INTERNATIONAL COMMISSION

FOR THE

NORTHWEST ATLANTIC FISHERIES

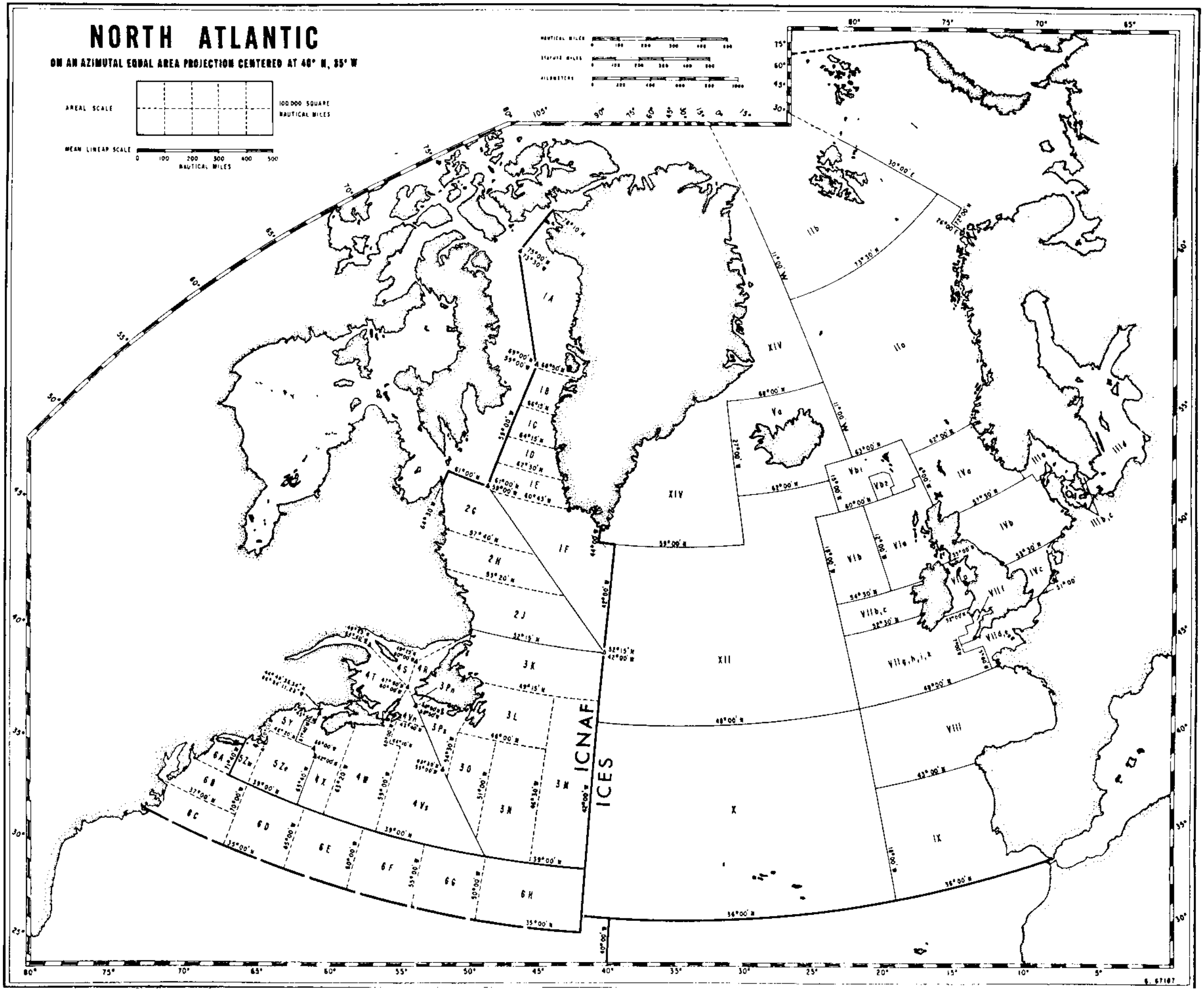
RESEARCH BULLETIN

NUMBER 7

Issued from the Headquarters of the Commission

Dartmouth, N. S., Canada

1970


NORTH ATLANTIC
ON AN AZIMUTAL EQUAL AREA PROJECTION CENTERED AT 40° N, 35° W
AREAL SCALE
100 000 SQUARE NAUTICAL MILES
MEAN LINEAR SCALE
0 100 200 300 400 500
NAUTICAL MILES
NAUTICAL MILES
STATUTE MILES
KILOMETERS
ICNAF
ICES
1A
1B
1C
1D
1E
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2G
2H
2J
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42°00' W
52°15' N
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43°00' N
36°00' N
40°00' W
35°00' N
39°00' N
S. 67187

Contents

Note on Growth of American Plaice, *Hippoglossoides platessoides* (Fabr.), in ICNAF Subarea 5

By F. E. Lux[1]

Abstract

American plaice from off New England (ICNAF Subarea 5) grow faster than in western north Atlantic waters farther to the north. Von Bertalanffy growth equations were

$$l_t = 450 \left[1 - e^{-0.27\,(t-0.41)}\right] \text{ for males and}$$

$$l_t = 675 \left[1 - e^{-0.15\,(t-0.10)}\right] \text{ for females.}$$

Introduction

The arctic-boreal *H. platessoides* occurs in coastal waters across the entire north Atlantic (Bigelow and Schroeder, 1953). In the ICNAF Convention Area, where it commonly is called the American plaice, it is found as far south as Cape Cod and Georges Bank, the general area considered in this paper. The US fishery for this species in waters off New England is comparatively small: landings in 1960-67 averaged 2,600 metric tons per year. About 95% of this catch came from ICNAF Subarea 5, particularly from the western Georges Bank, Stellwagen Bank, and Great South Channel areas. Much of it was incidental to fishing for other species of trawl fishes.

Age and growth studies have been summarized by Powles (1965) who studied American plaice in the Gulf of St. Lawrence (ICNAF Division 4T) and by Pitt (1967) who determined ages of this fish from Newfoundland Banks, Grand Banks, and the Labrador Shelf (ICNAF Subareas 2 and 3). These two papers and a further one by Powles (1966) provided evidence that the number of hyaline rings on the otoliths corresponded with age in years.

Methods and Materials

Age and growth information presented here for fish of age group I and over is based on examination of otoliths from 825 plaice. Most of the fish were caught by otter trawl in a monthly sampling program conducted from March 1958 through January 1959. The trawling station was in 55-110 m of water just to the north of the tip of Cape Cod (approximately 42°10'N, 70°04'W). In addition, a sample of 1-group fish in this area collected in August 1960 otter trawl sampling was included to supplement growth information for this age-group.

Total length in millimeters and sex were recorded for each fish and otoliths were excised and stored in 50% glycerin. The otoliths were examined whole under a low power microscope, and the number of hyaline rings was counted.

Observations of gonad condition of these fish indicated that spawning began in late March, peaked in April, and was completed by late May. This agrees closely with information from other studies summarized by Bigelow and Schroeder (1953), and therefore 1 April was used as the birth date.

Results

No 0-group plaice were caught in the trawl samples, and growth during the first year therefore was estimated from lengths of pelagic stage fish. Marak and Colton (1961) found that larvae, of eggs collected on Georges Bank in March to early May and hatched aboard ship, were about 5.5 mm long at hatching. Mean lengths of 84 pelagic plaice caught in late July and of 13 in early September were 26 and 34 mm, respectively (Fig. 1).[2]

Lengths at age by sex of age 1 and older fish (Table 1, Fig. 1) indicate that the males and females grow at the same rate until age 4. Following age 4 the females grow faster. This pattern is similar to that shown by Powles (1965) and Pitt (1967) for plaice from more northern areas.

Von Bertalanffy growth equations of the form

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

in which l_t is length at age t, L_∞ is the theoretical maximum length, K is the rate of change in length increment, and t_o is the age at which growth theoretically begins were fitted, by the method of Ricker (1958), to the growth data of Table 1 (Fig. 1). The resulting equations

[1] Bureau of Commercial Fisheries, Biological Laboratory, Woods Hole, Massachusetts 02543, USA.

[2] Unpublished data from collections by G. F. Kelly aboard R/V *Albatross III* in the Gulf of Maine in 1957.

$$l_t = 450 \left[1 - e^{-0.27\,(t-0.41)} \right] \text{(male)}$$

$$l_t = 675 \left[1 - e^{-0.15\,(t-0.10)} \right] \text{(female)}$$

provide estimates of the growth rates for fish beyond age 2.

The values of L_∞ given in millimeters, were estimated from plots of length at age t against length at age $t+1$ (Walford, 1946). However, female plaice as large as 700 mm were observed in landings from Subarea 5. The equations given here therefore may be slightly in error because of the paucity of large fish in the age samples. The rather poor fit of the equation to the female length at age data for older fish also is attributed to the small numbers of fish represented in these groups.

A comparison of growth in different ICNAF Subareas (Fig. 2) indicates that plaice grow faster in Subarea 5 than in Div. 4T (Powles, 1965) or in Subareas 2 and 3 (Pitt, 1967). Pitt (1967) has shown that growth of plaice in Subareas 2 and 3 appeared to be directly related to the water temperature. In view of the generally higher water temperatures in Subarea 5 (Colton, 1968) compared with those in Div. 4T (Lauzier, 1957) and Subareas 2 and 3 (May *et al.*, 1965), it appears likely that temperature was a factor in more rapid growth in Subarea 5.

TABLE 1. Number of fish (n) and mean lengths in centimeters at each age (cm) for American plaice, by calendar quarter, from trawl catches in 1958-60.

Age-group	Apr. - June		July - Sept.		Oct. - Dec.		Jan. - Mar.	
	n	cm	n	cm	n	cm	n	cm
Males and females								
1			41	10.2	1	11.9	13	14.4
Males								
2	20	17.9	41	18.8	36	20.6	25	22.0
3	23	23.9	42	25.6	35	26.5	26	28.2
4	10	29.4	11	29.5	5	30.0	2	30.0
5	1	35.0	1	33.0	1	28.0	1	33.0
6	1	33.0	–	–	–	–	4	38.8
Females								
2	32	18.1	38	20.5	45	20.9	47	22.1
3	49	24.5	46	26.9	60	28.1	36	28.4
4	24	30.8	18	32.0	22	32.9	15	34.4
5	7	37.4	5	38.4	4	37.0	13	39.8
6	9	40.1	1	35.0	3	36.0	3	43.3
7	2	43.5	–	–	–	–	1	47.2
8	1	41.7	–	–	–	–	1	46.0
9	1	49.9	–	–		–	1	49.9
10	–	–	1	45.9	–	–		

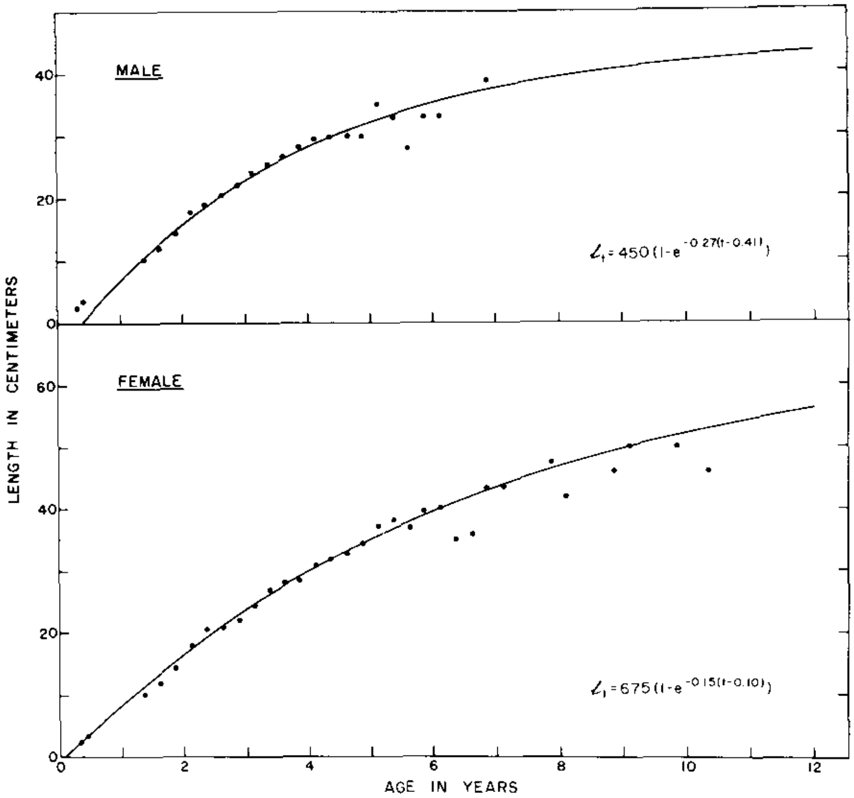

Fig. 1. Length at age of male and female American plaice from Subarea 5, based on mean lengths of Table 1, and the computed Von Bertalanffy growth equations.

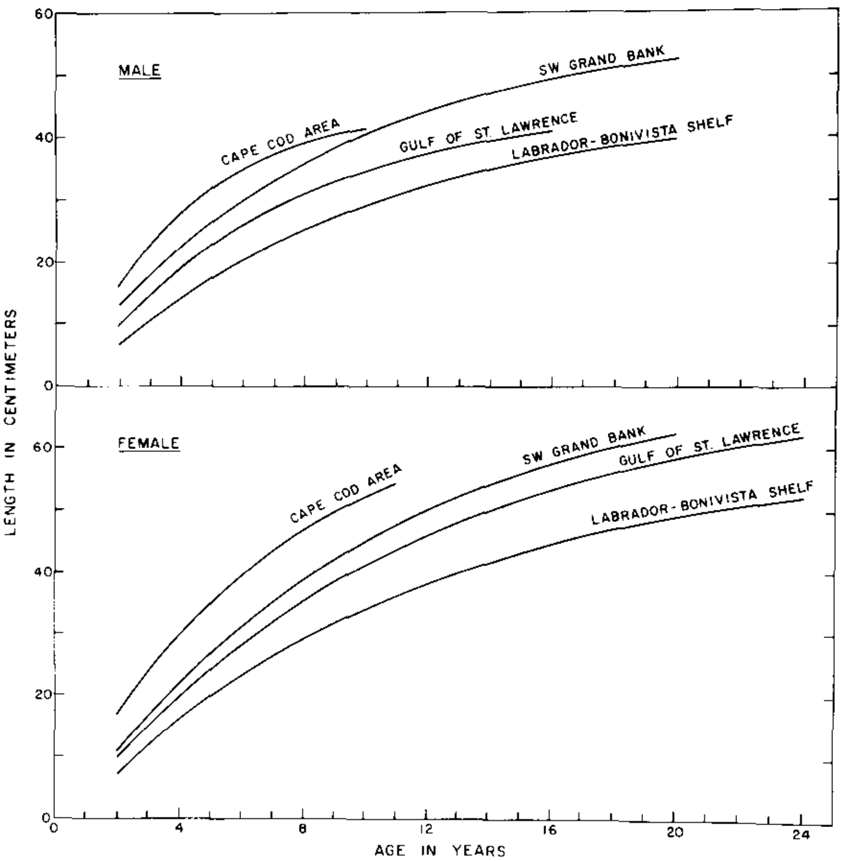

Fig. 2. Comparative growth rates, based on Von Bertalanffy growth equations, of American plaice from four North American locations. (The data for the Gulf of St. Lawrence are from Powles, 1965; data for SW Grand Bank and the Labrador Shelf to Bonivista Shelf are from Pitt, 1967).

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Movements of Haddock Tagged off Digby, Nova Scotia

R. G. Halliday[1] and F. D. McCracken[1]

Abstract

Of 981 haddock tagged off Digby, Nova Scotia (4Xr) in 1963 and 1966, 148 were returned by June 1969. Returns indicated that much of the stock present in 4Xr in summer moved offshore in the autumn to Browns Bank (4Xn, p). Some fish, probably belonging to an inshore stock, remained in 4Xr throughout the winter. Apparently there was no substantial mixing among this inshore stock and those along the southern coast of Nova Scotia. Some mixing of 4Xr haddock occurred with those of 4Xs in the summer but very little with those of Subarea 5.

Introduction

Tagging experiments off the southwest coast of Nova Scotia (4Xm, o – see Fig. 2) and on the western side of the Bay of Fundy (4Xs) showed that haddock stocks there mixed little with the geographically intermediate stock on the eastern side of the Bay of Fundy (4Xr) (Needler, 1930; McKenzie, 1940; McCracken, 1956, 1960). Results from taggings of 1,100 haddock by Needler (1930) in St. Mary's Bay, Nova Scotia, and of 70 by McCracken (1960) off Digby, Nova Scotia, were inconclusive due to the small number of returns (12 and 15 respectively). However, these returns suggested that eastern Bay of Fundy haddock were most closely associated with those of Browns Bank, off southwestern Nova Scotia (4Xn, p).

Haddock landings from 4Xr averaged almost 8,000 metric tons round weight over the 5 year period 1964-68, which was 22% of the average total landings from Division 4X. Therefore, to determine the relationship of this important haddock stock to those in other areas, 981 haddock were tagged at approximately 44° 45′ N, 65° 50′ W off Digby, Nova Scotia.

Methods

Six hundred and sixty-two haddock were tagged between 26 and 29 November 1963 and a further 319 on 19 October 1966. All were caught by otter trawl in depths of 68-91m (37-50 fathoms). Bottom temperatures in the area fished during the 1963 tagging ranged from 6.5° to 8.0°C and surface temperatures from 6.6° to 7.6°C. No temperatures were recorded in 1966. Yellow Petersen disc-type tags were attached through the back by stainless steel wire, and no fish were tagged which showed signs of injury during capture. Most haddock tagged in 1963 were 45-60 cm fork length, those in 1966 mainly 35-50 cm (Fig. 1). All fish tagged were large enough to be included in commercial landings in 4Xr (Fig. 1).

For purpose of analysis, winter is defined as the period from January to March; spring – April to June; summer – July to September; and autumn – October to December. ICNAF divisions and Canadian groundfish unit areas are shown in Fig. 2.

Results

Any mortality which occurred due to tagging was not size-selective as all length groups were represented in returns approximately in the proportions tagged (Fig. 1)

Ninety-two (14%) of the haddock tagged in November 1963 and 56 (18%) of those tagged in October 1966 were returned by June 1969 (Table 1). Those returns for which the location and time of capture are known are plotted in Fig. 2.

Three fish were recaptured near the area of tagging within a month of their release in November 1963. In the following winter and spring, seven returns were from near the mouth of the Bay of Fundy but most were from offshore banks, southwest of Nova Scotia (4Xn, p). One was taken in 4W, and two in Subarea 5. In the summer and autumn of 1964 almost all recaptures were from the Bay of Fundy, mainly 4Xr, but also in moderate numbers from 4Xs. In succeeding years the seasonal pattern of returns was similar to that in the first year.

Four fish from the 1966 tagging were recaptured near the area of release within 2 months. In the following winter and spring there were five returns from the Bay of Fundy. But, unlike the pattern of returns from the 1963 tagging, only two fish were returned from the offshore banks. Subsequently, the pattern of returns was very similar to that for the 1963 tagging: most returns from 4Xr in the summer and autumn; from the

[1] Fisheries Research Board of Canada, Biological Station, St. Andrews, New Brunswick.

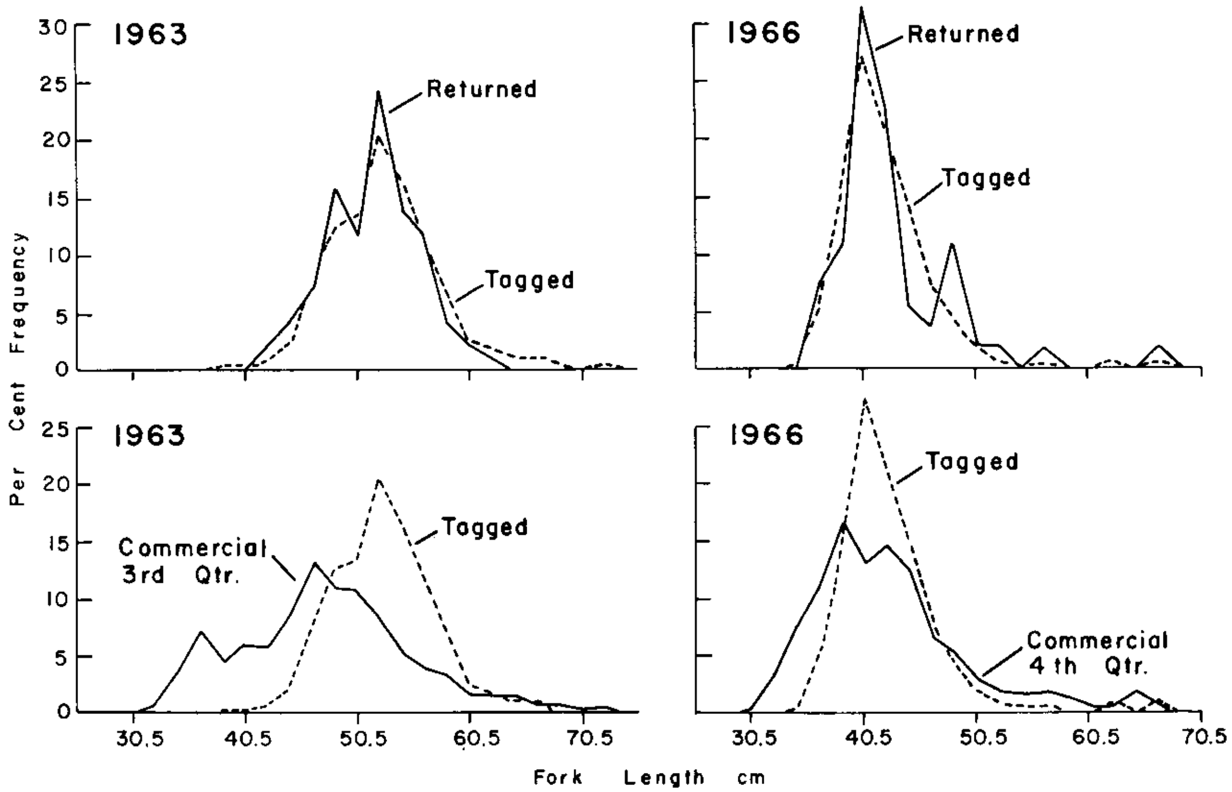

Fig. 1. Length frequencies of tagged haddock in relation to length at tagging of recaptured fish (upper panels), and length composition of commercial landings about at period of tagging (bottom panels).

offshore banks (4Xn, p) in the winter and spring; and moderate numbers taken in 4Xs in the summer and autumn.

Thus, of returns for which the location of capture was known, 81% were from off western Nova Scotia (4X excluding 4Xs); 10% were from 4Xs; 5% from 5Z; 3% from 5Y; and 1% from 4W. These results agree closely with those of earlier tagging experiments by Needler (1930) and McCracken (1960). Grosslein (1962) reports that unpublished results of United States taggings south and west of Digby Neck and on Browns Bank also show 75-80% returns from western Nova Scotia.

Discussion

The haddock fishery in 4Xr (inshore) is prosecuted mainly in late spring and summer, and that in 4Xn, p (offshore) in the winter and early spring months. Fluctuations in landings closely reflect fluctuations in availability (Fig. 3). The reduced availability in 4Xr in winter is coincident with the period when tags are taken offshore in greatest numbers. This appears to reflect an offshore movement, 4Xr haddock joining the pre-spawning and spawning concentrations on which the winter and spring offshore fishery is based.

However, tag recaptures in 4Xr were not proportional to landings there, but were reported relatively more frequently in autumn and winter when landings were low (Table 2). Tagging in 4Xr was carried out during the autumn period of decreasing availability, presumably after part of the offshore migration had taken place, and tags were apparently put on many fish which were to remain inshore during winter. The disproportionate number of tags recaptured inshore during the second winter in both experiments also suggests that there is a resident inshore stock. The lack of movement offshore does not appear to have been a result of immaturity. Over 90% of the haddock belonging to the stock which spawns on offshore banks of 4X are mature at 45 cm and 50% are mature at 40 cm (unpublished data). Thus, virtually all haddock tagged in 1963 were large enough to be mature. Also, those recaptured inshore in winter and spring (16 fish) were not, on average, significantly different in size at the time of tagging from those caught offshore in 4Xn, p (22 fish)

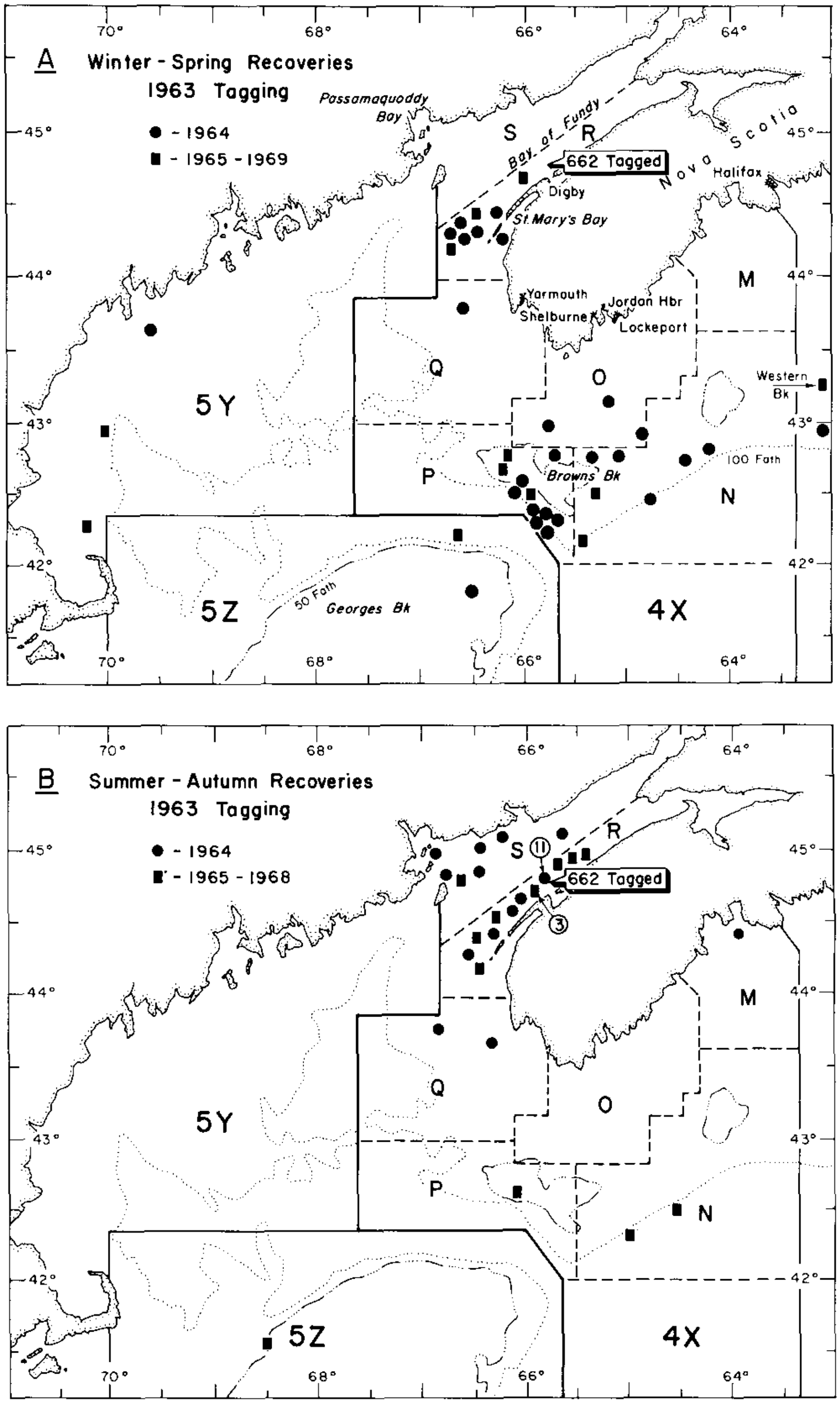

Fig. 2. Distribution of recoveries of haddock tagged in 1963 off Digby, Nova Scotia. A – Winter-Spring recoveries. B – Summer-Autumn recoveries.

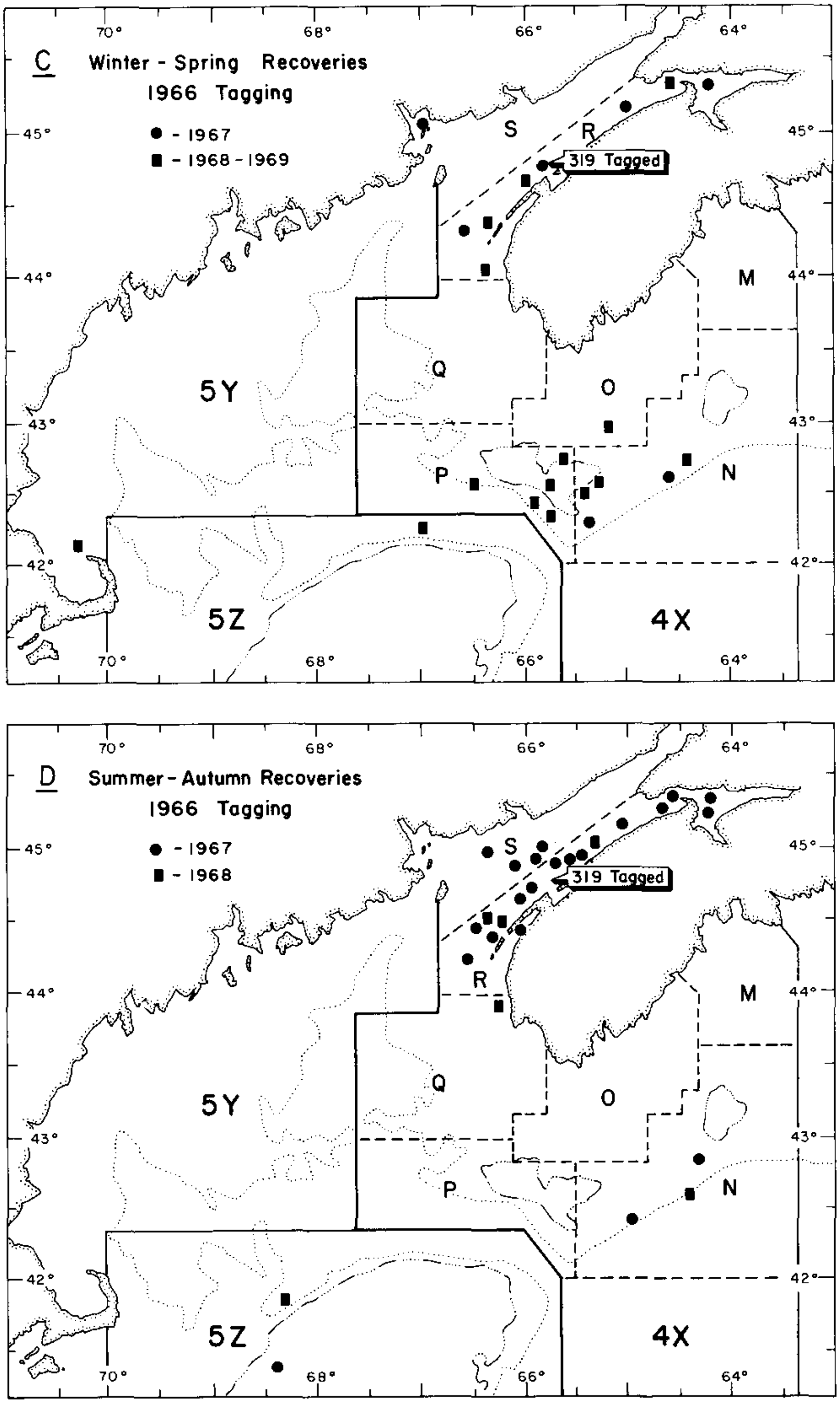

Fig. 2 (continued). Distribution of recoveries of of haddock tagged in 1966 off Digby, Nova Scotia. C – Winter-Spring recoveries. D – Summer-Autumn recoveries.

