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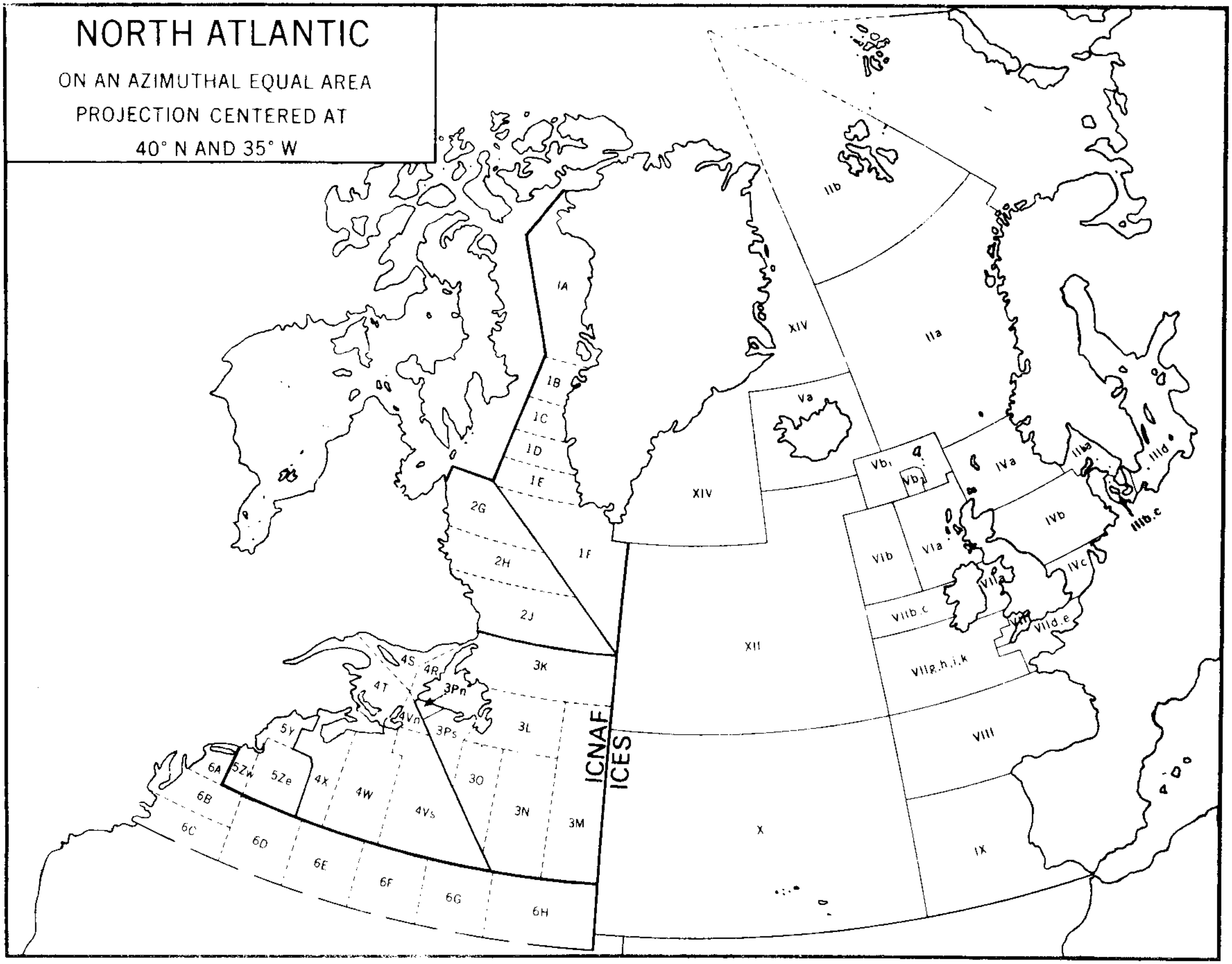

NORTH ATLANTIC

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

Contents

Use of Meristic Characters and a Discriminant Function for Classifying Spring-and Autumn-Spawning Atlantic Herring

By L. S. Parsons[1]

Abstract

From 79 to 91 percent of individual spring- and autumn- spawning Atlantic herring were correctly classified to their respective spawning groups by the use of a linear discriminant function based on three meristic characters – pectoral and anal fin rays and gill rakers. These discriminant function analyses demonstrate that the spring- and autumn-spawning components of the Southwest Newfoundland-southern Gulf of St. Lawrence herring stock complex constitute distinct breeding populations, the amount of interchange between spawning groups being slight.

Introduction

The herring concentrations which overwinter in the fjords of southwestern Newfoundland from late November to April and support an intensive winter purse seine fishery consist of two spawning groups, autumn spawners comprising two-thirds of the population, spring spawners the remainder (Hodder, 1970; Hodder and Parsons, MS, 1970; 1971). Studies on this herring stock complex have revealed significant meristic differences between spring- and autumn-spawning herring (Parsons and Hodder, 1971*a*). Mean numbers of gill rakers and of pectoral, anal and dorsal fin rays are all higher for autumn spawners than for spring spawners, with gill raker and pectoral fin-ray numbers exhibiting the greatest degree of difference between spawning groups.

Several Canadian investigators who have studied the vertebral counts of herring in the western North Atlantic have found no significant difference between the mean vertebral numbers of spring and autumn spawners (Jean, 1956; Day, 1957; Tibbo, 1957; Parsons and Hodder, 1971*a*). From similarities in mean vertebral numbers and head length of spring- and autumn-spawning herring at Grande Rivière, Quebec, Jean (1956) concluded that each spawning population was a mixture of fish hatched in the spring and fish hatched in the autumn. However, the distinct differences in mean numbers of fin rays and gill rakers found by Parsons and Hodder (1971*a*) indicate that spring- and autumn-spawning herring belong to relatively distinct breeding populations.

To further evalute the use of meristic characters as indices for racial separation, it is necessary to consider several characters simultaneously. Fisher (1936) derived the linear discriminant function, a multivariate statistical technique for classifying individuals to one of two populations. This technique has been widely used in recent years for discriminating between racial groups (Hill, 1959; Fukuhara *et al.*, 1962; Kilambi, MS, 1965; Anas and Murai, 1969). Basically this method involves reducing a set of counts or measurements from an individual to a single value by which the individual can be classified as being from one group or the other. Detailed discussions of the statistical techniques employed in the construction of a discriminant function are given by Fisher (1936), Mahalanobis (1936), Rao (1952), Fukuhara *et al.*, (1962) and Andersen (1966).

This paper applies the technique of discriminant function analysis to herring meristic data for spring and autumn spawners and assesses the usefulness of such data for classifying individual herring to their respective spawning groups.

Materials and Methods

The samples used in this study were taken at random from the landings of purse seiners which obtained their catches along southwestern Newfoundland and in the vicinity of the Bird Rocks, just north of the Magdalen Islands (Table 1).

Stage of maturity was determined by gross examination of gonads using the various stages of gonadal development as adopted by ICNAF in 1964 (ICNAF, 1964). Immature specimens have not been included in the data analyses. Since there was little change in gonadal development during the period under consideration (November-April), each of the adults could be assigned to one of two categories on the basis

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TABLE 1. Date and locality of capture and maturity condition of herring samples used in this study.

Sample No.	Date of capture	Locality	Maturity condition			
			Immature	Spring spawners	Autumn spawners	Total
	1969					
1	22 Nov.	Burgeo, Southwest Nfld.	–	10	40	50
2	25 Nov.	Burgeo, Southwest Nfld.	1	11	38	50
3	25 Nov.	White Bear Bay, Southwest Nfld.	–	13	37	50
4	29 Nov.	Cape LaHune, Southwest Nfld.	–	9	41	50
5	30 Nov.	Bay de Vieux, Southwest Nfld.	1	14	35	50
6	1 Dec.	White Bear Bay, Southwest Nfld.	–	14	36	50
7	1 Dec.	Burgeo, Southwest Nfld.	–	25	25	50
8	4 Dec.	La Poile Bay, Southwest Nfld.	1	10	39	50
9	5 Dec.	White Bear Bay, Southwest Nfld.	1	22	27	50
10	12 Dec.	Burgeo, Southwest Nfld.	–	11	39	50
			4	139	357	500
11	1 Nov.	Magdalen Islands	–	11	39	50
12	2 Nov.	Magdalen Islands	4	10	36	50
13	2 Nov.	Magdalen Islands	6	11	33	50
14	8 Nov.	Magdalen Islands	5	14	31	50
15	9 Nov.	Magdalen Islands	–	14	36	50
16	17 Nov.	Magdalen Islands	1	6	43	50
17	17 Nov.	Magdalen Islands	3	14	33	50
18	17 Nov.	Magdalen Islands	–	10	40	50
19	17 Nov.	Magdalen Islands	1	10	39	50
20	17 Nov.	Magdalen Islands	–	12	38	50
			20	112	368	500
21	21 Jan.	La Poile Bay, Southwest Nfld.	–	16	34	50
22	28 Jan.	La Poile Bay, Southwest Nfld.	–	26	24	50
			–	42	58	100
	1970					
23	1 Apr.	Grand Bay, Southwest Nfld.	–	16	34	50
24	1 Apr.	Pigeon Island, Southwest Nfld.	–	19	31	50
			–	35	65	100

of gonadal development. Those with well-developed gonads (Stage IV) were designated as spring spawners and those showing little if any gonad development (Stage VIII) were classed as autumn spawners.

Meristic counts were determined as described by Parsons and Hodder (1971*a*). Three meristic characters were used in the discriminant function analyses – pectoral and anal fin rays and gill rakers on the lower branch (hypobranchial and ceratobranchial) of the first left gill arch. The few damaged specimens for which meristic data were incomplete were not included in these analyses. Discriminant analyses were made with the Multiple Discriminant Analysis Program (DISCR) for the IBM 1130 computer (Pienaar and Thomson, MS, 1967) as modified by E. J. Sandeman of the St. John's Biological Station.

Results

Analyses of variance showed no significant ($P > 0.05$) meristic variation between samples within each major period and area for either spring or autumn spawners. Arithmetic regression coefficients of meristic number on total length did not differ significantly ($P > 0.05$) from the null hypothesis; hence, length was not considered to be a source of variation.

A linear discriminant function was computed for 131 spring spawners and 343 autumn spawners from southwestern Newfoundland taken during late November-early December 1969. Means and differences between means of the two spawning groups are given in Table 2. The discriminant function for these data is

$$Y = 0.9157X_1 + 0.3420X_2 + 0.2110X_3$$

In this equation X_1, X_2 and X_3 represent the numbers of pectoral and anal fin rays and gill rakers respectively.

TABLE 2. Means and differences between means for autumn and spring spawners from southwestern Newfoundland (November-December 1969).

Character	Mean for autumn spawners	Mean for spring spawners	Difference
Pectoral fin rays (X_1)	18.571	17.183	1.388
Anal fin rays (X_2)	18.149	17.595	0.554
Gill rakers (X_3)	49.163	47.573	1.590

The estimated mean values of the coefficients of the discriminant function for the spring spawners ($\overline{Y}_s$) and the autumn spawners ($\overline{Y}_a$) were determined by substituting $\overline{X}_i$, the mean numbers of each of the three meristic characters for each spawning group, into the function. The values of $\overline{Y}_s$ and $\overline{Y}_a$ were 31.792 and 33.588 respectively. Therefore, in discriminating between the two spawning groups, those fish with a value of Y less than 32.690 are classified as spring spawners and those with values of Y more than 32.690 are classified as autumn spawners. An analysis of variance revealed that differences between the two spawning groups were significant at less than the 0.001 level ($F_{3,470} = 129.34$).

The variance of Y is D^2 and is given by

$$D^2 = l_1 d_1 + l_2 d_2 + l_3 d_3$$

where l_1, l_2 and l_3 are the coefficients of the discriminant function and d_1, d_2 and d_3 are the differences between the estimated population means of the three characters (Table 2). The probability of correctly assigning an individual fish to its respective spawning group is equal to the probability that a normal deviate with mean zero and standard deviation of 1 will be less than or equal to ½D (Rao, 1952). Since D^2 in this instance is 1.796, the probability of misclassification is approximately 25.2%. This error of classification would be the proportion of spring spawners having Y values less than 32.690 and the proportion of autumn spawners having Y values more than 32.690.

This discriminant function was then used to classify individual fish in the original samples from which the function was derived and also to classify individuals in January 1969 and April 1970 samples from southwestern Newfoundland and November 1969 samples from the Magdalen Islands area. The resulting frequencies and percentages of Y values above and below the critical value 32.690 (Y_o) are shown in Table 3. The percentages of misclassification of autumn spawners in the January 1969 and April 1970 samples from southwestern Newfoundland and the November 1969 samples from Magdalen Islands were in close agreement

TABLE 3. Frequency and percentage of the values (Y) of the discriminant function above and below the critical value 32.690 (Y_o) for autumn and spring spawners from southwestern Newfoundland and Magdalen Islands.

		Classification matrix				
		Frequency			Percent	
Locality and time of capture	Spawning[1] group	$Y > Y_o$[2]	$Y < Y_o$[3]	Total	$Y > Y_o$[2]	$Y < Y_o$[3]
Southwestern Nfld. (Nov.-Dec. 1969)[4]	Autumn	287	56	343	83.7	16.3
	Spring	18	113	131	13.7	86.3
Southwestern Nfld. (Jan. 1969)	Autumn	47	11	58	81.0	19.0
	Spring	8	34	42	19.0	81.0
Southwestern Nfld. (Apr. 1970)	Autumn	56	9	65	86.2	13.8
	Spring	7	27	34	20.6	79.4
Magdalen Islands (Nov. 1969)	Autumn	290	70	360	80.6	19.4
	Spring	10	98	108	9.3	90.7

[1] Based on gonad maturity. [2] Classified as autumn spawners. [3] Classified as spring spawners. [4] Source data for discriminant function.

with the percentage of misclassification of the southwestern Newfoundland autumn spawners used in the construction of the discriminant function. Percentages of misclassification of spring spawners in the January 1969 and April 1970 southwestern Newfoundland samples were very similar to that resulting from classification of the southwestern Newfoundland spring spawners upon which the function was based. The percentage of misclassification for Magdalen Islands spring spawners (9.3%) was even less than for those from southwestern Newfoundland.

The actual errors of misclassification for both spawning groups were in all instances less than the 25.2% average error of misclassification inherent to the function. Percentages of correct classification range from 80.6 to 86.2% for autumn spawners and from 79.4 to 90.7% for spring spawners.

Discussion

Meristic characters exhibit plasticity under the influence of environmental factors, especially temperature, during the incubation period and early larval life (Schmidt, 1921; Vladykov, 1934; Tåning, 1944; Lindsey, 1954; Barlow, 1961). Hempel and Blaxter (1961) demonstrated that the myotome count of Atlantic herring is determined before hatching and that vertebral number is modified by incubation temperature. However, Barlow (1961) cites several studies which have shown a genetic as well as a phenotypic basis for meristic characters in various fish species. Differences in the mean numbers of fins rays of spring- and autumn-spawning Atlantic herring appear to be related to water temperatures during early development and to differences in developmental rates of spring- and autumn-hatched larvae (Parsons and Hodder, 1971*a*). Autumn-hatched larvae develop during a period of declining water temperatures in the autumn; spring-hatched larvae develop during a period of increasing water temperatures. Thus temperatures at the time of fin ray fixation, which apparently occurs during the larval stage (Lebour, 1921; Tåning, 1944; Blaxter, 1962), are higher for spring-hatched than for autumn-hatched larvae. Autumn-hatched larvae have a longer period of development than spring-hatched larvae (Jean, 1956) and, hence, would be expected to have higher mean fin ray numbers than spring-hatched larvae.

Blaxter (1958) presented evidence which suggests that the difference in spawning season between the two groups is genetical and is based on different responses to the environment. In an earlier paper Blaxter (1956) reported that under experimental conditions spring-spawned eggs were markedly inviable at autumn spawning temperatures. He concluded that in typical spring- and autumn-spawning herring groups reproductive isolation exists, although a slight amount of interchange probably occurs, and suggested that spring- and autumn-spawning herring may be referred to as different sibling species, using the main criterion of difference in breeding season.

The results of the discriminant function analyses reported here support the conclusion of Parsons and Hodder (1971*a*) that the spring- and autumn spawning components of the herring stock complex which migrates eastward from the southern Gulf of St. Lawrence in the autumn to overwintering areas along southwestern Newfoundland and westward again into the Gulf in the spring (Hodder and Parsons, MS, 1970; 1971; Hodder and Winters, MS, 1970; Winters, 1970; Parsons and Hodder, 1971*b*) are not members of a homogeneous group but constitute distinct breeding populations which developed at different times of the year under different environmental conditions. From 79 to 91% of individual spring and autumn spawners can be correctly classified to their respective spawning groups by the use of a linear discriminant function based on three meristic characters. This clearly demonstrates that the vast majority of autumn spawners are the progeny of herring which spawned in the autumn and spring spawners of herring which spawned in the spring. The amount of interchange between the two spawning groups is probably slight.

Acknowledgements

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References

ANAS, R. E., and S. MURAI. 1969. Use of scale characters and a discriminant function for classifying sockeye salmon (*Oncorhynchus nerka*) by continent of origin. *Bull. int. N. Pacif. Fish. Comm.*, **26**: 157-192.

ANDERSEN, K. P. 1966. Classification of Inopidae by means of principal components and discriminant functions. *Galathea Rept.*, **8**: 77-90.

BARLOW, G. W. 1961. Causes and significance of morphological variation in fishes. *Syst. Zool.*, **10**(3): 105-117.

BLAXTER, J.H.S. 1956. Herring rearing – II. The effect of temperature and other factors on development. *Mar. Res.*, No. 5, 19p.

1958. The racial problem in herring from the viewpoint of recent physiological, evolutionary and genetical theory. *Rapp. Cons. Explor. Mer*, **143** (II): 10-19.

1962. Herring rearing – IV. Rearing beyond the yolk-sac stage. *Mar. Res.*, No. 1, 18 p.

DAY, L. R. 1957. Populations of herring in the southern Gulf of St. Lawrence. *Bull. Fish. Res. Bd. Canada*, **111**: 121-137.

FISHER, R. A. 1936. The use of multiple measurements in toxonomic problems. *Ann. Eugen.*, 7(2): 179-188.

FUKUHARA, F. M., S. MURAI, J. J. LaLONNE, and A. SRIBHIBHADH. 1962. Continental origin of red salmon as determined from morphological characters. *Bull. int. N. Pacif. Fish. Comm.*, **8**: 15-109.

HEMPEL, G., and J.H.S. BLAXTER. 1961. The experimental modification of meristic characters in herring (*Clupea harengus* L.). *J. Cons.*, **26**: 336-346.

HILL, D. R. 1959. Some uses of statistical analysis in classifying races of American shad (*Alosa sapidissima*). *Fish. Bull., U.S.*, **147**: 269-286.

HODDER, V. M. 1970. Recent developments in the Newfoundland herring fishery. *Fish. Res. Bd. Canada, Biol. Sta. St. John's, Nfld., Circ.*, **18**: 1-19.

HODDER, V. M., and L. S. PARSONS. MS, 1970. A comparative study of herring taken at Magdalen Islands and along southwestern Newfoundland during the 1969 autumn fishery. *Annu. Meet. int. Comm. Northw. Atlant. Fish. 1970*, Res. Doc. No. 77. Serial No. 2425 (mimeographed).

1971. Comparison of certain biological characteristics of herring from Magdalen Islands and southwestern Newfoundland. *Res. Bull. int. Comm. Northw. Atlant. Fish.*, No. 8, p. 59-65.

HODDER, V. M., and G. H. WINTERS. MS, 1970. Preliminary results of herring tagging in southwestern Newfoundland, March 1970. *Annu. Meet. int. Comm. Northw. Atlant. Fish. 1970*, Res. Doc. No. 89, Serial No. 2440 (mimeographed).

ICNAF. 1964. Report of Standing Committee on Research and Statistics. App. I. Report of *ad hoc* group on herring and other pelagic fish. *Int. Comm. Northw. Atlant. Fish. Redbook 1964*, Part I: 23-30.

JEAN, Y. 1956. A study of spring- and fall-spawning herring at Grande Rivière, Bay of Chaleur, Quebec. *Contr. Dept. Fish., Quebec*, No. 49, 76 p.

KILAMBI, V. R. MS, 1965. Heterogeneity among three spawning populations of the surf smelt, *Hypomesus pretiosus* (Girard) in the State of Washington. Ph.D. Thesis. University of Washington.

LEBOUR, M. V. 1921. The larval and post-larval stages of the pilchard, sprat and herring from the Plymouth District. *J. mar. biol. Ass. U.K.*, **12**(3): 427-457, 12 figs.

LINDSEY, C. C. 1954. Temperature-controlled meristic variation in the paradise fish *Macropodus opercularis* (L.). *Canad. J. Zool.*, **32**: 87-98.

MAHALANOBIS, P. C. 1936. On the generalized distances in statistics. *Proc. Nat. Inst. Sci. India*, **2**(1): 49-55.

PARSONS, L. S., and V. M. HODDER. 1971*a*. Meristic differences between spring- and autumn-spawning Atlantic herring (*Clupea harengus harengus* L.) from southwestern Newfoundland. *J. Fish. Res. Bd. Canada*, **28**: 553-558.

1971*b*. Variation in the incidence of larval nematodes in herring from Canadian Atlantic waters. *Res. Bull. int. Comm. Northw. Atlant. Fish.*, No. 8, p. 5-14.

PIENAAR, L. V., and J. A. THOMSON. MS, 1967. A program for multiple discriminant function (FORTRAN 1130). *Fish. Res. Bd. Canada, Tech. Rept.*, No. 40, 32 p.

RAO, R. C. 1952. Advanced statistical methods in biometric research. John Wiley and Sons, Inc., New York, 390 p.

SCHMIDT, J. 1921. Racial investigations. VII. Annual fluctuations of racial characters in *Zoarces viviparus* L. *C. R. Lab. Carlsberg*, **14**: 1-24.

TÅNING, Å. V. 1944. Experiments on meristic and other characters in fishes. I. On the influence of temperature on some meristic characters in sea-trout and the fixation-period of these characters. *Medd. Komm. Fisk. Havundersøg.*, **11**(3): 1-66.

TIBBO, S. N. 1957. Herring of the Chaleur Bay area. *Bull. Fish. Res. Bd. Canada*, **111**: 85-102.

VLADYKOV, V. D. 1934. Environmental and taxonomic characters of fishes. *Trans. R. Canad. Inst.*, **20**: 99-140.

WINTERS, G. H. 1970. Preliminary results of herring tagging in southwest Newfoundland coastal waters, 1970. *Fish. Res. Bd. Canada, Biol. Sta. St. John's, Nfld., Circ.*, **18**: 20-24.

Measured Towing Characteristics of Canadian East Coast Otter Trawls

By P. J. G. Carrothers[1] and T. J. Foulkes[1]

Abstract

Nine different commercial types of groundfish trawls in 15 different riggings have been measured by recording instruments over a wide range of towing speeds during special experimental tows.

The dependence of headline height, wing spread, total trawl drag, and average warp tension on the speed of the trawl through the water is presented graphically, and some of the more obvious functional trends are discussed.

The Trawl Research Program

The purpose of the major fishing gear engineering research program at the Fisheries Research Board of Canada Biological Station, St. Andrews, New Brunswick, is to establish verified engineering principles for the rational design of groundfish otter trawls such as are used by the Canadian fisheries in the Northwest Atlantic. The first phase of the program was the development of suitable, specialized instrumentation, as described by Carrothers (1968) for measuring pertinent variables in full-scale trawls while under tow. The second phase of the program was to take measurements with typical commercial trawls under experimental conditions at sea. The data so acquired have been subjected to primary reduction and have been reported in detail by Carrothers *et. al.*, 1969. The third phase of the program, now under way, is the analysis of these data, including the extension of information available from them through recognized engineering principles.

Preliminary Results

The purpose of this paper is to present a summary of the most salient features of Canadian otter trawl behaviour as revealed by these experimental data. The attached charts give curves for the total drag force at the towing block (in pounds divided by 100), the average of the two warp tensions (in pounds divided by 100), the distance between the two wing tips (in feet), and the height of the centre of the headline above the sea floor (in feet multiplied by 10), all plotted against the speed of the trawl through the water in knots. The trawl speed was calculated from the hydrodynamic or stagnation pressure as measured by a recording pitotmeter suspended in the mouth of the trawl from near the centre of the headline.

The range of the data points about these curves is, on the average: headline height ± 0.5 ft, wing spread ± 2.0 ft, total drag force ± 500 lb, average warp tension ± 300 lb. The data points were not scattered randomly about the given curves, but tended to be concentrated in discrete curves for different tows, indicating that some factor in addition to speed through water was affecting the variable being measured. This was particularly true of headline height.

In general, as a result of ocean currents, the speed of the trawl through the water was different from the speed of the vessel through the water and from the speed of tow relative to the sea floor. The plots against trawl speed through the water gave the most consistent results and, hence, are presented here. The other speeds plus the ocean currents near the surface and near the sea floor were measured and will be included in the detailed analysis.

Most of the measurements were taken on Sable Island Bank, Western Bank, Emerald Bank, and in Northumberland Strait between Prince Edward Island and Cape Breton Island, under relatively good conditions. Sites were selected to have relatively smooth and level sea floor for a radius of about 5 miles, and experiments were conducted in relatively good weather to avoid excessive data fluctuations from vessel motion. Generally, the codend was left open to avoid variations resulting from accumulating catch and to improve the reproducibility of the data.

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Headline Height

In all but one case, the height of the headline above the sea floor is seen to decrease with increasing trawl speed. This correlation was also observed by Crewe (1964) in British trawls and is a result of the changing balance of forces on the headline. Generally, the hydrodynamic forces, including drag of the headline, floats, etc., increase approximately as the square of the towing speed through the water. On the other hand, the hydrostatic lift (buoyancy) of the floats remains essentially constant, independent of the towing speed. Thus, because the headline is towed by its ends from points near the sea floor, as speed is increased in the absence of increase in lift force, the increasing drag force, acting sternward on the headline, forces the centre of the headline aft and down. Obviously, the desired towing speed must be taken into account when selecting the number of floats, higher speeds requiring more floats for the same headline height. This trend applies only to the range of conditions encountered while the measurements were being taken; the effect of added flotation decreases as the amount of flotation present and the towing speed are increased.

Wing Spread

Generally, the transvere distance between the two wing tips (wing spread) is seen to remain essentially constant with changing towing speed. By contrast with the constant hydrostatic lift force from the floats, the spreading force from the doors is predominantly hydrodynamic in nature, increasing approximately as the square of the towing speed through the water. Thus, as the drag force increases with increasing speed, the ratio between the spreading force and the drag force, and hence also the wing spread, remain essentially constant.

Trawl Drag

The total drag of British trawls was reported by Crewe (1964) to increase essentially linearly with increase in speed. However, our data from Canadian trawls consistently show a curvilinear relationship. The drag of a trawl may be described by the expression

$$D = C_D \cdot A \cdot (0.5\,\rho\,V^2)$$

Where D = total drag of the trawl in pounds,

A = effective hydrodynamic area of the trawl in square feet,

ρ = mass density of sea water $\simeq 1.99$ lb-sec^2/ft^4 ($SG \simeq 1.026$; $\gamma \simeq 64$ lb-f/ft^3 ; $g = 32.17$ ft/sec^2)

V = towing speed in relation to the water in feet per second (1 knot = 1.688 ft/sec),

$0.5\,\rho\,V^2 = q$ = hydrodynamic or stagnation pressure in pounds per square foot,

C_D = dimensionless drag coefficient, characteristic of a particular trawl but generally dependent on the towing speed and on the particular shape assumed by the trawl in the water.

Crewe (1964) used the frontal area of his trawl as the effective hydrodynamic area (A) and considered the drag coefficient (C_D) to be essentially constant within his range of experimental conditions. The linear relationship between the trawl drag (D) and the towing speed (V) then implies that the frontal area of the trawl varies inversely as the towing speed. The Canadian data agree with this concept in a very general way, e.g., at constant wing spread, the headline height vs speed curve is concave upward and slopes down to the right (rectangular hyperbola). However, contrary to Crewe, the Canadian drag vs speed data are persistently curvilinear, and generally the curves extrapolate to the $V = 0$ axis at some finite drag, i.e., they are not of the form $D = kV^2$ where k a constant. This implies that the drag coefficient (C_D) is not constant but assumes higher values at lower towing speeds — a trend in common with most submerged objects at relatively low Reynold's numbers.

The selection of the frontal area of the trawl as the "characteristic" hydrodynamic area (A) should also be questioned further, even though changes in frontal area help to explain apparent anomalies in the drag vs speed relationship. The hydrodynamic drag of a trawl is caused primarily by inertial pressure forces exerted by the water on the various solid parts of the trawl; but the frontal area of a trawl is by no means solid. At constant frontal area, trawl drag at a given towing speed is changed by changes in the ratio of twine thickness to mesh size or by changes in the taper rates, causing corresponding changes in the value of the drag coefficient (C_D) when the frontal area is taken as the hydrodynamic area. Also, the frontal area of a given trawl varies during the course of a tow and would have to be monitored continuously in order to be useful. Modern hydrodynamic theory for screens uses the plane area of the screen as the hydrodynamic area, but if this were done for trawl netting, the drag coefficient (C_D) would become very much a function of the angle of attack of the water onto the netting. The solid area of the knots and mesh bars projected onto the plane of the netting and the frontal area of floats, etc. are constant and measureable for any given trawl, but if these areas are totalled for the effective hydrodynamic area (A), then known hydrodynamic interference between various trawl components would cause the drag coefficient (C_D) to be very much a function of the particular shape assumed by the trawl under various towing conditions. The selection of the most useful hydrodynamic area (A) will have to await a deeper understanding of the fluid mechanics of netting.

Warp Tensions

The average of the tensions in the two warps is greater than half the total drag of the trawl because two other force components, in addition to trawl drag, contribute to the tensions in the warps. These other components originate in the spreading forces exerted transversely by the doors and in the downward force exerted by the weight of the warps in the water and by part of the weight of the doors as the warps try to lift them off the sea floor. The total drag is the only force from the trawl which must be overcome by the propulsion of the vessel. The warp tension, which is the vector sum of the drag force, the spreading force, and the weight force, is the stress which determines the required strength of the warps, towing block, gallows, etc.

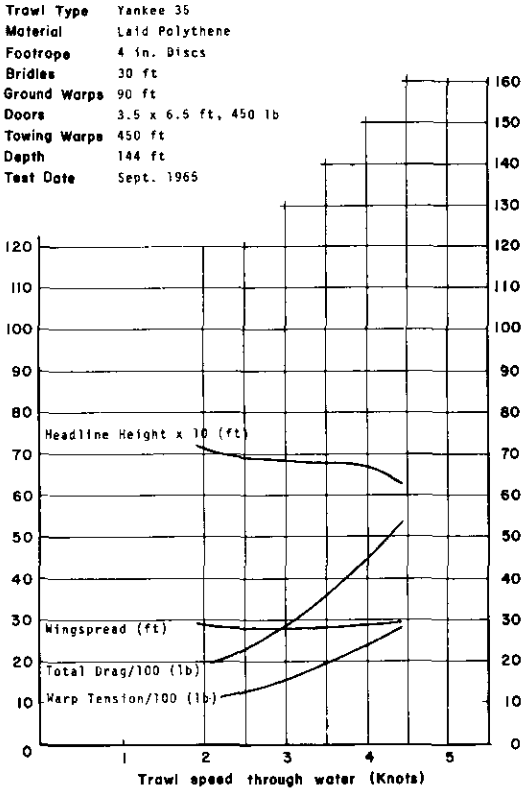


Fig. 1

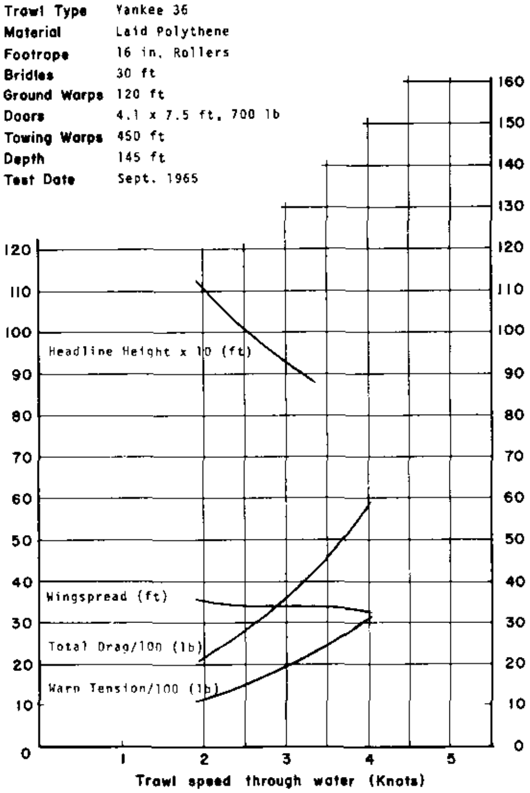


Fig. 2

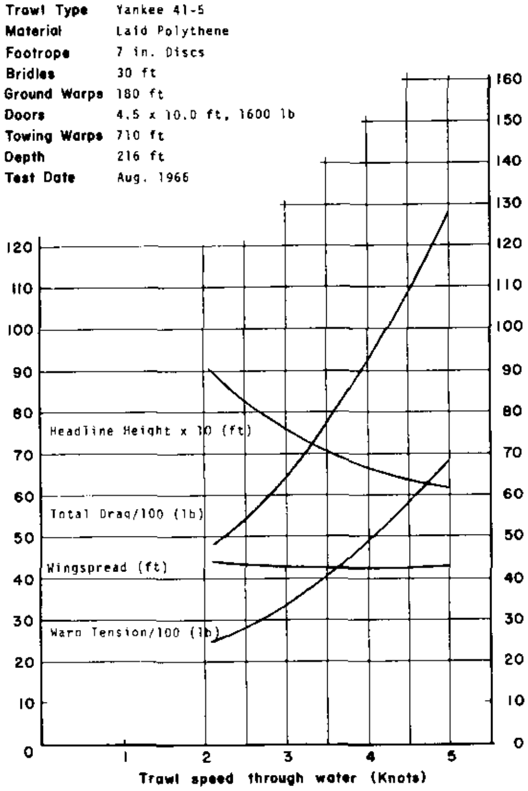
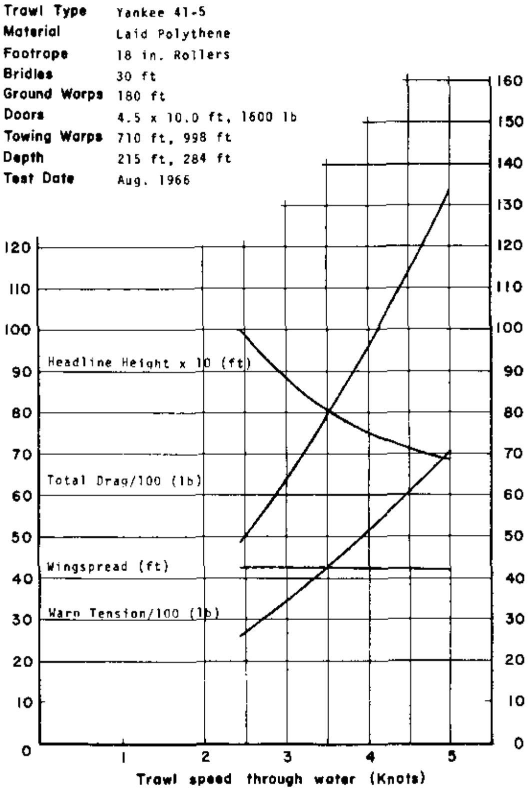


Fig. 3

Specific Functional Trends

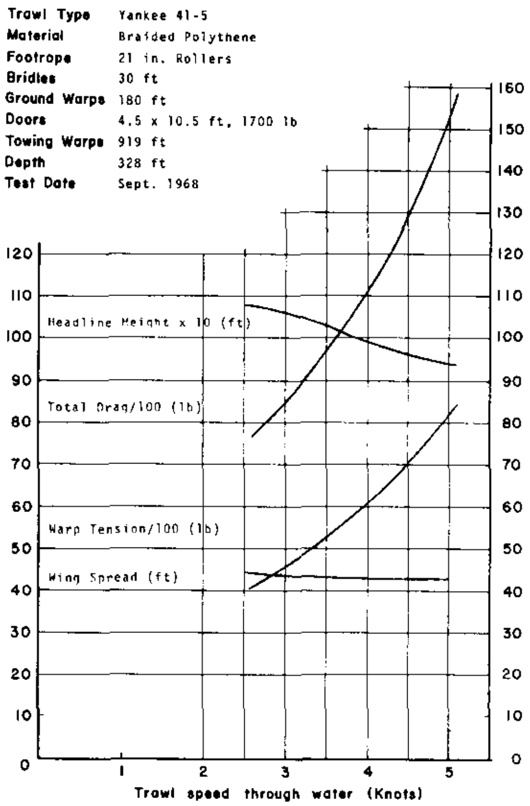
The Yankee 35 trawl (52-ft headline, 76-ft footrope) and the Yankee 36 trawl (60-ft headline, 80-ft footrope) of Figs. 1 and 2 are essentially the same except that the Yankee 36 has longer wings and, in this case, is fitted with heavier footrope and doors and with longer ground warps. The higher headline of the Yankee 36 trawl probably results from the longer wings. The wing spread of the Yankee 36 trawl was the wider of the two, in spite of the longer ground warps, both because of the longer wings and because of the larger doors. The greater drag of the Yankee 36 can be expected from the larger doors and heavier footrope and, to some extent, from the longer wings.

The data in Figs. 3, 4, and 5 are for three Yankee 41-5 trawls (79-ft headline, 100-ft footrope) in which the most pronounced difference was the weight of the footrope. The wing spread of the three trawls is remarkably consistent. The progressively higher headline with successively heavier footrope is probably caused by the bosom of the footrope being pushed aft with respect to the wing tips by the increased drag, providing slack in the netting and allowing the headline to rise. The trawl for Fig. 5 also had somewhat more flotation in the bosom, lifting the headline even further. Warp tensions and total drag are expectedly higher with heavier



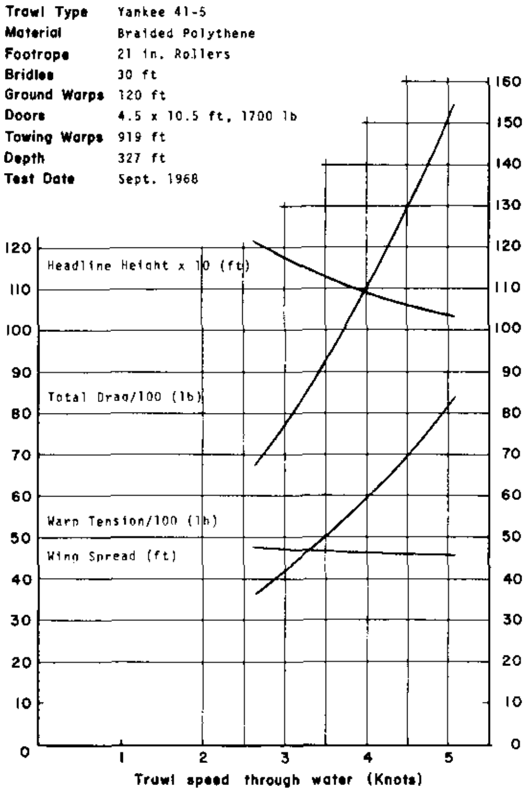
Trawl Type	Yankee 41-5
Material	Laid Polythene
Footrope	18 in. Rollers
Bridles	30 ft
Ground Warps	180 ft
Doors	4.5 x 10.0 ft, 1600 lb
Towing Warps	710 ft, 998 ft
Depth	215 ft, 284 ft
Test Date	Aug. 1966

Fig. 4



Trawl Type	Yankee 41-5
Material	Braided Polythene
Footrope	21 in. Rollers
Bridles	30 ft
Ground Warps	180 ft
Doors	4.5 x 10.5 ft, 1700 lb
Towing Warps	919 ft
Depth	328 ft
Test Date	Sept. 1968

Fig. 5



Trawl Type	Yankee 41-5
Material	Braided Polythene
Footrope	21 in. Rollers
Bridles	30 ft
Ground Warps	120 ft
Doors	4.5 x 10.5 ft, 1700 lb
Towing Warps	919 ft
Depth	327 ft
Test Date	Sept. 1968

Fig. 6

footrope. Changing the depth and correspondingly changing the warp length for the trawl in Fig. 4 made no noticeable difference to its towing characteristics.

The data in Figs. 5 and 6 are for the same trawl except that the ground warps were shorter for Fig. 6. The shorter ground warps expectedly extended the spread of the wings, but the higher headline is a little harder to explain. It is possible that the wider wing spread shifted the division of load on the wing bridles toward the upper bridles or that the greater tension in the shorter ground warps reduced sag, thereby raising the forward ends of the wing bridles and elevating the whole headline, or it is possible that the wider spread permitted a greater hydrodynamic lift on the netting and/or headline. The warp tensions and total drag are, if anything, decreased by using the shorter ground warps, despite the associated increase in frontal area of the trawl.

The data in Fig. 7 are for the same trawl as those in Figs. 5 and 6 except that the 30-ft bridles have been replaced by shorter bridles, Danleno butterflies, and bobbins. The total distance from the wing tips to the doors is essentially the same in the trawl for Fig. 7 as in the trawl for Fig. 6. Unfortunately, the wing-spread meter was not functioning with the Danleno gear. The headline was noticeably lower with the Danleno gear than with either of the trawls with wing bridles, showing the advantage of bridles, even as short as 30 ft, when towing on smooth sea floor. The Danleno gear also increased the total drag and the tensions in the warps; at the same engine speed the trawl with the Danleno gear towed more slowly than the trawls with wing bridle gear.

The data in Fig. 8 are for a Yankee 41-5 trawl made of bitumen-treated nylon netting which is slightly heavy in sea water (weight in sea water ≃ 9.3 lb/100 lb weight in air) compared with the polyethylene netting, which is slightly buoyant (residual buoyant force in sea water ≃ 6.8 lb/100 lb weight of netting in air), used in all the trawls so far reported. For Fig. 8: the doors were the same size as for Figs. 5 and 6, larger than for Fig. 4, and heavier than for all three; the footrope was about the same as for Fig. 4 and lighter than for Figs. 5 and 6; and the ground warps were shorter than for all three. Unfortunately, the headline height meter was inoperative on the nylon trawl. The wing spread was about the same as in Figs. 4 and 5; the tendency for shorter ground warps and larger doors to increase wing spread was off-set by the greater drag of the trawl-net itself. The greater total drag of the nylon trawl is in part due to the heavier doors and in part to the netting.

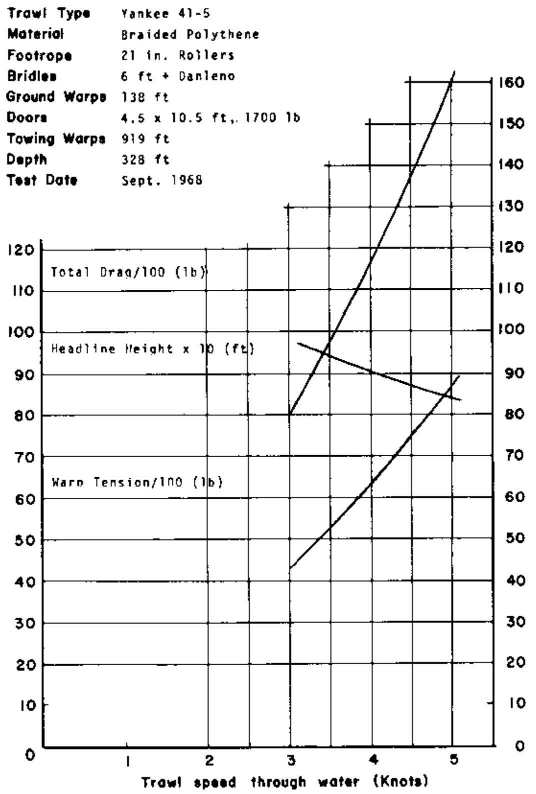


Fig. 7

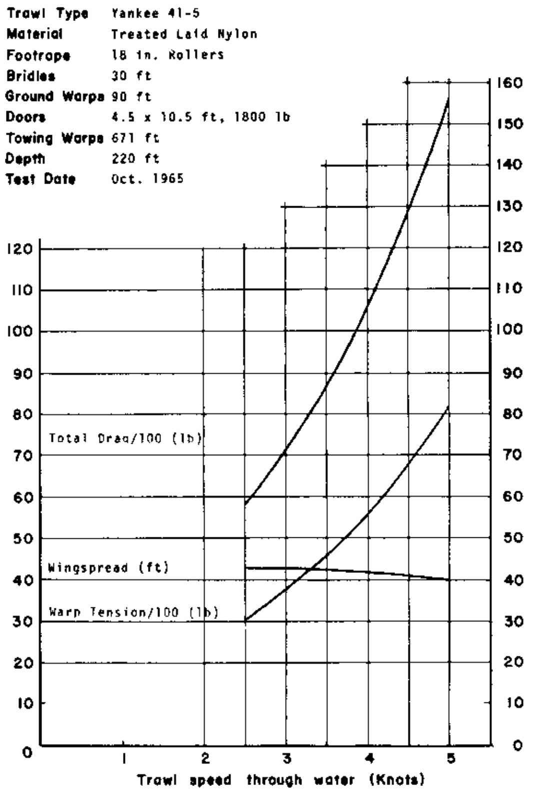


Fig. 8

Figures 9 and 10 vis-à-vis Figs. 11 and 12 compare a Yankee 41 trawl (79-ft headline, 100-ft footrope) made from bitumen-treated, iso-tactic polypropylene, multifilament (Ulstron) netting with a similar trawl made from the usual, high-density polyethylene netting. The treated-Ulstron netting was slightly less buoyant (residual buoyant force in sea water ≃ 5.7 lb/100 lb weight of netting in air) than the polyethylene netting. Both trawls were measured while being towed in two different rigs. In both rigs, the treated-Ulstron trawl had about 15% more flotation on the headline than did the polyethylene trawl. With rectangular doors, the total drags of the two trawls are very similar, but for some reason the treated-Ulstron trawl displays a narrower wing spread. The higher headline of the treated-Ulstron trawl results from this narrower wing spread and the greater flotation. With slotted, oval doors, the wing spreads of the two trawls are very similar, but the treated-Ulstron trawl has lower total drag. Apparently the lower total drag is a reflection of lower netting drag which, combined with the greater flotation, results in the higher headline. The higher headline of the treated-Ulstron trawl at the same wing spread as the polythene trawl gives a larger frontal area in association with lower drag, once more contradicting the functional dependence of drag on frontal area claimed by Crewe (1964). The treated-Ulstron trawl behaves much more like a polyethylene trawl than does the treated nylon trawl (Fig. 8), even though the nylon netting and the Ulstron netting are very similar in general appearance.

