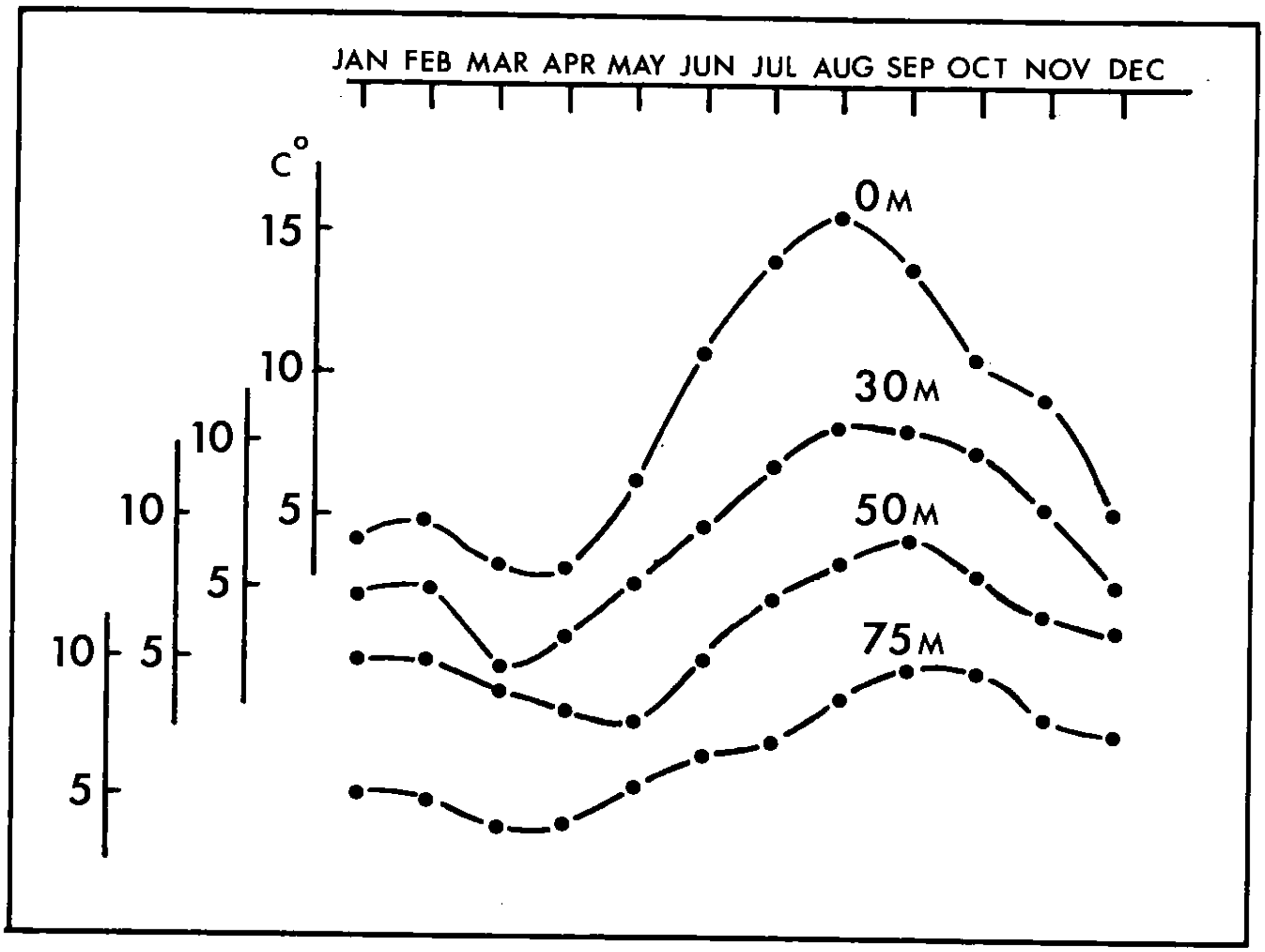

Fig. 2. Annual trends in water temperature on the spawning grounds of Georges Bank at various depths.

important in the planning of complex surveys for investigating the ecology of herring.

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The Capelin, *Mallotus villosus*, Population Spawning on the Southeast Shoal of the Grand Bank, 1976[1]

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Abstract

In 1976, the capelin stock on the Southeast Shoal exhibited unusual characteristics. These included low abundance, an early end to the spawning season, the presence of large proportions of mature unspawned fish up to the end of the fishing season, the occurrence of unusually high proportions of immature capelin in the spawning aggregations and smaller mean lengths-at-age. The presence of the strong 1973 year-class in the population may have resulted in slow growth and consequently a low maturation rate for this year-class. The implications of reducing fishing quotas and the application of other conservation measures are discussed.

Introduction

Capelin spawning on the Southeast Shoal of the Grand Bank was first observed in 1950 (Pitt, 1958). With the advent of a commercial capelin fishery in the early 1970's, the capelin population became exploited as it moved through ICNAF Divisions 3L and 3O to the spawning grounds on the Southeast Shoal in Div. 3N. The nominal catch of capelin in Div. 3LNO increased from 22,005 tons in 1972 to 165,880 tons in 1975 (ICNAF, 1972-1975). USSR and Norway have the largest capelin fisheries in this area.

In 1976, Norwegian and Icelandic fishermen reported that capelin catches on the Southeast Shoal were lower than in 1975 and that capelin were not as abundant. The Norwegian catches of capelin support these observations: 35,903 tons in 1975 and 23,183 tons in 1976, the quota being 53,000 tons. The catch per tow of USSR fishing vessels, estimated by Canadian fisheries officers, was also down in 1976 (D. Barrett and D. Aylward, personal communication). Calculations of catch per tow in Div. 3O yielded averages of 10 tons per tow in 1976 whereas averages of 15-20 tons per tow were common in 1975.

The capelin fishery on the Southeast Shoal normally occurs during the duration of capelin spawning season (from about 15 June to 15 July). However, in 1976, the fishery ended rather abruptly in the first few days of July. The Canadian research vessel *A.T. Cameron* was in the area until 30 June, and on that day few capelin concentrations were detected although some USSR vessels were still fishing. The Norwegian fishermen reported that by 4 July capelin, whales and birds had disappeared from the area and after that only one catch (10 July) was taken. The factory ship *Norglobal* and Norwegian fishing vessels left the area on 12 July (G. Sangolt, personal communication). In contrast to the situation on the Southeast Shoal, qualitative observations on spawning in inshore Newfoundland waters indicate that capelin were abundant in 1976.

The low abundance of capelin on the Southeast Shoal in 1976 was also unexpected in view of Winter's analysis (MS 1975). He suggested that, because of the decline in the stocks of three of the major capelin predators (cod, seals and whales), there would be a surplus of capelin available for human harvest. Incidental catches of capelin by the *A.T. Cameron* during the last few years (Fig. 1) also suggested that capelin were abundant.

The purpose of this paper is to examine possible causes for the decline of the Southeast Shoal capelin stock in 1976.

Results

Capelin stock discrimination and migration

To some extent, the significance of the decline in capelin abundance on the Southeast Shoal depends on whether this stock is considered to be discrete from capelin spawning inshore. For instance, if capelin migrated either inshore or to the Southeast Shoal to spawn because of changes in environmental factors from year to year, the decline of the Southeast Shoal capelin stock might be explained by changes in hydrographic conditions in 1976.

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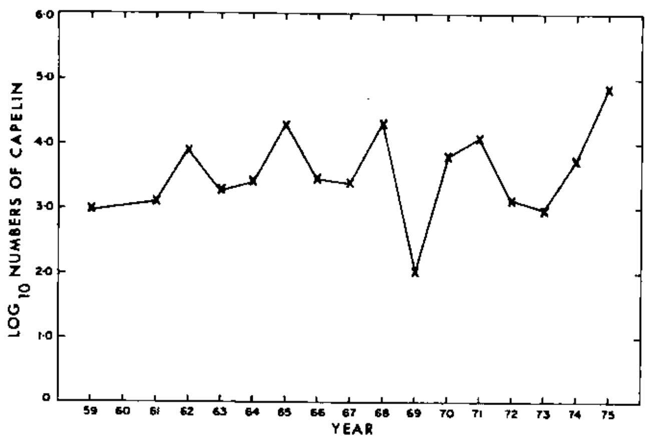

Fig. 1. Catches of capelin by bottom trawl on R/V *A.T. Cameron* cruises in Div. 3L and 3O during March-May, 1959-75.

Therefore, it is necessary to examine the evidence in support of or against the existence of discrete spawning stocks of capelin.

Prokhorov (1968) reported that Barents Sea capelin change their spawning area depending on the temperature regime. In cold years, capelin spawn in the western parts of the spawning area and in warm years they spawn to the east. He suggested that the temperature regime of the Barents Sea observed for the last three months of the previous calendar year determines which area the capelin approach. Olsen (1968) also noted that temperature was an important factor in determining the site of capelin spawning. He noted that the good year-classes of 1956, 1957, 1962 and 1963 resulted from late spawning at low temperatures in the eastern area. In 1960 and 1961, the spawning stock was large, spawning occurred early in warm water and poor year-classes were produced.

There have been no detailed studies in the Newfoundland area relating annual abundance of capelin and capelin movements to hydrographic conditions. Bakanev *et al.* (MS 1976) reported that, in samples of capelin from Labrador and the North Newfoundland Bank, the 1973 year-class was strong. This year-class was also dominant in Carscadden's (MS 1976) samples from ICNAF Div. 2J and 3K in October and November 1975. Water temperatures in 1972 were unusually low and water temperatures for many places in the Newfoundland region were lower than average in 1973 although not as low as the 1972 temperatures (Templeman, 1975). Water temperatures in 1974 and 1975 were generally lower than the long-term mean over the Newfoundland and Labrador areas (ICNAF, 1975 and 1976). Winters (MS 1974a) suggested that water temperatures influenced growth and maturation rate but their effect on survival to spawning and migration is not known.

The pattern of capelin migrations to the Southeast Shoal appears to be relatively constant each year. Schools of capelin first appear in ICNAF Div. 3L in March or April, at which time the USSR capelin fishery usually begins. These capelin gradually move south through Div. 3L and into Div. 3O, arriving on the spawning grounds in Div. 3N in June. Evidence from cod tagging suggests that some of these capelin move inshore to spawn on Newfoundland beaches (Templeman and Fleming, 1962). This general movement through Div. 3L and 3O to Div. 3N is a predictable annual occurrence and, unlike the movement of the Barents Sea capelin, hydrographic influences in the Newfoundland area would appear to be less important.

Inspection of the age composition and age-at-length of mature capelin, taken in June from the Southeast Shoal (Table 1), inshore in Div. 3P (Table 2) and Div. 3L (Table 3), shows that there is little resemblance among the three areas. Capelin spawning on the Southeast Shoal have exhibited a great deal of variation in age composition from year to year. With the exception of 1976, 4-year-olds have dominated the spawning population in Div. 3L, and 3-year-olds have been most numerous in Div. 3P for the years in which data are available. These differences in dominance of age-classes would suggest that capelin spawning in different areas belong to different stocks. Winters (MS 1974b) demonstrated that growth of capelin differed in different areas.

Leggett *et al.* (MS 1976) have presented morphometric and meristic evidence suggesting that capelin spawning on the Southeast Shoal represents a discrete population. Although these data are preliminary, when taken with the knowledge that this migration is a predictable annual occurrence and that the spawning on the Southeast Shoal occurs at the same time as inshore spawning, it seems probable that the capelin spawning on the Southeast Shoal comprise a distinct stock. Hence, for the purpose of this paper, this spawning population is assumed to be discrete.

Catch and effort statistics

The first offshore capelin catches from Div. 3L, 3N and 3O, reported to ICNAF, were taken in 1971. Consequently, long-term catch and effort records do not exist. However, all available catch-per-unit-effort (CPUE) data for 1972-76 from Div. 3LNO are given in Table 4. In 1972, 1973 and 1974, the Industrial Development Branch of the Canadian Fisheries and Marine Service chartered a number of midwater trawlers to assess the capelin potential in the Northwest Atlantic (Hinds, 1975) and CPUE data were calculated from information in that report. In 1974, personnel from the Newfoundland Biological Station were observers on the Norwegian vessel *Meloyvaer* fishing for capelin on the Southeast Shoal, and calculations of CPUE

TABLE 1. Percentage age composition and mean length-at-age (mm) of mature capelin in samples from Div. 3N in June, 1967-76.

		Age-groups					
Sex	Year	2	3	4	5	6	Number of fish
Male	1967	—	66 (184)	30 (191)	4 (198)	—	307
	1969	6 (164)	23 (182)	68 (193)	4 (193)	—	811
	1970	4 (166)	52 (184)	40 (189)	4 (198)	—	25
	1972	—	36 (178)	63 (185)	1 (190)	—	106
	1973	—	5 (175)	86 (179)	9 (182)	—	44
	1974	—	29 (187)	41 (193)	29 (194)	2 (192)	350
	1975	5 (168)	51 (181)	42 (194)	2 (197)	—	539
	1976	—	59 (174)	37 (176)	4 (180)	1 (181)	295
	Mean[1]	4 (165)	37 (182)	52 (192)	7 (194)	2 (192)	
Female	1967	—	49 (166)	31 (173)	18 (179)	2 (189)	323
	1969	16 (146)	47 (159)	32 (170)	5 (184)	1 (194)	1000
	1970	—	52 (165)	28 (176)	20 (182)	—	25
	1972	—	43 (158)	52 (169)	5 (183)	1 (186)	244
	1973	1 (148)	10 (158)	82 (165)	7 (173)	—	256
	1974	1 (146)	28 (166)	27 (176)	42 (179)	3 (185)	400
	1975	7 (148)	39 (163)	30 (177)	12 (185)	11 (189)	1126
	1976	—	72 (155)	23 (162)	4 (175)	1 (182)	1119
	Mean[1]	7 (146)	39 (161)	36 (172)	13 (185)	5 (189)	

[1] Excluding 1976 data.

TABLE 2. Percentage age composition and mean length-at-age (mm) of mature capelin in samples from Div. 3P in June, 1973-76.

		Age-group					
Sex	Year	2	3	4	5	6	Number of fish
Male	1973	1 (170)	48 (174)	42 (182)	8 (186)	—	577
	1974	15 (173)	55 (185)	21 (191)	8 (195)	—	978
	1975	3 (162)	71 (187)	24 (192)	1 (190)	1 (194)	563
	1976	—	73 (184)	25 (187)	2 (192)	—	890
Female	1973	3 (144)	49 (160)	34 (170)	14 (173)	—	95
	1974	21 (160)	50 (171)	22 (178)	7 (179)	1 (187)	219
	1975	6 (139)	54 (170)	29 (180)	8 (184)	2 (197)	187
	1976	—	72 (167)	22 (177)	5 (191)	2 (191)	60

TABLE 3. Percentage age composition and mean length-at-age (mm) of mature capelin in samples from Div. 3L in June, 1967-76.

		Age-group					
Sex	Year	3	4	5	6	7	Number of fish
Male	1967	21 (188)	63 (198)	15 (201)	1 (206)	—	920
	1969	20 (192)	76 (194)	4 (185)	—	—	50
	1970	—	—	—	—	—	—
	1972	5 (179)	95 (188)	—	—	—	100
	1973	3 (178)	79 (185)	18 (187)	—	—	767
	1974	24 (187)	47 (193)	29 (196)	<1 (195)	—	904
	1975	26 (187)	69 (198)	4 (200)	<1 (206)	—	1241
	1976	51 (185)	48 (194)	1 (196)	—	—	1189
Female	1967	16 (166)	19 (176)	62 (182)	3 (186)	—	613
	1969	—	—	—	—	—	—
	1970	—	—	—	—	—	—
	1972	18 (157)	75 (168)	7 (176)	—	—	100
	1973	7 (171)	67 (171)	19 (176)	2 (193)	—	81
	1974	17 (166)	29 (177)	51 (181)	4 (184)	—	342
	1975	15 (164)	51 (179)	23 (186)	24 (187)	7 (189)	156
	1976	45 (164)	28 (175)	20 (182)	—	5 (200)	60

TABLE 4. Catch-per-unit-effort data for the capelin fishery in Div. 3LNO, 1972-76.

Year	ICNAF Div.	Country and/or vessel	Gear	GRT	Months	Catch per day	Catch per hour	Source
1972	3N	Canada—Foam V	OTM	399	May	6.8	2.3	Hinds (1975)
					June	79.4	32.2	
					July	86.6	38.4	
		Canada—Lady Janice	OTM	434	June	232.5	39.0	Hinds (1975)
					July	167.0	53.9	
		Canada—Combined data			—	100.8	38.1	Hinds (1975)
		USSR	OT	>2000	June	49.4	4.8	ICNAF Stat. Bull. Vol. 22
1973	3N	Canada—Foam V	OTM	399	June	62.8	6.8	Hinds (1975)
					July	47.5	6.8	
		Canada—Lady Patricia	OTM	207	June	87.5	11.7	Hinds (1975)
					July	55.3	9.5	
		Canada—Newfoundland Hawke	OTM	835	June	102.5	9.5	Hinds (1975)
					July	43.2	5.7	
		Canada—Combined data			—	54.5	7.5	Hinds (1975)
		USSR	OT	>2000	June	47.5	5.4	ICNAF Stat. Bull. Vol. 23
	3L	USSR	OT	>2000	May	24.9	2.3	ICNAF Stat. Bull. Vol. 23
1974	3N	Canada—Elizabeth Anne	OTM	198	June	55.0	29.9	Hinds (1975)
		Norway—Meloyvaer	OTM	708	June	226.7	52.3	St. John's Biological Station records
					July	70.5	17.5	
		Norway (all months)			—	125.5	29.6	
	3NO	USSR	OTM	>2000	May-June	34.9	3.4	ICNAF Stat. Bull. Vol. 24
1975	3L	USSR	OTM	>2000	Mar-May	46.2	3.5	ICNAF Stat. Bull. Vol. 25
						38.7	—	Canadian inspection reports
	3N	USSR	OTM	>2000	May-July	47.4	4.9	ICNAF Stat. Bull. Vol. 25
		Norway	OTM	500-999	June	85.4	16.7	ICNAF Stat. Bull. Vol. 25
					July	137.2	23.5	
			PS	500-999	June	472.0	—	ICNAF Stat. Bull. Vol. 25
					July	475.1	—	
	3NO	Spain	OTM	1500	June-July	90.4	11.6	Labarta (MS 1976)
	3O	USSR	OTM	>2000	May-July	53.2	4.5	ICNAF Stat. Bull. Vol. 25
1976	3L	USSR				45.5		Canadian inspection reports
	3NO	USSR				35.5		Canadian inspection reports

were made for two trips. For 1972-75, USSR catch and effort data for capelin were taken from Table 5 of ICNAF Statistical Bulletins, and it was assumed that all catches of the "other finfish" column were capelin. No adjustments were made in the effort statistics although some effort may have been expended for species other than capelin. It is therefore possible that CPUE data calculated for USSR are underestimates. However, the data were not used unless the catch in the "other finfish" column comprised a substantial portion of the total catch of all species in the last column of the Table. Calculations of CPUE from information collected by Canadian inspection officers, operating under the ICNAF Scheme of Joint International Enforcement (R. Prier, personal communication), are also given in Table 4.

The estimates of CPUE for USSR based on ICNAF statistics are relatively constant from 1972 to 1975. It is known from inspections carried out by Canadian fishery officers that most (about 95%) of the USSR capelin catch is

TABLE 5. Percentage age composition and mean length-at-age (mm) of mature capelin in samples from Div. 3N in July, 1967-75.

		Age-group					
Sex	Year	2	3	4	5	6	Number of fish
Male	1967	28 (156)	49 (178)	20 (189)	2 (197)	—	255
	1968	1 (158)	36 (184)	61 (194)	1 (197)	—	332
	1969	1 (166)	26 (188)	73 (195)	—	—	100
	1972	—	33 (176)	64 (179)	2 (198)	2 (201)	272
	1973	1 (163)	8 (174)	83 (182)	9 (184)	—	1,049
	1974	—	36 (185)	40 (192)	23 (194)	2 (197)	342
	1975	—	50 (172)	25	—	25	4
	Mean	4 (157)	24 (180)	64 (185)	8 (189)	<1 (196)	
Female	1967	20 (142)	61 (155)	11 (173)	7 (180)	—	70
	1968	13 (143)	71 (154)	14 (168)	1 (180)	—	255
	1972	—	50 (152)	27 (170)	13 (189)	8 (199)	114
	1973	5 (142)	24 (152)	67 (160)	4 (157)	—	199
	1974	7 (151)	47 (158)	28 (169)	19 (175)	—	58
	1975	—	4 (176)	41 (182)	20 (191)	35 (190)	46
	Mean	8 (143)	49 (154)	33 (160)	7 (180)	3 (193)	

frozen for human consumption (D. Barrett, personal communication). USSR factory vessels are known to have a daily freezing capacity of 30-50 tons, but, because capelin are small and freeze more quickly, the daily capacity is at least one-third higher, that is, 40-66 tons (R. Prier, personal communication). Thus, the estimated daily catches of USSR vessels, based on ICNAF statistics, are well within the processing capacity of these vessels and, in fact, it would appear that total freezing potential may not have been reached. Estimates of CPUE for USSR vessels in 1975, based on ICNAF Statistical Bulletin data, were higher than those of other years and estimates for Spanish vessels (Labarta, MS 1976) were also high. Thus the CPUE of USSR vessels was apparently low in 1976 compared to 1975, and perhaps lower than that for 1972, 1973 and 1974.

Seliverstov and Kovalev (MS 1976) indicate that pre-spawning schools of mature and immature capelin normally form in March and April in Div. 3L. These schools and the catches from them would be expected to be smaller than the spawning schools which concentrate later in Div. 3N. CPUE data for 1973 and 1975 support this view. However, Canadian surveillance data suggest that the opposite occurred in 1976, indicating that capelin were not abundant on the Southeast Shoal in that year.

Fishing intensity on the Southeast Shoal is heavy over a relatively small area, as up to 60 fishing vessels have been observed to be actively fishing in an area of approximately 400 square miles. Thus, when fish concentrations are heavy and there is a limit to the daily processing capacity of fishing vessels, the use of CPUE data based on catch per day may not be useful if the processing capacity is reached within a fishing day. However, the fact that the Canadian estimates of catch per day for USSR vessels in Div. 3NO were well below the processing capacity of these vessels adds further support to the observation that capelin were not abundant in Div. 3N in 1976.

Biological characteristics

Calculations of age composition and length-at-age of mature capelin, sampled during June on the Southeast Shoal, revealed that age 3 (1973 year-class) was strong in males and dominated in females (Table 1). Although 3-year-old fish have dominated in the spawning population in June of other years (e.g. 1967, 1970, 1975), the highest percentage of 3-year-old fish occurred in 1976. Mean lengths-at-age of all age-classes in 1976 were smaller than in previous years. In fact, fish of a year-class taken in 1976 were smaller than those of the same year-class taken in 1975. This supports Winter's (MS 1974b) suggestion that slow-growing fish mature at an older age. Errors in age reading are not believed to account for this variation, as the otoliths were read at least three times by an experienced reader. The reader did note that these otoliths were more difficult to read than usual, because the annual zones were closer together possibly due to slower growth.

Winters (MS 1974a) and Templeman (1948) observed that older and larger fish spawn first. It was therefore suspected that the capelin spawning season on the Southeast Shoal had occurred earlier in 1976 and that the smaller sizes of fish taken in June 1976 were from the latter part of the spawning run. A comparison of the mean length of capelin taken in June 1976 (Table 1) with those for July of previous years (Table 5) revealed that males were smaller in 1976 than the long-term mean for previous years. For females, however, the mean lengths in 1976 were smaller for ages 5 and 6 and slightly larger for ages 3 and 4. In 1976, the Norwegian vessels landed the first catches of capelin on the Southeast Shoal to the *Norglobal* on 15 June (G. Sangolt, personal communication), and Canadian surveillance reports indicated that, during 4-9

June, most fishing activity for capelin was in Div. 3O with very little activity in Div. 3N (D. Aylward, personal communication). This would indicate that the fishery and hence the capelin spawning season did not start earlier than usual in 1976. Thus, the smaller lengths-at-age of capelin observed on the Southeast Shoal in 1976 would appear to be a real phenomenon and not due to the unusual timing of the spawning season.

Analysis of capelin samples from Div. 2J and 3K during October and November 1976 (Table 6) revealed that age 3 males and females were still small even after a full-growing season. Age 4 males were only slightly larger than those of the same year-class sampled earlier in the year on the Southeast Shoal, whereas age 4 females were substantially larger. These results support the observation that fish of the 1973 year-class were smaller than fish of other year-classes.