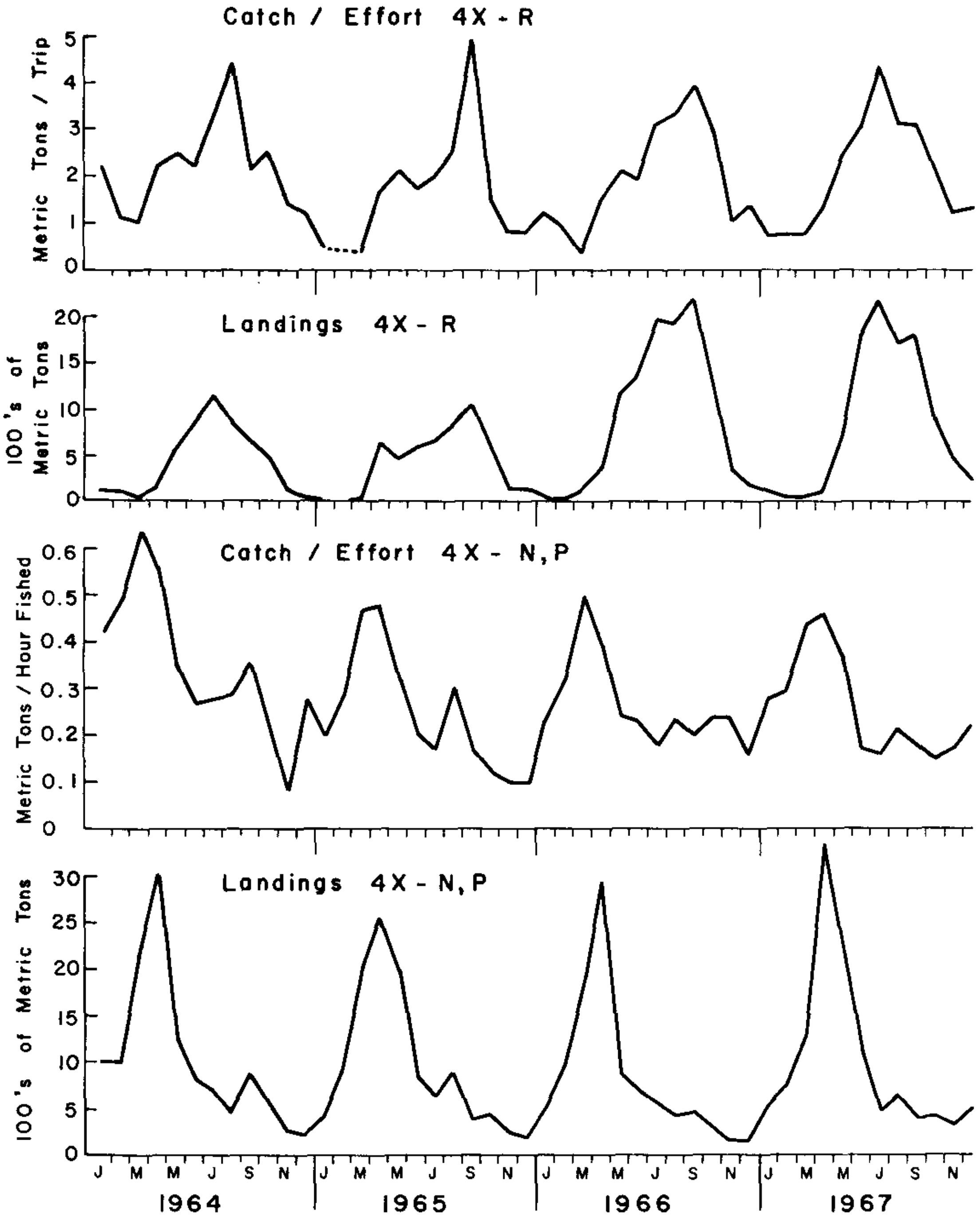

Fig. 3. Canadian haddock landings and catch per unit of effort in 4Xr and 4Xn, p, 1964-67. (Catch/effort in 4Xr is for Canadian otter trawlers of 26-50 gross tons. Catch/effort in 4Xn, p is for Canadian side otter trawlers of 151-500 gross tons.)

TABLE 1. Season and location of returns from haddock tagged off Digby, Nova Scotia.

	4Xr	4Xm-n-o-p-q	4Xs	4W	Subarea 5	Area unknown	Total
November 1963 tagging							
December 1963	3	–	–	–	–	–	3
Winter – spring 1964	6	17	–	1	2	2	28
Summer – autumn 1964	15	3	6	–	–	1	25
Winter – spring 1965-69	3	5	–	1	3	–	12
Summer – autumn 1965-68	9	3	1	–	1	2	16
Date unknown	4	1	2	–	1	–	8
Total	40	29	9	2	7	5	92
Number tagged = 662; returns = 92 (14%)							
October 1966 tagging							
Nov. – Dec. 1966	4	–	–	–	–	–	4
Winter – spring 1967	4	2	1	–	–	–	7
Summer – autumn 1967	14	2	4	–	1	1	22
Winter – spring 1968-69	4	9	–	–	2	1	16
Summer – autumn 1968	3	2	–	–	1	–	6
Date unknown	–	1	–	–	–	–	1
Total	29	16	5	–	4	2	56
Number tagged =319; returns =56 (18%)							

TABLE 2. The relationship between tag returns by Canadian vessels and Canadian haddock landings from 4Xr (landings in metric tons round fresh).

1963 tagging				1966 tagging			
	Landings	Tags	Tags/ 1,000 tons		Landings	Tags	Tags/ 1,000 tons
Dec. 1963	185	3	16	Nov. – Dec. 1966	546	4	7
Winter 1964	285	5	18	Winter 1967	214	2	9
Spring – summer 1964	4,463	5	1	Spring – summer 1967	8,325	11	1
Autumn 1964 – winter 1965	867	12	14	Autumn 1967 – winter 1968	1,783	5	3
Spring – summer 1965	4,300	5	1	Spring – summer 1968	6,316	3	0
Autumn 1965 – winter 1966	1,102	3	3	Autumn 1968	637	1	2

in winter and spring ($p = 0.05$). The similar size and probably, maturity, of the inshore haddock to those moving offshore support the conclusion that they belong to a separate inshore stock.

The conclusion concerning an inshore resident stock fits results of inshore tagging along the southwest Nova Scotia coast (4Xm, o) off Halifax, Shelburne, Seal Island (Needler, 1930), Jordan Harbour (McKenzie, 1940), and Lockeport (McCracken, 1956), which indicated that a proportion of the haddock in these regions also were year-round inshore residents.

These earlier tagging experiments also showed that 4Xm-o haddock tended to move eastwards along the coast. Very few moved westwards and only one fish was taken in 4Xr. The results presented here show that haddock from the eastern side of the Bay of Fundy do not exhibit an eastward coastal migration, only one tagged fish being recovered inshore east of Yarmouth. Neither were any of the few returns from fish tagged by Needler (1930) in St. Mary's Bay or by McCracken (1960) off Digby recaptured along the south coast of Nova Scotia. Thus, there appears to be little mixing of the inshore haddock stock from the eastern side of the Bay of Fundy with those off the south coast of Nova Scotia.

Acknowledgments

We thank Mr N. J. McFarlane and Mr R. J. Thurber who did the tagging and Mrs Irma Thompson who processed and plotted the return data. We are also most grateful to the captain and crew of the M. V. *Harengus* for their help during tagging operations and to the many fishermen and others who reported the capture of tagged fish.

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Forecasting Cod Distribution at West Greenland by Means of Water Temperature

By I. I. Svetlov[1]

Abstract

This paper deals with the results of investigations into the use of water temperatures to forecast cod distribution off West Greenland (ICNAF Subarea 1). Otter-trawl catches in each statistical division or divisions of Subarea 1 expressed as a percentage of the total annual otter-trawl catch in Subarea 1 is taken as an index of the distribution of cod. Water temperatures from Fyllas Bank in July 1953-66 and from Godthaab Fjord in 1953-61 are taken as an index of environmental conditions. The equations for five prognostic relationships show correlation coefficients varying from 0.68 to -0.96. Tests of the relationships showed that the method described may be applied to forecasting cod catches from 2 to 6 months and 12 months.

Introduction

It is known that the distribution of cod in the West Greenland area depends to a considerable extent on the seasonal changes in water temperature. Such a relationship has also been demonstrated in the Barents Sea by Konstantinov (1967) who, using the regularities of the seasonal migrations of the Barents Sea cod, has developed a method of forecasting cod distribution according to the temperature factor. In the present paper this method has been used in an attempt to reveal similar relationships in the waters off West Greenland.

Materials and Methods

Water temperatures obtained mainly by Danish research vessels in July of each year from 1953 to 1966 at two stations on Fyllas Bank (63°44′N, 54°30′W and 63°53′N, 53°22′W) and reported by Hermann (1967) were taken as an index of the environmental conditions. Data on water temperatures in Godthaab Fjord from 1953 to 1961 (Hermann, 1953-61) were also used.

The trawl catch of cod in the different statistical divisions (1A, 1B, 1C, 1D, 1E, and 1F) of Subarea 1 of the International Commission for the Northwest Atlantic Fisheries (ICNAF) expressed as a percentage of the total annual yield of cod in Subarea 1 was taken as an index of cod distribution. Data on catch statistics were obtained from Volumes 4 to 16 of the ICNAF Statistical Bulletins for the years 1954-68.

Results

Twenty-six possible relationships between water temperature (t) and the cod distribution indices (F) for the different Divisions were examined. Attempts have been made to express the general relationship in terms of $F = a + bt$. The most striking relationship was found in a comparison between the water temperatures in the 0- to 200-m layer on the Godthaab station in October and the cod distribution indices for Div. 1D and 1E combined in April-June of the following year (Table 1 and Fig. 1). The correlation coefficient of this relationship is -0.96. The regression equation is $F=57.3-16.2t$, where F = cod distribution index in percent for Div. 1D + 1E and t = water temperature in the 0- to 200-m layer in the Godthaab Fjord. Comparison of the water temperatures in the 200- to 300-m layer in the Godthaab Fjord in October with the cod distribution indices for Div. 1D and 1E in April-June of the following year (Fig. 2) gives a correlation coefficient of -0.80, and the regression equation is $F=45.6-10.3t$.

A significant positive correlation was observed between the average water temperatures in the 300- to 400-m layer in July at the two Fyllas Bank stations and the cod distribution indices for Div. 1A, 1B, and 1C combined in the following year (Fig. 3). The correlation coefficient is 0.70 and the regression equation $F = 10.7 + 6.7t$.

Figure 3 shows that, if the temperature increases on Fyllas Bank in July, then the cod distribution index for Div. 1A, 1B, and 1C combined will also increase in the following year. By contrast, the cod distribution index for the southern Div. 1D and 1E combined decreases during that period.

During the cod growing season, there was a relationship obtained between the water temperature in the 0- to 200-m layer at Station 1 on Fyllas Bank in July and the cod distribution index for Div. 1D and 1C combined in August-October (Fig. 4). This relationship has a correlation coefficient of 0.68 and the regression equation is $F = 0.12 + 2.2t$.

Observations necessary to determine the cod distribution index for the various divisions for the

[1]Polar Research Institute of Marine Fisheries (PINRO), 6 Knipovich Street, Murmansk, USSR.

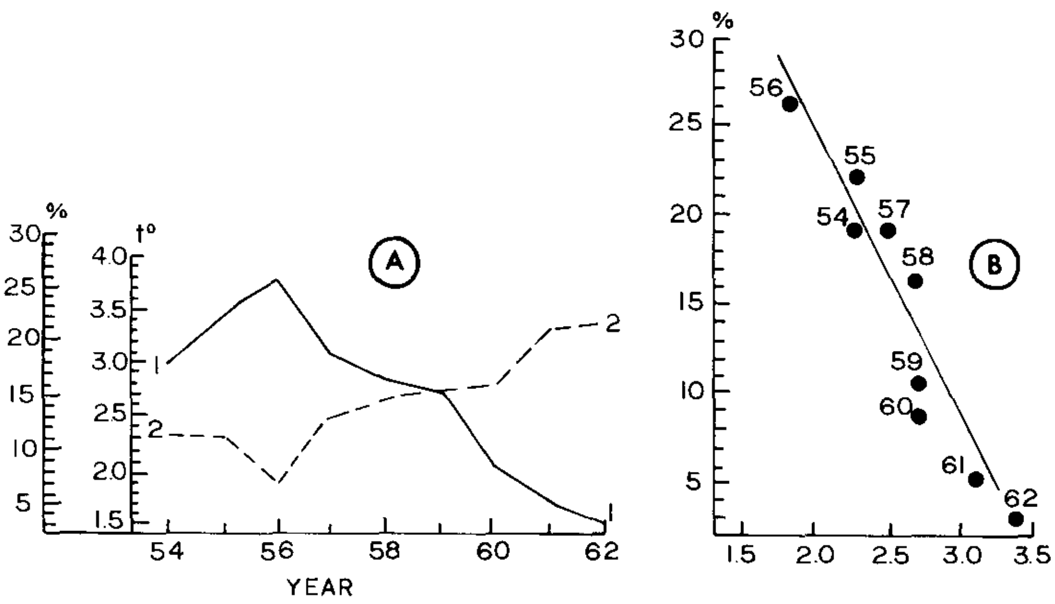

Fig. 1. (A) Cod distribution indices (%) for ICNAF Div. 1D and 1E combined in April-June (1) and water temperature (°C) in the 0- to 200-m layer in the Godthaab Fjord in October of the previous year (2).

(B) The relationship between the cod distribution indices for Div. 1D and 1E combined in April-June and water temperatures in the 0- to 200-m layer in the Godthaab Fjord in October of the previous year.

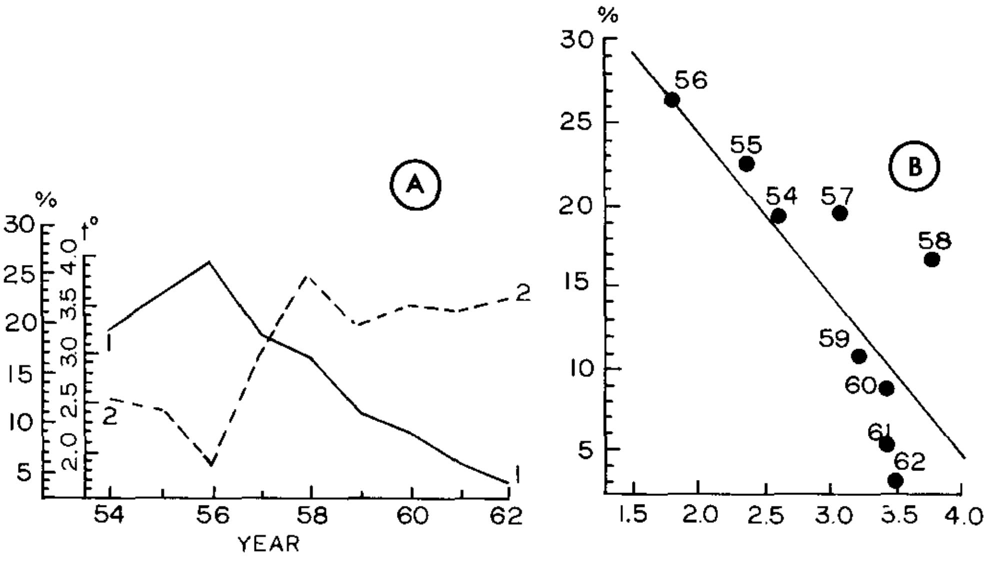

Fig. 2. (A) The cod distribution indices for Div. 1D and 1E combined in April-June (1) and water temperatures in Godthaab Fjord in the 200- to 300-m layer in October of the previous year (2).

(B) The relationship between the cod distribution indices for Div. 1D and 1E combined in April-June and water temperatures in the 200- to 300-m layer in Godthaab Fjord in October of the previous year.

wintering period of cod are incomplete. Water temperatures in the 0- to 100-m layer on Lille Hellefiske Bank in September (data from the Soviet research vessels in 1961-67) were compared with the cod distribution index for Div. 1B in October-December (Fig. 5). Figure 5 shows that, if the water temperature is higher, the cod distribution index in Div. 1B increases, but if the temperature is lower, it decreases.

Conclusions

Relationships obtained from an analysis of available data confirm that, with increasing water temperatures, cod in West Greenland waters migrate northward and, with decreasing water temperatures, cod are distributed far to the south. The same relationship is probably true also for the Labrador area (Konstantinov, 1968).

The equations obtained provide a means of forecasting, from 2 to 6 months and up to 1 year in advance, the location of the best areas for scouting for cod.

TABLE 1. Calculation of cod distribution indices for ICNAF Div. 1D and 1E combined in April-June for 1954-66.

Year	Cod trawl catches (tons) in Div. 1D + 1E in April-June (A)	Annual cod catch (tons) in Subarea 1 (B)	Fishery importance of Div. 1D + 1E $\frac{A}{B} \times 100\%$
1954	57,740	301,875	19.1
1955	59,478	265,318	22.4
1956	84,588	321,245	26.3
1957	51,384	269,035	19.1
1958	52,010	318,821	16.3
1959	24,278	233,542	10.4
1960	20,440	241,346	8.5
1961	17,661	345,391	5.1
1962	12,661	450,658	2.8
1963	49,517	405,741	12.2
1964	43,993	349,738	12.6
1965	34,237	360,341	9.5
1966	34,226	366,126	9.3

Test of the actual and calculated values of the cod distribution index for Div. 1A, 1B, and 1C combined from the equation $F = 10.7 + 6.7t$ showed that, in 77% of cases, the error was not greater than 20% of the long-term amplitude of the forecasting index. This indicates that the method is satisfactory for tentative fishery forecasting.

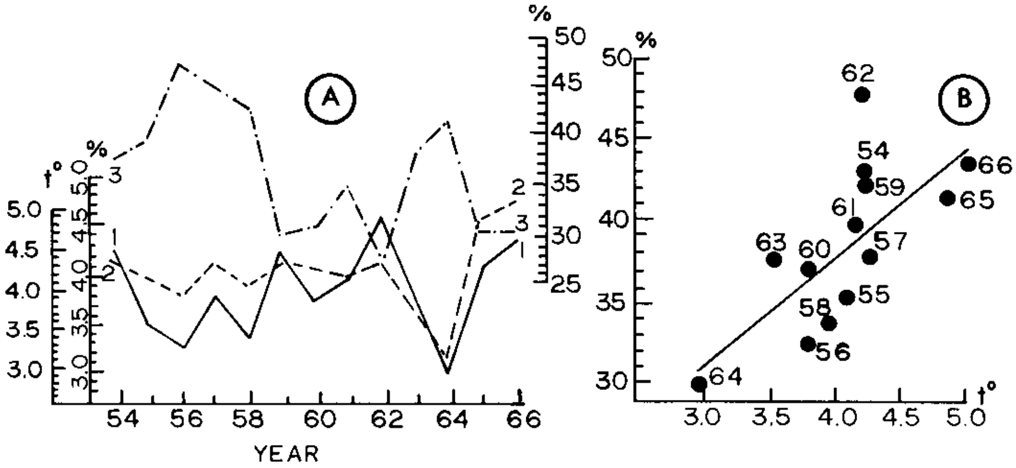

Fig. 3. (A) The cod distribution indices for Div. 1A, 1B, and 1C combined per year (1), water temperatures in the 300- to 400-m layer on Fyllas Bank in July of the previous year (2) and the cod distribution indices for Div. 1D and 1E (3).

(B) The relationship between the cod distribution indices for Div. 1A, 1B, and 1C combined per year and water temperatures in the 300- to 400-m layer on Fyllas Bank in July of the previous year.

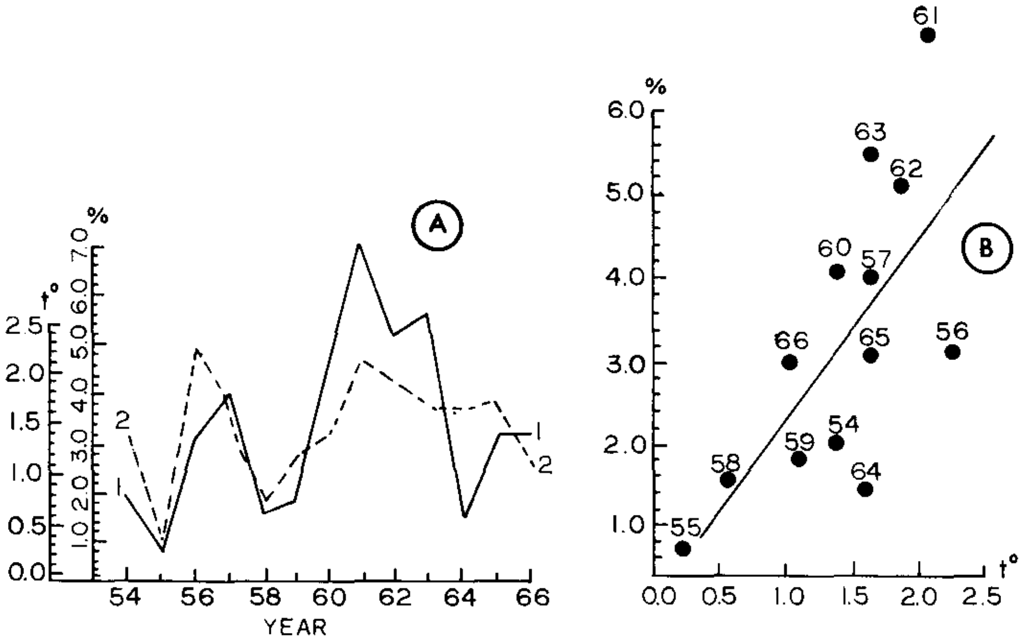

Fig. 4. (A) The cod distribution indices for Div. 1D and 1C combined in August-October (1) and mean temperature of the 0- to 200-m layer in July on Fyllas Bank (2).

(B) The relationship between the cod distribution indices for Div. 1D and 1C combined in August-October and water temperature in the 0- to 200-m layer in July on Fyllas Bank.

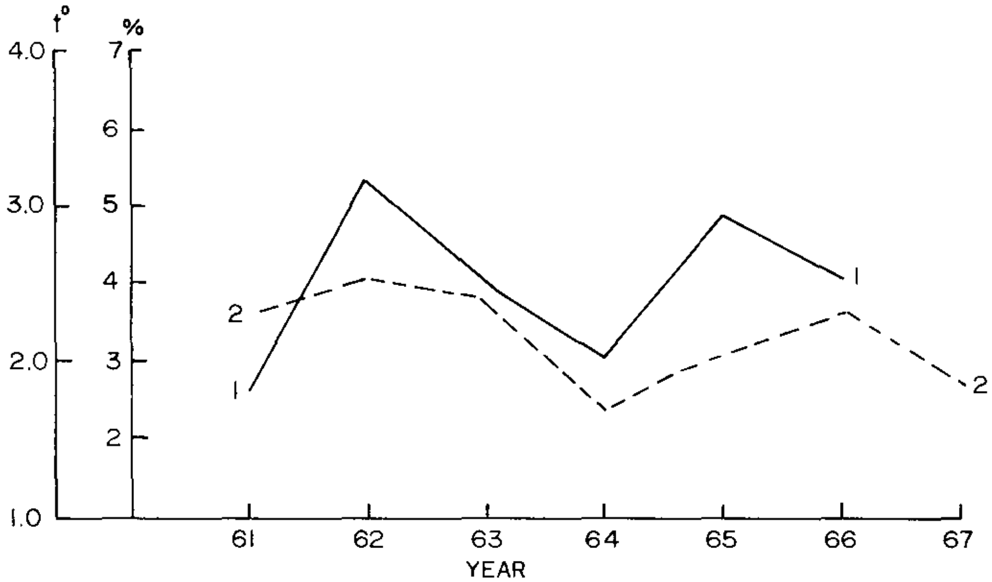

Fig. 5. The relationship between the cod distribution indices for Div. 1B in October-December (1) and water temperature in the 0- to 100-m layer on Lille Hellefiske Bank in September (2) (from data collected by Soviet research vessels).

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Coastal Currents of the Western Gulf of Maine

By Joseph J. Graham[1]

Abstract

Coastal currents during 1962-65 are described for an area extending from the headlands to 28 km offshore and from Cape Ann, Massachusetts (42°39'N, 70°35'W), to Machias Bay, Maine (44°40'N, 67°20'W). Recoveries of drift bottles confirm the major features of the surface circulation described previously by other authors. Recoveries of sea-bed drifters suggested movements of water shoreward, as well as into bays and estuaries; and along the coast for varying distances. This study suggests that upwelling is the most prominent feature of the coastal circulation. Exceptions occurred at times when, (1) surface water moved inshore along a dynamic gradient within the eastern sector of the coast, (2) winds, dynamic topography at the surface, and bottom topography directed surface drift shoreward within the central and western portions of the coast, and (3) bottom water moved parallel with the coast.

Introduction

Concentrations of larval herring, *Clupea harengus harengus* L, are associated with circulation features which transport the larvae or favor their survival. The circulation of the coastal Gulf of Maine was examined to determine which of its features might concentrate herring inshore and thus merit special study. This paper presents a comprehensive description of the coastal circulation and integrates new findings with descriptions provided by earlier researchers in the Gulf.

Colton (1964) summarized 23 publications concerned exclusively with circulation features of the Gulf. Among these, the largest contribution to our knowledge of coastal waters was made in Bigelow's (1927) famous study of the physical oceanography of the Gulf of Maine. His interpretation of circulation features was corroborated by studies of plankton drift by Redfield and Beale (1940) and others. An atlas of drift bottle recoveries by Bumpus and Lauzier (1965) depicted the surface circulation of the Gulf with greater exactitude than did previous works; and included the following seasonal changes: in autumn, a counterclockwise eddy in the northeastern part of the Gulf retreats northward to an area between Cape Sable, Nova Scotia, and the coast. This area has several smaller irregular eddies in winter. A southerly flow develops along the western side of the Gulf. The spring discharge from rivers strongly activates the Gulf eddy and this large cyclonic gyre occupies all of the Gulf during May. Water moves into the gyre from the Scotian Shelf and then north into the Bay of Fundy or west to the coast of Maine. Less saline water from the Bay of Fundy moves down the eastern side of the bay and joins the westward moving gyre. At times water moves down the western side of the bay through Grand Manan Channel directly to the coast of Maine. The flow continues down the coast past Cape Ann and into Cape Cod Bay (42°00'N, 70°30'W) or eastward and then north of Georges Bank. The eddy slows down in June and by autumn the southern side diverts into a drift across Georges Bank.

Materials and Methods

Coastal currents during 1962-65 are described for an area (Fig. 1) extending from the headlands to 28 km offshore and from Cape Ann, Massachusetts (42°39'N, 70°35'W), to Machias Bay, Maine (44°40'N, 67°20'W). Data on temperature, salinity, and surface and bottom drifts were collected from 21 stations during the 11 hydrographic cruises of 1962-65 (Table 1). In addition, the same observations were made at 10 of these stations during four plankton cruises (one each season) in 1964 and one in the winter of 1965 (Sherman 1966, 1967). At each station a bathythermograph was lowered to the bottom with Nansen bottles spaced along the wire at the surface, 10, 20, and 30m and at the bottom. Also, five surface drift bottles and five sea bed drifters were released at each station. The bottles were similar to those used by Bumpus and Lauzier (1965). The sea bed drifters were provided by the Woods Hole Oceanographic Institution, Woods Hole, Massachusetts (Bumpus 1965).