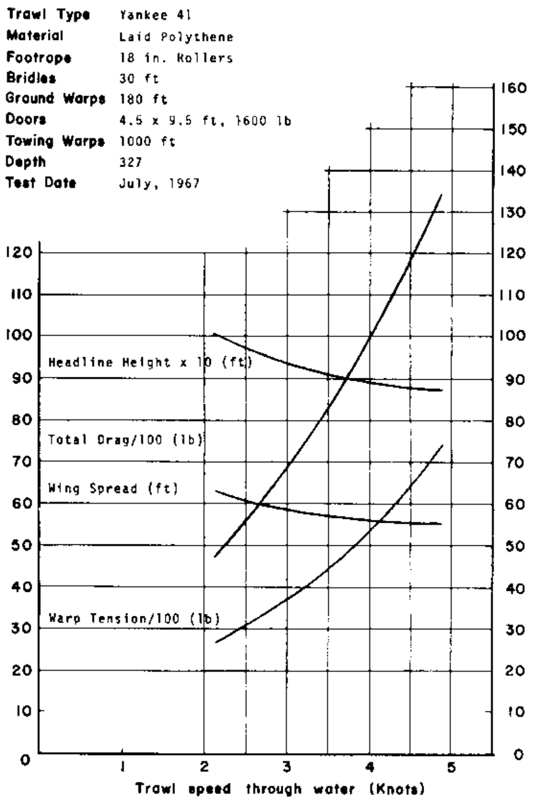


Fig. 9

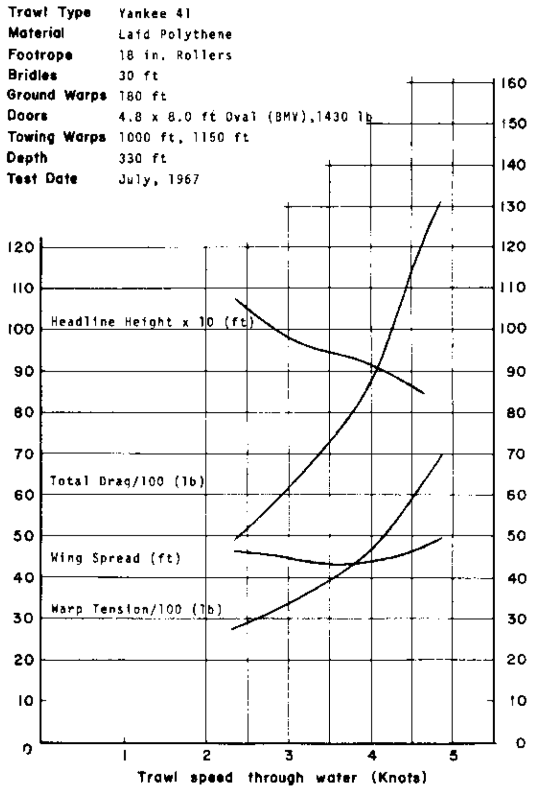


Fig. 10

Figures 9 and 11 vis-à-vis Figs. 10 and 12 compare the behaviour of the usual rectangular trawl doors with single-slot oval doors on the same Yankee 41 trawls. The oval doors were smaller (30 sq ft vs 43 sq ft) and lighter (1,430 lb vs 1,600 lb) than the rectangular doors. With this size disadvantage, the oval doors produced a narrower wing spread, although this wing spread was similar to that reported in Figs. 3 to 6 for Yankee 41-5 trawls with rectangular doors. The wing spreads reported for the rectangular doors in Figs. 9 and 11, particularly with the polyethylene trawl, are exceptionally wide. Associated with the narrower wing spread when using the oval doors is the expected higher headline. Of particular interest is the shape of curves for wing spread and headline height when using the oval doors. The correlation between wing spread and headline height is sustained through the serpentine shape of both sets of curves, with the increased drag at higher speeds superimposing a downward trend on the headline height curves. This serpentine shape probably results from the lift (spreading force)/drag characteristics of the oval doors, which apparently pass through a minimum at about 3.8 knots and result in an unusual increase in wing spread with increase in spreed above this point. This change in lift/drag ratio with towing speed may be a function of the heel angle of the doors, in which case the

Trawl Type	Yankee 41
Material	Treated Laid Ulstron
Footrope	18 in. Rollers
Bridles	30 ft
Ground Warps	180 ft
Doors	4.5 x 9.5 ft, 1600 lb
Towing Warps	1000 ft, 1002 ft
Depth	327 ft
Test Date	July, 1967

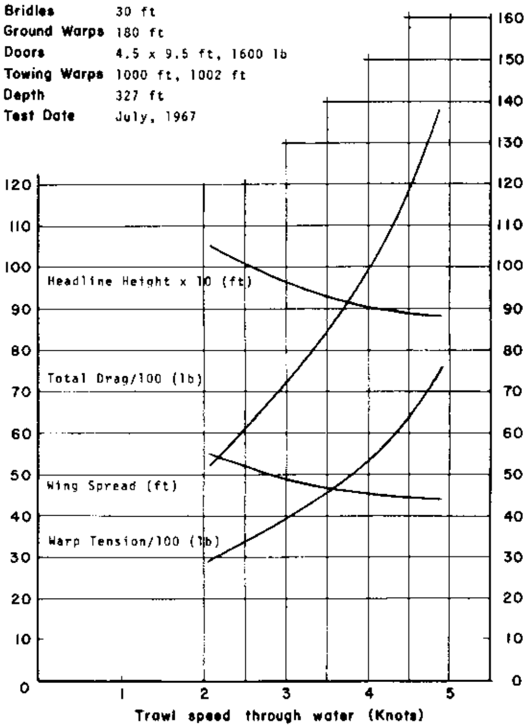


Fig. 11

Trawl Type	Yankee 41
Material	Treated Laid Ulstron
Footrope	18 in. Rollers
Bridles	30 ft
Ground Warps	180 ft
Doors	4.8 x 8.0 ft Oval (BMV), 1430 lb
Towing Warps	1150 ft, 1000 ft
Depth	330 ft
Test Date	July, 1967

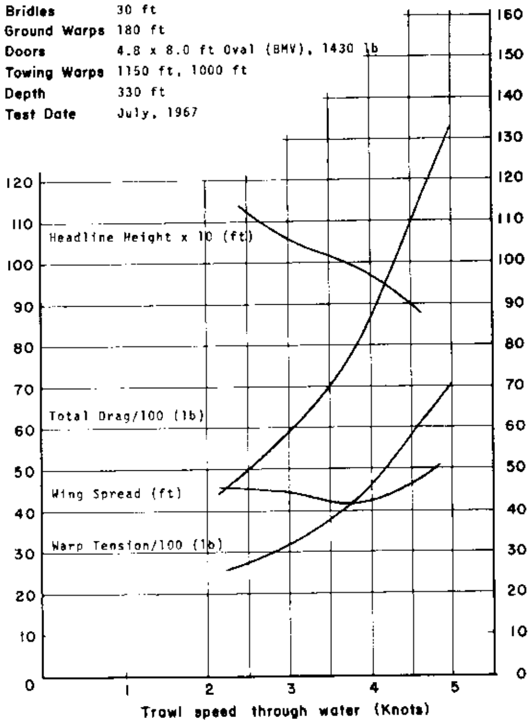


Fig. 12

Trawl Type	Skagen
Material	Braided Polythene
Footrope	Rounded
Bridles	120 ft
Ground Warps	180 ft
Doors	4.5 x 10.0 ft, 1600 lb
Towing Warps	710 ft
Depth	220 ft
Test Date	Aug. 1966

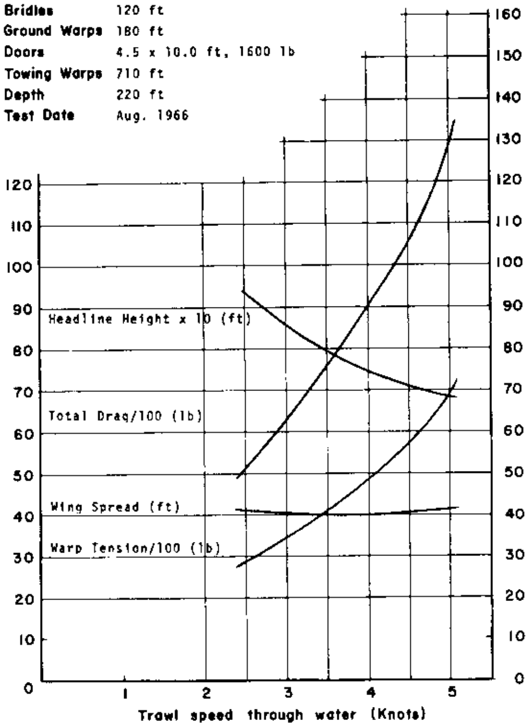


Fig. 13

Trawl Type	Granton
Material	Laid Polythene
Footrope	31 in. Rollers
Bridles	30 ft
Ground Warps	120 ft
Doors	4.5 x 10.5 ft, 1700 lb
Towing Warps	919 ft
Depth	326 ft
Test Date	Sept. 1968

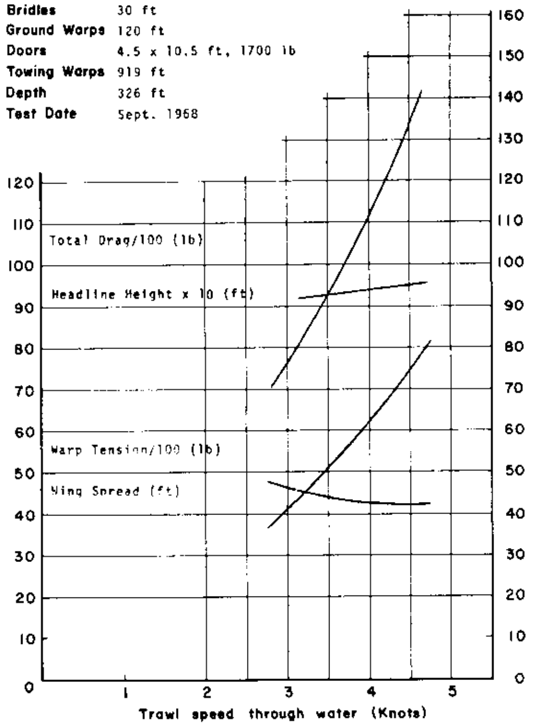


Fig. 14

speed for minimum lift/drag ratio will be a function of the scope ratio (warp length/trawl depth) of the towing warps.

Figure 13 gives data for a Skagen (vinge) trawl (82-ft headline, 116-ft footrope) which is sometimes used, lightly rigged, on sandy sea floor. There is considerably more netting in the Skagen trawl than in the Yankee 41 trawl, which probably accounts for the similar drag characteristics despite the lighter footrope. The headline of the Skagen trawl is only slightly longer than that of the Yankee 41 and the wing spread is very similar. The Skagen footrope, then, must fish in a deeper "catenary" than does the Yankee 41 footrope. The effect of the longer headline and longer and lighter footrope of the Skagen trawl to increase wing spread is probably being offset by the longer wing bridles. Despite these longer wing bridles and longer wing lines, the headline of the Skagen trawl was not appreciably higher than that of the Yankee 41 trawls. The meshes of the Skagen trawl must have been more closed than those in the Yankee 41 trawls, contributing somewhat to the drag.

Figure 14 gives data for a Granton trawl (79-ft headline, 120-ft footrope) such as is being used by some of the larger Canadian vessels. This trawl contains quite a bit more netting than the Yankee 41 trawls so naturally produces more drag. However, the wing spreads and the headline heights are very similar in both types of trawl; the Granton trawl has more drag than the Yankee 41 trawls despite a similar frontal area. The similar wing spread despite the longer footrope of the Granton trawl probably results from its greater drag. The headline height of the Granton trawl is probably more restricted by the shorter wing lines (4 ft) than is the headline height of the Yankee 41 trawls (6-10 ft wing lines). Some of the commercial vessels are using longer wing bridles (up to 90 ft) than were used for Fig. 14. However, the gain in headline height normally realized with longer wing bridles is lost in this trawl because of the short wing lines. The reason for the increase in headline height with increase in towing speed in not apparent. This trend is opposite to that for all other trawls studied and opposite to the findings of Crewe, 1964 for the Granton trawl, however, it is consistent with the decrease in wing spread with increasing towing speed.

Figure 15 gives data for the Atlantic Western III trawl (79-ft headline, 115-ft footrope) specificially designed by W. W. Johnson for the Canadian east coast fisheries. This is a 4-side-seam net, and the advantage of this side panels and long wing lines is obvious in the notably higher headline. This is a big trawl, fitted with a heavy footrope, and had a drag similar to that of the Granton trawl but greater than that of the Yankee 41. This greater drag probably accounts for the narrower wing spread; the Atlantic Western III trawl should be fitted with larger doors than were used for Fig. 15. Even with this abnormally narrow wing spread, the Atlantic Western III trawl had a larger frontal area than either the Granton trawl or the Yankee 41 trawl. This large frontal area of the Atlantic Western III trawl results in a drag coefficient smaller than that for the Granton trawl and similar to that found with the Yankee 41 trawls.

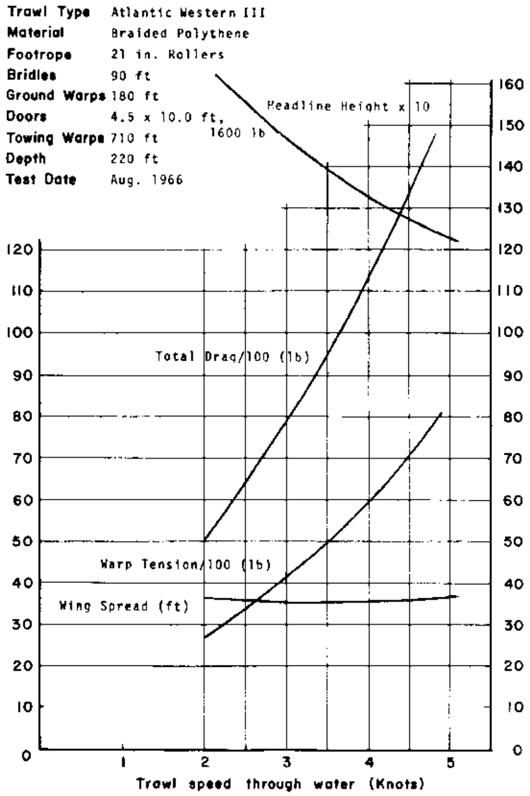


Fig. 15

Conclusions

Undoubtedly these general observations, based on an examination of the attached summary of data from an extensive engineering study of Canadian Northwest Atlantic groundfish otter trawls, leave many questions unanswered. It is hoped that a more detailed analysis of the basic data will reveal more extensive and more specific conclusions at some future date, but it is believed that this more general presentation is of some value at the present time.

Acknowledgements

Sincere appreciation is expressed for the very considerable financial assistance rendered by the Industrial Development Branch of the Canadian Department of Fisheries and Forestry during the instrumentation and experimental phases of this project.

References

CARROTHERS, P. J. G. 1968. Instrumentation for the engineering study of otter trawls. *Bull. Fish. Res. Bd. Canada*, No. 163.

CARROTHERS, P.J.G., T.J. FOULKES, M.P. CONNORS, and A. G. WALKER. 1969. Data on the engineering performance of Canadian east coast groundfish otter trawls. *Fish. Res. Bd. Canada, Tech. Rep.*, No. 125.

CREWE, P. R. 1964. Some of the general engineering principles of trawl gear design. *Mod. Fish. Gear World*, No. 2, p. 165-180.

A Volumetric Statistical T-S Analysis of the Nova Scotia Shelf and Georges Bank Water Masses

By A. A. Barinov[1] and V. A. Bryantsev[1]

Abstract

Using the method of volumetric statistical T-S analysis, the Nova Scotia Shelf and Georges Bank waters were analyzed for winter and summer periods in greater detail than similar analysis by other authors.

Two T-S diagrams are obtained for the two main seasons with the following values: water volumes by T-S classes, sizes of 0.5° and 0.1°/₀₀; water volumes by the three main water masses; total water volume in the area; heat and salt reserve; mean values of temperature and salinity. The analysis showed that the upper intermediate layer (inshore and Labrador waters) makes up from 76% in summer to 86% in winter of the total volume. The bottom waters decrease in volume during winter, and their heat and salt density drops down. This phenomenon may be associated with the local seasonal transformation, but the suggestion of the effect of the changes in the Gulf Stream outlay cannot be ignored.

Introduction

For the purpose of fisheries prognosis on the Nova Scotia Shelf and the Georges Bank it is necessary to know the disposition and characteristics of the main water masses which were studied earlier (Bryantsev, 1963), and also to have information on the quantitative relations between them.

To obtain the volumes of the main water masses, to see their quantitative correlation, and, consequently, to estimate the significance of each of them in the formation of the local thermohaline structure – all this is made possible by a volumetric statistical T-S analysis. This method was used for the analysis of the water masses in the World Ocean, in the Atlantic (Montgomery, 1958; Wright and Worthington, 1970), Indian (Pollak, 1958), and Pacific (Cochrane, 1958) Oceans, in the Arabian and Red Seas (Dubrovin, 1965) and in the seas of Indonesia (Nefediev, 1961).

However, the authors of the above-mentioned publications used for their analysis only a small number of stations (Nefediev – 158 stations for the seas of Indonesia; Dubrovin – 33 stations for the Arabian and 10 for Red Seas; Cochrane – 150 stations for the Pacific Ocean) and excluded the upper 200-m-water layer which is subject to sharp seasonal changes in temperature.

Also, the above authors made their analyses for one season only (Dubrovin, 1965), or completely disregarded the season.

The uniqueness of the present paper lies in the fact that we have analyzed the previously excluded upper 200-m layer in an area with an extremely complex bottom configuration for the two main seasons, winter and summer, using a great number of stations and the smallest unit area.

Materials and Methods

It is known that the Nova Scotia Shelf and Georges Bank are characterized by a rather complex bottom configuration, with the depths varying both by area and by fishing squares (Fig. 1). Therefore, in estimating the volumes, a square of the fishing grid was taken for a unit area having sides of 20′ of latitude and 30′ of longitude. Since the area of the square increases from south to north from 1420 to 1577 km^2, an average value of 1500 km^2 was taken. In case of a sharp heterogeneity of bottom configuration, i.e., with the depth variations within the square of 50 to 100 and more meters, the square was divided into parts of 1/3 to 2/3 (1/3, 1/2, 2/3) of the square area. For a vertical unit of the volume measurement the depth of 1 m was used.

For the analysis all hydrological stations made by AtlantNIRO were used through the period 1961-66 for the two main seasons: winter (January, February, March) and summer (July, August, September). Total number of stations was 1,153, with 374 of them occupied in winter and 779 in summer.

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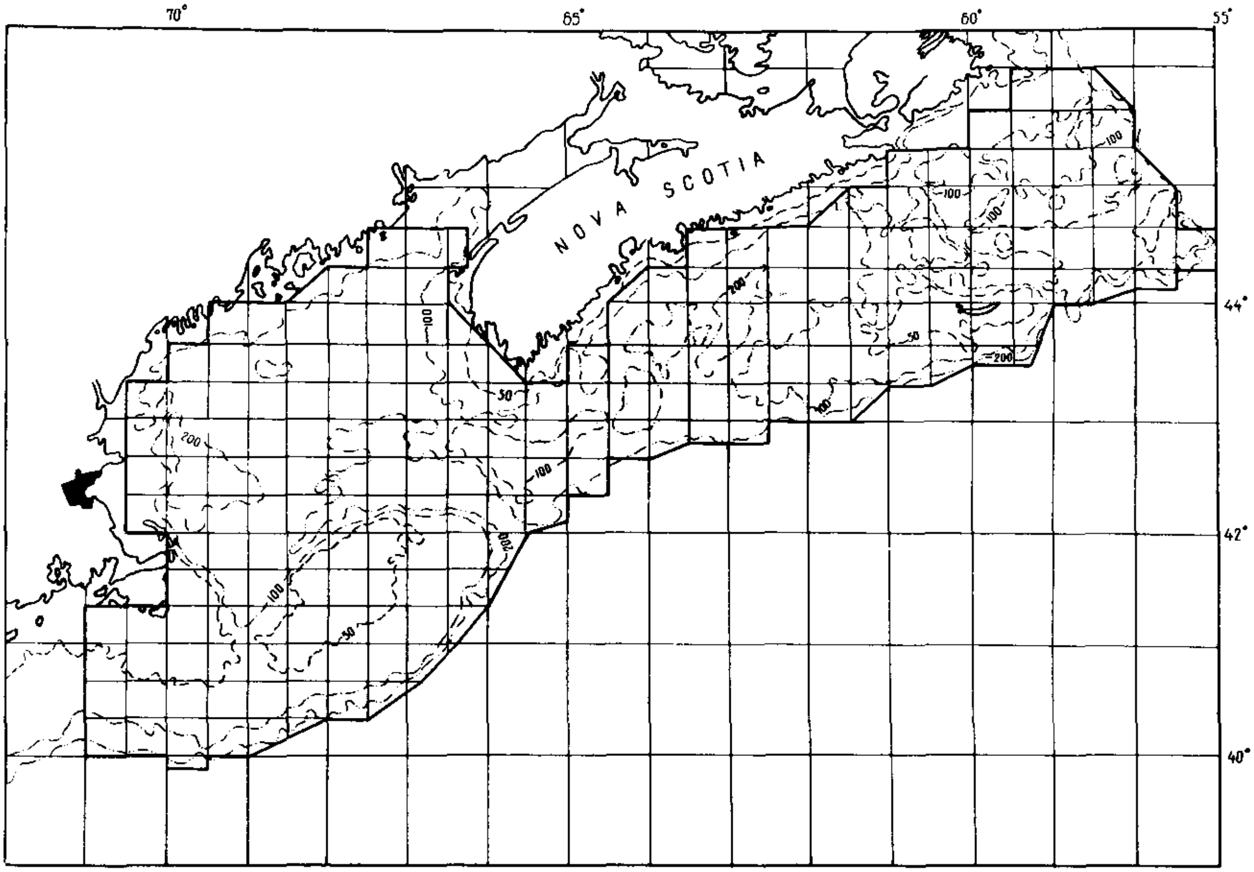

Fig. 1. The Nova Scotia Shelf and Georges Bank study area (depth in m).

Temperature and salinity data were averaged in each square or its part for all 6 years and, thus, were reduced to one T-S curve. In some cases where data were lacking (winter), the same T-S curve was applied to the adjoining square or parts of the square which are homogeneous in bottom configuration and hydrological conditions.

T-S curve fields were divided into classes of 0.5° in temperature and 0.1°/₀₀ in salinity. In each class, layer thickness was determined in meters as a part of the T-S curve cut off the class boundaries. Product of that value multiplied by the area of the square or that of its part to which T-S curve was applied is the water volume for the corresponding temperature and salinity.

The final results of the volumetric statistical T-S analysis are given in two T-S diagrams for summer (Fig. 2) and winter (Fig. 3) periods. They show water volumes in km^3.

Results

According to general anaylsis of the water masses (Bryantsev, 1963) the whole water column on the Nova Scotia Shelf and Georges Bank regions may be divided into three main water masses:

1) surface waters of low salinity or inshore waters;
2) intermediate cold waters or Labrador waters;
3) warm bottom waters and those of high salinity.

Boundaries are determined by the 32.5°/₀₀ isohaline separating the inshore and Labrador waters, and the 33.5°/₀₀ separating the Labrador and bottom waters. The diagrams show the lines corresponding to these salinity values (Figs. 2 and 3).

As a result of the statistical T-S analysis we obtained the following estimates: water volumes by T-S classes, water volumes by three main water masses, and the total volume of the water masses (Figs. 2 and 3). Also obtained are data on the relative quantity of waters of certain temperature and salinity in percentage with a histogram as an illustration. Apart from that, there were also computed the values of the total heat reserve in kg-cal X 10^{12} (with regard to the specific heat of the waters in the area which is 0.94 cal/g), reserve of heat and that of salt in tons, mean temperature and mean salinity. The dotted line on the diagrams shows the volume equal to 75% of the total, the dashed line – that of 50%, and the regular one shows the classes with a maximum volume by three divided grounds.

Three characteristic layers are well traced on the T-S diagrams by disposition of the volumes, the

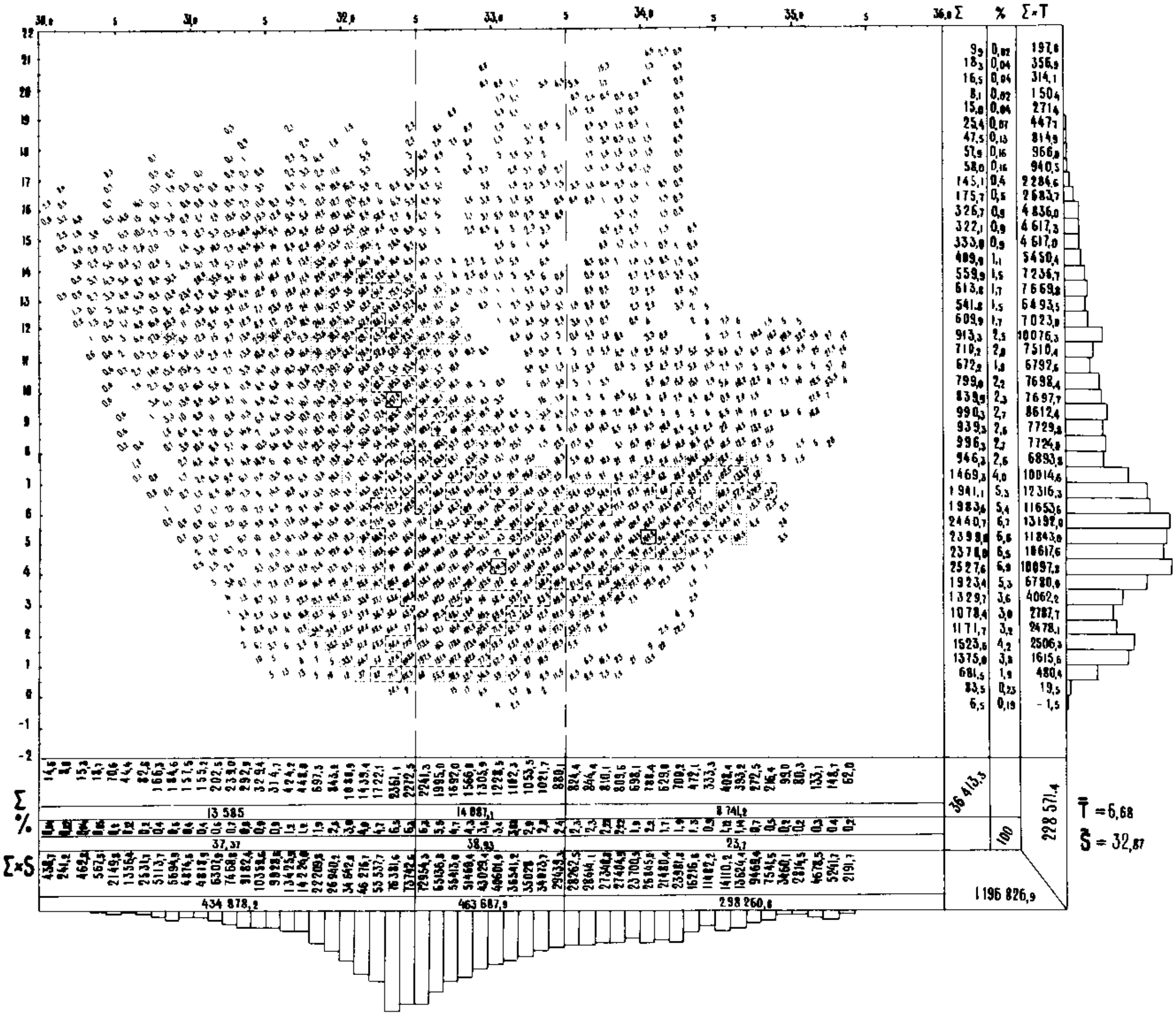

Fig. 2. Volumetric statistical T-S diagram for the Nova Scotia Shelf and Georges Bank regions (summer).

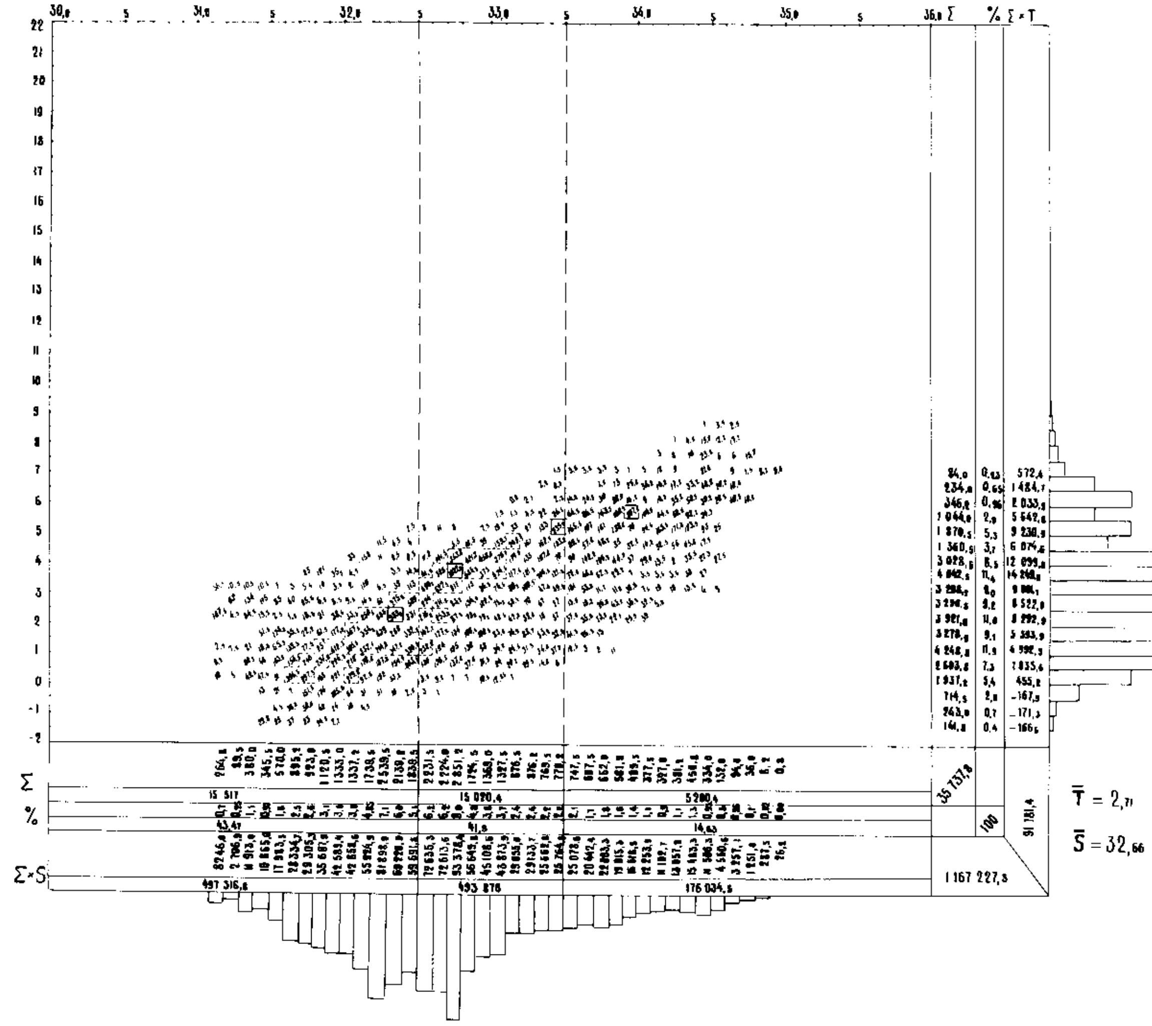

Fig. 3. Volumetric statistical T-S diagram from the Nova Scotia Shelf and Georges Bank regions (winter).

character of volumes distribution by T-S classes confirming the correctness of the preliminary approtionment of the water masses. Zones of 75 and 50% of volume have configuration of T-S curves characteristic for the given area in summer and winter periods.

Classes of maximum volume constitute a nucleus of the corresponding water mass limited by the above-mentioned salinity values. T-S diagram for the winter period suggests that the surface and intermediate waters constitute a general cold surface layer as a result of the autumn-winter convection, although judging by a typical winter T-S curve we should formally separate the two water masses. These are really somewhat different not only in salinity, but also in the disposition of classes of maximum volumes – 989.8 and 1022.8 km^3 (Fig. 3). In the boundary area between the intermediate layer and the warm bottom waters, Fig. 3 also shows a trace of another class with the largest volume, as compared with other classes surrounding it (235.2 km^3). This fact indicates the presence of two modifications of the bottom water masses and gives evidence that it would be more correct to use the 33.3°/$_{oo}$ isohaline as a lower boundary of the Labrador water masses.

Estimates of the total water volumes for summer and winter differ by 675.5 km^3 (Table 1).

TABLE 1. Volumes of water masses in the Nova Scotia Shelf and Georges Bank regions.

Water masses	Volume, km^3 Summer	Volume, km^3 Winter	Summer – winter volume variations
(1)	13,585	15,517	+ 1,932
(2)	14,087	15,020	+ 933
(3)	8,741	5,200	– 3,541
Total	36,413	35,738	– 676

This difference is the result of errors in the processing of T-S curves. As we can see, the difference is insignificant (about 2% of the total volume). With regard to this fact, we may distribute this "discrepancy" between all the waters proportionally without any great damage to the preciseness. Table 2 presents the ultimate results: values of the three main water masses, their correlation and changes from summer to winter.

TABLE 2. Volumes of water masses in the Nova Scotia Shelf and Georges Bank regions after distribution of the "discrepancy".

Water masses	Summer Volume, km^3	Summer %	Winter Volume, km^3	Winter %	Summer – winter volume variations
(1)	13,459	37.3	15,664	43.5	+ 2,205
(2)	13,956	38.7	12,162	42.0	+ 1,206
(3)	8,680	24.0	5,249	14.5	– 3,411
Total	36,075	100.0	36,075	100.0	0000

Discussion

Based on the results given in Table 2 we may draw the following conclusions:

1) The most significant changes are observed in the volume of the warm bottom waters of oceanic origin which penetrate into the area in question through the deep-water troughs and canyons. Their volume decreases from summer to winter from 8,660 km^3 to 5,249 km^3, that is, from 24 to 14% of the total volume.
2) The Labrador and inshore waters in both seasons are approximately equal in volume and constitute the main part of the total water volume in the region – 76% in summer and 86% in winter.
3) Changes in the correlation of the water volumes from summer to winter may be a result of the seasonal transformation which causes in winter a decrease of the warm bottom waters and an increase of volume of the cold upper layer which is intensively mixed and consists of the surface and Labrador waters. However, we cannot ignore a suggestion of more intensive inflow of the bottom waters in summer period that may displace other within the region under survey.
4) The increase in the inflow of the bottom waters from the ocean in summer period may be associated with the seasonal changes in the Gulf Stream outlay. Evidently, this fact also accounts for increase of average salinity of the bottom waters in summer. This phenomenon is demonstrated in Table 3 which gives mean salinity values for each water mass obtained in the analysis.

TABLE 3. Mean salinity values of the water masses in the Nova Scotia Shelf and Georges Bank region.

Water masses	Mean salinity, ‰ Summer	Mean salinity, ‰ Winter	Summer–winter variations of the mean salinity, ‰
(1)	32.01	32.05	+ 0.04
(2)	32.92	32.88	– 0.04
(3)	34.12	33.85	– 0.27
Total	32.87	32.66	– 0.21

It is rather notable that the total mean salinity in the layer of the surface and Labrador waters does not change from summer to winter. After the autumn-winter convection and the wind mixing, the salinity of the surface layer somewhat increases, while the waters of the intermediate layer decrease their salinity to an equal degree. Similarly, the bottom waters in winter not only decrease in volume, but also obtain a lower mean salinity. The latter may indicate a decrease in inflow of the bottom waters from the ocean in winter period.

References

BRYANTSEV, V. A. 1963. Water masses of the Nova Scotia shelf. *Trudy AtlantNIRO, X.*

DUBROVIN, B. I. 1965. Volumetric statistical analysis of the water masses in the Arabian and Red Seas. *Okeanologiya*, v. V, 4.

NEFEDIEV, V. P. 1961. Deep-water masses of the Indonesia seas. *Okeanologiya*, v. I, 1.

COCHRANE, I. D. 1958. The frequency distribution of characteristics in the Pacific Ocean. *Deep-Sea Research*, Vol. 5, No. 2.

MONTGOMERY, R. B. 1958. Water characteristics of Atlantic Ocean and of World Ocean. *Ibid*, Vol. 5, No. 2.

POLLAK, M. I. 1958. Frequency distribution of potentional temperatures and salinities in the Indian Ocean. *Ibid*, Vol. 5, No. 2.

WRIGHT, W. R., and L. V. WORTHINGTON. 1970. The water masses of the North Atlantic Ocean. A volumetric consensous of temperature and salinity. *American Geographical Society Serial Atlas of the Marine Environment.* Folio No. 19.

Food and Feeding of Atlantic Salmon in Coastal Areas and Over Oceanic Depths

By W. H. Lear[1]

Abstract

Examination of the contents of 2,350 stomachs from coastal areas and over oceanic depths of the Northwest Atlantic Ocean suggests that Atlantic salmon, *Salmo salar* L., feed almost continuously and fairly intensively while at sea and cease feeding as they approach the estuaries of their home river. Main items of diet were capelin, launce, herring, *Paralepis coregonoides borealis*, amphipods, and euphausiids.

Introduction

Very little information is available on the food and feeding of Atlantic salmon, *Salmo salar*, in the open ocean. Templeman (1967) on the basis of 10 stomachs examined in the Labrador Sea during 18 July to 23 August 1965 found that the salmon were feeding mainly on Arctic squid, *Gonatus fabricii*, and *Notolepis rissoi krφyeri*. On the West Greenland Banks salmon were feeding mainly on capelin, *Mallotus villosus*, and launce, *Ammodytes* sp., during 5-16 August 1965. During March-April, salmon were feeding mainly on *Paralepis coregonoides*, lantern fishes, amphipods, Arctic squid, and pelagic fish in the Labrador Sea and over oceanic depths east of the Grand Bank, Flemish Cap, and Northeast Newfoundland Shelf (Templeman, 1968).

In coastal areas such as in the Baltic, salmon are known to feed mainly on sprat, *Clupea sprattus;* herring, *Clupea harengus;* launce, *Ammodytes lanceolatus;* stickleback, *Gasterosteus* sp.; cod, *Gadus morhua*; and *Belone belone* with smaller quantities of amphipods and shrimps (Thurow, 1966; Christensen, 1961; Chrzan, 1970). Dahl (1918) found that grilse caught near the Skagerrak contained herring, capelin, and small amounts of euphausiids while one stomach was full of pelagic amphipods, *Parathemisto.* Hansen (1965) reported that salmon close to the Greenland coast in autumn ate mainly euphausiids and capelin with some launce. Blair (1965) examined the stomachs of 919 grilse and older salmon in Bay of Islands during June-July 1942. Of these, 127 contained food items maily capelin and launce with small amounts of shrimp, smelt, *Osmerus mordax;* cod, herring, and brook trout, *Salvelinus fontinalis.* Lindsay and Thompson (1932) report that capelin and launce were found in the stomachs of salmon examined during the spring of 1931 in White Bay, Newfoundland.

Kendall (1935) examined stomachs of salmon which were returning from sea in the estuaries of the Penobscot and Saint John River in New Brunswick. In most instances he found that the stomachs were empty but in some Penobscot fish smelts were found and in a few of the Saint John River fish, medium-sized alewives, *Alosa pseudoharengus*, were found.

Power (1969) examined the stomachs of 300 adult salmon entering the rivers in Ungava Bay, none of which contained any food. Two salmon taken in Whale River had unidentified fish remains in the lower intestine. A kelt which had spawned as a grilse in Whale River had sawflies and simulium larvae in its stomach prior to its arrival in the sea indicating that it had fed while in fresh water.

Keenleyside (1962) observed that adult salmon did not feed during the daytime in the Miramichi River, New Brunswick.

Jones (1959) stated that sexually maturing salmon generally cease feeding even before entering fresh water from the sea.

Methods

The salmon stomachs (2,350) examined in this investigation were collected during research vessel cruises of the *A. T. Cameron* during August-October 1969 and 1970 and during May 1971 using surface driftnets at a

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

depth of 3 m; adult returns of tagged North American smolts recaptured along the West Greenland coast from Frederiksdal to Godhavn (Fig. 1), routine commercial sampling in West Greenland, Newfoundland and Labrador coastal areas, routine parasite investigations of Atlantic salmon at Carleton, Saint John River, and in the Miramichi, and during a driftnet tagging cruise of the research vessel *Marinus* in the Miramichi esturary.

The complete viscera were frozen and subsequently thawed out at the Biological Station where they were first examined for internal parasites. The stomachs were then cut open by the author and the contents, if any, separated by species and weighed in grams to the nearest tenth.

The research samples and tagged fish returns were weighed in kilograms to the nearest hundredth and were measured to the nearest millimeter. The commercial samples were weighed in kilograms to the nearest tenth and were measured to the nearest whole centimeter.

TABLE 1. Stomach contents of Atlantic salmon caught in various areas and at different seasons, 1968-71, showing weight of food (g) and number of occurrences (in parentheses). All length groups combined.

	St. John, N.B. 26 June - 2 July/70	Miramichi 12 June - 9 July/70	Carleton 15 June - 16 June/70	Port aux Basques 20 May - 15 June/70	St. John's, Nfld. 8 June - 14 June/69	Bonavista 8 June - 24 June - 1970-71	St. Anthony 26 June - 6 July/70	Packs Hr. 6 July - 25 July/70	ICNAF "1A" 10 Sept - 1 Nov - 1969-70
Salmon length (cm):	55-86	49-103	66-113	63-90			52-85	54-87	58-100
Empty	– (110)	– (291)	– (182)	(10)	(1)	– (45)	(3)	– (70)	- (20)
Unidentified material	...	...	...	...	377.4(43)	...	...	...	...
Fish remains	81.1(19)	14.0(5)	21.9(14)	65.2(14)	...	104.0(19)	9.0(2)	5.8(4)	364.4(87)
Unidentified invertebrates	...	...	...	2.6(1)	...	...	...	...	29.5(4)
Bird feather	...	...	...	...	...	...	...	...	...
Lepeophtheirus salmonis	...	...	...	...	...	...	...	...	0.2(2)
Terrestrial insects	...	1.7(1)	...	...	...	...	...	...	...
Plant material	...	...	0.1(1)	0.1(1)	...	...	...	...	0.2(1)
Clupea harengus harengus	149.6(4)	191.4(1)	...	237.3(3)	...	6099.1(67)	...	...	...
Alosa pseudoharengus	97.1(1)	...	...	...	...	...	...	...	...
Mallotus villosus	...	...	1736.8(45)	1658.5(31)	5122.3(59)	17419.3(172)	10652.7(96)	19.8(1)	3795.6(127)
Osmerus mordax	...	...	117.7(6)	...	...	...	...	...	...
Lantern fish	...	...	...	...	...	...	...	...	...
Paralepis sp.	...	...	...	25.0(3)	...	...	...	...	...
Paralepis coregonoidesborealis	...	...	...	...	...	...	...	...	...
Notolepis rissoi krøyeri	...	...	...	...	...	...	...	...	...
Gasterosteus aculeatus	1.7(3)	...	7.2(4)	...	...	...	...	...	...
Gadus morhua	...	...	...	...	...	56.5(4)	29.0(2)	30.9(2)	3.6(1)
Boreogadus saida	...	...	...	...	...	...	...	...	...
Ammodytes sp.	...	...	...	2048.8(68)	2210.8(47)	178.2(11)	43.1(11)	44.4(1)	602.3(70)
Scomber scombrus	67.2(1)	...	...	...	...	...	...	...	...
Anarhichas lupus	...	...	...	...	...	...	...	...	3.1(1)
Lumpenus maculatus	...	...	...	...	...	...	...	...	9.1(4)
Sebastes marinus	...	...	...	...	...	...	...	...	1.1(4)
Cottunculus microps	...	...	...	...	...	...	...	...	3.4(3)
Myoxocephalus scorpioides	...	...	...	...	...	...	...	...	1.4(1)
Agonus decagonus	...	...	...	...	...	...	...	...	0.4(1)
Cyclopterus lumpus	1.2(1)	...	...	...	...	...	...	...	...
Reinhardtius hippoglossoides	...	...	...	...	...	59.8(1)	...	...	23.3(7)
Clam shell[a]	...	...	...	...	...	...	...	...	...
Spiratella helicina	...	...	...	...	...	...	...	237.6(5)	...
Gonatus fabricii	...	...	...	...	...	...	...	...	...
Polychaete worm	3.3(1)	...	...	...	...	...	...	...	4.5(3)
Amphipod	...	...	...	144.0(12)	0.5(1)	...	30.7(6)	0.1(1)	163.5(36)
Euphausiid	2.5(7)	...	1.7(1)	0.6(2)	...	0.1(1)	...	0.1(1)	529.2(86)
Sergestes arcticus	...	...	...	...	...	...	...	...	...
Pasiphaea tarda	...	...	...	...	...	...	...	...	...
Total salmon stomachs examined (No.)	144	298	250	92	75	268	104	82	234
Total round weight of salmon whose stomachs were examined (kg)	681.45	1277.80	1457.48	406.60	300.00[b]	1111.90	350.90	341.70	885.00
Total food in stomachs (g)	403.7	207.1	1885.4	4182.1	7711.0	23917.0	10764.5	338.7	5534.8
Total food (g) per kg of salmon round weight	0.6	0.2	1.3	10.3	25.7	21.5	30.7	1.0	6.3
Average weight of food (g) per salmon examined	2.8	0.7	7.5	45.5	102.8	89.24	103.5	4.1	23.7
Condition factor	1.10	1.17	1.14	1.14		1.17	1.12	1.08	1.18

[a] Launce caught in hole of empty shell.

[b] Average weight of St. John's salmon estimated by averaging the weights of the combined samples from Port aux Basques and Bonavista.

Results

Atlantic salmon fed at different intensities and on a wide variety of organisms in the various areas considered (Table 1). There was also a considerable amount of variation between areas in the amount of food per kilogram of salmon round weight (0.2 to 30.7 grams) and in the amount of food per salmon examined (0.7 to 103.5 grams) (Table 1). In addition to this there was a great deal of variation with length in amount of food per kilogram of salmon (Fig. 2) and per salmon examined (Fig. 3). The condition factors also varied a great deal between areas (1.08 to 1.18) (Table 1) and between 10 cm length groups (0.98 to 1.27) (Tables 2-7). The condition factors for salmon from the Saint John River, New Brunswick, displayed the greatest variation with length (1.07 to 1.26) while those from ICNAF Divisions 1B and 1E-F displayed the least (1.03 to 1.07 and 1.05 to 1.10 respectively).