TABLE 6. Percentage age composition, mean length-at-age (mm) and percentage mature in capelin samples from Div. 2J and 3K, October-November 1976. (Data based on 167 males and 132 females.)

	Male			Female		
Age	% at age	Mean length	% mature	% at age	Mean length	% mature
1	2	128	33	1	127	0
2	51	152	100	44	140	98
3	45	173	100	47	158	100
4	2	182	100	7	187	100
5	—	—	—	1	202	100

Winters (MS 1974a) suggested that growth-induced differences in maturation rate were more important in explaining year-class dominance than variation in survival rate. Furthermore, he found consistent positive correlations between temperature and growth for each age-group of each sex. This suggested that the length achieved by any age-group was at least partially controlled by the bottom temperature 2 years previous to the sampling year. A similar analysis was performed using mean lengths from Table 1 and deviations from the long-term bottom temperatures (80 m). Temperature data, from which deviations from the long-term (1953-75) mean were calculated, were from hydrographic station 36 (47°00'N, 49°07'W) for the 2 years previous to the sampling year. It was found that correlations between temperature deviations and mean lengths were not significant for 3- and 4-year-old males and females. Data for 1974 and 1975 appeared to deviate most from the trend noted by Winters (MS 1974a). Mean lengths of fish for these years were larger but water temperatures during the 2 years previous to 1974 and 1975 respectively were colder than the long-term mean. When regressions were recalculated, omitting 1974 and 1975 data, all correlations were significant ($p < 0.05$) and positive. No explanation for the 1974 and 1975 deviations from the trend is provided.

Winters (MS 1974a) also found a positive correlation between mean lengths of 3-year-old fish and the proportion mature at age 3 and a negative correlation between mean lengths of 4-year-old fish and proportion maturing at age 4. This analysis was repeated using data for 3- and 4-year-old males and females in Table 1, but no significant correlations were found.

The presence of a strong 1973 year-class was also noted by Bakanev *et al.* (MS 1976) and was evident in Carscadden's (MS 1976) data from Div. 2J and 3K from samples taken in the autumn of 1975. This year-class was also dominant in populations of capelin spawning inshore in Div. 3P and 3L (Tables 2 and 3). Age 4 males and females are usually dominant in Div. 3L catches but age 3 fish were more prevalent in 1976. In Div. 3P, age 3 fish are normally more common, but capelin of this year-class were even more numerous than in any previous year. Mean length-at-age of capelin in both Div. 3L and 3P have been fairly constant from year-to-year, including 1976, in contrast to the significant decrease in mean length-at-age observed for capelin in Div. 3N in 1976.

Maturity ogives for Grand Bank capelin were given by Winters (MS 1974a), using data collected to 1973. Similar ogives have been calculated for data from 1966 to 1976. Because of the difficulty of obtaining large numbers of immature fish, per mille length compositions were calculated for each sex and used in the calculation of the maturity ogives shown in Fig. 2. Capelin samples used in

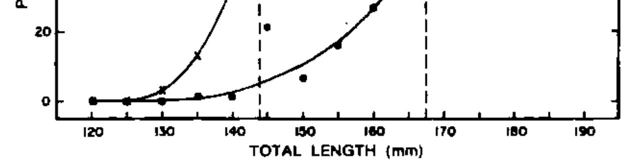

Fig. 2. Maturity ogives for male and female capelin in samples from Div. 3L, 3N and 3O during January-July, 1966-76.

the analysis were from offshore areas of Div. 3L in January-May and from Div. 3NO in May-July. The curve for male capelin is similar to that given by Winters (MS 1974a) and shows the 50% maturity at 168 mm. The shape of the curve for female capelin is slightly different from that of Winters (MS 1974a) and shows the 50% maturity at 144 mm.

Samples from the Southeast Shoal in 1976 contained mostly mature fish. However, when the immatures were included, the mean lengths of age 3 for males and females were 171 mm and 155 mm respectively. The actual proportions of immatures for this age-group were 8% for males and 1% for females. Because this is a spawning population, it is believed that the sampling was biased towards mature fish and that the observed mean lengths may therefore be larger than those of that age-group in the population. These mean lengths represent the length at which 65% of males and 80% of the females at age 3 would be mature. Since the mean lengths calculated mainly from mature fish may be over-estimated, the percent at maturity values are probably maximum estimates. To properly use the calculated maturity ogive, representative samples of both immature and mature fish are needed, but such samples are difficult to obtain as mature and immature fish usually occur in separate schools (Seliverstov and Kovalev, MS 1976).

Samples from the Southeast Shoal population in past years also consist almost entirely of mature fish. However, using the estimates of mean lengths of mature fish as indicators and realizing that subsequent estimates of the percentage mature are maximum estimates, it is evident that a lower proportion than normal of age 3 capelin was maturing in 1976. The proportions of mature males approached this low level in 1973 and proportions of mature females were also low in 1972 and 1973, but those for 1976 are the lowest on record. From samples taken in the autumn of 1975, Carscadden (MS 1976) reported that 33% of the males and 51% of the females of the 1973 year-class in Div. 3K were mature, while 80% of the males and 74% of the females of the 1973 year-class were mature in Div. 2J.

In the past, only small numbers of immature capelin have been taken with spawning fish on the Southeast Shoal (Table 7), and these were usually taken in the early part of the spawning season. Prior to 1976, the highest proportions of immatures were taken in June 1969 (2% of the males and 4% of the females). In 1976, a greater percentage of immature males occurred but relatively few immature females were recorded. The proportion of immature capelin varied from catch to catch (0 to 76% for males and 0 to 15% for females). However, because males were not as numerous as females in the catches, the proportion of immatures in the entire catch was relatively small.

As indicated in Fig. 3, a large proportion of both males and females had not spawned in June. In fact, a large proportion of capelin were still in maturity stage 1, indicating that these fish would probably not spawn for at least a week. On 29 June 1976, four midwater trawl sets

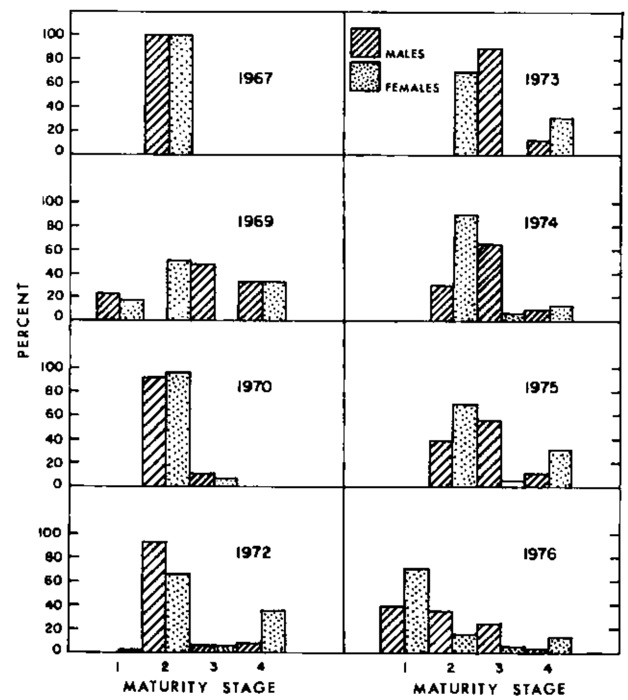

Fig. 3. Maturity composition of male and female capelin in samples from the Southeast Shoal in June. (1 = maturing, 2 = ripe, 3 = spawning and 4 = spent.)

TABLE 7 Number and percentage of immature capelin in samples from the Southeast Shoal in June 1967-76.

	Male			Female			Sex ratio (%)	
Year	No. of Imm.	Total in samples	% Imm.	No. of Imm.	Total in samples	% Imm.	Male	Female
1967	3	310	1	2	325	1	49	51
1969	17	828	2	40	1040	4	45	55
1970	0	25	0	0	25	0	50	50
1972	0	106	0	0	244	0	30	70
1973	0	44	0	0	256	0	15	85
1974	0	350	0	0	400	0	47	53
1975	1	540	<1	2	1128	<1	32	68
1976	225	902	25	124	3595	3	21	79

were made, from which the maturity examination of 1,225 fish revealed that 13% of the males were immature and 48% were maturing but had not spawned. Of the females examined, 1% were immature and 85% were maturing but had not spawned. Thus, samples taken near the end of June indicated that a large proportion of both sexes were ripening but has not spawned. Only small concentrations of capelin were detected on 30 June 1976.

The sex ratios of capelin from Div. 3N for June are given in Table 7. In many years, females were taken more often than males. This is especially apparent since 1972 when most samples were taken with midwater trawl. This agrees with Winter's (MS 1974a) suggestion that sexes are segregated vertically on the Southeast Shoal with males near the bottom and females located pelagically.

Hydrographic Conditions

Capelin spawning on beaches in Newfoundland and Labrador prefer water temperatures of 5.5° to 8.5°C, although some spawning does occur at water temperatures up to 10°C (Jangaard, 1974). Pitt (1958) reported bottom temperatures on the Southeast Shoal ranging from 2.8° to 4.7°C during capelin spawning in 1950 and 1951. Templeman (1965) listed the following dates and bottom temperatures for catches of capelin from the Southeast Shoal in 1961: 1,400 kg on 8 July, 2.9°C; 1,700 kg on 9 July, 3.1°C; and 1,500 kg on 22 July, 2.2°C. These earlier observations of preferred capelin spawning temperatures have been confirmed by recent trips to the Southeast Shoal (Table 8). In a survey of the area, southward of the region where the greatest capelin concentrations occurred in 1976, only a few small concentrations were observed. The bottom temperatures and positions from this survey were as follows: 5.4°C at 44°25'N, 50°00'W; 5.0°C at 44°30'N, 50°00'W; and 4.1°C at 44°35'N, 50°00'W. Although these are the only temperature data available for 1976, it appears that bottom temperatures were higher than usual on the southern part of the Southeast Shoal. This may have restricted the capelin concentrations to a relatively small area on the northern part of the Shoal, centered approximately at 45°00'N, 50°10'W. Large concentrations of spawning capelin and heavy fishing activity were observed in the same area in 1975. Seliverstov and Kovalev (MS 1976) confirmed this observation, but they did report that large concentrations of capelin occurred to the south of this area as well. Thus, capelin spawning on the Southeast Shoal occurred in a relatively smaller area in 1976 than in 1975, and presumably smaller than in previous years.

Typical profiles of water temperatures on the Southeast Shoal in 1976 are shown in Fig. 4. These profiles more closely resemble the profiles for 1975 than for 1972 (Sangolt and Ulltang, MS 1976), except that the bottom temperatures shown for 1976 are slightly lower (see also Table 8). Purse seining in 1975 was more successful than in other years when trawling was more efficient, and Sangolt and Ulltang (MS 1976) attributed this to temperature differences. It is not likely that differences in schooling pattern influenced by water temperature could account for the decrease in the Norwegian catch in 1976.

Discussion

This study has revealed a number of unusual points concerning the Southeast Shoal capelin population in 1976. Observations by fishermen indicated that abundance of capelin was low and this was substantiated by Norwegian catches and CPUE data. The spawning season ended earlier than usual although evidence indicated that spawning had started on or about the usual dates. Near the end of the spawning period, there were large proportions of mature, but unspawned, fish in the samples. There were unusually high proportions of immature capelin mixed with the mature capelin on the spawning grounds. The spawning area on the Southeast Shoal in 1976 was apparently restricted in area, perhaps because of unfavourable temperature conditions on other parts of the Shoal. Mean lengths-at-age of mature capelin were smaller than those of previous years and smaller than the long-term means for both males and females.

TABLE 8. Summary of information on bottom temperatures in areas where capelin were caught on the Southeast Shoal, 1968-76.

Year	Dates	Boundaries of area from which capelin catches were taken	Number of temperature observations	Mean temperature (°C)	Range of temperature (°C)	Remarks
1968	8-18 July	43° 34'N, 49° 07'W 44° 46'N, 50° 22'W	8	4.7	0.2-6.3	Capelin were dead and spawning completed
1969	19 June-2 July	44° 56'N, 49° 25'W 42° 51'N, 50° 20'W	18	3.3	0.1-4.7	Large capelin concentrations on southern and western parts of Southeast Shoal
1975	20 June-2 July	44° 57'N, 49° 11'W 44° 05'N, 50° 40'W	30	2.6	0.4-5.5	
1976	15-30 June	45° 13'N, 50° 12'W 44° 55'N, 50° 25'W	21	2.3	1.5-2.9	

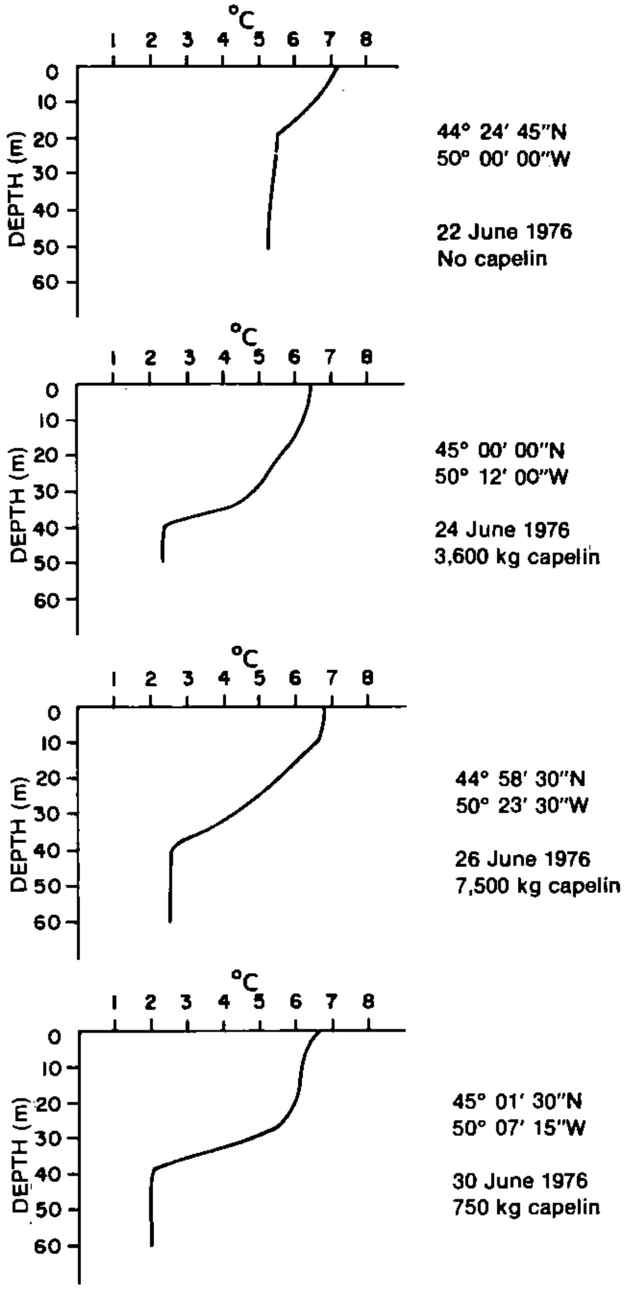

Fig. 4. Typical temperature profiles and capelin catches at certain locations on the Southeast Shoal in June 1976.

The low abundance of capelin on the Southeast Shoal may be due to the low proportion of the 1973 year-class maturing. Samples from autumn catches of the previous year and from inshore and offshore spawning populations indicated that this year-class was relatively strong. However, a low percentage of this year-class may have matured because of slow growth. Comparisons of mean lengths of spawning capelin with the maturity ogives and samples from the previous autumn add support to such a conclusion. The presence of relatively low numbers of the 1972 year-class spawning on the Southeast Shoal in 1976 would tend to accentuate the dominance of the 1973 year-class. In 1975, the 1972 year-class was fairly strong and the mean length was approximately equal to the long-term mean. Thus, most of the 1972 year-class may have matured in 1975, leaving few to mature in 1976. This, in combination with low proportions of the 1973 year-class maturing in 1976, would contribute to the low abundance of capelin on the Southeast Shoal during the 1976 spawning season. The unusual presence of immature capelin with the mature fish is further evidence that a larger proportion than usual of the age 3 fish did not mature.

The lower proportion of 4-year-old capelin on the Southeast Shoal in 1976 suggests that this age-group may have spawned elsewhere. Samples of inshore spawning capelin from Div. 3P do not support such a conclusion, as age 3 fish normally dominate this population and 1976 was no exception. Samples from Div. 3L are more difficult to interpret; in general, the proportion of 4-year-olds was lower than usual, but this may be misleading because of the strength of age-group 3. The mean lengths of capelin from Div. 3L were relatively constant from year-to-year and, until 1976, were comparable to mean lengths of mature capelin from Div. 3N. However, in 1976, capelin spawning in Div. 3L were larger. This suggests that larger fish of the 1972 year-class moved inshore while smaller fish of this year-class spawned offshore, but such an occurrence seems improbably in view of the similarities of mean lengths from previous years.

There are probably a number of factors influencing the growth rate and maturation of a year-class. Although Winters (MS 1974a) found that temperature influences growth, the results from the present study suggest that the influence of temperature may not be great. Density-dependence may be a factor in that a large year-class may exert a heavy demand on the available food supply thus resulting in poor growth. Winters' (MS 1975) surplus production model suggested that, because of the reduction in numbers of major capelin predators, there would be a surplus of approximately 1.25 million metric tons of capelin. The overall quota is presently set at 500,000 tons, indicating that there would still be an abundance of capelin. This surplus of capelin, coupled with a strong year-class, could have resulted in density-dependent effects such as poor growth and fewer maturing fish. Ulltang (MS 1975) suggested that, for Barents Sea capelin, poor growth had resulted because the available food supply was not adequate to support a series of abundant year-classes. He also noted that these strong year-classes had occurred after the Norwegian fishery had removed a large proportion of the spawning stock each year for several years.

The influence of density-dependence was not evident in inshore spawning stocks in 1976. In Div. 3L, for instance, the 1973 year-class was strong in contrast to the situation of earlier years when 4-year-olds dominated the spawning population. In this case, the mean length of 3-year-olds was approximately the same as the mean length of that age-class in previous years. In Div. 3P, where 3-year-olds normally dominate, the strength of the 1973 year-class was maintained, especially for females. Growth in this year-class was apparently not affected by its abundance in these areas.

The effect of the capelin fishery on the population dynamics of the Southeast Shoal stock is unknown. Although the fishery has been intense for at least 3 years, sampling data for periods of the year other than the spawning season are not available to follow year-class growth and maturation rates. It is therefore not possible to determine the effect of the fishery on year-class strength and consequently on growth rate, as Ulltang (MS 1975) suggested may have occurred for Barents Sea capelin.

In 1975, when the establishment of a total allowable catch of capelin was being considered for a 3-year period (1975-77), Winters (MS 1975) suggested that the quota for the stocks in Subareas 2 and 3 should be 250,000 tons. This suggestion was based on Gjosaeter's (MS 1972) observations that the lowest estimate of abundance of Barents Sea capelin had been about 20% of the average. Thus, for Northwest Atlantic capelin, 20% of the surplus of 1.25 million tons would be 250,000 tons. However, the overall quota was set by ICNAF at 500,000 tons, with 200,000 tons allocated for Div. 3LNOP and 300,000 tons for Div. 2J+3K.

Because of the low abundance of capelin on the Southeast Shoal in 1976, a reduction in the quota may be desirable in order to protect the stock. Lacking detailed knowledge of stock mixing in each of the two major components of capelin stocks in Subareas 2 and 3 (i.e. in Div. 2J+3K and Div. 3LNOP), it may be preferable to reduce the overall quotas for these areas by common facrots rather than imposing catch reductions in specific parts of the stock area (e.g. Div. 3N).

Because of the incidence of immature fish in the catches on the Southeast Shoal in June 1976 and because midwater trawls apparently are selective for females, it may be necessary to offer special protection to these elements of the population in Div. 3N. A reduction in the quota would reduce both the numbers of immatures and females taken. A closed fishing season, either during part of the spawning season or on specific days, would also allow some escapement. However, increased fishing effort during the open fishing periods might counteract any advantage gained by imposing a closed season.

Ulltang (MS 1974) discussed the problems of setting quotas on the capelin stock in the Newfoundland area. Low quotas result in a loss in yield and this would probably extend the time necessary to get a reasonable estimate of the biomass. Quotas that are too high would result in serious consequences both for the capelin stock and its predators, especially if applied over a number of years. In addition, if the immatures were exploited, the consequences would be serious. Because immature fish were prevalent in catches on the Southeast Shoal in 1976 and in catches in 1975 in Div. 2J+3K and because it is now considered desirable to rebuild predator stocks, such as cod, reduction in the present quota to a more conservative level would be desirable.

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Age and Growth of Butterfish, *Peprilus triacanthus* (Peck), in ICNAF Subarea 5 and Statistical Area 6[1]

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Abstract

Age and growth of butterfish in ICNAF Subarea 5 and Statistical Area 6 were investigated from the mean radii of year marks observed in the otoliths and the relationship between fork length and otolith radius. Von Bertalannfy growth curves were fitted to the fork lengths back-calculated from otoliths for males, females and sexes combined. The monthly modal lengths of butterfish caught by Japanese trawlers are consistent with the von Bertalannfy growth curves in most cases, but a stair-like growth pattern is evident, with slower growth in winter and spring and faster growth from summer to autumn There is the possibility that one year mark may be missed in the age determinations, in which case the early growth may be very slow. Japanese catches of butterfish consist mainly of ages 0+ and 1+ if the early growth is fast, or ages 1+ and 2+ if the early growth is slow.

Introduction

Butterfish are found on the continental shelf from Newfoundland to the Gulf of Mexico but are most common from Georges Bank to Cape Hatteras within Subarea 5 and Statistical Area 6. According to Waring (MS 1975), nominal catches in this area (entirely by USA) averaged 3,500 tons annually during 1920-63. Catches by several countries averaged 5,400 tons annually during 1963-68 and more than 10,000 tons during 1969-75 with considerable annual fluctuation in yield. The butterfish stock has therefore been extensively exploited in recent years mainly by Japan, Poland, USSR and USA, whose catches constituted more than 95% of the annual yields.

As in the case of the Japanese fishery for long-finned squid, *Loligo pealei*, the fishing grounds for butterfish are located along the edge of the continental shelf from the eastern tip of Georges Bank to Cape Hatteras (Fig. 1), and the bulk of the catch is taken in the five months from November to March (Fig. 2). On the other hand, the USA fishery for butterfish takes place from May to November. Using biological material collected over several years on Japanese trawlers, this paper presents some basic information on the age and growth of butterfish as a first step toward an assessment of the stock.

Materials and Methods

The data used in this study were derived from 3,850 specimens taken from the catches of Japanese trawlers from October 1970 to July 1976 (Table 1). Examination of the specimens involved the recording of fork length (mm), body weight (g), sex, gonad weight (g), and the extraction of otoliths which were preserved in 50% glycerin saturated with thymol.

The otolith is oval in shape and rather thin with irregular margins (Fig. 3). The central part is opaque with alternating hyaline and opaque zones. Otolith reading was carried out with a stereoscopic microscope at a magnification of 20× using reflected light. The otolith radius R (distance from the center to the outer-most edge) and the radius of each year mark r_n (distance from the center to the outer margin of the (n)th hyaline zone) were measured along a fixed axis.

The absence of data for certain fishing grounds and months in the various years (Table 1) necessitated the combination of the data for all years and divisions in order to illustrate the seasonal changes in growth.

Results

Fork length and otolith radius

The least squares regression of otolith radius (R) on the fork length (L) for male and female butterfish resulted in the following relationships:

$$R = 0.01580\ L + 0.4346\ \text{(male)} \quad (1)$$

$$R = 0.01549\ L + 0.4759\ \text{(female)} \quad (2)$$

[1] Submitted to the June 1977 Annual Meeting as ICNAF Res.Doc. 77/VI/27.