Salinity was determined by the Knudsen method and relative density (sigma *t*) was determined from salinity and temperature measurements to obtain the anomaly of dynamic heights relative to 30m at each station during the 11 hydrographic cruises (Lafond 1951, p. 88). This depth is usually below the seasonal pycnocline. Correction terms for salinity and temperature were omitted from the calculations of dynamic heights, because of the shallow depths involved. Four assumptions were made in the interpretation of dynamic

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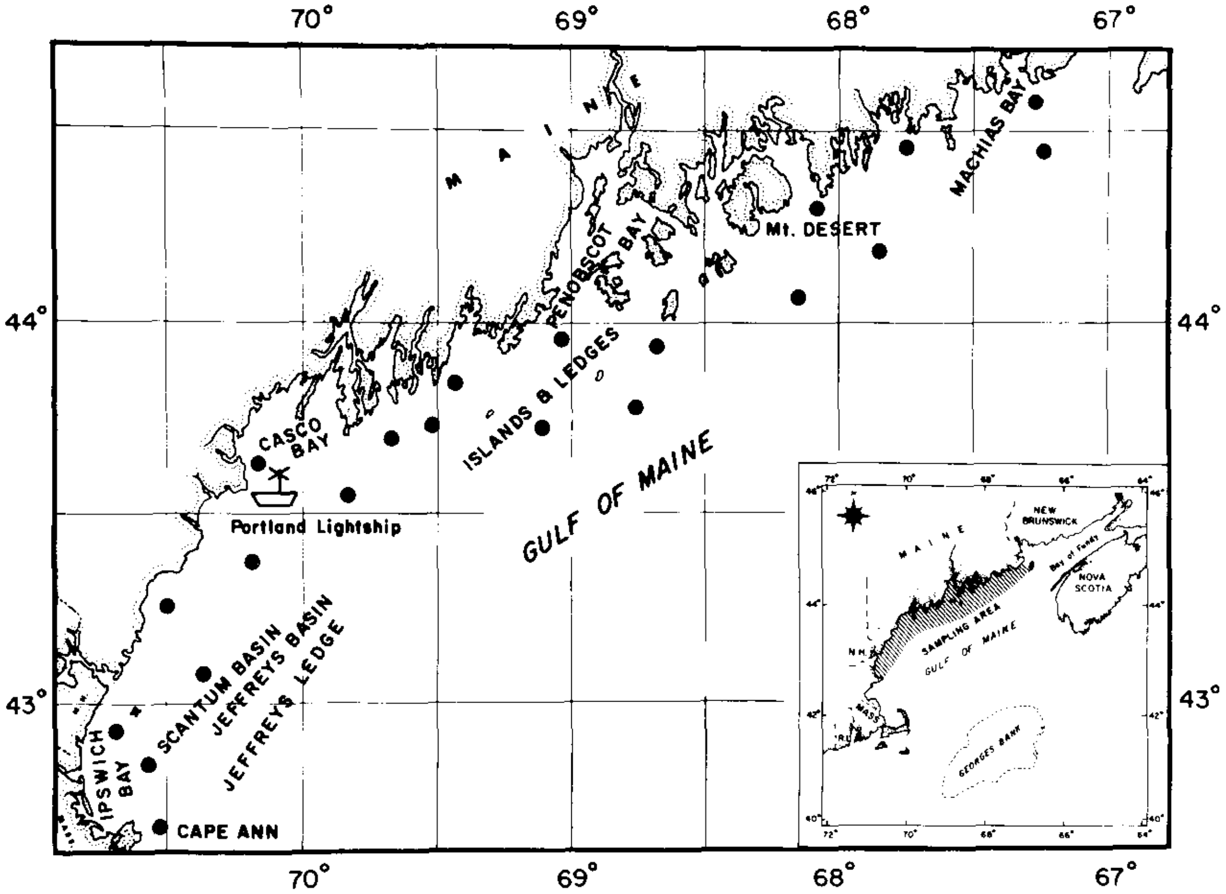

Fig. 1. Sampling stations and area of investigation.

TABLE 1. Coastal cruises during which data were collected on currents in the Gulf of Maine (Graham 1970).

Season and cruise	Dates
Autumn	
R-1-62	26 Sept. - 14 Oct., 1962
R-7-63	12 - 19 Oct., 1963
R-2-62	30 Oct. - 6 Nov., 1962
R-8-64	3 - 12 Nov., 1964
Spring	
R-3-64	5 - 20 May, 1964
R-4-65	21 - 26 May, 1965
R-4-63	25 May - 2 June, 1963
Winter	
R-1-63	8 - 16 Jan., 1963
R-2-65	24 Feb. - 4 March, 1965
Summer	
R-5-63	11 - 22 July, 1963
R-5-64	5 - 10 Aug., 1964

topographies: (1) the currents were relative to a reference depth thought to have little or no motion; (2) accelerations were ignored; (3) frictional forces were neglected; and (4) the collections of temperature and salinity data were considered synoptic. Data on the releases and recoveries of drift bottles and sea bed drifters were processed by the Woods Hole Oceanographic Institution.

Contours of dynamic heights are relatively inaccurate for shallow water but Bigelow (1927) and Redfield and Beale (1940) calculated dynamic heights for the entire Gulf of Maine, and Watson (1936) calculated them for the northern part of the Gulf and the Bay of Fundy. Bigelow and Watson used the contours with drift bottle trajectories to describe successfully features of the circulation in the sense that both of them coincided. A similar approach is used in this paper.

Surface Drift

During 1963 and 1964, 1,389 drift bottles were released along the coast. The average rate of residual drift, based on the minimal distance between locations of release and recovery, was 3.0 km per day. The drift of some bottles was negligible, whereas others exceeded 10 km per day.

The largest number of releases was in the autumn, but recoveries were few (Table 2). Only a few bottles stranded inshore after traveling short distances and none made a circuit of the Gulf (Fig. 2). Recoveries from an early January cruise (1963) were lowest, because an offshore component in winter drift of bottles made their recovery unlikely if they did not strand by early winter (Bumpus and Lauzier, 1965). Bottles released during a late January to early February cruise (1964) apparently entered the subsequent spring circulation. This probability was indicated by the large number of recoveries, the increase in the number of days the bottles were out, and the circuitous route of two of the bottles. Many bottles released in the spring circled the Gulf, and remained in circulation for a long period. Others stranded inshore, after moving only a short distance. These two features of drift were also present in the summer data. After some releases, the bottles drifted southward past Cape Ann and then inshore; this drift was most pronounced for bottles released in summer.

These results suggested that the major features of the coastal circulation were similar to those of previous years (e.g., Bigelow 1927; Bumpus 1960; Day 1958; and Fish and Johnson 1937).

TABLE 2. Percentage recovery, time out, and rate of movement of surface drift bottles and sea bed drifters released during different seasons.

Season and year	Number released	Percent recovered	Av. time out *(days)*	Av. rate of travel *(km/day)*
		Drift bottles		
Autumn				
1963	220	7	24	3
1964	215	5	9	3
Winter				
1963	159	1	12	18
1964	105	12	68	5
Spring				
1963	130	13	109	1
1964	205	7	80	2
Summer				
1963	135	6	91	3
1964	220	11	42	4
		Sea bed drifters		
Autumn				
1962	205	21	288	0.5
1963	222	43	199	0.2
1964	215	17	167	0.1
Winter				
1963	115	20	174	0.2
1964	120	18	167	0.2
Spring				
1963	130	23	271	0.2
1964	100	22	164	0.2
Summer				
1963	130	42	241	0.1
1964	100	45	178	0.3

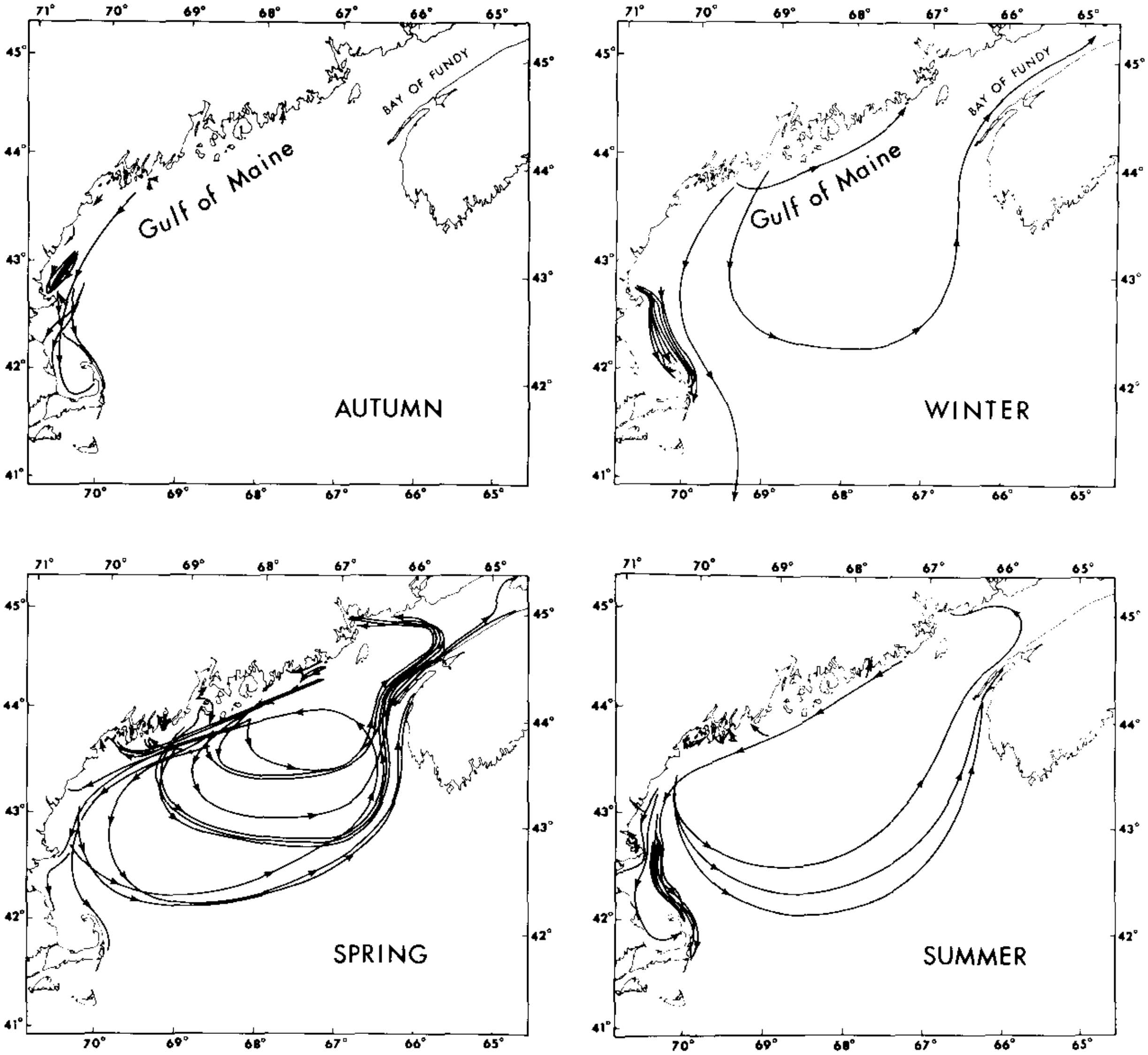

Fig. 2. Localities of release, assumed routes of drift (drawn from the charts of Bumpus and Lauzier, 1965), and localities of recovery of surface drift bottles released during different seasons, 1963-64. Occasionally, more than one bottle traveled the same route; they are represented by a single track.

Bottom Drift

The releases of sea bed drifters during different seasons in 1962-64 ranged from 100 to 222; the percentage recovered was relatively high from all releases (Table 2). Grouped by season of release, tracks were drawn to indicate the movement of drifters along paths that avoided ledges of rock rising from the bottom (Fig. 3), as suggested by a detailed topographic chart of the coast (Uchuppi 1965). The salient movements of the drifters along the bottom were: (1) shoreward as well as into bays and estuaries, and (2) along the coast for varying distances. The movement of water along the bottom partly resembled that at the surface. Movements along the coast were usually from east to west, and, in the west, drifters moved offshore and southward past Cape Ann. The movement of bottom water onto shore and into bays and estuaries was in compensation for the removal of less saline water along the surface.

The movement of three drifters into the Bay of Fundy from the vicinity of Machias Bay was probably unusual. Lauzier (1967) found that the average movement of drifters in this area was from the Bay of Fundy into the Gulf of Maine, and that some drifters turned towards the coast of Maine. Bottom water usually moved into the Bay of Fundy on the Scotian side of the deep trough penetrating the Bay from the Gulf.

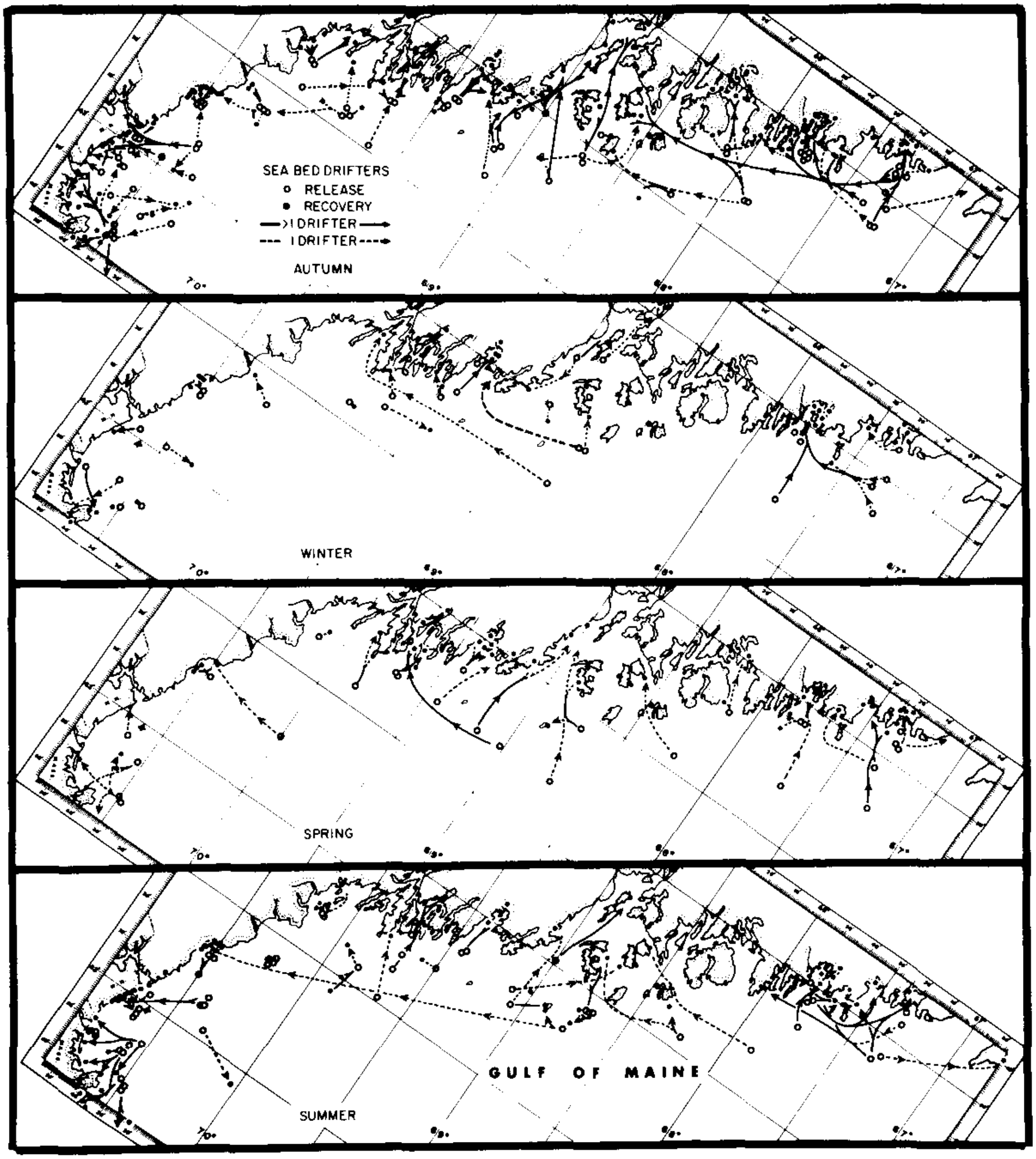

Fig. 3. Localities of release (open circles), assumed routes of drift, and localities of recovery (solid circles) of sea bed drifters released during different seasons, 1962-65. A dotted line indicates movement of one drifter; a solid line, more than one.

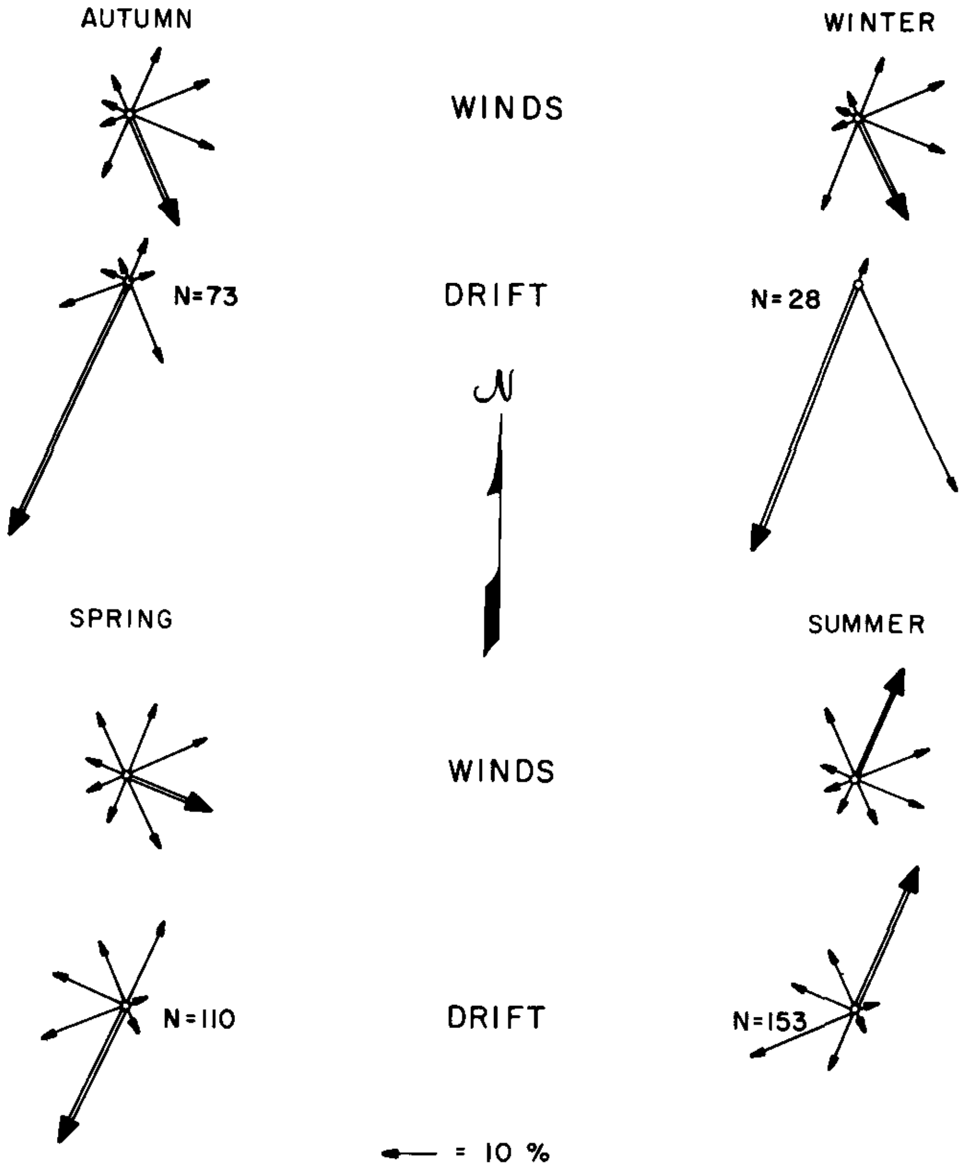

Fig. 4. Frequencies of the prevailing directions of winds and the straight line drift of bottles released from the Portland Lightship. A double-line arrow indicates the largest percentage for each rosette of frequencies.

The residual drift averaged 0.09 to 0.54 km per day. This rate of drift was slightly less than that obtained on the continental shelf of the Canadian Atlantic coast (0.4-1.3) by Lauzier (1967) and on the continental shelf of the American Middle Atlantic Bight (0.2-0.9) by Bumpus (1965). The average ratio of bottom drift to surface drift (0.03-0.19) was less than, but overlapped, the ratio (0.10-0.33) obtained by Lauzier (1967) for the Canadian coast.

Factors Affecting Non-Tidal Drift

The major forces causing non-tidal drift of the coastal water are winds and dynamic pressure gradients influenced by variations in temperature and river discharge. The direction of water movement is affected by Coriolis force and contours of the bottom and shore.

Winds

To determine the relation of wind and currents near shore, the seasonal releases and recoveries of drift bottles from the Portland Lightship (43°32′N, 70°06′W) south of Casco Bay were compared with prevailing winds. Frequencies of wind directions were obtained from the U.S. Weather Bureau at the Portland airport, approximately 25 km from the lightship. The average prevailing winds at the airport were westerly, varying from north to south, during the present study. Seasonal prevailing winds were also tabulated for coastal weather stations at Portsmouth, New Hampshire, and Brunswick, Maine, which are west and east, respectively, of the Portland airport. The average prevailing winds differed little among the stations and from those usually encountered offshore (U.S. Navy, 1955). Seasonal frequencies for the direction of prevailing winds at the Portland airport and for drift bottles released from the lightship were determined for 45° intervals of the compass. The value determined within each interval was then plotted at a distance from the point of release relative to its frequency of occurrence (Fig. 4). The few bottles that were assumed to have traveled a circuitous route around the Gulf – eight in the spring and three in summer – were omitted from the plot.

The seasonal directions of prevailing winds and straight-line drifts of the bottles were correlated when the expected deflection of drift to the right of the prevailing winds by Coriolis force was considered. In autumn, winds were mostly from north to west, and recoveries were to the southwest and along the coast. In winter, easterly winds were less and southwest winds were slightly greater than in the autumn, presumably leading to a greater loss of bottles to offshore waters than in other seasons. Although recoveries were few, they increased in the southeast direction, then offshore. In spring, winds were more variable and so were the directions of recovery. Northern and western wind components still drove some bottles southwest, but a relative increase in southerly and easterly winds increased recoveries to the northeast. In summer, comparatively greater frequency of winds from the southwest to southeast increased the recoveries to the northeast. Bigelow (1927) also found a similar movement of bottles shoreward in the summer, from a southerly line of stations passing through the present location of the lightship to 27 km offshore. Beyond this distance his bottles usually entered the offshore circulation of the Gulf – possibly the Gulf of Maine eddy.

Day (1958) demonstrated the effect of Coriolis force in deflecting the direction of the net drift of surface water to the right of wind direction in the offshore Gulf of Maine, and Bigelow (1927) showed this effect for autumn and summer currents at the Portland Lightship. When winds blew toward the southern half of the compass at the lightship, the monthly resultant surface drift was usually directed slightly to the right of the wind. Winds blowing against the presumably southern drift sometimes reversed the resultant surface drift either to the right or slightly to the left of the wind, depending on the interaction of wind direction and strength, original direction of the current, and configuration of the coast. This complex interaction is also suggested by the variability of wind and current directions in spring, when it is accentuated by increased river discharge.

Dynamic pressure gradients

Anomalies of dynamic height and streamlines for the coastal cruises suggest the direction, variability, and complexity of surface currents (Fig. 5). The northward retreat of the counterclockwise eddy, located in the northeastern part of the Gulf, was evident in the autumnal plots of dynamic contours. During the September-October cruise, streamlines followed the coastline from east to west to Penobscot Bay, where they curved offshore. In subsequent cruises, the streamlines curved offshore farther to the east and in October 1963 the periphery of the retreating counterclockwise eddy was apparent. In early autumn, the strong gradient within a body of lower salinity west of Penobscot Bay, implies a current paralleling the coast to Cape Ann where the streamlines curved offshore. Subsequent cruises showed a strong gradient south of Penobscot Bay and weaker gradients to the west. A small clockwise eddy was also present south of Casco Bay in October 1963. In winter, shoreward convergence was indicated in the eastern sector of the coast that was not evident during other seasons. Winter winds generally drive the surface water westward and offshore. When these winds are quiescent, presumably, the orientation of the dynamic gradient would suggest a movement of surface water inshore at a low velocity. Estuarine discharge strongly activates the large Gulf of Maine eddy during the spring, but the spacing of the rivers along the western sector of the coast complicates the circulation near shore. In May 1964, the streamlines followed the coast closely from east to west with a single interruption, in Ipswich Bay. In May 1965, streamlines were directed offshore just west of Penobscot Bay. A number of eddies were depicted from Casco Bay to Cape Ann. The arrangement of dynamic contours also suggested eddies during July 1963 in the western sector of the coast. During August 1964 eddies were lacking, and the streamlines were directed obliquely offshore over a large sector of the coast – producing conditions similar to those observed in the September to October cruise of 1962.

The major surface currents depicted by the streamlines agreed with the general circulation known for the Gulf of Maine. Certain irregularities in the streamlines are also indicated by the drift bottle atlas of Bumpus and Lauzier (1965): the winter convergence shoreward, the summer clockwise eddy east of Casco Bay, and the clockwise or anticlockwise eddy south of Casco Bay. It is assumed that the shoreward recovery of drift bottles in these areas is indicative of the eddies, which would retain the bottles near the coast and further their shoreward recovery.

The spring eddy and the summer shoreward movement indicated by the streamlines in the vicinity of Ipswich Bay had no counterpart in the atlas. Bigelow (1927) did report, however, an indraft of offshore water in the vicinity of the Isles of Shoals in Ipswich Bay during May; perhaps an indication of the development of

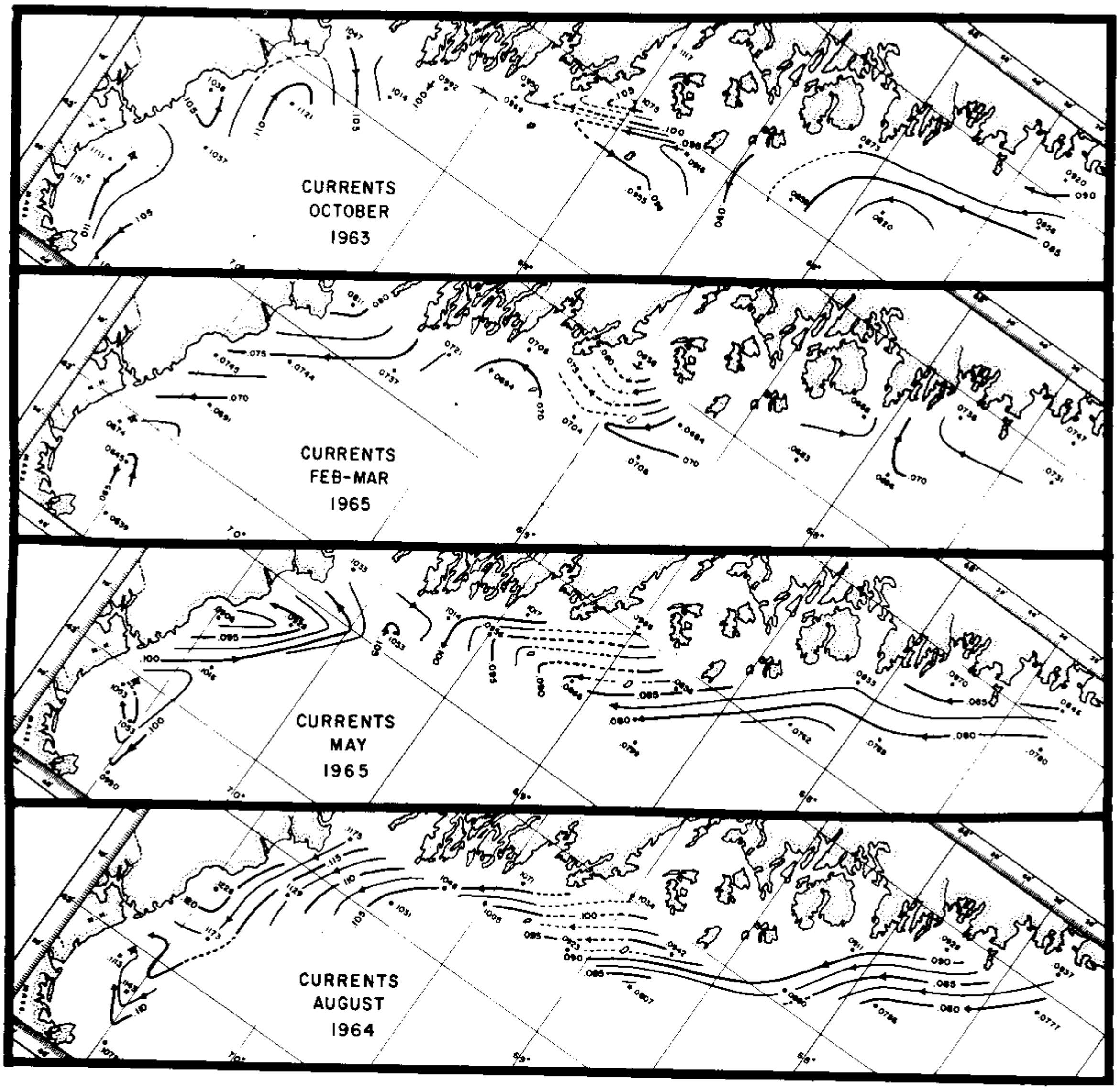

Fig. 5. Dynamic topography at the surface relative to 30m.

an eddy. The irregular appearance of the streamlines pointing shoreward off Ipswich Bay can be attributed to the bottom topography of this area. The coastal circulation is apparently more complex than the single clockwise eddy located by Bigelow (1927) south of Casco Bay in the summer.

Topography

Bottom

Variations in topography and configuration of the shoreline affected the coastal circulation. For example, the irregular appearance of streamlines off Ipswich Bay in August (Fig. 5) can be explained by the effect of shoaling on currents (Sverdrup, Johnson, and Fleming 1942, p. 466). This effect was possible in Ipswich Bay because other factors were apparently inactive; wind velocities were low and estuarine discharge was reduced by drought. Water flowed through Jefferys Basin and ascended from 146m to 54m as it passed over a submarine ridge, Old Scantum and New Scantum (Fig. 6). The velocity of flow increased with this reduction in volume and Coriolis force deflected the current to the right of the direction of flow. Once over the ridge, water descended into Scantum Basin (120m deep), and the flow reversed to the left (upper arrow in Fig. 6). As water ascended from Scantum Basin to the shelf, the streamlines followed the contours of the shelf.