ICNAF "1B" 1 Sept. - 10 Nov. 1968-70	ICNAF "1C" 24 Aug. - 4 Nov. 1968-70	ICNAF "1D" 15 Aug. - 1 Nov. 1969-70	ICNAF "1E-F" 1 Aug. - 26 Oct. 1969-70	Davis Strait 5 Sept. - 6 Sept./70	Labrador Sea 6 Sept. 4 Oct. 1969-70	Lab. Sea NE Nfld. Shelf 14 May - 24 May/71	Total 1968-71	Percent by weight	
57-90	52-102	56-88	52-86	60-80	57-88	44-80	44-113		
(31)	-(31)	-(8)	-(4)	-(2)	-(16)	-(7)	-(831)	-	Empty
...	369.1(92)	...	...	...	...	0.2(1)	746.7(136)	1.02	Unidentified material
194.1(42)	332.9(48)	132.7(19)	275.4(37)	...	37.8(14)	153.6(43)	1791.9(367)	2.45	Fish remains
17.5(6)	...	12.6(2)	24.5(4)	...	...	0.1(1)	86.8(18)	0.12	Unidentified invertebrates
...	...	...	...	...	...	0.1(1)	0.1(1)	<0.01	Bird feather
...	...	...	...	...	...	...	0.2(2)	<0.01	*Lepeophtheirus salmonis*
...	...	...	...	...	...	...	1.7(1)	<0.01	Terrestrial insects
...	...	...	...	...	...	...	0.4(3)	<0.01	Plant material
7.9(1)	...	...	...	...	24.5(2)	...	6709.8(78)	9.18	*Clupea harengus harengus*
...	...	...	...	...	...	...	97.1(1)	0.13	*Alosa pseudoharenguss,*
795.2(31)	4618.8(185)	1009.9(28)	2149.1(65)	...	7.5(1)	...	48985.5(841)	67.01	*Mallotus villosus*
...	...	...	...	...	...	...	117.7(6)	0.16	*Osmerus mordax*
...	...	...	...	...	42.2(5)	434.0(39)	476.2(44)	0.65	Lantern fish
...	...	...	...	...	...	...	25.0(3)	0.03	*Paralepis* sp.
234.2(4)	102.9(4)	...	...	231.9(3)	332.2(12)	1043.3(29)	1944.5(52)	2.66	*Paralepis coregonoides borealis*
...	...	...	...	...	...	104.6(8)	104.6(8)	0.14	*Notolepis rissoi krøyeri*
...	...	...	...	...	...	...	8.9(7)	0.01	*Gasterosteus aculeatus*
...	...	...	13.2(1)	...	...	...	133.2(10)	0.18	*Gadus morhua*
...	...	34.1(1)	81.9(2)	...	...	...	116.0(3)	0.16	*Boreogadus saida*
1068.7(57)	1008.5(95)	257.5(27)	54.1(13)	...	...	...	7516.4(400)	10.28	*Ammodytes* sp.
...	...	...	...	...	...	...	67.2(1)	0.09	*Scomber scombrus*
...	...	...	...	...	...	...	3.1(1)	<0.01	*Anarhichas lupus*
...	12.8(1)	...	...	...	...	...	21.9(5)	0.03	*Lumpenus maculatus*
...	...	0.5(2)	20.2(2)	...	...	...	21.8(8)	0.03	*Sebastes marinus*
...	...	...	8.2(4)	...	...	...	11.6(7)	0.02	*Cottunculus microps*
...	...	...	...	...	...	...	1.4(1)	<0.01	*Myoxocephalus scorpioides*
...	...	...	...	...	...	...	0.4(1)	<0.01	*Agonus decagonus*
...	...	...	...	...	...	...	1.2(1)	<0.01	*Cyclopterus lumpus*
...	...	...	...	...	...	...	83.1(8)	0.11	*Reinhardtius hippoglossoides*
2.0(1)	...	...	...	...	...	...	2.0(1)	<0.01	Clam shell[a]
...	...	...	...	...	...	...	237.6(5)	0.33	*Spiratella helicina*
...	...	...	...	...	97.5(16)	36.8(11)	134.3(27)	0.18	*Gonatus fabricii*
0.8(1)	1.8(3)	1.7(1)	12.4(3)	...	...	...	24.5(12)	0.03	Polychaete worm
225.9(61)	166.1(41)	473.8(28)	953.4(64)	0.1(1)	71.7(2)	59.1(45)	2288.9(298)	3.13	Amphipod
222.3(46)	128.0(35)	37.2(11)	413.4(40)	...	0.1(1)	1.4(5)	1336.6(236)	1.83	Euphausiid
...	...	...	...	...	...	1.2(1)	1.2(1)	<0.01	*Sergestes arcticus*
...	...	...	...	...	...	5.7(1)	5.7(1)	0.01	*Pasiphaea tarda*
171	294	64	127	5	57	85	2350		Total salmon stomachs examined (No.)
572.98	886.44	180.70	352.65	20.40	200.38	322.06	9348.44		Total round weight of salmon whose stomachs were examined (kg)
2768.6	6740.9	1960.0	4005.8	232.0	613.5	1840.1	73105.2	99.98	Total food in stomachs (g)
4.8	7.6	10.8	11.4	11.4	3.1	5.7	7.8		Total food (g) per kg of salmon round weight
16.2	22.9	30.6	31.5	46.4	10.8	21.6	31.1		Average weight of food (g) per salmon examined
1.08	1.15	1.12	1.08	1.17	1.08	1.11	-		Condition factor

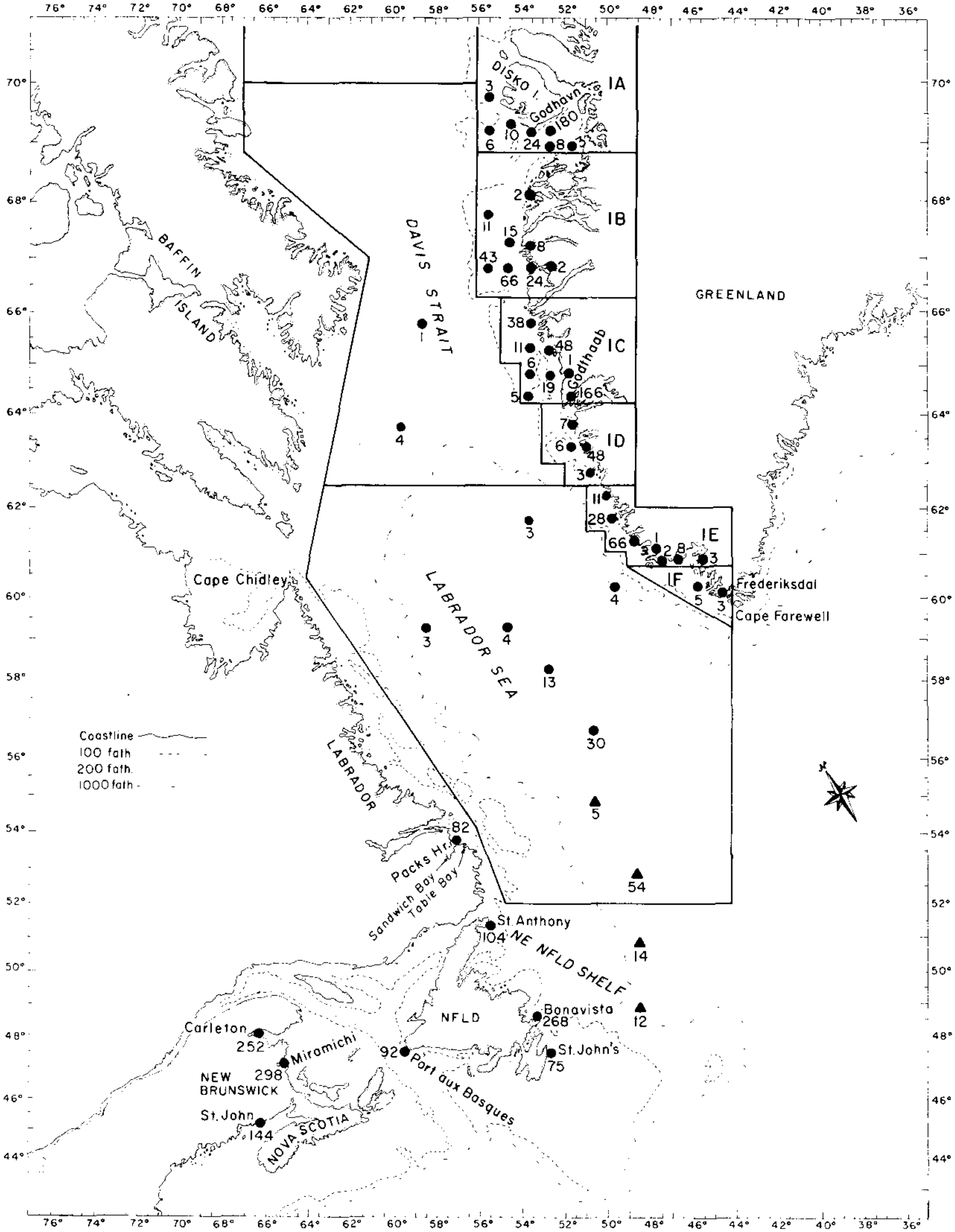

Fig. 1. Area map showing sampling stations, number of stomachs sampled in each locality and place names mentioned in the text. Closed triangles indicate positions from which stomach samples were obtained during May 1971.

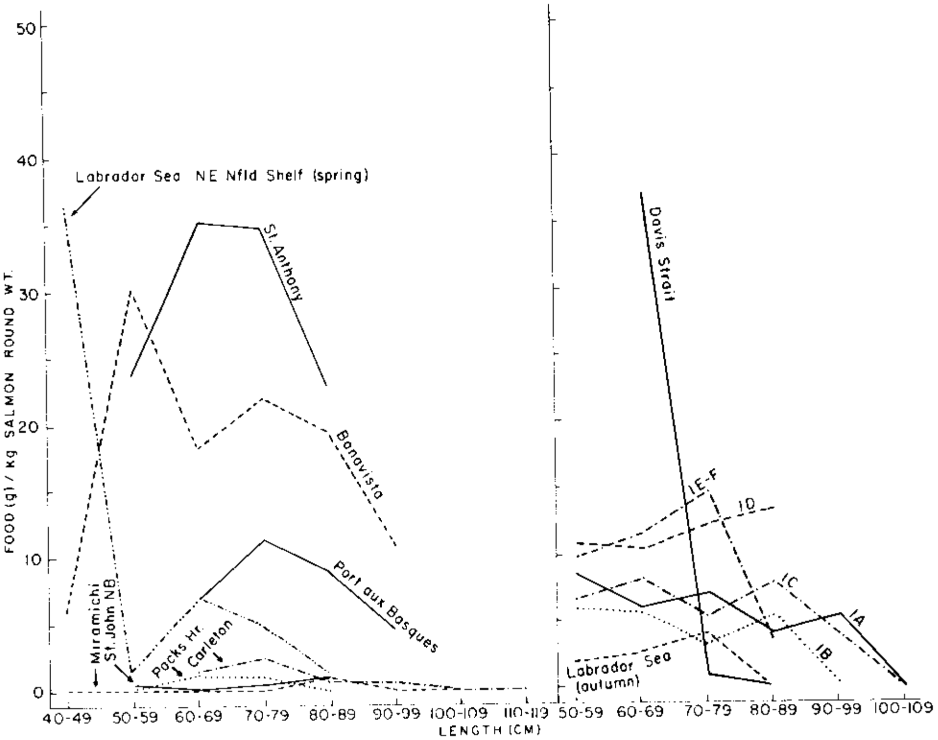

Fig. 2. Average weight of food (g) per kilogram of salmon round weight by 10 cm length groups for different areas.

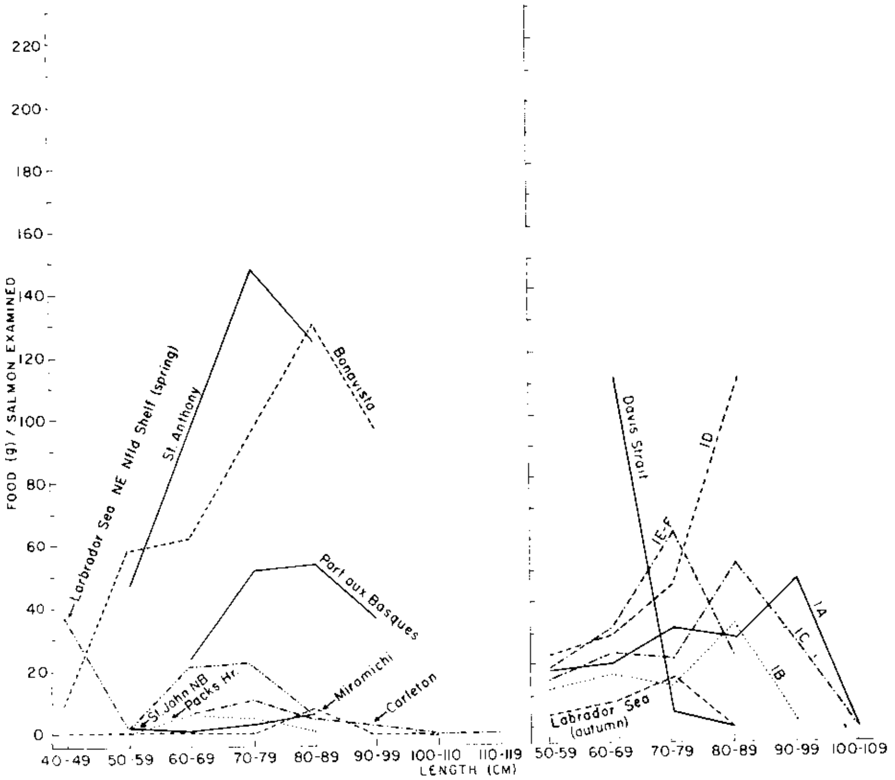

Fig. 3. Average weight of food (g) per salmon examined by 10 cm length groups for different areas.

TABLE 2. Stomach contents of Atlantic salmon caught in various areas and at different seasons, 1968-71, showing weight of food (g) and number of occurrences (in parentheses). Length group (40-59 cm).

	St. John, N.B. 30 June-2 July/70	Miramichi 12 June-9 July/70	Bonavista 8 June-24 June 1970-71	St. Anthony 26 June-6 July/70	Pack's Hr. 24 July-25 July/70	ICNAF "1A" 23 Sept.-1 Oct. 1969-70	ICNAF "1B" 16 Sept.-26 Oct. 1969-70
Salmon length (cm):	55-58	49-56	49-59	52-59	54-57	58	57-59
Empty	– (3)	– (34)	– (4)	– (2)	– (5)	– (0)	– (1)
Unidentified material	...	...	...	...	...	...	...
Fish remains	5.6(2)	...	1.1(1)	...	0.1(1)	...	0.7(1)
Unidentified invertebrates	...	...	...	...	...	...	...
Terrestrial insects	...	1.7(1)	...	...	...	...	...
Mallotus villosus	...	...	3159.4(50)	1710.7(34)	...	37.9(3)	29.5(2)
Lantern fish	...	...	...	...	...	...	...
Ammodytes sp.	...	...	4.6(1)	11.7(4)	...	12.4(2)	7.7(2)
Spiratella helicina	...	...	...	...	0.7(1)	...	...
Polychaete worm	...	...	...	...	...	...	...
Amphipod	...	...	...	19.9(3)	...	...	6.3(2)
Euphausiid	...	...	...	...	...	20.6(1)	2.3(2)
Total salmon stomachs examined (No.)	5	35	55	37	7	4	4
Total round weight of salmon whose stomachs were examined (kg)	9.75	54.90	105.30	73.20	14.00	8.29	7.94
Total food in stomachs (g)	5.6	1.7	3165.1	1742.3	0.8	70.9	46.5
Total food in stomachs (g) per kg of salmon round weight	0.6	0.0	30.1	23.8	0.1	8.6	5.9
Average weight of food (g) per salmon examined	1.1	0.0	57.5	47.1	0.1	17.7	11.6
Condition factor	1.09	1.10	1.17	1.12	1.16	1.06	1.00

TABLE 3. Stomach contents of Atlantic salmon caught in various areas and at different seasons, 1968-71, showing weight of food (g) and number of occurrences (in parentheses). Length group (60-69 cm).

	St. John, N.B. 26 June-2 July/70	Miramichi 16 June-9 July/70	Carleton 15 June/70	Port aux Basques 22 May-15 June/70	Bonavista 8 June-24 June 1970-71	St. Anthony 27 June-6 July/70	Pack's Hr. 8 July-25 July/70	ICNAF "1A" 10 Sept.-1 Nov. 1969-70
Salmon length (cm):	62-69	62-69	66-69	63-69	61-69	60-69	61-69	60-69
Empty	– (4)	(29)	(8)	– (2)	– (6)	– (1)	– (8)	– (13)
Unidentified material	...	...	...	...	...	...	...	...
Fish remains	2.0(2)	0.6(1)	2.2(3)	7.4(3)	10.5(5)	1.2(1)	0.6(1)	239.2(65)
Unidentified invertebrates	...	...	...	...	...	...	...	28.2(3)
Lepeophtheirus salmonis	...	...	...	...	...	...	...	0.2(2)
Clupea harengus harengus	...	...	...	...	370.3(5)	...	...	...
Mallotus villosus	...	...	76.2(4)	94.1(4)	1209.8(14)	1376.9(12)	19.8(1)	2050.2(82)
Lantern fish	...	...	...	...	...	...	...	...
Paralepis coregonoides borealis	...	...	...	...	...	...	...	...
Notolepis rissoi krøyeri	...	...	...	...	...	...	...	...
Gadus morhua	...	...	...	...	...	...	...	3.6(1)
Boreogadus saida	...	...	...	...	...	...	...	...
Ammodytes sp.	...	...	...	373.5(15)	47.3(2)	...	44.4(1)	331.2(44)
Anarhichas lupus	...	...	...	...	...	...	...	3.1(1)
Lumpenus maculatus	...	...	...	...	...	...	...	5.8(2)
Sebastes marinus	...	...	...	...	...	...	...	0.7(1)
Cottunculus microps	...	...	...	...	...	...	...	2.9(2)
Myoxocephalus scorpioides	...	...	...	...	...	...	...	1.4(1)
Reinhardtius hippoglossoides	...	...	...	...	...	...	...	15.0(2)
Clam shell[a]	...	...	...	...	...	...	...	...
Gonatus fabricii	...	...	...	...	...	...	...	...
Polychaete worm	...	...	...	...	...	...	...	4.5(3)
Amphipod	...	...	...	17.4(2)	...	...	0.1(1)	148.2(29)
Euphausiid	0.1(1)	...	...	0.1(1)	...	...	...	326.1(61)
Pasiphaea tarda	...	...	...	...	...	...	...	...
Total salmon stomachs examined (No.)	6	30	15	21	26	14	11	157
Total round weight of salmon whose stomachs were examined (kg)	21.65	105.70	49.36	71.50	88.70	39.10	35.50	506.12
Total food in stomachs (g)	2.1	0.6	78.4	492.5	1637.9	1378.1	64.9	3160.3
Total food in stomachs (g) per kg of salmon round weight	0.1	0.0	1.6	6.9	18.5	35.2	1.8	6.2
Average weight of food (g) per salmon examined	0.4	0.0	5.2	23.5	63.0	98.4	5.9	20.1
Condition factor	1.26	1.14	1.08	1.12	1.12	1.09	1.10	1.15

[a] Launce caught in hole of empty clam shell.

ICNAF "1C" 1 Sept.-30 Oct. 1968-70	ICNAF "1D" 16 Aug.-10 Oct. 1969-70	ICNAF "1E-F" 1 Aug.-16 Oct. 1969-70	Labrador Sea 30 Sept.-4 Oct./71	Lab. Sea NE Nfld. Shelf 17 May-24 May /70	Total 1968-71	Percent by weight	
52-59	56-59	52-59	57-59	44-55	44-59		
– (5)	- (2)	– (1)	(0)	– (1)	– (58)	-	Empty
43.5(17)	...	...	...	...	43.5(17)	0.71	Unidentified material
34.7(5)	13.0(3)	45.1(4)	0.2(1)	4.7(1)	105.2(19)	1.71	Fish remains
...	...	12.6(1)	...	...	12.6(1)	0.21	Unidentified invertebrates
...	...	...	...	...	1.7(1)	0.03	Terrestrial insects
361.7(24)	128.9(4)	70.2(7)	...	...	5498.3(124)	89.52	*Mallotus villosus*
...	...	...	7.2(1)	8.4(1)	15.6(2)	0.25	Lantern fish
78.8(11)	13.8(3)	3.5(1)	...	...	132.5(24)	2.16	*Ammodytes* sp.
...	...	...	...	...	0.7(1)	0.01	*Spiratella helicina*
0.6(1)	...	...	...	...	0.6(1)	0.01	Polychaete worm
1.2(2)	63.1(6)	119.4(9)	...	30.2(3)	240.1(25)	3.91	Amphipod
0.5(1)	35.1(4)	31.9(5)	...	0.5(2)	90.9(15)	1.48	Euphausiid
36	11	15	2	4	215		Total salmon stomachs examined (No.)
78.13	23.22	28.48	4.10	5.69	413.00		Total round weight of salmon whose stomachs were examined (kg)
521.0	253.9	282.7	7.4	43.8	6141.7	100.00	Total food in stomachs (g)
6.7	10.9	9.9	1.8	7.7	14.9		Total food in stomachs (g) per kg of salmon round weight
14.5	23.1	18.8	3.7	11.0	28.6		Average weight of food (g) per salmon examined
1.16	1.07	1.04	1.05	1.12			Condition factor

ICNAF "1B" 1 Sept.-10 Nov. 1968-70	ICNAF "1C" 24 Aug.-4 Nov. 1968-70	ICNAF "1D" 15 Aug.-1 Nov. 1969-70	ICNAF "1E-F" 6 Aug.-26 Oct. 1969-70	Davis Strait 5 Sept./70	Labrador Sea 6 Sept.-4 Oct. 1969-70	Lab. Sea, NE Nfld. Shelf 17 May-24 May/71	Total 1968-71	Percent by weight	
60-69	60-69	60-69	60-69	60-69	61-69	61-69	60-69		
– (19)	(21)	– (6)	- (2)	– (0)	(9)	– (1)	– (129)	–	Empty
...	279.4(67)	...	...	...	...	...	279.4(67)	1.40	Unidentified material
148.6(24)	250.8(40)	91.0(14)	228.9(32)	...	24.1(7)	49.7(13)	1056.8(211)	5.31	Fish remains
17.5(6)	...	8.4(1)	11.9(3)	...	...	...	66.0(13)	0.33	Unidentified invertebrate
...	...	...	...	...	...	...	0.2(2)	< 0.01	*Lepeophtheirus salmonis*
7.9(1)	...	...	...	...	...	...	378.2(6)	1.90	*Clupea harengus harengus*
586.2(22)	3687.8(147)	652.1(20)	1828.6(53)	...	7.5(1)	...	11589.2(360)	58.24	*Mallotus villosus*
...	...	...	...	...	20.0(3)	198.0(19)	218.0(22)	1.10	Lantern fish
108.9(2)	95.0(3)	...	...	222.9(2)	86.4(3)	297.1(13)	810.3(23)	4.07	*Paralepis coregonoides borealis*
...	...	...	...	...	...	48.9(3)	48.9(3)	0.25	*Notolepis rissoi krøyeri*
...	...	...	13.2(1)	...	...	...	16.8(2)	0.08	*Gadus morhua*
...	...	34.1(1)	81.9(2)	...	...	...	116.0(3)	0.58	*Boreogadus saida*
629.7(37)	795.9(72)	243.7(24)	49.3(11)	...	...	...	2515.0(206)	12.64	*Ammodytes* sp.
...	...	...	...	...	...	...	3.1(1)	0.02	*Anarhichas lupus*
...	12.8(1)	...	...	...	...	...	18.6(3)	0.09	*Lumpenus maculatus*
...	...	0.5(2)	0.2(1)	...	...	...	1.4(4)	0.01	*Sebastes marinus*
...	...	...	8.2(4)	...	...	...	11.1(6)	0.06	*Cottunculus microps*
...	...	...	...	...	...	...	1.4(1)	0.01	*Myoxocephalus scorpioides*
...	...	...	...	...	...	...	15.0(2)	0.08	*Reinhardtius hippoglossoides*
2.0(1)	...	...	...	...	...	...	2.0(1)	0.01	Clam shell[a]
...	...	...	...	...	78.8(11)	13.4(4)	92.2(15)	0.46	*Gonatus fabricii*
0.8(1)	1.2(2)	1.7(1)	12.4(3)	...	...	...	20.6(10)	0.10	Polychaete worm
178.6(43)	162.8(37)	379.9(20)	775.9(52)	0.1(1)	...	13.4(17)	1676.4(202)	8.43	Amphipod
213.3(37)	126.9(33)	2.0(6)	286.8(34)	...	0.1(1)	...	955.4(174)	4.80	Euphausiid
...	...	...	...	...	...	5.7(1)	5.7(1)	0.03	*Pasiphaea tarda*
114	231	48	104	2	28	29	836		Total salmon stomachs examined (No.)
336.81	670.91	134.30	285.97	6.00	85.50	89.33	2526.45		Total round weight of salmon whose stomachs were examined (kg)
1893.5	5412.6	1413.4	3297.3	223.0	216.9	626.2	19897.7	100.00	Total food in stomachs (g)
5.6	8.1	10.5	11.5	37.2	2.5	7.0	7.9		Total food in stomachs (g) per kg of salmon round weight
16.6	23.4	29.4	31.7	111.5	7.7	21.6	23.8		Average weight of food (g) per salmon examined
1.07	1.13	1.11	1.06	1.12	1.08	1.06			Condition factor

TABLE 4. Stomach contents of Atlantic salmon caught in various areas and at different seasons, 1968-71, showing weight of food (g) and number of occurrences (in parentheses). Length group (70-79 cm).

	St. John, N.B. 26 June-2 July/70	Miramichi 12 June-9 July/70	Carleton 15 June-16 June/70	Port aux Basques 22 May-15 June/70	Bonavista 8 June-19 June 1970-71	St. Anthony 26 June-6 July/70	Pack's Hr. 6 July-25 July/70	ICNAF "1A" 12 Sept.-27 Oct. 1969-70
Salmon length (cm):	70-79	70-79	70-79	70-79	70-79	70-79	70-79	70-79
Empty	– (83)	(203)	– (96)	(8)	– (30)	(0)	– (48)	(5)
Unidentified material	...	...	...	...	...	...	...	...
Fish remains	69.0(13)	2.4(1)	1.6(2)	57.8(11)	49.5(9)	7.8(1)	0.6(1)	84.2(19)
Unidentified invertebrates	...	...	...	2.6(1)	...	...	...	1.3(1)
Bird feather	...	...	...	...	...	...	...	...
Plant material	...	...	0.1(1)	0.1(1)	...	...	...	...
Clupea harengus harengus	63.9(2)	...	...	173.8(2)	4055.0(47)	...	...	...
Alosa pseudoharengus	97.1(1)	...	...	...	...	...	...	...
Mallotus villosus	...	...	1286.3(28)	1450.5(23)	10282.7(87)	6328.3(41)	...	1356.0(32)
Osmerus mordax	...	...	117.7(6)	...	...	...	...	...
Lantern fish	...	...	...	...	...	...	...	...
Paralepis sp.	...	...	...	25.0(3)	...	...	...	...
Paralepis coregonoides borealis	...	...	...	...	...	...	...	...
Notolepis rissoi krøyeri	...	...	...	...	...	...	...	...
Gasterosteus aculeatus	0.7(1)	...	2.6(2)	...	...	...	...	...
Gadus morhua	...	...	...	...	51.9(3)	26.0(1)	30.9(2)	...
Ammodytes sp.	...	...	...	1513.4(46)	126.3(8)	29.9(6)	...	206.3(19)
Lumpenus maculatus	...	...	...	...	...	...	...	3.3(2)
Sebastes marinus	...	...	...	...	...	...	...	0.4(3)
Cottunculus microps	...	...	...	...	...	...	...	0.5(1)
Agonus decagonus	...	...	...	...	...	...	...	0.4(1)
Cyclopterus lumpus	1.2(1)	...	...	...	...	...	...	...
Reinhardtius hippoglossoides	...	...	...	...	59.8(1)	...	...	7.8(4)
Spiratella helicina	...	...	...	...	...	...	236.9(4)	...
Gonatus fabricii	...	...	...	...	...	...	...	...
Polychaete worm	3.3(1)	...	...	...	...	...	...	...
Amphipod	...	...	...	106.9(9)	...	0.8(2)	...	15.3(7)
Euphausiid	2.2(5)	...	1.7(1)	0.5(1)	0.1(1)	...	0.1(1)	178.0(22)
Sergestes arcticus	...	...	...	...	...	...	...	...
Total salmon stomachs examined (No.)	106	204	133	64	151	43	54	59
Total round weight of salmon whose stomachs were examined (kg)	485.30	915.60	590.89	292.00	661.35	183.80	237.80	260.81
Total food in stomachs (g)	237.4	2.4	1410.0	3330.6	14625.3	6392.8	268.5	1853.5
Total food in stomachs (g) per kg of salmon round weight	0.5	0.0	2.4	11.4	22.1	34.8	1.1	7.1
Average weight of food (g) per salmon examined	2.2	0.0	10.6	52.0	96.9	148.7	5.0	31.4
Condition factor	1.07	1.12	1.06	1.14	1.09	1.05	1.06	1.17

TABLE 5. Stomach contents of Atlantic salmon caught in various areas and at different seasons 1968-71 showing weights of food (g) and number of occurrences (in parentheses). Length group (80-89 cm).

	St. John, N.B. 26 June-2 July /70	Miramichi 18 June-5 July /70	Carleton 15 June-16 June /70	Port aux Basques 20 May-4 June /70	Bonavista 8 June-24 June 1970-71	St. Anthony 26 June-6 July /70	Pack's Harbour 8 July-23 July /70	ICNAF "1A" 12 Sept.-16 Oct. 1969-70
Salmon length (cm):	80-86	80-89	80-89	80-88	80-89	80-85	80-87	80-88
Empty	(20)	– (23)	– (44)	(0)	– (4)	(0)	(9)	– (1)
Unidentified material	...	...	...	...	...	...	...	...
Fish remains	4.5(2)	11.0(3)	17.0(8)	...	41.9(3)	...	4.5(1)	14.1(2)
Clupea harengus harengus	85.7(2)	191.4(1)	...	63.5(1)	1321.4(12)	...	...	...
Mallotus villosus	...	...	295.7(9)	113.9(4)	2434.4(18)	1236.8(9)	...	208.4(7)
Paralepis coregonoides borealis	...	...	...	...	...	...	...	...
Gasterosteus aculeatus	1.0(2)	...	4.6(2)	...	...	...	...	...
Gadus morhua	...	...	...	...	4.6(1)	3.0(1)	...	...
Ammodytes sp.	...	...	...	124.9(6)	...	1.5(1)	...	31.6(3)
Scomber scombrus	67.2(1)	...	...	...	...	...	...	...
Sebastes marinus	...	...	...	...	...	...	...	...
Reinhardtius hippoglossoides	...	...	...	...	...	...	...	0.5(1)
Amphipod	...	...	...	19.7(1)	...	10.0(1)	...	...
Euphausiid	0.2(1)	...	..	...	...	...	...	4.5(2)
Total salmon stomachs examined (No.)	27	27	63	6	29	10	10	9
Total round weight of salmon whose stomachs were examined (kg)	164.75	180.80	425.25	35.30	195.40	54.80	54.40	63.05
Total food in stomachs (g)	158.6	202.4	317.3	322.0	3802.3	1251.3	4.5	259.1
Total food in stomachs (g) per kg of salmon round weight	1.0	1.1	0.7	9.1	19.5	22.8	0.1	4.1
Average weight of food (g) per salmon examined	5.9	7.5	5.0	53.7	131.1	125.1	0.5	28.8
Condition factor	1.09	1.16	1.13	1.03	1.15	0.99	0.98	1.14

ICNAF "1B" 1 Sept.-Nov. 1968-70	ICNAF "1C" 31 Aug.-12 Oct. 1968-70	ICNAF "1D" 24 Aug.-6 Sept. 1969-70	ICNAF "1E-F" 18 Aug.-12 Oct./70	Davis Strait 5 Sept./70	Labrador Sea 6 Sept.-4 Oct. 1969-70	Lab. Sea, NE Nfld. Shelf 14 May-24 May/71	Total 1968-71	Percent by weight	
70-79	70-77	70-71	70-75	70-73	70-76	70-79	70-79		
- (10)	(3)	(0)	– (0)	– (1)	– (5)	– (5)	– (497)		Empty
...	16.8(4)	...	...	...	...	0.2(1)	17.0(5)	0.05	Unidentified material
25.7(13)	8.1(2)	10.1(1)	1.4(1)	...	13.5(6)	97.6(28)	429.3(108)	1.37	Fish remains
...	...	4.2(1)	...	...	...	0.1(1)	8.2(4)	0.03	Unidentified invertebrates
...	...	...	...	...	...	0.1(1)	0.1(1)	< 0.01	Bird feather
...	...	...	...	...	...	...	0.2(2)	< 0.01	Plant material
...	...	...	...	...	24.5(2)	...	4317.2(53)	13.83	*Clupea harengus harengus*
...	...	...	...	...	...	...	97.1(1)	0.31	*Alosa pseudoharengus*
149.0(5)	253.7(9)	138.9(3)	243.5(4)	...	...	...	21488.9(232)	68.82	*Mallotus villosus*
...	...	...	...	...	...	...	117.7(6)	0.38	*Osmerus mordax*
...	...	...	...	...	15.0(1)	227.6(19)	242.6(20)	0.78	Lantern fish
...	...	...	...	...	...	...	25.0(3)	0.08	*Paralepis* sp.
...	7.9(1)	...	...	9.0(1)	245.8(9)	734.2(15)	996.9(26)	3.19	*Paralepis coregonoides borealis*
...	...	...	...	...	...	55.7(5)	55.7(5)	0.18	*Notolepis rissoi krøyeri*
...	...	...	...	...	...	...	3.3(3)	0.01	*Gasterosteus aculeatus*
...	...	...	...	...	...	...	108.8(6)	0.35	*Gadus morhua*
375.6(15)	102.5(10)	...	1.3(1)	...	...	...	2355.3(105)	7.54	*Ammodytes* sp.
...	...	...	...	...	...	...	3.3(2)	0.01	*Lumpenus maculatus*
...	...	...	...	...	...	...	0.4(3)	< 0.01	*Sebastes marinus*
...	...	...	...	...	...	...	0.5(1)	< 0.01	*Cottunculus microps*
...	...	...	...	...	...	...	0.4(1)	< 0.01	*Agonus decagonus*
...	...	...	...	...	...	...	1.2(1)	< 0.01	*Cyclopterus lumpus*
...	...	...	...	...	...	...	67.6(5)	0.22	*Reinhardtius hippoglossoides*
...	...	...	...	...	...	...	236.9(4)	0.76	*Spiratella helicina*
...	...	...	...	...	18.7(5)	23.4(7)	42.1(12)	0.13	*Gonatus fabricii*
...	...	...	...	...	...	...	3.3(1)	0.01	Polychaete worm
37.1(13)	0.9(1)	30.6(1)	40.2(2)	...	71.7(2)	15.5(25)	319.0(62)	1.02	Amphipod
6.7(7)	0.6(1)	...	94.7(1)	...	...	0.9(3)	285.5(43)	0.91	Euphausiid
...	...	...	...	...	...	1.2(1)	1.2(1)	< 0.01	*Sergestes arcticus*
45	18	4	6	2	25	50	964		Total salmon stomachs examined (No.)
178.21	72.80	14.93	25.80	8.70	98.98	215.38	4242.35		Total round weight of salmon whose stomachs were examined (kg)
594.1	390.5	183.8	381.1	9.0	389.2	1156.5	31224.7	99.98	Total food in stomachs (g)
3.3	5.4	12.3	14.8	1.0	3.9	5.4	7.4		Total food in stomachs (g) per kg of salmon round weight
13.2	21.7	46.0	63.5	4.5	15.6	23.1	32.4		Average weight of food (g) per salmon examined
1.05	1.09	1.07	1.19	1.10	1.06	1.10	–		Condition factor

ICNAF "1B" 8 Sept.-Nov. 1968-70	ICNAF "1C" 22 Sept.-Oct. 1968-70	ICNAF "1D" 30 Sept. /69	ICNAF "1E" 27 Aug.-27 Sept. 1969	Davis Strait 6 Sept. /70	Labrador Sea 10 Sept.-3 Oct. 1969-70	Lab. Sea NE Nfld. Shelf 19 May-23 May/71	Total 1968-71	Percent by weight	
81-87	80-87	88	82-86	80	81-88	80	80-89		
(1)	(1)	(0)	(1)	(1)	- (2)	– (0)	– (107)	–	Empty
...	29.4(4)	...	...	...	...	...	29.4(4)	0.41	Unidentified material
18.6(3)	39.3(1)	18.6(1)	...	...	...	1.6(1)	171.1(25)	2.40	Fish remains
...	...	...	...	...	...	...	1662.0(16)	23.30	*Clupea harengus harengus*
30.5(2)	315.6(5)	90.0(1)	6.8(1)	...	...	...	4732.1(56)	66.33	*Mallotus villosus*
125.3(2)	...	...	...	...	...	12.0(1)	137.3(3)	1.92	*Paralepis coregonoides borealis*
...	...	...	...	...	...	...	5.6(4)	0.08	*Gasterosteus aculeatus*
...	...	...	...	...	...	...	7.6(2)	0.11	*Gadus morhua*
55.7(3)	31.3(2)	...	...	...	...	...	245.0(15)	3.43	*Ammodytes* sp.
...	...	...	...	...	...	...	67.2(1)	0.94	*Scomber scombrus*
...	...	...	20.0(1)	...	...	...	20.0(1)	0.28	*Sebastes marinus*
...	...	...	...	...	...	...	0.5(1)	0.01	*Reinhardtius hippoglossoides*
2.1(2)	1.2(1)	0.2(1)	17.9(1)	...	...	...	51.1(7)	0.72	Amphipod
...	...	0.1(1)	...	...	...	...	4.8(4)	0.07	Euphausiid
7	8	1	2	1	2	2	204		Total salmon stomachs examined (No.)
42.52	52.83	8.25	12.40	5.70	11.80	11.66	1318.91		Total round weight of salmon whose stomachs were examined (kg)
232.2	416.8	108.9	44.7	0.0	0.0	13.6	7133.7	100.00	Total food in stomachs (g)
5.5	7.9	13.2	3.6	0.0	0.0	1.2	5.4		Total food in stomachs (g) per kg of salmon round weight
33.2	52.1	108.9	22.4	0.0	0.0	6.8	35.0		Average weight of food (g) per salmon examined
1.05	1.18	1.21	1.05	1.11	0.98	1.14	–		Condition factor

In the Saint John River estuary, Miramichi River estuary, and near Carleton, Quebec, 74-100% of the stomachs examined were empty (Fig. 4). The main food items in terms of volume were capelin, *Mallotus villosus;* unidentified (digested) fish remains, Atlantic herring, *Clupea harengus harengus;* smelt, *Osmerus mordax;* mackerel, *Scomber scombrus;* and stickleback, *Gasterosteus aculeatus;* (Table 1, Fig. 4). The salmon had very high condition factors (1.10 to 1.17).

In the coastal areas of Newfoundland, most of the stomachs contained food mainly capelin, herring, and launce, *Ammodytes* sp. The condition factors were high ranging from 1.12 to 1.17.

In the Pack's Harbour area of Labrador, 85% of the stomachs were empty. The main food items in terms of volume were pteropods, *Spiratella helicina;* launce, baby Atlantic cod, *Gadus morhua;* and capelin. The condition factors decreased with the length of the salmon from 1.12 for the 50-59 cm group to 0.99 for the 80-89 cm length group (Tables 2-5). In the combined coastal areas of Newfoundland and Labrador, the percentage of empty salmon stomachs ranged from 0 to 28 (Fig. 4).

Along the coast of West Greenland from Disko Island to Frederiksdal, most of the stomachs contained food, the main items of diet being capelin, launce, amphipods, euphausiids, unidentified (digested) fish remains and some *Paralepis coregonoides borealis* (Fig. 4). The condition factors for salmon of all lengths combined along the West Greenland coast were fairly high ranging from 1.08 to 1.18 (Table 1).

In the Davis Strait and Labrador Sea during August-November, feeding was fairly intensive with most of the stomachs containing food, mainly *Paralepis coregonoides borealis,* lantern fish, Arctic squid, *Gonatus fabricii;* amphipods, and unidentified fish remains. The condition factors (1.08 to 1.17) are in the same range as those for the West Greenland coastal waters.

TABLE 6. Stomach contents of Atlantic salmon caught in various areas and at different seasons 1968-71 showing weights of foods (g) and number of occurrences (in parentheses). Length group (90-99 cm).

	Miramichi 18 June 1970	Carleton 15 June-16 June 1970	Port aux Basques 15 June 1970	Bonavista 8 June-22 June 1970-71	ICNAF "1A" 29 Sept.-15 Oct. 1969-70	ICNAF "1B" November 1968	Total 1968-71	Percent by weight
Salmon length (cm):	90	90-99	90	90-95	91-92	90	90-99	
Empty	- (1)	(28)	– (0)	– (1)	– (0)	– (0)	– (30)	–
Fish remains	...	1.1(1)	...	1.0(1)	26.9(1)	0.5(1)	29.5(4)	2.96
Plant material	...	...	...	...	0.2(1)	...	0.2(1)	0.02
Clupea harengus harengus	...	...	...	352.4(3)	...	...	352.4(3)	35.37
Mallotus villosus	...	78.6(4)	...	333.0(3)	143.1(3)	...	554.7(10)	55.67
Ammodytes sp.	...	...	37.0(1)	...	20.8(2)	...	57.8(3)	5.80
Amphipod	...	...	...	...	...	1.8(1)	1.8(1)	0.18
Total salmon stomachs examined (No.)	1	33	1	7	4	1	47	
Total round weight of salmon whose stomachs were examined (kg)	9.00	307.10	7.80	61.15	36.30	7.50	428.85	
Total food in stomachs (g)	0.0	79.7	37.0	686.4	191.0	2.3	996.4	100.00
Total food in stomachs (g) per kg of salmon round weight	0.0	0.3	4.7	11.2	5.3	0.3	2.3	
Average weight of food (g) per salmon examined	0.0	2.4	37.0	98.1	47.8	2.3	21.2	
Condition factor	1.23	1.16	1.07	1.14	1.17	1.03		

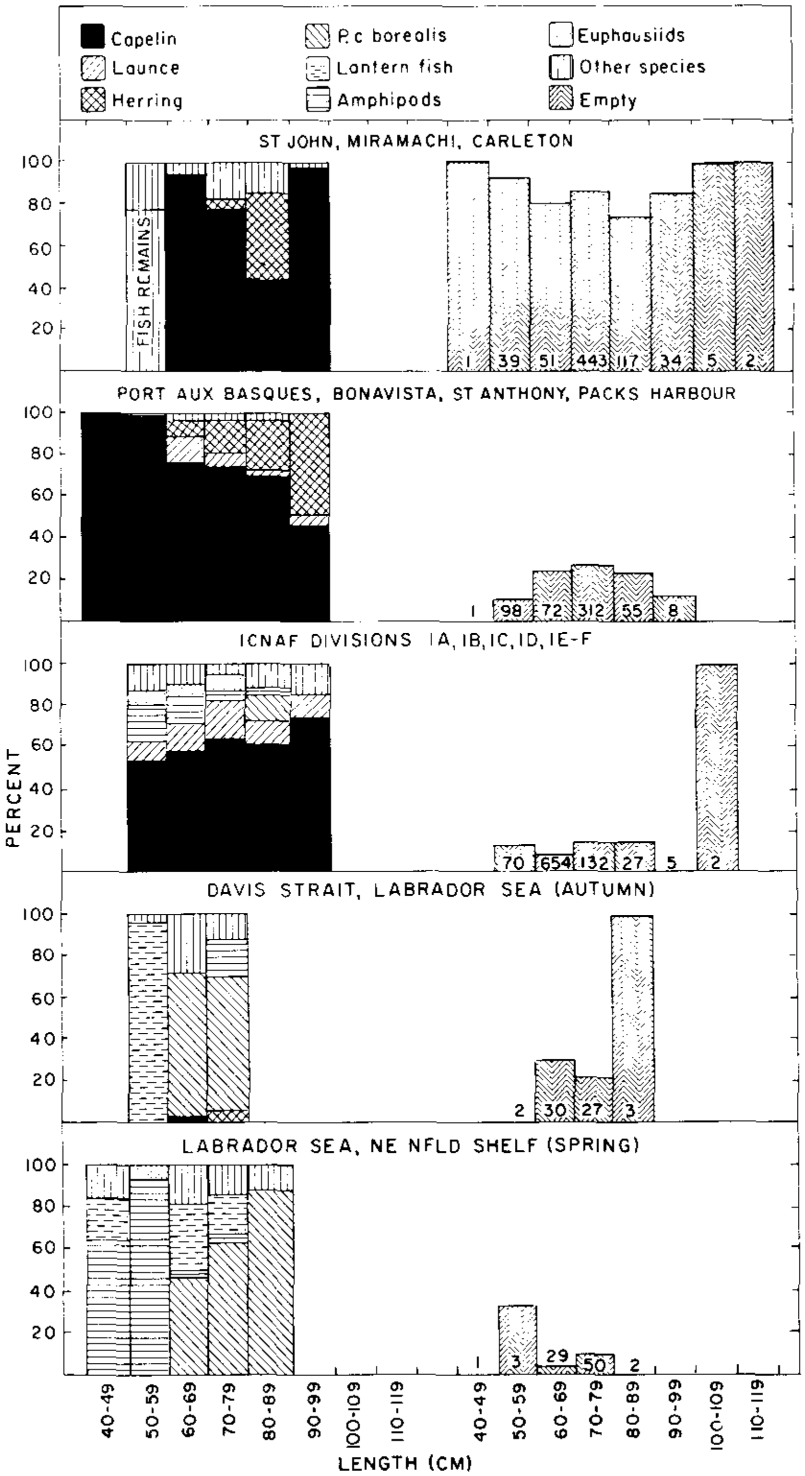

Fig. 4. Percentage by weight of various food items in the stomachs of Atlantic salmon from various areas by 10 cm length groups. Percentage empty are shown on the right. Numbers indicate the number of stomachs examined in each length group and area.

TABLE 7. Stomach contents of Atlantic salmon caught in various areas and at different seasons 1969-70 showing weights of food (g) and number of occurrences (in parentheses). Length group (100-119 cm).

	Miramichi 18 June /70	Carleton 15 June-16 June /70	ICNAF "1A" 14 Oct./70	ICNAF "1C" 1 Oct./69	Total 1969-70	Percent by weight
Salmon length (cm):	103	101-113	100	102	100-113	
Empty	- (1)	– (6)	(1)	(1)	- (9)	...
Total salmon stomachs examined (No.)	1	6	1	1	9	
Total round weight of salmon whose stomachs were examined (kg)	11.80	84.88	10.43	11.77	118.88	
Total food in stomachs (g)	0.0	0.0	0.0	0.0	0.0	0.00
Total food in stomachs (g) per kg of salmon round weight	0.0	0.0	0.0	0.0	0.0	
Average weight of food (g) per salmon examined	0.0	0.0	0.0	0.0	0.0	
Condition factor	1.08	1.15	1.04	1.11		

In the Labrador Sea and off the Northeast Newfoundland Shelf during May 1971, 77-100% of the salmon stomachs contained food (Fig. 4). The main items of diet were *Paralepis coregonoides borealis*, lantern fish, amphipods, fish remains, and *Notolepis rissoi krøyeri* (Table 1). The condition factor for all lengths combined was 1.11 and ranged from 1.06 to 1.19 between 10 cm length groups.

Discussion

It is obvious from this investigation that Atlantic salmon cease to feed when they enter the estuary of their home river, since most of the food found in the stomachs at this time was almost all partially digested except for a few terrestrial insects and sticklebacks which had apparently just been eaten before the salmon were caught. These results agree with those of Power (1969); Kendall (1935); Jones (1959); and Keenleyside (1962).

In the Newfoundland coastal areas salmon eat a considerable volume of food during May-July and the amount eaten per salmon generally increases with each 10 cm increase in length. The amount of food per kg of salmon round weight also increases up to 79 cm but then decreases with increasing length. The main food items are capelin, launce, and herring at this time of year. Blair (1965) and Lindsay and Thompson (1932) reported that the main food items were capelin and launce. The large amounts of food in the stomachs at this time are reflected in the high condition factors especially for the Bonavista area (1.17).