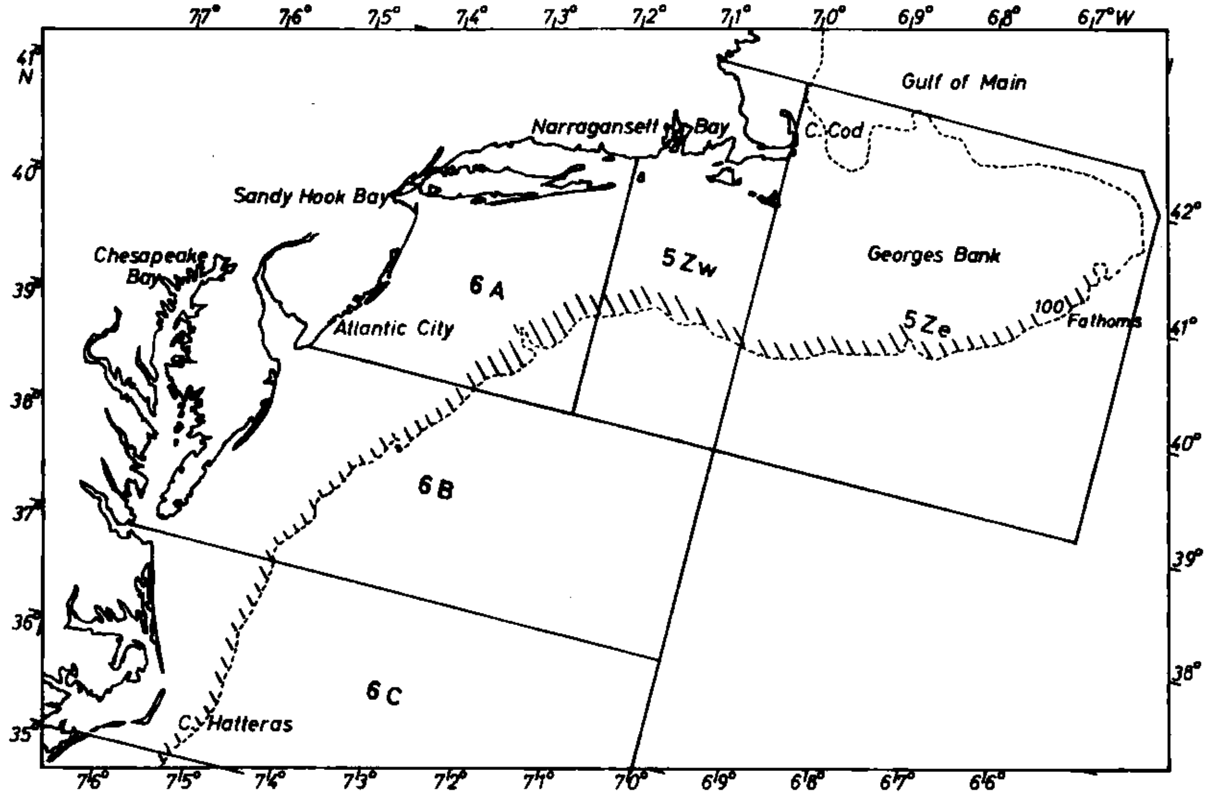

Fig. 1. Fishing grounds of Japanese trawlers for butterfish in winter and spring.

where both R and L are in millimeters. Because the deviations from the regression lines increase in proportion to the length of the fish and specimens greater than 20 are nearly all females, the difference between the mean squares of residuals by sex is significant at the 1% level, using the F-test. However, there was no significant difference in the parameters of the regression lines by sex. Thus, the combination of data for both sexes resulted in the regression line

$$R = 0.01559\ L + 0.4630 \quad (3)$$

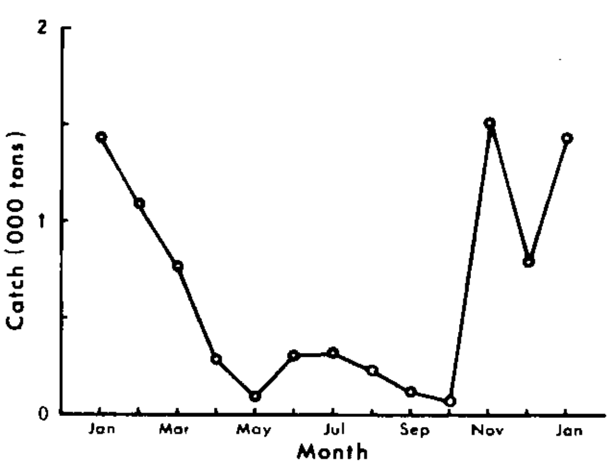

Fig. 2 Monthly changes in average catch of butterfish by Japanese trawlers in Subarea 5 and Statistical Area 6 during 1970-74.

TABLE 1. List of sampling data by month, area and depth for age determination of butterfish in Subarea 5 and Statistical Area 6.

Year	Month	ICNAF Div.	Depth (m)	Number of specimens
1970	Oct	5Z	—	42
1971	Aug	6A	108	98
	Oct	6C	103	98
1972	Apr	5Z, 6B	130-141	179
	Dec	5Z, 6A, 6B	82-160	658
1973	Jan	5Z, 6A	78-129	821
	Feb	5Z	153	170
	Mar	6B	94	60
1974	Feb	5Z	111-122	107
	Mar	5Z, 6A, 6B	81-163	831
	Apr	6A, 6B	116-223	345
	Sep	6B	120	111
1976	Jun	6A, 6B	121-155	134
	Jul	6A, 6B	153-160	198
Total				3,850

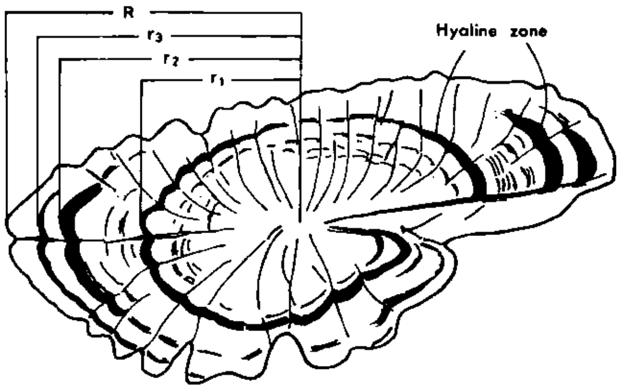

Fig. 3. Diagram of butterfish otolith showing criteria for measurement.

Mean radii of year marks and back-calculated fork length

Of 3,850 specimens collected, 3,343 could be aged, the difficulty in age determination increasing with size of fish. About 45% of the otoliths had no hyaline zone and the remainder had up to three hyaline zones. The results of the age determinations and the mean radii of the year marks are summarized in Table 2. Although the mean radii of the year marks in the otoliths of females tend to be slightly larger than for males with the same number of year marks and the mean radii for the younger specimens of both sexes are larger than those for the older fish, the differences are not significant.

The fork lengths (L_n), corresponding to the times of hyaline zone formation, were back-calculated by substituting the values of r_n in Table 2 for R in equation (3).

Time of mark formation and spawning

In order to calculate a growth curve for butterfish in terms of age in years, it was necessary to examine the relationship between the time of hyaline zone formation and spawning. The time of zone formation was estimated from the monthly changes in relative marginal increment (RMI) by the equation

$$RMI = (R - r_n) / (r_n - r_{n-1}) \qquad (4)$$

where R is the otolith radius, and r_n and r_{n-1} are the radii of the n(th) and (n-1)th marks respectively ($r_{n-1} = 0$ for the first mark). Figure 4 shows that the RMI values are on the average higher in winter and spring than in summer and autumn. Therefore, mark formation in the otolith was considered to occur once a year from May to June.

Examination of monthly changes in gonad weight relative to fork length indicated that the gonad weight in butterfish larger than 15 cm (fork length) increases rapidly in March and April, reaches a maximum in May-July and decreases thereafter. Hildebrand Schroeder (1928) reported that the spawning of butterfish occurred during June and July and that the minimum size of spawning fish in Chesapeake Bay was 15 cm. Bigelow and Schroeder (1953) reported that the spawning season in the Gulf of Maine is from June to August. According to Herman (1963), butterfish eggs are found only from June to August in Narragansett Bay.

From the evidence available it is concluded that the spawning season of butterfish possibly extends over 4 or 5 months from April or May to August, with peak spawning in June. Since the time of hyaline zone formation in the otolith seems to coincide with the time of spawning, June 1 is taken as the birthdate for convenience in calculating the growth equation.

Growth

In view of the conclusion about the time of hyaline zone formation in the otolith, the average back-calculated fork lengths (L_n) in Table 2 can be taken as the mean fork lengths (L_t) at age t with no adjustment. The resultant von

TABLE 2. Mean radii (r_n) of year marks and corresponding back-calculated fork lengths for butterfish in Subarea 5 and Statistical Area 6.

Year mark	Sex	No. of fish	Mean radius (mm)			Calculated length (mm)		
			r_1	r_2	r_3	L_1	L_2	L_3
0	M	696	—	—	—	—	—	—
	F	705	—	—	—	—	—	—
1	M	556	2.435	—	—	126.5	—	—
	F	718	2.478	—	—	129.2	—	—
2	M	98	2.335	3.116	—	121.4	170.2	—
	F	243	2.375	3.233	—	122.6	177.7	—
3	M	11	2.168	3.073	3.500	109.4	167.4	194.8
	F	29	2.374	3.111	3.509	122.6	169.9	195.4
All ages	M	1361	2.419	3.112	3.500	125.5	169.9	194.8
	F	1695	2.450	3.220	3.509	127.5	176.8	195.4
	M+F	3056	2.437	3.189	3.507	126.6	174.9	195.3

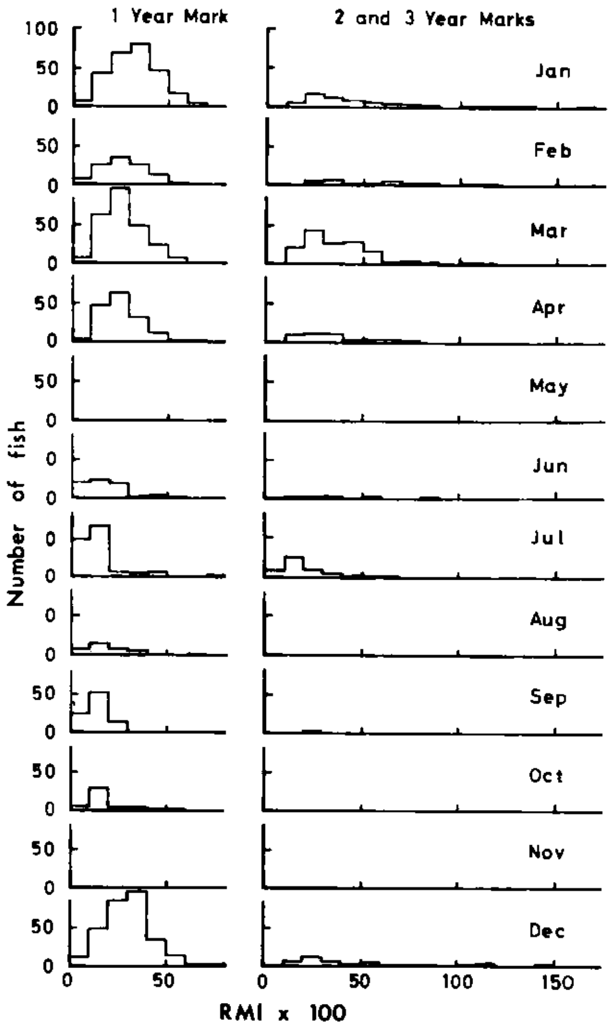

Fig. 4. Relationship between fork length and body weight of butterfish from Subarea 5 and Statistical Area 6.

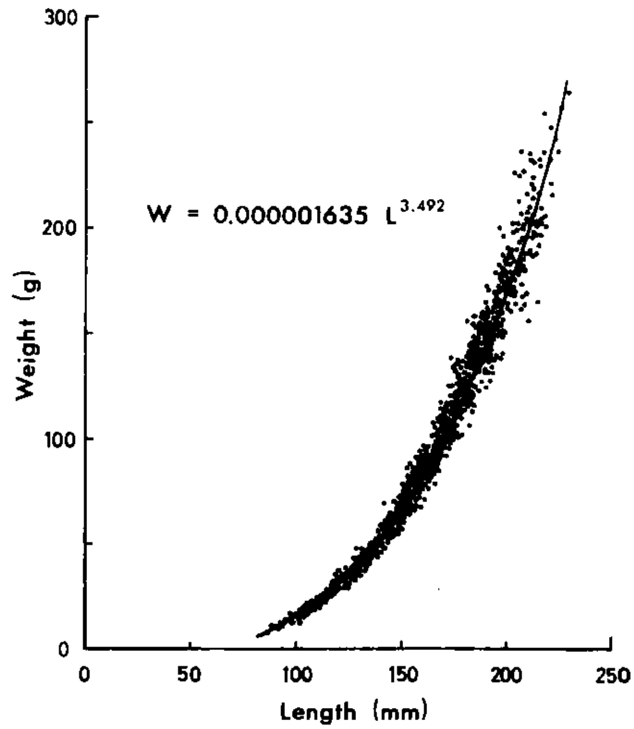

Fig. 5. Monthly changes in relative marginal increment (RMI) of year marks in butterfish otoliths from Subarea 5 and Statistical Area 6.

Bertalanffy growth curves in terms of length-at-age are defined by the following equations:

$$L_t = 227\left\{1-e^{-0.578(t+0.40)}\right\} \quad \text{(male)} \qquad (5)$$

$$L_t = 207\left\{1-e^{-0.975(t+0.02)}\right\} \quad \text{(female)} \qquad (6)$$

$$L_t = 210\left\{1-e^{-0.862(t+0.07)}\right\} \quad \text{(combined)} \qquad (7)$$

The relationship between body weight (W) and fork length for sexes combined (Fig. 5) is given by the equation

$$W = 0.000001635\ L^{3.492} \qquad (8)$$

which, when used with equation (7) gives the expression

$$W_t = 211\left\{1-e^{-0.862(t+0.07)}\right\}^{3.492} \qquad (9)$$

where W_t is the body weight (g) at age t.

Age-length keys for butterfish

Quarterly age-length keys for butterfish in Subarea 5 and Statistical Area 6, for years and sexes combined, are given in Table 3. It is evident that the catches of Japanese trawlers consist mainly of ages 0+ and 1+ fish if early growth is assumed to be fast, or of ages 1+ and 2+ fish if the early growth is slow.

Discussion

Some information on the age and growth of butterfish has been reported for the Northwest Atlantic. Bigelow and Schroeder (1953) reported that two size groups, one averaging about 12 cm and the other with a length range of 19-27 cm, were observed off Atlantic City, N.J., in August 1921 and concluded that these fish were in their second and third (some in their fourth) summers respectively. These sizes are probably total lengths, in which case the

TABLE 3. Quarterly age-length keys for butterfish in Subarea 5 and Statistical Area 6 for years and sexes combined. (Birthdate used is 1 July.)

Length (cm)	Age-group				Total
	0	1	2	3	
Quarter 1 (January-March)					
8	2	—	—	—	2
9	40	—	—	—	40
10	111	—	—	—	111
11	144	—	—	—	144
12	132	—	—	—	132
13	179	3	—	—	182
14	143	24	—	—	167
15	85	125	3	—	213
16	11	188	6	—	205
17	2	152	22	—	176
18	—	103	53	1	157
19	—	41	71	3	115
20	—	9	60	6	75
21	—	—	20	14	34
22	—	—	3	4	7
23	—	—	—	1	1
Total	849	645	238	29	1761
Quarter 2 (April-June)					
10	5	—	—	—	5
11	17	—	—	—	17
12	37	—	—	—	37
13	51	—	—	—	51
14	89	3	—	—	92
15	66	29	—	—	95
16	15	80	2	—	97
17	—	64	8	—	72
18	—	36	16	—	52
19	—	6	22	1	29
20	—	1	5	2	8
21	—	—	4	—	4
Total	280	219	57	3	559
Quarter 3 (July-September)					
11	—	1	—	—	1
12	—	54	—	—	54
13	—	49	—	—	49
14	—	51	—	—	51
15	—	74	10	—	84
16	—	12	31	—	43
17	—	—	30	1	31
18	—	—	2	—	2
19	—	—	1	—	1
Total	—	241	74	1	316
Quarter 4 (October-December)					
9	12	—	—	—	12
10	27	—	—	—	27
11	54	—	—	—	54
12	73	—	—	—	73
13	68	—	—	—	68
14	56	24	—	—	80
15	15	74	1	—	90
16	7	91	4	—	102
17	—	69	4	—	73
18	—	58	9	—	67
19	—	19	21	1	41
20	—	1	10	2	13
21	—	—	1	4	5
22	—	—	—	2	2
Total	312	336	50	9	707

corresponding fork lengths would be 11 cm and 17-24 cm. Waring (MS 1975) studied the age and growth of butterfish, using otoliths of specimens collected during the USA bottom trawl survey in the autumn of 1974. Four age-groups were observed with mean lengths of 123, 169, 188 and 186 mm, to which a Bertalanffy growth curve was fitted, the parameters of which are: $L_\infty = 212$ mm, $K = 0.446$ and $t_0 = -1.2$. Wilk and Silverman (1976) reported that the modal sizes of butterfish caught in Sandy Hook Bay, N.J., in

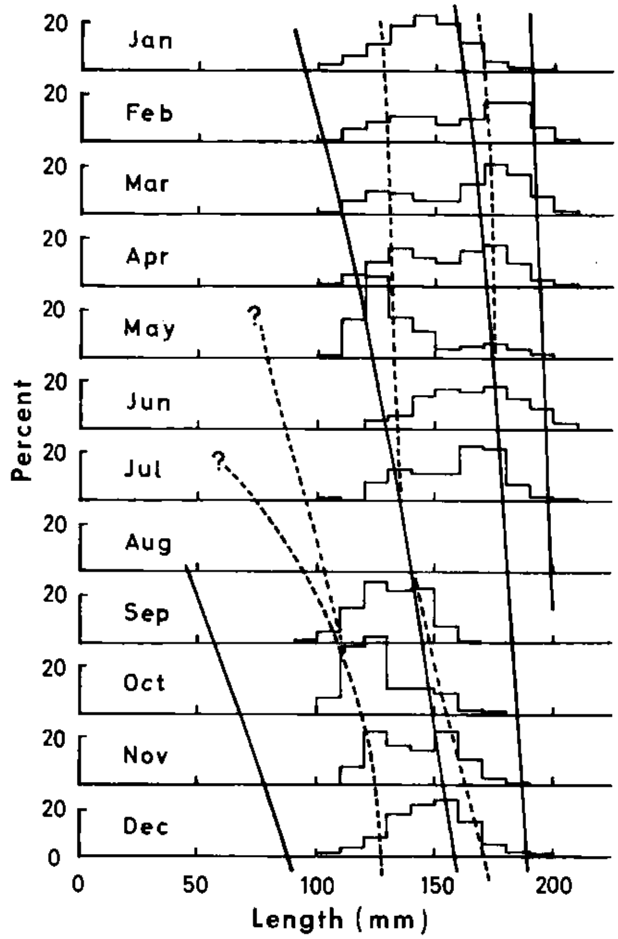

Fig. 6. Monthly length distributions of butterfish samples from the catches of Japanese trawlers in Subarea 5 and Statistical Area 6 during 1968-76. (Solid line represents von Bertalanffy growth; broken line represents stair-like growth.)

1970 were 9 and 16 cm in July, 10 cm in August, and 11 cm in September and October, and they concluded that the majority of butterfish observed in the Bay were in their second and third summers.

Most of the monthly length frequencies for butterfish sampled from the catches of Japanese trawlers in Subarea 5 and Statistical Area 6 during 1968-76 were bimodal (Fig. 6). The mode at about 12 cm in the September-November samples corresponds to the mean size reported by Bigelow and Schroeder (1953) and by Wilk and Silverman (1976) for the second summer group. It also corresponds to the size of age-group I reported by Waring (MS 1975). Similarly, the modes at 14-16 cm in the autumn samples agree well with the modal size of the third summer group as reported by Wilk and Silverman and with the mean length of age-group II reported by Waring.

The von Bertalanffy growth curve estimated in this paper shows reasonably good agreement with the modal lengths of the fish sampled from the catches of Japanese trawlers except in winter and at the youngest age (Fig. 6). A stair-like growth curve (broken lines), with very slow growth during winter and spring and faster growth in late summer and autumn could account for the disagreement with the von Bertalanffy curve in winter. However, it is doubtful that butterfish about 10 cm in length (15 g in weight), observed by Wilk and Silverman (1976) late in the spawning season, are 1 full year of age, because the early growth (0.7 cm per month) is too slow. Therefore, until further information on the early growth of butterfish becomes available, it is better to assume that fish around 10 cm in length are "young of the year" and originated from early spawning.

Acknowledgements

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Estimates of Variance of Age Composition of Mackerel Catches in ICNAF Subarea 5 and Statistical Area 6[1]

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Abstract

A procedure for estimating the precision of quarterly estimates of numbers caught at age was developed and applied to mackerel length and age samples taken in ICNAF Subarea 5 and Statistical Area 6 by Poland (1972-74) and German Democratic Republic (1974). Monthly and quarterly age-length keys were applied to monthly length frequency samples. Coefficients of variation were found to be less than 50% (and most less than 20%) for age-groups 2 to 8 in cases where there were more than one length sample per quarter of the year and at least one age sample for the months in which samples were taken. These coefficients of variation are considered to be underestimates of the true variation, since the absence of individual length samples precluded the inclusion of a sample-to-sample component of variance for the length samples used Differences between the estimated numbers caught based on the quarterly age-length keys and the estimated numbers caught based on the monthly keys were found to be more than 20% in 40% of the cases and more than 10% in 82% of the cases examined. In all cases, the coefficient of variation of the total number caught per quarter was less than 8%.

Introduction

In recent years, interest has risen in knowing the precision of routinely calculated statistics in fisheries biology. This is due in part to the need for fishery managers to know precisely the consequences of setting catch quotas at various levels of fishing intensity. Among the critical statistics needed for determining these quotas are estimates of the numbers caught by age-group.

The International Commission for the Northwest Atlantic Fisheries (ICNAF) has established guidelines on length and age sampling of catches taken in the Northwest Atlantic (ICNAF, 1976). The minimum sampling requirement is one sample per 1,000 metric tons of each species caught in each ICNAF division by gear and quarter of the year, where a sample generally consists of 200 fish measured for length, and at least one fish per centimeter length interval for ageing. These guidelines have not been followed, as less than 60% of the stocks under quota regulation in 1974 were not adequately sampled in that year (Akenhead, MS 1976). Since length frequency data are routinely reported on a monthly basis, the absence of individual samples prevents the estimation of the variability in length distributions within and between months. Sampling data for age are generally reported by quarter in the form of age-length keys, and thus no estimates of month-to-month variability can be made.

At the 1974 Annual Meeting of ICNAF, a special working group was set up to examine the requirements for more detailed sampling of the catches. Consequently, member countries were requested to report individual length and age samples for cod, silver hake and mackerel taken in Subareas 3 to 5 and Statistical Area 6 during 1972-74 (ICNAF, 1974). The availability of these data permitted for the first time the estimation of variability in length samples reported on a monthly basis and in age samples reported on a quarterly basis. Canada, German Democratic Republic (GDR) and Poland submitted mackerel age samples and Federal Republic of Germany (FRG), Poland, United States of America (USA) and Union of Soviet Socialist Republics (USSR) submitted mackerel length samples. Doubleday (MS 1976) examined a selected number of the 1973 length samples of mackerel from certain divisions and concluded that, since the important length groups in the samples tended to differ by month or season, the time of sampling was a more significant factor than the location of sampling within division. No firm conclusions were made concerning time *versus* spatial sampling for the age samples.

This paper presents a method for estimating the precision of the quarterly estimates of numbers of mackerel caught by age-groups, using some of the individual age samples and monthly length frequencies reported to ICNAF for this purpose.

Materials and Methods

The length samples examined by Doubleday (MS 1976) were not used in the present analysis, since there

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[1] Submitted to the December 1976 Special Meeting as ICNAF Res.Doc. 76/XII/134.

was little overlap by country and area between the length samples and the available age-length samples. Also, since Doubleday noted differences in mean length-at-age for samples taken within the same month by different countries, the length samples of one country could not be used with the age-length keys of another. Therefore, the data examined include mackerel length and age samples reported for Div. 5Z and Statistical Area 6 (Fig. 1) by Poland for 1972-74 and by GDR for 1974. For the years, quarters and areas (divisions or subareas) where the sampling consisted of length samples for more than 1 month and at least one age sample for each of those months, estimates of numbers caught at age, calculated by applying monthly age-length keys to monthly length frequencies and then summing within quarters, were compared with those obtained by applying quarterly age-length keys to monthly length samples and summing within quarters. Associated variances and biases were also estimated.