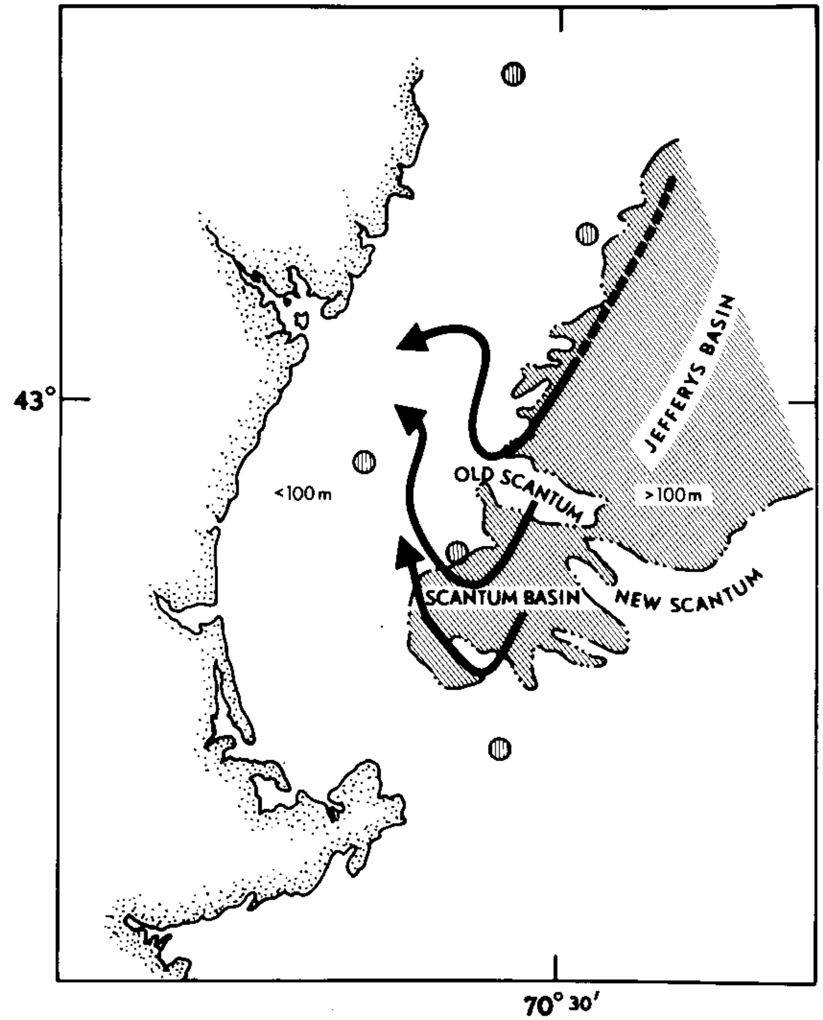

Fig. 6. Detail of figure 5 (August 1964), the effect of bottom irregularities on the dynamic topography.

Shoreline Configuration

Currents in the coastal embayments are complicated by the irregulaar shape of the shoreline, by islands and ledges, and by estuaries within or adjacent to the embayments. The less saline water as it left Penobscot Bay was deflected westerly by Coriolis force through a complex of channels, ridges, and islands as surface salinity increased seaward from 28.5 ‰ to 31.2 ‰ (Fig. 7). More saline water occurred at the opening to the eastern side of the bay to compensate for the mixing of salt water with river discharge and its loss from the bay. The Kennebec and Sheepscot Rivers discharged estuarine water from long narrow drowned river valleys onto a shelf that was less complex and rough than that off the Penobscot. Thus, the surface salinity was nearly constant from the mouth of the estuary to the vicinity of the 90-m isobath, although the flow was also deflected westerly.

Movement of Coastal Water

The immediate sources of water for the coastal shelf (30-100m depth) are estuarine discharge, the western basin of the Gulf of Maine, and the Bay of Fundy. After a sojourn over the coastal shelf, water moves offshore, generally in the vicinities of Penobscot Bay and Cape Ann. The sources, movement, and destinations of coastal water are summarized in Table 3 and the inferred routes of travel of a particle of water are shown in Fig. 8. They suggest that surface water generally moves along the coast and bottom water moves shoreward.

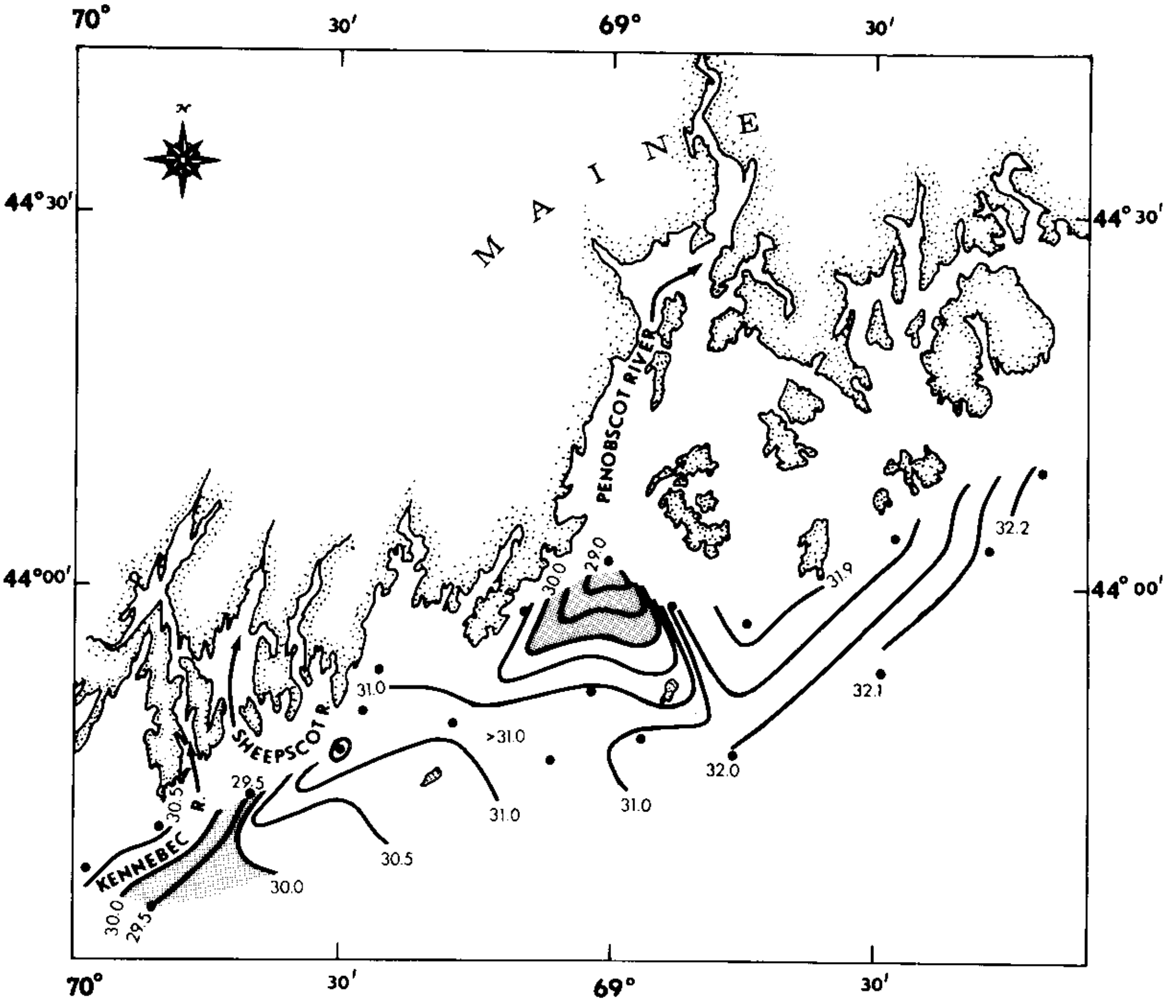

Fig. 7. Effects of estuarine discharge from the Penobscot, Kennebec and Sheepscot Rivers during May 1965. Stipled areas have salinities less than 30 ‰

Thus, upwelling was the most prominent feature of the circulation along the coast of the Gulf of Maine. As described by Lauzier (1967) for the Canadian Atlantic shelf, water was carried parallel to or offshore from the coast at the surface with a compensatory movement inshore along the bottom. Exceptions to upwelling occurred when, (1) surface water moved inshore along a dynamic gradient within the eastern sector of the coast; (2) winds, dynamic topography at the surface, and bottom topography directed surface drift shoreward within the central and western portions of the coast; and (3) bottom water at times moved parallel with the coast.

Shoreward movements of water are important to the transport and accumulation of small herring inshore and to the accumulation and retention of forage (plankton) that partly determines their survival. Indrafts of offshore water associated with estuarine discharge in the central and western sectors of the coast, with bottom topography in the vicinity of Ipswich Bay and with dynamic gradients in the eastern sector merit further investigation.

Summary

Drift bottles, sea bed drifters, and dynamic topography (surface) were used to describe the circulation of the western coast of the Gulf of Maine during 1962-65.

Recoveries of drift bottles released in autumn and winter were fewer in number and were made after fewer days at sea than those released in spring and summer. Bottles moved in a circuitous route around the Gulf in the spring and summer, and many drifted southward past Cape Ann. The average residual drift for all bottles was 3 km per day. The results suggested that the major

TABLE 3. Movements of coastal water. Figures cited are from this paper.

Initial location			Destination	
Area	Depth	Movement	Area	Depth
1. Bay of Fundy	Surface	West of Grand Manan Island to Maine coast, or to east side of the Island and then west to the coast of Maine. Primarily in spring, autumn, and winter (Chevier and Trites 1960)	Eastern sector of coast	Surface
2. Western Basin off the eastern sector of the coast	Surface	Inshore during winter (Fig. 7)	Inshore	Surface
3. Eastern sector of the coast	Surface	Westward along the coast, then offshore near Penobscot Bay, and parallel to the western sector of the coast, finally inshore as a compensatory current or a current diverted by bottom topography. During autumn, spring, and summer (Figs. 6, 8, and 9; also Bigelow 1927)	Inshore	Surface
4. Western Basin off eastern and central coastal sectors	100m and deeper, bottom	Inshore along the bottom. All seasons (Fig. 4; also Lauzier 1967)	Shore	Surface
5. Jefferys and Scantum Basins	100m and deeper, bottom	Inshore along the bottom. All seasons (Fig. 4)	Shore	Surface
6. Coastal	30-100m, bottom	From east to west along the bottom and then inshore. All seasons. Occasionally eastward into the Bay of Fundy (Fig. 4)	Shore	Surface
7. Penobscot Bay	Surface	Sinking during winter in a southerly direction to 150 m and deeper (Bigelow 1927). Possible return along the bottom (Fig. 4)	Offshore Shore	100m Surface

features of the circulation of the Gulf of Maine were similar to those of previous years.

Recoveries of sea bed drifters released during each of the four seasons were relatively high. Drifters moved shoreward into bays and estuaries and along the coast for varying distances. The residual drift averaged 0.09 to 0.54 km per day, or slightly less than that found by other workers on the Canadian Atlantic coast and the American Middle Atlantic Bight. The ratio of bottom drift to surface drift averaged 0.03-0.19, also slightly less than that on the Canadian Atlantic coast.

Although the net drift was usually from east to west along the coast, winds and dynamic pressure gradients were influenced by Coriolis force and bottom topography to propel water shoreward. Water moved inshore during winter within the eastern sector of the coast and inshore in the central and western sectors of the coast during the spring, summer, and autumn.

Information from this study and that of previous studies was combined to summarize the sources, movement and destinations of coastal water.

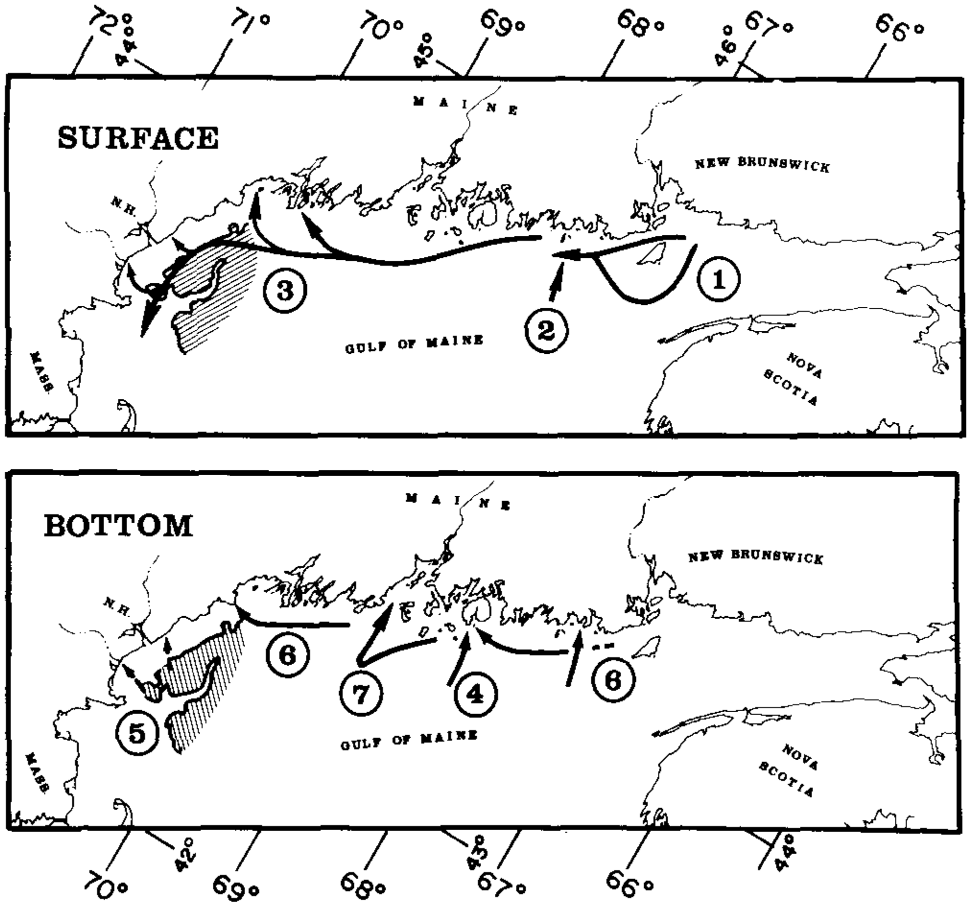

Fig. 8. Inferred routes of travel of a particle of water from immediate sources of water to the coastal shelf (30 to 100m depth). Numbers 1-7 refer to Table 3. Shaded depths exceed 100m.

The most prominent feature of the circulation along the coast was upwelling; water was carried parallel to or offshore from the coast at the surface with a compensatory movement inshore along the bottom.

Acknowledgments

I thank Dr L. M. Lauzier and Dr R. W. Trites for helpful reviews of the manuscript, and Mr Dean F. Bumpus for supplying data on drift bottles released at the Portland Lightship.

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Assessments of the Effects of Increases in the Mesh Sizes of Trawls on the Cod Fisheries in the Southern Grand Bank Area (ICNAF Divisions 3N and 3O)

By A. T. Pinhorn[1]

Abstract

Total cod landings were lower in the 1956-64 period than in 1954-55 but then increased steadily to 1966, with a greater than two-fold increase in 1967 attributed to an intensive fishery on the 1964 year-class. Otter trawl and pair trawl were the most prominent gears and Spain, Portugal, and USSR the most prominent countries. Landings per hour fished were at a high level in 1954-57 but decreased about 50% in 1958-62 followed by an increase to the former level in 1963-67. These changes were attributed to a lack of recruitment of successive year-classes to the fishery in 1958-62. Total effort was slightly lower in 1956-58 than in 1954-55 but returned to the former level in 1959-61. It then decreased 100% in 1962-64 but increased steadily to a high level in 1967. Estimates of total effort based on country were lower than those based on tonnage class.

The greatest long-term gain for otter trawlers was predicted at 5½-inch mesh for the lowest value of E and at 6-inch mesh for the other values of E in the 1959-62 period, and for all values of E in the 1963-66 period. The greatest gain to the offshore line landings and total landings was predicted at 6-inch mesh for all values of E in both periods. Immediate losses would have been 10% or less in 1959-62 and 13% or less in 1963-66 for increases from 4- to 5½-inch mesh. The predicted immediate losses were greater at the larger mesh sizes during 1963-66 than 1959-62 due to the larger numbers of smaller fish caught and landed in 1963-66. The same was true in comparing 1959-62 with 1955-58, the greater immediate losses being predicted in 1959-62. The predicted long-term gains at the two higher values of E were greater in 1959-62 than in 1955-58 and in 1963-66 than in 1959-62 because of an increase from 1955-58 to 1963-66 in the proportion of small fish that would have been released by a larger mesh.

The necessity of more adequate sampling of cod catches in 3NO is emphasized.

Introduction

Previous assessments on 3NO cod were reported by Beverton and Hodder (1962) for the 1955-58 period. In view of more recent data on mortality and growth of 3NO cod, it was suggested at the 1968 ICNAF Annual Meeting that "the Research and Statistics Committee should be asked to provide new assessments as soon as practicable" for this area. New assessments have been made for 3NO cod based on 1959-62 and 1963-66 combined data and the results are presented in this paper.

Trends in Landings, Effort and Landings per Effort During 1954-67

Total landings[2]

Total cod landings from 3NO decreased from about 120,000 metric tons in 1954-55 to an average level of 60,000 tons in 1956-64. Landings then increased to 106,000 tons in 1966, followed by a greater than two-fold increase in 1967 to 220,000 tons (Table 1 and Fig. 1A).

Otter trawl and pair trawl accounted for most of the landings with offshore line contributing very little, especially in recent years. Otter trawler landings were high in the early 1950's but decreased to about the level of pair trawler landings until 1964. They then increased steadily in the 1965-67 period, with a two and one-half fold increase in 1967 over 1966. Pair trawler landings remained reasonably stable at about 20,000 - 30,000 tons during 1954-62, after which they increased to about 60,000 tons in 1965-67. Offshore line landings have decreased since 1959 to a very low level in 1967 (Table 1 and Fig. 1A).

Portugal and Spain were the largest contributors to the total landings until 1960, when USSR entered the fishery. Portuguese landings declined during the entire period while Spanish landings increased after 1962. USSR landings increased after 1964 with a three-fold increase in 1967. Thus, the increase in total landings after 1962 was due to increased landings by Spain and USSR, and the sudden increase in 1967 was mainly due to increased landings by USSR (Table 1 and Fig. 1B).

Total effort and landings per effort

Several methods have been used by various authors to estimate total effort and landings per unit of effort for particular species or combinations of species (Hodder, 1965; Wiles, 1967; May, 1968). Since no comparisons of these different methods have been reported, it was decided to estimate total effort and

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[2] Landings as used in this paper refer to the live equivalent weight of the landings, now commonly called nominal catch.

TABLE 1. Cod landings (metric tons) by country and gear, from ICNAF Div. 3NO, 1954-67 (37,498 metric tons taken in Subarea 3 were not reported by ICNAF division and are not included below). PT = pair trawl; DV = dory vessel; LL = long line; Can (M) = Canada (Maritimes and Quebec); Can (N) = Canada (Newfoundland); Fr (M) = France (Metropolitan); Fr (SP) = France (St. Pierre and Miquelon).

	Otter trawl														PT	DV	LL	
Year	Can(M)	Can(N)	Fr(M)	Por	Spa	USSR	UK	USA	Fr(SP)	Ita	Ger	Pol	Ice	Total	Spain	Por	Can(M)	Total All gears
1954	8,456	5,530	3,033	15,910	59,933	–	–	–	–	–	–	–	–	92,862	28,741	9,860	3,401	134,864
1955	2,098	1,511	13,658	14,782	36,860	–	595	3	–	–	–	–	–	69,507	28,127	12,929	2,444	113,007
1956	3,220	1,808	417	176	11,678	–	971	2	–	–	–	–	–	18,272	30,946	15,329	335	64,882
1957	4,912	4,152	1,985	910	15,167	–	219	–	–	–	–	–	–	27,345	36,823	20,830	577	85,575
1958	2,009	2,381	53	37	2,984	–	–	–	–	–	65	–	–	7,529	26,452	11,571	422	45,974
1959	1,345	2,091	191	587	3,883	48	809	6	–	–	–	–	–	8,960	36,111	17,143	156	62,370
1960	1,008	2,167	328	286	3,227	24,204	1,053	–	409	1	–	–	–	32,683	30,745	14,061	233	77,722
1961	2,179	3,123	128	131	476	22,854	724	2	923	–	52	–	–	30,592	31,808	8,928	126	71,454
1962	983	2,073	–	31	2,370	7,971	1,699	2	420	–	–	12	–	15,561	15,043	3,622	179	34,405
1963	1,416	3,566	994	832	11,611	10,184	2,869	–	873	–	–	42	–	32,387	26,021	9,172	97	67,677
1964	826	2,007	2,491	192	5,308	9,504	1,526	–	297	–	–	–	–	22,151	31,876	7,903	51	61,981
1965	298	3,896	2,715	216	2,142	17,166	2,529	–	363	–	2,177	77	34	31,613	62,510	1,476	36	95,635
1966	1,018	5,464	750	2,613	2,941	39,023	1,172	–	121	–	–	765	11	53,878	49,592	2,457	19	105,946
1967	470	2,987	1,906	7,971	9,471	118,905	4,721	–	101	–	–	3,545	–	150,077	68,477	1,732	22	220,308
Total	30,238	42,756	28,649	44,674	168,051	249,859	18,887	15	3,507	1	2,294	4,441	45	593,417	503,272	137,013	8,098	1,241,800

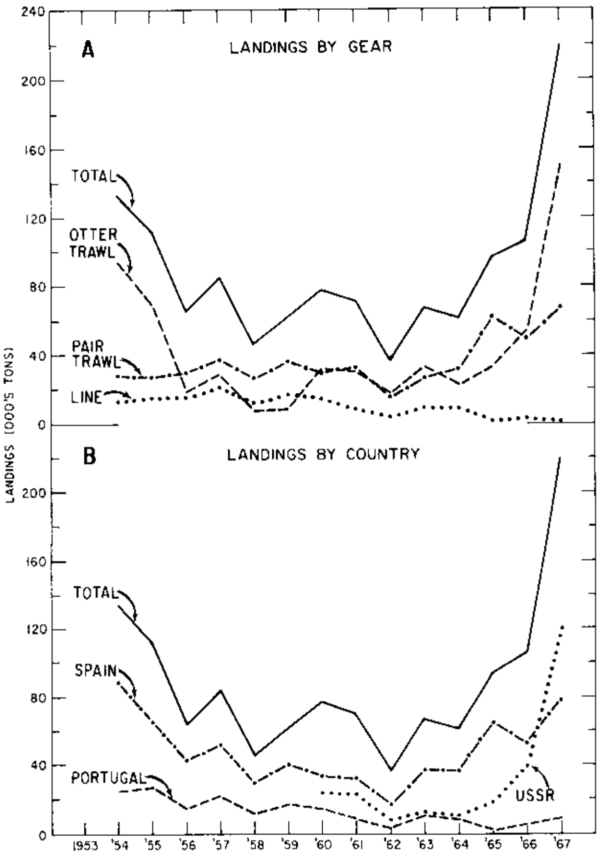

Fig. 1. Landings by gear and country, 3NO, 1954-67. The 1953 landings are omitted because of incomplete reporting by divisions.

landings per effort for 3NO cod by several different procedures.

Four methods were used in the present study and these are outlined below.

Method 1 (Effort adjusted by country)

1. Entries for cod landings and hours fished where cod was the main species landed and presumably caught (i.e. cod was greater than 50% of the total fish landed) were selected from the ICNAF Statistical Bulletins for the years 1959-67 and tabulated by gear, country, and month for each year. Landings per hour fished were then calculated for each month. In cases where countries reported days fished but not hours fished, the hours were estimated on the basis of the hours per day fished for the countries reporting both.

2. Landings per hour fished for Spanish otter trawlers were then plotted against landings per hour for Spanish pair trawlers for each month in which both fished at least 100 hr. A straight line drawn by eye through the origin gave a conversion factor of 1.2 (Fig. 2A).

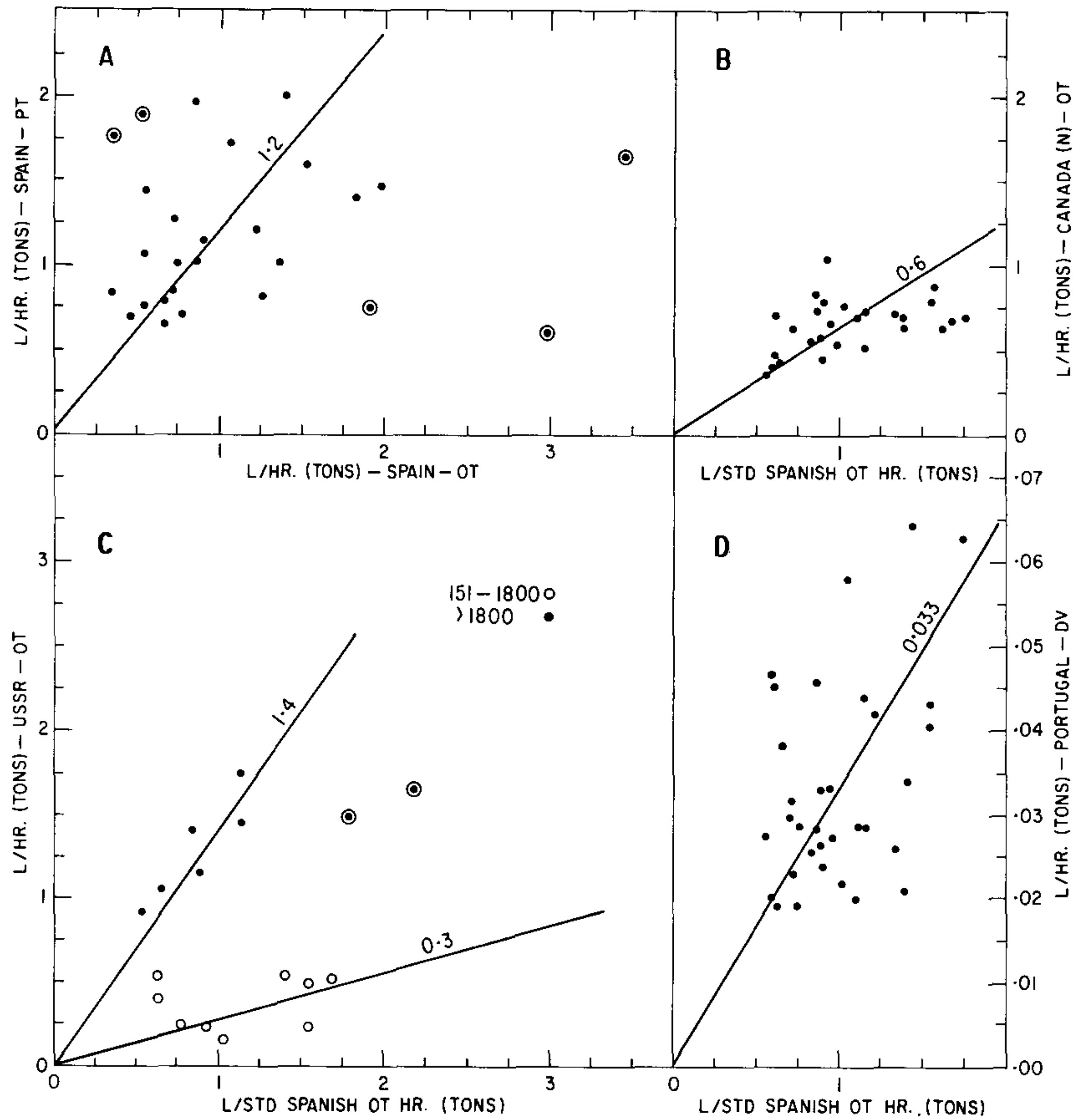

Fig. 2. Plots of main species cod landings per unit effort for the major countries and gears fishing in 3NO, 1959-66, with corresponding straight lines fitted by eye. Circled points were not used in drawing straight lines.

3. Spanish pair trawler hours for each month were then adjusted by a factor of 1.2 and added to Spanish otter trawler hours for the corresponding month. The resulting figures were divided into the combined landings of Spanish otter trawlers and pair trawlers for main species cod to produce landings per standard Spanish otter trawler hour for each month.

4. These values were then plotted against landings per hour for (a) USSR otter trawlers, tonnage classes 151-1800, (b) USSR otter trawlers, tonnage class >1800, (c) Canada (Nfld.) otter trawlers, (d) Portugal dory vessels, producing conversion factors of 0.3, 1.4, 0.6 and 0.033, respectively (Fig. 2, B-D).

5. The effort for these countries (hours fished) for each year was then adjusted by the appropriate factor to standard Spanish otter trawler hours and added to the standard Spanish otter trawler hours derived in (3) above.

6. The total landing of these countries when cod was main species was then divided by the total hours in standard Spanish otter trawler units for each year to produce landings per standard Spanish otter trawler hour. These values were then divided into the total cod landings of all countries and gears regardless of main species to obtain total effort figures for all countries and gears combined in standard Spanish otter trawler units.

This method provides estimates of the total effort expended for cod if all countries landing cod had been fishing primarily for cod. A similar method was used by Hodder (1965) for Subarea 2 and 3K-3L cod, by Wiles (1967) for 4R and 4S cod and by Pinhorn (1969) for 3Pn cod.

Method 2 (Effort adjusted by tonnage class)

Tonnage classes referred to are as follows:

Tonnage Class	1 –	0-50
" "	2 –	51-150
" "	3 –	151-500
" "	4 –	501-900
" "	5 –	901-1800
" "	6 –	>1800

1. Entries for cod landings and hours fished where cod was the main species (using the 50% criterion) were selected and tabulated by gear, tonnage class, and month for each year. Landings per hour fished were then calculated for each month.

2. Plots of landings per hour fished for otter trawlers yielded no clear relationships between different tonnage classes and thus no conversion factors. Consequently, landings and hours for total groundfish were selected and tabulated by gear, tonnage class and month for each year, and landings per hour fished for each month calculated.

3. Total groundfish landings per hour fished for otter trawlers, tonnage class 3, were plotted against otter trawlers, tonnage classes 5 and 6, for each month in which each fished at least 100 hr. Straight lines drawn by eye to these points yielded conversion factors of 2.4 for tonnage class 6 and 1.2 for tonnage class 5 (Fig. 3).