In the Pack's Harbour area, 85% of the stomachs examined were empty. This was probably because of a lack of capelin and herring in the area since a report on cod investigations in this area states that during August 1970 no capelin, herring, or mackerel had been seen up to 10 August. It is also probable that many of these salmon had ceased feeding as they may have been enroute to home rivers such as the North, Eagle, and Paradise rivers in Sandwich Bay and the Sand Hill River in Table Bay. The main items of diet in terms of volume were pteropods, *Spiratella helicina*.

In the West Greenland coastal areas, salmon were feeding almost continuously but less intensively than in the Newfoundland coastal areas of Bonavista and St. Anthony (Figs. 1 and 2) but at about the same intensity as at Port aux Basques. In ICNAF Division 1A (mainly Disko Bay) salmon stomachs contained a wide range of food items but mainly capelin, launce, unidentified (digested) fish remains, amphipods, euphausiids with smaller amounts of Greenland halibut fry, *Reinhardtius hippoglossoides;* daubed shanny, *Lumpenus maculatus;* striped wolffish fry, *Anarhichas lupus;* redfish fry, *Sebastes marinus;* polar sculpin, *Cottunculus microps;* and Arctic sculpin, *Myoxocephalus scorpioides.* In Division 1B mainly over the shallow banks off Holsteinsborg, specimens of *Paralepis coregonoides borealis* were found in 4 of 171 stomachs examined. The large amounts of capelin, launce, and euphausiids agree with the results of Hansen (1965) but also of importance in the stomachs at this time are amphipods.

In the Davis Strait *Paralepis coregonoides borealis* was the main species occurring in the three stomachs which contained food.

In the Labrador Sea during August—November *Paralepis coregonoides borealis* account for the largest volume of food eaten and Arctic squid, *Gonatus fabricii*, next in importance. These large amounts of Arctic squid were also found by Templeman (1967) in this area but during this investigation the paralepidids were found only in the 1970 samples from West Greenland and Labrador Sea during August-November with none being found in those for 1968 and 1969.

In the Labrador Sea and off the Northeast Newfoundland Shelf during May 1971 the main food items were *Paralepis coregonoides borealis*, lantern fish, fish remains, and *Notolepis rissoi krøyeri*. Feeding was intensive with only 8% of the stomachs being empty. The condition factor (1.08) is high compared to that for the same area during April 1971 (0.97) (unpublished data) and suggests that the salmon increase their feeding intensity during April-May in the south Labrador Sea and off the Northeast Newfoundland Shelf.

It is to be noted that although condition factors fluctuate from area to area, all have a value above 1 when all the length groups are combined and only in three areas (St. Anthony, Pack's Harbour and the Labrador Sea) for the 80-89 cm length group do the values decrease below 1. This would tend to indicate that the salmon, while at sea, are feeding almost continuously and fairly intensively.

Acknowledgments

I am indebted to Dr A. W. May and Mr J. H. C. Pippy for making available to me stomachs of salmon collected during the course of some of their field trips.

References

BLAIR, A. A. 1965. Bay of Islands and Humber River Atlantic salmon investigations. *J. Fish. Res. Bd. Canada,* 22 (2): 599-620.

CHRISTENSEN, O. 1961. Preliminary results of an investigation on the food of Baltic Salmon. *ICES, Salmon and Trout Committee, C. M.,* Doc. No. 93, 6 p. (mimeographed).

CHRZAN, F. 1960. Results of investigations on the food of the salmon and sea trout off the Polish Baltic coasts. *ICES, Salmon and Trout Committee, C.M.,* Doc. No. 70, 4 p. (mimeographed).

DAHL, K. 1918. Salmon and trout: A Handbook. *Salmon Trout Ass. London,* p. 1-107.

HANSEN, P. M. 1965. Report on recaptures in Greenland waters of salmon tagged in rivers in America and Europe. *Int. Comm. Northw. Atlant. Fish. Redbook 1965,* Part III, p. 194-201.

JONES, J. W. 1959. The salmon. Collins, London. 192 p.

KEENLEYSIDE, M. H. A. 1962. Skin-diving observations of Atlantic salmon and brooktrout in the Miramichi River, New Brunswick. *J. Fish. Res. Bd. Canada,* 19(4): 625-634.

KENDALL, W. C. 1935. The fishes of New England. The salmon family. Part 2 – the salmons. *Mem. Boston Soc. nat. Hist.,* 9 (1): 1-166.

LINDSAY, S. T., and H. THOMPSON. 1932. Biology of the salmon (*Salmo salar* L.) taken in Newfoundland waters in 1931. *Rep. Newfoundland Fish. Res. Comm.,* 1 (2): 1-80.

POWER, G. 1969. The salmon of Ungava Bay. *Arctic Inst. North America,* Tech. Paper No. 22, 72 p.

TEMPLEMAN, W. 1967. Atlantic salmon from the Labrador Sea and off West Greenland, taken during *A. T. Cameron* cruise, July-August 1965. *Res. Bull. int. Comm. Northw. Atlant. Fish.,* No. 4, p. 5-40.

1968. Distribution and characteristics of Atlantic salmon over oceanic depths and on the bank and shelf slope areas off Newfoundland, March-May, 1966. *Res. Bull. int. Comm. Northw. Atlant. Fish.,* No. 5, p. 62-85.

THUROW, F. 1966. Beitraege zur Biologie und Bestandkunde des Atlantischen Lachses (*Salmo salar* L.) in der Ostsee. *Ber. dtsch. Komm. Meeresforsch.,* 18(3/4): 223–379. (Transl. from German by Fish. Res. Bd. Canada Transl. Ser. No. 1211, 1969).

Studies of the Food Habits of Silver and Red Hake in the Northwest Atlantic Area, 1965-67

By V. I. Vinogradov[1]

Abstract

The present paper contains the results of the studies of the food habits of silver hake, *Merluccius bilinearis* (Mitchell), and red hake, *Urophycis chuss* Walbaum, conducted in 1965-67 on the Scotian Shelf, Georges Bank, and on the Shelf south of New England from Cape Cod to Cape Hatteras (Figs. 1 and 2). Data obtained from more than 48,000 stomachs showed differences in the feeding patterns of both male and female silver and red hakes by size-groups and in the composition of food-species by areas and season. Coefficients of food similarity between silver and red hake were calculated. Food competition between these species would seem to be very light.

Introduction

Feeding patterns and food relationships are often the factors determining the behaviour and distribution of fish during their whole life history. Because of their abundance in the Northwest Atlantic, silver and red hake are of particular interest for their feeding relationships. Nevertheless, the food and feeding of these species has been practically ignored until recently. Limited information is available in works by Bigelow and Schroeder (1953), Schaefer (1960), Sauskan (1966), and Rikhter (1968).

Since 1965 AtlantNIRO has been collecting material for the investigation of feeding patterns and the competition for food of these two species. The present paper summarizes the available material and attempts to fill in some of the existing gaps.

Material and Methods

The present paper is based on data collected during studies of the food habits and feeding of silver hake and red hake in 1965-67. Generally, samples consisted of 100 specimens of each species. The amounts of food in each stomach was recorded in four categories: 0 – empty; 1 – partly full; 2 – half full; 3 – full; and 4 – overfilled. Food items in the stomachs were identified in the laboratory and sometimes at sea. Quantitative analysis of the material was limited to determining the frequency of occurrence (percentage) of the food items by counting the number of stomachs in which each food item was found. Only stomachs containing food were used to estimate this frequency of occurrence. Rate of feeding was determined by the degree of fullness of the stomachs examined, while the proportion of feeding specimens was determined from the total number of stomachs analyzed. Regurgitated stomachs were not included. Food items of silver and red hake were compared using a method of comparison of frequencies of occurrence of food organisms which was suggested by Yanulov (1963) in his studies of feeding of redfish (*mentella* and *marinus*) and of cod from the Newfoundland and Labrador areas. His method calculated a coefficient of food similarity between the two hakes species,

$$\mathrm{CFS} = \frac{n \times 100}{\mathrm{N}}$$

where N is the sum of the highest percentages of frequency of occurrence of food organisms for the compared species, and *n* is the sum of the lowest percentages of frequency of occurrence of the general food components. According to this formula, with complete difference in the food composition of stomachs of the two species compared, the CFS will be 0, whereas with complete similarity it will be 100.

A total of 48,001 stomachs, 42,515 from silver hake and 5,486 from red hake, from ICNAF Statistical Subarea 6 and ICNAF Divisions 4W, 4X, and 5Z were examined. Of the total number of stomachs examined, 16,597 from silver hake and 2,013 from red hake contained food items.

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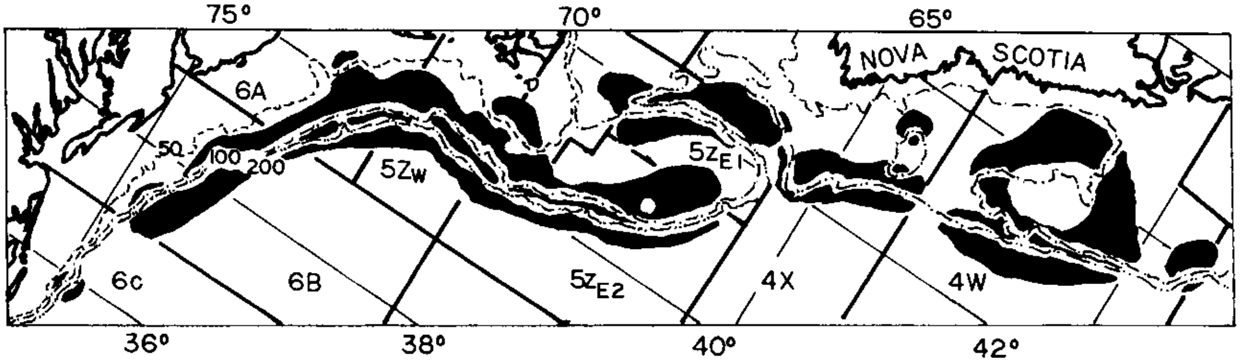

Fig. 1. Sampling areas in the studies of silver hake feeding.

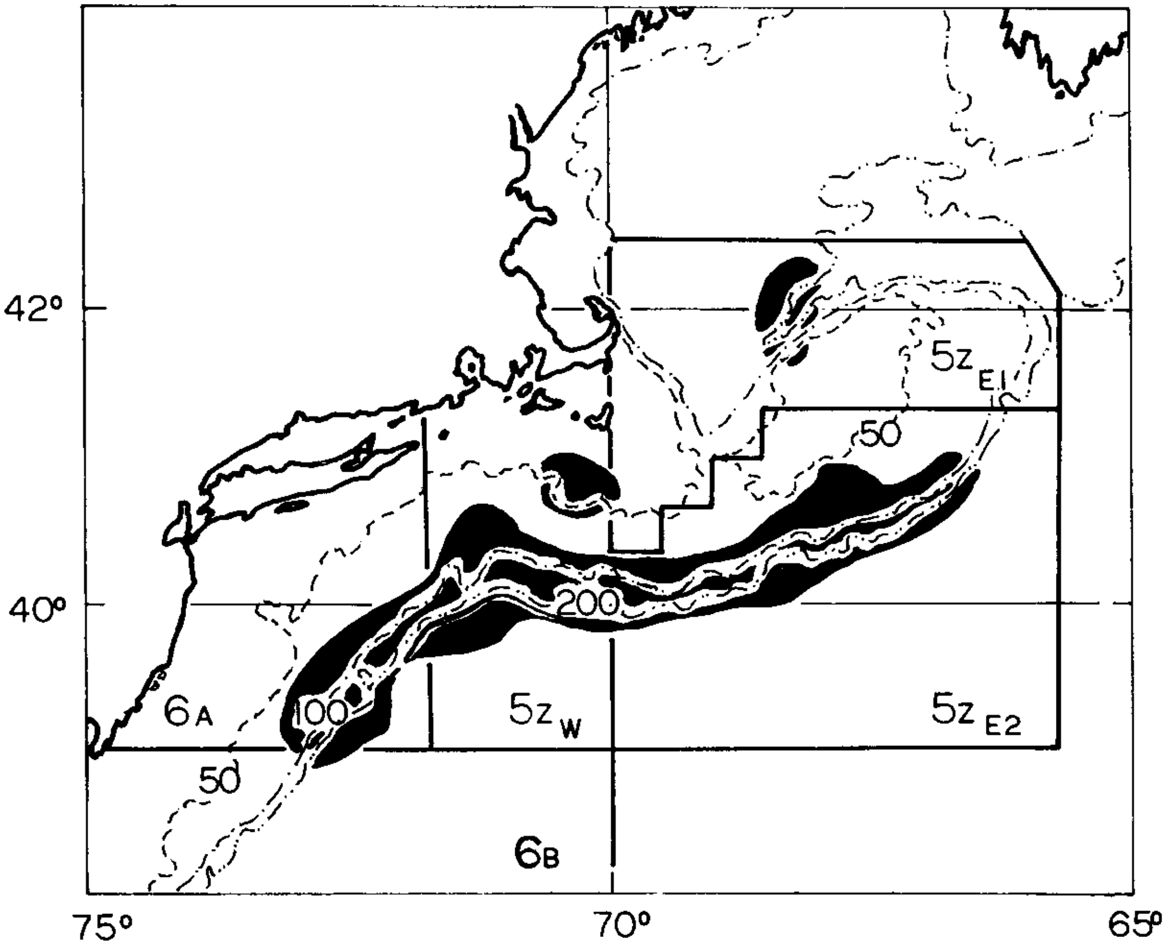

Fig. 2. Sampling areas in the studies of red hake feeding.

Results

Food of silver hake

a) by species composition of food items

Table 1 shows that 59 species of invertebrates and fishes were found in the stomachs. Among them were 24 species of each of fishes and crustaceans, 3 species of molluscs (mostly squids), 3 echinoderms and 5 other species. Of the 59 species, 41 were typical planktonic and bathypelagic species, 18 were benthic or more or less related to bottom.

TABLE 1. List of food organisms found in the stomachs of silver hake, (+ very seldom, ++ seldom, +++ often, ++++ very often).

Phaeophyta	
1. *Fucus* sp.	++
Polychaeta	
2. *Tomopteris* sp.	++
Copepoda	
3. *Calanus finmarchicus* (Gunnerus)	++++
4. *Calanus hyperboreus* Krøyer	+++
5. *Centropages typicus* Krøyer	++
Thoracica	
6. *Balanus eburneus* Leach	+
Mysidacea	
7. *Mysis* sp.	++++
Hyperiidea	
8. *Hyperia galba* (Montagu)	++
9. *Themisto compressa* Goës	++++
10. *Themisto libellula* Mandt	+++
Gammaridea	
11. "Unidentified"	++++
Euphausiacea	
12. *Meganyctiphanes norvegica* (M. Sars)	++++
13. *Thysanoessa inermis* (Krøyer)	++++
14. *Thysanoessa raschii* (M. Sars)	++
15. *Thysanoessa longicaudata* (Krøyer)	++
16. *Namatoscelis megalops* (G.O. Sars)	+
Decapoda	
17. *Pandalus montagui* Leach	++++
18. *Pandalus borealis* Krøyer	++++
19. *Crago septemspinosus* (Say)	++
20. *Homarus americanus* Milne-Edwards	+
21. *Panulirus argus* (Latreille)	+
22. *Pagurus acadianus* Benedict	++
23. *Pagurus longicarpus* Say	+
24. *Cancer irroratus* Say	+
25. *Cancer borealis* Stimpson	+
26. *Panopeus* (?)	+
Pelecypoda	
27. *Nucula tenuis* (Montagu)	+
Cephalopoda	
28. *Illex illecebrosus* (Lesueur)	++++
29. *Loligo peali* Lesueur	+++
Chaetognatha	
30. *Sagitta elegans* Verrill	++
31. *Sagitta serratodentata* Krohn	+
32. *Eukrohnia hamata* Möbius	+
Asteroidea	
33. *Leptasterias groenlandica* (Lütken)	+
Ophiuroidea	
34. *Gorgonocephalus arcticus* Leach	+
Echinoidea	
35. *Echinarachnius parma* (Lamarck)	++
Pisces	
36. *Etrumeus sadina* (Mitchill)	+++
37. *Clupea harengus harengus* Linnaeus	++++
38. *Alosa pseudoharengus* (Wilson)	+++
39. *Alosa aestivalis* (Mitchill)	++
40. *Anchoa mitchilli* (Valenciennes)	+++
41. *Mallotus villosus* (Müller)	+
42. *Argentina silus* Ascanius	++++
43. *Ceratoscopelus maderensis* (Lowe)	+++
44. *Aethoproro (Diaphus) effulgens* Goode and Bean	+
45. *Myctophum affine* (Lütken)	++++
46. *Maurolicus muelleri* (Gmelin)	++++
47. *Scomberesox saurus* (Walbaum)	+
48. *Merluccius bilinearis* (Mitchill)	++++
49. *Urophycis chuss* (Walbaum)	+++
50. *Hippoglossoides platessoides* (Fabricius)	++
51. *Limanda ferruginea* (Storer)	+
52. *Citharichthys arctifrons* Goode	+
53. *Paralepis* sp.	+
54. *Scomber scombrus* Linnaeus	++++
55. *Paprilus (Poronotus) triacanthus* (Peck)	++
56. *Stenotomus chrysops* Linnaeus	++
57. *Sebastes marinus* (Linnaeus)	++
58. *Ammodytes americanus* De Kay	++++
59. *Macrozoarces americanus* (Block and Schneider)	+

Invertebrates had the greater number of species represented (34) in the stomachs (57.6%). Almost all of them were widely spread, euribathic mass organisms.

Twenty-four species, of which 12 were fishes, occurred often or very often, while the rest occurred rarely.

Vertebrates were represented by 24 fishes with anchovy, herring, hakes, argentines, mackerel, and sand lance being most common in stomachs.

Invertebrates were mainly represented by both number of species and in frequency of occurrence. The bulk were euphausiids (62% by frequency of occurrence)

TABLE 2. Percentage occurrence of food items in stomachs of silver hake of various size-groups in ICNAF Subareas 4, 5, and in Statistical Subarea 6 in 1965-67. Figures in the numerator are for females, in the denominator for males.

Food items	Length groups (cm)											Total numbers (%)
	21 s.e.	21	21-25 s.e.	21-25	26-30 s.e.	26-30	31-35	36-40	41-45	46-50	50	
Copepods	2.6	0.9 –		2.1 1.4		1.1 0.5	0.5 0.1	0.1 –	—	—	—	118 0.71
Euphausiids	69.5	67.0 59.5	79.2	65.5 69.4	88.2	64.9 68.0	56.3 65.4	41.7 62.1	26.4 –	4.7 –	4.3 –	10319 62.18
Amphipods		—	5.1	1.2 1.4		2.5 3.8	2.4 2.6	2.2 –	2.2 –	1.5 –	—	434 2.61
Shrimp	16.7	11.3 13.1		6.0 5.7		5.3 4.6	5.9 7.3	3.8 –	2.2 –	4.7 –	—	58 5.48
Benthic organisms		—	1.7	0.1 –		0.1 0.1	0.1 0.1	0.1 –	—	—	—	14 0.08
Squid		—		1.1 0.8		1.2 1.1	2.0 1.0	4.4 3.4	8.2 –	14.1 –	—	266 1.60
Anchovy		– 5.9	1.7	5.4 5.6		4.5 2.8	1.5 1.4	0.7 3.4	1.1 –	—	—	494 2.98
Herring		– 2.4		0.1 –		0.03 0.10	0.5 0.1	1.1 –	2.2 –	7.8 –	21.7 –	52 0.30
Sand lance		—		0.7 0.5		3.5 2.8	14.0 7.1	13.7 –	3.8 –	—	—	1001 6.08
Silver hake		2.8 0.8		1.5 1.1		1.0 0.4	0.6 0.6	2.2 3.4	4.4 –	6.3 –	8.7 –	151 0.91
Other fishes		6.7 1.2	1.7	6.3 6.0	3.9	7.6 6.9	9.5 8.1	24.0 10.5	45.1 –	54.7 –	65.3 –	1521 9.18
Summary percentage of fishes		9.5 14.3	3.4	13.8 13.2	5.9	16.6 12.9	26.1 17.3	41.7 17.3	56.6 –	68.8 –	95.7 –	3219 19.39
Food remnants	11.2	11.3 13.1	10.6	10.2 8.1	5.9	8.3 9.1	6.6 6.2	6.0 17.2	4.4 –	6.2 –	—	1318 7.94
Number of stomachs with food	36	106 84	58	1229 1317	17	3078 4205	3844 1408	917 29	182 –	64 –	23 –	16597

with *Meganyctiphanes norvegica* and *Thysanoëssa inermis*, the main food item (Table 2).

b) by size groups and sex of silver hake

The data were analyzed according to size-groups for silver hake. A clear picture of the qualitative changes in the food composition with size of silver hake was obtained (Table 2). Immature silver hake were not larger than 28 cm and had fed mainly on euphausiids (70-90% by frequency of occurrence).

Mature specimens had fed on almost all groups of food items. However, the bulk of their food was euphausiids whose occurrence increased with size of

TABLE 3. Percentage occurrence of food groups in the stomachs of silver hake, by months in ICNAF Divisions 4W, 5Z, and in Statistical Subarea 6 in 1965-67.

Food groups	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
					Division 4W							
Copepods	–	–	–	–	0.3	–	–	–	45.4	–	–	–
Euphausiids	–	–	–	52.0	77.8	67.0	68.1	57.0	27.3	92.1	78.8	–
Amphipods	–	–	–	–	8.0	10.7	–	31.0	–	–	–	–
Shrimp	–	–	–	–	0.1	–	12.0	–	–	3.2	19.5	–
Benthic organisms	–	–	–	–	–	–	–	–	0.7	–	–	–
Anchovy	–	–	–	–	0.1	–	3.3	–	–	4.7	–	–
Squid	–	–	–	–	0.2	7.0	–	1.0	–	–	–	–
Herring	–	–	–	–	–	–	–	–	–	–	–	–
Sand lance	–	–	–	–	2.3	–	10.7	–	25.8	–	–	–
Silver hake	–	–	–	2.0	–	–	1.0	–	–	–	–	–
Unidentified fishes	–	–	–	46.0	11.2	15.3	4.9	11.0	0.8	–	1.7	–
					Division 5Z							
Copepods	–	–	–	10.4	5.7	4.8	–	–	–	–	–	–
Euphausiids	–	–	60.0	79.7	81.7	60.3	28.7	66.8	42.0	66.2	67.1	66.2
Amphipods	–	–	–	0.5	–	11.8	–	–	31.6	4.5	–	–
Shrimp	–	–	–	–	2.9	0.3	35.6	22.5	9.5	12.0	26.7	–
Benthic organisms	–	–	–	–	–	0.3	–	–	–	–	–	–
Anchovy	–	–	–	–	–	0.4	–	0.3	–	–	–	–
Squid	–	–	–	–	1.3	2.8	1.8	0.9	–	–	–	–
Herring	–	–	–	–	–	–	–	0.3	1.6	–	–	–
Sand lance	–	–	–	–	–	–	–	–	–	–	–	–
Silver hake	–	–	–	–	–	–	–	–	–	–	–	–
Unidentified fishes	–	–	40.0	9.4	8.4	19.3	33.9	9.2	15.3	17.3	6.2	33.8
					Statistical Subarea 6							
Copepods	–	–	–	–	–	–	–	–	0.6	–	0.2	–
Euphausiids	24.7	78.7	77.4	77.5	100.0	81.8	76.4	–	16.6	45.5	47.6	56.4
Amphipods	–	–	0.6	–	–	–	–	–	18.2	–	0.2	–
Shrimp	–	0.8	–	–	–	–	–	–	10.8	0.9	1.8	0.5
Benthic organisms	1.4	0.5	0.5	–	–	–	–	–	0.3	–	–	–
Anchovy	2.5	2.9	5.0	–	–	–	–	–	–	–	–	–
Squid	13.5	3.9	11.5	0.3	–	6.7	8.3	–	0.3	2.8	2.7	13.2
Herring	–	–	–	–	–	–	–	–	8.9	–	–	–
Sand lance	–	–	–	–	–	–	–	–	–	–	–	–
Silver hake	–	–	1.0	–	–	–	–	–	1.0	–	–	–
Unidentified fishes	58.9	13.2	4.0	22.2	–	11.5	15.3	–	43.3	50.8	47.5	29.9

silver hake, up to a length of 35 cm. At this size the silver hake had fed intensively on fishes. The smaller size-groups at the beginning fed on lantern fish, young fish and then changed to mature fish of various species. The occurrence of euphausiids in the stomachs of the older silver hake decreased sharply, while the other food groups disappeared entirely and were substituted by shrimps and squids.

The main food of silver hake larger than 40 cm was fishes. Judging from their frequency of occurrence in silver hake males of increasing length, euphausiids were the most common in silver hake stomachs, then fishes and squids. Percentage of occurrence of fish food items in the stomachs of males of all size-groups remained constant, while that of euphausiids varied from 59.5 to 69.4%. Of the fishes, the silver hake males fed on anchovy and young fish, including young hake. Euphausiids and fishes, being the main food-groups, were always present in the silver hake ration.

In the feeding of the silver hake female, four food-groups were well represented: euphausiids, fish, shrimp, and squid. Proportion of fish and squid in stomachs of females increased with length of the silver hake, while the frequency of occurrence of euphausiids and shrimp decreased. Silver hake females of maximum size fed exclusively on fishes.

c) by areas and seasons

Analysis of silver hake feeding by area and season shows considerable change in the qualitative composition of food items. Two food-groups, euphausiids and fish, are present in all the areas and seasons (Table 3).

Silver hake feed most intensively in the spring-summer and autumn periods. Reduction in the feeding rate on Georges Bank in summer is associated with spawning. In late summer and in autumn another rise in feeding rate is observed. In winter the feeding rate drops in all areas, except in the Hudson Canyon area where silver hake feed intensively even in winter. This fact was also noted by Rikhter (1968).

As stated above, the basic food of silver hake in all areas under study are fishes and euphausiids. No significant differences were observed in the feeding on fish and euphausiids, except on the Scotian Shelf where euphausiids were the highly dominant food item. Differences in feeding throughout a year are due to variations from area to area in the species composition of the fish food and the rate of feeding. On the Scotian Shelf the maximum feeding intensity occurs in the spring months on sand lance, argentine, lantern fish and young silver hake. On Georges Bank the maximum rate of feeding occurs in the autumn months on herring, mackerel, young silver hake and lantern fish. It is possible that the difference in frequency of occurrence of the food-groups in stomachs from all areas is determined by the availability of the various food-groups and by their density spatially and seasonally. However, euphausiids and fishes are the most available and thus the main food items for silver hake.

Food of red hake

a) by species composition of the red hake food

Table 4 shows that a total of 56 species of invertebrates and fishes were found in the red hake stomachs. There were 19 species of fishes, 18 crustaceans, 9 molluscs, and 8 echinoderms species.

Only 8 invertebrates and 8 fishes were typically pelagic and bathypelagic. The other 40 species (71.4%) were benthic or closely related to the bottom. Invertebrates were dominant in the feeding by number of species (36, 64.2%). Of the 56 species, 27 were found often or very often in red hake stomachs, while the rest were rare. The most common food fishes were Atlantic herring, silver hake, yellowtail flounder, butterfish, mailed sculpin, and haddock which constitute 16% of the total.

The main food of red hake were two species, *Themisto compressa* and *Gammaridea (Talorchestia) longicornis*, of Amphipoda (frequency of occurrence, 42%). Less common are squid (6.1%), shrimp (6.0%), and decapods, euphausiids, molluscs, polychaetes, and echinoderms.

b) by size-groups and sex of red hake

Young immature red hake below 25 cm in length fed mostly on amphipod crustaceans (Table 5). Hake from 26 to 40 cm fed on all the listed food-groups. The main food-group was amphipods, followed by the fishes, squids, shrimp, and other decapods. With increasing length red hake, similar to silver hake, tends to become ichtyophagos and the largest size-group (51-55 cm) had fed on three food-groups: fish (57.2% in frequency of occurrence), squid, and amphipods. Analysis of feeding by size-groups indicates that there were no great differences in the qualitative composition of food, except that smaller hake fed on smaller organisms and larger hake on larger organisms.

For male and female fish in the same size-group, amphipods and shrimp were dominant in the male stomachs, while squid and decapods were dominant in female stomachs.

c) by areas and seasons

The intensity of feeding throughout the whole area of distribution increased in spring during pre-spawning and post-spawning periods. It reached a peak

TABLE 4. List of food organisms found in the stomachs of red hake (+ very seldom, ++ seldom, +++ often, ++++ very often).

Phaeophyta	
1. *Fucus* sp.	++
Polychaeta	
2. *Aphrodite aculeata* Linnaeus	++++
Thoracica	
3. *Lepas hilli* Leach	++
4. *Balanus eburneus* Gould	++++
Amphipoda	
5. *Themisto compressa* Goës	++++
6. *Themisto libellula* Mandt	+++
7. *Gammaridea (Talorchestia) longicornis* (Say)	++++
Euphausiacea	
8. *Meganyctiphanes norvegica* (M. Sars)	++++
9. *Thysanoessa raschii* (M. Sars)	+++
10. *Thysanoessa longicaudata* (Krøyer)	+
Decapoda	
Natantia	
11. *Pandalus montagui* Leach	++++
12. *Pandalus borealis* Krøyer	+++
Reptantia	
13. *Homarus americanus* Milne-Edwards	++
14. *Panulirus argus* (Latreille)	+++
Anomura	
15. *Pagurus acadianus* (Benedict)	++++
16. *Pagurus longicarpus* Say	+++
17. *Cancer irroratus* Say	++++
18. *Cancer borealis* Stimpson	+++
19. *Panopeus* (?)	++
Stomatopoda	
20. *Squilla empusa* Say	++
Pelecypoda	
21. *Nucula tenuisulcata* (Couthouy)	+++
22. *Nucula proxima* (Say)	+++
23. *Pecten islandicus* (Müller)	++
24. *Placopecten magellanicus* (Gmelin)	++
25. *Mytilus edulis* Linnaeus	++
Gastropoda	
26. *Corithiopsis* sp.	++
27. *Nassa* sp.	++
Cephalopoda	
28. *Illex illecebrosus* Lesueur	+++
29. *Loligo pealii* Lesueur	+++
Asteroidea	
30. *Ctenodiscus crispatus* (Retzius)	++
31. *Pentagonaster granularis* (O.F. Müller)	++
32. *Henricia sanguinolanta* (O.F. Müller)	++
33. *Leptasterias groenlandica* (Lütken)	+++
Ophiuroidea	
34. *Gorgonocephalus arcticus* Leach	+++
35. *Amphiura denticulata* Koehler	++
36. *Ophiura robustra* Ayres	+
Echinoidea	
37. *Echinarachius parma* (Lamarck)	++++
Pisces	
38. *Myxine glutinosa* Linnaeus	+
39. *Clupea harengus harengus* Linnaeus	+++
40. *Alosa pseudoharengus* (Wilson)	++
41. *Brevoortia tyrannus* (Latrobe)	+
42. *Merluccius bilinearis* Mitchill	++++
43. *Lepophidium cervinum* Goode and Bean	+
44. *Limanda ferruginea* (Storer)	+++
45. *Pseudopleuronectes americanus* (Walbaum)	++
46. *Scomber scombrus* Linnaeus	++
47. *Paprilus (Poronetus) triacantlus* (Peck)	+++
48. *Triglops ommatistius* Gilbert	++++
49. *Myoxocephalus scorpius* Linnaeus	++
50. *Aspidophoroides monopterygius* (Bloch)	++
51. *Cyclopterus lumpus* Linnaeus	+
52. *Prionotus carolinus* (Linnaeus)	+
53. *Tautogolabrus adspersus* (Walbaum)	++
54. *Tautoga onitis* (Linnaeus)	++
55. *Ammodytes americanus* De Kay	++
56. *Melanogrammus aeglefinus* (Linnaeus)	+++

TABLE 5. Percentage occurrence of food items in the stomachs of red hake, by size-groups in ICNAF Subarea 5 and Statistical Subarea 6, in 1956-67. Figures in the numerator are for females, in the denominator for males.

	Length groups (cm)							
Food groups	21-25	26-30	31-35	36-40	41-45	46-50	51-55	Total numbers (%)
Euphausiids	– 1.4	4.5 4.1	4.2 2.8	5.4 3.4	5.0 –	—	—	76 3.80
Amphipods	62.5 69.1	45.0 43.9	38.6 44.5	37.1 41.9	27.3 35.8	40.5 50.0	28.5 –	837 41.85
Shrimp	6.2 5.6	10.0 3.7	6.6 6.0	5.4 6.9	4.4 –	2.1 50.0	—	119 5.90
Polychaetes	—	2.0 0.4	2.2 1.0	0.6 0.8	—	2.1 –	—	22 1.10
Decapods	4.3 2.8	4.0 4.0	3.9 3.5	7.7 6.9	7.6 7.1	2.1 –	—	98 4.90
Molluscs	—	0.5 2.0	1.7 1.2	1.2 0.8	6.3 –	8.5 –	—	36 1.80
Other benthic organisms	—	0.5 –	1.4 1.0	1.8 3.3	—	—	—	20 0.95
Squid	6.2 2.8	7.0 3.7	5.8 4.7	5.9 3.4	14.6 7.1	12.8 –	14.3 –	123 16.10
Summary percentage of fishes	10.4 4.2	12.0 11.0	15.6 14.6	23.0 14.6	27.9 28.6	21.3 –	57.2 –	329 16.30
Food remnants	10.4 14.1	14.5 27.2	20.0 20.7	11.9 18.0	6.9 14.3	10.6 –	—	346 17.30
Number of stomachs with food	500 71	207 246	360 398	335 118	158 14	47 2	7 –	2013

by mid-autumn (October) and decreased sharply in winter.

In June, the food of red hake from the northwest slopes of Georges Bank consisted almost entirely of all the listed food-groups, except for euphausiids (Table 6). Feeding rate was 2.3. Late in autumn (November) the consumption of amphipods increased sharply, while in winter the variety of food-groups increased, but the average amount of food in the stomach declined sharply. In autumn, the feeding rate reached 3.5, while in winter it was reduced to almost zero.

On the southern slopes of Georges Bank, the main food of red hake in spring and summer was amphipods, fishes, squid, and decapods (mainly *Cancer* and *Pagurus*) (Table 6).

In the same period on Nantucket Shoals and on the slopes of the Shelf, red hake fed on the same organisms as they do on the slopes of Georges Bank. However, in autumn crabs, brittlestars, and euphausiids were the main food. In winter, the variety of food items increased, while the feeding rate declined. In the Hudson Canyon area, the feeding rate is also low, the variety of

TABLE 6. Percentage occurrence of food groups in red hake stomachs by months in ICNAF Subarea 5 and Statistical Subarea 6 in 1965-67.

Food groups	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Subdivision $5Ze_1$												
Euphausiids	–	–	–	–	–	–	–	–	–	1.7	4.7	–
Amphipods	–	–	–	–	–	33.2	–	–	–	53.7	80.9	–
Shrimp	–	–	–	–	–	38.4	–	–	–	6.6	6.5	–
Decapods	–	–	–	–	–	1.0	–	–	–	3.4	1.9	–
Polychaetes	–	–	–	–	–	–	–	–	–	0.6	0.3	–
Molluscs	–	–	–	–	–	–	–	–	–	6.4	4.7	–
Benthic organisms	–	–	–	–	–	–	–	–	–	4.5	–	–
Squid	–	–	–	–	–	9.3	–	–	–	2.3	–	–
Fishes	–	–	–	–	–	18.1	–	–	–	20.8	1.0	–
Subdivision $5Ze_2$												
Euphausiids	–	–	–	–	22.0	–	–	–	–	–	–	–
Amphipods	–	–	47.1	–	28.5	30.0	27.4	–	71.6	–	–	57.4
Shrimp	–	–	2.4	–	–	–	26.4	–	–	–	–	1.1
Decapods	–	–	6.2	–	4.8	1.9	5.5	–	12.6	–	–	4.6
Polychaetes	–	–	1.2	–	0.7	–	–	–	–	–	–	4.6
Molluscs	–	–	–	–	–	–	–	–	–	–	–	2.3
Benthic organisms	–	–	–	–	0.2	0.9	1.9	–	–	–	–	–
Squid	–	–	4.8	–	15.7	5.7	11.3	–	–	–	–	13.5
Fishes	–	–	38.3	–	28.1	61.5	27.5	–	15.8	–	–	26.5
Subdivision 5Zw												
Euphausiids	–	–	–	–	–	–	5.2	–	–	–	50.8	6.5
Amphipods	–	–	–	–	–	–	44.0	–	–	–	–	64.7
Shrimp	–	50.0	–	–	–	–	4.1	–	–	–	–	1.8
Decapods	–	–	–	–	–	–	6.8	–	–	–	30.0	4.7
Polychaetes	–	–	–	–	–	–	–	–	–	–	–	5.6
Molluscs	–	–	–	–	–	–	–	–	–	–	–	–
Benthic organisms	–	–	–	–	–	–	0.5	–	–	–	19.2	2.8
Squid	–	–	–	–	–	–	13.2	–	–	–	–	6.5
Fishes	–	50.0	–	–	–	–	26.2	–	–	–	–	7.4
Statistical Subarea 6												
Euphausiids	31.0	72.8	21.3	24.7	–	–	–	–	–	–	–	–
Amphipods	–	–	49.2	3.6	–	–	–	–	–	–	–	–
Shrimp	38.4	–	13.3	–	–	–	–	–	–	–	–	–
Decapods	10.2	–	–	30.0	–	–	–	–	–	–	–	–
Polychaetes	7.3	–	1.7	–	–	–	–	–	–	–	–	–
Molluscs	5.8	–	–	7.3	–	–	–	–	–	–	–	–
Benthic organisms	–	–	1.7	–	–	–	–	–	–	–	–	–
Squid	–	–	5.3	2.3	–	–	–	–	–	–	–	–
Fishes	7.3	27.2	7.5	32.1	–	–	–	–	–	–	–	–

food items is high, with benthic organisms (polychaetes, molluscs, and brittlestars) constituting a significant percentage.

Comparison of feeding of silver hake and red hake

Coefficients of food similarity (CFS) between silver hake and red hake were found to be as low as 13.1 in ICNAF Subdivision $5Ze_1$, through 28.3 for $5Ze_2$, 23.3 for 5Zw, to 30.1 for ICNAF Statistical Division 6A, suggesting that competition for food is not a serious limiting factor in the production of silver and red hake stocks.

The main food of silver and red hake in the summer-autumn period on Georges Bank was fish, shrimp, and euphausiids. In the winter-spring period on Nantucket Sound in the Hudson Canyon area, in addition to the above-mentioned food organisms, squid, fish, and amphipods were common in the stomachs of both species. Since, in winter both species have decreased their feeding rate and increased their variety of food items, the chances for competition for food are very small. From April the food spectrum of red hake and, particularly, of silver hake narrows considerably but, by that time, a feeding migration of both species has already begun.

Summary

1. Euphausiids and fish were the main food for silver hake.

2. Immature silver hake fed mostly on euphausiids, and with increased size, change gradually from a crustacean diet to fish. The feeding pattern of older silver hake was nectophagos.

3. Silver hake males of 35 cm length were abundant, of 36-40 cm few and above 40 cm in length were absent in the catches. The pattern of feeding in males and females of these size-groups was virtually the same. Females above 40 cm in length were exclusively ichtyophagos.

4. The feeding rate in silver hake reached its maximum in the spring, decreased in the summer due to the spawning to a minimum in winter.

5. Immature red hake fed on amphipods. At maturity the proportion of bottom crustaceans, benthos and fish in its ration increased.

6. The feeding patterns of silver and red hake overlap insignificantly and the chance of food competition between them in most of the area is very small.

References

BIGELOW, H. B., and W. C. SCHROEDER. 1953. Fishes of the Gulf of Maine. *Fish. Bull., U.S.*, Vol. 53, No. 74, Washington.

GOODE, G. B. 1884[1]. The silver hake and the merluccio. *In:* The fisheries and fishery industries of the United States. Section I Natural history of useful aquatic animals. U.S. Comm. Fish and Fisheries. Gov't. Printing Office, Washington 240-243.

JENSEN, A. C., and R. L. FRITZ. 1960.[1] Observations on the stomach contents of the silver hake. *Trans. Amer. Fish. Soc.*, 89(2): 239-240.

MUSICK, J. A. 1969[1]. The comparative biology of two American Atlantic hakes, *Urophycis chuss* and *U. tenuis* (Pisces, Gadidae). Ph.D. thesis, Harvard University, Cambridge, Mass.

NICOLS, J. T., and C. M. BREDER, Jr. 1927[1]. The marine fishes of New York and southern New England. *Zoologica*, 9: 163-164.

RIKHTER, V. A. 1968. Some features in behaviour and distribution of silver hake from the West Atlantic in spring. *Ryb. Khoz.*, No. 11, Moscow.

SAUSKAN, V. I. 1966. Biological basis of the fishery for silver hake (*Merluccius bilinearis*, Mitchell) and taxonomy of the Atlantic species, Genus *Merluccius.* Thesis for Master's Degree, Kaliningrad.

SCHAEFER, R. R. 1960. A study of the growth and feeding habits of the whiting or silver hake, *Merluccius bilinearis* (Mitchell) of the New York Bight. *N.Y. Fish Game J.*, Vol. 7, No. 2.

YANULOV, K. P. 1963. Pattern of feeding of redfish (*Sebastes mentella* Travin) in Newfoundland and Labrador waters. *Vop. Ikhtiol.*, Vol.3, iss. 4(29), Moscow, Also *Annu. Meet. int. Comm. Northw. Atlant. Fish. 1961.* Res. Doc. No. 62, Serial No. 1005.

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[1] References not read by the author.

The Fishery on the Southern Gulf of St. Lawrence Cod Stock, 1960-70

By R. G. Halliday[1]

Abstract

Landings from the southern Gulf of St. Lawrence cod stock declined from 110,000 tons in 1956 to 41,000 tons in 1967, then rose to 64,000 tons by 1970. In 1960-70, numbers landed varied between 26 million and 49 million fish. They had an average length of 52-56 cm and most were between 40 cm and 70 cm. Modal age was normally age 5 or age 6. Substantial changes in growth rate resulted in decreasing mean length at age from 1960 to 1963 and increasing mean length at age from 1965 to 1969, which resulted in recruitment at a younger age in more recent years. Catch-per-unit-effort of otter trawlers declined from 1962 to 1966 and increased from 1966 to 1970. Variations in population number and biomass estimated from cohort analysis agreed well with those of catch-per-unit-effort. Fishing mortality varied among years and age-groups due to substantial changes in the intensity and nature of the fishery, averaging F = 0.43 for fully recruited age-groups in 1960-68. The mortality rate of those age-groups in which the mortality is generated mainly by trawl and line gear, ages 7-10, was correlated with the fishing effort of those gears.

Introduction

The southern Gulf of St. Lawrence cod population is migratory, spending the summer months in the Magdalen Shallows region (ICNAF Division 4T) and migrating to overwinter in deep water off Cape Breton Island (ICNAF Subdivision 4Vn and southeastern Division 4T) (Martin and Jean, 1964; McCracken, 1959; McKenzie, 1956).

In the 1940's, landings ranged from 30,000 to 50,000 metric tons when this stock was fished solely by Canada, mainly by hand-line and long-line gear. In the early 1950's, because both Canadian and foreign otter trawlers entered the fishery, landings increased rapidly, reaching 110,000 metric tons in 1956. Landings subsequently declined to about 60,000 metric tons in 1965 because of a decrease in foreign otter trawl and Canadian line landings.

The dymanics of this stock during the 1949-65 period were studied by Paloheimo and Kohler (1968). They described major changes in size and age composition of the population, growth, and recruitment during this period. However, they were unable to derive a satisfactory relationship between mortality and fishing effort, concluding that year-to-year variations in the catchability coefficient, q, or in natural mortality rate, M, were greater than variations in total mortality rate, Z, due to changes in fishing effort. The present paper describes events in the fishery during the 1960-70 period and, by using different methods of analysis from Paloheimo and Kohler, describes a correlation between fishing effort and mortality for some age-groups in the fishery.

Landings

Landings from the southern Gulf of St. Lawrence cod stock were obtained from ICNAF Statistical Bulletins for the years 1960-69, and from unpublished landings statistics on file at ICNAF Headquarters for 1970. Division 4T landings for the whole year and those from Subdivision 4Vn for the months January to April inclusive were referred to this stock.

Landings in the years 1960 through 1962 averaged 66,000 metric tons. In 1963 they increased to 70,000 tons, but declined to 41,000 tons by 1967. Slight increases occurred in 1968 and 1969 and a substantial increase occurred in 1970 when 64,000 metric tons were landed (Table 1). Canada's share increased from 61% of landings in 1960 to 96% in 1969, falling to 73% in 1970. The remainder was accounted for by French, Spanish and, to a lesser extent, by Portuguse landings.

Annual landings by trawlers comprised from 57% to 77% of the total and those of seiners from 1% to 5% (Table 2). Long-line and hand-line landings declined in

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TABLE 1. Division 4T and Subdivision 4Vn Cod. Landings (metric tons round) by Country and Division, 1960-70. (Subdivision 4Vn January-April landings only.)

Year	Canada (M)	Canada (N)	Spain	Portugal	France (M)	Others	Total	4T	4Vn
1960	40,451	3	8,526	3,927	13,276	240	66,423	43,022	23,401
1961	41,836	617	7,883	1,974	13,272	1	65,583	51,750	13,833
1962	50,331	1,243	6,941	2,700	5,213	236	66,664	53,218	13,446
1963	50,902	2,761	11,814	4,496	228	1	70,202	50,715	19,487
1964	43,792	6,201	8,583	–	1,356	615	60,547	41,618	18,929
1965	47,124	9,217	2,962	1,392	1,132	1,200	63,027	46,471	16,556
1966	42,852	4,813	2,185	138	3,806	1,057	54,851	38,248	16,603
1967	34,713	1,071	3,281	85	1,879	285	41,314	34,245	7,069
1968	39,721	3,960	2,317	25	130	398	46,551	37,910	8,641
1969	41,154	4,612	1,060	307	326	53	47,512	40,905	6,607
1970[a]	43,814	3,531	11,666	2,474	2,964	7	64,456	43,408	21,048

[a] Preliminary statistics.

TABLE 2. Division 4T and Subdivision 4Vn Cod. Landings (metric tons round) by gear, 1960-70. (Percentage of annual landings in parentheses.)

Year	Otter and pair trawls	Danish and Scottish seines	Long- and hand-lines	Gillnet	Total
1960	41,019 (62)	229 (<1)	25,171 (38)	4 (<1)	66,423
1961	42,808 (65)	716 (1)	21,888 (33)	171 (<1)	65,583
1962	43,526 (65)	1,475 (2)	20,517 (31)	1,146 (2)	66,664
1963	50,862 (72)	1,621 (2)	15,323 (22)	2,396 (3)	70,202
1964	45,325 (75)	1,985 (3)	10,237 (17)	3,000 (5)	60,547
1965	48,373 (77)	2,673 (4)	8,410 (13)	3,571 (6)	63,027
1966	36,684 (67)	2,391 (4)	6,362 (12)	9,414 (17)	54,851
1967	23,982 (58)	2,212 (5)	5,178 (13)	9,942 (24)	41,314
1968	28,217 (61)	982 (2)	4,419 (9)	12,933 (28)	46,551
1969	27,075 (57)	1,204 (3)	9,655 (20)	9,578 (20)	47,512
1970[a]	43,009 (67)	1,721 (3)	9,937 (15)	9,789 (15)	64,456

[a] Preliminary statistics

importance from 1960 to 1968 (38% to 9% of total) but increased in 1969-70. Gillnet landings increased from 1960 to 1968 (< 1% to 28% of total) but declined in 1969-70. All gillnet, line, and seine landings were made by Canada.