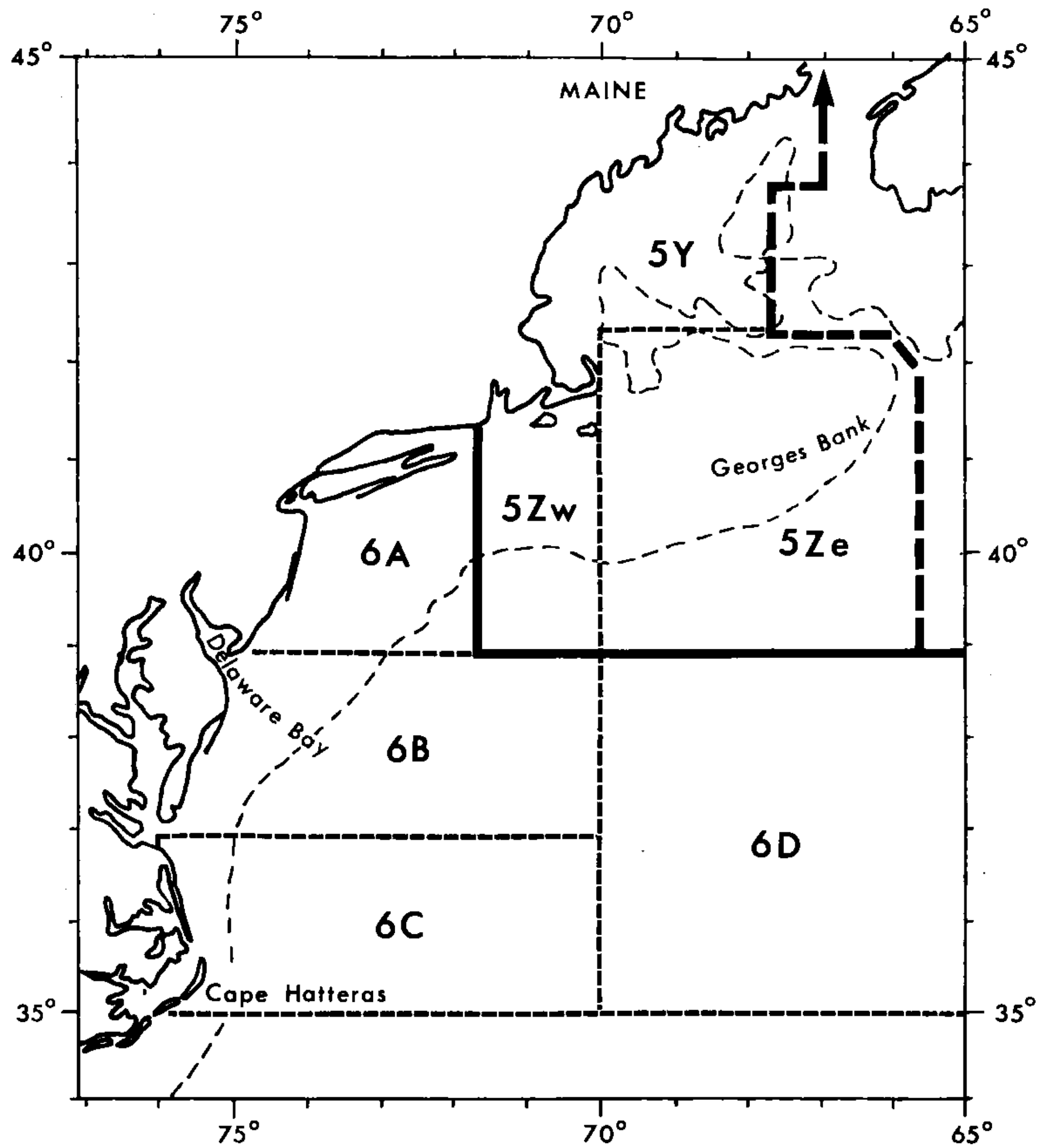

Fig. 1. Northwest Atlantic partitioned by ICNAF Areas and Divisions.

Estimates of numbers caught at age

The standard formulae were used in calculating the necessary statistics from the available data, according to the routine procedure outlined by Gulland (1955). The numbers caught at age (N_a) by year, quarter, gear and division (henceforth called a stratum) were estimated by the formula

$$N_a = Np_a \qquad (1)$$

where N = estimated number caught in a stratum, and
P_a = estimated proportion caught at age.

The estimate of N used was

$$N = M/W \qquad (2)$$

where M = reported nominal catch (kg) in a stratum, and
W = average weight of the fish caught.

The length-weight relationship reported by Moores *et al.* (1975)

$$w = (3.96 \times 10^{-6})\, l^{3.21} \qquad (3)$$

was used to estimate the values of W from the monthly length samples. The correct procedure of calculating w for each fish and then averaging over all fish in the sample to estimate the average weight of fish was not used. For simplicity the average length of fish in the sample was used in equation (3) to provide an estimate of the average weight. This procedure introduces a small bias which has an insignificant effect on the relative precision of the estimates of N_a.

The proportion caught at age (p_a) within a stratum was estimated by the formula

$$p_a = \sum_{l=1}^{m} p_{al}\, p_l \qquad (4)$$

where p_{al} = proportion of age a fish among those of length l,
p_l = proportion of length l fish, and
m = maximum length of fish sampled.

Quarterly estimates of p_{al} and p_l were obtained by applying the following formulae to the age-length keys and associated length frequencies:

$$p_{al} = \sum_{i=1}^{n} Y_{il} \Big/ \sum_{i=1}^{n} X_{il} \qquad (5)$$

$$p_l = \sum_{j=1}^{k} M_j\, p_{jl} \Big/ \sum_{j=1}^{k} M_j \qquad (6)$$

where Y_{il} = number of fish of age a and length l in sample i
X_{il} = number of fish of length l in sample i,
n = number of age samples containing length l fish,
M_j = nominal catch (kg) for month j in the stratum,
p_{jl} = proportion of length l fish in month j sample, and
k = number of months in which catches were sampled.

Combining equations (2), (5) and (6), equation (1) therefore becomes

$$N_a = (M/W) \sum_{l=1}^{m} \left[\left(\sum_{j=1}^{k} M_j \, p_{jl} \Big/ \sum_{j=1}^{k} M_j \right) \left(\sum_{i=1}^{n} Y_{il} \Big/ \sum_{i=1}^{n} X_{il} \right) \right] \quad (7)$$

The same formulae were used to calculate the monthly estimates of N_a, except that n is then the number of age samples for a month, and k = 1.

Estimates of variance

The variance of N_a in equation (7) was estimated from the following formulae:

$$Var(N_a) = Var(Np_a) = p_a^2\, Var(N) + N^2 Var(p_a) \quad (8)$$

$$Var(N) = L^2 Var(W)/W^4 \quad (9)$$

Estimates of N and p_a were assumed to be statistically independent, so that the covariance term, not included in equation (8), was assumed to be zero. The coefficient of variation of W was assumed to be 2%, so that equation (9) reduces to

$$Var(N) = 0.0004(L/W)^2 \quad (10)$$

The assumption that the coefficient of variation is 2% seems reasonable, as Wilk (1975), from a length-weight relationship for mackerel collected in the New York Bight area during June 1974-June 1975, found that the coefficients of variation for mackerel weights between 150 and 450 g were 3 and 1% respectively.

The variance of p_a is given by the formula

$$Var(p_a) = \sum_{l=1}^{m} p_{al}^2\, Var(p_l) + p_l^2\, Var(p_{al}) + 2p_{al}\, p_l\, Cov(p_{al}, p_l) \quad (11)$$

in which the covariance term was assumed to be zero for the purpose of this study.

According to Mendenhall *et al.* (1971), the variance of p_l is given by

$$Var(p_l) = \frac{K-k}{K} (k\bar{M}^2)^{-1} S_a^2 + (kK\bar{M}^2)^{-1} \sum_{j=1}^{k} \left[M_j^2 p_{jl}\, q_{jl} / (m_j - 1) \right] \quad (12)$$

where

$$S_a^2 = \left(\frac{1}{K-1}\right) \sum_{j=1}^{k} M_j^2 (p_{jl} - p_l)^2$$

$$\bar{M} = \sum_{j=1}^{k} (M_j/k)$$

$$q_{jl} = (1.0 - p_{jl})$$

m_j = number of fish sampled in month j

and K = number of months in a quarter (stratum) in which catches were made, k of these having been sampled.

All other notation in the above equations is as defined earlier, particularly following equations (5) and (6). The finite population correction for the second term of equation (12) was assumed to be 1.0, since the number of fish measured in a month was negligible compared with the number of fish caught.

In deriving the expression for the variance of p_{al}, it was assumed that each age sample was a subsample of the 200-fish length sample, in accordance with the ICNAF requirements outlined earlier. According to Cochran (1959), the variance of p_{al} is given by

$$Var(p_{al}) = \left[\frac{N-n}{N}\left[n(n-1)\bar{X}_l^{\,2}\right]^{-1}\sum_{i=1}^{n}\left[Y_{il}^{\,2} - 2p_{al}X_{il}Y_{il} + p_{al}^{\,2}X_{il}^{\,2}\right]\right] + \left[(nN\bar{M}^2)^{-1}\sum_{i=1}^{n}\left[\frac{Z_i - m_i}{Z_i(m_i-1)} M_i^{\,2} p_{ali}\, q_{ali}\right]\right] \qquad (13)$$

where N = number of possible samples with length l fish,
n = number of samples taken with length l fish,
Z_i = number of fish in length sample i,
m_i = number of fish in the age sample taken from length sample i,
p_{ali} = proportion of fish of age a among those of length l in length sample i,
q_{ali} = (1.0 - p_{ali}), and

$$\bar{X}_l = \frac{1}{n}\left(\sum_{i=1}^{n} X_{il}\right)$$

Since n is negligible compared to N, the expression (N-n)/N was assumed to be 1.0, and the second term of equation (13) was assumed to be zero.

As in the case for calculating the estimates of numbers caught at age by month, when estimating the precision of N_a for individual month, K = k = 1 in equation (12) and the values for N and n of equation (13) are the appropriate entries as defined above for each month.

In this paper the "range" of N_a is defined by the expression

$$\text{Range} = \pm\, 2.0\sqrt{Var(N_a)} \qquad (14)$$

and the 95% confidence limits for N_a can be calculated as

$$(N_a - \text{Range},\ N_a + \text{Range}) \qquad (15)$$

Coefficients of variation (C.V.) of N_a were calculated by the standard formula

$$C.V. = \sqrt{Var(N_a)}/N_a \qquad (16)$$

Relative precision of quarterly *versus* monthly age sampling

The relative precisions of the estimates of N_a, obtained in the first instance from the application of quarterly age-length keys to monthly length frequencies and in the second instance from the application of monthly age samples to monthly length frequencies, were calculated from the expression

$$R.P. = Var(N_a)_1 / Var(N_a)_2 \qquad (17)$$

where $Var(N_a)_1 = Var(N_a)$ from equation (8) based on quarterly age samples,

$$\text{and} \quad Var(N_a) = \sum_{j=1}^{k} \left[M_j^2 \, Var(N_{a,j}) \right] \Big/ M^2$$

in which $Var(N_{a,j}) = Var(N_a)$ calculated for month j. Other parameters are as defined earlier. The calculations are based on the assumption that the age samples were randomly drawn from the monthly catches.

Estimation of bias

In order to assess the bias introduced into the estimates of N_a because of the use of quarterly rather than monthly age-length keys, a comparison of the results derived by the two methods was made. It was assumed that the parameters p_{al} and p_l are independent and that p_l was estimated without bias. The bias of the estimated numbers caught at age (N_a) was determined by the equation

$$Bias(N_a) = \sum_{j=1}^{k} \sum_{l=1}^{m} M_j \, p_{jl} \, Bias(p_{al}) \qquad (18)$$

where the bias of p_{al}, according to Cochran (1953), is given by

$$Bias(p_{al}) = \frac{(N-n)p_{al}}{Nn(n-1)\overline{X}_l^2} \sum_{i=1}^{n} (X_{il}-\overline{X}_l)^2 - \sum_{i=1}^{n} (X_{il}-\overline{X}_l)(Y_{il}-\overline{Y}_l) \qquad (19)$$

with all notations as defined earlier. The above expressions hold where the quarterly age-length keys are applied to monthly length frequencies. When monthly age-length keys are applied to monthly length frequencies, the values of N and n refer to monthly data and the resultant estimates of Bias (N_a) by month are added to yield estimates by quarter, comparable to those obtained by using equation (18).

Data base

The estimates of the proportion caught at age (p_a), the number caught at age (N_a) and the associated variances were made for the data sets cited in Table 1, for which both length and age data were available. The statum breakdown was

TABLE 1. Nominal catches of mackerel by gear, area and month relevant to sampling data reported by Poland (1972-74) and German Democratic Republic (1974). (Notation in parentheses indicates that length samples (1) and age samples (2) were reported for the associated catches.)

Country	Year	Sampling gear[1]	Area	Nominal catches (metric tons) Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Poland	1972	OT	5Z	5,764	—	1,805 (1,2)	1,279 (1,2)	3,789 (1,2)	4,322	2,156	3,572	2,180 (1,2)	3,585	9,878	23,018
			6	21,482	14,838	19,588 (1,2)	14,912 (1,2)	7,938	40	—	—	—	—	—	1,715
	1973	MT	5Z	9,960	12,747 (2)	14,135 (2)	9,847	13,292 (1)	457	819 (1,2)	161 (1,2)	1,385 (1,2)	7,815 (1,2)	16,936	13,175
			6	4,646 (2)	1,406 (2)	719 (2)	2,832 (1,2)	99	—	—	—	—	—	—	6,223 (1,2)
	1974	MT	5Z	7 (1,2)	—	6,627 (1,2)	8,001 (1,2)	4,479 (1,2)	1,114 (1,2)	— (2)	86 (2)	170 (1)	2,134 (1,2)	9,159	6,765
			6A	20,018 (1,2)	11,501 (1,2)	354 (1,2)	959 (1,2)	125	—	—	—	—	—	—	9,845
			6B	8,689	4,819 (1,2)	130	— (2)	—	—	—	—	—	—	—	796
GDR[2]	1974	MT	5Z	1,640	—	1,002	1,186	186	—	—	8	26	5	2,773	3,269
			6	15,361 (1,2)	13,275	11,586 (1)	4,785 (1,2)	—	—	—	—	—	—	— (1,2)	4,461 (1,2)

[1] OT = otter trawl; MT = midwater trawl.

[2] Age samples were reported for areas 5Z and 6 combined.

governed by the way in which the length samples of Poland and GDR were reported to ICNAF. The individual age samples reported by Poland typically consisted of 100 fish each and those by GDR of 50 fish. Other entries in Table 1 include catches for which no sampling data were provided, catches for which only length or only age data were provided, and cases where sampling data were provided by no catches reported.

Results

Estimation of numbers caught by month and quarter

Estimates of the proportions caught at age (p_a) and the numbers caught at age (N_a), as determined by the methods described above, are listed in Table 2, together with relevant data on catches and mean weight of fish in the samples for the periods indicated. The significant decline in the mean weight of fish in the samples between 1972 and 1974 reflects the decline in average age of mackerel in the catches, even though there were no significant changes in the gears used during the period. The data also show that younger fish were usually more prevalent in the latter part of the year.

There was general consistency in the age compositions of the catches by Poland in Div. 5Z and Statistical Area 6 for each year and quarter, in which the length sampling occurred during the same months in each area. However, the lack of consistency in the age composition of Polish catches in Div. 5Z for October 1973 and in Statistical Area 6 for December of the same year (Table 2, data sets E and L) illustrates the variability inherent in the sampling data for the same quarter of the year.

In order to examine the month by month variability for data sets in which there were more than one length frequency and at least one age sample (Table 2, data sets B, D, F, G, M and R), estimates of the proportions caught at

TABLE 2 Age composition and variance estimates for mackerel catches in Subarea 5 and Statistical Area 6, based on sampling data of Poland in 1972–74 (data sets A to O) and data of German Democratic Republic in 1974 (data sets P to R). (Supplementary data given for each data set are (a) nominal catch for the months indicated, (b) average weight of mackerel, and (c) percentage of reported length distribution accounted for.)

Date set	Country	Year	Area	Quarter of year (months)	Age (a)	Percent at age (P_a ×100)	Number at age (N_a)	Variance [Var(N_a)]	± Range	Coefficient of variation (CV)
A.	Poland	1972	5Z	1 (Mar)	3	15.2	671,813	1.45×10^{10}	240,850	0.18
					4	8.8	388,155	6.82×10^{9}	165,222	0.21
					5	50.8	2,234,971	2.44×10^{10}	312,896	0.07
			(a) 1,805 tons		6	15.7	691,185	5.35×10^{9}	146,306	0.11
			(b) 0.410 kg		7	3.6	158,803	2.94×10^{9}	108,365	0.34
			(c) 100%		8	1.1	49,705	2.32×10^{8}	30,480	0.31
					9	2.9	129,431	4.98×10^{8}	44,651	0.17
					10	1.8	79,849	7.60×10^{8}	55,159	0.35
B.	Poland	1972	5Z	2 (Apr-May)	2	6.6	72,410	1.87×10^{9}	86,620	0.60
					3	5.5	627,508	7.27×10^{9}	171,660	0.14
					4	5.8	660,759	9.89×10^{9}	198,908	0.15
			(a) 5,068 tons		5	56.0	6,435,785	7.37×10^{10}	543,048	0.04
			(b) 0.441 kg		6	16.5	1,900,281	2.81×10^{10}	335,512	0.09
			(c) 100%		7	6.4	733,467	1.15×10^{10}	214,022	0.15
					8	2.2	254,572	2.31×10^{9}	96,121	0.19
					9	2.6	293,331	3.31×10^{9}	115,053	0.20
					10	4.4	510,531	6.31×10^{9}	158,881	0.16
C.	Poland	1972	5Z	3 (Sep)	2	5.5	29,074	1.45×10^{8}	24,226	0.41
					3	29.4	1,709,542	1.17×10^{9}	68,381	0.02
			(a) 2,180 tons		4	46.3	2,693,851	2.90×10^{9}	107,754	0.02
			(b) 0.375 kg		5	11.1	642,735	1.86×10^{9}	86,231	0.07
			(c) 93%		6	1.2	71,823	1.18×10^{8}	21,738	0.15
					7	4.3	250,033	1.12×10^{9}	67,091	0.13
					8	0.6	34,888	1.78×10^{8}	26,598	0.38
D.	Poland	1973	5Z	3 (Jul-Sep)	1	34.9	2,740,106	1.38×10^{10}	234,990	0.04
					2	8.3	648,995	1.10×10^{10}	209,975	0.16
					3	3.2	252,260	5.80×10^{9}	152,374	0.30
			(a) 2,365 tons		4	17.5	1,374,454	1.70×10^{10}	260,957	0.07
			(b) 0.301 kg		5	9.8	774,010	6.88×10^{9}	153,323	0.10
			(c) 99%		6	14.2	1,114,214	1.18×10^{10}	217,621	0.10
					7	7.2	566,587	7.11×10^{9}	168,615	0.15
					8	3.1	241,007	1.13×10^{9}	67,239	0.14
					9	0.8	60,391	3.41×10^{8}	36,908	0.31
					10	0.1	9,632	1.50×10^{8}	24,550	0.27

TABLE 2. Continued

Date set	Country	Year	Area	Quarter of year (months)	Age (a)	Percent at age (P_a ×100)	Number at age (N_a)	Variance [Var(N_a)]	± Range	Coefficient of variation (CV)
E.	Poland	1973	5Z	4 (Oct)	1	47.1	18,377,460	1.35×10^{11}	735,098	0.02
					2	7.9	3,097,418	3.84×10^{9}	123,897	0.02
			(a) 7,815 tons		3	13.4	5,230,774	1.23×10^{11}	701,782	0.07
			(b) 0.200 kg		4	8.1	3,166,725	4.91×10^{10}	443,342	0.07
			(c) 90%		5	8.5	3,326,852	5.42×10^{10}	465,759	0.07
					6	3.8	1,499,537	1.10×10^{10}	209,935	0.07
					7	0.8	311,974	4.91×10^{9}	140,076	0.22
F.	Poland	1974	5Z	1 (Jan, Mar)	1	1.5	526,061	7.62×10^{10}	552,000	0.52
					2	50.4	17,455,570	2.20×10^{12}	2,964,658	0.08
			(a) 6,634 tons		3	21.5	7,435,068	1.64×10^{12}	2,527,686	0.17
			(b) 0.192 kg		4	12.8	4,429,677	5.89×10^{11}	1,535,321	0.17
			(c) 100%		5	7.6	2,625,458	2.84×10^{11}	1,065,783	0.20
					6	3.0	1,037,005	8.36×10^{10}	578,112	0.27
					7	2.8	960,479	9.53×10^{10}	617,299	0.32
					8	0.4	151,630	6.55×10^{9}	161,877	0.53
G.	Poland	1974	5Z	2 (Apr-Jun)	1	6.7	3,998,335	4.38×10^{11}	1,323,468	0.17
					2	38.3	22,891,010	1.74×10^{12}	2,637,992	0.06
					3	20.4	12,236,400	1.01×10^{12}	2,014,835	0.08
			(a) 13,590 tons		4	7.9	4,731,037	1.88×10^{11}	866,426	0.09
			(b) 0.227 kg		5	13.8	8,286,391	2.17×10^{11}	930,760	0.06
			(c) 100%		6	7.4	4,411,935	8.48×10^{10}	582,550	0.07
					7	4.4	2,648,586	7.00×10^{10}	529,241	0.10
					8	0.8	479,276	1.04×10^{10}	203,572	0.21
					9	0.2	134,656	2.16×10^{9}	92,950	0.35
					10	0.04	26,171	1.63×10^{9}	80,700	1.54
H.	Poland	1974	5Z	4 (Oct)	1	26.1	4,304,072	7.41×10^{9}	172,163	0.02
					2	21.6	3,559,572	5.07×10^{9}	142,383	0.02
			(a) 2,134 tons		3	23.0	3,778,298	5.71×10^{9}	151,132	0.02
			(b) 0.130 kg		4	4.2	686,796	1.89×10^{8}	27,472	0.02
			(c) 86%		5	3.3	538,746	1.42×10^{9}	75,424	0.07
					6	3.0	487,300	1.16×10^{9}	68,222	0.07
					7	0.3	42,803	2.44×10^{7}	9,872	0.12
					8	4.6	749,668	2.75×10^{9}	104,953	0.07
I.	Poland	1972	6	1 (Mar)	2	0.8	378,260	3.18×10^{10}	356,549	0.45
					3	10.9	5,128,301	1.38×10^{12}	2,353,880	0.23
					4	8.0	3,737,613	3.99×10^{11}	1,262,794	0.17
			(a) 19,588 tons		5	57.5	27,030,880	2.97×10^{12}	3,447,496	0.06
			(b) 0.417 kg		6	17.6	8,259,249	8.95×10^{11}	1,892,688	0.11
			(c) 100%		7	3.6	1,669,581	5.72×10^{11}	1,512,755	0.45
					8	0.7	353,602	3.13×10^{10}	354,088	0.50
					9	0.6	266,257	3.38×10^{10}	367,892	0.69
					10	0.1	46,959	6.89×10^{8}	52,500	0.56
J.	Poland	1972	6	2 (Apr)	1	6.4	2,678,260	9.09×10^{9}	190,725	0.03
					2	2.4	1,022,824	2.24×10^{10}	299,019	0.15
					3	12.4	5,212,419	8.71×10^{11}	1,866,428	0.18
			(a) 14,912 tons		4	9.9	4,148,004	1.04×10^{12}	2,038,564	0.25
			(b) 0.355 kg		5	37.3	15,674,670	1.19×10^{12}	2,181,746	0.07
			(c) 100%		6	20.7	8,717,272	1.16×10^{12}	2,157,880	0.12
					7	7.1	2,965,717	9.53×10^{10}	617,397	0.10
					8	1.6	677,867	1.03×10^{11}	641,841	0.47
					9	0.9	366,471	6.67×10^{9}	163,300	0.22
					10	1.3	543,971	7.01×10^{9}	167,451	0.15
K.	Poland	1973	6	2 (Apr)	1	7.7	1,158,363	1.78×10^{10}	267,178	0.12
					2	90.0	13,537,650	7.33×10^{10}	541,506	0.02
			(a) 2,832 tons		3	1.9	284,848	3.61×10^{9}	120,178	0.21
			(b) 0.187 kg							
			(c) 100%							
L.	Poland	1973	6	4 (Dec)	1	13.3	2,173,194	1.15×10^{11}	679,106	0.16
					2	11.3	1,840,668	2.51×10^{11}	1,001,151	0.27
					3	8.6	1,408,045	2.34×10^{11}	967,875	0.34
			(a) 6,223 tons		4	20.0	3,267,235	1.21×10^{11}	788,213	0.12
			(b) 0.381 kg		5	13.1	2,134,152	2.75×10^{11}	1,049,696	0.25
			(c) 99%		6	25.0	4,072,322	1.56×10^{11}	789,606	0.10