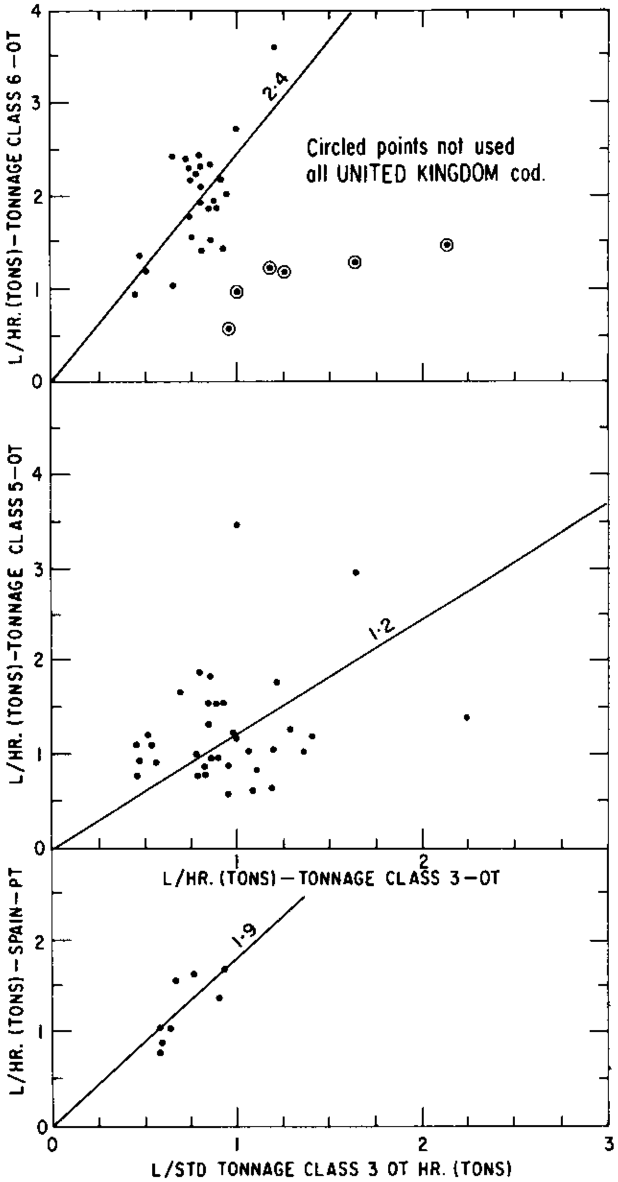

Fig. 3. Plots of total groundfish landings per hour fished for the major otter trawler tonnage classes and for pair trawlers fishing in 3NO, 1959-66, with corresponding straight lines fitted by eye. Circled points were not used in drawing straight lines.

4. Hours fished in each month when *cod was the main species caught* for tonnage classes 5 and 6 were then adjusted to standard tonnage class 3 hours by the appropriate conversion factors and the resulting figures added to unadjusted hours for tonnage class 3. These were then divided into the total landings by trawlers in the three tonnage classes when cod was the main species to provide landings per standard tonnage class 3 hour.
5. These values were then plotted by year against Spanish pair trawler landings per hour, since monthly plots yielded no clear relationships. The slope of the line by eye through the origin (1.9) was then used to adjust the hours fished in each year by Spanish pair trawlers to standard tonnage class 3 trawler hours (Fig. 3).
6. These adjusted Spanish pair trawler hours were then added to the standard tonnage class 3 trawler hours for each year and the result divided into the total landings by otter trawlers, tonnage classes 3, 5, and 6, and pair trawlers, when cod was main species. This produced landings per standard tonnage class 3 trawler hour for each year. Dividing these values into the total landings by all tonnage classes of otter trawlers and all gears resulted in estimates of total effort for the entire fleet in standard tonnage class 3 trawler hours.

This method provides estimates of the total effort expended for cod in terms of tonnage class 3 hours if all tonnage classes of otter trawlers and all gears landing cod had been fishing primarily for cod.

Method 3 (Effort expressed in terms of one tonnage class)

1. Cod landings and hours for otter trawlers and pair trawlers where cod was the main species were tabulated by tonnage class for each year, after pair trawler hours had been adjusted by 1.9 to tonnage class 3 otter trawler hours. Landings per hour were then calculated for each tonnage class.
2. Landings per hour for tonnage class 3 were divided into the total landings of cod by all tonnage classes of otter trawlers and all gears for each year, resulting in estimates of total effort in standard otter trawler tonnage class 3 hours.

This method provides estimates of total effort expended for cod if all tonnage classes of otter trawlers and all gears landing cod had been fishing primarily for cod with the same efficiency as tonnage class 3 otter trawlers. Thus, the effort measure derived is in the same terms as that derived by Method 2, though the estimating procedures are different. A procedure similar to Method 3 was used by May (1968) for total groundfish in Subareas 2 and 3, except that he used days fished rather than hours fished.

Method 4 (Effort expressed in terms of one country)

1. Landings per standard Spanish otter trawler hour derived from adjusting Spanish pair trawler hours to Spanish otter trawler hours in Method 1 were divided into the total cod landings by all countries and gears to obtain estimates of total effort in standard Spanish trawler units.

This method provides estimates of total effort expended for cod if all countries and gears landing cod had been fishing primarily for cod with the same efficiency as Spanish otter trawlers. A similar method was used by Hodder (1964). Again, this gives effort measures in the same terms as by Method 1, but by different means.

It is evident from Fig. 4 that all four methods produced similar trends in total effort and landing per effort, but the actual values were different between Methods 1 and 4 and Methods 2 and 3. Methods 1 and 4 produced almost identical results and this is not surprising since, as can be seen from Fig. 1, Spain accounted for most of the landings up to 1966. Methods 2 and 3 also produced almost identical results in terms of absolute fishing effort and landings per effort. Again, this is to be expected since both are based on tonnage class 3 otter trawlers (including pair trawlers), which accounted for most of the landings, at least up to 1966 (Fig. 5).

Landings per hour fished were at a high level in 1954-57 but decreased about 50% in 1958 and remained at this lower level during 1958-62. Landings per hour again increased to the 1954-57 level in 1963 and fluctuated about this higher level during the remainder of the period. Total effort was slightly lower in 1956-58 than in 1954-55 but returned to the former level again in 1959-61. It then decreased 100% to a lower level in 1962-64 but increased steadily to a high level in 1967. The effort in 1967 was 2-3 times greater than the effort in 1966.

Tonnage class 3 otter trawlers were used in Fig. 4 to estimate total effort by Method 4, since this class contributed most heavily to the total cod landings over the period. However, the trends in landings per hour were somewhat different for the three major tonnage classes and different conclusions regarding trends in effort would be reached by using tonnage classes 5 and 6 instead of 3 (Fig. 5). On the other hand, calculations based on these larger tonnage classes might be of little meaning because of their relatively small contribution to the landings prior to 1966.

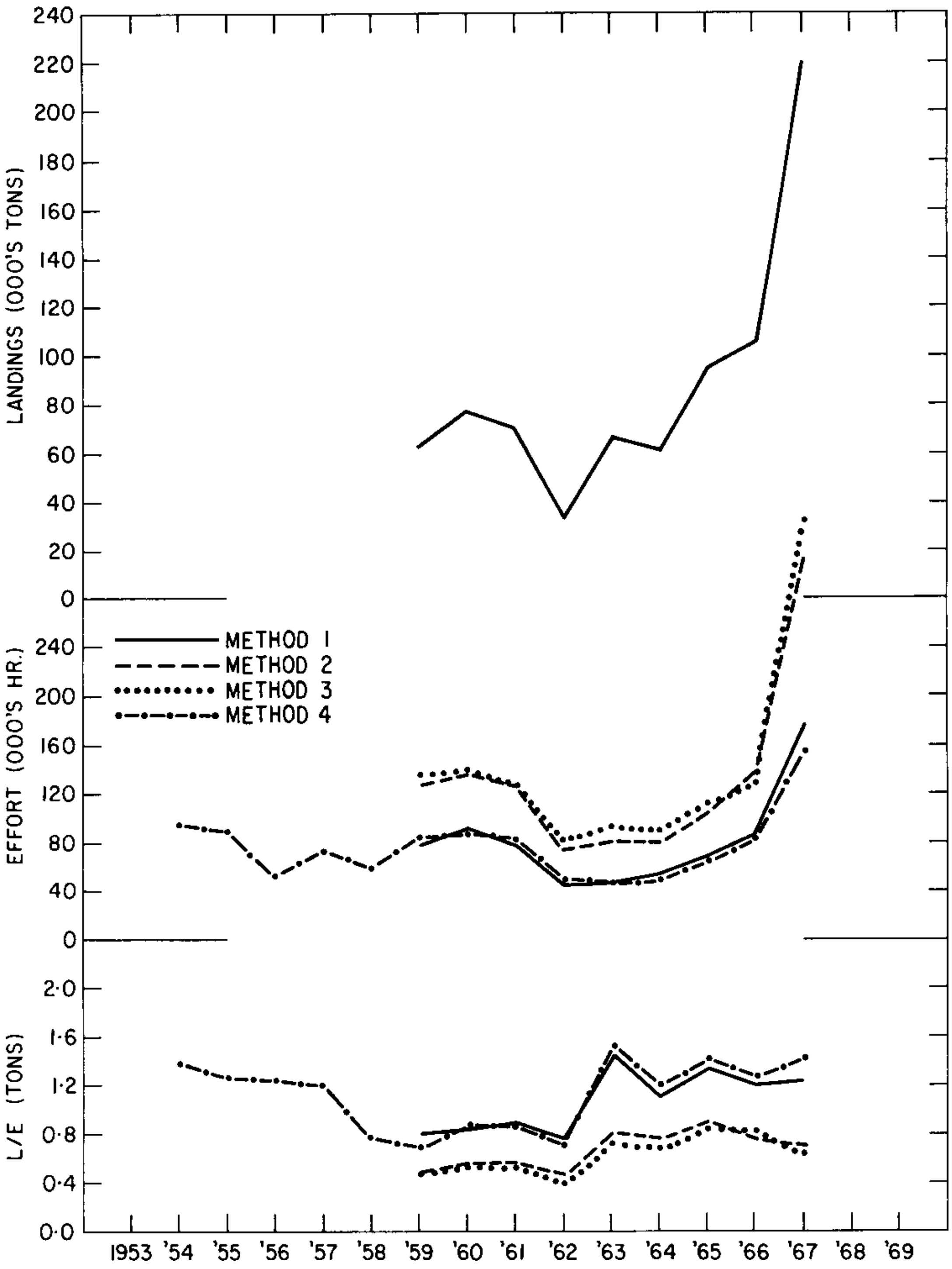

Fig. 4. Landings, effort and landings per unit effort for cod in 3NO, 1954-67. Four methods of estimating landing per unit effort and total effort are compared.

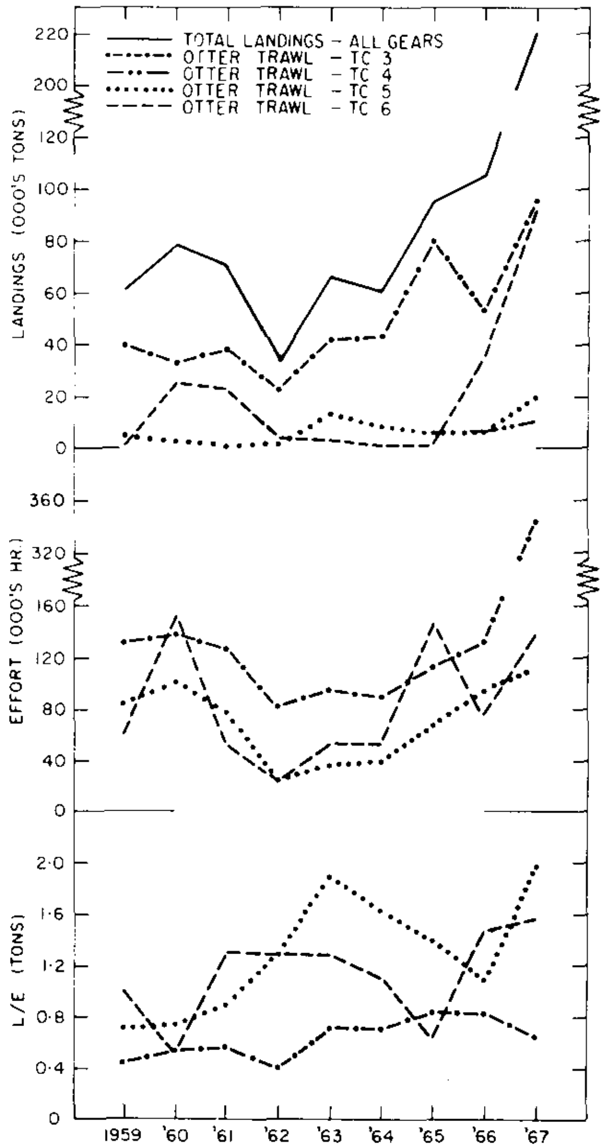

Fig. 5. Landings, effort and landings per unit effort for different tonnage classes of otter trawlers fishing for cod in 3NO, 1959-67.

Assessments of the Effects of Increases in Mesh Sizes of Otter Trawls

From 1959 to 1962, with the exception of USSR length measurements totalling about 30,000, there were only 1,100 length measurements of catches before discards from the commercial cod fishery by all other countries fishing in 3NO. In addition, Canada (Nfld.) obtained about 25,000 length measurements of cod caught on research vessel cruises. Consequently, it was decided to combine USSR commercial length frequencies and Canada (Nfld.) research vessel length frequencies in these assessments to obtain representative length frequencies of the commercial catches before discards in the 1959-62 period.

Similarly, since there were only 3,200 and 3,700 length measurements of catches before discards in 1963 and 1964, respectively, and no measurements in 1965 and 1966, it was decided to use Canada (Nfld.) research vessel length frequencies totalling 32,000 to derive representative length frequencies of the commercial catches before discards in the 1963-66 period.

Since the Canada (Nfld.) length frequencies were of fish caught with a 41-5 otter trawl with the codend lined with a $1\frac{1}{8}$-inch nylon liner, a 4-inch selection curve was applied to the length frequencies for each year to arrive at a frequency representative of a 4-inch mesh catch, the minimum regulation mesh size in force during both periods. Canada (Nfld.) and USSR frequencies were combined for each year during 1959-62 and the resulting frequency considered to be representative of the commercial catch before discards in 3NO for each year. From 1963 to 1966, the Canada (Nfld.) research frequencies alone, adjusted to 4-inch mesh for each year, were considered to be representative of the commercial cod catch before discarding for that year.

Since there were only 5,000 length measurements of landings after discards in 1959-62 and less than 9,000 in 1963-66 and since the numbers of fish measured varied from none in 1960 to 4,000 in 1965, it was decided to use a landing frequency derived from the catch frequency used above. Assuming knife-edge discarding between 39-41 cm and 42-44 cm (Beverton and Hodder, 1962) and by applying a weight-length key to the catch frequency above the discard length, the average weight of fish landed in each year was calculated. From a knowledge of the weight landed by all countries and the average weight of fish landed, the total number landed in each year was calculated. Using the percentage discarded from the catch frequency, the number caught in each year could then be estimated. The catch frequency for each year was then adjusted to the number caught in that year and by combining years, the average catch and landing frequencies for 1959-62 and 1963-66 were derived.

The method used in the assessments for predicting immediate losses and long-term changes was identical to that outlined by Gulland (1961) and as applied by Beverton and Hodder, eds. (1962). Total mortality estimate (Z) and growth parameters (L_∞, k, t_o) used for the 1959-62 assessments were from Williamson (1965). Growth parameters used for the 1963-66 assessments were from Wells (1969), while Z was determined from Polish age frequencies for 1965 (ICNAF Sampling Yearbook, Vol. 10). Since it was impossible to separate Z into its natural and fishing components, the same range of values of M was used as in Beverton and Hodder, eds. (1962).

TABLE 2. Summary of assessments for 3NO cod, 1959-62 (offshore line unadjusted).

Mesh size change (inches)	l_c (cm)	t_c (yr)	Gear group	Percentage change in 1959-62 landings: Immediate loss	Long-term change for			
					0.44	0.63	0.81	E
					0.24	0.34	0.44	F
From 4 to	35.16	3.22			0.30	0.20	0.10	M
4½	39.16	3.58	Trawl	− 1.73	+3.45	+5.82	+8.15	
			Line	0	+5.27	+7.68	+10.05	
			Total	− 1.42	+3.78	+6.15	+8.49	
5	43.19	3.95	Trawl	− 4.55	+6.17	+11.37	+16.69	
			Line	0	+11.23	+16.68	+22.25	
			Total	− 3.72	+7.09	+12.34	+17.70	
5½	49.10	4.48	Trawl	− 10.43	+8.52	+18.75	+29.77	
			Line	0	+21.63	+33.10	+45.45	
			Total	− 8.54	+10.89	+21.35	+32.61	
6	52.81	4.91	Trawl	− 16.26	+8.23	+21.91	+37.19	
			Line	0	+29.24	+45.58	+63.83	
			Total	− 13.31	+12.04	+26.20	+42.02	

TABLE 3. Summary of assessments for 3NO cod, 1963-66 (offshore line unadjusted).

Mesh size change (inches)	l_c (cm)	t_c (yr)	Gear group	Percentage change in 1963-66 landings: Immediate loss	Long-term change for			
					0.33	0.56	0.78	E
					0.15	0.25	0.35	F
From 4 to	33.21	3.08			0.30	0.20	0.10	M
4½	38.01	3.54	Trawl	− 2.35	+3.35	+7.40	+11.60	
			Line	0	+5.84	+9.98	+14.29	
			Total	− 2.20	+3.52	+7.56	+11.78	
5	42.60	3.99	Trawl	− 6.06	+5.92	+14.87	+24.58	
			Line	0	+12.75	+22.28	+32.62	
			Total	− 5.67	+6.36	+15.35	+25.10	
5½	48.44	4.60	Trawl	− 13.26	+7.63	+24.36	+43.54	
			Line	0	+24.08	+43.37	+63.48	
			Total	− 12.42	+8.67	+25.56	+44.93	
6	52.73	5.07	Trawl	− 19.90	+7.81	+31.22	+59.09	
			Line	0	+34.59	+63.82	+98.62	
			Total	− 18.62	+9.53	+33.32	+61.64	

Tables 2 and 3 summarize the assessments for 3NO cod during 1959-62 and 1963-66 respectively. Table 4 presents the previous assessments for 1955-58, for which the mesh size in use by commercial trawlers was considered to be 3-inch.

From 1959 to 1962 the greatest long-term gain for otter trawl was predicted at 5½-inch mesh for the lowest value of E and at 6-inch mesh for the other values of E. *The greatest gain to the offshore line landings and total* landings was predicted at 6 inch for all values of E. Immediate losses were 10% or less for increases from 4 to 5½ inches.

From 1963 to 1966 greatest predicted long-term gains were at 6-inch mesh for otter trawl, offshore line and total landings for all values of E. Immediate losses were 13% or less for increases from 4 to 5½ inches.

Except for the initial increase to 4½-inch mesh, *where the immediate losses were approximately the* same in the three periods, the losses would have been

TABLE 4. Summary of assessments for 3NO cod, 1955-58 (offshore line unadjusted).

Mesh size change (inches)	l_c (cm)	t_c (yr)	Gear group	Percentage change in 1955-58 landings: Immediate loss	Long-term change for			
					0.57	0.71	0.87	E
					0.40	0.50	0.60	F
From 3 to	39.2	3.2			0.30	0.20	0.10	M
4	41.3	3.4	Trawl	− 1.3	+2.7	+3.7	+4.8	
			Line	0	+4.0	+5.0	+6.1	
			Total	− 1.0	+3.0	+4.0	+5.1	
4½	43.1	3.6	Trawl	− 3.2	+4.3	+6.3	+8.5	
			Line	0	+7.5	+9.5	+11.8	
			Total	− 2.5	+5.0	+7.0	+9.2	
5	45.5	3.9	Trawl	− 6.6	+5.6	+9.1	+13.1	
			Line	0	+12.2	+15.7	+19.7	
			Total	− 5.2	+7.0	+10.5	+14.5	
5½	49.6	4.3	Trawl	− 14.3	+6.2	+12.7	+20.2	
			Line	0	+20.5	+26.9	+34.4	
			Total	− 11.3	+9.2	+15.7	+23.3	
6	53.3	4.8	Trawl	− 22.5	+4.7	+14.2	+25.7	
			Line	0	+27.2	+36.7	+48.1	
			Total	− 17.8	+9.4	+18.9	+30.4	

less in 1959-62 than in either 1955-58 or 1963-66. The losses in fact would have been very similar in the 1955-58 and 1963-66 periods.

At the lowest value of E the long-term changes are very similar for the three periods, although there is a slight difference at mesh sizes 5½ and 6 inch, the 1959-62 and 1963-66 values being slightly higher than the 1955-58 values.

At the two higher values of E the predicted long-term changes (gains) were greatest in 1963-66 and least in the 1955-58 period. This was more pronounced at the larger mesh sizes; in fact the differences were small at 4½-inch mesh.

Discussion

Analysis of landing and effort figures indicated a lower landing per unit of effort in 1958-62 than in the 1955-57 or the 1963-67 periods. Age and length distributions of research vessel survey cruises in 3NO presented by May (1965) indicated that in 1955-57 a succession of year-classes of at least moderate strength entered the fishery. However, in 1958-62 only two significant year-classes, 1955 and 1958, entered the fishery. With mortalities of the order of those determined for the 3NO fishery (Fig. 8), a series of fairly strong year-classes is necessary to sustain landing per effort at a continuing high level and the decrease in 1958-62 was probably caused by a lack of these year-classes. Also, although a decrease in effort may be caused by a decrease in landing per effort and thus a decrease in productivity of a fishery, it is also possible that a decrease in effort can itself cause some decrease in landing per effort related to the lesser efficiency of a smaller fleet in locating concentrations of fish. The increase in landing per effort in 1963 was probably caused by the entrance into the fishery of two good year-classes, 1958 and 1959. Since the ages have not been determined for the survey cruises during the remainder of the period, it is not known whether a succession of strong year-classes occurred here or not.

Total landings in 1967 increased over two-fold compared to 1966 and most of this increase was accounted for by USSR otter trawlers. However, the landing per hour in weight did not change significantly from 1966 and thus the estimates of total effort increased in proportion to the landings. Length frequencies of research vessel survey cruises to 3NO indicated a strong 1964 year-class first captured as 2-year-olds in 1966. In 1967 this year-class produced a peak in the research length frequencies at 36-41 cm (Fig. 6). Also, preliminary analyses of catch per unit of effort data for these survey cruises indicated a significant increase in the numbers caught per hour over 1966, confirming the strength of this year-class. Length frequencies of USSR catches before discards with 4- to 4½-inch meshes indicated a peak at 39-41 cm (Fig. 6), obviously the 1964 year-class. Thus, the increase in landings was accounted for by the greater abundance of the 1964 year-class together with the increase in effort. The fact that the landing per hour in weight did not change is probably explained by the low average weight

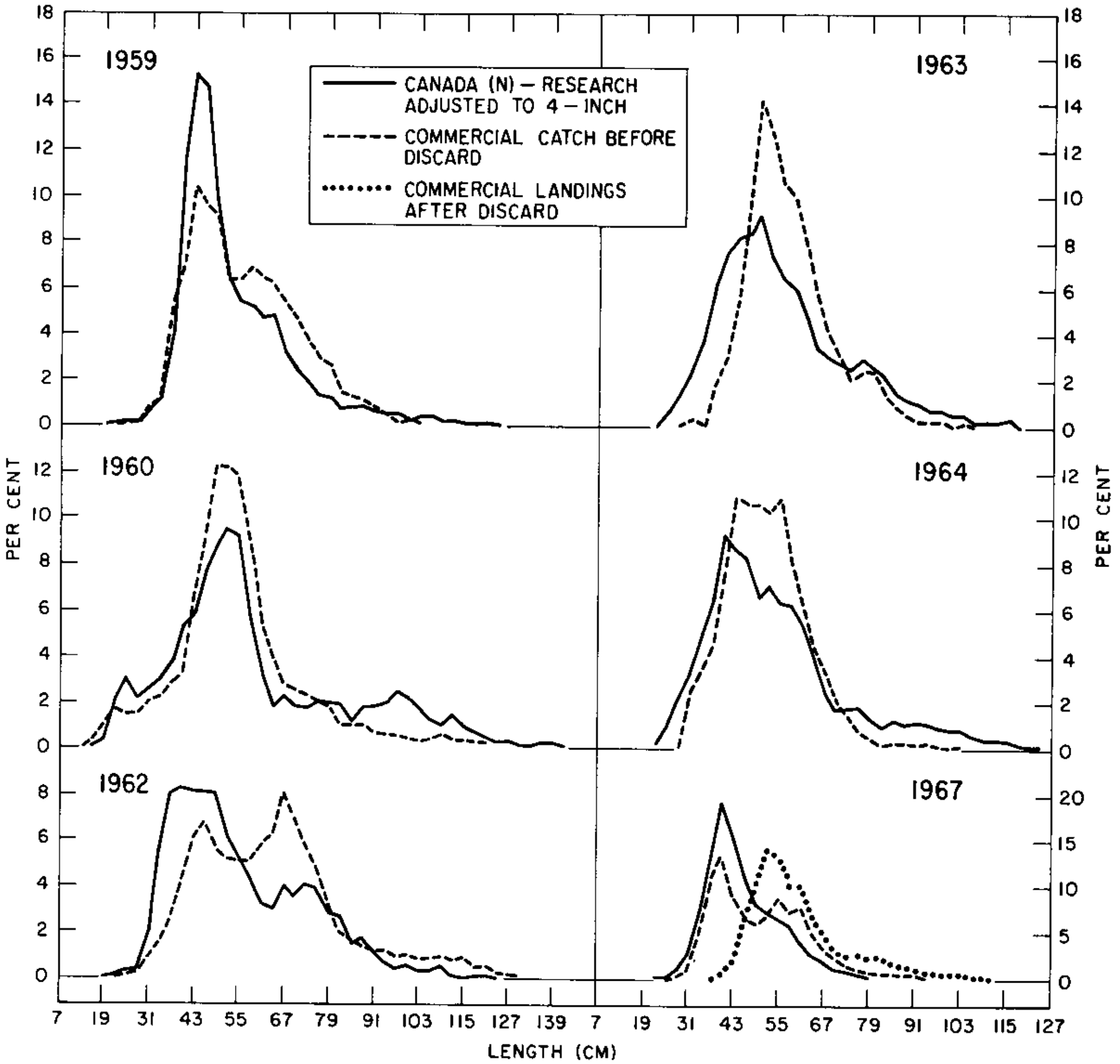

Fig. 6. Comparisons of Canada (Nfld.) research length frequencies adjusted to 4-inch mesh with unadjusted commercial catch frequencies, 3NO, 1959-67. The 1967 commercial landing frequency is shown for comparison.

of these 3-year-old fish. Also, if these fish were being sought for by the commercial fleet, smaller numbers of larger fish would probably be caught than in 1966.

The validity of the results obtained from any mesh assessment depends on the availability of reliable catch and landing frequencies representative of the commercial fleet, and of reliable growth parameters and mortality estimates. In the present study commercial catch frequencies were estimated from research vessel survey data adjusted to a 4-inch mesh. The question therefore arises as to whether the frequencies so derived are representative of the catch by the commercial fleet. The comparisons of research and commercial catch frequencies in Fig. 6 indicate that although there is a tendency for the research frequencies to underestimate the proportion of larger fish and overestimate the smaller fish, the agreement is close enough to allow their use in mesh assessments. These differences are probably caused in part by the commercial fleet tending to concentrate their efforts in depths which larger cod are known to inhabit especially at spawning time, whereas research vessel cruises will fish more randomly.

Due to the paucity of length frequencies of landings after discards or discard curves, a knife-edge discard length was chosen, below which it was assumed that all fish caught were discarded. This, of course, is never the case, discarding taking place over a range of sizes.

The point chosen was between 39-41 cm and 42-44 cm. The vertical lines in Fig. 7 are drawn at the points below which, if all fish caught were discarded, the number would be approximately equal to the number discarded estimated from comparing the catch and landing curves. Although the landing curves are sometimes based on small numbers of measurements, it does indicate that the discard lengths chosen are in line with the existing data. In fact, it was found that by using discard lengths above or below the length group chosen, the immediate losses and long-term changes were affected very little.

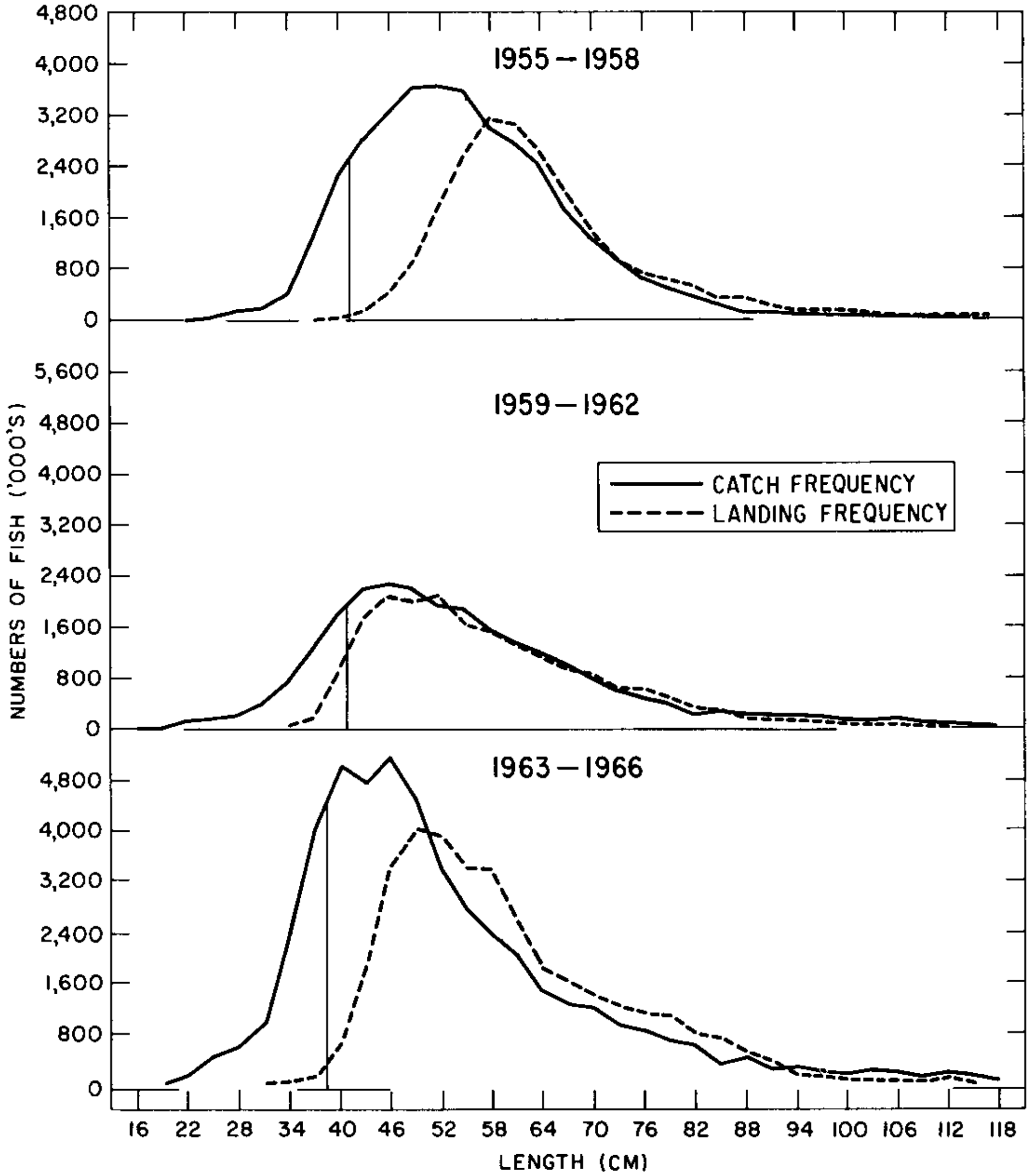

Fig. 7. Length frequencies of cod catches before discards and cod landings after discards, 3NO, 1955-58, 1959-62, and 1963-66. Catch frequencies: 1955-58 – determined from commercial measurements; 1959-62 – determined by combining Canada (Nfld.) research measurements adjusted to 4-inch mesh and USSR measurements; 1963-66 – determined from Canada (Nfld.) research measurements adjusted to 4-inch mesh only. Landing frequencies: determined from commercial measurements in each year.