Length and Age Composition of Landings and Numbers Landed

Methods

The difficulties encountered by Paloheimo and Kohler (1968) in deriving meaningful mortality estimates for this stock demonstrate the necessity of taking the seasonal nature of the fishery and the different gears employed into account in determining the size and age composition of removals. In the present study six categories of landings were considered: otter trawl landings in the periods January-April, May-August, and September-December, seine, line, and gillnet landings. Biological sampling for length and age composition of landings in these categories in the 1960-70 period was good only for the Magdalen Shallows "summer" (May-December) trawl fishery (Table 3). It was considered more appropriate to treat the winter Cape Breton fishery separately despite poor sampling coverage by all countries. Danish and Scottish seine landings were treated separately when samples were

TABLE 3. Division 4T and Subdivision 4Vn Cod. Commercial samples, 1960-70.

	Jan.-Apr. trawl			May-Aug. trawl			Sept.-Dec. trawl			Seine			Line			Gillnet		
Country	No. of samples	No. measured	No. aged	No. of samples	No. measured	No. aged	No. of samples	No. measured	No. aged	No. of samples	No. measured	No. aged	No. of samples	No. measured	No. aged	No. of samples	No. measured	No. aged
1960																		
Portugal	9	1284	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Spain	21	9848	–		–	–	–	–	–	–	–	–	–	–	–	–	–	–
Canada		–	–	12[a]	5490[a]	856[a]	–	–	–	–	–	–	14	4533	477	–	–	–
1961																		
Portugal	4	550	–		–	–	–	–		–	–	–	–	–	–	–	–	–
France (M)	10	541	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Canada	–	–	–	18	8125	819	5	1475	104	–	–	–	12	2428	217	1	589	–
1962																		
Canada	2	850	123	15	7051	640	7	2062	209	3	932	185	7	2592	184	5	1554	69
1963																		
Canada	3	1326	199	22	8832	553	11	4999	190	2	735	87	5	1103	–	4	368	–
1964																		
Spain	5	1233	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Canada	8	2638	124	23	8886	614	6	2630	71	–	–	–	3	1275	–	–	–	–
1965																		
Canada	8	2678	163	21	7787	645	13	4840	228	2	733	70	3	545	–	6	1023	–
1966																		
Canada	7	2424	281	17	5006	457	13	3220	437	–	–	–	–	–	–	3	1065	–
1967																		
Canada	2	806	106	17	3544	492	18	4379	572	1	345	27	1	195	–	2	448	–
1968																		
Canada	2	661	128	19	4467	781	9	1848	467		–	–	–	–	–	2	554	–
1969																		
Canada	4	1208	204	7	1399	287	7	1834	303	3	717	98	–	–	–	1	58	28
1970																		
Canada	2	596	102	5	1274	206	4	730	148	8	1704	305	–	–	–	–	–	–

[a] May-December inclusive.

available and combined with otter-trawl landings when there were no seine samples. While seine landings differed slightly from trawl caught fish, being smaller and younger (Fig. 1), they formed such a small part of the total that the error introduced by combining seine with trawl landings is small. However, gillnet and line landings could not be combined with trawl landings when sampling was inadequate, as length and age composition of landings by these gears differed markedly from those of trawl caught fish and from each other (Fig. 1). When there were no length frequency samples from line or gillnet landings in a particular year, those of the preceding and subsequent years were combined (and some 1971 samples were applied in this way to the immediately preceding years). When age samples were inadequate or missing for a landings category, the most appropriate ages from within the same year were applied to the length-frequency.

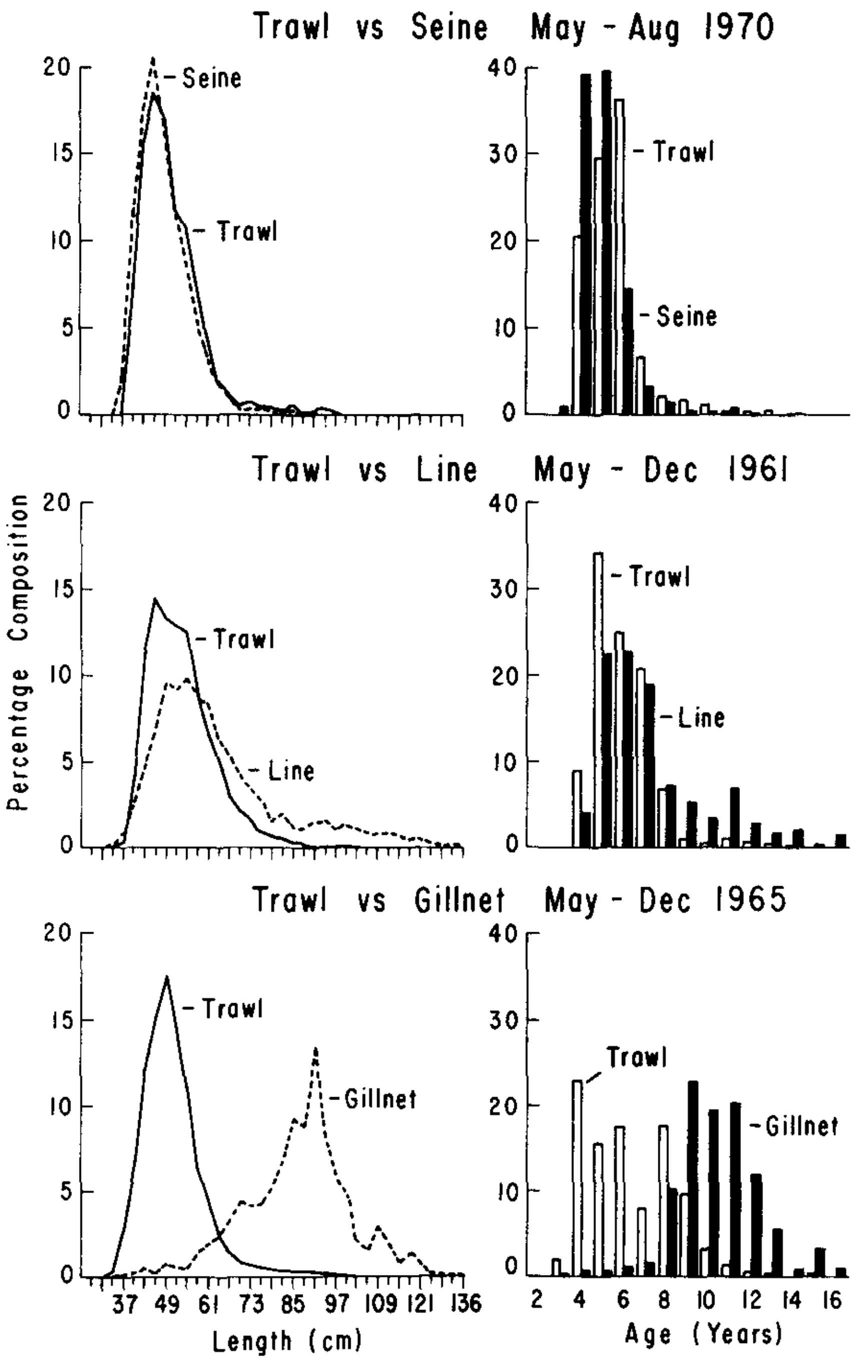

Fig. 1. Comparisons of length and age compositions of cod landings by gear, Div. 4T and Subdivision 4Vn.

In the Canadian fishery, cod landings were frequently separated by size into "scrod", "market", and "large" grades, and each grade was sampled. It was assumed that the proportion of these grades in the landings of the vessels sampled was representative of the whole fleet, and the length and age compositions of each grade were weighted in this proportion.

In contrast to Canadian samples which were of landings after discard, non-Canadian samples were of catches before discard. However, as discards were apparently negligible by non-Canadians (see below) this should not greatly affect the results.

Spain, Portugal, and Canada conform to the ICNAF convention of measuring fork length to the nearest centimeter. However, French samples in 1961 were probably total length to the centimeter below. In cod, fork and total length are virtually equivalent. Thus, the length-frequency of French catches in 1961 is displaced 0.5 cm toward zero in comparison with those of other countries. As this could not be readily corrected, these samples were used as they stood in the belief that the increased information they provided outweighed the slight error introduced.

Numbers of cod landed at age by each of the six gear-season categories in each year were calculated from the length and age compositions, and quantities landed by each category, using appropriate length-weight relationships. These were summed to give total numbers landed at age.

Results

Annual mean lengths of total landings ranged from 52.0 to 56.3 cm (Table 4), 85-95% of the fish being in the range 40-70 cm. Modal length of landings was 46 cm or 49 cm in all years except 1960 (Fig. 2).

TABLE 4. Division 4T and Subdivision 4Vn Cod. Mean age, length (cm), and weight (kg) of landings.

	Trawl						Seine		Line		Gillnet		All gears		
	Jan.-Apr.		May-Aug.		Sept.-Dec.		May-Dec.		May-Dec.		May-Dec.		January-December		
Year	Mean length	Mean age	Mean length	Mean age	Mean length	Mean age	Mean length	Mean age	Mean length	Mean age	Mean length	Mean age	Mean length	Mean age	Mean weight
1960	53.7	6.0	54.9[a]	6.0[a]	–	–	–	–	62.5	6.9	–	–	56.3	6.2	1.73
1961	50.1	5.9	53.6	6.1	52.9	5.9	–	–	63.3	7.3	77.7	9.3	53.7	6.2	1.58
1962	53.9	6.8	51.2	6.1	50.6	5.6	49.4	5.9	57.7	6.6	67.9	7.5	53.2	6.3	1.44
1963	51.5	6.9	51.3	6.6	50.4	5.9	48.0	5.8	61.5	7.5	65.0	7.9	52.8	6.7	1.44
1964	49.5	7.1	53.0	6.9	50.9	6.3	–	–	69.6	8.4	80.6	9.4	52.8	7.0	1.48
1965	49.9	7.3	52.3	6.7	49.4	5.6	47.8	6.1	67.6	8.5	86.2	10.3	52.0	6.9	1.42
1966	50.1	5.9	53.2	6.3	50.1	4.8	–	–	67.6	8.0	92.1	10.8	53.2	6.1	1.57
1967	51.5	6.1	51.4	5.5	49.5	4.7	–	–	67.6	7.7	69.0	7.9	54.3	6.0	1.61
1968	53.1	6.2	48.1	5.1	50.1	4.8	–	–	67.5	7.7	72.0	8.4	53.8	5.9	1.62
1969	47.9	5.5	53.7	5.6	51.9	5.2	51.9	5.0	67.5	7.4	82.0	8.5	54.2	5.8	1.65
1970	51.8	5.9	50.6	5.6	54.1	5.6	49.7	4.9	67.5	7.4	75.9	8.4	54.4	6.1	1.61

[a] May-December inclusive.

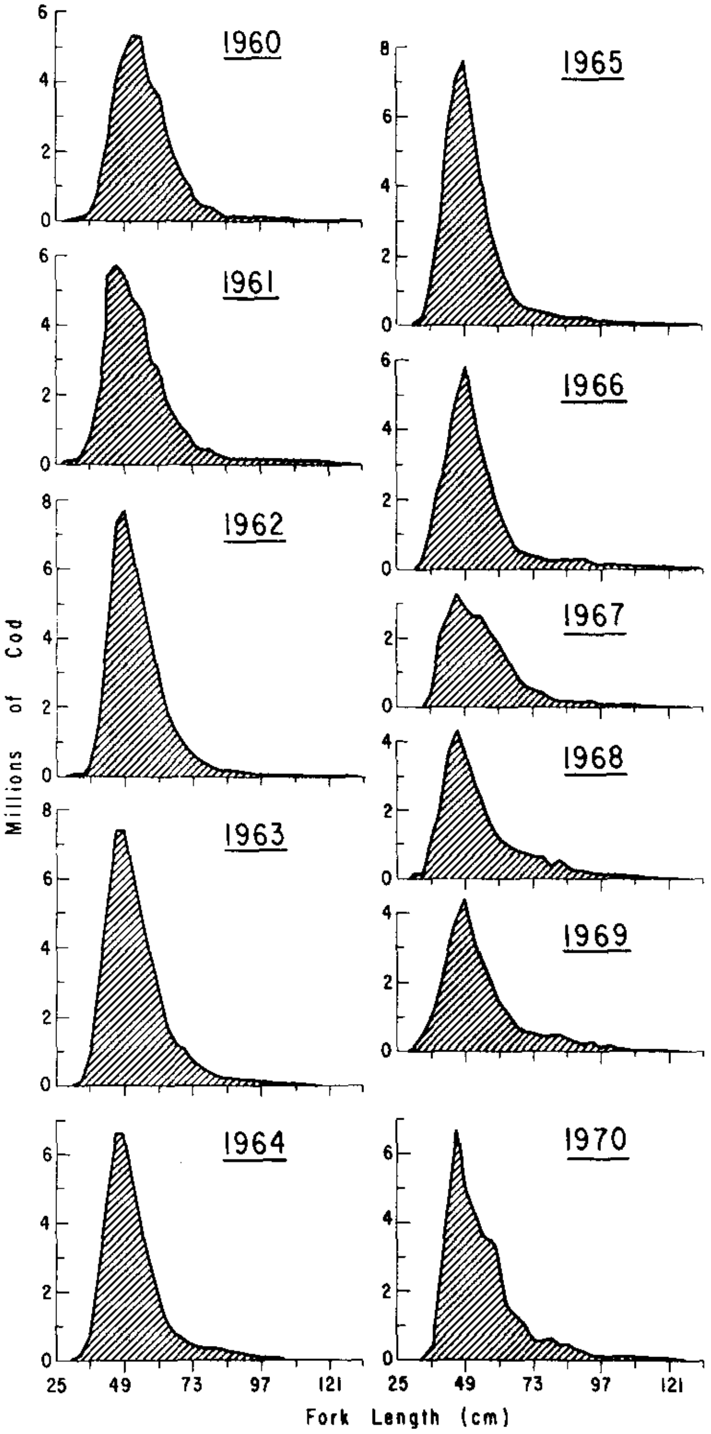

Fig. 2. Length composition of cod landings, 1960-70, Div. 4T and Subdivision 4Vn.

Mean ages of landings ranged from 5.8 to 7.0 years. Modal age-group was normally age 5 or age 6, but on occasion age 4 or age 7 was the most abundant in landings (Fig. 3).

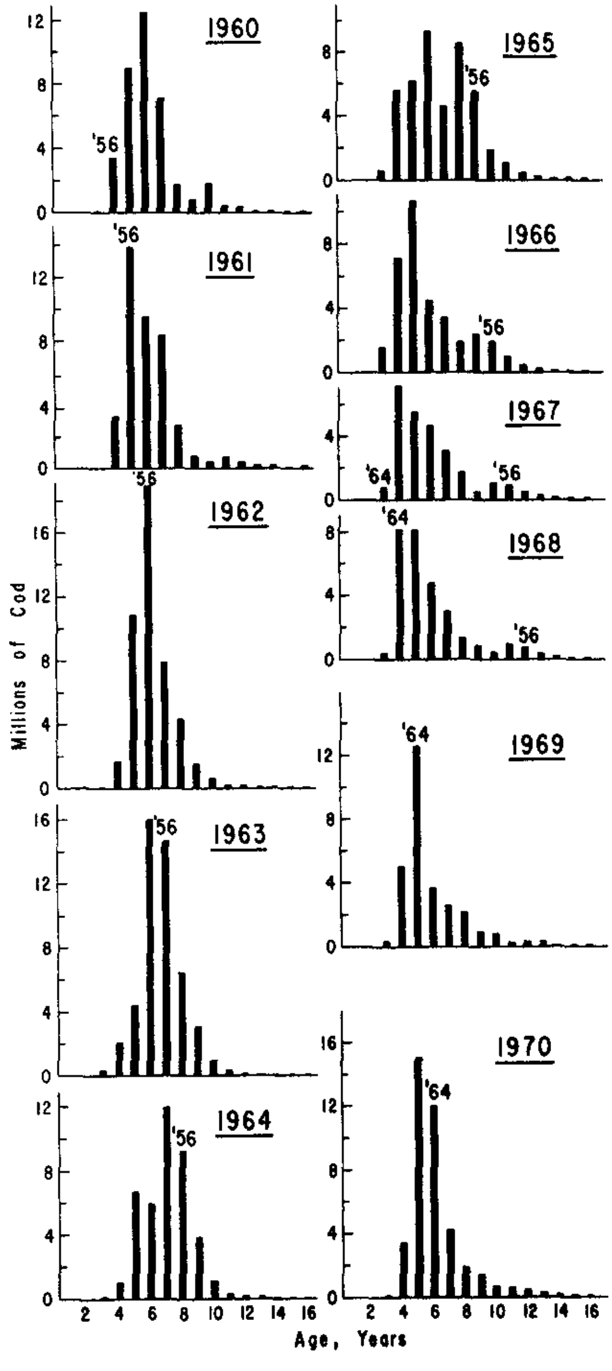

Fig. 3. Age composition of cod landings, 1960-70, Div. 4T and Subdivision 4Vn.

Number landed increased from 38 million fish in 1960 to 49 million in 1963, declined to 26 million in 1967, then rose again to 40 million in 1970 (Table 5).

Discards

Information on discards of small cod at sea in the 1960-70 period is missing or incomplete for all sectors of the fishery. It can reasonably be assumed for all gillnet and line catches that discards were essentially zero. Reported discards in the Subdivision 4Vn trawl fishery by Spain, France, and Portugal were low (frequently 0-2%) (e.g. ICNAF, 1968-70). Canadian discards from Subdivision 4Vn must also have been low as landings from this fishery normally contained small ungraded and ungutted cod. As these sizes were apparently acceptable to the processor it is unlikely that large numbers were discarded. Canadian discard data for Subdivision 4Vn, as submitted to ICNAF, do not give an accurate measure of discard rates due to substantial biases in collection methods. This is also true of Canadian Div. 4T data subsequent to 1964. However, in the 1960-64 period fairly accurate measures of discards were obtained for the Div. 4T otter-trawl fishery by intensive sea and shore sampling of commercial catches and landings (Paloheimo and Kohler, 1968). Discards declined from 10.5% by numbers in 1960 to 1.6% in 1964. There is no reason to believe that discards subsequently increased much above that low value.

Estimated total discards from the Div. 4T otter-trawl fishery declined from almost one million fish in 1960 to 325,000 in 1964. They were mainly fish of 35-45 cm length, and of 3 and 4 years old (Table 6).

Thus, as far as can be judged from inadequate data, wastage due to discarding small fish at sea is not an important factor in analysis of this fishery in the 1960's.

Growth

Paloheimo and Kohler (1968) described substantial changes in growth rate in the 1949-65 period with increasing mean length at age between 1950 and 1956, and subsequent decreasing mean length at age to 1965. Mean length at age then increased again until 1969 (Fig. 4). In the 1960-70 period, these changes in mean length result from change in growth rate from a low level in 1960-63 to a high level in 1963-69 (Table 7).

TABLE 5. Division 4T and Subdivision 4Vn Cod. Numbers landed X 10^{-3} per age-group, 1960-70.

	Year										
Age	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
2	–	-	22	–	–	–	–	–	–	–	–
3	75	–	16	255	100	464	1498	700	310	327	26
4	3967	3304	1720	2123	970	5504	7055	7068	8140	4936	3395
5	8983	13921	10887	4352	6728	6148	10689	5503	8086	12530	14972
6	12515	9475	18889	16021	5863	9292	4505	4586	4674	3571	11925
7	7144	8313	7870	14742	12038	4481	3423	3040	2916	2516	4194
8	1736	2661	4290	6390	9261	8524	1841	1735	1276	2136	1905
9	795	777	1480	3108	3760	5534	2262	407	753	917	1444
10	1812	506	589	984	1133	1845	1890	1021	434	785	727
11	388	741	153	392	347	1004	867	901	899	212	569
12	279	385	178	137	149	423	357	383	698	283	360
13	76	188	37	102	103	150	242	171	259	292	239
14	93	174	26	37	88	52	76	82	139	55	139
15	51	33	36	50	24	124	42	23	65	21	30
16+	39	130	2	35	56	49	79	17	43	40	42
Total	37953	40608	46195	48728	40620	43594	34826	25637	28692	28621	39967

TABLE 6. Discards of cod from the Div. 4T otter-trawl fishery, 1960-64, as total numbers per age-group X 10^{-3}.

	Age							
Year	1	2	3	4	5	6	7	Total
1960	–	12	212	620	101	2	1	948
1961	7	44	115	323	154	18	–	661
1962	–	4	223	292	197	14	1	731
1963	–	11	122	277	51	31	7	499
1964	–	2	200	98	18	3	4	325

Abundance

Catch-per-unit-effort

There is no available measure of gillnet, longline, or hand-line effort in the 1960-70 period, and the Danish and Scottish seine fishery is probably too small and too localized to accurately reflect abundance changes of the entire cod stock. Among otter trawlers, the most consistent data series is available for Gloucester class vessels fishing from New Brunswick ports. These vessels

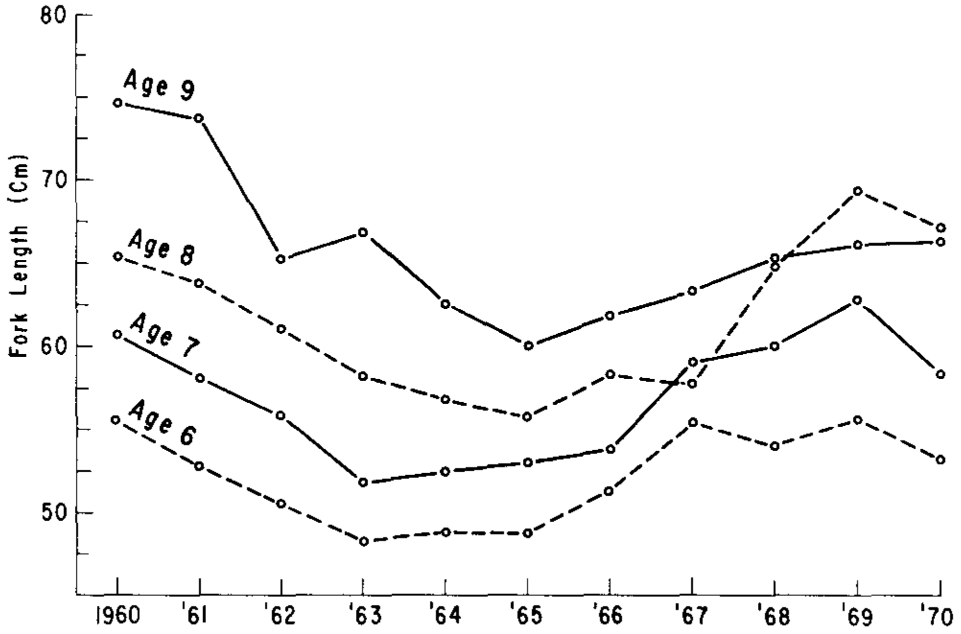

Fig. 4. Div. 4T and Subdivision 4Vn cod. Mean length at age of 6-9 year olds in May-August otter-trawl samples, 1960-70.

TABLE 7. Division 4T and Subdivision 4Vn Cod. Specific growth rate, $g = \dfrac{\log_e L_2 - \log_e L_1}{t_2 - t_1} \times 100$

Year	Ages 6-7	Ages 7-8	Mean
1960-61	4.41	5.15	4.78
1961-62	5.90	5.04	5.47
1962-63	2.54	3.86	3.20
1963-64	8.54	9.22	8.88
1964-65	8.26	5.74	7.00
1965-66	9.96	9.70	9.83
1966-67	14.18	7.00	10.59
1967-68	7.98	9.37	8.68
1968-69	14.94	14.41	14.68
1969-70	4.92	6.78	5.85

of 26-50 gross tons entered the summer Magdalen Shallows fishery in the late 1940's and the fleet composition remained virtually unchanged until the early 1960's, when vessels were progressively retired from the fishery or diverted to the developing snow crab fishery in the area. Comparable vessels of 26-50 gross tons fishing from Quebec ports have maintained a high level of effort in the summer fishery in recent years. Fairly reliable catch-per-unit-effort (cpe) data are available for both groups of vessels for the 6 years 1962-65, 1967-68. Trends in cpe values were similar for both series, the correlation coefficient being 0.71 (with a probability, P = 0.12, of so high a value occurring by chance). Over the 6-year period the ratio of Gloucester class vessel cpe to that of Quebec 26-50 gross ton vessels was 0.93. A composite cpe series was obtained by adjusting Quebec values by 0.93, averaging these with Gloucester values in the years when both were available, using adjusted Quebec values alone for 1969-70, and Gloucester values alone for other years (Fig. 5, Table 8).

Taking catch-per-effort as a measure of stock abundance indicates that cod became more abundant from 1960 to 1962, declined in abundance until 1966, then increased again, reaching the highest value for the period in 1970.

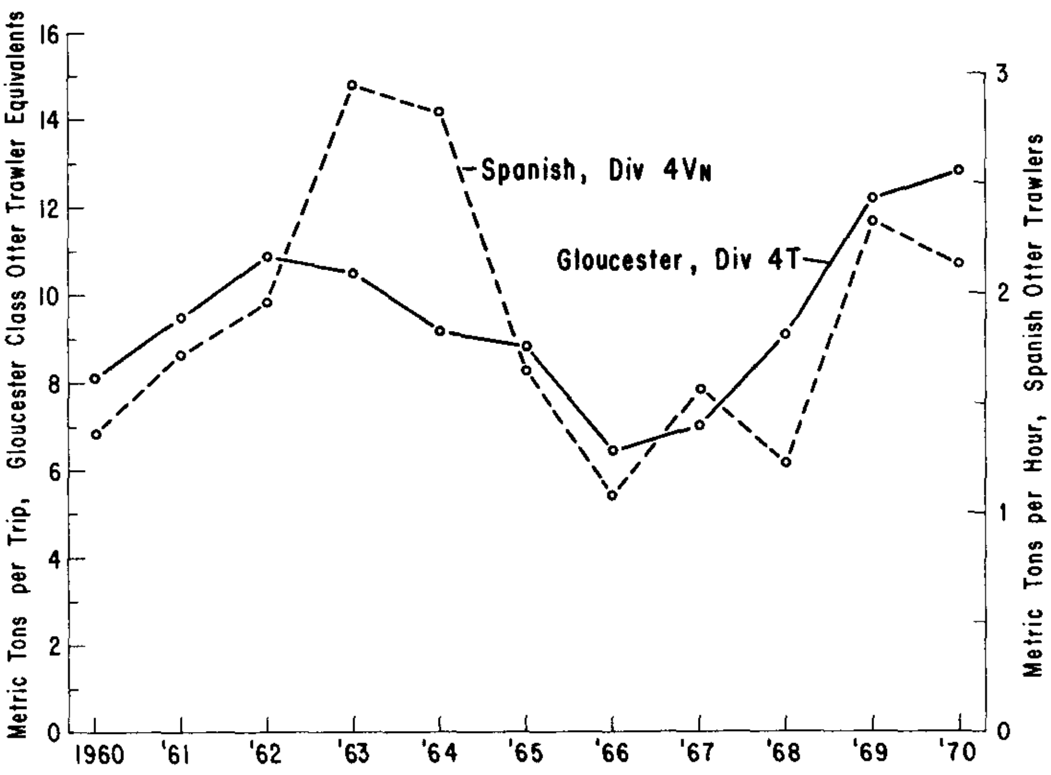

Fig. 5. Div. 4T and Subdivision 4Vn cod. Catch-per-unit-effort, 1960-70.

TABLE 8. Division 4T and Subdivision 4Vn Cod. Catch-per-unit-effort, 1960-70 and "available biomass" calculated from cohort analysis.

Year	Division 4T Metric tons/trip Gloucester class equivalents	Subdivision 4Vn Metric tons/hour Spanish otter trawlers	"Available Biomass" $\times 10^{-3}$ m.t.
1960	8.1	1.37	186
1961	9.5	1.73	202
1962	10.9	1.97	211
1963	10.5	2.96	206
1964	9.2	2.83	181
1965	8.8	1.65	144
1966	6.4	1.08	164
1967	7.0	1.56	157
1968	9.1	1.23	171
1969	12.2	2.33	–
1970	12.8	2.13	–

Although landings from the winter Cape Breton fishery were moderately high between 1960 and 1970, no country exploited the fishery in a consistent manner throughout the period. Catch-per-effort data series for different countries showed different trends indicating that cod abundance was not the prime factor affecting cpe in some series. Among national fleets, the cpe values of Spanish otter trawlers, despite large fluctuations in effort among years, were most similar to those of Div. 4T (Fig. 5, Table 8). The correlation coefficient of Subdivision 4Vn Spanish values with Div. 4T values for the following summer was 0.60, with values for the previous summer it was 0.67, and with the mean of the previous and following summer values it was 0.68. All correlations were significant at the 5% level.

Cohort analysis

Population numbers by age-group in each year were derived by Pope's cohort analysis technique (Pope, 1972) from numbers landed at each age (Table 5). An assumed value of natural mortality (M) of 0.20 was used. (Paloheimo and Kohler (1968) derived a value of M = 0.19 from 1949 to 1965 data.) For year-classes which had passed through the fishery a starting value of fishing mortality (F) of 0.50 was assumed. For year-classes still contributing to the fishery starting F values were obtained by averaging the calculated F values for fully recruited year classes for that age-group. Biomass of the proportion of the stock available to the fishery, called here "available biomass", was calculated as the product of population numbers at age and mean weight at age, adjusting for partial recruitment (see below) of the youngest age-groups.

Abundance of 3-14 year olds calculated in this way declined from 433 million fish at the beginning of 1960 to 199 million at the beginning of 1966, then increased to 313 million by 1968 (Table 9). "Available biomass" increased from 186,000 tons in 1960 to 211,000 tons in 1962, declining to 144,000 tons in 1965 and then increasing to 171,000 tons in 1968 (Table 8).

TABLE 9. Division 4T and Subdivision 4Vn Cod. Population numbers ($\times 10^{-3}$) by age-group, 1960-68, derived by Pope's Cohort Analysis.

Age	Year 1960	1961	1962	1963	1964	1965	1966	1967	1968
3	134,963	48,907	61,785	45,084	64,983	51,924	63,405	119,469	131,256
4	143,111	110,431	40,042	50,571	36,681	53,113	42,092	50,556	97,180
5	70,667	113,580	87,424	31,227	39,483	29,154	38,505	28,078	34,996
6	47,602	49,729	80,395	61,726	21,629	26,238	18,306	21,853	18,009
7	19,983	27,649	32,141	48,730	36,040	12,403	13,074	10,911	13,742
8	6,224	9,896	15,115	19,194	26,557	18,614	6,100	7,607	6,182
9	2,751	3,525	5,694	8,493	9,933	13,363	7,527	3,353	4,658
10	4,460	1,533	2,183	3,323	4,141	4,730	5,933	4,116	2,376
11	1,330	2,012	797	1,254	1,830	2,365	2,203	3,147	2,446
12	880	738	977	514	672	1,184	1,028	1,019	1,761
13	468	468	256	639	297	416	587	519	488
14	152	314	213	176	431	150	205	262	270
Totals 3-14 incl.	432,591	368,782	327,022	270,931	242,677	213,654	198,965	250,890	313,364

These data are in fairly good agreement with the relative abundance by weight estimates provided by cpe data (Table 8). "Available biomass" and Gloucester otter trawler cpe values have a correlation coefficient r = 0.72 for the 1960-68 period which is statistically significant (P = 0.05). The high population number in 1960 was largely due to the good year-classes of 1955-57. As these became more fully recruited to the fishery cpe increased, but with declining mean weight at age and the recruitment of the less strong 1958-63 year-classes cpe declined after 1962. However, the trend of increasing mean weight at age from 1965 followed by the entry of strong 1964 and 1965 year-classes in 1967 and 1968, led to an increase in cpe from 1966 through 1970.

TABLE 10. Number of cod caught per trip at age in Division 4T otter-trawl fishery, 1960-70.

	Age											
Year	3	4	5	6	7	8	9	10	11	12	13	14+
1960	19	746	1317	1639	914	246	73	158	38	32	8	3
1961	–	605	2279	1647	1388	452	80	40	66	53	20	7
1962	–	473	2902	3760	1039	538	160	37	7	11	1	1
1963	41	594	817	3178	2454	836	325	78	45	12	15	5
1964	33	315	1474	824	1980	1254	472	192	31	20	7	15
1965	148	1552	1048	1189	551	1196	652	235	94	34	13	7
1966	374	1399	1327	458	342	244	303	184	57	28	15	9
1967	269	2076	1560	916	338	184	61	88	91	39	13	13
1968	156	3733	2528	929	470	175	104	40	79	35	10	14
1969	85	1659	4479	1224	565	308	136	128	22	59	34	17
1970	–	1764	3545	3416	672	194	177	106	31	41	36	18
Mean	–	–	2116	1744	974	512	231	117	51	33	16	–

TABLE 11. Division 4T and Subdivision 4Vn Cod. Survival rates from Division 4T otter trawl catch and effort data.

	Ages			Mean	Σ8-13 / Σ7-12
Year	7-8	8-9	9-10	(ages 7-10)	
1960-61	0.49	0.33	0.55	0.46	0.49
1961-62	0.39	0.35	0.46	0.40	0.36
1962-63	0.80	0.60	0.49	0.63	0.73
1963-64	0.51	0.56	0.59	0.55	0.53
1964-65	0.60	0.52	0.50	0.54	0.56
1965-66	0.44	0.25	0.28	0.32	0.30
1966-67	0.54	0.25	0.29	0.36	0.41
1967-68	0.52	0.57	0.66	0.58	0.55
1968-69	0.66	0.78	1.23	0.89	0.76
1969-70	0.34	0.57	0.78	0.56	0.48
Mean	0.53	0.48	0.58	0.53 (Z=0.64)	0.52 (Z=0.66)

Mortality

Number of cod caught per trip at each age in the May-December Div. 4T otter-trawl fishery were derived from the appropriate age compositions and weight landed per trip data (Table 10), and survival rates between successive ages of each year-class calculated (Table 11). Ages greater than 10 years were omitted from the calculations of Table 11 because they were poorly represented in the catches, and those younger than 7 years were omitted to remove the effects of partial recruitment on the means.

Survival rates of 7-10 year olds showed considerable fluctuation without apparent trends, the 11-year average being 0.52, equivalent to an instantaneous total mortality rate (Z) of 0.65. The catch curve of mean numbers at age over the period, fitted from ages 7 to 13 (Table 10), gave an estimate of Z = 0.70.

Cohort analysis also provided estimates of fishing mortality rates (F) and these are independent of mortality rates provided by catch-per-unit-effort analysis. Cohort analysis gave the more consistent results (Table 12) and these can be reasonably interpreted in terms of the events in the fishery. In the 1960-65 period, full recruitment of year classes to the fishery, as judged from calculated F values, occurred at about age 7, and mortality of cod 7-10 years old was greater than that of ages 11-14. (The results of 1961 are anomalous in this regard.) The decrease in F of 7-10 year olds in 1961 and 1962 coincided with increased abundance but fairly constant landings while increased mortality in 1963-65 coincided with continuing high landings and declining abundance. The decline in F for 7-10 year olds in 1966-68 corresponded with increasing stock abundance and decline in otter trawl and line landings and thus declining effort. In this 1966-68 period, F of 11-14 year olds increased becoming substantially greater than that of 7-10 year olds, reflecting the increasing importance of the gillnet fishery on large cod.

TABLE 12. Division 4T and Subdivision 4Vn Cod. Instantaneous fishing mortality (F) by age-group and year derived by Pope's Cohort Analysis.

	Year									$\bar{F}$	$\bar{F}$	$\bar{F}$	$\bar{F}$
Age	1960	1961	1962	1963	1964	1965	1966	1967	1968	60-62	63-65	66-68	60-68
3	<.01	–	<.01	.01	<.01	.01	.03	.01	<.01	<.01	.01	.01	.01
4	.03	.03	.05	.05	.03	.12	.20	.17	.10	.04	.07	.16	.09
5	.15	.15	.15	.17	.21	.27	.37	.24	.29	.15	.22	.30	.22
6	.34	.24	.30	.34	.36	.50	.32	.26	.34	.29	.40	.31	.33
7	.50	.40	.32	.41	.46	.51	.34	.37	.27	.41	.46	.33	.40
8	.37	.35	.38	.46	.49	.71	.40	.29	.26	.37	.55	.32	.41
9	.39	.28	.34	.52	.54	.61	.40	.14	.20	.34	.56	.25	.38
10	.60	.45	.35	.40	.36	.56	.43	.32	.26	.47	.44	.34	.41
11	.39	.52	.24	.42	.24	.63	.57	.38	.52	.38	.43	.49	.43
12	.43	.86	.22	.35	.28	.50	.48	.54	.58	.50	.38	.53	.47
13	.20	.59	.17	.19	.48	.51	.61	.45	.88	.32	.39	.65	.45
14	1.14[a]	.94	.14	.26	.26	.48	.53	.43	.84	.54	.33	.60	.49
$\bar{F}_{7-10}$	.47	.37	.35	.45	.46	.60	.39	.28	.25	.40	.50	.31	.40
$\bar{F}_{11-14}$	.34	.73	.19	.31	.32	.53	.55	.45	.71	.44	.38	.57	.46
$\bar{F}_{7-14}$	.41	.55	.27	.38	.39	.56	.47	.37	.48	.42	.44	.44	.43

[a] Omitted from averages

Thus, F of 7-10 year olds increased to 0.50 in 1963-65 from 0.40 in 1960-62, then declined to 0.31 in 1966-68. F of ages 11-14 year olds increased substantially in recent years to 0.57. The average F for 7-14 year olds in 1960-68 was 0.43, which is in reasonable agreement with the 0.45 (assuming M = 0.20) obtained from catch-per-unit-effort analysis.

Mortality rate on partially recruited age-groups increased during the 1960-68 period, in contrast to the mortality rate on 7-10 year olds. There has been an apparent trend of increase in the proportion of a year class recruited at age. The following recruitment pattern to the trawl fishery was deduced from the calculated F values of Table 12:

	Percentage recruited		
Age	1960-62	1963-65	1966-68
3	0	2	3
4	10	14	52
5	38	44	97
6	73	80	100
7	100	100	100

Accurate growth data for partially recruited age-groups are not available from commercial samples. Assuming growth conditions were similar to those for 6-8 year olds which were almost or fully recruited to the trawl fishery, growth rate was higher in the post-1963 period than in 1960-63 (Table 7). Thus, an increasing mean length at age, and hence increasing degree of recruitment to the fishery, would occur among 3-6 year olds over the succeeding 6 years from 1963. The low growth rate of 1960-63 probably also prevailed in the immediately preceding years as mean length at age was declining from about 1956 (Paloheimo and Kohler, 1968). However, it is unlikely that size at age of partially recruited age-groups was smaller in 1960-62 than in 1963-65 (Fig. 4) and, in fact, was probably a little greater. The slightly higher age at recruitment in the 1960-62 period is most likely an artifact from the higher discard rate of partially recruited age-groups prevalent at this time (Table 6).

Discussion

The fishery in the southern Gulf of St. Lawrence cod stock has been continuously changing since the entry of otter trawlers to the fishery in the early 1950's which resulted in annual landings increasing from less than 50,000 tons in the 1940's to 110,000 tons by 1956. Landings subsequently declined, reflecting reduced interest in the fishery by foreign otter trawlers and declining Canadian line landings, reaching a low of 41,000 tons in 1967. However, during this period there was a considerable increase in gillnet landings which partly offset the decline in landings from other gears. This decline in total landings was accompanied by a decline in abundance of those sizes of cod on which the trawl and line fisheries are based (Paloheimo and Kohler, 1968; present paper). Between 1967 and 1970 stock abundance and trawl and line landings increased, total landings increasing to over 64,000 tons by 1970.

Estimates of population numbers of 3+ fish in the 1960-68 period (derived by Pope's cohort analysis) are in good agreement with abundance estimates from otter trawl cpe data. The high population numbers in 1960-61 were largely due to the large year-classes of 1955-57. As these became more fully recruited, weight caught per trip increased, but subsequently decreased with the entry of the poor 1958-63 year-classes. The entry of the better 1964 and 1965 year-classes in 1967 and 1968 reversed the trend of decreasing abundance by weight.

Substantial growth changes which occurred in the 1950's (Paloheimo and Kohler, 1968) continued in the 1960's, mean length, and presumably mean weight, at age declining from 1960 to 1964-65 and subsequently increasing (Fig. 4). These growth changes emphasize the effects of changes in population numbers on weight caught per trip. Changes in age at recruitment to the fishery also resulted from these growth changes. Fishing mortality rates (from cohort analysis and assuming M is constant at 0.2) vary in a manner which is explicable in terms of the events in the fishery. Gillnet landings are composed of considerably older fish than are trawl and line landings, and the development of the gillnet fishery, particularly after 1965, is reflected by the substantial increase in mortality rate of the oldest age-groups in the stock. Those age-groups which sustain the bulk of the trawl and line fisheries (7-10 year olds) showed a decrease in F in 1961 and 1962 coincident with increased abundance but fairly constant landings by these gears. Increased mortality in 1963-65 coincided with continuing high landings and declining abundance, while the decline in F in 1966-68 corresponded with the decline in otter trawl and line landings and increased abundance. The declining mortality rate with age in the 1960-65 period indicates that the older cod become progressively less catchable by trawl and line gear.

Thus, cohort analysis, which assumes a constant value of M for all age-groups and years, produces estimates of population numbers which are in good agreement with independent estimates of abundance from cpe of the commercial fleet, and produces estimates of F, the variations of which are largely explicable in qualitative terms by changes in the nature of the fishery. However, Paloheimo and Kohler (1968) could not derive a satisfactory relationship between mortality and effort from 1949 to 1965 data and concluded that year-to-year variations in the catchability coefficient, q, or in M, were greater than variations in Z due to changes in fishing effort.

In their analysis, Paloheimo and Kohler obtained numbers landed at age by weighting total landings by age compositions obtained from the Div. 4T summer otter trawl fishery only. Total effort was calculated by dividing total catch of all age-groups by catch-per-unit-effort in Div. 4T of Canadian otter trawlers of 26-50 gross tons. Relative abundance of particular age-groups in successive years was obtained by multiplying total numbers caught per unit effort by the proportion of these age-groups in the respective catches. Mortality rates were then obtained from the relative abundance of the same year classes in successive years. This method of analysis does not take account of the substantial differences in age composition among gears, fleets, and areas, i.e. it assumes that the relative catchability of different age-groups is constant between and within different parts of the fishery. Garrod (1967), in his analysis of the Arcto-Norwegian cod stock, found that modified methods of catch-per-effort analysis which took account of these factors were successful in describing the relationship of mortality to effort, whereas earlier attempts had been less than satisfactory.

Total annual effort calculated for the 1960-70 period by the method of Paloheimo and Kohler is not correlated with the mean F for 7-14 year olds obtained by cohort analysis. However, the development of the gillnet fishery has had an obvious effect in increasing mortality on the oldest age-groups. Recalculating total effort by excluding gillnet landings and correlating these values with F for 7-10 year olds, i.e. with those ages where mortality is generated mainly by the trawl and line fisheries, gives a correlation coefficient $r = 0.69$ (d.f. = 7) which is significant at the 5% level (Fig. 6).

The present analysis, in demonstrating a relationship between effort and mortality, implies that variations in M and q are not so great as to mask variations in F due to changes in effort. It further demonstrates the necessity of taking full account of differences in age composition of removals by the various sectors of the fishery. The value of cohort analysis in allowing estimates of F for individual age-groups in each year to be obtained independent of any measurement of effort is also shown. It remains to describe the effective effort on each age-group of the various gears involved by taking account of their different selective properties and also of differences in age composition of the parts of the stock to which this effort is applied, if the effects of the fishery on the stock are to be known with accuracy.

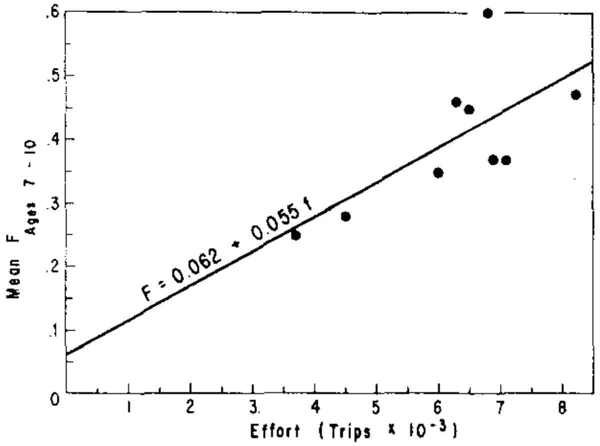

Fig. 6. Div. 4T and Subdivision 4Vn cod. The regression of fishing mortality, F, of 7-10 year olds on fishing effort.

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References

GARROD, D. J. 1967. Population dynamics of the Arcto-Norwegian cod. *J. Fish. Res. Bd. Canada*, 24: 145-190.

ICNAF, 1968-70. Summary of statistics on discards (whole fish returned to the sea), 1966-68. *Int. Comm. Northw. Atlant. Fish. Redbook, Part III, 1968* p. 29-36; *1969* p. 115-123; *1970* p. 181-188.

MARTIN, W. R., and JEAN, Y. 1964. Winter cod taggings off Cape Breton and on offshore Nova Scotia banks, 1959-62. *J. Fish. Res. Bd. Canada*, 21: 215-238.

McCRACKEN, F. D. 1959. Cod tagging off northern New Brunswick in 1955 and 1956. *Fish. Res. Bd. Canada, Atlant. Progr. Rept.*, No. 72, p. 8-19.

McKENZIE, R. A. 1956. Atlantic cod tagging off the southern Canadian mainland. *Bull. Fish. Res. Bd. Canada*, No. 105, 93 p.

PALOHEIMO, J. E., and KOHLER, A. C. 1968. Analysis of the southern Gulf of St. Lawrence cod population. *J. Fish. Res. Bd. Canada*, 25: 555-578.

POPE, J. G. 1972. An investigation of the accuracy of virtual population analysis. *Res. Bull. int. Comm. Northw. Atlant. Fish.*, this volume p. 65-74.

An Investigation of the Accuracy of Virtual Population Analysis Using Cohort Analysis

By J. G. Pope[1]

Abstract

Cohort analysis is a simplified, approximate form of Gulland's virtual population analysis. As such it may be used to obtain estimates of the instanteous rate of fishing mortality and the population surviving for each age of a year-class, given the catch-at-age data, and an estimate of the instanteous rate of natural mortality and an estimate of the fishing mortality at the final age of exploitation. More importantly, the simplicity of cohort analysis makes it possible to investigate the errors generated in such estimates by the arbitrary choice of the rate of fishing mortality on the last age exploited and by the sampling errors of the catch-at-age data.

Introduction

Gulland's virtual population analysis (Gulland, 1965) is an extremely useful technique when assessing a fishery, because it enables estimates of population at age and fishing mortality to be made independently of the measurement of effort. These estimates are however subject to various errors which might adversely affect an assessment. What causes these errors and how can their magnitude be calculated?