TABLE 2. Continued

Date set	Country	Year	Area	Quarter of year (months)	Age (a)	Percent at age (P_a ×100)	Number at age (N_a)	Variance [Var(N_a)]	± Range	Coefficient of variation (CV)
L.	Poland Continued	1973	6	4 (Dec)	7	5.4	873,849	9.35×10^{10}	873,849	0.35
					8	2.4	399,398	5.13×10^{10}	453,150	0.57
					9	0.0	—		—	—
					10	0.2	32,604	1.09×10^{9}	66,292	1.02
M.	Poland	1974	6A	1 (Jan-Mar)	1	0.3	416,047	1.18×10^{10}	217,449	0.26
					2	33.4	40,689,230	1.27×10^{13}	7,128,200	0.09
					3	18.0	21,881,500	1.06×10^{13}	6,515,532	0.15
			(a) 31,873 tons		4	10.4	12,687,910	3.74×10^{12}	3,870,148	0.15
			(b) 0.262 kg		5	12.1	14,690,190	4.57×10^{12}	4,273,652	0.15
			(c) 99%		6	11.6	14,140,580	4.32×10^{12}	4,161,340	0.15
					7	10.8	13,212,080	2.54×10^{12}	3,190,354	0.12
					8	1.3	1,642,423	2.58×10^{11}	1,007,748	0.31
					9	0.4	526,031	1.15×10^{11}	678,984	0.63
					10	0.3	329,697	8.17×10^{10}	571,728	0.86
N.	Poland	1974	6A	2 (Apr)	1	0.9	53,802	1.55×10^{8}	24,933	0.23
					2	38.5	2,181,335	1.59×10^{10}	252,297	0.06
					3	27.3	1,551,165	1.99×10^{10}	282,163	0.09
			(a) 959 tons		4	8.4	478,616	7.34×10^{9}	171,313	0.18
			(b) 0.169 kg		5	8.4	475,467	3.91×10^{9}	125,189	0.13
			(c) 100%		6	9.0	512,989	5.25×10^{9}	144,940	0.14
					7	5.9	334,056	2.20×10^{9}	93,815	0.14
					8	1.0	59,310	6.78×10^{8}	52,079	0.44
					9	0.4	22,184	1.02×10^{8}	20,174	0.45
					10	0.04	2,269	2.74×10^{6}	3,311	0.73
O.	Poland	1974	6B	1 (Feb)	2	46.3	11,531,800	5.32×10^{10}	461,272	0.02
					3	23.6	5,863,759	5.41×10^{10}	465,170	0.02
			(a) 4,619 tons		4	11.7	2,915,661	4.17×10^{10}	408,193	0.07
			(b) 0.194 kg		5	7.6	1,890,572	3.15×10^{10}	354,703	0.09
			(c) 99%		6	2.1	534,834	5.15×10^{9}	143,511	0.13
					7	7.3	1,815,945	2.90×10^{10}	340,701	0.09
P.	GDR	1974	5+6	1 (Jan,Mar)	1	12.4	9,053,819	3.93×10^{11}	1,254,534	0.07
					2	10.5	7,664,140	7.83×10^{11}	1,769,957	0.12
					3	8.2	5,948,091	1.36×10^{12}	2,335,210	0.20
			(a) 29,589 tons		4	16.0	11,631,480	1.30×10^{12}	2,283,249	0.10
			(b) 0.407 kg		5	19.6	14,280,150	5.33×10^{12}	4,617,003	0.16
			(c) 98%		6	24.6	17,901,380	3.08×10^{12}	3,514,025	0.10
					7	5.2	3,781,977	1.50×10^{12}	2,445,546	0.32
					8	1.9	1,347,294	4.39×10^{10}	419,180	0.16
Q.	GDR	1974	5+6	2 (Apr)	1	18.0	2,979,139	3.99×10^{10}	399,693	0.07
					2	20.0	3,309,667	1.23×10^{11}	702,606	0.11
					3	9.5	1,572,970	7.16×10^{10}	535,074	0.17
			(a) 5,971 tons		4	7.3	1,204,716	2.83×10^{10}	336,951	0.14
			(b) 0.362 kg		5	9.7	1,599,329	7.93×10^{10}	544,040	0.17
			(c) 98%		6	17.6	2,913,914	5.87×10^{10}	484,597	0.08
					7	9.2	1,526,920	3.78×10^{10}	388,690	0.13
					8	3.0	495,298	2.65×10^{10}	325,737	0.33
					9	1.0	161,036	7.97×10^{9}	178,603	0.55
					10	0.9	144,520	6.28×10^{9}	158,533	0.55
					11	0.8	136,262	4.17×10^{9}	129,111	0.47
					12	0.5	90,841	8.32×10^{9}	182,425	1.00
R.	GDR	1974	5+6	4 (Nov,Dec)	1	46.4	21,891,380	4.21×10^{12}	4,105,122	0.09
					2	13.7	6,449,451	5.29×10^{12}	1,454,361	0.11
					3	5.8	2,744,519	2.10×10^{12}	916,963	0.17
			(a) 10,503 tons		4	11.1	5,272,915	5.02×10^{12}	1,417,579	0.13
			(b) 0.223 kg		5	8.6	4,037,684	3.05×10^{12}	1,104,281	0.14
			(c) 97%		6	7.6	3,563,452	3.37×10^{12}	1,160,979	0.16
					7	3.3	1,540,829	7.92×10^{12}	562,717	0.18
					8	0.7	331,422	2.31×10^{12}	303,808	0.46
					9	0.2	71,888	4.25×10^{12}	130,366	0.91

age (p_a) and the numbers caught at age (N_a) by month were determined for comparison with estimates of the same parameters for the corresponding data sets based on quarterly age-length keys. The results of these calculations are given in Table 3. The differences between the quarterly estimates of N_a (T_2) and the corresponding

TABLE 3. Monthly age composition of mackerel catches in Subarea 5 and Statistical Area 6, based on the application of monthly age-length keys to monthly length frequency samples, for selected data sets of Table 2. (Supplementary data given for each data set are the numbers of individual age samples used to construct the monthly age-length keys. Relative precision estimates calculated from equation (17).)

Data set	Country	Age (a)	% at age by month (1)	(2)	(3)	Number at age (N_a) by month (1)	(2)	(3)	Total 1 (T_1)	$\frac{T_2 - T_1}{T_1}$	Relative precision
B.	Poland	2	0.7	0.6	—	20,803	49,296	—	70,099	0.03	1.42
		3	6.2	5.9	—	185,654	499,634	—	685,288	0.08	1.13
	1972, Qtr 2	4	4.6	6.2	—	138,657	521,552	—	660,209	0.00	1.72
	Div. 5Z	5	48.9	62.7	—	1,473,682	5,314,861	—	6,788,543	0.05	2.59
		6	20.0	12.6	—	603,741	1,066,489	—	1,670,230	0.14	2.90
	Age samples	7	9.5	4.0	—	287,716	377,954	—	625,670	0.17	2.31
	Apr 6	8	1.6	2.8	—	48,087	233,895	—	281,982	0.10	1.18
	May 6	9	3.4	2.4	—	101,228	208,441	—	309,669	0.05	1.69
		10	5.1	2.8	—	153,338	241,455	—	394,793	0.29	3.29
			100.0	100.0	—	1,279 t	3,789 t	—			
D.	Poland	1	—	44.2	30.1	—	281,520	1,351,520	1,633,040	0.68	
		2	19.5	8.3	4.1	533,305	52,563	187,697	773,565	0.15	
	1973, Qtr 3	3	1.0	6.7	0.5	27,349	43,006	23,741	94,096	1.68	
	Div. 5Z	4	25.6	15.1	17.9	699,970	96,294	804,865	1,601,129	0.14	
		5	6.0	10.9	10.1	164,515	69,095	453,679	687,289	0.13	
	Age samples	6	11.3	11.2	14.6	308,387	70,543	657,366	1,036,295	0.08	
	Jul 1	7	5.4	2.4	9.6	147,933	15,085	431,659	594,677	0.06	
	Aug 3	8	0.7	0.9	3.9	19,828	5,957	177,628	203,413	0.19	
	Sep 3	9	—	—	0.7	—	—	31,392	31,392	0.92	
		10	—	—	0.2	—	—	9,633	9,633	0.00	
			69.5	99.7	91.7	819 t	161 t	1,385 t			
F.	Poland	1	0.1	—	1.4	27	—	485,702	485,729	0.08	
		2	44.4	—	43.9	12,176	—	15,199,690	15,211,866	0.15	
	1974, Qtr 1	3	20.2	—	25.1	5,545	—	8,685,558	8,691,103	0.14	
	Div. 5Z	4	10.0	—	13.6	2,745	—	4,724,704	4,727,449	0.06	
		5	13.0	—	7.5	3,586	—	2,606,863	2,610,449	0.01	
	Age samples	6	1.3	—	4.2	365	—	1,444,653	1,455,018	0.28	
	Jan 1	7	3.8	—	3.7	1,055	—	1,269,930	1,270,985	0.24	
	Mar 2	8	5.3	—	0.5	1,466	—	172,958	174,424	0.13	
			98.1	—	99.4	7 t	—	6,627 t			
G.	Poland	1	2.1	0.3	26.0	856,342	50,544	1,314,204	2,221,090	0.80	9.38
		2	50.9	18.5	7.9	20,565,600	2,884,052	398,426	23,848,478	0.40	4.42
	1974, Qtr 2	3	25.4	30.6	5.3	10,273,660	4,756,628	1,281,741	16,312,029	0.25	3.12
	Div. 5Z	4	7.1	13.3	12.4	2,882,667	2,069,776	628,623	5,581,066	0.15	2.00
		5	5.0	19.6	27.5	2,007,139	3,040,519	1,386,067	6,443,725	0.29	4.50
	Age samples	6	4.6	13.3	12.1	1,846,963	2,066,881	611,590	4,525,434	0.03	2.60
	Apr 3	7	1.6	3.7	7.4	664,131	574,664	372,275	1,611,070	0.64	3.42
	May 5	8	0.6	0.2	1.1	254,624	31,135	55,214	340,973	0.41	2.38
	Jun 21	9	—	—	0.3	—	—	17,244	17,244	6.68	N/A
		10	—	—	0.1	—	—	3,053	3,053	7.67	N/A
			97.3	99.5	100.0	8,001 t	4,479 t	1,114 t			
M.	Poland	1	—	0.2	—	—	146,785	—	146,785	1.83	
		2	27.4	39.5	6.7	17,974,500	23,173,820	87,784	41,236,104	0.01	
	1974, Qtr 1	3	23.5	24.8	29.8	15,403,760	14,583,140	392,518	30,379,418	0.18	
	Div. 6A	4	9.7	23.7	14.8	6,376,388	13,940,700	194,884	20,511,972	0.38	
		5	11.8	3.1	18.2	7,617,891	1,800,055	239,819	9,657,765	0.52	
	Age samples	6	9.8	0.7	18.2	6,406,421	422,741	239,565	7,068,727	1.00	
	Jan 3	7	11.0	5.6	8.2	7,199,899	3,296,323	208,370	10,604,592	0.25	
	Feb 1	8	1.6	—	1.1	1,075,814	—	14,414	1,090,228	0.51	
	Mar 2	9	0.5	—	0.5	327,832	—	6,258	334,090	0.57	
		10	0.05	—	0.3	32,783	—	3,505	36,288	8.09	
			95.2	73.9	97.8	20,018 t	11,501 t	354 t			
R.	GDR	1	—	24.1	25.0	—	2,391,978	9,450,045	11,842,023	0.85	11.79
		2	—	17.9	8.1	—	1,780,049	3,071,198	4,851,247	0.33	1.96
	1974, Qtr 4	3	—	10.9	5.5	—	1,082,272	2,079,265	3,161,537	0.13	1.46
	5Z+6	4	—	15.9	9.2	—	1,574,248	3,492,450	5,066,678	0.04	2.54
		5	—	11.7	8.2	—	1,160,652	3,082,039	4,242,691	0.05	4.12
	Age samples	6	—	11.6	6.0	—	1,154,979	2,284,292	3,439,271	0.04	2.41
	Nov 3	7	—	5.9	2.2	—	581,671	848,693	1,430,364	0.08	3.58
	Dec 3	8	—	—	0.9	—	—	354,538	354,538	0.07	N/A
		9	—	0.5	0.1	—	51,740	10,642	62,382	0.15	N/A
			—	96.5	65.0	—	2,773 t	7,730 t			

sums of the monthly estimates of N_a (T_1) ranged from 0 to 800% of the latter. The differences were greater than 10% in 65% of the cases and greater than 20% in 40% of the cases. Since not all of the monthly age samples covered the range of ages in the length samples (e.g. Table 3, data sets D, M and R), firm conclusions about the ages, for which the differences are greatest, cannot be made. It is evident, however, that the age compositions of catches determined by the two methods do not agree in most cases, and, more importantly, the ordering of the catches by age-group as determined by one method do not always agree with that by the other method. If the entire length range of the catch in each month had been sampled for age, the values of N_a based on monthly age-length keys (Total 1) would tend to be greater than the values of N_a based on quarterly age-length keys and the ratios would thus be lower.

Variance of the number at age

The variances of the estimated numbers at age (N_a) are listed in Table 2. The lower bound of each variance was dictated by the assumed coefficient of variation (2%) of W [see equation (10)]. Reducing the coefficient of variation to 1% does not substantially alter the results.

In interpreting the results of Table 2, caution must be taken where there is no month-to-month variance estimated for length samples and no sample-to-sample variance for age samples. Consequently, firm conclusions can only be drawn from the results of data sets B, D, F, G, M and R of Table 2 for ages 2 to 8, since the sampling was not always adequate for the other age-groups. For the strata (data sets) and age-groups noted, the coefficient of variation (CV) of N_a ranged from 4 to about 50% but most CV's were between 6 and 20%. There was no trend by year or quarter, but the number at age was inversely related to the CV, i.e. the larger the value of p_a or N_a, the smaller the CV. It can be assumed therefore that the estimates of N_a for these year-classes are all within 100% of the true number caught and most within 40%. Reduction in the confidence (power) of the results would allow smaller ranges to be associated with N_a, but such calculations were not included in this study.

Relative precision of quarterly *versus* monthly age-length keys

The relative precision of N_a, calculated by applying monthly age-length keys to monthly length samples and summing over months, are given in Table 3 for data sets B, G and R. Only these cases were considered since they were the only strata where there was more than one age sample in each month. Although the age sampling was not in strict accordance with the assumptions of a stratified random sample, with stratification according to catches, the calculations suggest a considerable improvement in the precision of N_a. For Polish data from Div. 5Z in second quarter of 1972 (data set B) and GDR data from Div. 5Z + Statistical Area 6 in fourth quarter of 1974 (data set R), the gain in precision for each age averaged about 200% of the variance of the N_a estimated from quarterly age-length keys. For the Polish data from Div. 5Z in the second quarter of 1974 (data set G), the increases in precision are much more substantial. The relative precision ranged from 2.00 to 9.36, with an average gain in precision of about 300%. Examination of the data which generated these results indicated that the percent-at-age values of data set G varied more from month to month than did those of data set B or R. In no case was the number of samples in each month strictly proportional to the catches during each month in each quarter. However, there were more samples in data set G than in the other two. Limitations of the data preclude further investigation of this aspect of the problem.

Estimation of bias

The biases of N_a, estimated from the quarterly and the monthly age-length keys by considering the bias only in the estimates of p_{ai}, indicated that, in most cases N_a was overestimated or underestimated by no more than 12% (Table 4), with over90% of the biases being less than 5% of the N_a values. There were no consistent trends in the bias by age or by method of estimating N_a. However, there were marked differences, especially for ages 1 to 3, in the biases obtained from the two procedures of estimating N_a.

Coefficient of variation in numbers caught

The results of the calculations for the various data sets in Table 2 are summarized in Table 5. Quarterly estimates of numbers caught (N) and associated variances were obtained by summing over ages the entries for the various data sets. All values of CV for the resultant estimates of numbers caught were less than 8%, a considerable reduction from the range of CV's for the individual age-groups. This reduction follows algebraically for n independent age-groups as follows:

$$\sum_{i=1}^{n} N_i = N$$

Let $CV(N_i) = a_iC$

where $C = CV(N)$

then $$C^2 = Var(N)/N^2 = \sum_{i=1}^{n} (a_i^2 C^2 N^2 N_i^2)/N^2$$

for at least one $a_i > 1.00$. Moreover, unless a_i is significantly greater than 1.00 for some i, all a_i must satisfy $a_i > 1.00$.

TABLE 4. Estimates of numbers at age by quarter and associated biases for selected data sets, based on the application of quarterly and monthly age-length keys.

Data set	Country	Age (a)	Quarterly age-length keys used: Number at age (N_a)	Bias of (N_a)	Percent bias of (N_a)	Monthly age-length keys used: Number at age (N_a)	Bias of (N_a)	Percent bias of (N_a)
B.	Poland	2	72,410	1,363	1.9	70,099	8,058	11.4
		3	627,508	-3,315	0.5	685,288	-10,208	1.5
	1972, Qtr 2	4	660,759	155	<0.1	660,209	6,024	0.9
	Div. 5Z	5	6,435,785	8,326	0.1	6,788,543	-2,110	<0.1
		6	1,900,281	-10,141	0.5	1,670,230	-21,151	1.3
		7	733,467	-6,155	0.8	625,670	-9,300	1.5
		8	254,572	882	0.3	281,982	2,319	0.8
		9	293,331	-5,033	1.7	309,669	20,908	6.8
		10	510,531	13,917	2.7	394,793	19,299	4.9
G.	Poland	1	3,998,335	130,887	3.2	2,221,090	24,576	1.1
		2	22,891,010	-123,345	0.5	23,848,478	-84,734	0.3
	1974, Qtr 2	3	12,236,400	-54,516	0.4	16,312,029	59,274	0.3
	Div. 5Z	4	4,731,037	26,992	0.6	5,581,066	119,384	2.1
		5	8,286,391	21,257	0.2	6,443,725	62,111	1.0
		6	4,411,935	10,118	0.2	4,525,434	-123,625	2.7
		7	2,648,586	-40,380	1.5	1,611,070	-76,668	4.8
		8	479,276	19,507	4.1	340,973	-39,893	11.7
		9	134,656	—	—	17,244	—	—
		10	26,171	—	—	3,053	—	—
R.	GDR	1	21,891,380	91,407	0.4	11,842,023	52,112	0.4
		2	6,449,451	-93,423	1.4	4,851,247	-3,236	0.1
	1974, Qtr 4	3	2,774,519	37,330	1.3	3,161,537	51,948	1.6
	5Z+6	4	5,272,915	-13,274	0.3	5,066,678	-142,093	2.8
		5	4,037,654	33,800	0.8	4,242,691	89,846	2.1
		6	3,563,452	-34,960	1.0	3,439,271	-60,819	1.8
		7	1,540,829	-17,563	1.1	1,430,364	16,501	1.2
		8	331,422	-7,730	2.3	354,538	-660	0.2
		9	71,888	3,081	4.3	62,382	-3,608	5.8

TABLE 5. Summary of mackerel data presented in Table 2, and coefficients of variation of estimated numbers caught by country, year, quarter and area for the months in which length frequency samples were available for analysis (Table 1).

Country	Year	Quarter	Area	Estimated number caught	Variance	Coefficient of variation (CV)
Poland	1972	1	5Z	4,403,412	5.55×10^{10}	0.05
		2	5Z	11,488,644	14.44×10^{10}	0.03
		3	5Z	5,431,946	0.75×10^{10}	0.02[1]
	1973	3	5Z	7,781,656	7.40×10^{10}	0.03
		4	5Z	35,010,740	38.11×10^{10}	0.02[1]
	1974	1	5Z	34,620,948	497.47×10^{10}	0.06
		2	5Z	59,843,797	376.20×10^{10}	0.03
		4	5Z	14,147,255	2.37×10^{10}	0.01[1]
	1972	1	6	46,890,702	631.36×10^{10}	0.05
		2	6	42,007,475	450.45×10^{10}	0.05
	1973	2	6	14,980,861	9.47×10^{10}	0.02[1]
		4	6	16,168,863	129.79×10^{10}	0.07
	1974	1	6A	120,225,688	$3{,}893.65 \times 10^{10}$	0.05
		2	6A	5,671,193	5.54×10^{10}	0.04
		1	6B	24,552,571	21.47×10^{10}	0.02[1]
GDR	1974	1	5+6	71,608,331	$1{,}344.63 \times 10^{10}$	0.05
		2	5+6	16,134,612	48.97×10^{10}	0.04
		4	5+6	45,903,540	691.24×10^{10}	0.06

[1] *Only one age sample and one length sample available for analysis.*

Discussion

The variance estimates presented for the numbers caught at age have some deficiencies, not the least of which is the absence of covariance between p_{al} and p_l (assumed to be zero in this analysis). Moreover, the absence of individual length samples precludes the inclusion of a true within-month component of the variance in the variance estimate of equation (12). Improvements in the estimates could be achieved if the length range of the age samples covered the range of the length frequencies, since the entire range of the length distributions for some data sets in Table 2 were not fully accounted for in terms of age.

The consistency between age distributions of catches in Div. 5Z and Statistical Area 6, where the length sampling occurred in the same months, and the lack of consistency between age distributions for the same quarter of the year but not in the same month (e.g. October 1973 length samples from Div. 5Z and December 1973 samples from Statistical Area 6) suggest the importance of the time factor in sampling, as noted by Doubleday (MS 1976). However, the differences between the estimates of numbers caught at age, using monthly age-length keys applied to monthly length samples (Table 3) and those calculated by using quarterly age-length keys applied to monthly length samples for the same data (Table 2, data sets B, D, F, G, M and R), possibly reflect growth changes in mackerel during a quarter and therefore indicate the importance of collecting samples for ageing from the same catches sampled for length.

Despite the shortcomings in the samples used to obtain estimates of the precision of the numbers caught at age, the results are valuable for providing insight into the variability of other parameters. For example, Pope (1972) has developed a procedure for estimating the coefficients of variation of a year-class of size N_i, where the N_i are derived from a cohort analysis approach. The coefficient of variation of the fishing mortality on a year-class can also be readily derived, and such information would be of immediate use to fisheries managers.

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Distribution of Squid, *Illex Illecebrosus*, on the Scotian Shelf 1970-76[1]

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Abstract

The distribution of squid, *Illex illecebrosus*, from Canadian research catches in the years 1970-76 on the Scotian Shelf is described. Squid were widely distributed in all years, but mean catch rates varied erratically from year to year, with 1976 showing much the highest catches, associated with exceptionally high mean bottom temperature.

Introduction

Starting in 1970, the staff of the Department of Fisheries and Environment Biological Station, St. Andrews, New Brunswick, has carried out an annual summer (June-August) bottom-trawling survey of groundfish on the Scotian Shelf. Each survey extended from the Fundian Channel and Bay of Fundy in the southwest to the Laurentian Channel in the northeast (Fig. 1A). The outward limit was the 200-fm (366 m) contour on the slope of the continental shelf. The inner limit was dictated by the suitability of the sea bed for trawling. It was about the 50-fm (91 m) contour between the Nova Scotia coast and the offshore banks, but extended into about 20 fm (36 m) in the Bay of Fundy. The areas off Southwest Nova Scotia and the continental slope (100-200 fm, 183-366 m) in the northeastern part of the Shelf were excluded because of excessively rough bottom and consequent difficulties in operating the fishing gear

The extensive area covered (approximately 50,000 square nautical miles) and limited vessel time available resulted in minimal sampling coverage of the area with an average of one fishing station per 300-350 square nautical miles on each annual survey. This coverage was sufficient to provide a gross measure of annual changes in relative abundance of the various fishes and a general picture of fish distribution in each year. Aggregate catch distribution of finfish for the years 1970-74 was reported previously (Scott, 1976). Squid catches were not included in the report, but indications of exceptionally high abundance of squid in 1976 from research cruises, fishing vessels and other sources suggested an examination of annual distribution and abundance of squid in the research surveys, which is presented here.

Materials and Methods

The survey was based on a depth-stratified random sampling design (Halliday and Kohler, MS 1971) using the same research vessel (*A.T. Cameron*), a standard #36 Yankee otter trawl with a ½-inch mesh codend liner, and standard ½-hour trawl tows. At each preselected station, the total weight and number of each fish species and squid were recorded as well as the starting and ending position of the tow, depth to bottom, surface and bottom temperatures and numerous other data. No distinction was made between day and night tows but fishermen's observations suggest that squid concentrate on the bottom in daylight and disperse at night so that day-time catches should be higher than night-time catches.

Results and Discussion

The number of trawl sets made in each survey ranged from 124 in 1971 to 165 in 1974, and mean numbers and weights of squid caught per tow ranged from 5.25 with a mean weight of 0.37 kg in 1970, to 187.14 with a mean weight of 35.16 kg in 1976 (Table 1).