Mortality estimates for 1955-58 and 1963-66 were obtained from commercial age distributions whereas that used in 1959-62 was from research age distributions, there being no commercial ages available during this period (Fig. 8). Since research age distributions represent the entire population while commercial ages represent only that sector of the population captured by the commercial gears, the two sets of mortality estimates need not be comparable and it is desirable to have mortalities based on commercial data. Mortality rates derived from length frequencies, although only approximate, did indicate a higher level of mortality in 1955-58 than the two later periods.

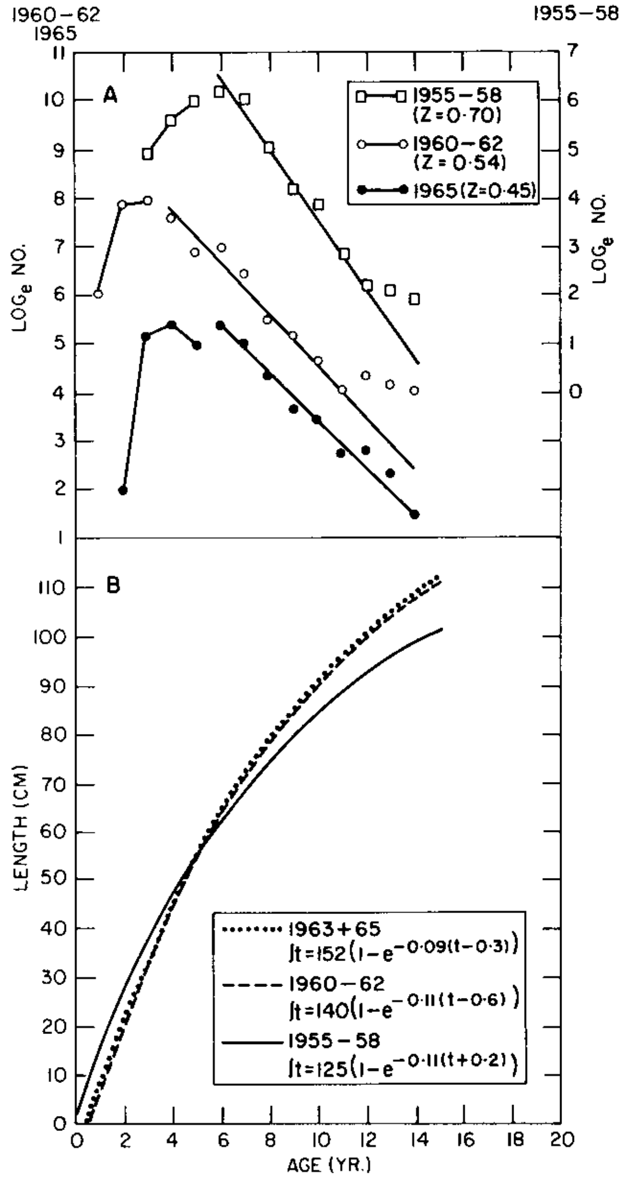

Fig. 8. A. Plots of natural logarithms of the age composition data used in estimating total mortality coefficients. B. Growth curves used to estimate growth parameters.

Average sizes at each age were very similar in the 1959-62 and 1965 periods, while in 1955-58 they were greater up to age 5 and less above age 5 (Fig. 8). This explains the small changes in t_c in relation to l_c in Tables 2-4.

The predicted immediate losses were greater at the larger mesh sizes during 1963-66 than the 1959-62 period. This was due to the larger numbers of smaller fish caught and landed in 1963-66. Thus an increase in mesh size would release more smaller fish in relation to the total catch than in 1959-62 (Fig. 9). The predicted immediate losses in 1955-58 were as high as in the 1963-66 period at comparable mesh sizes but this was mainly because the former assessment was based on 3-inch mesh. If comparable increases are compared (e.g. 3 inch to 4 inch compared with 4 inch to 5 inch), the losses are less in 1955-58 than in the other two periods.

Except at the initial increase to 4½-inch mesh, where very little difference was found, the predicted long-term gains at the two higher values of E were greater in 1959-62 than in 1955-58 and in 1963-66 than in 1959-62. At the lowest value of E there was very little difference in the long-term gains in the three periods. This was because, although the value of E and consequently the proportion of released fish that would have been captured by the larger mesh decreased from 1955-58 to 1963-66 due to a decrease in total mortality, the proportion of small fish that would have been released by a larger mesh increased considerably during the same interval (Fig. 9).

Adequacy of Catch Sampling

The assessments were hampered by lack of adequate length measurement data, both of catches before discarding and of landings after discarding. Table 5 illustrates this point. Measurements ranged from 20 to 1,800 per one million fish landed. The intensity of sampling was about the same in 1955-58 and 1959-62 but only one-third as great in 1963-66.

In addition to the paucity of measurements, sampling was not adequately spread over the fishing season and in some years all measurements were in the same quarter.

Commercial age distributions were totally lacking in 1959-62 and only available for 1965 (1,200 ages) in the 1963-66 period.

If meaningful assessments for 3NO cod are to be carried out in future, more adequate length and age sampling of the commercial catch must be instituted.

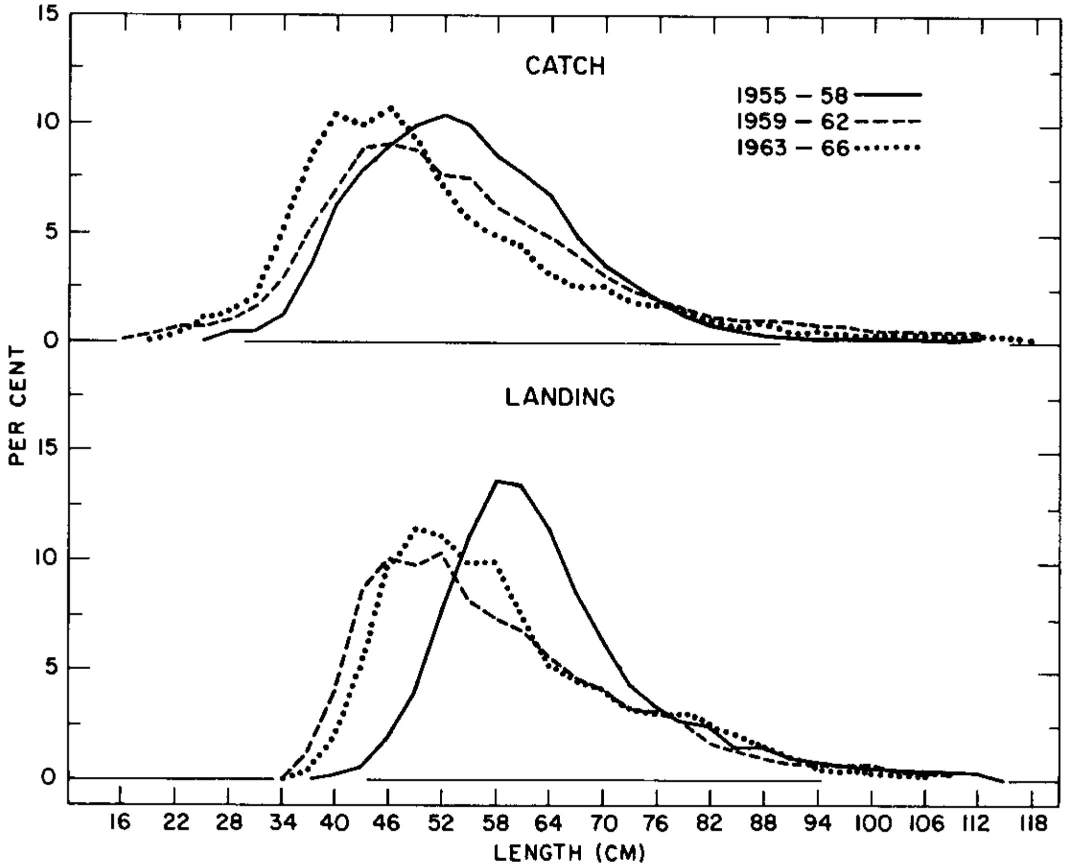

Fig. 9. Length frequencies of cod catches before discards and landings after discards, 3NO, 1955-58, 1959-62, and 1963-66.

TABLE 5. Length measurements of catches and landings of 3NO cod, 1955-66.

Year	Before discard	After discard	Total	Estimated number landed ('000)	Number measured per 1 million fish landed
1955	8,076	1,522	9,598	44,582	215
1956	3,499	1,000	4,499	18,666	241
1957	8,027	3,825	11,852	11,811	1,003
1958	1,320	1,656	2,976	15,722	189
1955-58	20,922	8,003	28,925	90,781	319
1959	6,351	683	7,034	22,447	313
1960	9,839	–	9,839	28,217	349
1961	194	1,434	1,628	20,962	78
1962	14,249	3,043	17,292	9,513	1,818
1959-62	30,633	5,160	35,793	81,139	441
1963	3,196	2,820	6,016	20,958	287
1964	3,744	666	4,410	23,177	190
1965	–	4,040	4,040	37,720	107
1966	–	1,145	1,145	58,457	20
1963-66	6,940	8,671	15,611	140,312	111
1967	9,327	1,618	10,945	–	–

Acknowledgements

The author is grateful to Dr A. W. May for helpful discussion and suggestions during the course of these assessments and for critically reading the manuscript.

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A Device for Automatically Recording Fishing Effort Aboard Otter Trawlers

By James M. Crossen[1]

Abstract

The Fishnet Bathykymograph (FBK) was developed to measure fishing effort aboard commercial trawlers for the Bureau of Commercial Fisheries. The system employs a shock isolated, 14-day time-depth recorder, and Dockside-Support Equipment (DSE) for instrument calibration and retrieval of data. Effort data are recorded on magnetic tape which, with additional processing, is computer compatible. The FBK attached to an otter-trawl headrope records the number of tows and the duration and depth of each during a fishing trip.

Introduction

Fishing effort information at New England ports presently is collected by interviewing vessel captains when catches are unloaded. This method does not provide completely accurate data since reports on number of tows, tow duration, and depth depend to a large extent on the memory of the captains. In order to fill this gap, the Bureau of Commercial Fisheries has developed an instrumented headrope float which, attached to a commercial trawl (Knake, 1958), will record the number of tows made during a fishing trip and the duration and depth of each. This device, shown in Fig. 1, has been named the Fishnet Bathykymograph (FBK) (Hester, 1963).

The function of the FBK as a part of the data collection system was the primary consideration in defining requirements. First, it must accurately produce the desired data, i.e., the length of time and depth at which the net has been used; second, it must withstand the use conditions to which it is exposed; and third, the data format must be computer compatible and easily converted to an analog record by a Dockside-Support Equipment (DSE) (Fig. 1).

The use conditions of the FBK on a commercial trawler are extremely severe. The instrument is exposed to temperatures ranging from $-25°$ to $+60°C$; it is intermittently slammed against the side of the trawler, and dropped on the deck. In winter it is covered with ice, and in summer exposed to direct sunlight while the net is on deck between tows and en route to and from the fishing grounds. It is also subjected to ocean pressure, salt water, and salt atmosphere. Inspection, calibration, and servicing is only possible between trips.

Accuracy requirements for depth were ± 3 m over the range from 5 to 30 m, and an overall accuracy of $\pm$ 10% of the actual depth over the range from 30 to 400m. The total time error in final format was not to exceed $\pm$ 3 hr over a 14 day operating period (1%).

In order to give a reliable measure of the effort of the New England fishing fleet, a sizeable fraction of the vessels will have to be equipped with FBKs. The present estimate is for about 100 instruments at sea at any one time, 100 ready to be sent out, and about 50 in the depot for maintenance and calibration.

Prototype Experiments

Initially, a standard spherical headrope float was chosen as an instrument housing. The commercially produced floats are ideally suited as under-water housings for instruments such as pressure recorders, temperature recorders, etc. They withstand pressures to 100 kgs/ sq cm (over 1,000m). The aluminum alloy machines easily, and is resistant to corrosion. The spherical float was split at its equator, and flanges welded to each hemisphere. One of the flanges was machined to accept an O-ring for water-tight integrity.

Extensive searching and testing was performed on pressure sensors, recording methods, and time drive mechanisms. Since cost was a prime consideration, it was decided to use a pressure sensitive strip chart in the recorder. The recorder was driven by battery powered solenoid wound clocks and direct current motors. The pressure sensors used were Bourdon tubes and piston-spring devices. Several prototypes were designed, then fabricated and tested aboard the research vessel, *Albatross IV*. Some success resulted from these early sea tests; however, the severe shock experienced during trawling operations resulted in excessive failures. At this point, we prepared a reliability engineering specification; and requested bids for the design, development, and fabrication of the FBK from oceanographic instrumentation firms.

FBK Shock Tests

One of the performance requirements was that the FBK survive a 5 ft (1.5m) drop to a steel deck. A

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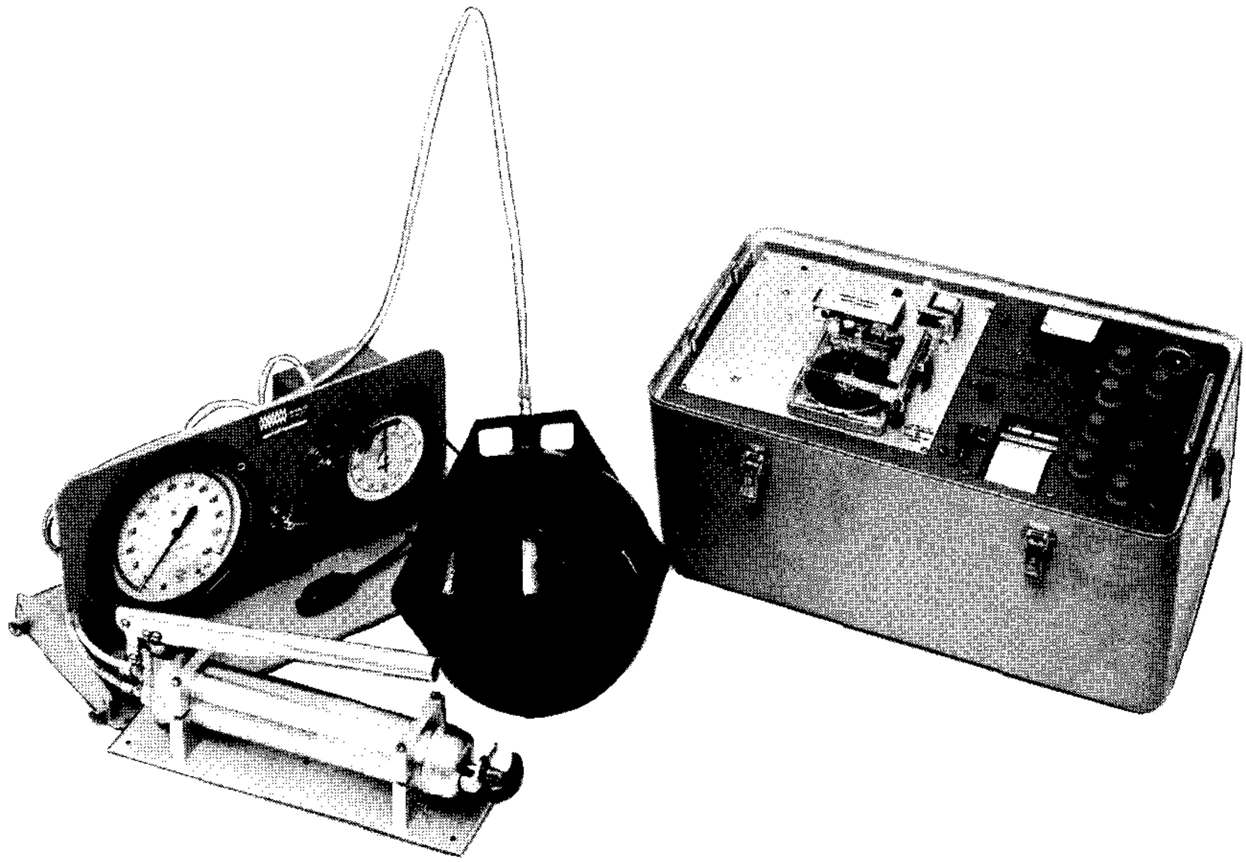

Fig. 1. The FBK and Dockside-Support Equipment. The FBK is connected to the time and pressure calibrator (left). The analog playback system is shown on the right. (Photo courtesy of Geodyne Division, EG&G International)

suitably instrumented 20cm (8 inch) headrope float was drop tested; and showed a peak shock of 1,200-1,500 g's at the hard-mounted instrument platform.

Other drop tests on the components of the instrument showed that the instrument package would not survive shocks over about 300 g's Therefore, it was necessary to isolate the instrument platform from the pressure case. We tested a resilient foam filling the void spaces, and a rubber ring supporting the instrument package before settling on the rubber ring.

System Design of FBK

Housing

The standard 20 cm (8 inch) aluminum headrope float could not contain the instrumentation and still meet the floatation requirements. Therefore, two hemispheres (Fig. 2) 24.4 cm (9.625 inches) in diam and 7.9 mm wall thickness were cast (Table 1) of aluminum, and covered with a layer of poly vinyl chloride plastic. The housing with enclosed recorder weighs 7.6 kg (16.6 lb.) in air, and is buoyant 0.628 kg (1.4 lb.) in fresh water. The depth capability is 600m. The two hemispheres are held together with six recessed screws compressing an O-ring seal.

Aluminum was selected for its resistance to salt water, shock, pressure, and weather. Other housing materials were considered early in the program. This study was pursued with the basic trade offs between four candidate materials as listed in Table 2. The shock index factor represents a calculated stiffness characteristic for each material assuming a consistent geometry. Materials investigated were aluminum (356-T6), stainless steel (316), titanium, and a poly carbonate resin (Lexan)[2]. The Lexan, while ideal from the standpoint of weight, stress, and shock resistance, required an injection molding technique which was too costly ($10,000 for tooling).

[2] Mention of commercial products does not imply endorsement by the Bureau of Commercial Fisheries.

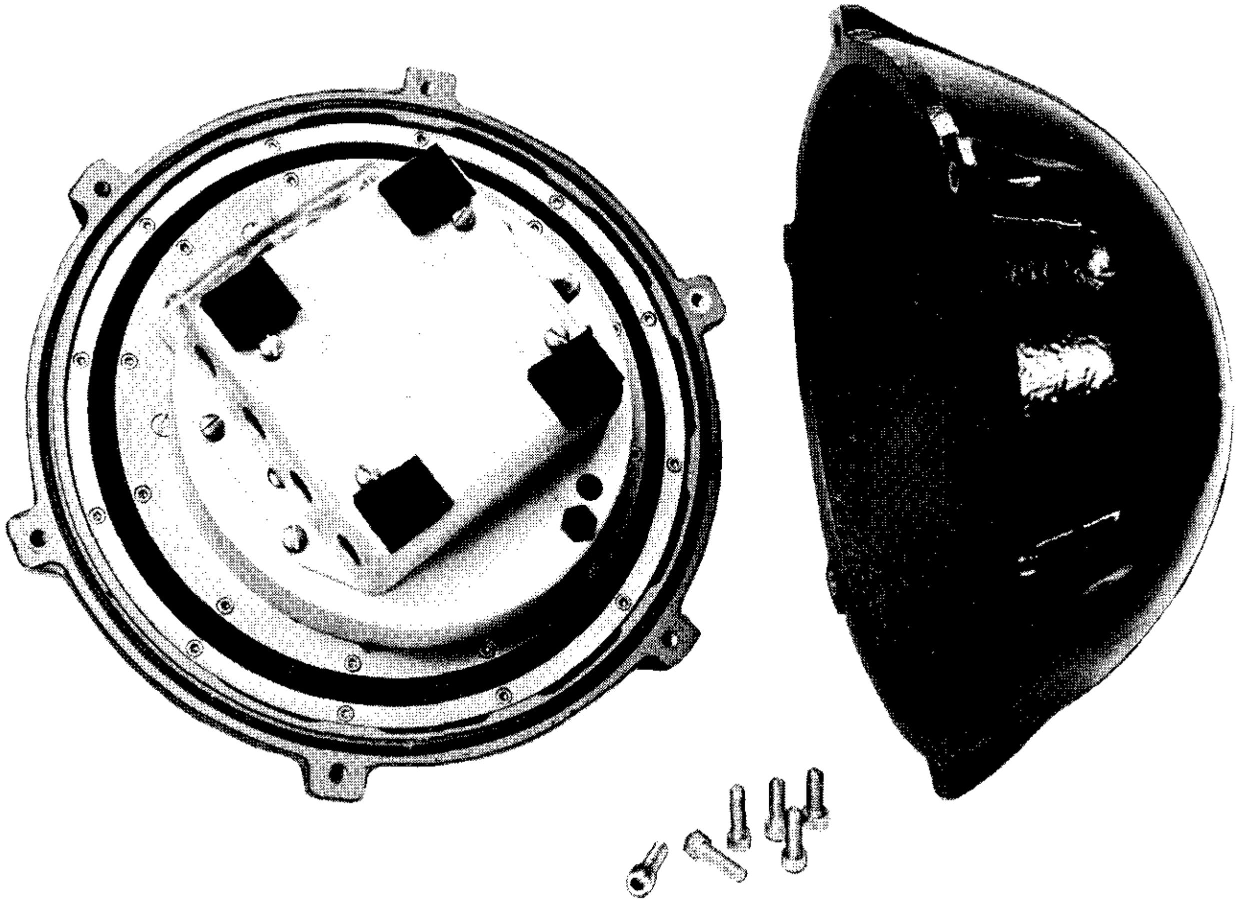

Fig. 2. View of instrument platform mounting plate group with top hemisphere removed. Battery package is visible with rubber "bumpers" at each corner. Tape cartridge partially visible upper left. Shock isolator assembly and housing O-ring can be seen in place. (Photo courtesy of Geodyne Division, EG&G International)

TABLE 1. A comparison of fabrication techniques for aluminum spheres.

Fabrication technique	Tooling	Sphere[a] unit price[b]	Additional fabrication	Machining
Spinning	$ 550.00	$32.00	Yes	Yes
Forging	3500.00	34.60	No	Yes
Casting	200.00	12.25	No	Yes

[a]20 cm O.D.
[b]500 units.

TABLE 2. Material comparison.

Material[a]	Thickness (*cm*)	Weight (*kg*)	Relative cost	Shock index
Aluminum 356-T6	0.794	3.7	1.0	1.8
Stainless Steel 316	0.477	6.97	2.5	1.1
Titanium	0.634	4.86	6.1	1.5
Lexan	1.427	2.93	2.8	1.0

[a]Spheres are 20 cm O.D.

Pressure Sensor

The pressure sensor is a bonded semiconductor strain guage. A Bourdon tube was tested, but it failed to meet the specifications for accuracy between 0- and 30-m depth.

The strain guage was tested at static pressure, pressure versus temperature and pressure versus shock. At static pressure, the error of the strain gauge was half that of the specifications. One of the units tested survived 150 drop tests.

Automatic switch

A piston-actuated microswitch closes when the instrument is at a depth of about 5m starting the recording. The switch remains closed for the duration of the mission of up to 14 days. With the housing open, the switch can be opened and closed manually to check the operation of the recorder.

Electronics

The solid state electronics module (Fig. 3) is packaged to combine minimum volume with maximum shock resistance. Two printed circuit boards are assembled in a can, and encapsulated in a semi-rigid silicone potting compound (Dow Corning Sylgard 182).

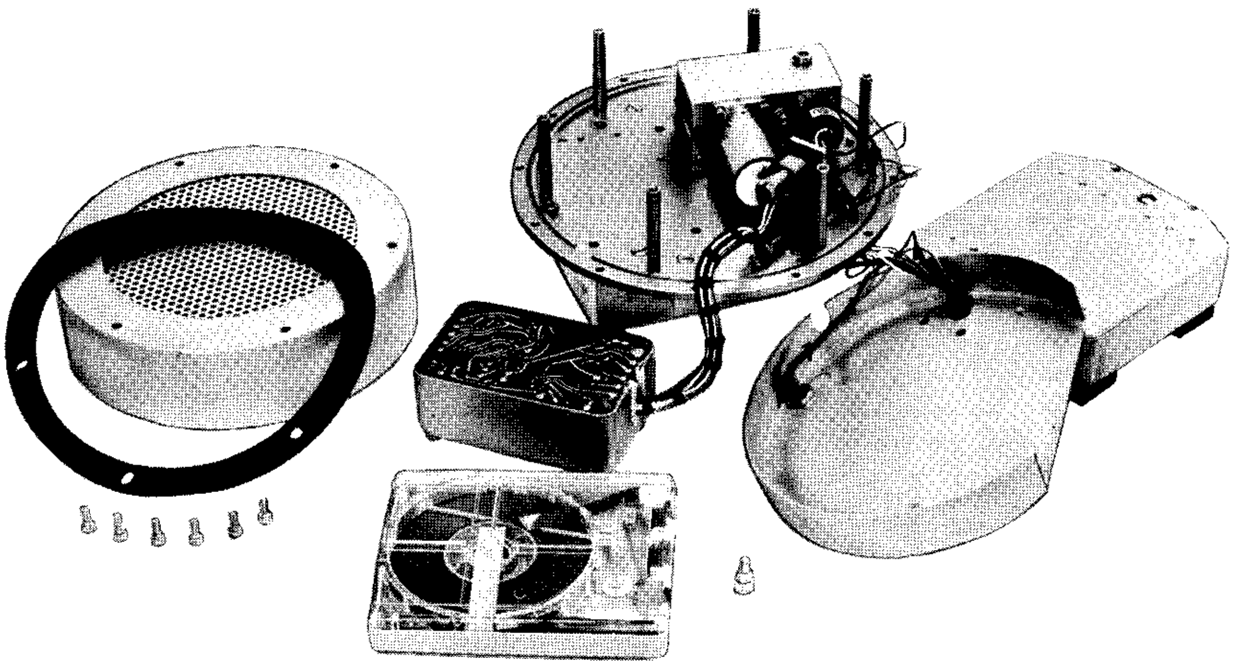

Fig. 3. The disassembled FBK. The micromotor and drive assembly is at upper center. The electronics module is in the center. The magnetic tape cartridge is at bottom. (Photo courtesy of Geodyne Division, EG&G International)

The electronic circuits include a timer, control counter, motor control, bridge encoder, signal gate and conditioner, and tape recorder amplifier.

The timer is a 1-min multivibrator which provides the basic time interval reference. Frequency stability of the timer over the 14-day period is required to stay within ± 3 hr. The motor control turns the tape recorder on for a 4-sec period every minute. During this period, three pulses are recorded. The position of the second pulse in relation to the first and the third is a function of depth (Fig. 4).

Tape recorder and cartridge

The tape recorder (Fig. 3) consists of a recording head, tape guides, contactor (grounding switch), tape cartridge housing, pressure roller and assembly, and tape drive assembly.

The basic data are recorded on a 400 ft endless reel of 6.3mm (0.25 inch) magnetic tape (3M type 153). The cartridge assembly (Fidelipak) was chosen as the most durable design and for its ease of handling.

The contactor provides a short circuit to ground when actuated by a metallic splice on the magnetic tape, causing the recorder to shut off when a complete reel has been recorded. This would occur if the instrument was operated beyond its 14-day limit.

The tape drive assembly consists of a direct current micromotor, a gear box, and capstan. The micromotor (Portescap, model SR) is extremely shock resistant. It withstood shocks of 700 g's at a time duration of 1.5 milliseconds. The micromotor is encapsulated in semi-rigid silicone potting compound (Dow Corning Sylgard 182) within a metal housing.

Power pack

The batteries are required to provide 6 VDC at an average of 5ma for 336 hr (1.7 amp-hr) with a safety factor of about two. They must be able to do this at ambient temperatures of from –25° to +60°C. They had to fit in a space about 115 X 115 X 40mm (4.5 X 4.5 X 1.5 inches).

Carbon-zinc, mercury, alkaline-manganesezinc, and nickel-cadmium cells were tested. Only nickel-cadmium and alkaline cells met the requirements, therefore, eight alkaline "C" cells (Eveready E93) mounted in stainless steel holders were used.

Dockside-Support Equipment

The DSE is made up of the playback system which provides an analog record of the FBK tape cartridge data and the calibration system for time and pressure.

Analog Playback System

The Analog Playback System (APS) (Fig. 1) converts the pulse interval code signals to an analog reading. The tape cartridge is inserted in the APS and a strip chart recorder (Technirite) prints out the recent history of the FBK. It takes 5 min to print out a 14-day record. A meter provides for direct observation of the data.

Time and pressure calibrator

The calibration system (TPC) (Fig. 1) consists of a hydraulic hand pump, a vernier pressure control, a pressure test gauge, and an electric-timing clock. Calibration pressure points are established by a rough setting with the hand pump and a fine setting with the pressure control. The Bourdon pressure gauge is accurate to 0.25%.