Section 1. Cohort Analysis as an Approximation to Virtual Population Analysis

In the text and appendices the following symbols are used:

M is the instantaneous coefficient of natural mortality;
F is the instanteous coefficient of fishing mortality;
Z is the instantaneous coefficient of total mortality;
N_i is the population of a year-class at the ith birthday;
C_i is the catch of a year-class at age i;
t is the last age of a year-class for which catch data are available;
exp is the exponential function.

Virtual population analysis is an ingenious stepwise procedure developed by Gulland to calculate, for a year-class, the instanteous fishing mortality and population at each age, given a knowledge of the catch at each age and the natural mortality. Details of the method are given in Appendix A but basically it is based on the solution of the formula:

$$\frac{N_{i+1}}{C_i} = \frac{(F+M)\exp\{-(F+M)\}}{F\left(1-\exp\{-(F+M)\}\right)} . \qquad (1.1)$$

Since this formula does not yield an analytical solution for F it has to be solved numerically, either by reference to tables or by using an iterative procedure. Either method makes calculation of F and N by hand somewhat laborious. More importantly, the lack of an explicit formula for F makes it difficult to comprehend the effect that errors in the input information cause in the results.

Cohort analysis is a new form of virtual population analysis developed by the author to overcome these problems. It is in fact an approximation to Gulland's virtual population analysis which is usable at least up to values of M = 0.3 and F = 1.2. A detailed explanation of the method is given in Appendix B. The method is based on the approximate formula:

$$N_i = C_i \exp\{M/2\} + N_{i+1} \exp\{M\} . \qquad (1.2)$$

Thus, using 1.2 as a recurrence relationship,

$$N_i = \left(C_i \exp\{M/2\}\right) + \left(C_{i+1} \exp\{3M/2\}\right) + \qquad (1.3)$$

$$+ \left(C_{i+2} \exp\{5M/2\}\right) + \ldots + \left(N_t \exp\{(t-i)M\}\right)$$

As with Gulland's virtual population analysis, N_t has two possible forms. The first form is when C_t refers to the

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catch in year t only, which is the case with the last year's catch of a year-class that is still being fished.

In this case

$$N_t = \frac{C_t\,Z_t}{F_t\,(1 - \exp\{-Z_t\})} \qquad (1.4)$$

and consequently

$$N_i = \left(C_i \exp\{M/2\}\right) + \left(C_{i+1} \exp\{3M/2\}\right) + \left(C_{i+2} \exp\{5M/2\}\right) + \cdots + \left(\frac{C_t\,Z_t \exp\{(t-i)\,M\}}{F_t\,(1 - \exp\{-Z_t\})}\right) \qquad (1.5)$$

The second form is when C_t refers to the catch in year t and all subsequent years. This is usually the case with a completely fished year-class. In this case

$$N_t = \frac{C_t\,Z_t}{F_t} \qquad (1.6)$$

and consequently

$$N_i = \left(C_i \exp\{M/2\}\right) + \left(C_{i+1} \exp\{3M/2\}\right) + \left(C_{i+2} \exp\{5M/2\}\right) + \cdots + \left(\frac{C_t\,Z_t \exp\{(t-i)\,M\}}{F_t}\right) \qquad (1.7)$$

In either case

$$F_i = \log_e \{N_i / N_{i+1}\} - M\,. \qquad (1.8)$$

The closeness with which these formulae approximate the results of virtual population analysis can be judged from Table 1, where results of both methods are compared. It can be seen that in no case do the estimates given by the two methods differ by more than 2%. Consequently an investigation of the errors of cohort analysis is an approximate investigation of the errors of Gulland's virtual population analysis. It can be seen from equations 1.5 and 1.7 that errors in N_i, and consequently errors in F_i, can be introduced by the incorrect choice of F_t and by the sampling errors in the C_i. These two sources of error are investigated in the next two sections. Errors in M can also cause errors in N_i and F_i, but for the purpose of this document M will be considered as fixed.

TABLE 1. Comparison of the results of virtual population analysis and cohort analysis. Arcto-Norwegian cod, 1956 year-class, M = 0.3.

	Fishing mortality, F_n			Population, $N_i \times 10^{-6}$		
Age (years)	Virtual population analysis	Cohort analysis	% error	Virtual population analysis	Cohort analysis	% error
12	0.8000[a]	0.8000[a]		0.2	0.2	
11	1.3400	1.3670	2	1.1	1.1	0
10	0.7826	0.7806	–	3.1	3.2	2
9	0.6768	0.6747	–	8.3	8.5	2
8	0.6582	0.6570	–	21.7	22.2	2
7	0.8636	0.8657	–	69.6	71.2	2
6	0.7341	0.7333	–	195.6	200.1	2
5	0.4289	0.4261	1	405.5	413.6	2
4	0.1874	0.1854	1	660.2	672.0	2
3	0.0411	0.0405	1	928.5	944.7	2
2	0.0024	0.0024	–	1256.4	1278.2	2
1	0.0007	0.0007	–	1697.1	1726.6	2

[a] Assumed.

Section 2. Error in Cohort Analysis Due to the Incorrect Choice of F_t

If an incorrect value F_t is chosen for the terminal fishing mortality when its true value is $\overline{F}_t$, then the proportional error in N_t, $\rho(N_t)$, is given as follows in the case when C_t is the catch in year t only:

$$\rho(N_t) = \frac{Z_t \overline{F}_t (1 - \exp\{-\overline{Z}_t\})}{\overline{Z}_t F_t (1 - \exp\{-Z_t\})} - 1 \qquad (2.1)$$

Since

$$\rho(N_i) = \rho(N_{i+1}) \exp\{-F_i\} \qquad (2.2)$$

it follows that

$$\rho(N_i) = \left(\frac{Z_t \overline{F}_t (1 - \exp\{-\overline{Z}_t\})}{\overline{Z}_t F_t (1 - \exp\{-Z_t\})} - 1\right) \times$$
$$\times \left(\exp\{-F_i - F_{i+1} \ldots - F_{t-1}\}\right) \qquad (2.3)$$

For small values of Z_t this is approximately given by

$$\rho(N_i) \simeq \left(\frac{\overline{F}_t - F_t}{F_t}\right) \times$$
$$\times \left(\exp\{-F_i - F_{i+1} \ldots - F_{t-1}\}\right) \qquad (2.4)$$

while for larger values of Z this formula tends to overstate the error and is therefore still of some value.

A formula similar to 2.4 gives $\rho'(N_i)$, the proportional error in N_i when C_t is the catch in year t and all subsequent years. In this case

$$\rho'(N_i) = \frac{M}{\overline{Z}_t} \left(\frac{\overline{F}_t - F_t}{F_t}\right) \times$$
$$\times \left(\exp\{-F_i \ldots - F_{t-1}\}\right) \qquad (2.5)$$

and therefore

$$\rho'(N_i) = \frac{M}{\overline{Z}_t} \rho(N_i). \qquad (2.6)$$

It is therefore simple to convert a table of $\rho(N_i)$ into a table of $\rho'(N_i)$. The porportional error of F_i, $\rho(F_i)$, is given approximately by a formula due to Agger *et al.*, (1971):

$$\rho(F_i) = \rho(N_i) \left(\frac{1 - \exp\{F_i\}}{F_i}\right) \qquad (2.7)$$

This form supersedes a cruder formula in Pope (1971). However, for the purpose of discussion 2.7 may be simplified to the assumption that $\rho(F_i)$ is less than twice the numerical value of $\rho(N_i)$ and of opposite sign provided F_i is less 1.2 (the viable range of cohort analysis) since within this range

$$-2 < \left(\frac{1 - \exp\{F_i\}}{F_i}\right) \leqslant -1. \qquad (2.8)$$

Figure 1 shows graphs of $\rho(N_i)$ plotted against the sum of the fishing mortality from year i to year $t - 1$ (cumulative fishing mortality). Figure 1 is based on formula 2.4 which increasingly overestimates $\rho(N_i)$ as $\overline{Z}_t$ increases. Consequently the value of $\rho(F_i)$ is given approximately by:

$$\rho(F_i) \approx -\ \{\text{value of } \rho(N_i) \text{ on Figure 1}\} \qquad (2.9)$$

provided $F_i \leqslant \overline{F}_t$. It can be seen that the underestimation of F_t results in estimates of N_i which are too large and estimates of F_i which are too small, whereas overestimating F_t has the reverse effect. It can also be seen that as the cumulative fishing mortality increases, both types of error decrease. As an example, if F_t was overestimated by 100% for a year-class and the cumulative fishing mortality from year i to year $t - 1$ was 2.0, then the percentage error in N_i would at most be -7% and the percentage error in F_i would be about +7% (see 2.9). If, however, F_t was underestimated by 50% and the cumulative fishing mortality was equal to 2.0, then the percentage error in N_i would be at the most 14% and the percentage error in F_i would be about -14% (see 2.9).

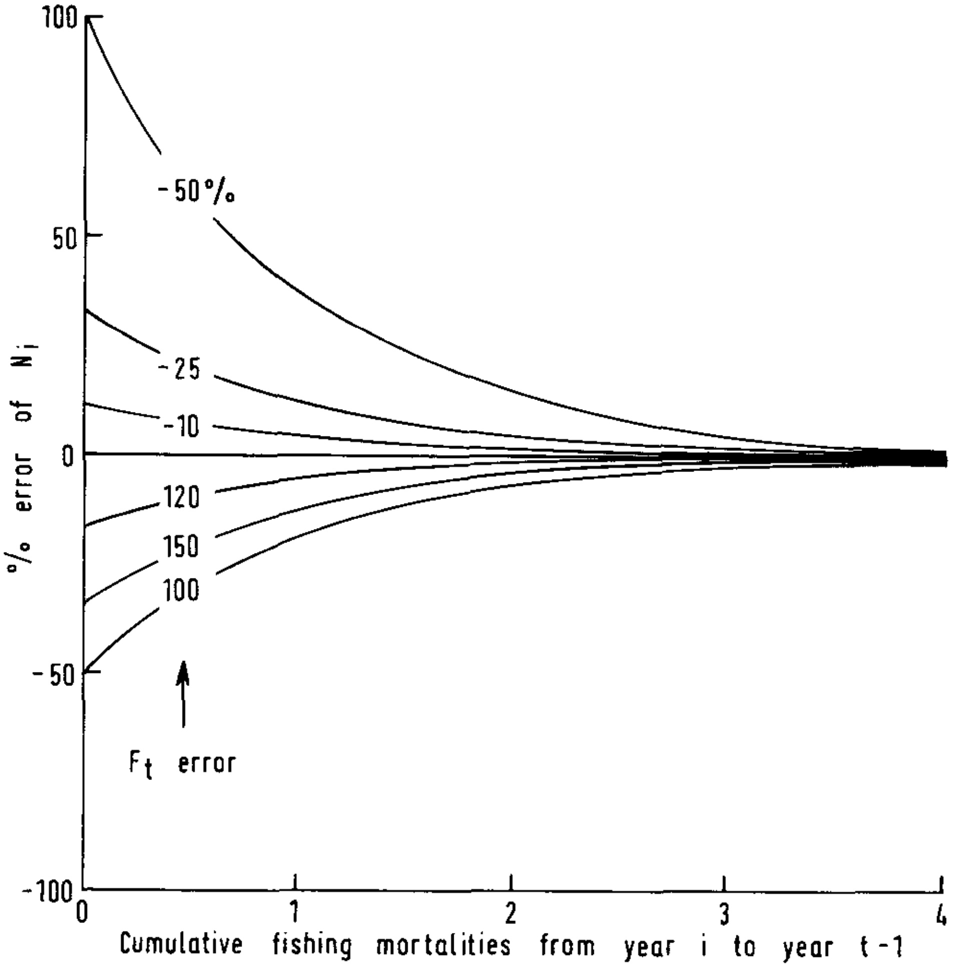

Fig. 1. Graphs of the percentage error in N_i due to incorrect values of F_t plotted against the cumulative fishing mortalities from year *i* to year *t* – 1.

Thus, provided that F_t can be estimated within this range and provided that the cumulative fishing mortality is greater than 2.0, the error in in the estimates of N_i and F_i should be small enough for many uses. If, however, the cumulative fishing mortality is small, which is the case when the number of recruits to a year-class is estimated from the catches of partially recruited age groups, then the accurate estimation of N_i and F_i will require the accurate choice of F_t. It should also be realized that since the cumulative fishing mortality is the sum of the fishing mortalities from age *i* to age *t* – 1 it must, for a particular year-class, be a monotonically decreasing function of age. Hence the bias in F_i caused by the incorrect choice of F_t will be greatest amongst the oldest age groups, and this may upset estimates of selectivity with age. Table 2 shows the results of a cohort analysis for the 1956 year-class of the Arcto-Norwegian cod. This assumes that the true values of M and F_t are 0.3 and 0.8 respectively and shows the percentage errors in N_i and F_i when F_t is overestimated by 100% or underestimated by 50%. These errors were computed by rerunning the data with the appropriate value of F_t and are therefore precise. It can be seen that these percentage errors are similar but, in general, smaller than their estimates in Fig. 1.

TABLE 2. The percentage in N_i and F_i when F_t is overestimated by 100% and when F_t is underestimated by 50% for the 1956 year-class of the Arcto-Norwegian cod, with M = 0.3 and when the true value of $F_t = 0.8$.

Age (years)	$N_i \times 10^{-6}$	F_i	Cumulative F_i	% error when F_t is taken as 0.4 in N_i	% error when F_t is taken as 0.4 in F_i	% error when F_t is taken as 1.6 in N_i	% error when F_t is taken as 1.6 in F_i
12	0.2	0.8000[a]	–	+ 68.66		- 32.27	
11	1.1	1.3670	1.3670	+ 17.50	- 26.44	- 8.22	+ 22.21
10	3.2	0.7806	2.1475	+ 8.02	- 10.77	- 3.77	+ 6.07
9	8.5	0.6747	2.8222	+ 4.08	- 5.50	- 1.92	+ 2.82
8	22.2	0.6570	3.4792	+ 2.12	- 2.91	- 0.99	+ 1.43
7	71.2	0.8657	4.3449	+ 0.89	- 1.40	- 0.42	+ 0.67
6	200.1	0.7333	5.0782	+ 0.43	- 0.63	- 0.20	+ 0.29
5	413.6	0.4261	5.5043	+ 0.28	- 0.35	- 0.13	+ 0.16
4	672.0	0.1854	5.6897	+ 0.23	- 0.22	- 0.11	+ 0.16
3	944.7	0.0405	5.7302	+ 0.22	- 0.25	- 0.10	+ 0.25
2	1278.2	0.0024	5.7326	+ 0.22	- 0.00	- 0.10	+ 0.00
1	1726.6	0.0007	5.7333	+ 0.22	- 0.00	- 0.10	+ 0.00

[a] Assumed.

Section 3. Error in Cohort Analysis Due to the Sampling Error of C_i

Unlike the estimate of F_t, which is usually an arbitrary choice, each estimate of catch at age can be assigned a variance, although this is seldom available, due to the heavy work involved in its computation (see Gulland, 1955). Assuming such variances to be available it is a simple matter to compute the resulting variance of N_i and F_i, since

$$\operatorname{var}(N_i) = \Big(\operatorname{var}(C_i)\exp\{M\}\Big) + \Big(\operatorname{var}(N_{i+1})\exp\{2M\}\Big), \tag{3.1}$$

and this may be used as a recurrence relationship to obtain

$$\operatorname{var}(N_i) = \Big(\operatorname{var}(C_i)\exp\{M\}\Big) + \Big(\operatorname{var}(C_{i+1})\exp\{3M\}\Big) + \ldots + \Big(\operatorname{var}(C_t)\Big)\left(\frac{\exp\{2(t-i)M\}(F_t+M)^2}{F_t^2(1-\exp\{-F_t-M\})^2}\right) \tag{3.2}$$

which is a very similar formula to 1.5.

The equivalent variance of F_i can be approximated, since

$$F_i = \log_e\{N_i / N_{i+1}\} - M \tag{3.3}$$

which yields approximately

$$\operatorname{Var}(F_i) \approx \left(\frac{\operatorname{var}(N_i)}{N_i^2}\right) - \left(\frac{2\operatorname{var}\big(N_{i+1}\big)\exp\{M\}}{N_i N_{i+1}}\right) + \left(\frac{\operatorname{var}\big(N_{i+1}\big)}{N_{i+1}^2}\right) \tag{3.4}$$

Equations 3.2 and 3.4 should be used to calculate the respective variances of N_i and F_i in a particular case, but in order to appreciate the approximate magnitude of these variances the following approximate formulae are useful:

$$\left(\text{var ratio }(N_i)\right)^2 \approx \left(\text{var ratio }(C_i)\right)^2 \left(1-\exp\{-F_i\}\right)^2 + \left(\text{var ratio }(N_{i+1})\right)^2 \left(\exp\{-F_i\}\right)^2 \tag{3.5}$$

$$\left(\text{var ratio }(F_i)\right)^2 \approx \frac{\left(1-\exp\{-F_i\}\right)^2}{F_i^2}\left[\left(\text{var ratio }(C_i)\right)^2 + \left(\text{var ratio }(N_{i+1})\right)^2\right] \tag{3.6}$$

Details of the derivation of these formulae are given in Appendix C.

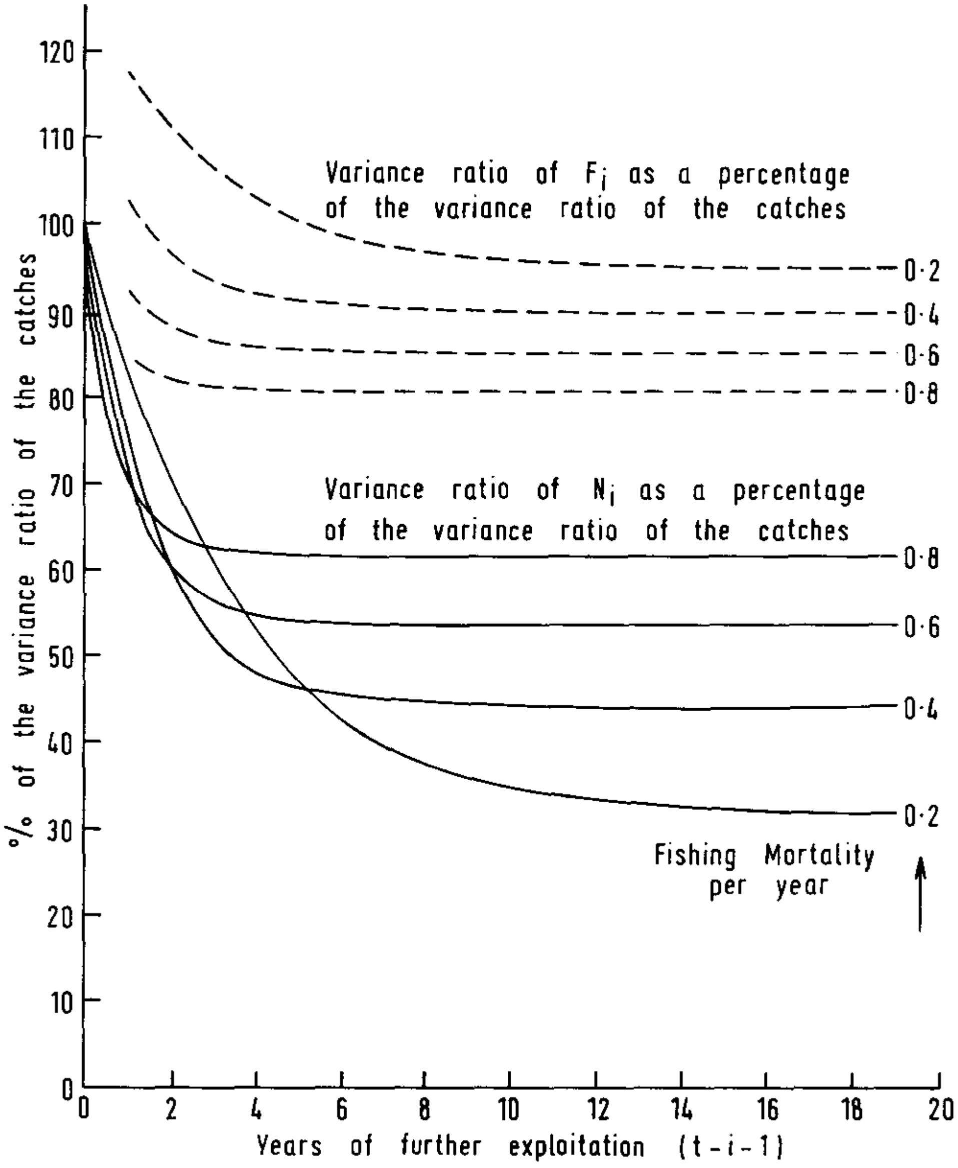

Fig. 2. Graphs of the percentage variance ratio of F_i and of N_i for various constant levels of fishing mortality plotted against the years of further exploitation.

Figure 2 shows graphs of these formulae for each year from the final year, that is for the number of years from the estimate in question to the final year. The graphs are given for the case when the variance ratio of the catch-at-age data is constant, and when the fishing mortality is constant throughout the life of the fish. Although these conditions are unrealistic, the rapid convergence of the graphs to asymptotic values does suggest that the graphs would indicate the approximate value of the variance ratio of the estimates of N_i and F_i, even when F_i is not constant from year to year. As an example of the use of the graphs, the estimate of N_5 (for a year-class with an oldest age group of 12 years old, experiencing a fishing mortality of 0.6 per year) would have a variance ratio of approximately 54% of the variance ratio of the catch data. Similarly, the estimate of F_5 would have a variance ratio of approximately 85% of the variance ratio of the catch data. Hence, if the variance ratio of the catch data was 10%, then the variance ratios of N_5 and F_5 would be 5.4% and 8.5% respectively. As a result the approximate 95% confidence limits for the estimates would be ± 10.8% of the estimate of N_5 and ± 17.0% of the estimate of F_5.

TABLE 3. Standard deviations and variance ratios of N_i and F_i calculated for the 1956 Arcto-Norwegian cod, assuming that the variance ratio for the catch at each age was 10% and that $M = 0.3$ and $F_t = 0.8$.

Age (years)	$N_i \times 10^{-6}$	F_i	Standard deviation $N_i \times 10^{-6}$	Standard deviation F_i	Variance ratio (%) N_i	Variance ratio (%) F_i
12	0.2	0.8000[a]	0.01449			
11	1.1	1.3670	0.08361	0.09192	7.60	6.72
10	3.2	0.7806	0.20763	0.06801	6.49	8.71
9	8.5	0.6747	0.50349	0.05865	5.92	7.51
8	22.2	0.6570	1.26666	0.05601	5.71	8.53
7	71.2	0.8657	4.46487	0.06669	6.27	7.70
6	200.1	0.7333	12.01878	0.06134	6.01	8.36
5	413.6	0.4261	21.65851	0.04047	5.24	9.50
4	672.0	0.1854	31.37061	0.01910	4.67	10.30
3	944.7	0.0405	42.51186	0.00439	4.50	10.83
2	1278.2	0.0024	57.38580	0.00026	4.49	10.77
1	1726.6	0.0007	77.46281	0.00007	4.49	10.59

[a] Assumed.

Table 3 shows the 1956 Arcto-Norwegian cod results, together with the standard deviations and variance ratios of N_i and F_i. These were computed from equations 3.2 and 3.4 on the assumption that the variance ratio of the catch data at each age was 10%. It can be seen that the variance ratios of these estimates are not very different from those which would have been predicted by entering the graphs of Fig. 2 with appropriate values of F_i at the asymptotic parts of the graphs. Thus Fig. 2 should prove to be of some value in providing quick estimates of the variance ratios of N_i and F_i for any year-class which has catch data which have approximately constant variance ratios.

Summary

This document provides formulae for calculating the error introduced in cohort analysis (and therefore virtual population analysis) by errors in F_t and by the sampling error of catch data. It also provides some quick estimates of the likely size of such errors. These estimates suggest that such errors converge to fairly

small values, but they also suggest that a knowledge of the approximate value of these errors will always be a safeguard against misinterpretation of data!

References

AGGER, P., I. BOËTIUS, and H. LASSEN. 1971. On errors in the virtual population analysis. *ICES C.M.* 1971 Doc. No. H: 16 (mimeographed).

GULLAND, J. A. 1955. Estimation of growth and mortality in commercial fish populations. *Fish. Invest., Lond. (2)*, 18 (9).

1965. Estimation of mortality rates. Annex to Arctic Fisheries Working Group Report (meeting in Hamburg, January 1965). *ICES, C.M.* 1965, Doc. No. 3 (mimeographed).

POPE, J. G. 1971. An investigation of the accurancy of virtual population analysis. *Annu. Meet. int. Comm. Northw. Atlant. Fish, 1971*, Res. Doc. No. 116, Serial No. 2606 (mimeographed).

Appendix A.

Gulland's Virtual Population Analysis

Gulland's virtual population analysis is based on the following two equations:

$$N_{i+1} = N_i \exp\{-(F_i + M)\} \tag{A.1}$$

$$C_i = N_i \frac{F_i\big(1 - \exp\{-(F_i + M)\}\big)}{F_i + M}. \tag{A.2}$$

It follows therefore that

$$\frac{N_{i+1}}{C_i} = \frac{(F_i + M)\exp\{-(F_i + M)\}}{F_i\big(1 - \exp\{-(F_i + M)\}\big)}. \tag{A.3}$$

Hence, if N_{i+1}, C_i, and M are known, then (as was explained in Section 1) it is possible to solve A.3/1.1 for F_i and then to use A.1 to obtain N_i. Then A.3/1.1 may be used to obtain F_{i-1} and so on. To start the procedure it is necessary to estimate N_t, the population size of the oldest age at which the year-class was fished. This is done by taking the best estimate (or guess) of F_t available and using A.2 to solve for N_t. It is shown in Section 2 that in general the accurate choice of F_t is not crucial to the accuracy of F or N for other ages.

Appendix B

Cohort Analysis

The basic equation of cohort analysis is obtained by rewriting A.1 as

$$N_{i+1} \exp\{+M\} = N_i \exp\{-F_i\}, \tag{B.1}$$

which can be expressed as

$$N_{i+1} \exp\{+M\} = N_i - N_i\,(1 - \exp\{-F_i\}). \tag{B.2}$$

Substituting A.2 in B.2,

$$N_{i+1} \exp\{+M\} = N_i - C_i\left(\frac{(F_i + M)\ (1 - \exp\{-F_i\})}{F_i\,(1 - \exp\{-(F_i + M)\})}\right). \tag{B.3}$$

However, within the range $M < 0.3$, $F_i < 1.2$ the function $\left(\frac{(F_i + M)\ (1 - \exp\{-F_i\})}{F_i\,(1 - \exp\{-(F_i + M)\})}\right)$ can be approximated by $\exp\{+M/2\}$ with an error that is always less than 4%. Thus, with little loss of accurancy, B.3 can be rewritten as:

$$N_i = N_{i+1} \exp\{+M\} + C_i \exp\{+M/2\}. \quad \text{(B.4)}$$

This is the basic equation of cohort analysis. Given a knowledge of N_{i+1}, C_i and M, it is possible to use B.4 (or 1.2) to obtain N_i and then to use B.1 to obtain F_i. Having found N_i, equation B.4 (or 1.2) can be used to obtain N_{i-1} and so on. The value of N_t is obtained as for virtual population analysis.

Appendix C

The Derivation of the Formulae of Section 3

If ΔN_i, ΔN_{i+1} and ΔC_i denote random errors in N_i, N_{i+1} and C_i that are a result of the sampling errors of the C_i, then making a Taylor expansion of 1.2 gives $\Delta N_i = \Delta C_i \exp\{M/2\} + \Delta N_{i+1} \exp\{M\}$. (C.1)

Squaring and summing gives

$$\text{var}(N_i) = \Big(\text{var}(C_i)\exp\{M\}\Big) + \Big(\text{var}(N_{i+1})\exp\{2M\}\Big) + \Big(\text{covar}(C_i, N_{i+1})\exp\{3M/2\}\Big). \quad \text{(C.2)}$$

Since C_i and N_{i+1} are unrelated, the covariance term will be equal to zero and C.2 will yield 3.1, that is:

$$\text{var}(N_i) = \Big(\text{var}(C_i)\exp\{M\}\Big) + \Big(\text{var}(N_{i+1})\exp\{2M\}\Big).$$

Dividing both sides of this by N_i^2 gives, after substituting A.1 and A.2,

$$\frac{\text{var}(N_i)}{N_i^2} = \Big(\text{var}(C_i)\exp\{M\}\Big)\left(\frac{F_i(1-\exp\{-(F_i+M)\})}{(F_i+M)\,C_i}\right)^2 + \left(\frac{\text{var}(N_{i+1})\exp\{2M\}}{N_{i+1}\exp\{F_i+M\}^2}\right). \quad \text{(C.3)}$$

Using the same approximation as in Appendix B, this simplifies to:

$$\Big(\text{var ratio}(N_i)\Big)^2 = \Big(\text{var ratio}(C_i)\Big)^2\Big(1-\exp\{-F_i\}\Big)^2 + \Big(\text{var ratio}(N_{i+1})\Big)^2\Big(\exp\{-F_i\}\Big)^2$$

which is the form of equation 3.5.

If ΔF_i is the error in F_i due to the sampling errors in the C_i, then expanding 3.3 as a Taylor series gives approximately:

$$\Delta F_i = \frac{\Delta N_i}{N_i} - \frac{\Delta N_{i+1}}{N_{i+1}}. \quad \text{(C.4)}$$

Squaring and summing this gives:

$$\text{var}\,(F_i) = \frac{\text{var}\,(N_i)}{N_i^2} - \frac{2\ \text{covar}\,(N_i, N_{i+1})}{N_i N_{i+1}} + \frac{\text{var}\,(N_{i+1})}{N_{i+1}^2} \tag{C.5}$$

Multiplying C.1 by ΔN_{i+1} and summing gives:

$$\text{covar}\,(N_i, N_{i+1}) = \left(\text{covar}\,(C_i, N_{i+1})\exp\{M/2\}\right) + \left(\text{var}\,(N_{i+1})\exp\{M\}\right). \tag{C.6}$$

And since there is no relation between C_i and N_{i+1}, C.6 becomes:

$$\text{covar}\,(N_i, N_{i+1}) = \text{var}\,(N_{i+1})\exp\{M\}\,. \tag{C.7}$$

Substituting C.7 in C.5 gives:

$$\text{var}\,(F_i) = \frac{\text{var}\,(N_i)}{N_i^2} - \frac{2\ \text{var}\,(N_{i+1})\exp\{M\}}{N_i N_{i+1}} + \frac{\text{var}\,(N_{i+1})}{N_{i+1}^2} \tag{C.8}$$

which is of course the same as 3.4. This can be further simplified by dividing both sides by F_i^2 and substituting in A.1, which gives:

$$\left(\text{var ratio}\,(F_i)\right)^2 = \frac{\left(\text{var ratio}\,(N_i)\right)^2 + \left(\text{var ratio}\,(N_{i+1})\right)^2 \left(1 - 2\exp\{-F_i\}\right)}{F_i^2} \tag{C.9}$$

Hence, using 3.5, this gives:

$$\left(\text{var ratio}\,(F_i)\right)^2 = \frac{\left(1 - \exp\{F_i\}\right)^2 \left[\left(\text{var ratio}\,(C_i)\right)^2 + \left(\text{var ratio}\,(N_{i+1})\right)^2\right]}{F_i^2} \tag{C.10}$$

which is the same form as 3.6.

Virtual Population Assessment of St. Pierre Bank-Newfoundland South Coast Cod Stock (ICNAF Subdivision 3Ps)

By A. T. Pinhorn[1]

Abstract

Assessment of the St. Pierre Bank-Newfoundland South Coast (ICNAF Subdivision 3Ps) cod stock, using the "virtual population analysis" technique, indicated fishing mortalities beyond the level of maximum sustainable yield per recruit during the 1959-68 period. Cod were fully recruited to the fishery at 7 years of age with very few 3-year-olds being taken. Total stock size has fluctuated in response to recruitment while numbers of fully recruited fish have declined steadily.

Introduction

As part of a continuing effort to assess the state of the various cod stocks in the ICNAF area, an assessment has been performed for ICNAF Subdivision 3Ps cod using the Gulland and Jones modifications of the "virtual population analysis" (VPA) technique. The results of this assessment are presented here.

Materials and Methods

The basic data used were length frequencies, age-compositions, and age-length keys published in ICNAF Sampling Yearbooks for 1959-70 and the nominal catches published in ICNAF Statistical Bulletins for the same period.

In addition age-length keys from Canada (Newfoundland) research vessel cruises to the area as well as those from the inshore fishery were used where necessary.

Compilation of length composition of otter trawl catches

The procedure used to obtain representative length composition of the total catch by otter trawl (Fig. 1) was identical to that used by Pinhorn (1971) for ICNAF Division 2J cod and consisted of adjusting the ‰ frequency of each country for each month to the estimated number of fish caught by that country in that month and then combining into semi-annual and annual frequencies. However, for this assessment, because of the relative scarcity of discard data and the low level of discards indicated by the few data available, no adjustment from landings to catches was made but the numbers estimated are numbers landed rather than numbers caught. In 1963 and 1964, no length frequencies were reported in the Sampling Yearbooks and the only available data were Canada (Newfoundland) research frequencies. These were adjusted to the minimum regulation mesh size in use at the time. However, it was found in years in which both research and commercial frequencies were available, that even after adjusting to the minimum regulation mesh size, the research frequencies still contained more smaller fish and less larger fish than the commercial frequencies, possibly because of the different pattern of fishing of the research and commercial cruises. By combining years conversion factors between research and commercial frequencies for each length group were derived and these were applied to the adjusted research frequencies in 1963 and 1964. This procedure was also used in 1969 where the available commercial frequencies were not considered representative of the fishery.

Compilation of numbers caught at each age

The method used to estimate numbers of cod caught at each age was again similar to that described by Pinhorn (1971) for ICNAF Division 2J cod and consisted of applying semi-annual age-length keys from various countries to the semi-annual otter trawl length frequencies derived above and then averaging the age distributions from the various countries and combining into annual frequencies. To these were added the estimated numbers landed by Canada (Newfoundland) inshore gears and by other gears. In obtaining the latter, the following gear groups were used:

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

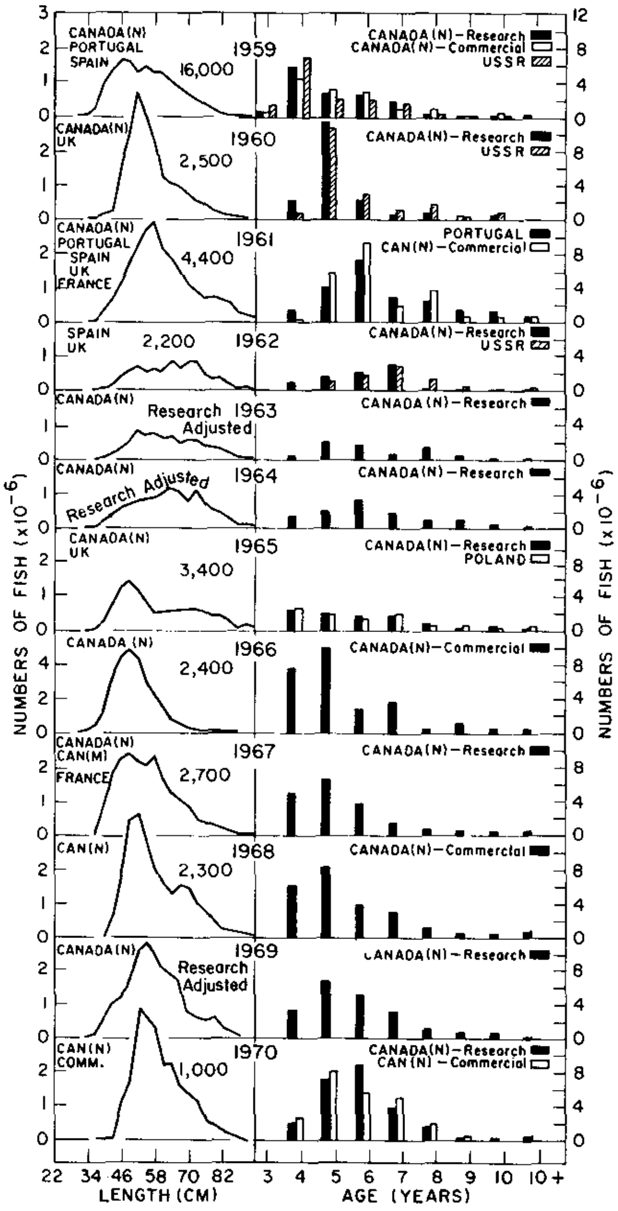

Fig. 1. Length and age distributions of otter trawl catches used in ICNAF Subdivision 3Ps cod assessment, 1959-70.

a) Canada (Nfld.) codtrap + handline + jigger;
b) Canada (Nfld.) gillnet;
c) Canada (Nfld.) linetrawl + longline + Danish seine + Canada (Maritimes) longline + dory vessel + Portuguese dory vessel + St. Pierre and Miquelon small boats.

The landings were divided into the various inshore gear groups from information contained in a manuscript series of the St. John's Biological Station on Breakdown of Cod Catch by Type of Gear in the Newfoundland Inshore Fishery. In each of these gear groups the Canada (Newfoundland) inshore age-compositions were used to estimate the numbers landed at each age and these were combined with otter trawl numbers to provide estimates of total numbers landed from the stock in each year (Fig. 2).

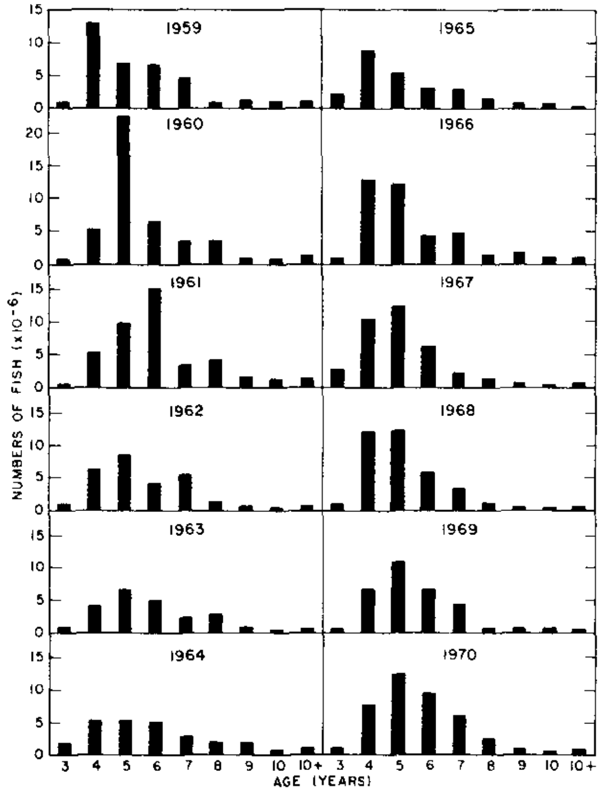

Fig. 2. Total numbers of cod caught per year and age-group by all gears, ICNAF Subdivision 3Ps, 1959-70.

No estimate of natural mortality (M) is available for this stock at present but calculations for ICNAF Subarea 1 cod (Horsted, 1968) and for Division 2J cod (Pinhorn, 1972) indicate that M is likely to be in the range of 0.15 to 0.20. An estimate of 0.2 was therefore used for this VPA and a few trial calculations indicated that an exploitation rate $E(1\text{-}e^{-Z})$ of 0.343 was probably close to the actual value.

Results

Fishing mortality

Table 1 shows estimates of numbers of cod caught per year and age-group during 1959-70. Table 2 shows fishing mortality estimates (F) for ages 3-11 calculated from the figures in Table 1.

TABLE 1. Number of cod caught per year and age-group ICNAF Subdivision 3Ps, 1959-70 ($X10^{-3}$).

	Year											
Age	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
2	–	–	–	–	–	–	12	–	–	55	–	–
3	1001	567	450	1245	961	1906	2314	949	2871	1143	774	756
4	13940	5496	5586	6749	4499	5785	9636	13662	10913	12602	7098	8114
5	7525	23704	10357	9003	7091	5635	5799	13065	12900	13135	11585	12916
6	7265	6714	15960	4533	5275	5179	3609	4621	6392	5853	7178	9763
7	4875	3476	3616	5715	2527	2945	3254	5119	2349	3572	4554	6374
8	942	3484	4680	1367	3030	1881	2055	1586	1364	1308	1757	2456
9	1252	1020	1849	791	898	1891	1218	1833	604	549	792	730
10	1260	827	1376	571	292	652	1033	1039	316	425	717	214
11	631	406	446	187	143	339	327	517	380	222	61	178
12	545	407	265	140	99	329	68	389	95	111	120	77
13	44	283	560	135	107	54	122	32	149	5	67	121
14	–	27	58	241	92	27	36	22	3	107	110	14
14+	–	83	33	148	192	206	129	53	52	399	110	167
Total	39280	46494	45236	30825	25206	26829	29612	42887	38388	39486	34923	41880

TABLE 2. Fishing mortality estimates by year and age-group for cod in ICNAF Subdivision 3Ps, 1959-68. Estimates in parentheses not used in calculation of averages.

	Year										$\overline{F}$	Change in F with age as % of F in fully recruited age-groups, 1959-68
Age	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1959-68	
3	0.02	–	0.01	0.03	0.03	0.03	0.03	0.01	0.03	0.02	0.02	4
4	0.16	0.13	0.14	0.21	0.14	0.21	0.21	0.25	0.18	0.20	0.18	38
5	0.26	0.43	0.40	0.34	0.35	0.26	0.33	0.49	0.40	0.33	0.36	77
6	0.40	0.39	0.59	0.31	0.35	0.47	0.26	0.48	0.47	0.32	0.40	85
7	0.38	0.34	0.38	0.44	0.29	0.34	0.62	0.72	0.48	0.53	0.45	100
8	0.20	0.52	(1.07)	0.24	0.45	0.36	0.43	0.73	0.42	0.54	0.43	100
9	0.43	0.35	0.57	0.51	0.25	0.56	0.42	(0.87)	0.59	0.30	0.44	100
10	0.60	0.56	(1.17)	0.34	0.36	0.29	0.70	0.76	0.35	(1.14)	0.50	100
11	0.39	0.39	0.68	0.46	0.13	0.93	0.23	0.97	0.72	0.45	0.54	100
Average ages 3-11	0.32	0.39	0.40	0.32	0.26	0.38	0.36	0.55	0.40	0.34		
Average ages 7-11	0.40	0.43	0.54	0.40	0.30	0.50	0.48	0.80	0.51	0.46		

Fishing mortality estimates for ages 3-11 fluctuated only moderately between 0.3 and 0.4 during 1959-68 except for 1966 when the estimate of F was unusually high especially for cod older than 6 years (Table 2). The cod in this area are fully recruited at 7 years of age with very few 3-year-olds being taken, the 50% recruitment age being approximately 4.5 years.

Stock size

Numbers present in the stock at the beginning of the year (Table 3 and Fig. 3) indicated that the total stock size of fish 4 years old and older decreased from about 200 million fish in 1959 to a low of 100 million in 1964 and then increased to 175 million in 1968. The

TABLE 3. Number of cod present in the stock at the beginning of the year ($X10^{-6}$), ICNAF Subdivision 3Ps, 1959-68.

	Year									
Age	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968
3	56	(50)	50	47	36	71	87	105	108	64
4	104	47	47	40	37	31	56	68	79	81
5	36	73	35	34	26	27	22	37	43	51
6	24	23	39	19	20	15	17	13	19	24
7	17	13	13	18	11	11	8	11	7	10
8	6	9	8	7	9	7	6	3	4	3
9	4	4	5	2	4	5	4	3	1	2
10	3	2	2	1	1	3	2	2	1	1
11	2	1	1	–	1	1	2	1	1	1
12	2	1	1	–	–	1	–	1	–	–
13	–	1	1	–	–	–	–	–	–	–
14	–	–	1	–	–	–	–	–	–	–
2+	254	224	203	168	145	172	204	244	263	237
3+	198	174	153	121	109	101	117	139	155	173
3-6	220	193	171	140	119	144	182	223	249	220
			843					1018		
					+21%					
6+	34	31	32	28	26	28	22	21	14	17
			151					102		
					–32%					

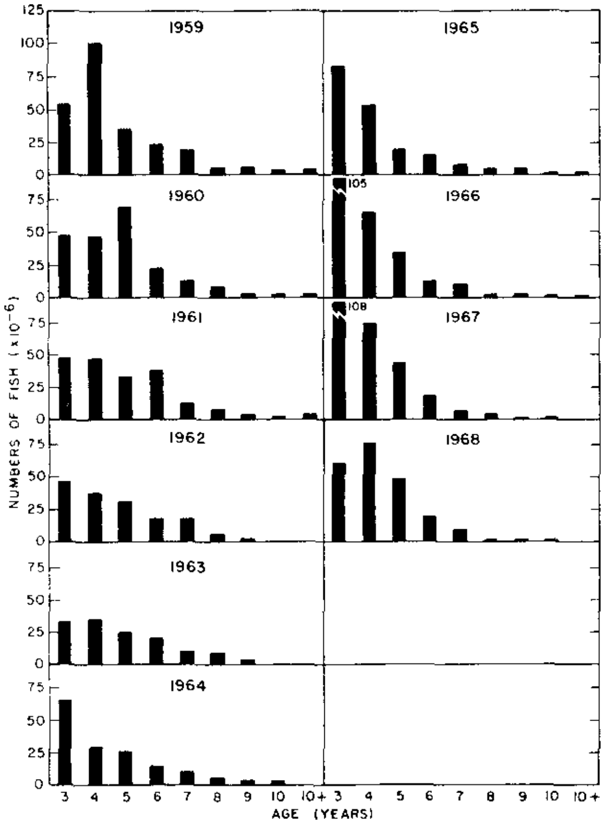

Fig. 3. Numbers of cod per age-group present in the stock at the beginning of the year, ICNAF Subdivision 3Ps, 1959-68.

numbers of 6+ fish have declined fairly steadily from 34 million in 1959 to 14 million in 1967 and 17 million in 1968.

Yield per recruit

Yield per recruit calculations incorporating the partial recruitment estimates shown in Table 2 produced a curve almost identical to that presented by Pinhorn and Wells (1970) (Fig. 4). The point of maximum sustained yield per recruit was at an F-level of 0.3. The level of F for fully recruited age-groups prevailing in the 1960's was between 0.3 and 0.55 and thus was beyond this level of maximum sustained yield per recruit, being in the range of 90-100% of the maximum (Fig. 4).

Discussion and Conclusions

There is some reason to doubt the validity of the high estimate of fishing mortality for 1966 (0.55 as compared to 0.3-0.4 for the other years) since neither the effort nor the catch increased significantly in this year. This resulted from a higher proportion of older fish being represented in the samples during 1966 and may have been caused by some inadequacy in the sampling data in this year or a greater vulnerability of older fish to one or the other gears. On the other hand, in some years there is some mixing of the slower growing West Newfoundland cod stock with the 3Ps stock in the vicinity of the western part of St. Pierre Bank and Burgeo Bank during the migration of the former stock out of the Gulf of St. Lawrence in winter (Templeman, 1962). If this occurred to a greater extent in 1966 than in 1965 or 1967 it would result in an apparent increase in older fish in the catches.