The geographical distribution of squid catches for each annual survey in 1970-76 is expressed graphically in Fig. 1 as weight (kg) per tow. Most of the catches were small (<10 kg per tow), possibly a reflection of the

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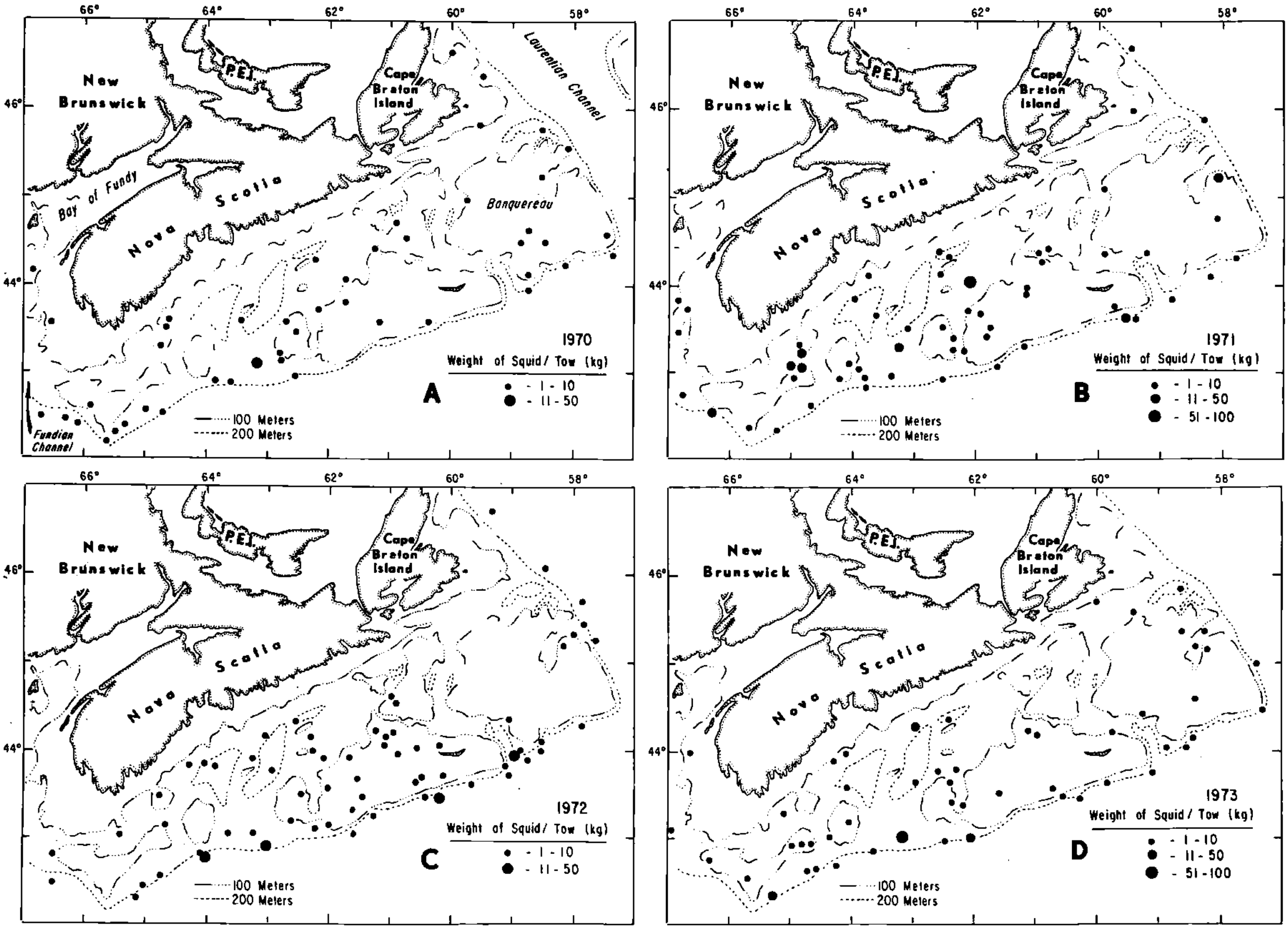

Fig. 1. A-G. Squid, *Illex illecebrosus*, catches per ½-hour tows on research vessel bottom trawl surveys in the summers of 1970-76.

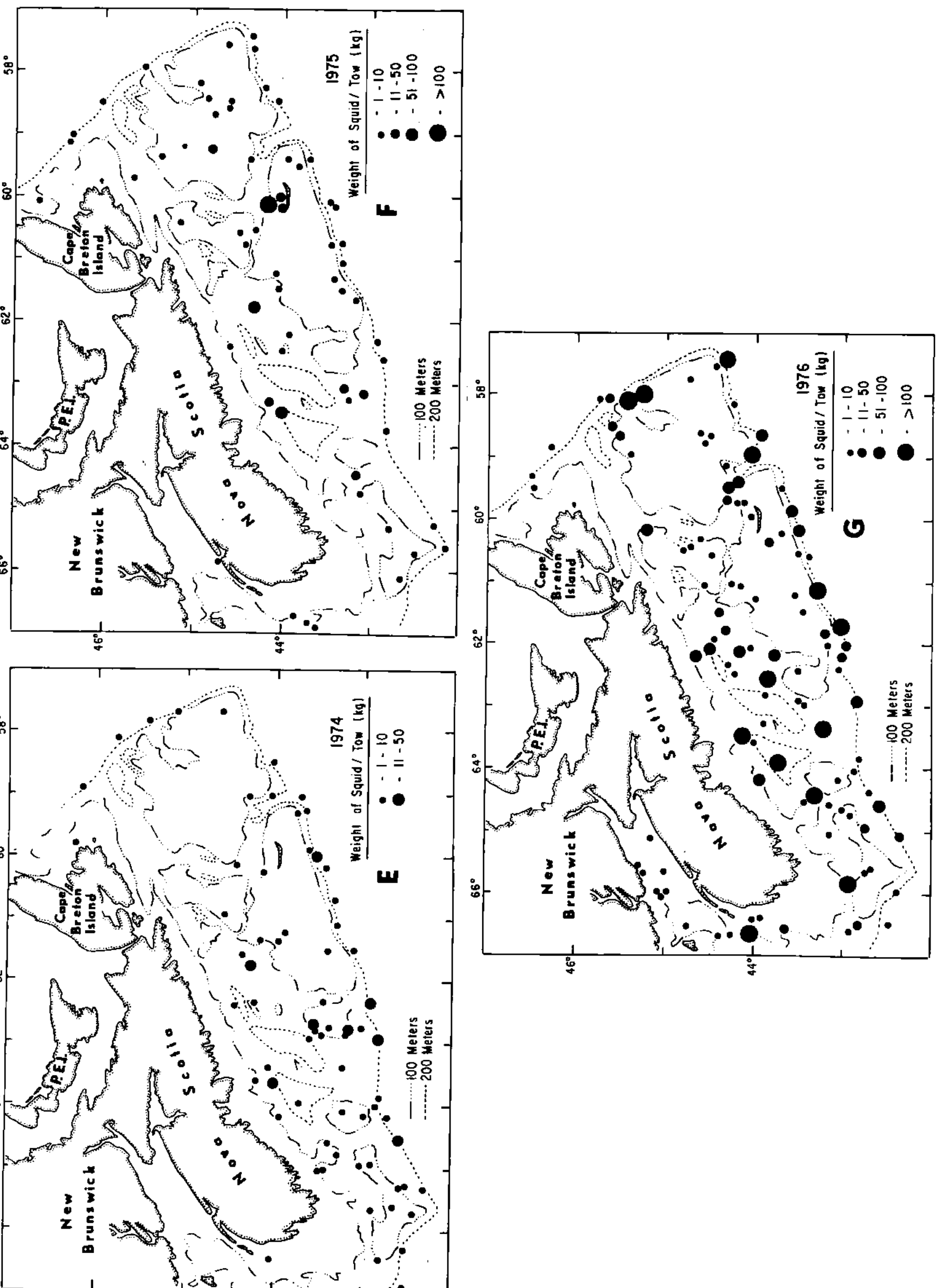

Fig. 1. (Continued)

TABLE 1. Mean numbers, weights and frequency of occurrence of squid, *Illex illecebrosus*, and mean bottom temperatures from summer (June-August) research survey cruises on the Scotian Shelf, 1970-76.

Year	Mean no. per tow	Mean wt. per tow (kg)	No. of tows	No. of tows with squid	% tows with squid	Mean bottom temp. (°C)
1970	5.25	0.37	143	47	32.9	5.3
1971	23.46	2.41	124	62	50.0	5.6
1972	7.61	0.82	156	65	41.7	5.6
1973	7.73	1.10	146	53	36.3	5.8
1974	11.61	1.61	165	71	43.0	5.7
1975	35.03	4.05	145	64	44.1	5.4
1976	187.14	35.16	141	116	82.3	6.9

inefficiency of the bottom trawl for capture of squid.

In general, squid appeared to be widely distributed on the Scotian Shelf in all years, with the greatest concentrations in the central part of the area, particularly in deeper water along the edges of the banks, and along the edge of the continental shelf. There was an apparent preference for intermediate depths between 50 and 100 fm (91-183 m) with relatively few and smaller catches on the banks and in the deep basins, but squid were notably absent from the catches, in most years, from the Bay of Fundy and the northeastern part of the Scotian Shelf to the north of Banquereau Bank (Fig. 1A), which area was characterized by particularly low bottom temperatures from 1970 to 1974 (Scott, 1976).

The research catches indicate that there was considerable variation in abundance of squid on the Scotian Shelf in the period under review (Table 1). In 1970 (Fig. 1A), squid were sparsely distributed with no major concentrations encountered; the mean catch rate was 5.25 squid per tow. In 1971 (Fig. 1B), squid were relatively abundant (23.46 per tow), but catch rates were again low in 1973 and there was little improvement until 1975 when the catch rate increased to 35.03 per tow. This was followed in 1976, evidently a year of exceptional abundance, by a catch rate of 187.14 squid per tow. In keeping with the increase in the number of squid per tow, the weight per tow increased from 0.37 kg in 1970 to 35.16 kg in 1976, and the percentage of tows in which squid were present increased from 32.87 in 1970 to 82.27 in 1976 (Table 1), indicating a much more dense distribution in the latter year. There was also an extension of the area of distribution of the catches into the Bay of Fundy in 1976 (Fig. 1G); catches were small, but extended to near the head of the Bay where they had not been made in previous years.

There is an apparent relationship between squid abundance and bottom temperature on the Scotian Shelf. The exceptionally high catches in 1976 were accompanied by exceptionally high bottom temperatures: in 1976, the mean bottom temperature for the stations sampled over the whole of the Scotian Shelf was 6.9°C compared with a range of 5.3-5.8°C for the years 1970-75.

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Intra-year Variability of Geostrophic Circulation on the Continental Shelf off New England and Nova Scotia[1]

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Abstract

From the analysis of charts of dynamic topography based on data collected in 1963-73, seasonal types of the geostrophic current fields on the New England and Nova Scotia shelves are described and intra-year variations in the circulation pattern considered. The various types are characterized by quasi-stationary gyres or zones of rising and sinking water, some of which coincide with important biological events, such as the spawning of herring on Georges Bank in September and the spawning of silver and red hake along the southern slopes in early summer.

Introduction

From studies undertaken in 1974 (Sigaev, 1975), the possibility of applying the dynamic method to a study of water circulation on the New England shelf became evident, and the summer-autumn type of geostrophic circulation in this area was determined from an analysis of dynamic topographic charts for 1972 and 1973. The second stage of the investigation involved an attempt to determine the types of current fields by month and to trace their intra-year variability. This paper presents the results of the latter study based on a longer series of observations, and certain qualitative relationships between the pecularities of the current fields and some annually-observed biological phenomena are noted. The traditional spawning grounds for herring are located on the northern part of Georges Bank, silver and red hake spawn along the southern slope of the Bank, and the young of many species inhabit the Nantucket Shoals area during various stages of their development.

Materials and Methods

This study is based on the analysis of 58 charts of dynamic topography drawn from temperature and salinity measurements, which were made during hydrological surveys by USSR research vessels (from AtlantNIRO) in 1963-75. The charts were drawn according to the traditional dynamic method (Zubov and Mamaev, 1956) and pecularities of its application to this study are indicated by Sigaev (1975). The types of geostrophic current fields (surface circulation) were determined by including the most frequently repeated patterns for the same month and area from the charts of dynamic topography. It was possible to typify the current patterns for 11 months (excluding February) in the New England area and for only 5 months in the Nova Scotia area. Due to the similarity of conditions shown on the charts of dynamic topography for June and July in the New England area and for April and May in the Nova Scotia area, water circulation in these monthly periods is represented by a single current field type for each area.

Results

Current fields on the New England Shelf

August. The geostrophic circulation (Fig. 1) is characterized by well developed anticyclonic gyres (zones of sinking water) over the central part of Georges Bank, in the Nantucket Shoals area, on the southern part of the Bank and over the Wilkinson Basin depression, with the gyre on the central part of Georges Bank occupying the largest area. A number of cyclonic gyres (zones of rising water) also exist in the Georges Bank area, the zone in the East Channel area being the most highly developed. These zones of rising water on the western, northern and eastern slopes of the Bank are adjacent to the herring spawning grounds and their development in late summer coincide with the herring spawning period, as indicated by Sigaev (1975).

September. The circulation field in this month (Fig. 2) is not significantly different from that of August. The

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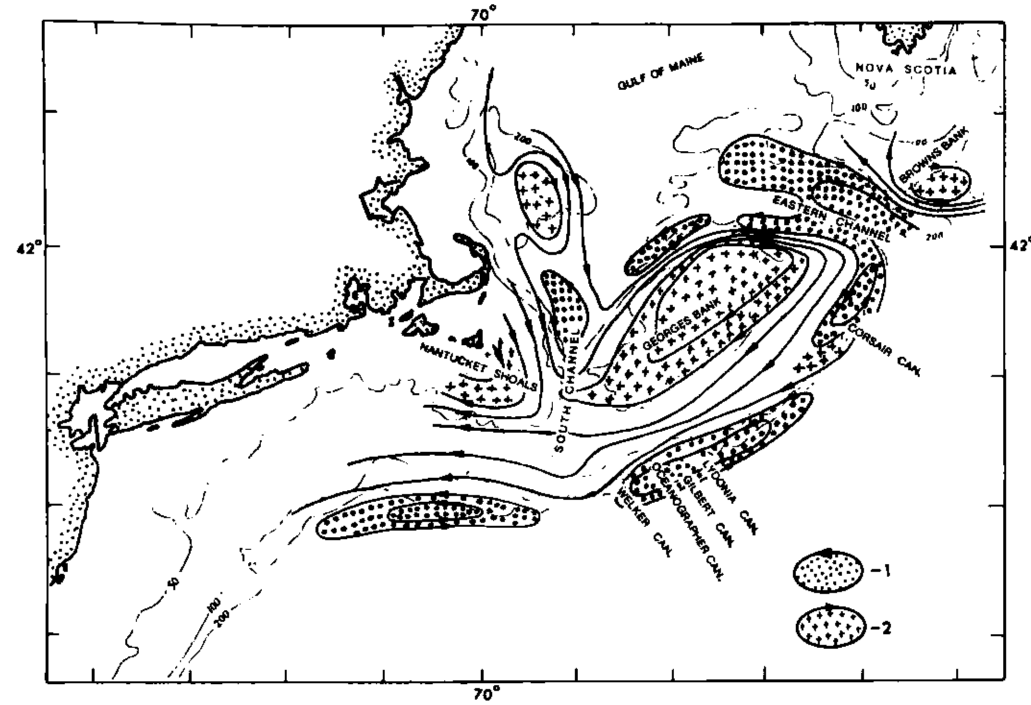

Fig. 1. Geostrophic circulation field for the New England Shelf in August.

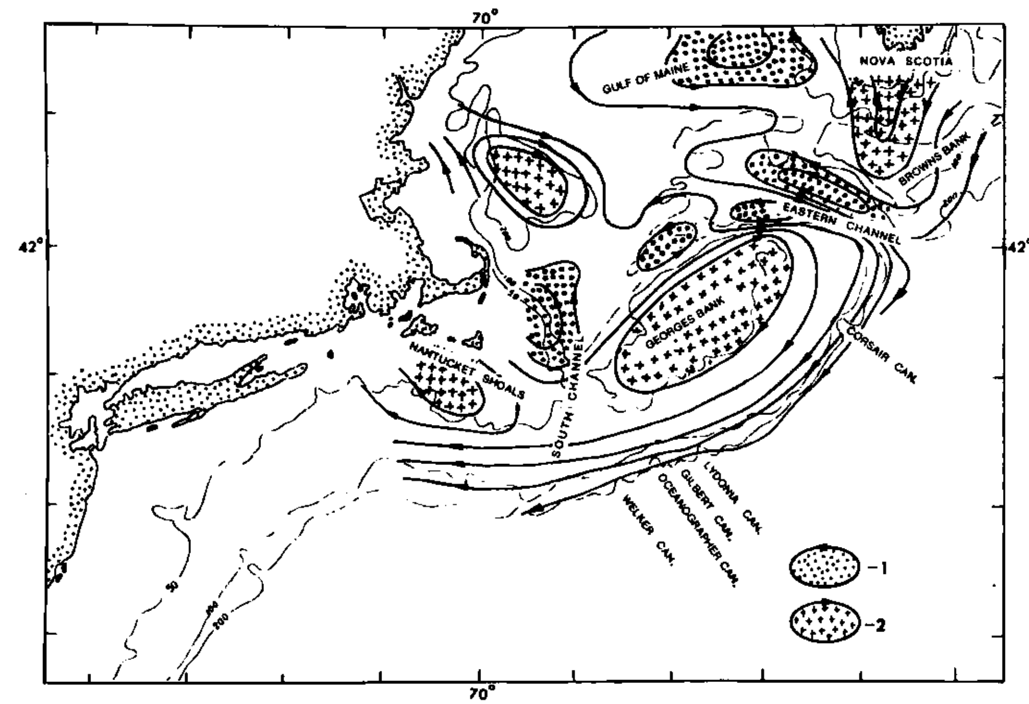

Fig. 2. Geostrophic circulation field for the New England Shelf in September.

anticyclonic gyres on Georges Bank and over the Wilkinson Basin continue to be well developed, but the gyre on Nantucket Shoals has moved slightly westward and weakened somewhat. The cyclonic gyres on the northern slope of Georges Bank are more clearly pronounced, with the East Channel gyre having now divided into two parts. The cyclonic gyre to the north of South Channel has further intensified, and a large zone of rising water is shown in the northeastern part of the Gulf of Maine.

October. The first indication of the destruction of the large anticyclonic gyre on Georges Bank is evident (Fig. 3). The northern part of the gyre has the appearance of being depressed by zones of rising water from the east and north. On the northern part of the Bank, the destruction of the gyre is enhanced by the zone of rising water over the Corsair Canyon and by intensification of cyclonic gyres to the north and west, particularly those of the East and South Channels. In the Nantucket Shoals area, the anticyclonic gyre has shifted markedly westward and its previous position (September) is now occupied by a weak zone of rising water. A well-developed anticyclonic zone is shown around the southwest extremity of Nova Scotia.

November. Destruction of the main Georges Bank gyre is continued in this month (Fig. 4), with the intensification of zones of rising water from the East and South Channel areas. In the Wilkinson Basin area, the anticyclonic gyre has shifted southward and a strong cyclonic zone has formed. Other dynamic features are not significantly different from those of the previous month.

December, The remaining part of the Georges Bank anticyclonic gyre has shifted to the southwest (Fig. 5) and the cyclonic zone on the southwest slope has intensified. The East Channel cyclonic gyre has moved slightly southward, but its extension (formed in November) has intensified significantly to cover a large part of the Gulf of Maine. An anticyclonic zone has developed between the two large cyclonic zones in this area. Conditions in the Nantucket Shoals area remain similar to those of the previous month.

January. The Georges Bank anticyclonic gyre has moved farther southward and has become considerably deformed (Fig. 6) on account of being surrounded by a number of cyclonic zones. The central part of the Bank is now occupied by a cyclonic gyre which is evidently an extension of the intensified East Channel gyre. In the area north of South Channel, a well-developed anticyclonic gyre is evident in place of the traditional zone of rising water observed during August-October. A cyclonic gyre dominates the Nantucket Shoals area, and the anticyclonic zone around the southwest extremity of Nova Scotia has been extended.

March. The structure of the current field (Fig. 7) is considerably different from that observed in January. The anticyclonic gyre over Georges Bank has almost disappeared, and has been replaced by an extended zone of rising water, bordered on the east and south by anticyclonic zones. A large anticyclonic gyre has formed in the western Gulf of Maine and a large cyclonic gyre is

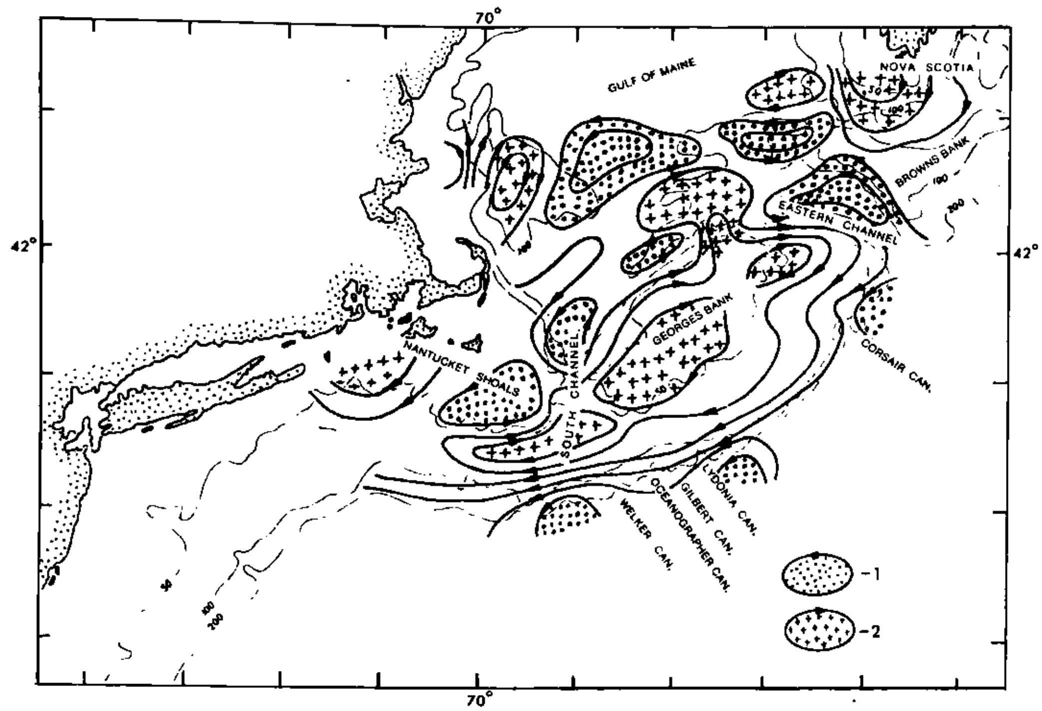

Fig. 3. Geostrophic circulation field for the New England Shelf in October.

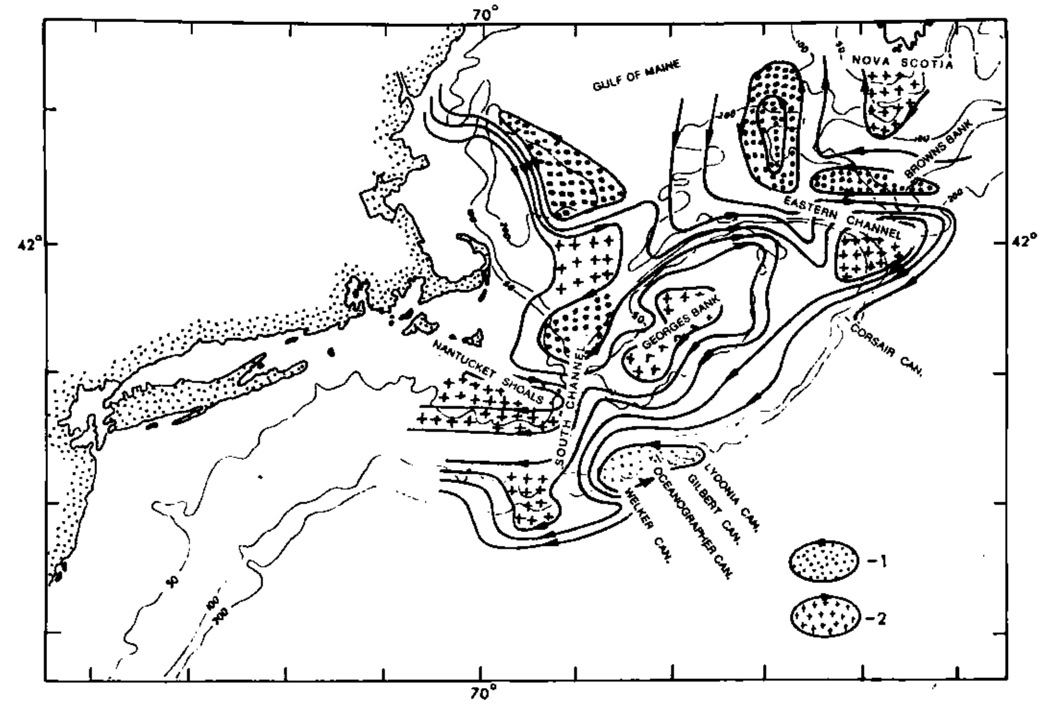

Fig. 4. Geostrophic circulation field for the New England Shelf in November.