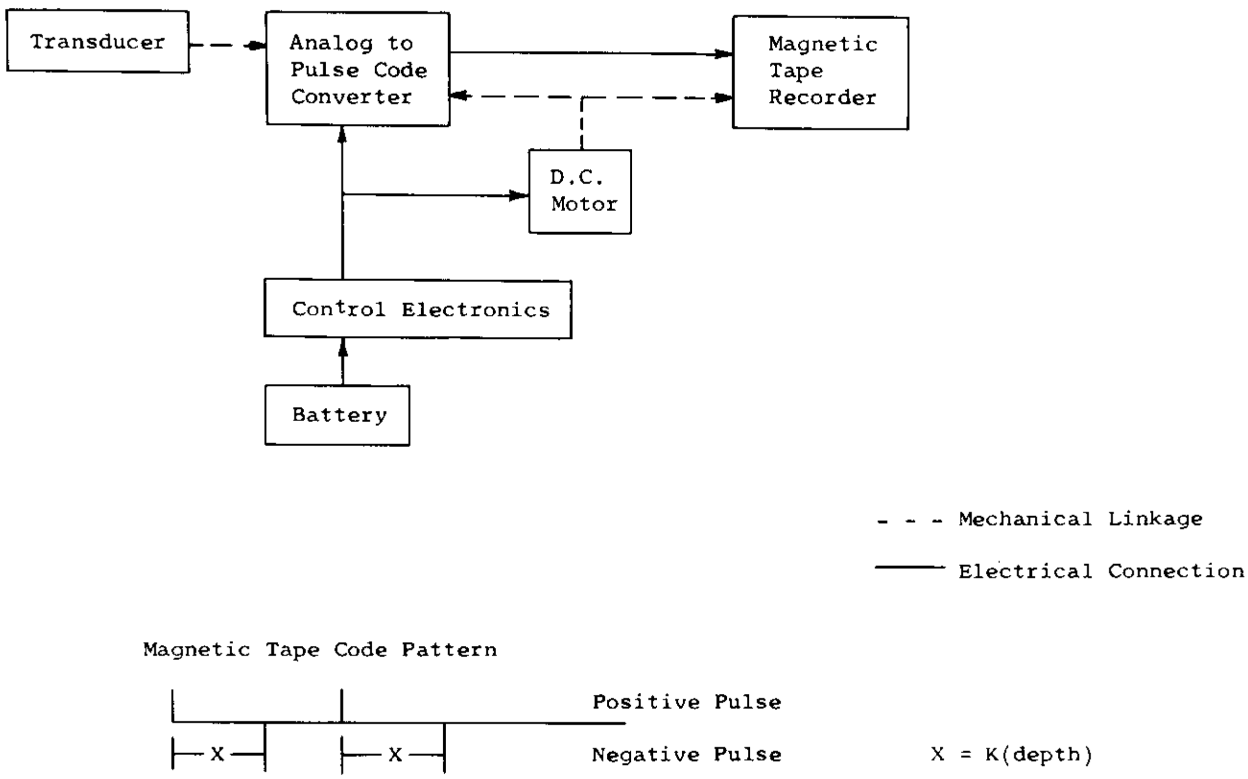

Fig. 4. Block Diagram of the Pulse Code Magnetic Tape Recording FBK.

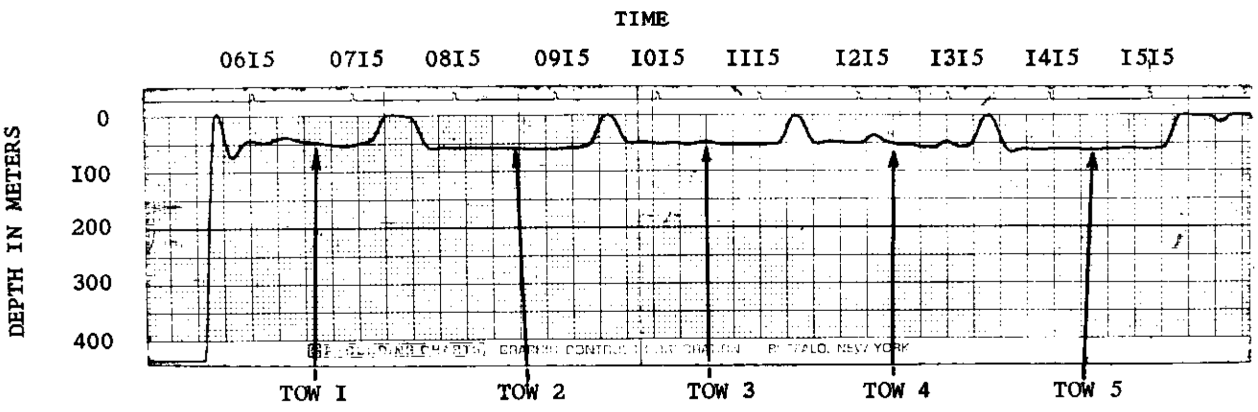

Fig. 5. Record of fishing trawls of *Liberty Belle.*

Operation in the Field

When a vessel carrying an FBK returns from a fishing trip, a Bureau of Commercial Fisheries port agent removes and replaces the tape cartridge and battery pack. Tapes are examined with dockside playback; and if the FBK has recorded properly, it is ready for another trip.

Field test

Tests were conducted on board the fishing trawler *Liberty Belle* out of Provincetown, Massachusetts during December 1968. The FBK was given a preliminary check by running overnight. Pressure calibration levels of 200- and 400-m depth were applied using the time-pressure calibrator. The unit was attached to the headrope adjacent to the port door of the #36 trawl. Five tows were made in water depths of 45-54m off Cape Cod, Massachusetts.

A copy of the playback tape, as recorded on the APS, is shown in Fig. 5.

Electronic Data Processing (EDP)

A tabulated printout of the FBK data, such as is shown in Table 3, may be obtained with additional equipment. This will require tape-to-tape code conversion, serial data to computer compatible conversion, and a computer program.

Tape-to-tape code conversion

This module will be required to receive data from the FBK tape cartridge in pulse interval coded form, and convert the data to a serial binary coded decimal form.

Serial data to computer compatible tape converter

This module will be required to accept the serial digital data, and convert to multi-channel computer compatible magnetic tape formats. This includes provision for manual insertion (addressing of BCD heading information and manual control of recorder) as may be required.

TABLE 3. Sample output data sheet format.

[a]Port departed	[a]Date	[a]Port returned	[a]Date	[a]Vessel name	[a]Agent
Boston	9/8/69	Boston	9/10/69	*Albatross IV*	JCE

	Tow No.	Duration *(hr)*	Mean depth *(m)*	Time between tows *(hr)*	Elapsed time *(hr)*
	1	1.2	70	–	1.2
	2	1.1	64	2.4	4.7
	3	1.3	82	4.5	10.5
	4	1.2	78	0.8	12.5
	5	1.5	80	0.5	14.5
Total	5	6.3	374	8.2	14.5
Averages		1.26	74.8	1.64	

[a]FBK Serial No.	[a]Record terminated Date	Time
101	9/10/69	0900

Calibration data:

Sample rate (seconds) Start of trip	End of trip	Reference pressure readings (meters) at 30	at 100	at 200	at 300	at 400
60.2	60.8	30.1	105	201	308	410

[a]Data entered by BCF agent on tape cartridge.

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Some Remarks on the Behaviour of Growth and Mortality Estimates Based on Age-Length Keys

By William Knight[1]

"The purpose of computing is insight, not numbers." Richard Hamming, Numerical Methods for Scientists and Engineers.

Abstract

In studying the properties of growth rate and mortality estimates, as opposed to actually calculating their numerical values, it is more important that the mathematics be simple than that it be accurate. Approximations are suggested for use with age-length keys with crudely linear growth curves, and these approximations applied to a few common questions concerning age-length keys.

1. Introduction

The first statistical problem with age-length data is how to estimate mortality, growth, year-class strength, etc. This paper is not concerned with that question. Once such estimates are found, "second order" questions come up: What are the properties of these estimates, and how can the data be collected to improve these properties

We need a different kind of answer to these "second order" questions. The answer to an estimation problem is a number, the estimate, but in the second case, "the purpose . . . is insight, not numbers". Whereas an estimate must be accurate and may be complicated, the description of its properties may be rough but must be simple if it is to be generally useful.

A few examples of such "second order" questions:

i) What lengths of fish should be selected for ageing by otolith or scale? Should length groups be sampled proportionately, by equal sample sizes from each length group, or some other allocation?

ii) How large is the statistical sampling error? How large sample sizes are needed? What sort of significance tests should be used?

iii) Sampling programs would be less expensive if age-length keys could be pooled. When can this be done? To what extent? What is the penalty of pooling when you shouldn't?

iv) What happens if the age-length key and the length distribution come from different populations? (This question was suggested by W. E. Ricker.)

Any study of questions like these is immediately entangled in the basic paradox of age-length keys. Although it is the age distribution (especially mortality) and the conditional distributions of length at fixed ages (especially the growth rate) which are wanted, it is the complements of these which are actually collected, the length distribution and the conditional distributions of age at fixed lengths. In such a pass, any simple formulae relating the directly measured quantities to those indirectly measured but more meaningful would be a boon, even were these formulae but crude approximations, useless to the person actually performing calculations to estimate growth, mortality, etc.

Thus we arrive at the main purpose of this paper: To devise formulae connecting the quantities measured to the quantities actually wanted, and explore these in terms of the questions (i) to (iv).

2. Basic Approximations

It is assumed that the growth curve is linear. Although for most data it can be verified that this is not the case, there are two justifications of such a simplification. First, linearity is often, perhaps even usually, correct as a first order description. Second is the remarkable success of crude linear approximations in varied applications.

For any given age-length distribution, the relation between the growth rate, G, the slope of the least squares line of length on age, and the slope of the least squares line of age on length which is denoted B, is

$$G = r^2 B^{-1} \qquad (2.1)$$

where r is the correlation coefficient. The contributions of the age-length key and the length distribution to r can be separated,

$$r^2 = B^2 / (B^2 + F) \qquad (2.2)$$
$$F = s_{t.l}^2 / s_l^2$$

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[1] Fisheries Research Board of Canada, Biological Station, St. Andrews, New Brunswick, and University of New Brunswick, Fredericton, New Brunswick.

where s_l is the standard deviation of the length distribution and $s_{t.l}{}^2$ is the mean square deviation of age from the least square line of age on length. Thus the age-length key enters the linear growth rate through B and $s_{t.l}$ and the length distribution through s_l. This would be a complete solution were it not that B is quite independent of the length distribution only if the regression of age on length is linear. (The factor $s_{t.l}$ also depends on the length distribution but as its influence is rather small, this is not likely to be important.) As it is, (2.1) is approximate, the degree of approximation depending on the linearity of the regression.

A relation between instantaneous mortality, Z, and growth rate, G, is

$$Z = GZ' \tag{2.3}$$

where Z' is something primarily determined by the length distribution. Ricker (1958) in Chapter 2, Section G, investigates (2.3) taking Z' as the decay rate of the right limb of the length distribution as Z is the decay rate of the right limb of the age distribution. His conclusion that the approximation is poor need not deter us altogether as our demands are less stringent than his.

There is also a choice of Z' which makes (2.3) exact under the assumptions of a linear regression of length on time, and that all recruitment takes place at age t_o. The second assumption is no real restriction as it can be achieved by truncating the data after collection. The first assumption again enters only through the demand that the least squares line of length on age be independent of the length distribution. This definition of Z' is

$$Z' = 1/(l - l_o) \tag{2.4}$$

where l is the mean length and l_o is the recruitment length in the sense that it corresponds to t_o on the least squares line. The derivation requires integration and is set out in Chapter 6. A related result is in Watson and Leadbetter (1964).

3. Sampling Error of the Primary Quantities

Formulae (4.1) and (4.2) give rough estimates of the error of the secondary quantities on the basis of estimates of the error of the primary quantities. There remains the need of estimating the errors of the primary quantities, a considerable problem and one outside the scope of this paper. To illustrate some of the considerations involved, I remark on an attempt which failed, an endeavour to assign error bounds to the growth rate and mortality rate derived from a routine age-length key for cod, commercially caught by otter trawl in ICNAF Division 4T in 1966, extracted from the files of the St. Andrews Biological Station of the Fisheries Research Board of Canada. The reader can skip the rest of this section with no loss of continuity.

The values of G and F are readily calculated while running textbook linear regressions of length on age and age on length.

The estimation of the coefficient of variation of B cannot be done with the distribution in its final form for presentation; the numbers do not represent real fish, but elaborate weighted combinations. I first considered the possibility of using the unweighted age-length key which, though not made up, is readily calculated from worksheets available. The regression of age on length could be run on the unweighted key yielding a regression equation of no interest whatever, and an error estimate of the slope of regression whose calculation is the purpose of the exercise. Unfortunately, the textbook error term assumes that the 28 samples whose combination make up the unweighted age-length key are homogeneous, an assumption hardly tenable after the report of Dickie and Paloheimo (1965), and a similar study by the author (unpublished).

The situation for length distributions is much worse than for the age-length keys. Dickie and Paloheimo in the study noted above found far greater heterogeneity among length distributions than conditioal age-at-length distributions (as measured by the likelihood ratio statistic for contingency tables). Moreover, while methods for estimating the error of a regression are commonly found in textbooks regardless of their applicability to the present situation, estimates of the error of the estimated standard deviation of the badly skewed distribution, such as the typical length distribution, and estimates of the error of the decay rate of the right limb of the length distribution are not easily found in textbooks or anywhere else.

4. Discussion

Although the manner of distribution of information between the age-length key and the length distribution is easily worked out, and some aspects at least, published before (Gulland, 1956, p. 24), an explicit statement should be made. Most of the information about growth is found in the age-length key. Equation (2.3) tells us that the length distribution informs us primarily about the ratio of mortality to growth. The comparison of strengths of adjacent year-classes can be made on the basis of the age-length key alone; for separated year-classes, some kind of correction for mortality is needed.

If a von Bertalanffy curve is fitted, the distribution of information is rather interesting. In what should be (Knight, 1968) the usual situation, the asymptote, L_∞, is determined by the size of the largest fish; this must come from the length distribution. On the other hand, the linear properties of the curve come from the age-length key. A line is determined by its intercept and slope; with the von Bertalanffy curve the intercept is given by t_o, and the slope is approximately KL_∞, (The slope at t_o is KL_∞ by a simple differentiation.) Thus t_o and the product, KL_∞, are determined primarily by the age-length key, and L_∞ by the length distribution!

We now return to the questions raised in the Introduction:

i) In sampling otoliths or scales for age reading, should each length class be sampled proportionately, sampled equally, or some other allocation? As far as mortality and growth, but not year-class strength, are concerned, the important thing is the accuracy with which the regression of age on length is measured, this being the dominant term in (2.1) and thence by implication the important part of the age-length key appearing in (2.3). (Z' is a property of the length distribution only.) A regression line is best estimated by concentrating effort near the ends of the line. Indeed, in principle, the only reason for taking any points near the middle is to check the adequacy of the linearity assumption. On the other hand, for estimating relative year-class strength, about equal attention to all ages, and thence by the approximate linearity of the growth curve, to all lengths, is called for. These considerations pretty clearly point to a practice already in use: Take a complete sample of the largest length classes and the smallest; then take equal numbers from the rest.

ii) What about confidence intervals and tests of significance for growth and mortality? For practical purposes it suffices to get an approximation to the variance, or what is as good, the coefficient of variation. Denoting by $v(*)$ the coefficient of variation of *, the usual linearization technique plus some crude approximation yields

$$v\,(G) \pm \sqrt{v\,(B)^2 + (GFv\,(F))^2} \tag{4.1}$$

The derivation is relegated to a later section. For the coefficient of variation of Z the usual approximation is

$$v\,(Z) = \sqrt{v\,(Z')^2 + v\,(G)^2} \tag{4.2}$$

iii) When can age-length keys be pooled, and what is the penalty of pooling without justification? Since the age-length key's information is mostly about year-class strength and growth rate, it suffices that these be the same. Put more generally, hence vaguely, the age-length key describes some of the biological properties of the stock at some time, whereas such man-created things as gear selection and fishing intensity show up in the length distribution, thus, as far as growth and mortality estimates are concerned, it should be safe to mix age-length keys for the same stock over such a time interval as it remains stable.

The penalties for pooling unlike keys are these: First, the year-class strengths will be mixed. Second, any difference in the length distributions will be interpreted primarily as a difference in mortalities, even if really a difference between growth rates, for most of the information which could distinguish between different growth rates has been lost in the pooling.

iv) What if the age-length key and the length distribution actually come from different populations? Upon considering Section 3, we find that some information can be salvaged for the population from which the age-length key was drawn, but little from the other. The growth rate, and the relative strengths of nearby year-classes, are relatively insensitive to the length distribution. Except in unusual cases, no information about mortality is available.

APPENDIX I

5. Derivation of Equation (2.2)

Equation (2.2) is a descriptive identity and holds whether or not growth is linear although it will not be relevant for extreme non-linearity. It is derived from the following well known formulae:

$$GB = r^2 \tag{5.1}$$

$$B\,s_l^2 = \text{mean of products about mean} = G s_t^2 \tag{5.2}$$

$$r^2 = 1 - s_{t.l}^2 \,/\, s_t^2 \tag{5.3}$$

where s_t is the age standard deviation; (5.1) and (5.3) can be found in Steel and Torrie (1960, p. 188); (5.2) is immediate from the definitions of B and G. Solving (5.2) for s_t^2,

$$s_t^2 = B\,s_l^2/G \tag{5.4}$$

and substituting (5.1) and (5.4) into (5.3) to eliminate r and s_t^2 respectively,

$$BG = 1 - G\,s_{t.l}^2 \,/\, B\,s_t^2$$

which is solved for G yielding (2.1).

APPENDIX II

6. Derivation of (2.4)

Equation (2.4) rests on the fact that the reciprocal of average age is an estimate of mortality. That this is true for the case of constant mortality is a simple exercise with the exponential distribution. For any distribution the following holds:

Let $Z(t)$ be the mortality at time t, that is

$$(df(t)/dt)/f(t) \tag{6.1}$$

where $f(t)$ denotes the age distribution density function. It is usually the mortality for large t in which we are interested; we express this by taking as our overall figure for mortality the weighted average, where the weight is age over the recruitment age, thus

$$Z = \int_{t_o}^{\infty} (t - t_o)\, Z(t) f(t)\, dt \Big/ \int_{t_o}^{\infty} (t - t_o) f(t)\, dt \tag{6.2}$$

The numerator is

$$\int_{t_o}^{\infty} (t - t_o) f'(t)\, dt = \int_{t_o}^{\infty} f(t)\, dt = 1 \tag{6.3}$$

by integration by parts. We then have weighted average

$$Z(t) = \frac{1}{t - t_o} = \frac{G}{l - l_o} \tag{6.4}$$

where t and l are respectively the average age and length of fish of age t_o or more. The right equality is merely a restatement of the equation for the least squares line, we have (2.4). Note however that G here is the slope of the line fitted to fish of age t_o or more, not the entire population, hence the necessity of the assumption that G is stable.

APPENDIX III

7. Derivation of (4.1)

Equation (4.1) follows from the usual approximation with partial derivatives, plus a crude approximation. The partial of G with respect to B:

$$\frac{\partial G}{\partial B} = \frac{\partial}{\partial B}\left[\frac{B}{B^2 + F}\right]$$

$$= G\left(\frac{1}{B} - \frac{2B}{B^2 + F}\right)$$

$$= \frac{G}{B}(1 - 2GB)$$

$$= \frac{G}{B}(1 - 2r^2) \tag{7.1}$$

In an approximate formula, subtractions can be downright dangerous, but noting that $1 - 2r^2 \leq 1$, the approximation below is conservative.

$$\frac{\partial G}{\partial B} \leq \frac{G}{B} \tag{7.2}$$

The partial of G with respect to F

$$\frac{\partial G}{\partial F} = -\frac{G}{B^2 + F} = -\frac{G^2}{B} \tag{7.3}$$

Taking V(*) to mean the variance of *, the usual linear approximation,

$$V(G) = \left(\frac{\partial G}{\partial B}\right)^2 V(B) + \left(\frac{\partial G}{\partial F}\right)^2 V(F) \tag{7.4}$$

leads to,

$$\frac{V(G)}{G^2} = \frac{V(B)}{B^2} + (GF)^2\, \frac{V(F)}{F^2} \tag{7.5}$$

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Spawning Dates of Georges Bank Haddock

By Robert R. Marak[1] and Robert Livingstone Jr.[1]

Abstract

Fish egg production curves are presented. When compared with previous data it was found that a 1.5° to 2.0°C temperature change can alter spawning times by a month.

Introduction

Data which can be used to fix the time of spawning of haddock, *Melanogrammus aeglefinus*, on Georges Bank has previously been collected by: Walford (1950) in 1931; Clarke, Pierce, and Bumpus (1943) in 1940 and 1941; Marak, Colton, Foster, and Miller (1961, 1962) in 1953, 1955, and 1956. Colton (1968) has demonstrated a relationship between spawning times of haddock and bottom temperatures in the Georges Bank area during the 1950's.

During 1968 we endeavored to find out what effect cold spring temperatures might have had on haddock spawning time. The gonads of 5,000 haddock brought in by the fishing fleet were examined, and plankton samples were collected on cruises of the R/V *Albatross IV*.

Gonads were obtained from haddock collected by the commercial fleet from Georges Bank between January and July (53 samples of about 100 fish). Developmental stages were determined by visual means based on criteria set forth in the FAO handbook (Kesteven, 1960). The eight stages used progress from resting or immature to spent. Because of the difficulty of accurately staging male gonads, only ovaries (2,500) were used in the analysis. Although only the actively spawning fish were used in the final analysis, plots of the ripening and spent fish validated the use of just these stages for showing egg production. The results of this part of the study show that very little spawning activity occurred during February and early March and was followed by a sharp increase peaking about the third week in April (Fig. 1). Spawning activity fell off gradually to less than 5% in the middle of June.

Plankton Samples

Seven biweekly plankton cruises of the R/V *Albatross IV* were made between March and June in a 2,500 sq mile area on the northeastern part of Georges Bank. Previous data has consistently shown this area to be a major haddock spawning ground (Colton and Temple, 1961). Each cruise consisted of 50 stations located in a stratified random sampling design (Posgay and Marak, MS, 1970). Step oblique tows from 50 m to the surface were made with BCF Bongo nets having 0.03 m^2 mouth area and 0.505 mm mesh (Sherman and Honey, 1968). Since the haddock spawning season overlaps that of the cod, and cod and haddock eggs are not separable in early stages, it was necessary to hatch a portion of the eggs collected. The ratio established was used to determine the numbers of haddock eggs. The stage of development (time of spawning) of the haddock eggs was determined by microscopic examination (Table 1). The number of eggs per m^3 of water filtered and the actual spawning times of the eggs were calculated in order to ascertain when the peak of spawning had occurred. Bathythermograph casts were made at each station. The egg production curves constructed from these data show that maximum spawning occurred in the third week of April (Fig. 1).

Previous Data

Egg abundance data collected on Georges Bank in six different years are presented in Fig. 2. The values for different years are not comparable since different collectors were used and the coverage differed. Values for 1940 and 1941 are based on samples collected in the upper 22 m of the water column (Colton, 1965, Table 2) and those for 1953, 1955, and 1956 on samples in the upper 10 m of the water column (Marak *et al.*, 1961, 1962). The area coverage in 1940 and 1941 was more extensive than in other years including western Georges Bank and the South Channel areas.

The data are useful, however, in indicating the variation in spawning time. The peak of spawning in 1940 appeared to be in late April to early May while in 1941 and 1953 the data suggests mid-March or earlier. In 1955 and 1956 spawning was apparently high in February and March. In 1968 the peak was definitely in April.

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Effect of Temperature

The sharp rise in spawning activity in late March 1968 was accompanied by a sharp rise in bottom temperatures (Fig. 1). Maximum spawning occurred between 3.3° and 5.6°C. A comparison of temperatures during spawning time from earlier surveys reveals similarities between 1940, 1941, and 1968, and 1931 and 1953, 1955, 1956 (Table 2). It was fortuitous that the four surveys had been carried out in years which Taylor, Graham and Bigelow (1957) and Welch (1967) show to include both "cold" and "warm" years. It is interesting to note that during the "warm" years (1931, 1950's) optimum spawning appeared to be prolonged whereas in "cold" years (1940, 1941, 1968) it was of shorter duration. It is also apparent that a 1.5° to 2.0°C temperature change can mean the difference of a month in spawning time.

TABLE 1. Distinguishing features of embryonic development in the six stages and the age in hours and days for eggs developing at 3.3°C (Marak and Colton, 1961)

Stage	Description and time of embryonic development
I	From fertilization to the formation of the early blastodermal cap = 0-72 hr.
II	From the completed blastodermal cap to the development of the segmentation cavity = 4-7 days.
III	From the appearance of the early embryonic axis to the approach of the germinal ring to an equatorial position = 7-9 days.
IV	From the equatorial position of the germinal ring to just before blastopore closure = 10-13 days.
V	From blastopore closure (half circle) to almost full circle (scattered pigmentation) = 14-17 days.
VI	From the formation of the characteristic pigment pattern to hatching = 18-21 days.

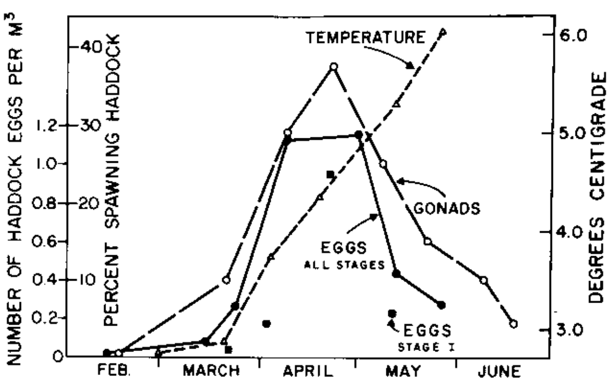

Fig. 1. Haddock spawning intensity in relation to time and temperature in 1968.

TABLE 2. Mean bottom temperatures (°C) on Georges Bank for March and April 1931, 1940, 1941, 1953, 1955, 1956, and 1968.

Year	March	April	
1931	4.1	5.3	Walford
1940	2.5	3.7	Clarke, *et al.*
1941	2.7	3.9	" "
1953	5.1	6.5	Marak, *et al.*
1955	4.5	5.1	" "
1956	3.5	4.3	" "
1968	2.9	4.0	" "

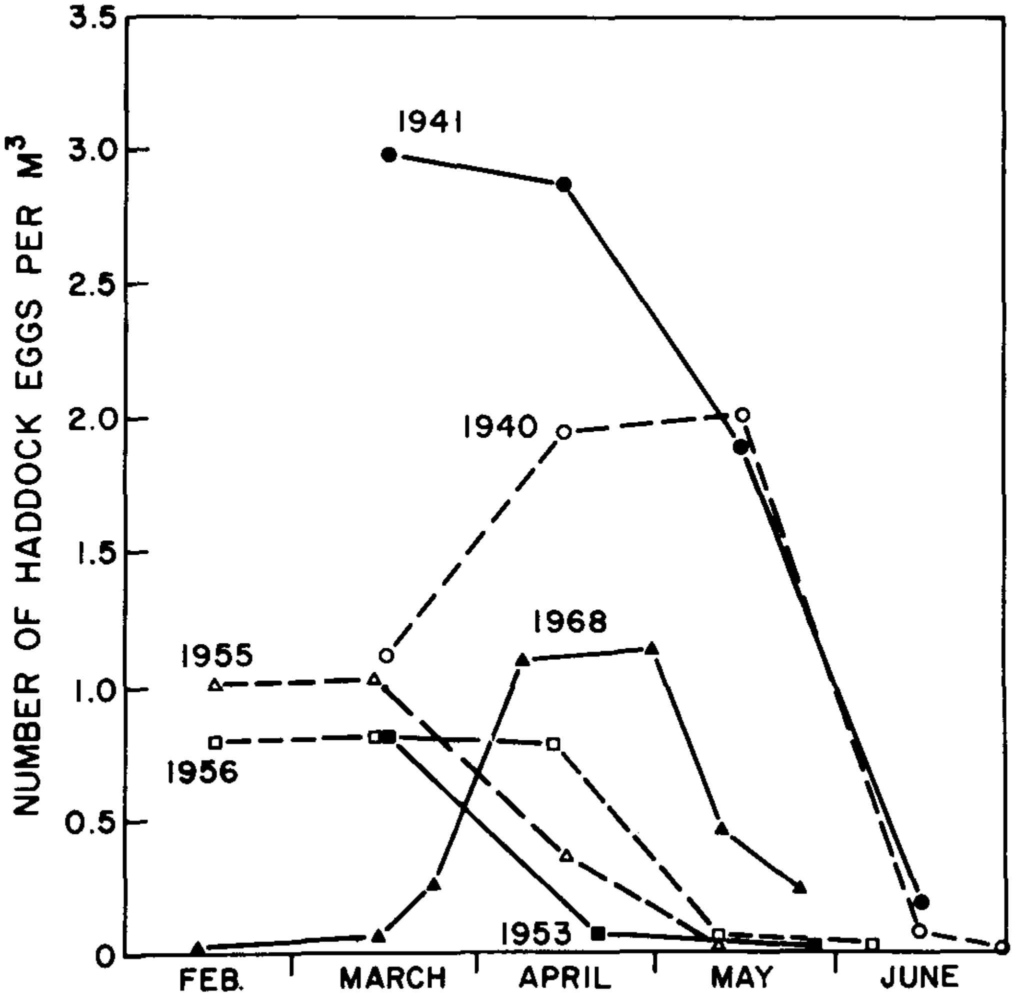

Fig. 2. Haddock egg production curves for 1940, 1941, 1953, 1955, 1956, and 1968.

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Immature Herring Populations in the Bay of Fundy

By Shoukry N. Messieh[1]

Abstract

Monthly length-frequency distributions of I-group herring in the Bay of Fundy were analysed by the probability paper method and three size-groups showed prominently. These groups indicate that herring stocks in this area probably arose from the progeny of spring-, summer-, and autumn-spawning populations. Fluctuations in mean lengths, and their overlapping within and between districts, indicate considerable movement of the different size-groups of herring and their free mixing within these districts.

Introduction

Identification of fish populations is important in forecasting fisheries and in formulating management policies. Hence it is necessary to know whether Atlantic herring of age-group I in the Passamaquoddy area of the Bay of Fundy are composed of one or more unit stocks.

Although some young herring (O-group fish) are recruited to the fishery at the end of their first year, it is mainly I-group fish which are exploited in the "sardine" fishery supporting a major industry in the Bay of Fundy.