Fluctuations in numbers of cod in the stock are correlated with changes in recruitment over the period

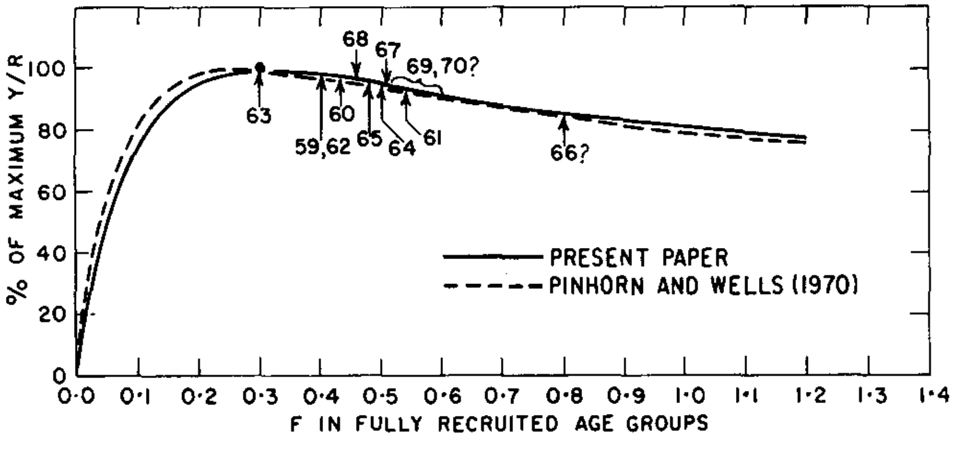

Fig. 4. Yield-per-recruit curves for ICNAF Subdivision 3Ps cod incorporating partial recruitment estimates. Arrows indicate levels of F in various years. Circled point represents level of maximum sustained yield per recruit.

(Fig. 5). The 1955 year-class was large but the 1956-60 year-classes were less than half as large. The 1958 year-class although estimated from surveys to be very strong, did not contribute significantly to the commercial fishery and the survey data are therefore questionable for this year. The 1961-65 year-classes were again larger in size. This pattern of recruitment resulted in a decrease in stock abundance between 1959 and 1964 and an increase between 1965 and 1968.

The general conclusion from the assessment is the same as from the previous catch/effort assessment (Pinhorn and Wells, 1970) that further increases in fishing effort on this stock will not result in long-term increases in yield and may result in long-term decreases in catch per unit effort. In fact some reduction in fishing effort would probably not impair the long-term yield and may result in an increased catch per unit of effort.

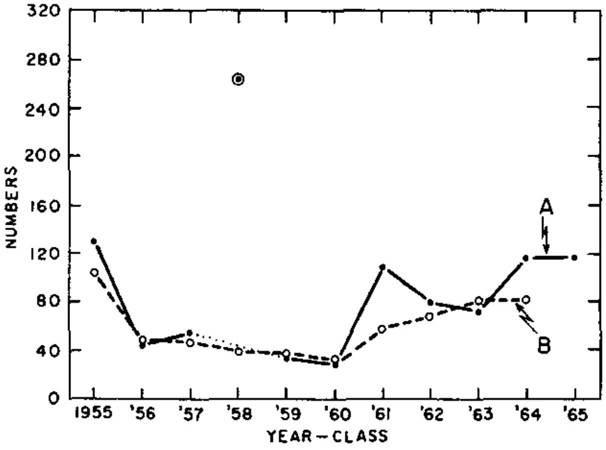

Fig. 5. A. Numbers of cod ages 2-3 years per standard hour from Canada (Newfoundland) research vessel surveys. B. Numbers of cod age 4 years (millions) in stock at beginning of year. ICNAF Subdivision 3Ps.

This assessment was greatly hampered by lack of data for the otter trawl fishery. In years when data did exist for the offshore fishery, there was lack of coverage throughout the year and samples were usually available for 1 or 2 months only and even then in many cases the length and age material was really insufficient to ensure adequate representation of the catches. In 2 years no data from the otter trawl fishery existed at all and in another year the existing data were obviously not representative of the entire catch. In these years research data were used as indicated above but these are usually poor substitutes for the actual data from the commercial fishery, especially in localities such as this where pre-recruit fish inhabit the same areas as adult fish. It is suggested that an effort be made to increase the sampling intensity in this area in future years.

References

HORSTED, Sv. Aa. 1968. Cod in Subarea 1. Review and revision of parameters. *Annu. Meet. int. Comm. Northw. Atlant. Fish. 1968,* Res. Doc. No. 57, Serial No. 2038 (mimeographed).

PINHORN, A. T. 1971. Virtual population assessment of ICNAF Division 2J cod. *Res. Bull. int. Comm. Northw. Atlant. Fish.,* No. 8, p. 75-85.

1972. Estimates of natural mortality for ICNAF Division 2J cod. *Annu. Meet. int. Comm. Northw. Atlant. Fish. 1972,* Res. Doc. No. 2, Serial No. 2681.

PINHORN, A. T., and R. WELLS. 1970. Catch/effort assessments for the major cod stocks in ICNAF Subareas 2 and 3. *Int. Comm. Northw. Atlant. Fish., Redbook 1970,* Part III, p. 65-74.

TEMPLEMAN, W. 1962. Division of cod stocks in the Northwest Atlantic. *Int. Comm. Northw. Atlant. Fish., Redbook 1962,* Part III, p. 79-123.

WELLS, R., and A. T. PINHORN. 1970. Growth and mortality changes in cod from ICNAF Subareas 2 and 3. *Annu. Meet. int. Comm. Northw. Atlant. Fish. 1970,* Res. Doc. No. 88, Serial No. 4239.

Short-Term Variations in Estimates of Chlorophyll Abundance

By John B. Colton, Jr.[1]

Abstract

Short-term variations in total chlorophyll and in the depth of maximum chlorophyll abundance were observed at a drogue station located in an area characterized by a well-defined vertical temperature gradient and strong tidal currents. These variations were associated with vertical oscillations of the thermocline caused by internal waves.

Introduction

From December 1964 to September 1966, a series of quarterly environmental surveys were made of Continental Shelf waters between Nova Scotia and Long Island (Colton *et al.*, 1968). As would be expected in an area characterized by strong tidal and non-tidal currents, marked spatial and temporal variations in physical, chemical, and biological properties were observed. To assess more accurately the degree of this variation and to establish confidence limits, time-series observations were made at specific locations (anchor stations) and in specific water masses (drogue stations) when time permitted. It is the purpose of this paper to illustrate the changes in chlorophyll abundance observed within a given water mass during June 1966 and to examine this variation in relation to hydrographic conditions and sampling techniques.

Methods

A bathythermograph lowering was made hourly and a Nansen bottle cast at 2-hr intervals alongside a buoy attached to a parachute drogue (Volkman *et al.*, 1956) set at 50-m depth. The 2-hr station location and the track of the parachute drogue during the 46-hr sampling period are shown in Fig. 1. The Nansen bottle depths were 1, 10, 20, 30, 40, 50, 75, and 100 m. Chlorophyll was determined by flouresence of extracts of 125 ml sea water according to the method described by Yentsch and Menzel (1963) with modifications given by Yentsch (1965). The specific absorption value (k) used was 65.0 (Richards, 1952). A.G.K. Turner Model 110 fluormeter which had been calibrated against a similar instrument at the Woods Hole Oceanographic Institution was used for these determinations. All chlorophyll values were corrected for the presence of phaeophytin.

Results

Figure 2 shows the 2-hr time-depth distribution of temperature and chlorophyll, the abundance of chlorophyll in mg/m^2 of sea surface integrated over 100 m (total chlorophyll), the average and range of temperature and chlorophyll at the eight sampling depths, and the average total chlorophyll for specific time intervals.

A well-defined temperature discontinuity layer, which continued to oscillate vertically, was present throughout the sampling period. The average depth of the thermocline was approximately 25 m and the maximum vertical displacement of an individual isotherm during a 2-hr period was 17 m. The vertical displacement of the thermocline was reflected in the range of temperature encountered at specific depths. These ranges were greatest between 10 and 30 m. Although tidal forces undoubtedly were instrumental in generating these internal waves, turbulent forces due to winds and bottom topography tended to mask the semidiurnal periodicity in the vertical oscillations. Hourly bathythermograph observations revealed the presence of internal waves of a shorter period than indicated by the 2-hr sampling interval.

At most stations the concentration of chlorophyll was greatest at 30 m. The average "chlorophyll depth" (determined by multiplying the concentration of chlorophyll by the depth sampled, summing the weighted samples, and dividing by the total chlorophyll at all depths) tended to oscillate as did the thermocline, but to a much lesser degree. The average chlorphyll depth for all stations was 30 m and the maximum vertical displacement during a 2-hr period was 9 m. The vertical displacement of the depth of maximum chlorophyll concentration was reflected in the range of chlorophyll values observed at specific depths. These ranges were greatest between 20 and 40 m.

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[1] National Marine Fisheries Service, Northeast Fisheries Service, Woods Hole, Massachusetts 02543, USA.

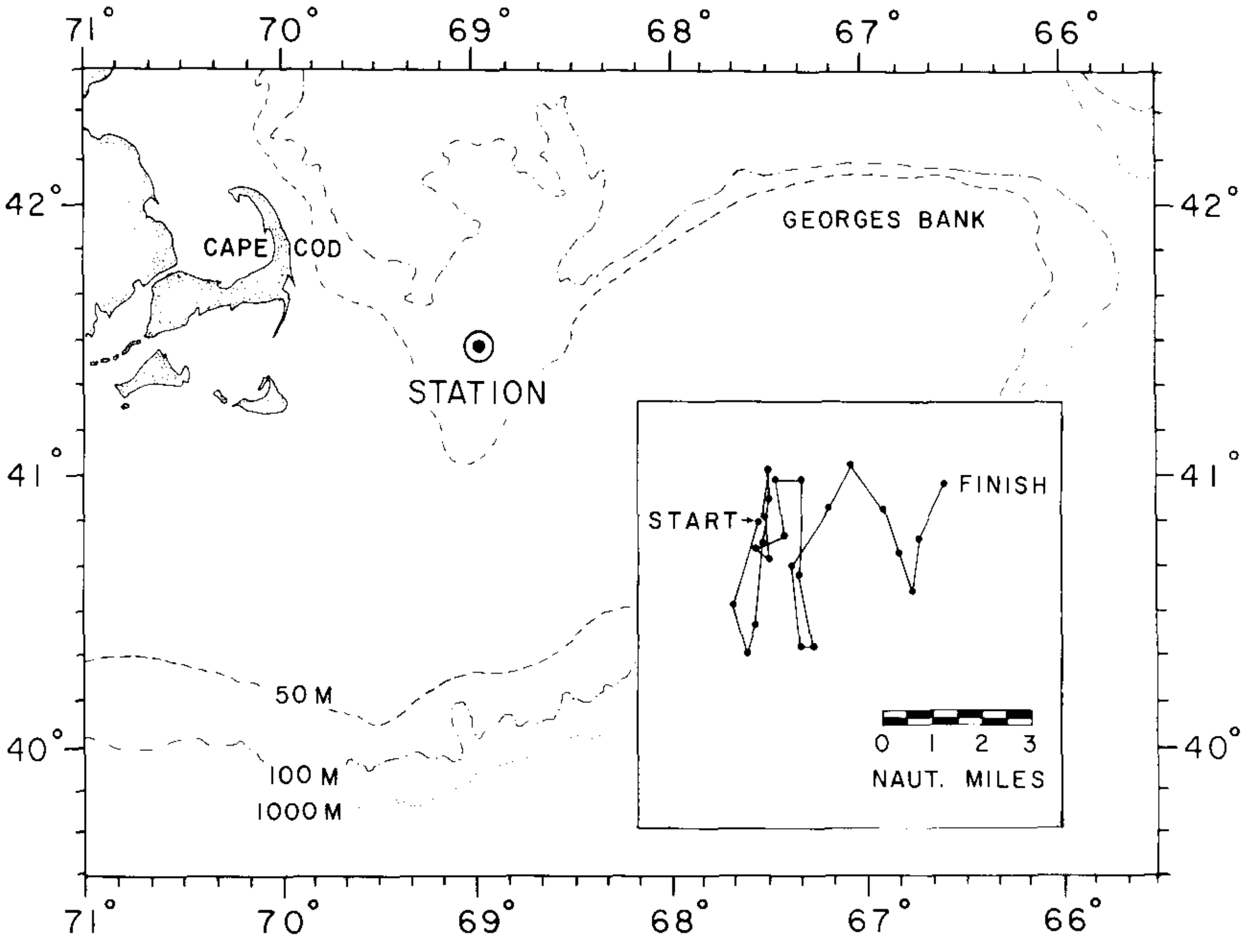

Fig. 1. Drogue station location. (Insert illustrates drogue track during sampling period.)

There was a considerable variation in the total chlorophyll (mg/m^2) values between the 2-hr sampling periods, the ratio of maximum to minimum values being 2.8. As with the depth fluctuations of the thermocline, there was no consistent pattern to the fluctuations in total chlorophyll. The average day (0700-1900 hr) and night (2100-0500 hr) values were similar. Maximum and similar average values occurred between 0700 and 1100 hr and 2100 and 2300 hr. Minimum and similar average values occurred between 0100 and 0500 hr and 1300 and 1900 hr. This is a significant departure from prediction, for on the basis of the observations of Yentsch and Ryther (1957), Shimada (1958), Yentsch and Scagel (1958), and Wood and Corcoran (1966), one would expect the maximum total chlorophyll values to occur during the morning and early afternoon hours.

To determine if there was a relation between the fluctuations in total chlorophyll values and the vertical oscillations of the thermocline, a regression of the difference in total chlorophyll between each 2-hr sampling period on the depth change of the thermocline in meters between corresponding 2-hr sampling periods was calculated. The average depth of the 5°, 6°, and 7° isotherms was used to estimate the thermocline depth. There was a significant linear correlation between thermocline depth and chlorophyll concentration fluctuations ($r = 446$, $t = 2.2835$, with $.03 < P < .05$).

Discussion

The data indicate that the phytoplankton was concentrated in a narrow stratum (or possibly strata) within the thermocline, that this stratum oscillated vertically with the thermocline, and that the high values of chlorophyll at specific depths or for the total water

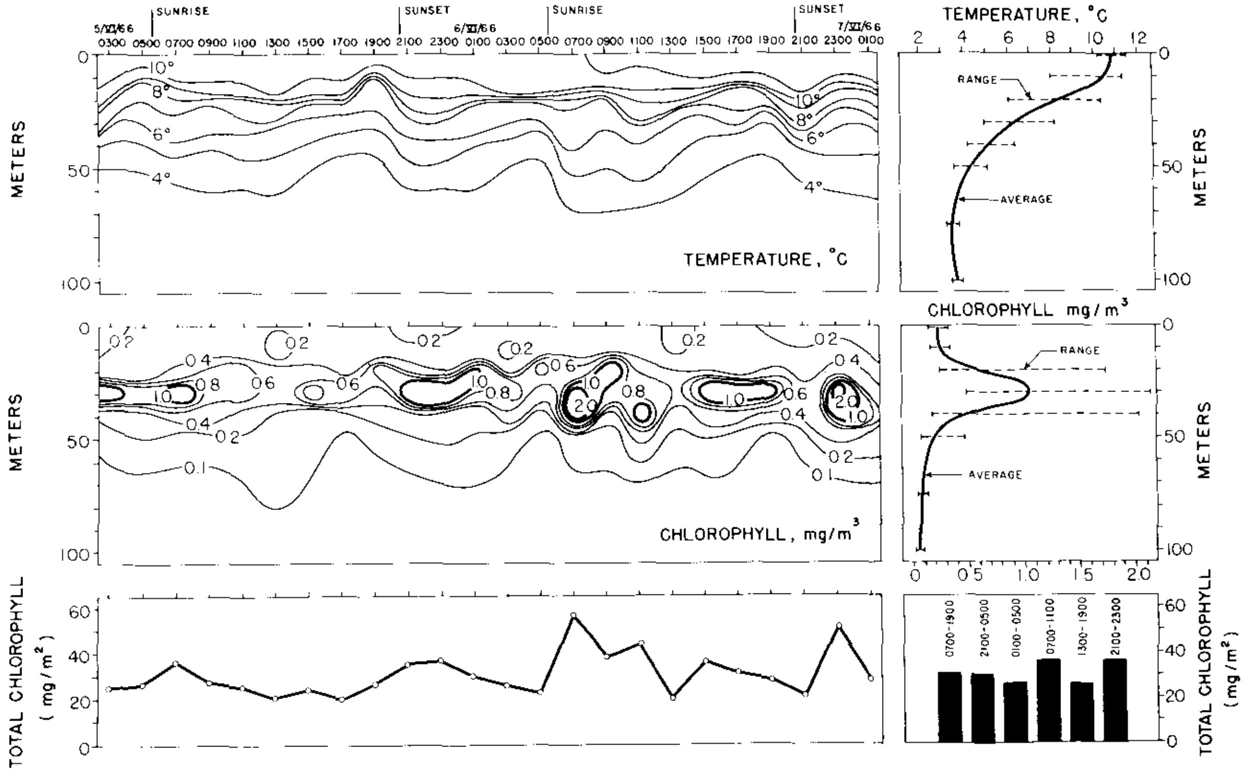

Fig. 2. Time and depth distribution of temperature and chlorophyll.

column occurred when the depth of this stratum coincided with a sampling depth. Obviously some of the variation in chlorophyll abundance observed resulted from changes in the amount of phytoplankton due to cell division and grazing and from changes in cellular pigment content, but in the main this variation appears to be associated with the vertical displacement of isotherms. Similar internal wave patterns and marked fluctuations in chlorophyll abundance were observed at anchor stations, but at these stations lateral shifts in water masses due to tidal currents tended to mask the relation between vertical oscillations of the thermocline and chlorophyll concentration fluctuations.

Marked vertical chlorophyll gradients and a relationship between the vertical distribution of phytoplankton and thermal density stratification have been noted in other areas (Gessner 1948, Halldal 1953, Sorokin 1960 and 1964, and Strickland 1968). Similar short-period oscillations of the thermocline and of the depth of maximum phytoplankton abundance have been observed off the coast of California (Barham *et al.*, 1966). Conditions favorable to the development of internal waves and for the concentration of phytoplankton within a narrow depth stratum (marked vertical density gradient and strong tidal action) exist over most of the Continental Shelf area between Cape Sable and Long Island for at least 6 months of the year. In all our observations where such hydrographic conditions prevailed, chlorophyll was concentrated within the thermocline, the maximum depth limit of which seldom exceeded 40 m.

In any large scale sampling program, it would be difficult, if not impossible, to eliminate the error in chlorophyll estimates due to advection, but it would be possible to reduce the error due to internal waves by closer vertical spacing of samples within the thermocline. As suggested by Strickland (1968), the use of a profiling hose and the continuous *in vivo* fluorescence method of chlorophyll concentration (Lorenzen 1966) would provide the most adequate measure of the phytoplankton crop. For plankton-net estimations of associated zooplankters oblique or vertical hauls would give a better estimate of the abundance in the total water column than horizontal tows at specific depth intervals.

References

COLTON, J.B., Jr., R.R. MARAK, S.R. NICKERSON, and R.R. STODDARD. 1968. Physical, chemical, and biological observations on the Continental Shelf, Nova Scotia to Long Island, 1964-1966. *U.S. Fish and Wildl. Serv., Data Rept.*, **23**: 190 p.

BARHAM, R.G., J.W. WILTON, and M.P. SULLIVAN. 1966. Plankton and turbidity. *N.E.L. San Diego, Calif. Research and Development Rept.*, **1386**: 81 p.

GESSNER, F. 1948. The vertical distribution of phytoplankton and the thermocline. *Ecology*, **29**: 386-389.

HALLDAL, R. 1953. Phytoplankton investigations from Weathership M in the Norwegian Sea. *Hvalråd. Skr.*, **38**: 1-91.

LORENZEN, C. J. 1966. A method for continuous measurement of *in vivo* chlorophyll concentration. *Deep-Sea Res.*, **14**: 381-389.

RICHARDS, F.A. 1952. The estimation and characterization of plankton populations by pigment analysis. I. The absorption spectra of some pigments in diatoms, dinoflagellates, and brown algae. *J. Mar. Res.*, **11**: 147-155.

SHIMADA, B.A. 1958. Diurnal fluctuations in photosynthetic rate and chlorophyll content from Eastern Pacific waters. *Limnol. & Oceanog.*, **3**: 336-339.

SOROKIN, J.I. 1960. Vertical distribution of phytoplankton and the primary organic production in the sea. *J. Cons.*, **26**: 49-56.

1964. On the primary production and bacterial activities in the Black Sea. *Ibid.*, **29**: 41-60.

STRICKLAND, J.D.H. 1968. A comparison of profiles of nutrient and chlorophyll concentrations taken from discrete depths by continuous recording. *Limnol. & Oceanog.*, **8**: 388-391.

VOLKMAN, G., J. KNAUSS, and A. VINE. 1956. The use of parachute drogues in the measurement of subsurface ocean currents. *Trans. Amer. geophys. Un.*, **37**: 573-577.

WOOD, E.J.F. and E.F. CORCORAN. 1966. Diurnal variation in phytoplankton. *Bull. Mar. Sci.*, **16**: 383-403.

YENTSCH, C.S., 1965. Distribution of chlorophyll and phaeophytin in the open ocean. *Deep-Sea Res.*, **12**: 653-666.

YENTSCH, C.S. and D.W. MENZEL. 1963. A method for the determination of phytoplankton chlorophyll and phaeophytin by fluorescence. *Deep-Sea Res.*, **10**: 221-231.

YENTSCH, C.S. and J.H. RYTHER. 1957. Short-term variations in phytoplankton and their significance. *Limnol. & Oceanog.*, **2**: 140-142.

YENTSCH, C.S. and R.F. SCAGEL. 1958. Diurnal study of phytoplankton pigments; and *in situ* study in East Sound, Washington, *J. Mar. Res.*, **17**: 567-583.

Biology of Scotian Shelf Cusk, *Brosme brosme*

By W. S. Oldham[1,2]

Abstract

Observations on the biology of cusk from the Scotian Shelf region, based on sampling from the summers of 1963, 1964, and 1965 in the Lockeport, Nova Scotia area, are presented. Landing statistics are used as an indicator of cusk distribution and show an increasing abundance of fish from ICNAF Division 4V through Division 4W and a predominance of cusk in Division 4X. Cusk are generally found on a rough, rocky bottom, preferring waters at a minimum of 4°C.

Data were gathered from approximately 3,000 commercial specimens from which growth, maturation, reproduction, length-weight relationships, and fecundity are examined.

An analysis of otolith edge types is presented as evidence for the validity of the otolith method of age determination.

Analysis of the age-length data revealed that male and female cusk do not differ in their rate of growth.

Commercially caught cusk from Inshore Grounds are significantly smaller than those from the LaHave Region. There appears to be no difference in Inshore males and females but LaHave females are smaller than LaHave males.

The length-eviscerated weight equation for females was significantly different from length-weight equations for round females and round and eviscerated males.

In 1964, males were 50% mature at 43.5 cm (age-group 5) and females were 50% mature at 50.7 cm (age-group 7). The 1964-spawning period lasted over the whole summer but peak spawning occurred towards the end of June.

Fecundity estimates made on 119 mature cusk ranged from 100,000 to 3,927,000 eggs per female. Fecundity depended mainly on body length and, to a lesser extent, on age.

Introduction

The cusk, *Brosme brosme* (Müller), is a demersal gadoid inhabiting Atlantic subarctic and boreal waters. Along the North American coast, it is found from the Newfoundland Grand Banks in the north to Cape Cod in the south, with its centre of abundance on the Scotian Shelf.

Little is known about the life history of cusk. With the exception of generalized accounts in Bigelow and Schroeder (1953) and Leim and Scott (1966), North American authors have discussed only its morphology and distribution (Huntsman, 1922; Jordan and Evermann, 1898; Perlmutter, 1961). Other aspects of its biology have not been described.

With primary commericial species declining in number, the cusk of the Northwest Atlantic represents a fish stock of increasing economic potential. This initial exploration of cusk biology is preliminary to a sound assessment of the fishery.

Methods and Materials

An estimate of cusk distribution in the ICNAF Convention Area was gained by examining landing statistics (ICNAF Statistical Bulletins, 1956-72).

The Lockeport, Nova Scotia area was selected as the centre of the sampling program because of the large proportion of round cusk landed there throughout the year. Cusk landed at Lockeport are taken generally from Div. 4X. Longline vessels fishing in Div. 4X used gear composed of a 16 lb. nylon groundline and 4 lb. cotton gangings. The hooks used were Mustad No. 15 or No. 16 or Pfleuger 6/0. The only specimens examined were those captured in this area by this type of gear.

Sampling involved a random selection of some 300-400 lb. of fish as a vessel was being unloaded. Commercial catches, however, did not include a representation of all sizes within the stock. Although fishermen did not cull, the smallest fish landed were 35 cm long. Presumably, fish smaller than this were not vulnerable to the gear.

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Cusk are landed at Lockeport in the round condition. The following information was recorded (weights by spring balance to nearest 1/10 kg):

Total length. The length to the nearest centimetre from the maxillary symphysis to the distal end of the longest caudal fin ray.

Round weight. Weight of the whole fish.

Eviscerated weight. Weight of fish after removal of viscera and gonads but with gills left in.

Sex and maturity. Sex was established by gonad examination. The gonads of each fish were placed in one of six classifications of maturity. The criteria used for the classification are similar to those used by Powles (1958) for cod and are shown in Table 1.

Cusk otoliths exhibited markings similar to cod and haddock otoliths and, upon successful validation, were used for ageing. Initially, the otoliths were kept dry but were too opaque to distinguish zonation. When placed in a 50% glycerin in water solution, they cleared

TABLE 1. Definition of the sexual stages of cusk.

Female	Male
Immature	
Ovaries are light orange and very small. Membrane is thin and transparent. Eggs are microscopic.	Testes appear as thin, narrow, transparent ribbons.
Ripening	
Ovaries are enlarged to about twice their previous volume. Colour is a bright orange with opaque eggs now clearly visible.	Testes are larger and distended into small lobules and convolutions. Colour is whitish with red blood vessels running over the surface. No milt runs when pressure is exerted on the testis.
Ripe	
Ovaries are much enlarged and swollen. Colour is reddish-orange due to vascularization. Opaque eggs still prevail but clusters of transparent eggs are appearing. Pressure causes some extrusion of eggs.	Testes are more distinctly wavy and the lobules have become larger. Only a small amount of milt may be obtained by pressure.
Spawning	
Nearly all eggs are transparent. Eggs run freely on slightest pressure to jelly-like ovary.	Testes are densely white and fully distended. Milt runs on slightest pressure.
Spent	
Ovaries are soft, flabby and purple in colour. Few residual eggs remain. Membrane begins to thicken.	Testes are red and shrunken, lying loose in the body cavity. Sperm duct is large and prominent.
Recovering	
Ovaries begin to turn orange again. Membrane is thick and whitish. Eggs are not visible.	Testes are reduced to flat white ribbons. Appears similar to ripening but without the lobules and convolutions.

sufficiently to reveal translucent and opaque rings (Fig. 1). Subsequently, all otoliths were preserved in glycerin solution as they were removed from the fish. Approximately 1,400 otolith pairs were used in age determinations.

Otoliths were read intact with convex side up. They were placed on a black watch glass, covered with a few drops of 50% glycerin solution and read under reflected blue light with a 9X binocular microscope. Each otolith of each pair was read without prior reference to length, sex, or date of capture of the fish. Detection of an annulus was sometimes made difficult by the presence of "false checks". This difficulty was overcome by using the "ring spacing" technique of Kohler (1964). Each fish was assigned to an age-group after obtaining a consistent reading of each otolith of a pair.

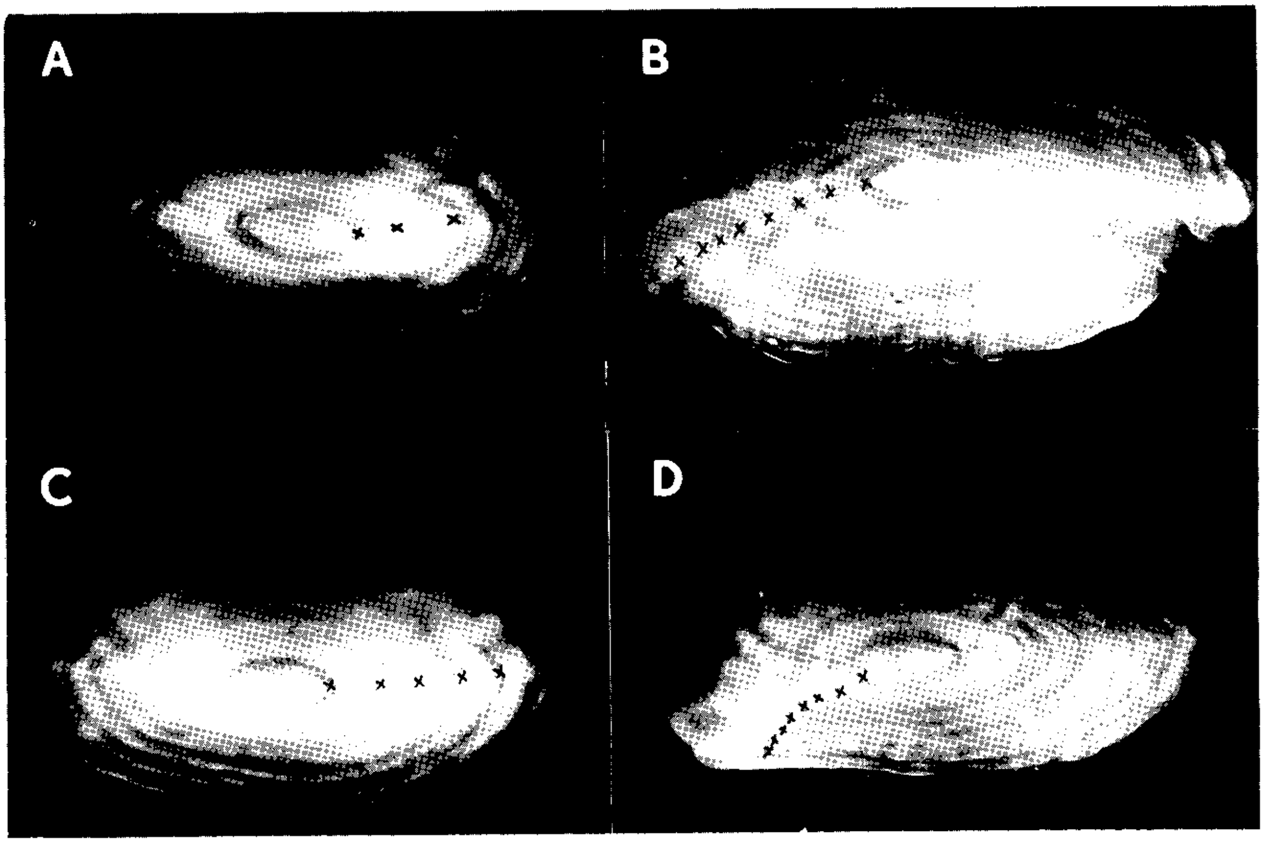

Fig. 1. Otoliths from cusk of different ages showing the two types of edge deposition. A. age-group 5, hyaline edge; B. age-group 11, hyaline edge; C. age-group 6, opaque edge; D. age-group 8, opaque edge.

In late May 1965, lengths, otoliths, and ovaries were obtained from 119 female cusk in the late ripening condition. In this stage the opaque maturing eggs were easily separated from the minute unyolked eggs of future generations. Also, the ovaries contained no ripe transparent eggs, thus ensuring that spawning had not already begun.

Preparation of ovaries and eggs for fecundity estimates followed the methods of Simpson (1951) and Powles (1958). Egg number of individual fish was estimated gravimetrically. Total mass of dried eggs was weighed on an analytical balance accurate to 0.0001 g. Three samples, each of 200 randomly selected eggs, were then weighed separately, mean weight of 200 eggs was calculated and total estimated fecundity determined. All fecundity estimates were rounded off to the nearest thousand eggs and these figures were logarithmically transformed for the analyses.

Distribution

From total cusk landings for ICNAF Subareas in the years 1954-70, taken by all gears and vessels (Table 2), it is clear that most cusk are taken from Subarea 4. Within that Subarea, largest landings and probably the greatest stock occur in Div. 4X (Table 3 and Fig. 2).

It may at first be thought that these landings are influenced by the large long-line fleet which concentrates in southwest Nova Scotia. However, research vessel trawl surveys on the Scotian Shelf show that cusk are most abundant in Div. 4X (Scott, 1971). That most cusk landed are captured by long-line, reflects the preference of cusk for a rough, rocky bottom where they are not vulnerable to trawl gear.

The principal fishing areas also coincide with regions having a minimum bottom temperature of about 4°C. The Roseway, LaHave and "toe" of Browns Banks in Div. 4X show high cusk concentrations and have year-round bottom temperatures of 4°C and above. Cusk are less abundant in Div. 4W but are taken from Emerald Bank and deeper water off the edge of the Shelf, where year-round bottom temperatures are above 4°C. Cusk captured in Division 4V come from the Banquereau Region where temperatures are favourable. No cusk are

TABLE 2. Total cusk landings from the ICNAF Convention Area, 1954-70 (metric tons).

	Subarea					
Year	1	2	3	4	5	Total
1954	17	–	–	94	835	946
1955	16	–	–	1,018	942	1,976
1956	26	–	3	1,407	901	2,337
1957	18	–	10	1,240	707	1,975
1958	15	–	3	1,537	683	2,238
1959	4	–	37	2,253	910	3,204
1960	31	–	32	2,762	768	3,593
1961	259	–	87	3,302	726	4,374
1962	393	–	15	3,695	793	4,896
1963	225	–	24	1,909	782	2,940
1964	413	4	42	4,368	945	5,772
1965	230	4	15	4,635	1,112	5,996
1966	204	1	11	4,997	1,973	7,186
1967	158	–	20	4,630	2,362	7,170
1968	61	–	34	3,154	1,661	4,910
1969	119	27	208	2,735	1,168	4,257
1970	5	–	483	3,220	1,365	5,073

TABLE 3. Total cusk landings by Division of Subarea 4 (metric tons).

	Year									
Div.	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
4R	–	–	–	–	–	–	–	–	–	2
4S	4	–	–	1	–	–	–	–	–	–
4T	3	–	9	–	1	–	–	–	–	2
4Vn	7	4	1	6	1	1	–	–	–	1
4Vs	12	11	8	8	19	43	31	29	24	15
4W	236	481	257	255	669	601	497	505	335	378
4X	3,040	3,199	1,634	4,098	3,945	4,352	4,102	2,620	2,376	2,822

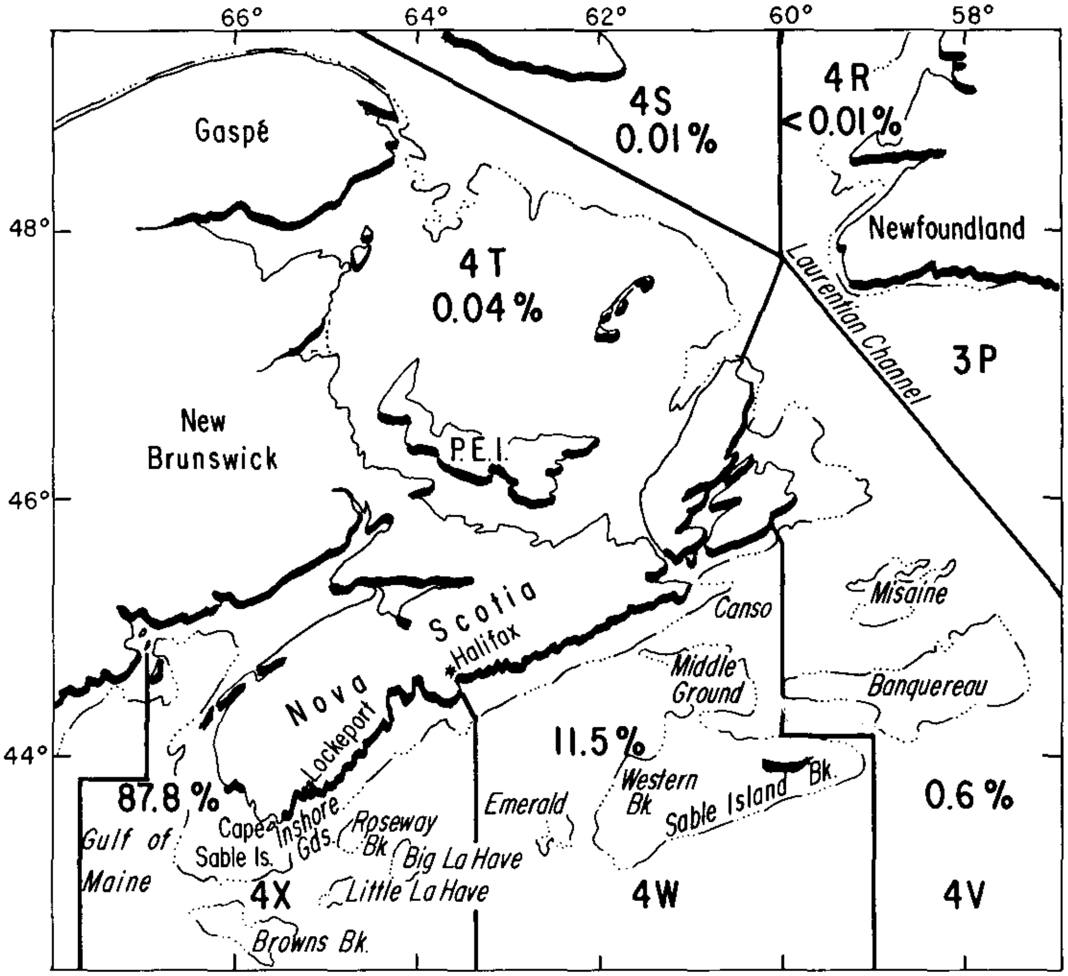

Fig. 2. Percent landings of Subarea 4 by Division averaged for the years 1961-70. Positions of places and banks mentioned in the text are also indicated.

taken from Canso or Misaine Banks where the bottom temperature is colder, ranging from 0° to 3°C (McLellan, 1954).

The Bay of Fundy portion of Div. 4X has well mixed waters with a normal bottom temperature range from less than 2°C in March to above 10°C in October (McLellan, 1954). Cusk are only found in the deep water of the Bay's mouth where temperatures are more stable.

That cusk has a preference for warmer water is further supported very generally by the higher landings in Subareas 5 and 1 than in Subareas 2 and 3, where temperatures are strongly influenced by the cold Labrador Current.

Age and Growth

Age validation

Determining age from otoliths depends on the presence of zones of modified appearance brought about by seasonal changes in the growth pattern. If one hyaline (translucent) and one opaque zone are deposited on the otolith each year, then this pattern may be considered to represent 1 year's growth. Some evidence must be provided indicating that the otolith method is a valid means of ageing the species under study.

Graham (1929) and Saetersdal (1953) point out that seasonal change is good evidence that the method is valid if turnover from one marginal type to the other is sharply defined during the year. Figure 3 shows the frequencies of opaque and hyaline edges for months in which samples were taken. Only fish 9 years old and under were used because, in older fish, peripheral crowding of zones made margin interpretation difficult. Opaque edges predominated from June to October, hyaline edges from November to May. Samples are lacking from December to March but, from the trend in Fig. 3, the time of lowest opaque edge percentage is probably in January or February. This annual rhythmicity of edge type validates age determination from cusk otoliths.

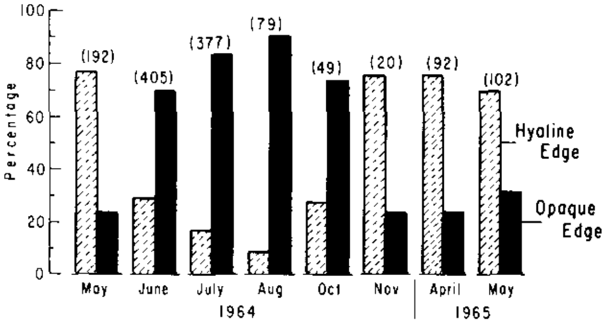

Fig. 3. Seasonal changes in otolith edges of cusk less than 9 years old. Numbers of fish in parentheses.

Zonation on otoliths of North Atlantic gadids has been shown to be related to periods of rapid and slow growth. Hickling (1933) demonstrated that time of hyaline zone formation on the hake otolith in autumn coincided with the period of slow growth. Saetersdal (1953) found a similar phenomenon in haddock. In cusk, otolith zonation fits this general pattern, suggesting rapid growth from June to November, slower growth in winter and spring.

Growth in length

Study of cusk growth is somewhat complicated by the bias of gear selectivity. Fish under 35 cm were not captured and this selection eliminates most fish up to 6 years of age. Mean lengths of age-groups 4, 5, 6, and 7 (Table 4) are too high since the larger fish in these age-groups were the only ones taken.

Plotting these data showed that the von Bertalanffy (1938) growth curve could not be applied. It appeared that the best possible fit for the points would be a straight line. Regression lines were fitted by the methods of least squares and equations were calculated. The high correlation coefficients (r = 0.99 for males and 0.98 for females) indicate that a straight line fits the data quite precisely for the age and size range available from these samples. The regression data produced the following equations:

Males $y = 20.37 + 4.76x$ (Fig. 4)
Females $y = 25.11 + 4.03x$ (Fig. 4)

Slopes of the female and male regressions did not differ significantly ($P > 0.05$) and it appears that rates of growth of male and female cusk do not differ significantly. The male mean length is greater than the female mean length for most age-groups but the intercepts of the two lines are not significantly different.

TABLE 4. Mean lengths (cm) of successive age-groups of Div. 4X commercially captured cusk in 1964.

Age-group	Males n	Males $\bar{x}$	Females n	Females $\bar{x}$
4	–	–	1	(44.00)
5	7	45.00	3	45.30
6	36	49.36	31	47.61
7	72	58.83	65	52.72
8	77	57.78	73	58.71
9	53	63.30	54	61.94
10	31	69.19	26	64.88
11	9	72.00	14	68.86
12	5	72.20	5	69.20
13	1	(94.00)	1	(72.00)
14	1	(95.00)	–	–

It is unlikely that cusk grow in linear fashion throughout their lives. Larger numbers of fish, especially in the older age-groups where there are very few individuals, and compensation for the straightening effect of gear selectivity in young fish, would almost certainly alter the shape of the curve to a more typical form. Absence of old fish from the present study might be due to migration of these fish from the inner banks (the present study area) to deep water on the continental slope or to inefficiency of the gear used (i.e. small hooks) in capturing large old fish.

Length frequencies

Samples from the Inshore Grounds of Div. 4X (Fig. 1) were shown by Student's t test to be significantly different ($P < 0.05$) from LaHave Bank samples in length frequencies. The differences are shown graphically in Fig. 5. A difference existed for both sexes with inshore samples having a higher percentage of small fish in each case. The polymodal character of the inshore length frequency plot is probably due to the small number of individuals composing each length grouping.

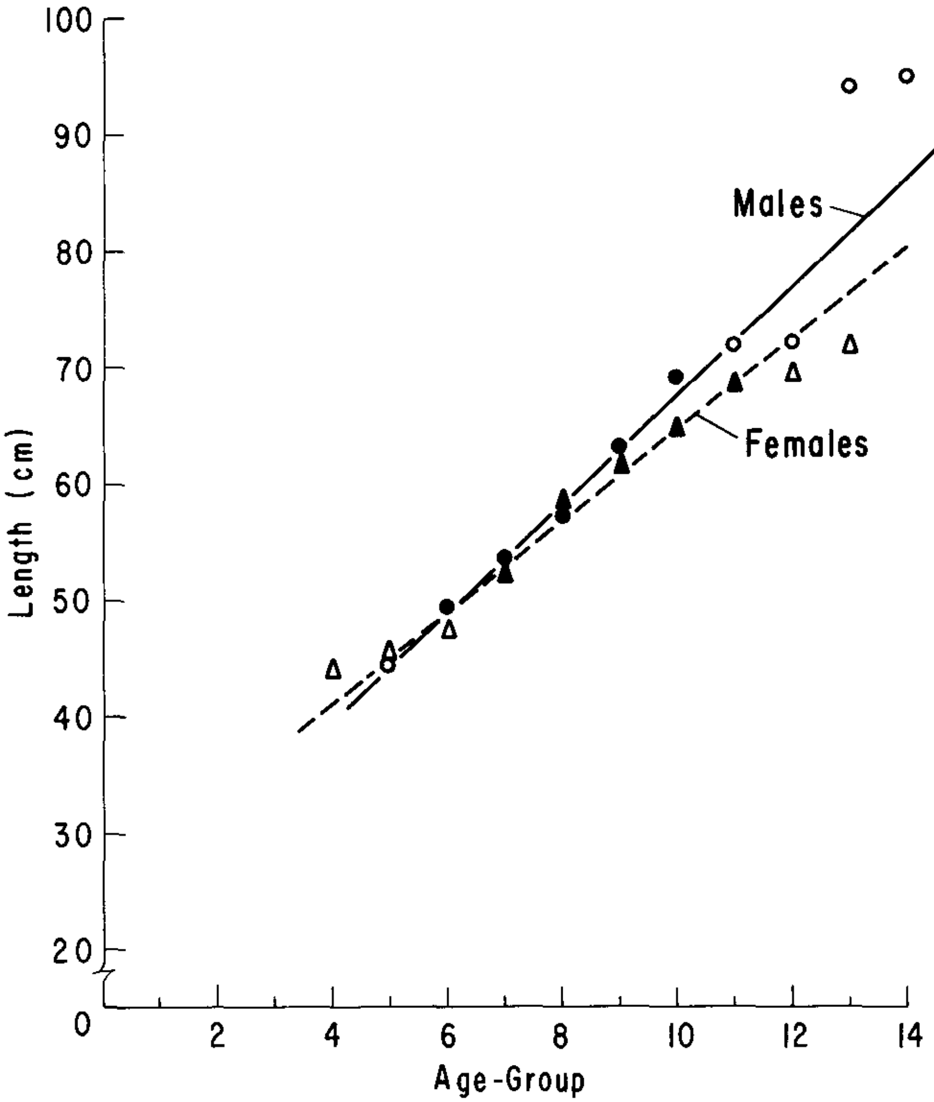

Fig. 4. Growth curves of LaHave and inshore cusk (1964). Circles, males; triangles, females; open symbols represent less than 10 fish in an age-group.

Size composition of both sexes were compared for each of the two regions sampled. No significant difference was found in the size of inshore male and female cusk. However, a significant difference ($P < 0.05$) was discovered in the size composition of LaHave males and females. Although males do not grow longer than females, the higher mode of male fish – 64 cm against 61 cm for the females – and the fact that there is a greater percentage of males among the larger fish would account for males being significantly larger. This could indicate a better survival of male fish.