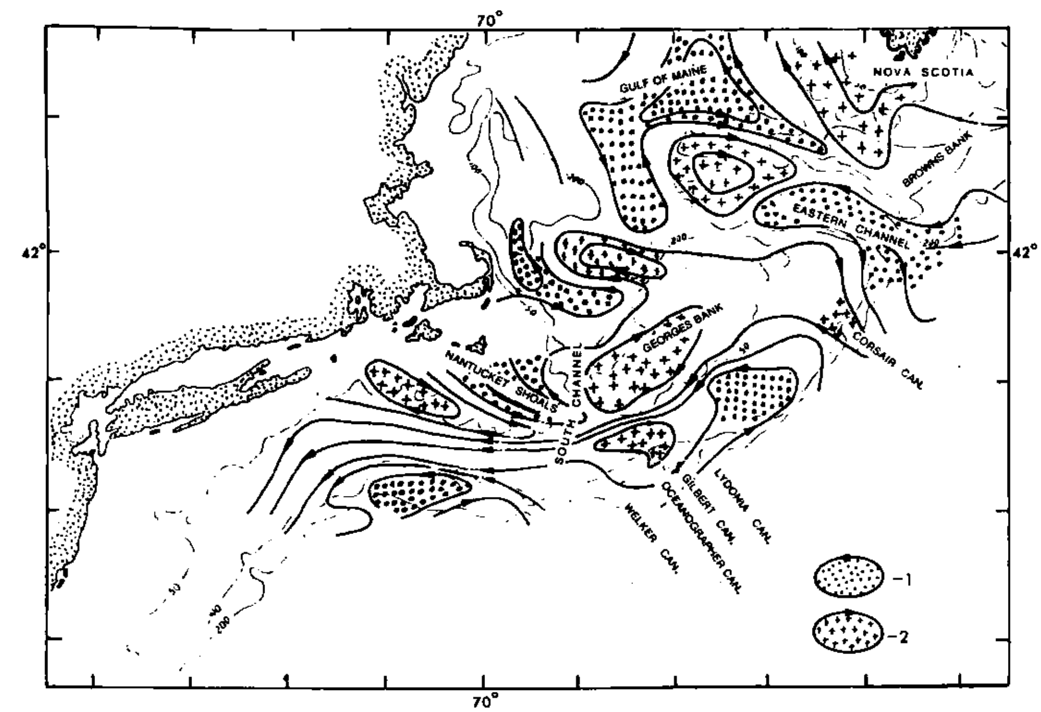

Fig. 5. Geostrophic circulation field for the New England Shelf in December.

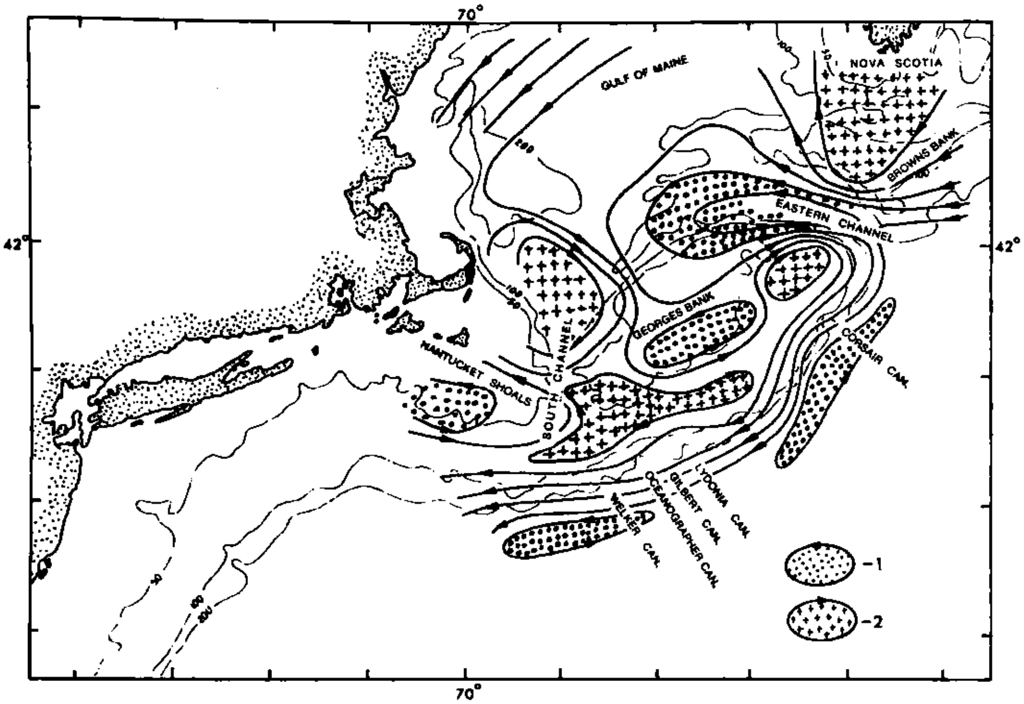

Fig. 6. Geostrophic circulation field for the New England Shelf in January.

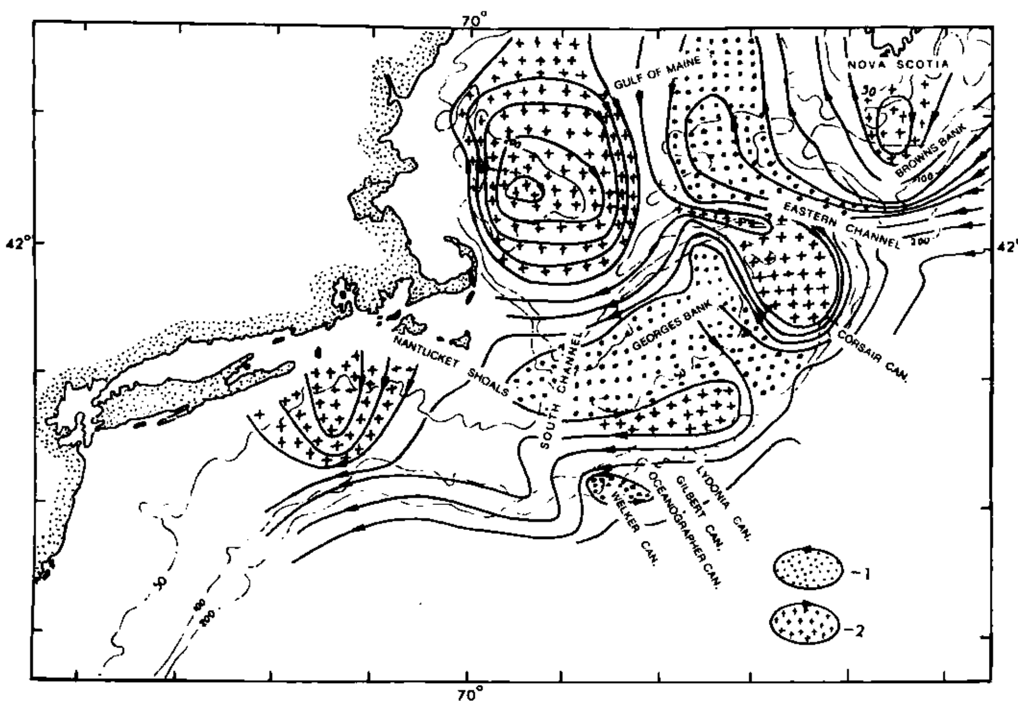

Fig. 7. Geostrophic circulation field for the New England Shelf in March.

evident in the eastern part of the Gulf. A well-developed anticyclonic zone is located to the west of Nantucket Shoals, and the zone off Southwest Nova Scotia has intensified.

April. The central part of Georges Bank is occupied by a large cyclonic gyre, with an anticyclonic zone over the southern slope (Fig. 8). The large anticyclonic zone in the western Gulf of Maine has become somewhat reduced relative to its size in March, and the zone of rising water in the East Channel area has become considerably less extensive. An anticyclonic zone covers the Nantucket Shoals area, and a cyclonic gyre has developed off Cape Cod. The anticyclonic zone off Southwest Nova Scotia has now become a well-developed gyre.

May. The circulation field in this month (Fig. 9) is characterized by the beginning of the formation of the main anticyclonic gyre over Georges Bank. This is evident from the appearance of a strong westward flowing current over the southern slope of the Bank. The northern part of the Bank is occupied by a number of small unstable gyres. The anticyclonic zone in the western Gulf of Maine area has become less extensive, but the cyclonic zone of East Channel and the anticyclonic zone on Nantucket Shoals remain well developed. A sharp intensification of vorticity along the southern slope of Georges Bank, probably caused by the advection of water from the frontal Gulf Stream zone, is one of the main features of the current field structure in May.

June-July. The circulation in these months is characterized by the formation of a new anticyclonic gyre over Georges Bank (Fig. 10), which in the initial stage of development appears to be somewhat deformed. Another peculiarity is the further development of vorticity along the southern slope of the Bank, where clearly pronounced local zones of rising and sinking water are evident. The spawning concentrations of silver hake and red hake are timed to coincide with these upwellings (Sigaev, 1975).

Summary. It is evident from the above descriptions of the current patterns off the New England coast that the circulation field undergoes considerable change throughout the year, some formations persisting for a long time and others for much shorter periods. The anticyclonic gyre on Georges Bank is the main component of the current structure in the area and it persists for several months. Its formation begins in May and complete development is reached during August-September. Gradual destruction of the gyre occurs in the following months and by March it is replaced by cyclonic gyres over much of the Bank. These gyres provide for the influx of nutrients to the upper water layers. In the absence of data for February, it may be assumed that the circulation pattern in that month is intermediate between those for January and March.

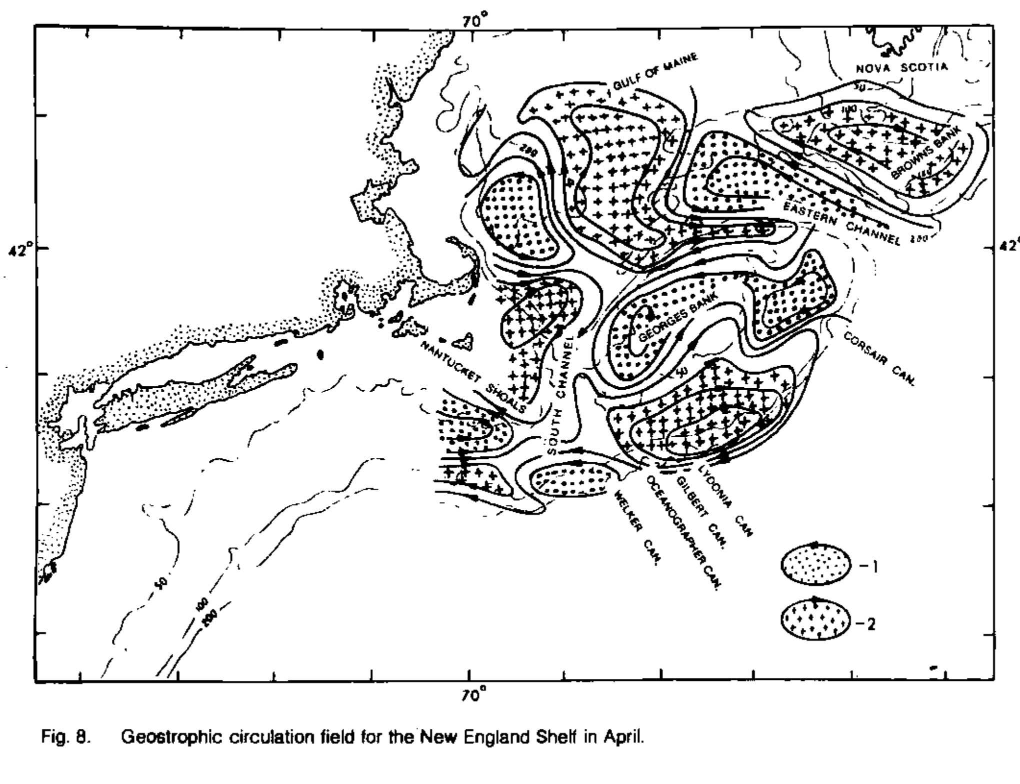

Fig. 8. Geostrophic circulation field for the New England Shelf in April.

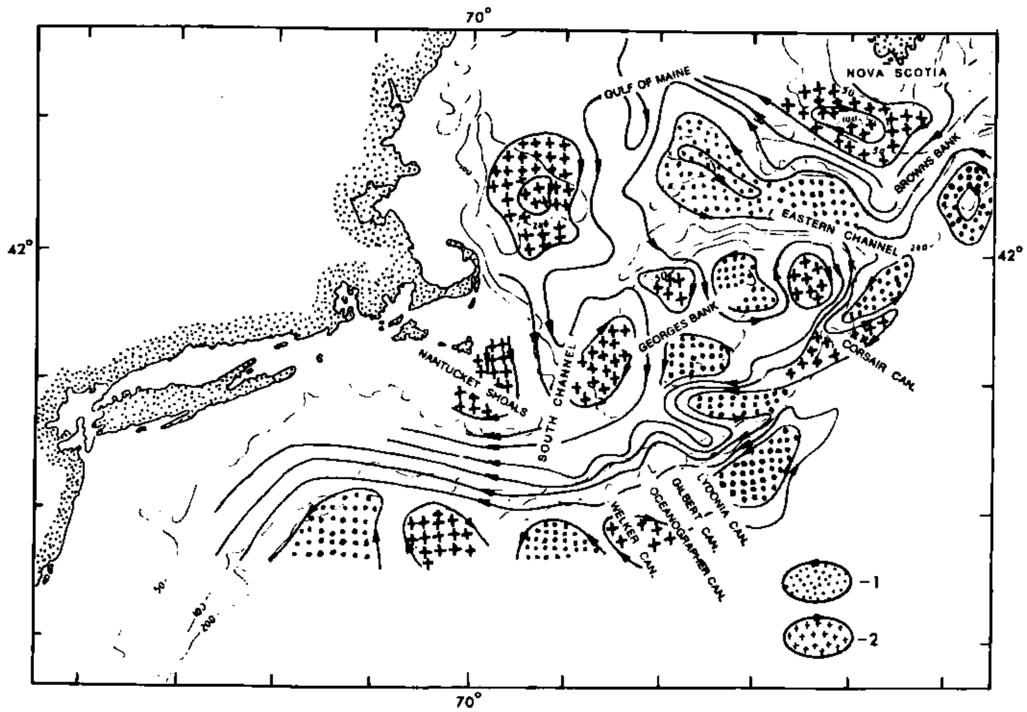

Fig. 9. Geostrophic circulation field for the New England Shelf in May.

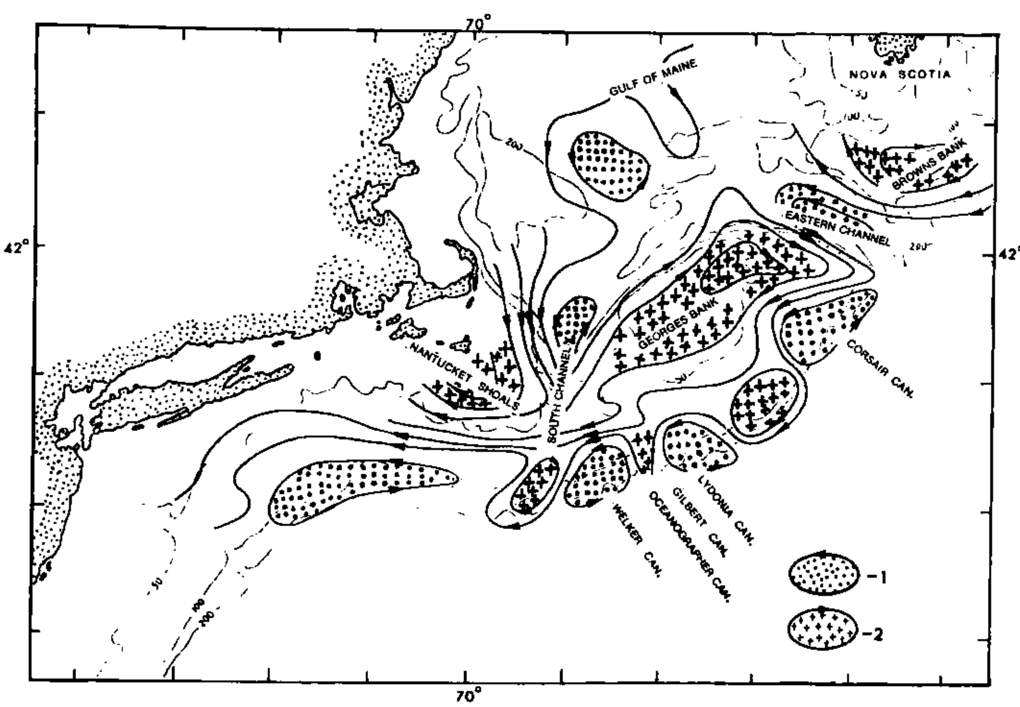

Fig. 10. Geostrophic circulation field for the New England Shelf in June-July.

Current fields on the Nova Scotia Shelf

August. A cyclonic gyre in the deepwater part of the Shelf, anticyclonic gyres over Emerald and Middles Bank and over Misaine and Banquereau Banks are characteristic of the current pattern at this time of the year (Fig. 11). A cyclonic zone is also evident in the area of Galli Deep. Relative to the Scotian Shelf, the cyclonic gyre over the Laurentian Channel has the same relationship as the East Channel gyre has to circulation in the Georges Bank area.

October. The zones of rising water over the deepest parts of the Shelf are separated by a well-developed anticyclonic gyre between LaHave and Emerald Banks (Fig. 12). Other anticyclonic zones occur in the vicinity of Middle, Banquereau and Misaine Banks. A cyclonic zone has developed northwest of Misaine Bank and the strong cyclonic gyre persists in the Laurentian Channel.

January. No significant change in the current field is noted for this month (Fig. 13), except for the marked intensification of the cyclonic zone over the deep-water part of the Shelf and of the anticyclonic zone in the Emerald and Sable Island Bank areas.

April-May. The current pattern in these months (Fig. 14) is characterized by still more intensive cyclonic zones over the deep-water part of the Shelf, by destruction of the anticyclonic zone in the Emerald Bank area, and by the intensified vorticity along the seaward slope of the Shelf.

Summary. As was noted for the Georges Bank area, considerable intra-year variation occurs in the water circulation on the Nova Scotia Shelf. One of the most stable features in this area is the Laurentian Channel cyclonic zone which, like the East Channel gyre in the Georges Bank area, was evident in all months for which observations were made.

Discussion

Studies on water circulation in the Nova Scotia and New England areas have been published by various authors. The earliest account (known to the author) of the water circulation in the New England area is that of Bigelow (1927) for July and August, in which he described the cyclonic gyre of the Gulf of Maine and the anticyclonic gyre of Georges Bank. His description represents the summer circulation type in general and lacks much of the detail of the current field types described above. Day(1958) presented a more detailed account of water movements in February-June, based on returns of drift bottles released during 17 cruises of the research vessel *Albatross III* during 1931-34 and 1953-56. He showed that, during the February to June period, certain variations are observed in the surface circulation pattern, which are especially marked in February-March, when "the gyre on Georges Bank is difficult to determine", and he attributes these variations to wind conditions in the area. Although the data from the drift bottle experiments added significantly to a knowledge of water circulation in the area, from which the drift of plankton in the early part of the year could be assessed, the lack of information on current directions over

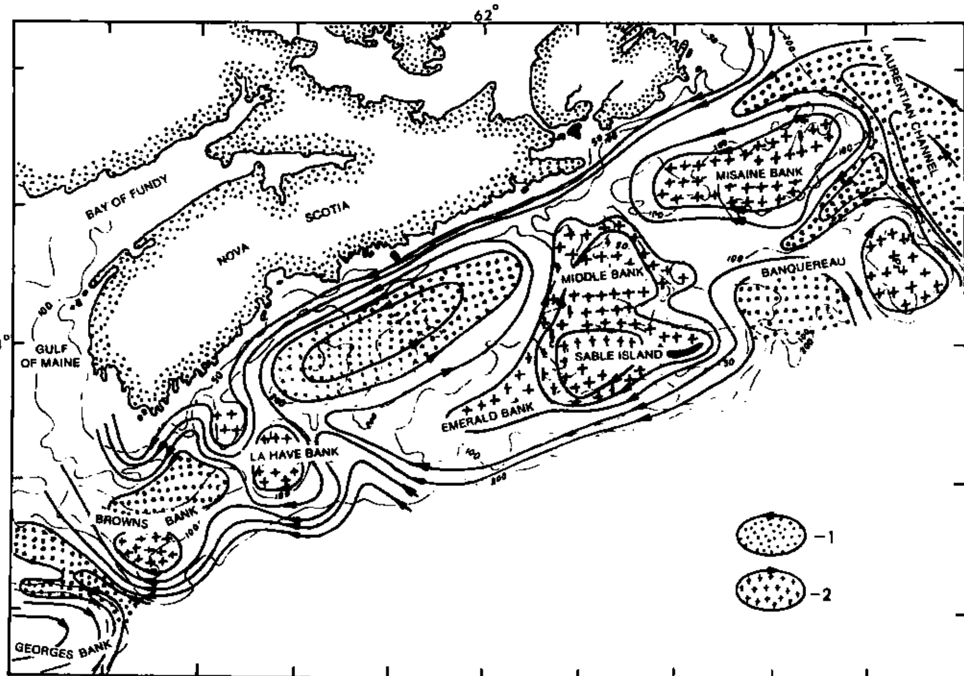

Fig. 11. Geostrophic circulation field for the Nova Scotia Shelf in August.

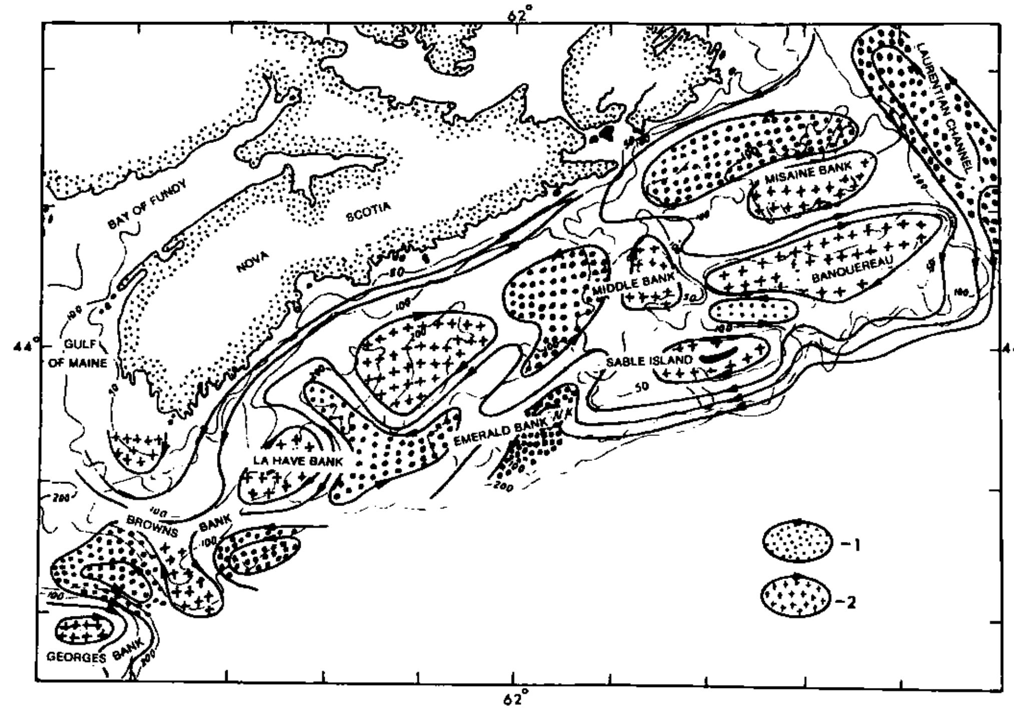

Fig. 12. Geostrophic circulation field for the Nova Scotia Shelf in October.