Huntsman (1919) suggested that herring in the area were spawned in spring and autumn, and later (1934) considered that, besides those spawned in the spring, fish were spawned from early summer to late autumn. Tibbo *et al.* (1958), on the basis of captures of recently hatched larvae, considered that the fish were spawned in spring and in late summer-autumn, those spawned in the latter season being the major contributors to the fishery.

In this study, length-frequency distributions of I-group fish for each month of the year were analysed by the probability paper method, and modal lengths were examined for possible size-groups. Length data were also separated by fishery districts to examine mixing of size-groups, if any, between districts.

Materials and Methods

This study is based on analysis and examination of 8,020 pairs of herring otoliths collected from commercial catches (Table 1). The fish ranged in length from 75-220 mm, and in age from 0-2 years.

Lengths were measured from the tip of the lower jaw to the longer lobe of the caudal fin extended straight back. They were recorded to the nearest millimetre, and grouped in 0.5-cm intervals.

Ages were estimated from otoliths on the basis of the number of winter zones. Since the majority of fish were hatched in late summer or autumn, a fish was considered age-group O until the end of the calendar year after the one in which it was hatched. For comparison, scales from some (156) fish were measured and used for back-calculating l_1's (fish length at the end of their first year's growth) according to Lee's (1920) method.

As length-frequency distributions of I-group fish appeared to be polymodal, they were analysed by plotting the cumulative frequencies on probability paper and fitting the probable normal curves (Harding, 1949; Cassie, 1950). An example is shown in Fig. 1. By this method, it is aimed to minimize subjective separations of the polymodal distribution. The assumption is that components of the distribution mixture are normal distributions. Length-frequency distribution of individual samples and l_1's distribution support this assumption.

As indices of growth, relative increments (C) and instantaneous (geometric) growth rates (K) were calculated (Briuzgin, 1963; Brody, 1945) as follows:

$$C = \frac{l_2 - l_1}{l_1}$$

$$K = \frac{\log_e l_2 - \log_e l_1}{t_2 - t_1}$$

where l_1 and l_2 are fish lengths at the beginning (t_1) and the end (t_2) of the year.

To test the reliability of age samples as representative of the catch, length-frequency distribution of age samples were compared with those of the catch samples. The latter included 11,727 fish which were

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TABLE 1. Summary of herring samples showing numbers of fish by districts and ages.

Sampling year	No. of samples	No. of fish	No. of fish by districts: Passama-quoddy	East Charlotte	West Iles	Grand Manan	Age distribution: 0	1	2
1965	30	1388	339	384	333	332	85	1303	
1966	39	1493	332	823	185	153	140	588	765
1967	52	2481	1093	901	198	289	703	1736	42
1968	58	2659	771	1055	194	639	480	2153	26
Total	179	8021	2535	3163	910	1413	1408	5780	833

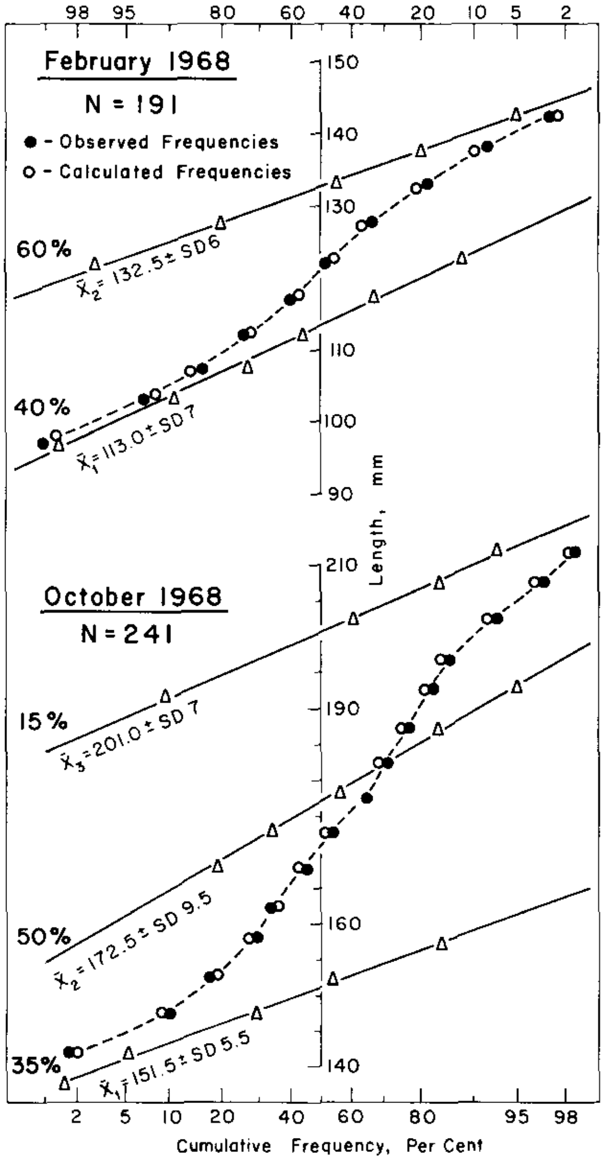

Fig. 1. Probability plot of length-frequency distribution for bimodal and trimodal samples.

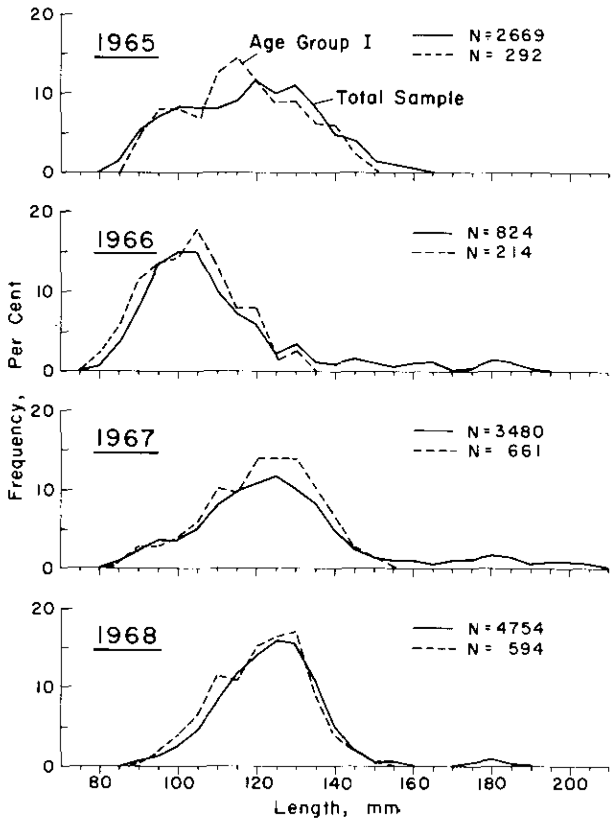

Fig. 2. Length-frequency distribution of age samples (I-group herring) and total samples in the first quarters of 1965 through 1968. (Data for total samples in 1965 through 1967 are extracted from Messieh *et al.* 1968).

sampled in the first quarters of 1965 through 1968 (Fig. 2).

Results

The mean lengths for monthly samples of the three age-groups (Fig. 3) showed similar trends in annual growth for I-group fish during the sampling years and that growth was negligible during winter.

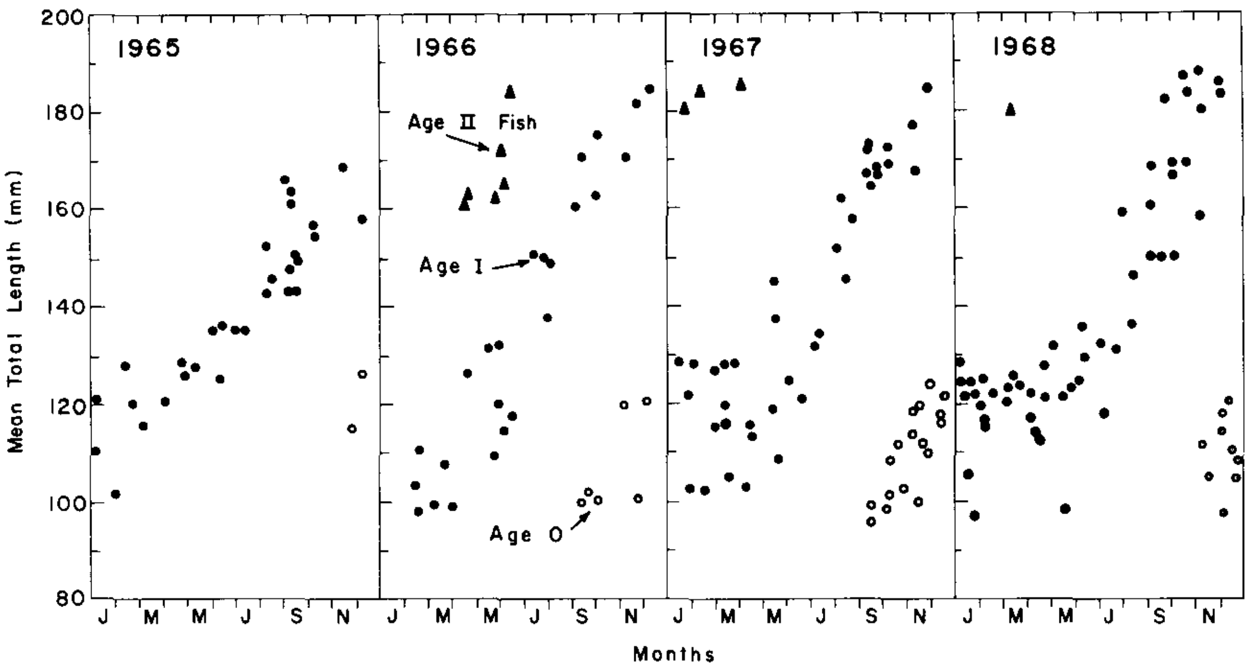

Fig. 3. Scatter diagram showing the relationship between mean length at age and capture date.

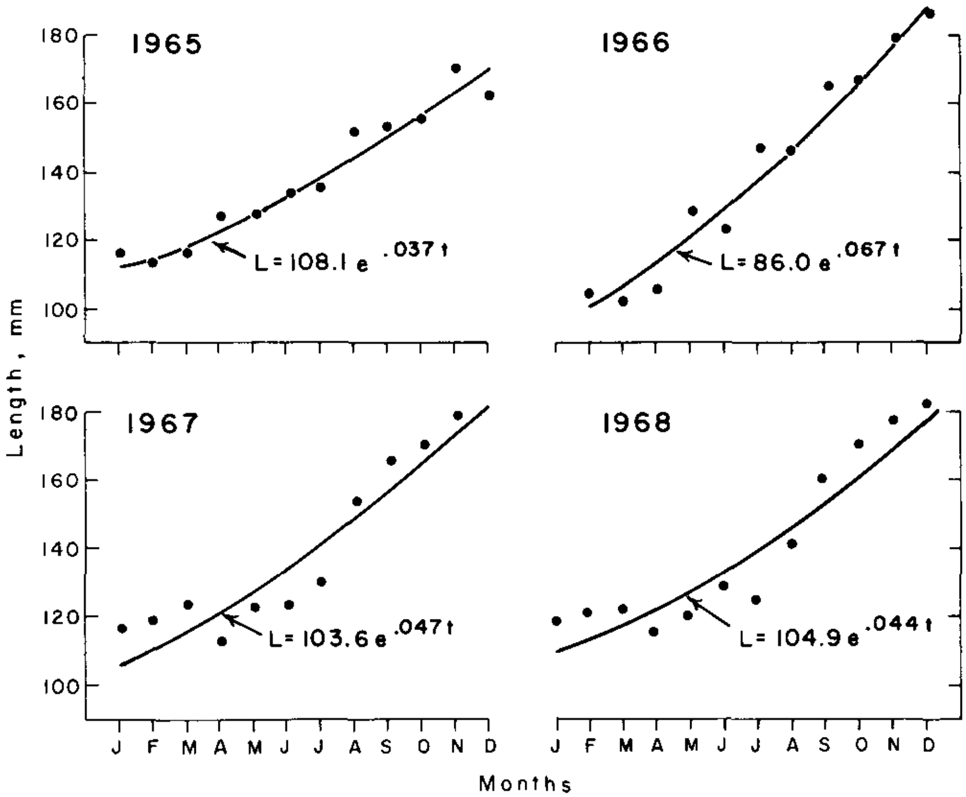

Fig. 4. Growth curves of I-group herring in four sampling years.

TABLE 2. Monthly mean lengths, increments, and growth rates of I-group herring in 1965-68 sampling years. N = number of fish; $\overline{X}$ = mean length (mm); S.D. = standard deviation; I = increment per month (mm)

Month	1965				1966				1967				1968			
	N	$\overline{X}$	S.D.	I	N	$\overline{X}$	S.D.	I	N	$\overline{X}$	S.D.	I	N	$\overline{X}$	S.D.	I
Jan.	97	115.8	12.4	–	–	–	–	–	163	118.2	14.7	–	273	120.5	12.6	–
Feb.	97	114.9	18.1	– 0.9	133	102.8	11.8	–	267	120.0	14.0	1.8	191	120.9	12.0	0.4
Mar.	98	117.7	13.2	2.8	81	102.5	12.0	0.3	231	123.9	14.2	3.9	130	122.3	10.9	1.3
Apr.	48	126.7	11.8	9.0	57	103.7	13.0	1.2	188	112.5	13.2	–11.4	278	118.9	13.9	– 3.4
May	99	129.4	15.9	2.7	7	128.6	15.5	24.9	235	122.5	18.4	10.0	227	120.9	16.0	2.1
June	153	132.4	11.6	3.0	63	121.3	12.3	– 7.3	48	125.5	14.8	3.0	236	130.6	11.7	9.7
July	49	135.3	13.9	2.9	23	145.7	20.3	24.4	82	132.6	14.7	7.1	99	125.3	12.7	– 5.3
Aug.	194	152.0	15.2	16.7	69	145.4	11.8	– 0.3	165	156.2	14.8	23.6	98	141.9	11.9	16.6
Sep.	319	152.5	13.6	0.5	29	164.8	9.8	19.4	195	167.2	13.2	11.0	211	162.9	18.7	21.1
Oct.	93	155.8	9.3	3.3	57	167.1	12.1	2.3	85	171.0	14.6	3.8	241	172.0	19.0	9.1
Nov.	49	169.8	9.7	14.0	51	177.4	10.6	10.3	77	180.3	15.2	9.3	121	179.5	–	7.4
Dec.	7	161.4	8.0	– 8.4	18	185.3	10.6	7.9	–	–	–	–	48	184.1	9.8	4.6
Increment per year			45.6			82.5				62.1				63.6		
Relative growth			.394			.803				.525				.528		
Instantaneous growth rate			.332			.589				.423				.423		

The mean lengths of I-group fish for the various months (Fig. 4) showed that growth was exponential in all years.

The least-squares fit of the mean lengths for the various months gave regression coefficients of .037, .067, .047, and .044 for 1965 through 1968, respectively.

Instantaneous growth rates were similar to relative growth (Table 2); each had the same fluctuations as the other. However, the former indicated lower values, as would be expected during the first year of life (Briuzgin, 1963).

Size-groups

Analysis of cumulative length frequencies on probability paper indicated that three size-groups were represented in some samples, as in 1968 (Fig. 5).

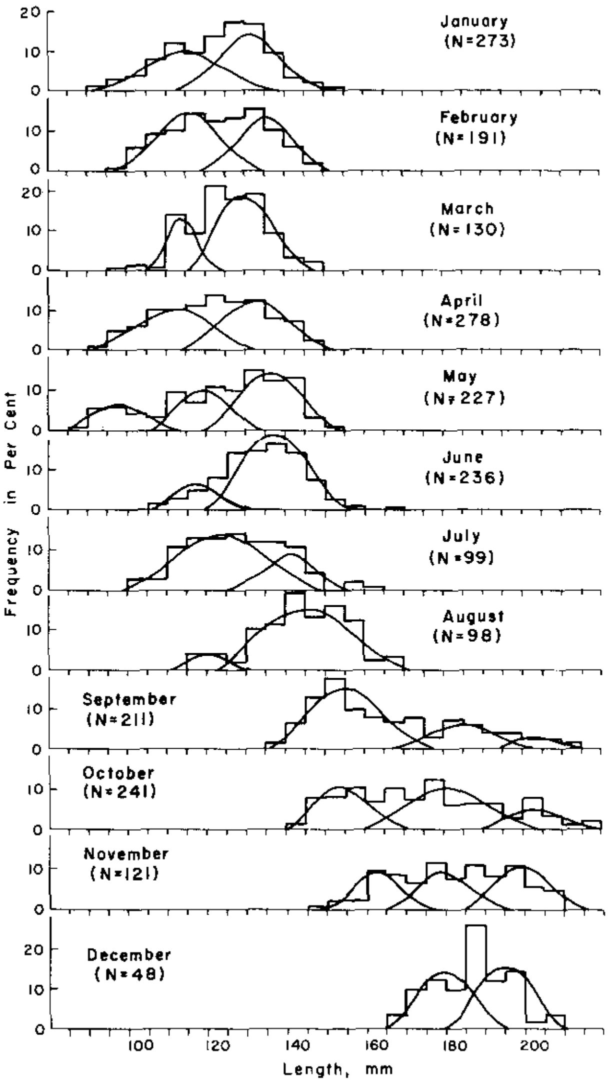

Fig. 5. Monthly length-frequency distributions of I-group herring in 1968 showing the probable normal curves.

Plotting mean lengths of normal curves for various months and joining the points visually (Fig. 6) showed three size-groups and, of these, two size-groups were well represented in all sampling years.

To test the significance of differences between these size-groups, data from 1968 samples (Table 3) were subjected to Z-test for comparing mean lengths. In all cases, the differences between mean lengths of size-groups within months were highly significant ($P < .001$).

Back-calculated l_1's from scales (Fig. 7) showed bimodal frequency distributions similar to observed lengths, and fell in similar length ranges, indicating agreement between calculated and observed length estimates based on scales and otoliths, respectively.

Monthly length increments of I-group fish (Table 2) showed wide fluctuations, and their values in some months were negative. These fluctuations reflect the heterogeneity of the fishery.

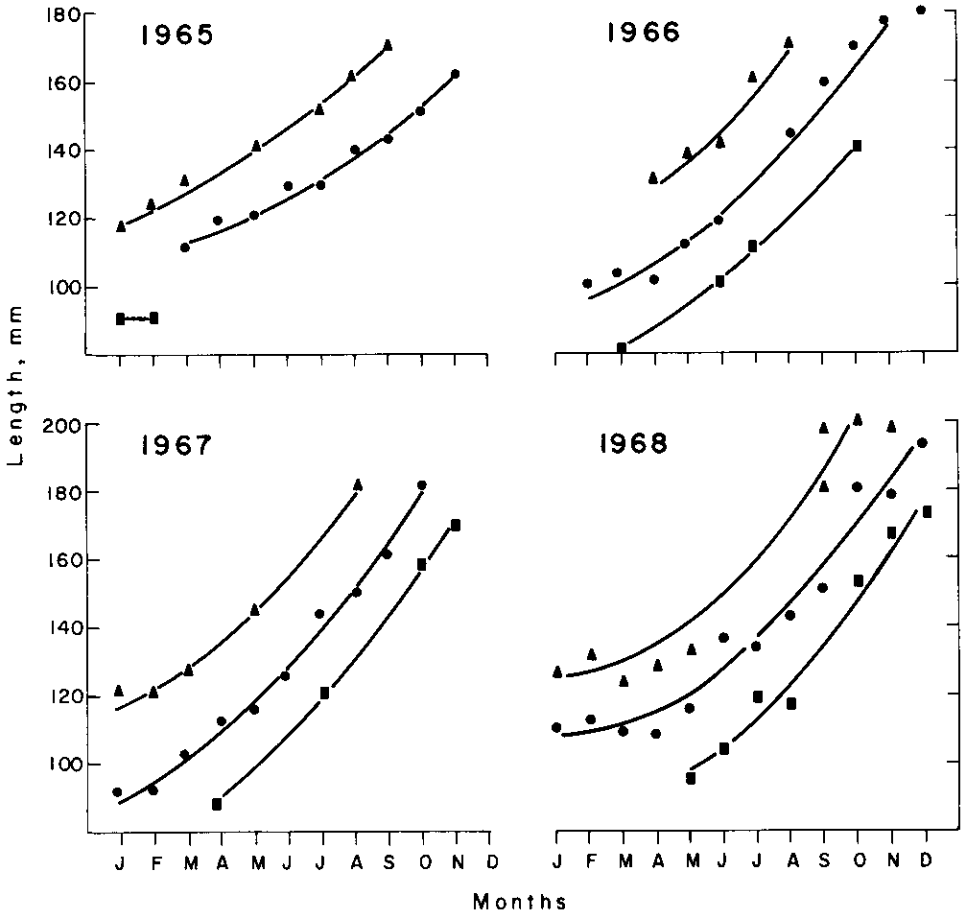

Fig. 6. Hypothetical growth curves of different size-groups within I-group herring.

TABLE 3. Mean lengths (mm) of probable normal curves of monthly length-frequency distributions for 1968 sampling year. Numbers of fish (N) and standard deviations (S.D.) of samples are included.

Month	N	L	S.D.	N	L	S.D.	N	L	S.D.
Jan.	133	111.3	9.57	135	129.1	7.30	–		–
Feb.	115	113.3	7.92	75	127.3	5.95	–		
Mar.	32	111.1	3.53	90	126.7	6.70	–		
Apr.	139	108.5	10.27	144	130.2	8.31		–	–
May	45	96.4	5.60	70	116.5	5.54	112	133.7	6.25
June	36	115.0	5.86	197	135.0	8.11	–	–	–
July	69	119.1	8.70	22	136.8	5.01		–	–
Aug.	9	118.3	3.54	87	141.8	11.10	–	–	–
Sep.	146	152.2	8.57	40	180.9	6.78	14	196.1	5.94
Oct.	85	151.3	6.08	121	177.4	9.53	34	200.2	5.97
Nov.	34	159.6	6.44	39	177.7	6.87	43	197.7	6.58
Dec.	22	177.9	6.11	24	192.5	6.08		–	–

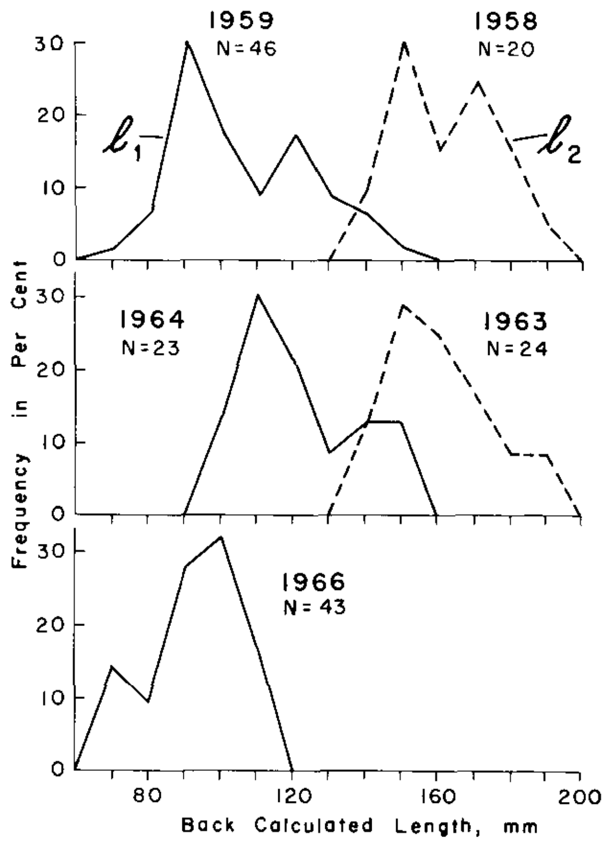

Fig. 7. Frequency distributions of back-calculated l_1's and l_2's for five year-classes of herring.

Distribution of size-groups by districts

Quarterly mean lengths of I-group fish in four fishery districts (Fig. 8) showed that the length increments within a district did not follow a particular order, and in some cases overlapped. This can be seen in the values for the third and fourth quarters of 1965 in West Isles, and in the first and second quarters of 1968 in East Charlotte. Overlapping of quarterly mean lengths between districts and, in many cases, for all sampling years was obvious (Fig. 8).

Discussion

The polymodal nature of length-frequency distributions of I-group herring reflects the diversity of population elements exploited by the fishery. The fact that the samples were taken mainly from weirs excludes the possibility of extrinsic factors resulting from selectivity of the gear. Hence the segregation of size-groups is attributed to intrinsic factors, probably behavioural differences. Graham (1936) found that herring were generally segregated into schools of similar lengths within an age-group.

The consistency of the different size-groups of herring in all sampling years coincides with the spawning seasons described for herring in the area, i.e. spring and autumn spawners (Huntsman, 1934; Tibbo *et al.*, 1958).

The origin of spring-spawned herring, whether from local stocks or immigrants, is still questionable (Huntsman, 1934; Das, 1968). However, they were

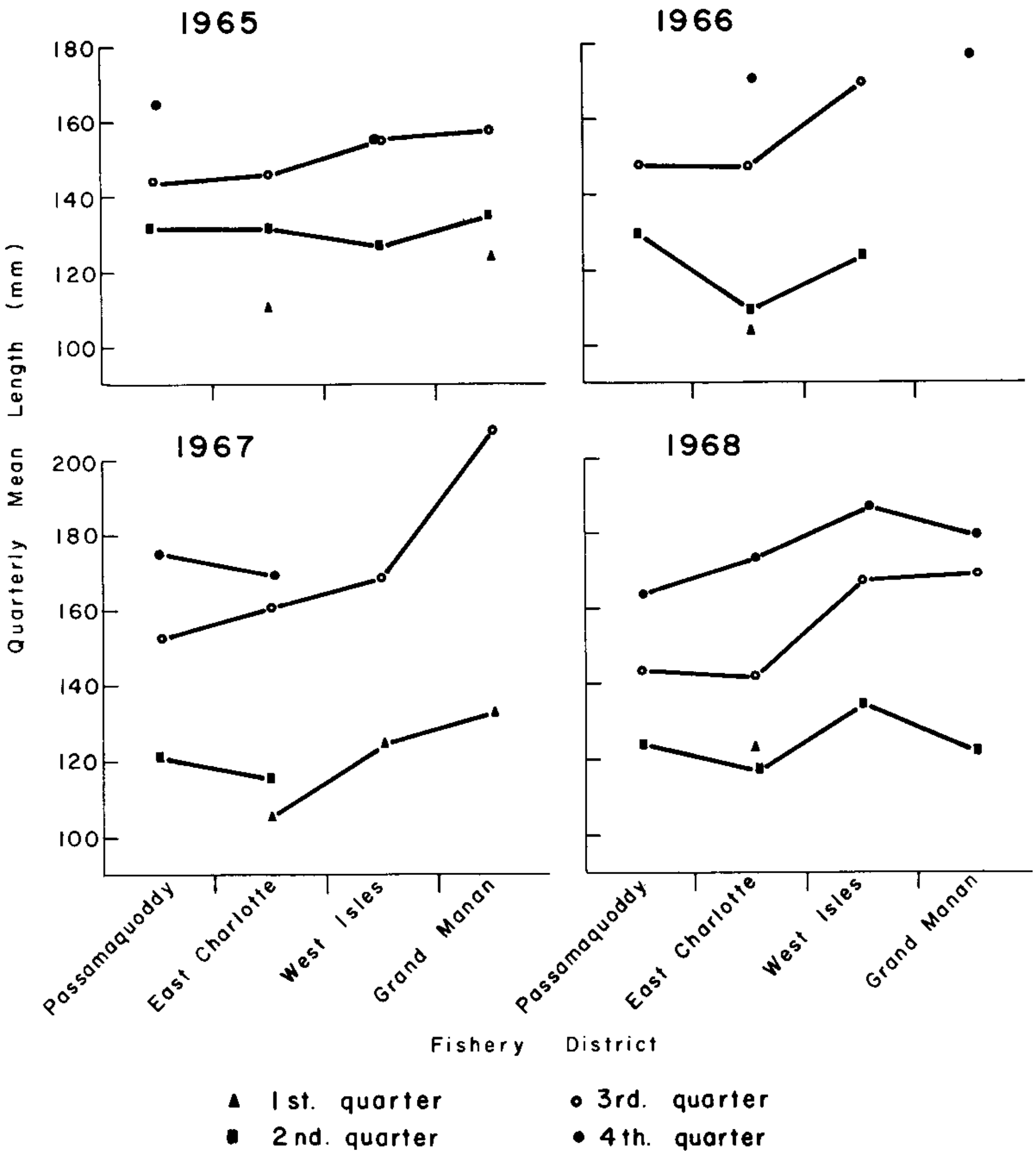

Fig. 8. Quarterly mean lengths of I-group herring by fishing districts.

considered to be minor contributors to the herring stocks in the Bay of Fundy. This group of fish was probably represented by the minor size-group which appeared in the spring, e.g. in May 1968 (Fig. 5).

The summer-autumn spawnings likely lead to two other size-groups resulting from early and late hatchings. Only the early spawned part of the hatched larvae could metamorphose before the winter; the remainder, spawned late, may fail to metamorphose due to the drop in water temperature and overwinter as larvae. Based on the existing knowledge of the absence of any winter-spawning herring in this area, the finding of herring larvae in the Bay of Fundy during winter (Tibbo *et al.*, 1958) supports the above hypothesis.

Fluctuation in mean lengths, and their overlapping within and between districts (Fig. 8), indicate considerable movement of the different size-groups of herring and their free mixing among these districts.

Huntsman (1952) suggested that herring are carried from the Gulf of Maine to the Bay of Fundy and then concentrated in Passamaquoddy Bay by the slow circulation of water due to Coriolis force. On such an assumption, the size-groups reported in the present study probably arose from different herring stocks transported partly from the Gulf of Maine.

A similar situation was described for North Sea herring (e.g. Cushing, 1962). Young herring derived from the different spawning grounds form a common pool of prerecruits, with a shared nursery ground on the Danish coast. With increasing age and growth they move off into deeper water until they join the adult population.

It is also worthy to note that Anthony and Boyar (1968) found that the herring population in the Gulf of Maine is composed of two groups: coastal Maine-Nova Scotia complex, and Georges Bank-Cape Cod complex. They indicated that within a complex there is probably more than one herring stock.

Acknowledgments

I am grateful to Mr S. N. Tibbo for his advice during this study, Mr A. Sreedharan for suggestions concerning statistical analysis, Mr Monaghan and Mrs Burnett for technical assistance.

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International Commission for the Northwest Atlantic Fisheries

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

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