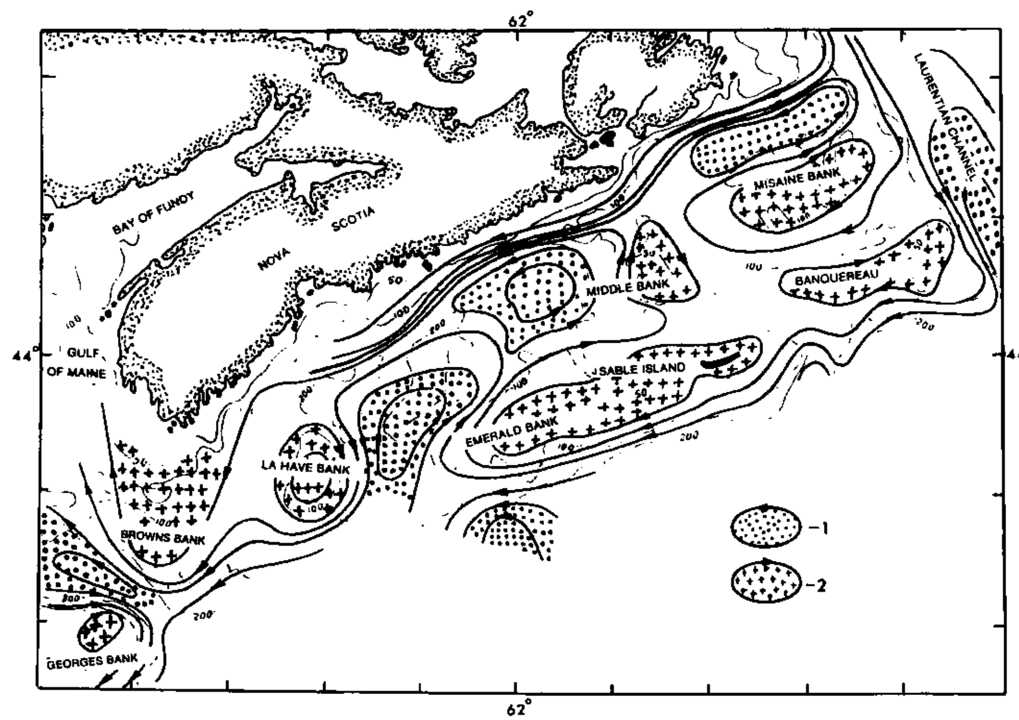

Fig. 13. Geostrophic circulation field for the Nova Scotia Shelf in January.

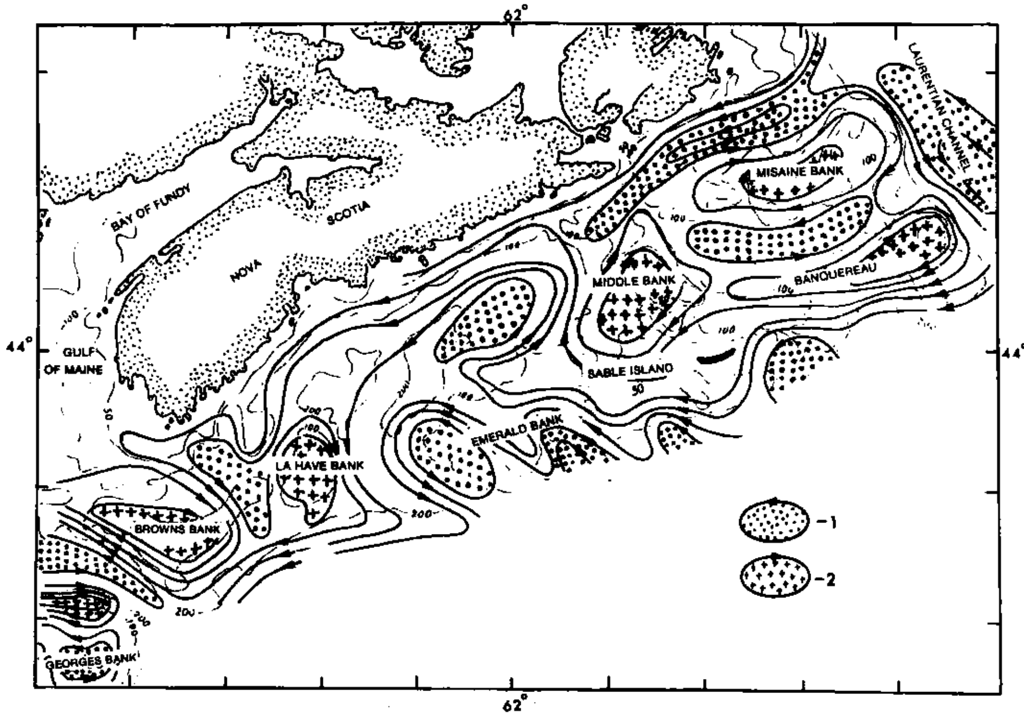

Fig. 14. Geostrophic circulation field for the Nova Scotia Shelf in April-May.

large sections of Georges Bank and Gulf of Maine and possible inaccuracies in interpreting the direction of bottle drift from the point of release to the place of recovery do not permit a detailed comparison of current patterns based on drift bottle data with those presented in this paper. Alekseev *et al.* (1971), from charts of dynamic topography presented geostrophic circulation patterns for the Georges Bank and Nova Scotia areas, which characterize the summer and winter seasons on the average for the 1961-66 period. However, due to the averaging of data over several months, he obtained rather smoothed current patterns, which lack a number of characteristic eddies evident in the foregoing diagrams of this paper. Nevertheless, Alekseev *et al.* (1971) suggested that the current patterns on the Nova Scotian Shelf were more complex than those reported by Trites and Banks (1958) from drift bottle data. This view is confirmed after examination of the monthly current patterns illustrated above.

In discussing the reasons for the intra-year variations in the surface water circulation on Georges Bank and the Nova Scotia shelf, one must agree with the view of various authors (Day, 1958; Trites and Banks, 1958) that wind activity exerts a considerable influence on water movements. In addition, advection processes are also likely to have a considerable effect on the formation of current fields.

Conclusions

1. The results of studies have confirmed the applicability of the dynamic method to determining the geostrophic circulation on the New England and Nova Scotia Shelves under conditions of sharply pronounced density stratification and complex bottom contours.

2. The circulation field structure on Georges Bank undergoes considerable change during the year and is indicated as a single closed cycle. The formation of an anticyclonic gyre on Georges Bank and of a cyclonic gyre (first phase) in the Gulf of Maine in August, and the complete destruction of the first and the division of the second into two anticyclonic eddies in February-March (second phase) are the main features of the cycle. During the year, a gradual transition from the first phase to the second and then again to the first is observed.

3. A number of characteristic quasi-stationary eddies and zones is indicated and their relationship to certain biological phenomena is noted.

4. The destruction of the anticyclonic gyre and the development of a cyclonic gyre on Georges Bank in February-March favours the intensive influx of

nutrients to the surface layer.

5. Significant intra-year variations in the geostrophic current field on the Nova Scotia Shelf is recorded for certain months of the year.

6. Wind activity and advection processes are considered to be the likely cause of intra-year variability in geostrophic circulation.

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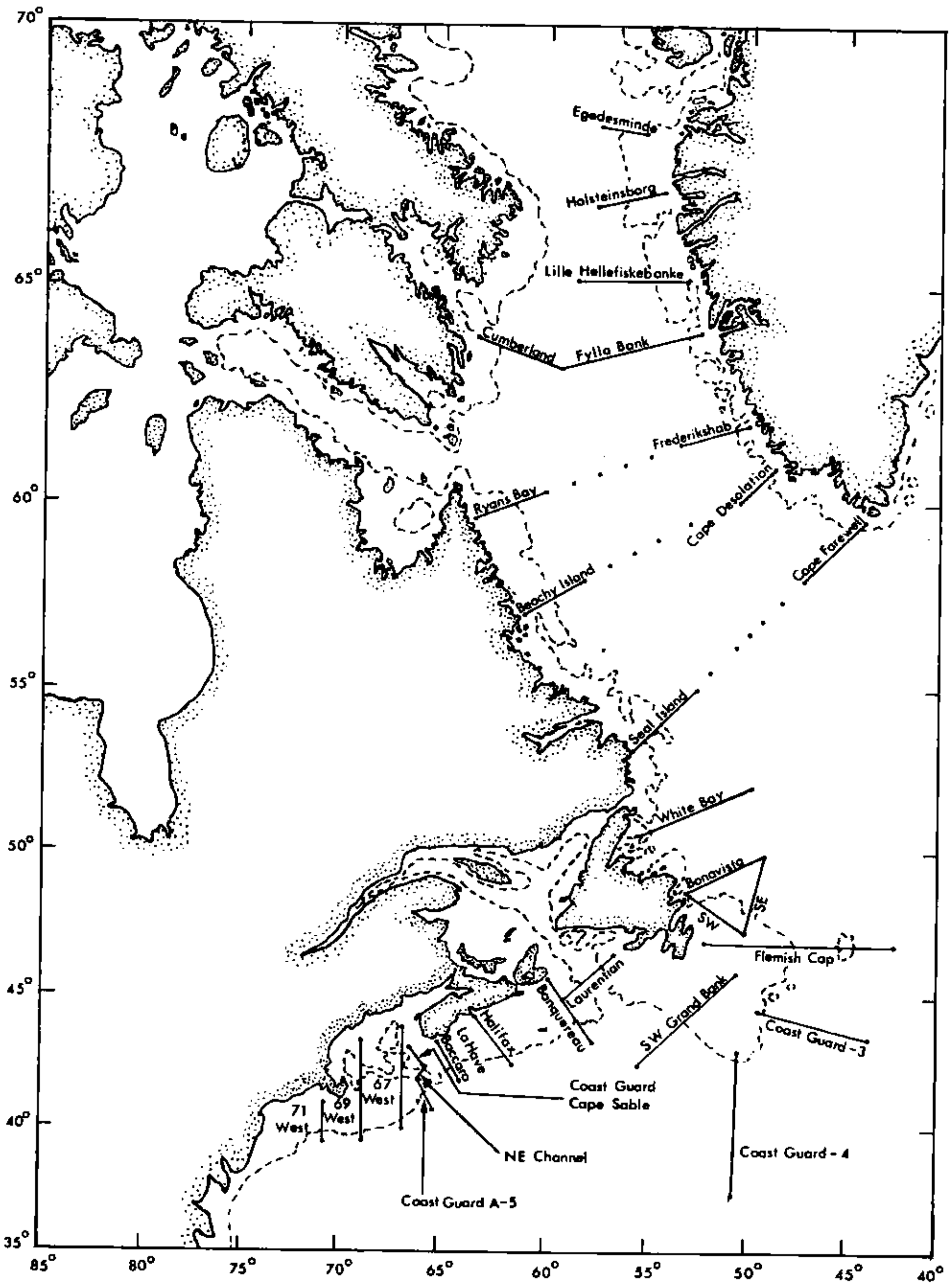
List of ICNAF Standard Oceanographic Sections and Stations[1]

At the 1976 Annual Meeting of ICNAF, the Standing Committee on Research and Statistics (STACRES) adopted a list of standard oceanographic sections and stations. Scientists who are responsible for planning and coordinating national research programs in the Northwest Atlantic are strongly urged to take account of these standard sections and stations in future oceanographic work.



[1] Additional copies of this paper are available from the Editor, International Commission for the Northwest Atlantic Fisheries, P.O. Box 638, Dartmouth, Nova Scotia, Canada, B2Y 3Y9.

ICNAF Subarea	Section name	Station Latitude	Station Longitude	Depth (m)
1	Cape Farewell	59°38'N	44°09'W	143
		59 27	44 30	165
		59 16	44 46	1,829
		59 00	45 20	2,118
		58 46	45 50	2,535
		58 23	46 34	2,688
		58 00	47 16	3,409
1	Cape Desolation	60°50'N	48°45'W	140
		60 43	49 11	652
		60 28	50 00	2,934
		60 15	50 44	3,146
		60 02	51 27	3,340
1	Frederikshab	61°57'N	50°00'W	206
		61 52	50 35	523
		61 47	51 09	2,605
		61 41	51 45	2,890
		61 34	52 30	3,016
		61 26	53 25	3,087
1	Fylla Bank	64°01'N	52°19'W	108
		63 58	52 44	49
		63 55	53 07	138
		63 53	53 22	605
		63 48	53 56	1,110
		63 45	54 30	1,172
		63 37	55 30	1,643
		63 31	56 25	1,482
		63 25	57 20	1,715
		63 19	58 15	1,390
		63 12	59 10	1,000
1	Lille Hellefiskebanke	65°06'N	53°00'W	150
		65 06	53 32	72
		65 06	53 59	74
		65 06	54 28	100
		65 06	54 58	609
		65 06	55 43	855
		65 06	56 30	678
		65 06	57 30	722
		65 06	58 32	540
1	Holsteinsborg	66°53'N	54°10'W	52
		66 50	54 42	48
		66 46	55 36	122
		66 43	56 07	166
		66 41	56 38	456
		66 36	57 30	620
1	Egedesminde	68°00'N	55°00'W	42
		68 02	55 28	79
		68 04	56 00	92
		68 07	56 44	250
		68 08	57 17	352

ICNAF Subarea	Section name	Station Latitude	Station Longitude	Depth (m)
2	Cumberland	63°52′N	63°32′W	180[a]
		63 41	62 30	208
		63 33	61 28	242
		63 28	60 56	403
		63 23	60 25	530[a]
		63 19	60 01	1,000[a]
		63 14	59 26	1,041
		63 12	59 10	975
2	Ryans Bay	59°38′N	63°34′W	100[a]
		59 43	63 04	147
		59 47	62 34	150
		59 53	62 05	174
		59 59	61 34	240
		60 05	61 03	300
		60 10	60 34	1,502
		60 15	60 04	1,922
2	Beachy Island	57°07′N	61°06′W	118
		57 16	60 41	183
		57 23	60 15	176
		57 31	59 49	178
		57 39	59 23	622
		57 45	59 00	1,532
		57 53	58 35	2,260
		58 03	58 09	2,561
2	Seal Island	53°14′N	55°39′W	43
		53 20	55 30	124
		53 37	55 00	300
		53 55	54 30	185
		54 12	54 00	215
		54 30	53 30	340
		54 38	53 15	610
		54 47	53 00	1,306
		55 04	52 30	2,686
1,2	Cumberland-Fylla Bank	63°52′N	63°32′W	180[a]
		63 41	62 30	208
		63 33	61 28	242
		63 28	60 56	403
		63 23	60 25	530[a]
		63 19	60 01	1,000[a]
		63 14	59 26	1,041
		63 12	59 10	975
		64 01	52 19	108
		63 58	52 44	49
		63 55	53 07	138
		63 53	53 22	605
		63 48	53 56	1,156
		63 45	54 30	1,135
		63 37	55 30	1,270
		63 31	56 25	1,452
		63 25	57 20	1,715
		63 19	58 15	1,390
		63 12	59 10	975

[a]Approximate depth.

ICNAF Subarea	Section name	Station Latitude	Station Longitude	Depth (m)
1,2	Ryans Bay-Frederikshab	59°38′N	63°34′W	100[a]
		59 43	63 04	147
		59 47	62 34	150
		59 53	62 05	174
		59 59	61 34	240
		60 05	61 03	300
		60 10	60 34	1,502
		60 15	60 04	1,922
		60 30	58 45	2,338
		60 42	57 24	2,926
		60 57	56 03	3,078
		61 10	54 44	2,907
		61 26	53 25	3,087
		61 32	52 30	3,016
		61 39	51 45	2,890
		61 45	51 09	2,605
		61 52	50 35	523
		61 57	50 00	206
1,2	Beachy Island-Cape Desolation	57°07′N	61°06′W	118
		57 16	60 41	183
		57 23	60 15	176
		57 31	59 49	178
		57 39	59 23	622
		57 45	59 00	1,532
		57 53	58 35	2,260
		58 03	58 09	2,561
		58 26	56 46	3,016
		58 49	55 30	3,229
		59 10	54 20	3,286
		59 35	52 52	3,430
		60 02	51 27	3,340
		60 15	50 44	3,146
		60 28	50 00	2,934
		60 43	49 11	652
		60 50	48 45	140
1,2	Seal Island-Cape Farewell	53°14′N	55°39′W	43
		53 20	55 30	124
		53 37	55 00	300
		53 55	54 30	185
		54 12	54 00	215
		54 30	53 30	340
		54 38	53 15	610
		54 47	53 00	1,306
		55 04	52 30	2,686
		55 35	51 40	3,408
		56 10	50 40	3,702
		56 34	49 54	3,670
		57 03	49 02	3,712
		57 30	48 10	3,310
		58 00	47 16	3,409
		58 23	46 34	2,688
		58 46	45 50	2,535
		59 00	45 20	2,118
		59 16	44 46	1,829
		59 27	44 30	165
		59 38	44 09	143

[a]Approximate depth.

ICNAF Subarea	Section name	Station		Depth (m)
		Latitude	Longitude	
3	White Bay	50°40'N	55°00'W	153
		50 48	54 30	217
		50 56.7	54 00	224
		51 05	53 30	240
		51 13.5	53 00	386
		51 22	52 29	439
		51 30	52 00	418
		51 38.8	51 30	407
		51 47.3	50 59.5	286
		51 52	50 42.4	1,370
		51 53.7	50 36	1,848
		51 55	50 28	2,046
		51 59.6	50 15	2,353
		52 07	49 45	2,932
3	Bonavista	48°44'N	52°58'W	68
		48 48	52 45	72
		48 50	52 39	79
		48 55	52 24	342
		49 01.5	52 04	294
		49 06	51 49.8	307
		49 11.4	51 32.5	284
		49 22	51 01	314
		49 31	50 32	331
		49 41	50 01	570
		49 51	49 30	1,618
		50 00	49 00	2,047
		NW (Bonavista)		
3	Triangle	48°44'N	52°58'W	68
		48 48	52 45	72
		48 50	52 39	79
		48 55	52 24	342
		49 01.5	52 04	294
		49 06	51 49.8	307
		49 11.4	51 32.5	284
		49 22	51 01	314
		49 31	50 32	331
		49 41	50 01	570
		49 51	49 30	1,618
		50 00	49 00	2,047
		SW		
		48°44'N	52°58'W	68
		48 38	52 44	100
		48 32	52 33.5	225
		48 30	52 29.3	218
		48 20	52 06	215
		48 13	51 50	192
		48 06	51 34	186
		47 56.8	51 14	200
		47 46.4	50 50.5	126
		47 34	50 23	241
		47 24	50 00	100

ICNAF Subarea	Section name	Station Latitude	Station Longitude	Depth (m)
		SE		
3	Triangle (continued)	47°24'N	50°00'W	100
		47 41	49 52	113
		47 58.2	49 45	158
		48 14	49 41	240
		48 26	49 36	287
		48 37.9	49 32.3	812
		48 56	49 25	1,408
		49 13.1	49 17.8	1,562
		49 38	49 09.5	1,810
		50 00	49 00	2,047
3	Flemish Cap	47°00'N	52°02'W	120
		47 00	51 00	102
		47 00	50 40	175
		47 00	50 00	81
		47 00	49 07	80
		47 00	48 37	103
		47 00	48 07	126
		47 00	47 30	220
		47 00	47 15	603
		47 00	47 01	1,018
		47 00	46 50	1,024
		47 00	46 40.2	1,000
		47 00	46 29	807
		47 00	46 01	308
		47 00	45 30	245
		47 00	44 59.3	152
		47 00	44 26	158
		47 00	44 05	327
		47 00	43 45	674
		47 00	43 24	1,284
		47 00	43 15	3,000
		47 00	43 00	3,650
		47 00	42 45	2,100[a]
		47 00	42 30	2,220[a]
		47 00	42 00	2,450
3	Coast Guard-3	43°38'N	43°44'W	4,755[a]
		43 45	44 26	4,688
		43 53	45 08	2,460
		44 00	45 50	4,343
		44 07	46 32	3,749
		44 15	47 12	3,840
		44 19	47 33	3,836
		44 23	47 54	3,475
		44 25	48 07	3,292
		44 27	48 21	3,291
		44 30	48 36	2,923
		44 33	48 50	732
		44 36	49 05	146
		44 40	49 20	58

[a]Approximate depth.

ICNAF Subarea	Section name	Station Latitude	Station Longitude	Depth (m)
3	Coast Guard-4	37°20′N	50°20′W	5,121
		37 50	50 20	5,218
		38 20	50 20	5,212
		38 50	50 20	5,176
		39 20	50 20	5,194
		39 50	50 20	5,176
		40 20	50 20	4,846
		40 50	50 20	3,726
		41 20	50 20	3,718
		41 50	50 20	3,731
		42 10	50 20	3,347
		42 30	50 20	2,578
		42 40	50 20	2,122
		42 50	50 20	887
		43 00	50 20	91
		43 10	50 20	
3	SW Grand Banks	46°02′N	51°10′W	77
		45 46	51 44	78
		45 37	51 58	75
		45 28	52 09	77
		45 20	52 22	97
		45 07.5	52 39	89
		45 01	52 48.5	84
		44 51	53 05	88
		44 38	53 24	104
		44 38	53 30	150
		44 28	53 37	183
		44 24	53 43	1,247
		44 20	53 50	1,829
		44 16	53 56	2,205
		44 09	54 05	2,417
		44 02	54 15	2,670
		43 43.2	54 26.2	3,017
		43 24.9	54 37.8	3,846
		43 09	54 47	4,080
		42 52	55 00	3,690
		42 33	55 15	4,502
3,4	Laurentian	46°35′N	56°23.3′W	106
		46 31.5	56 29.5	51
		46 20.4	56 48	48
		46 12	57 02	53
		46 08	57 09	201
		46 04	57 15	351
		45 55.8	57 29.5	452
		45 47	57 43.5	459
		45 42.8	57 51.5	420
		45 38	57 59	234
		45 29	58 13.5	199
		45 20	58 28.5	71
		45 11	58 42	102
		44 59	59 01.5	144

ICNAF Subarea	Section name	Station Latitude	Station Longitude	Depth (m)
4	Banquereau	45°49.5'N[b]	59°51'W	73
		45 43	59 45	146
		45 29	59 31	185
		45 12	59 14	95
		44 59	59 01.5	144
		44 49	58 51	261
		44 28	58 30	64
		44 11.7	58 14	183
		44 08	58 10	899
		43 47	57 50	2,633
		43 24	57 26	3,529
4	Halifax	42°32'N	61°24'W	2,042
		42 51	61 44	1,009
		43 10.3	62 06	101
		43 20	62 17	90
		43 29	62 26.5	81
		43 40.9	62 39.8	132
		43 49.8	62 48.9	225
		43 53	62 53	254
		43 58.8	62 59.5	227
		44 07.5	63 09.5	141
		44 16.3	63 19.2	143
		44 24 [b]	63 27.8	88
4	La Have-Baccaro	43°23.0'N	65°12.0'W	91
		43 15.5	65 06.0	146
		43 06.0	64 59.0	110
		42 56.5	64 51.0	82
		42 47.0	64 44.0	100
		42 37.5	64 36.0	128
		42 28.5	64 29.0	1,097
		42 19.0	64 22.0	1,829
		42 10.0	64 14.0	1,975
		42 00.0	64 07.0	2,377
4,5	Cape Sable, Northeast Channel and Coast Guard A-5		Cape Sable	
		43°11.5'N	65°39.1'W	64
		43 02.8	65 40.3	91
		42 55.0	65 41.4	137
		42 47.0	65 42.5	110
		42 37.0	65 43.7	88
		42 27.0	65 45.1	91
			Northeast Channel	
		42°21.1'N	65°50.9'W	196
		42 17.1	65 54.7	229
		42 12.3	65 59.5	223
		42 08.5	66 02.8	214

[b] Station inside 12-mile limit.

ICNAF Subarea	Section name	Station Latitude	Station Longitude	Depth (m)
4,5	Cape Sable, Northeast Channel and Coast Guard A-5 (continued)		Coast Guard A-5	
		42°02.3′N	66°09.0′W	95
		41 53.7	66 14.2	80
		41 45.0	66 19.4	80
		41 36.0	66 25.0	86
		41 20.0	66 04.5	366
		41 10.5	65 53.5	2,377
		40 50.0	65 27.0	3,658
4,5	67° West	44°00′N	67°00′W	165
		43 30	67 00	208
		43 00	67 00	165
		42 30	67 00	320
		42 00	67 00	57
		41 30	67 00	62
		41 00	67 00	73
		40 45	67 00	110
		40 30	67 00	914
		40 15	67 00	1,829
		40 00	67 00	2,377
5	69° West	43°30′N	69°00′W	128
		43 00	69 00	91
		42 30	69 00	219
		42 00	69 00	146
		41 30	69 00	146
		41 00	69 00	77
		40 30	69 00	69
		40 15	69 00	91
		40 00	69 00	183
		39 45	69 00	1,829
		39 30	69 00	2,936
5	71° West	41°00′N	71°00′W	46
		40 30	71 00	77
		40 00	71 00	366
		39 30	71 00	2,195