The relatively high percentage of small fish taken from the Inshore Grounds is probably related to the rocky ledge that occurs inside the 50-fathom contour, from east of Halifax to west of Cape Sable Island

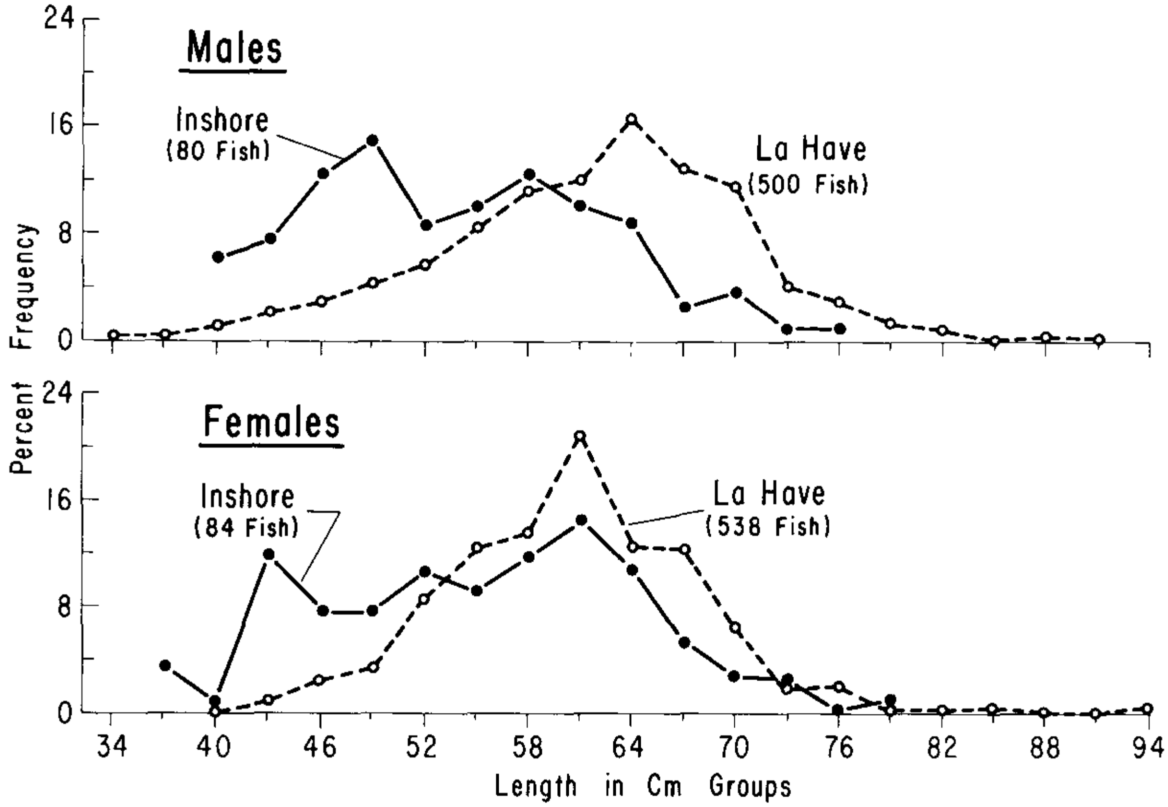

Fig. 5. Length composition of male and female cusk in commercial catches from inshore and LaHave grounds in 1963 and 1964.

transecting Div. 4X in the region of Inshore Grounds (Fig. 2). Hachey (1961) states that the general circulation pattern on the Scotian Shelf is anti-clockwise with a predominantly southwesterly drift along the coast of Nova Scotia. Since cusk inhabit rocky-bottomed areas, it seems reasonable that the prevailing currents might carry the young fry into this area from offshore, where they would encounter a rough bottom on which to begin their growth. The high percentage of small fish suggests that they remain here until they are roughly 50-60 cm in length. Perhaps, at that time, a migration occurs which takes them into deeper water of the outer banks and shelf where they complete their growth. Scott (1971), on analyzing research trawler data accumulated from 1958 to 1968, found that cusk in Div. 4X were far more numerous in depths of 50-149 fathoms than in water under 50 fathoms. Length frequencies for these fish, however, are unknown.

Length-Weight Relationship

The length-weight relationship in fishes is usually described by the equation

$$W = aL^b$$

where W is the weight of the fish (either round or eviscerated) and L its length. Linearly transformed this becomes

$$\log W = \log a + b \log L$$

where *b* represents the slope of the line and log *a* its intercept.

To compensate for the "condition" factor as described by Kohler (1960) for haddock, all fish sampled from May to August of 1963 and 1964 were pooled by sex. Mean weights, both round and eviscerated, were calculated for each centimetre length group. This way, an average condition factor would be obtained since the sampling would include fish in all stages of maturity. The pooled plots of length and weight on double logarithmic paper indicated linear regression in each of the four cases (Fig. 6). Regression lines were fitted to the plots by the method of weighted least squares and equations calculated.

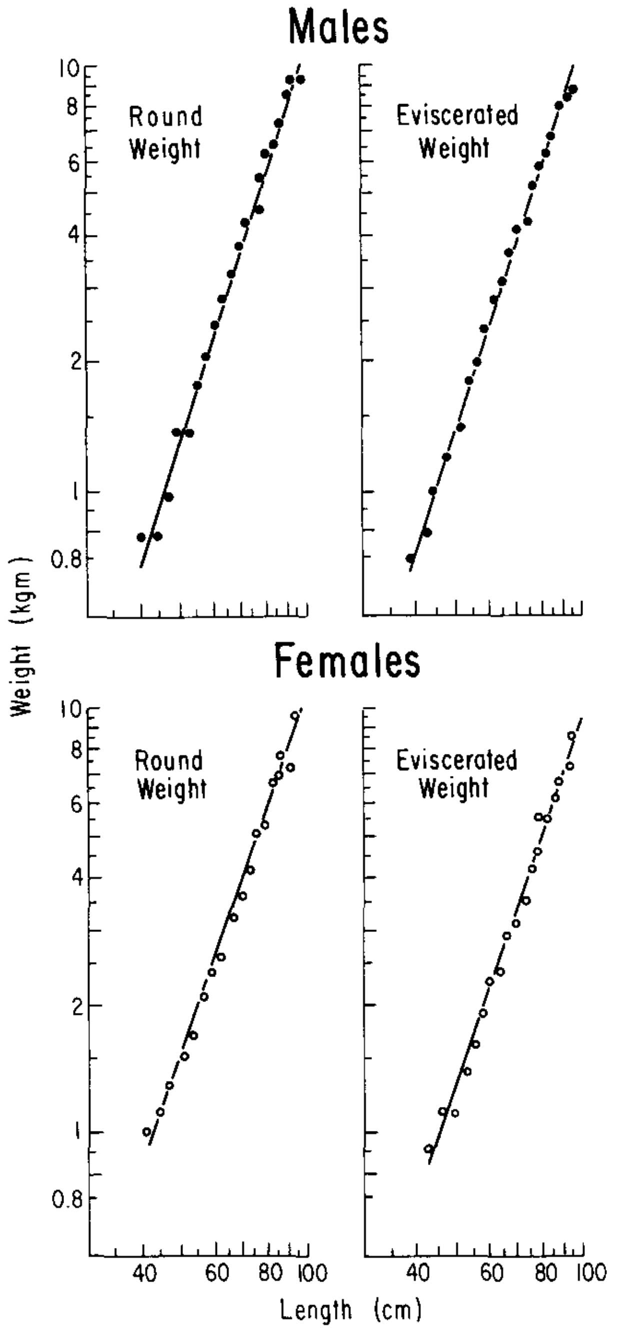

Fig. 6. Length-weight relationship of male and female cusk, 1963 and 1964 data pooled by sex.

It was found that the length-weight relationship of commercially caught cusk can best be represented by the following equations:

Male Eviscerated	$\log W = \bar{5}.0654 + 2.974 \log L$
Male Round	$\log W = \bar{6}.9918 + 3.025 \log L$
Female Eviscerated	$\log W = \bar{5}.4302 + 2.746 \log L$
Female Round	$\log W = \bar{5}.0270 + 3.000 \log L$

The *b* value for eviscerated females is significantly different from any other *b* value and is probably due to anisometric growth of ovaries.

Reproduction

Age and length at maturity

Classification of mature and immature fish of both sexes, in each age-group for a total of 954 fish, was carried out in 1964. Mature fish include those in any stage from Ripening to Recovering (Table 1). Some male fish were mature by age 5 and all were mature by age 10 (Fig. 7). The youngest mature female cusk were in age-group 6 and by 10 years all were mature.

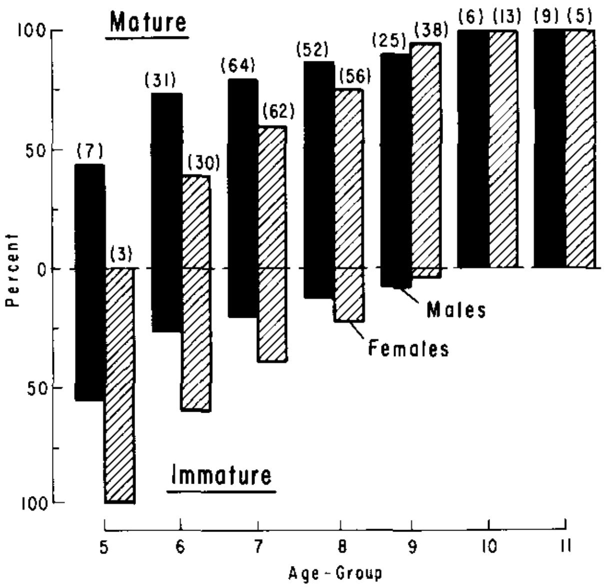

Fig. 7. Age at maturity of cusk sampled in 1964.

The age at which 50% of males and females are sexually mature was determined using the LD_{50} method as modified by Fleming (1960). It was calculated that 50% of male cusk were mature at 4.7 years while 50% of females were mature at 6.5 years, a significantly older age ($P < 0.05$).

A probit analysis of length at maturity (Fig. 8) showed that 50% of males were mature at 43.5 cm and 50% of females at 50.7 cm. The calculated age and size at 50% maturity may be slightly higher than naturally occurring because of the bias of gear selectivity to largest 5-, 6-, and 7-year-old fish.

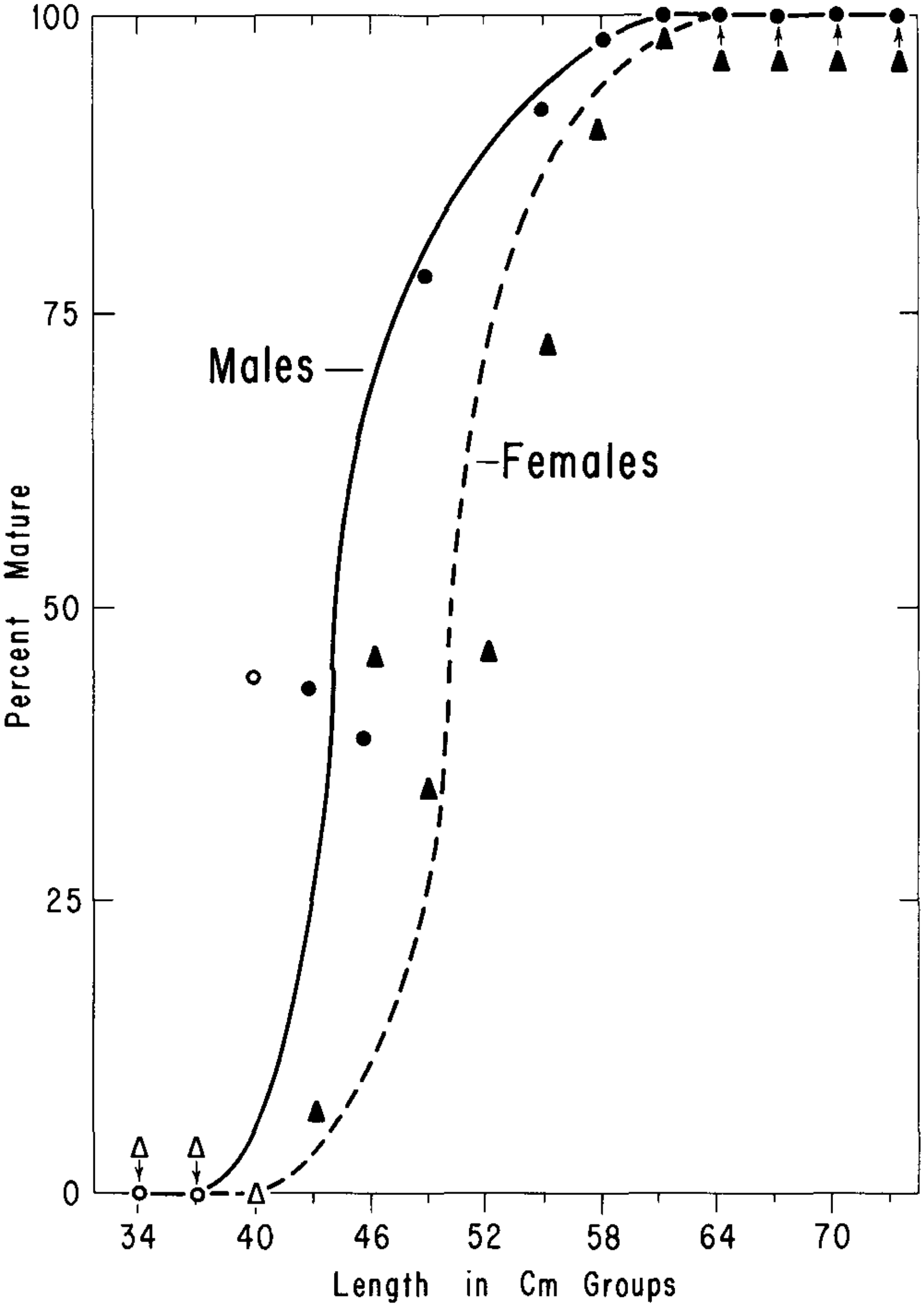

Fig. 8. Length at maturity of cusk sampled in 1964. Circles – males; triangles – females; open symbols – represent less than 10 fish.

Spawning

In determining spawning period, it is logical that this interval would be preceded by a high percentage of maturing fish and would be followed by a large number of spent fish. In both males and females, the highest percentage of ripe-spawning individuals occurred towards the end of June (Fig. 9). Ripening individuals were most common before this period and spent-recovering fish after it, indicating that most spawning in 1964 was accomplished during the last two weeks of June. However, some spawning took place throughout the sampling period of May to August.

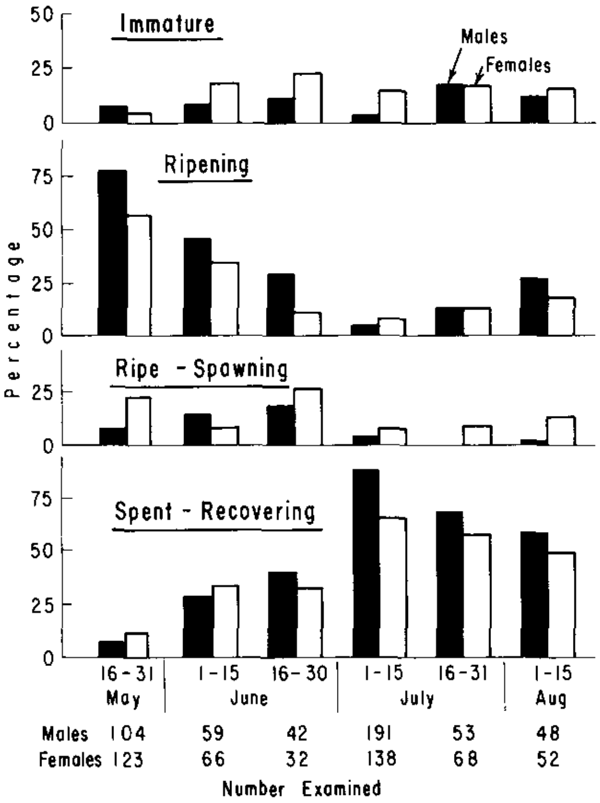

Fig. 9. Cusk maturity cycle, summer of 1964.

The low percentage of ripe and spawning individuals is probably caused by the same factors Kohler (1960) suggested in explaining a similar occurrence in haddock. These two stages occupy a relatively short period in the cycle, reducing the chance of catching haddock or cusk in this condition. Also in haddock and possibly cusk, a large proportion cease feeding as spawning time approaches, making them less available to the hook and line fishery.

The present study indicated that there were no discrete cusk spawning grounds and spawning occurred over the whole of Div. 4X. Fish in the ripe and spawning condition were taken from most areas sampled, but usually in depths less than 100 fathoms.

Fecundity

Statistical methods

Fecundity was investigated in relation to length and age. All data used were transformed to their logarithmic forms for two reasons. First, the investigation of fecundity involves a relationship between body size and egg number. This implies application of the general growth equation

$$Y = aX^b$$

where X represents body size and Y a dependent variable. For convenience, this equation can be reduced from its exponential to linear form by taking the common logarithm of both sides of the equation in which case it becomes

$$\log Y = b \log X + \log a$$

Secondly, in regression analyses, variance must be independent of the mean. In growth and form relationships, variance is positively correlated with size. By converting the data to logarithmic form, this relationship is eliminated.

Results and conclusions

Fecundity (F) vs length (L) showed a linear trend on a log-log plot (Fig. 10A). Fitting a least squares straight line to the data produced the relationship

$$\log F = 3.64 \log L - 0.74$$

The correlation coefficient 0.8211 is significantly different from zero ($P < 0.005$).

Similar treatment of fecundity vs age (A) data (Fig. 10B) gave the equation

$$\log F = 3.09 \log A + 2.91$$

The correlation coefficient for this relation ($r = 0.6924$) is also significantly different from zero ($P < 0.005$).

That fecundity is related more to length than age is reflected not only by the higher r-value but also the lesser variation (Fig. 10). However, since length is related to age, a multiple correlation was used to analyze the contribution of each to fecundity variation. The partial correlation coefficient for fecundity on length was 0.6133, whereas the corresponding figure for fecundity on age was very small, 0.0781. The multiple correlation coefficient was 0.8218.

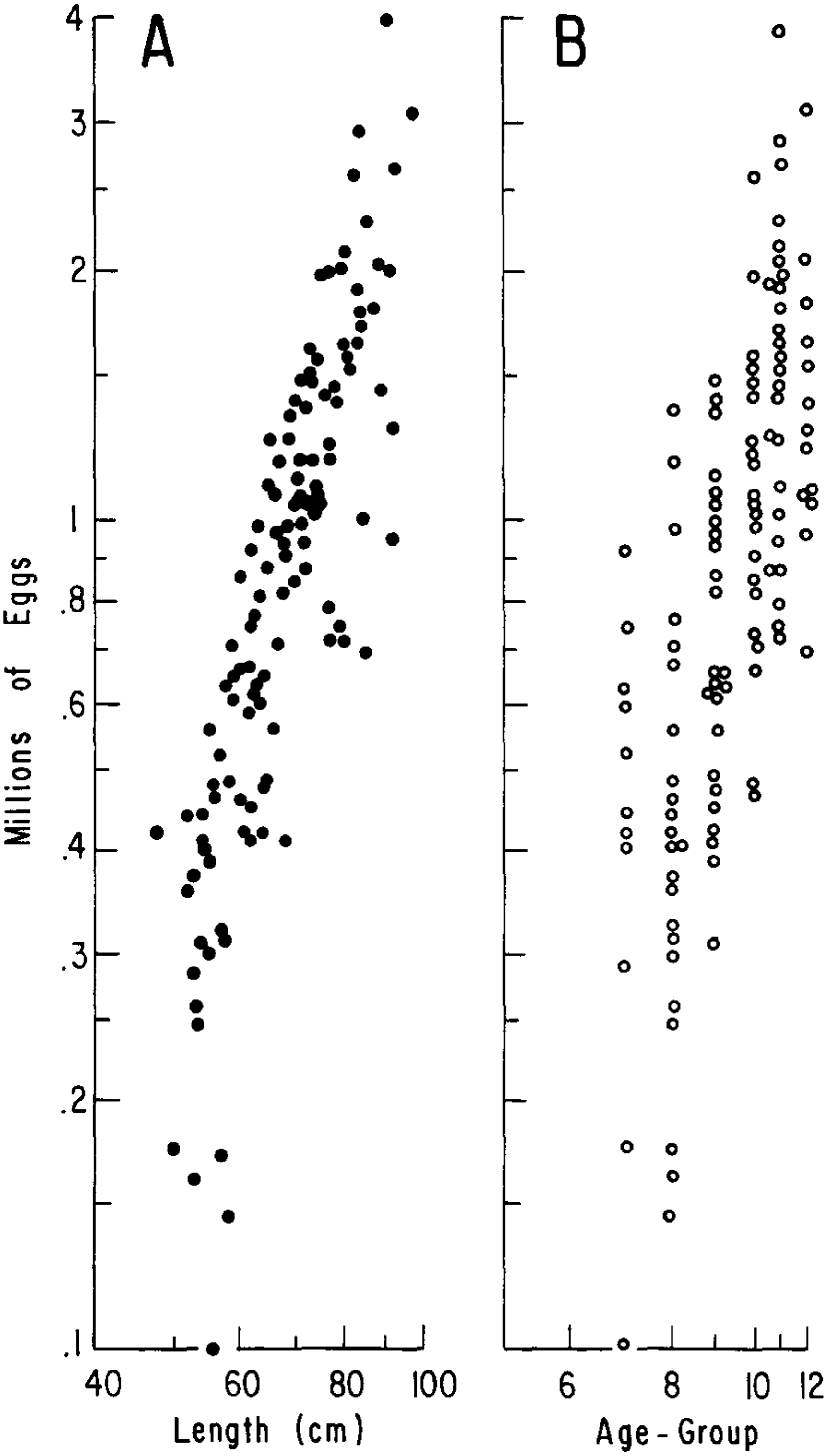

Fig. 10. Scatter diagrams of cusk fecundity plotted (A) against length, (B) against age.

From these results it appears that in cusk the closest correlation is between fecundity and length, and that a consideration of age adds little to the predictive value of the relationship. The fecundity-length regression coefficient of 3.64 indicates that cusk fecundity is approximately proportional to the cube of the length. This value is comparable to those found for many species including North Sea plaice (Simpson, 1951), American plaice (Pitt, 1964), and Atlantic cod (May, 1967).

Although the effect of age on fecundity is small, it can be demonstrated by calculating regression equations from the length vs fecundity data of each age-group:

Age-group 7 (n=11) $\log Y = 3.840 \log X - 1.085$
Age-group 8 (n=23) $\log Y = 4.211 \log X - 1.810$
Age-group 9 (n=25) $\log Y = 3.770 \log X - 0.963$
Age-group 10 (n=21) $\log Y = 3.371 \log X - 0.223$
Age-group 11 (n=26) $\log Y = 2.493 \log X + 1.479$
Age-group 12 (n=13) $\log Y = 1.441 \log X + 3.379$

With the exception of age-group 7, the regression coefficients show a decreasing progression. It can be concluded that in younger fish, fecundity increases at a more rapid rate with length than it does in older fish. This feature has been found by Raitt (1933) for haddock and Hickling (1940) for herring.

Discussion

There is very little information in the literature on the biology of cusk, *Brosme brosme*. The few scattered observations which have been made are well summarized in Wheeler (1969) for European waters and Bigelow and Schroeder (1953) for the Northwest Atlantic. The present study indicates that cusk of the Northwest Atlantic inhabit rough, rocky bottoms and are restricted in distribution by water less than 4°C. Bigelow and Schroeder (1953) state that cusk of the Gulf of Maine are found chiefly on hard ground composed of rocks, gravel, or pebbles and may possibly be found among offshore gorgonian corals as they are in Norwegian waters. They say that cusk spend their lives in water between 48° to 50°F (9° to 10°C) and 33° to 34°F (0.5° to 1.1°C). Present data indicate cusk are taken in areas where temperatures reach 9°C. However, it seems reasonable that if cusk can tolerate cold waters at 1°C, they should be found on hard-bottomed regions to the northeast of the Scotian Shelf.

Most cusk on the Scotian Shelf are taken from depths of between 50-150 fathoms with a few being captured from depths of over 200 fathoms (Scott, 1971). The greatest depth from which cusk are taken in the Northwest Atlantic is in accordance with the 200-300 fathoms reported by Bigelow and Schroeder. In European waters, cusk (torsk) appear to be most common in depths of 82-246 fathoms but are taken as deep as 546 fathoms (Wheeler, 1969).

Growth in length of European cusk differs markedly from growth of cusk from Div. 4X. Commercially captured cusk from European waters most frequently range between 45 and 60 cm and are between 10 and 12 years old. The majority of cusk landed by Canadian fishermen are 45-75 cm in length and 5-12 years of age. European cusk grow from an average of 22 cm at age 6 to between 36 and 48 cm at age 8. Comparatively, the mean length of Div. 4X cusk was 49 cm at age 6 and 58 cm at age 8. Wheeler gives maximum length of Northeast Atlantic cusk to be 110 cm. The largest cusk sampled by the author was 97 cm although Bigelow and Schroeder state cusk grow to 3½ ft (107 cm).

Although ripe fish were discovered from May to August, spawning occurs in the majority of cusk towards the end of June. Damas (1909) reported that the spawning season for European cusk lasts from the end of April to July while Bigelow and Schroeder (1953) stated that the situation is similar for Gulf of Maine cusk. It appears that a lengthy spawning season is consistent for cusk throughout its range.

In the present study there appeared to be no aggregation of spawning cusk in any one region of Div. 4X. Ripe fish were evenly distributed over the principal fishing areas in depths less than 100 fathoms. European cusk, on the other hand, also spawn maximally at depths of approximately 100 fathoms but appear to have principal spawning areas (Damas, 1909; Wheeler, 1969). Wheeler also says cusk may spawn over most of its entire range. The evidence for discrete spawning grounds off Europe may simply be a manifestation of cusk abundance in these areas.

Study of fecundity indicated cusk to be reasonably prolific. Fulton (1891), in a fecundity study of several marine species including cusk, estimated the fecundities of two 34-inch (86 cm) cusk to be 2,283,979 and 790,064. These values compare with the fecundity range of 86 cm fish of the present study. Egg number for Scotian Shelf cusk varied from 100,000 for a 7 year old, 56 cm specimen to 3,927,000 for an 11 year old, 90 cm fish.

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References

BERTALANFFY, L. VON. 1938. A quantitative theory of organic growth. *Hum. Biol.*, 10(2): 181-213.

BIGELOW, H. B., and W. C. SCHROEDER. 1953. Fishes of the Gulf of Maine. (First Revision). *Fish. Bull., U.S.*, **53**: 577 p.

DAMAS, D. 1909. Contribution à la biologie des Gadides. *Rapp. Cons. Expl. Mer*, 10(3): 277 p.

FLEMING, A. M. 1960. Age, growth and sexual maturity of cod (*Gadus morhua* L.) in the Newfoundland area, 1947-1950. *J. Fish. Res. Bd. Canada*, **17**: 775-809.

FULTON, T. W. 1891. The comparative fecundity of sea fishes. *Rept. Fish. Bd. Scot.* (1890), Part 3, p. 243-268.

GRAHAM, M. 1929. Studies of age determination in fish. Part II. A survey of the literature. *Fish. Invest., Lond.* (2), **11**: 50 p.

HACHEY, H. B. 1961. Oceanography and Canadian Atlantic waters. *Bull. Fish. Res. Bd. Canada*, No. 134, 120 p.

HICKLING, C. F. 1933. The natural history of the hake. Part IV. Age-determination and the growth-rate. *Fish. Invest., Lond.* (2) **13**: 120 p.

1940. The fecundity of the herring of the southern North Sea. *J. mar. biol. Ass. U.K.*, **24**: 619-632.

HUNTSMAN, A. G. 1922. The fishes of the Bay of Fundy. *Contr. Can. Biol. for 1921*, No. 3, p. 49-72.

JORDAN, D. S., and B. W. EVERMANN. 1898. The fishes of North and Middle America. *Bull. U.S. nat. Mus.*, 47(3): 2561 p.

KOHLER, A. C. 1960. The growth, length-weight relationship, and maturity of haddock (*Melanogrammus aeglefinus* L.) from the region of Lockeport, N.S. *J. Fish. Res. Bd. Canada*, **17**: 41-60.

1964. Variations in the growth of Atlantic cod (*Gradus morhua* L.). *Ibid*, **21**: 57-100.

LEIM, A. H., and W. B. SCOTT. 1966. Fishes of the Atlantic coast of Canada. *Bull. Fish. Res. Bd. Canada*, No. 155, 485 p.

MAY, A. W. 1967. Fecundity of Atlantic cod. *J. Fish. Res. Bd. Canada*, **24**: 1531-1551.

MCLELLAN, H. J. 1954. Bottom temperatures on the Scotian Shelf. *J. Fish. Res. Bd. Canada*, **11**: 404-418.

PERLMUTTER, A. 1961. Guide to marine fishes. New York University Press.

PITT, T. K. 1964. Fecundity of the American plaice, *Hippoglossoides platessoides* (Fabr.) from Grand Bank and Newfoundland areas. *J. Fish. Res. Bd. Canada*, 21(3): 597-612.

POWLES, P. M. 1958. Studies of reproduction and feeding of Atlantic cod (*Gadus callerias* L.) in the southwestern Gulf of St. Lawrence. *J. Fish. Res. Bd. Canada*, **15**: 1383-1402.

RAITT, D. S. 1933. The fecundity of the haddock. *Fish. Bd. Scot., Sci. Invest.*, 1932, No. 1, p. 1-42.

SAETERSDAL, G. S. 1953. The haddock in Norwegian waters. *Norweg. Fish. Mar. Invest.*, **10**: 46 p.

SCOTT, J. S. 1971. Abundances of groundfishes on the Scotian Shelf. *Fish. Res. Bd. Canada, Tech. Rept.* No. 260, 8 p. + 2 figures and 8 tables.

SIMPSON, A. C. 1951. The fecundity of the plaice. *Fish. Invest., Lond.* (2), **17**: 1-27.

WHEELER, A. 1969. The fishes of the British Isles and North-West Europe. MacMillan, London, Melbourne, Toronto. 613 p.

The Fecundity of Herring in Some Parts of the Newfoundland Area

By V. M. Hodder[1]

Abstract

The fecundity of herring in Newfoundland coastal waters was investigated from 278 ovaries collected in four different areas during January to August 1966. It was found that fecundity increased at a rate proportional to the 4.5 power of total length and to the 1.5 power of body weight, the correlation in both cases being quite similar. The egg production of spring spawners in three herring stocks of southern Newfoundland was about the same but it was considerably lower than that for autumn spawners of eastern Newfoundland, the latter being similar to values reported for Georges Bank, Gulf of Maine, and Southwest Nova Scotia autumn spawners. The differences in fecundity between spring and autumn spawners are discussed in relation to the very different environmental conditions existing during several months immediately preceding the spawning periods of spring and autumn spawners, conditions which are probably critical during the development and maturation of the ova.

Introduction

During the past decade, following the recent upsurge in exploitation of the herring stocks of the Northwest Atlantic (from Labrador southward to Cape Cod), much information has been published on their migratory behaviour and general biology, including comprehensive population dynamics studies. Of particular importance are the effects that high exploitation rates might have on the spawning potential of the stocks once the size and age structure changes, so that the propagation of the species must depend on the egg production of much younger spawners, and this is where fecundity studies may play an important role in determining the relation between spawning potential and recruitment. Also, fecundity like some other biological characteristics may be useful as an indicator in stock differentiation. Investigations on the fecundity of herring stocks in the Georges Bank, Gulf of Maine, Nova Scotian, and southern Gulf of St. Lawrence areas have been made (Yudanov, 1966; Barrett, MS 1968; Perkins and Anthony, 1969; Draganik and Rast, MS 1970), but none have previously been reported for the herring stocks of the Newfoundland area. This paper presents information on fecundity of herring taken in four areas of southern and eastern Newfoundland.

Materials and Methods

The herring specimens used for fecundity estimation were collected from January to August 1966 in the coastal waters of the south and east coasts of Newfoundland (Table 1). Ovaries were preserved in jars containing Gilson's fluid, and the method of preservation and cleaning was the same as that followed by Hodder (1963) for Grand Bank haddock. Information recorded routinely for each specimen included the total length of the fish in millimetres, the whole weight of the fish and the weight of the ovaries in grams, and the sex and maturity condition according to the numerical scale adopted by ICNAF (1964). Specimens taken along the south coast during January to April were generally stage 4 in the maturity scale, and those taken in late April and early May were stage 5; thus all of the south coast specimens were fish which would normally spawn in the spring (May). The specimens taken in the bays along eastern Newfoundland in July and August were likewise mostly stage 4 with some stage 5's in August, and these would normally spawn in the autumn.

Two methods of obtaining fecundity estimates were employed. Specimens taken during January to May were treated by the method described by Hodder (1963) using a whirling vessel of the type described by Wiborg (1951), while those taken in July and August were treated by a method similar to that used by Boyar and Clifford (1967) employing an electronic "Decca Mastercount". Ova samples from six specimens were treated by both methods for comparative purposes.

The whirling vessel technique involved the successive fractioning of egg samples. The first fraction yielded 10 samples, each of which was 1/10 of the

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TABLE 1. Number of herring ovaries sampled for fecundity estimation with area and date of capture and size range of fish (cm).

Area	Dates	Number of specimens	Length range
A. Southwest Nfld.	11-19 Jan	45	28-36
	10-12 Apr	20	27-36
B. Fortune Bay area	17-18 Mar	45	27-40
	4-7 May	43	25-39
C. Placentia Bay	22-23 Feb	36	27-38
	15 Apr	25	27-40
D. Eastern Nfld.	10-12 July	22	27-38
	2-12 Aug	42	27-40

original sample size. Two of these, selected at random, were combined and further fractioned to yield 10 subsamples, each of which was about 1/50 of the original egg sample. Four of these subsamples were randomly selected for counting of ova under the low power of a binocular microscope. The fecundity estimate was taken as the average of the four counts multiplied by a factor of 50. Subsample counts for all specimens generally ranged between 1,000 and 4,000 ova. Some indication of the reliability of the sampling technique with the whirling vessel is obtained by computing for each specimen the average percentage deviation of the four counts from their mean. The frequency distribution of the percentage deviations show that 75% of the observations deviated from their means by less than 10%.

Preparatory to counting with the "Mastercount" machine, the egg sample (previously cleaned and stored in 5% formalin solution) was poured from the jar on to fine-meshed bolting cloth, washed thoroughly, and left to dry on filter paper at room temperature for 2-3 hr. The complete ova sample was then weighed to the nearest 0.01 g and a subsample, in the weight range of 2-3 g, taken and weighed for counting. The dried eggs were next placed in the feeder bowl of the machine and moved by vibration singly along a sizing groove, from the end of which they fell individually through a detection aperture past a photo-electric cell which activated the digital counter. Of the 64 specimens treated by this method, all of the eggs were counted for two specimens and subsamples ranging from 9,000 to 40,000 ova were counted for the remainder. In order to maintain a check on the accuracy of the machine counts, eight batches of 100 ova each were taken during the course of the machine counting of each subsample and these were counted visually under a binocular microscope. The frequency distribution of the deviations indicate that on the average the visual counts deviated from the machine counts by 0.02% and that 95% of the deviations were within the limits of ± 3.44%. This degree of precision agrees favourably with the accuracy indicated by Boyar and Clifford (1967) who used a similar machine for counting herring eggs.

During the course of subsampling the egg samples with the whirling vessel, a 1/10 part of each sample was preserved in case it became necessary, due to unduly large variation in subsample egg counts, to carry out further verification checks of the fecundity estimates. Six of these subsamples were subsequently subjected to machine counting, and the results indicate good agreement with those obtained by the whirling vessel method (Table 2).

TABLE 2. Comparison of fecundity estimates for selected specimens using the whirling vessel and "Mastercount" methods.

Length (mm)	Fecundity estimates	
	Whirling vessel	"Mastercount"
305	66,600	66,290
325	99,150	94,910
328	115,600	111,550
349	111,900	115,850
351	82,900	90,270
354	100,650	98,310

For most of the South Newfoundland samples, the average egg diameter was estimated by taking the average of the linear distance (to the nearest 0.1 mm) occupied by 50 eggs lined up adjacent to each other singly in a small V-shaped groove cut in a piece of black plexiglass.

In tables where mm length measurements are grouped into cm intervals the lengths are given to the 0.5 cm below, i.e. lengths of 300 to 309 mm are grouped in the 30-cm interval.

Results

Fecundity related to length of fish

Fecundity estimates were made for 278 female herring ranging in total length from 258 to 408 mm. The estimates ranged from 12,750 eggs for a 278 mm fish to 241,630 eggs for a 370 mm specimen, but most of the fish were in the range 300-380 mm with fecundity estimates generally ranging between 40,000 and 200,000 ova.

On the basis of current knowledge of herring stocks in the Newfoundland area, the specimens were grouped by area into four lots as illustrated in the scatter diagrams of fecundity against body length (Fig. 1). The curvilinear relationships were determined by applying a

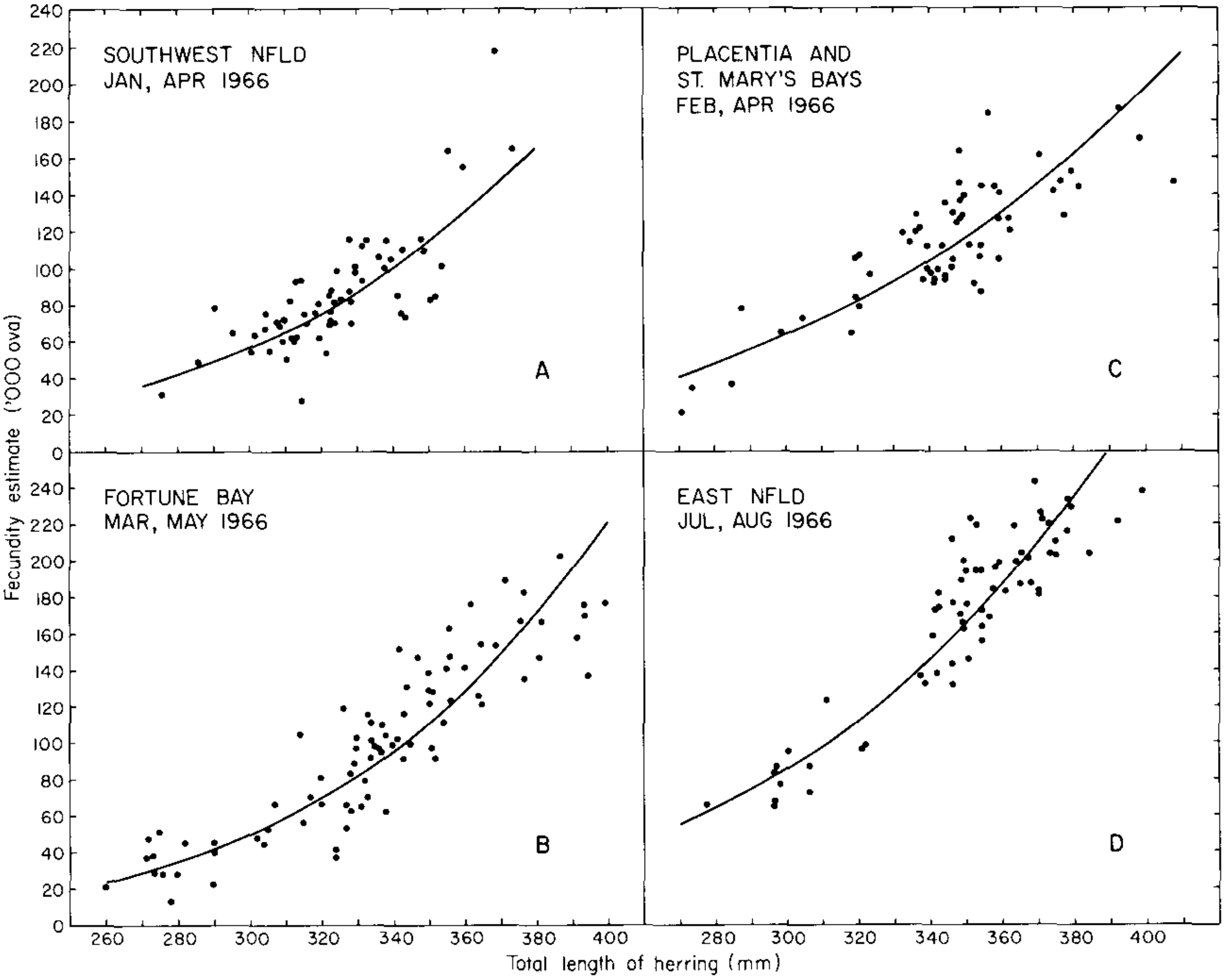

Fig. 1. Fecundity estimates by length of fish and the fitted regression lines for four groups of herring in the Newfoundland area.

logarithmic transformation to the two variables and computing the parameters of the linear model:

$$\log F = n \log L + \log k$$

Parameters for each of the four groups are given in Table 3. The resulting fecundity-length curves indicate that fecundity increases at a rate greater than the cube of the body length, the regression coefficient *n* ranging between 4.03 and 4.88.

The data of Fig. 1 show that for any one length of fish fecundity varies between fairly wide limits. This variation is greater than would be expected due to sampling errors and tends to mask any obvious differences in fecundity between areas. This aspect is

TABLE 3. The relationship between log fecundity and log body length for herring of four areas of southern and eastern Newfoundland 1966.

Area	No. of fish	Regression coefficient, *n*	Intercept log *k*	Correlation coefficient, *r*
A. Southwest Nfld.	65	4.495	–14.693	0.77
B. Fortune Bay	88	4.880	–16.981	0.90
C. Placentia and St. Mary's Bays	61	4.027	–11.933	0.85
D. Eastern Nfld.	64	4.242	–12.838	0.93

better shown by plotting in a single diagram the four curves as derived from the fitted log-log regressions (Fig. 2). Comparisons of the observed means (geometric) of fecundity-at-length data with the corresponding values from the fitted curves are given in Table 4.

To test the significance of the between-area differences in slope (rate of increase in log fecundity with log length) and in intercept (log fecundity adjusted to a common log length), an analysis of covariance was used according to Snedecor (1956). No significant difference was found between the regression coefficients of the samples by area, but when the test was applied to measure the variability in intercepts a significant difference at the 1% level resulted. The curve derived from the data for eastern Newfoundland (Fig. 2) lies considerably above the three curves derived from southern Newfoundland data. When the test was applied to the latter three sets of data, neither the regression

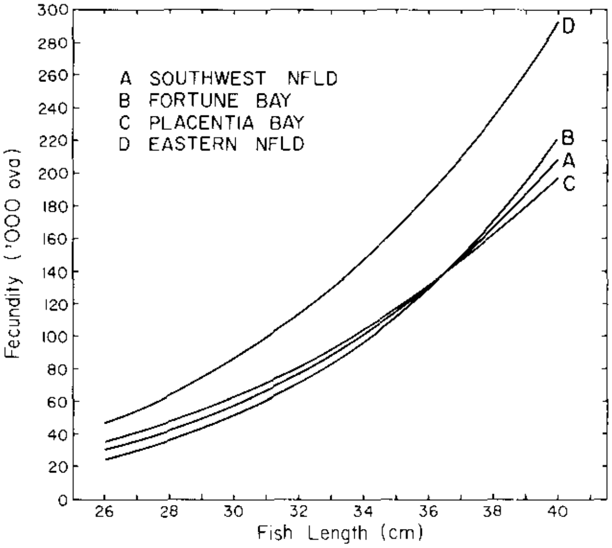

Fig. 2. Fecundity-length relationships for herring from Newfoundland coastal waters.

TABLE 4. Mean fecundity estimates ('000) and predicted values by length group (cm) for herring taken in Newfoundland coastal waters. (Means are geometric means, and numbers of specimens are given in parentheses.)

	A. Southwest Newfoundland			B. Fortune Bay area		
Length group (cm)	Predicted from curve	Observed		Predicted from curve	Observed	
		Mean	Range		Mean	Range
25	..	–	–	22.0	20.4 (1)	–
27	38.5	31.0 (1)	–	32.3	32.4 (1)	12.5 - 51.3
28	45.2	47.7 (1)	–	38.8	37.4 (3)	28.3 - 45.3
29	52.8	71.8 (2)	65.4 - 78.9	46.4	34.1 (3)	21.9 - 45.8
30	61.3	64.5 (7)	54.2 - 76.3	55.0	52.4 (4)	44.7 - 66.9
31	70.9	65.7 (15)	26.8 - 94.0	64.9	74.9 (3)	57.3 - 104.8
32	81.6	78.5 (16)	53.2 - 115.6	76.2	65.9 (10)	36.7 - 118.6
33	93.5	104.5 (8)	94.1 - 115.4	89.1	92.0 (16)	62.5 - 115.1
34	106.7	96.7 (8)	73.4 - 115.8	103.6	115.0 (8)	91.1 - 152.1
35	121.3	102.9 (4)	81.6 - 164.3	120.0	124.6 (12)	91.5 - 162.7
36	137.1	184.0 (2)	155.1 - 218.2	138.4	142.7 (7)	120.6 - 175.8
37	155.2	163.8 (1)	–	159.0	166.9 (4)	135.1 - 188.9
38	–	–	–	182.0	170.9 (3)	147.3 - 202.7
39	–	–	–	207.7	159.5 (4)	136.6 - 176.0
40	–	–	–	236.1	176.5 (1)	–
	C. Placentia and St. Mary's Bays			D. Eastern Newfoundland		
27	43.7	26.7 (2)	20.7 - 34.3	59.1	66.3 (1)	–
28	50.5	53.2 (2)	35.7 - 79.3	–	–	–
29	58.0	65.1 (1)	–	80.1	75.3 (5)	64.7 - 87.2
30	66.4	73.4 (1)	–	91.7	84.4 (3)	73.2 - 94.8
31	75.5	63.9 (1)	–	105.1	123.4 (1)	–
32	85.7	94.1 (4)	78.8 - 107.2	120.1	98.0 (2)	97.4 - 98.6
33	96.8	114.6 (6)	92.0 - 128.0	136.4	134.9 (2)	132.7 - 137.1
34	108.1	112.3 (18)	92.0 - 162.8	154.6	165.0 (10)	132.3 - 210.7
35	122.2	120.7 (11)	86.9 - 182.8	174.5	181.5 (17)	145.7 - 220.0
36	136.6	122.4 (5)	104.8 - 138.7	196.3	196.6 (8)	182.5 - 218.4
37	152.4	142.7 (4)	127.3 - 159.6	220.1	211.8 (11)	182.5 - 241.6
38	169.4	147.1 (2)	142.1 - 152.2	246.1	215.6 (2)	203.3 - 228.7
39	187.8	177.4 (2)	168.9 - 186.2	274.4	221.4 (1)	–
40	207.7	145.4 (1)	–	305.1	237.5 (1)	–

coefficients nor the intercepts were significantly different at the 5% level.

A feature of three of the four sets of fecundity-length data (Fig. 1, B, C, and D), for which there are several specimens greater than 36 cm in length, is the apparent change in rate of increase in fecundity with length. In fact, there is the tendency for fecundity to remain relatively constant within certain limits of variability for 37-40 cm herring. For Fortune Bay and Placentia Bay fish the fecundity of 37-40 cm specimens ranges from about 140,000 to 200,000 eggs, whereas for eastern Newfoundland herring the range is higher at 180,000 to 240,000 ova.

Fecundity related to weight of fish

Since fecundity has been shown to increase at a rate greater than the cube of the length and since the weight of fish is generally accepted as being approximately proportional to the cube of the length, the relationship between log fecundity and log weight, when treated by the usual method of least squares, should produce an equation of the form $F = kW^n$, where n is greater than 1.0. This is comfirmed by the log fecundity-log weight regression lines whose regression coefficients range from 1.24 to 1.60 (Table 5). As previously shown by the fecundity-length relationships, the curve derived from fecundity-weight data for eastern Newfoundland herring (Area D) is significantly different from those for southern Newfoundland (Areas A, B, and C). A quantitative indication of the differences in fecundity for selected weights (gm) is given in Table 6.

Egg diameter related to month and area

The average diameter of eggs was estimated for most of the specimens taken during January to May in the three areas of southern Newfoundland (Table 7). In each month and area the mean egg diameter was relatively constant for specimens 30 cm and larger in length. The lower values for some of the smaller herring are probably associated with fish maturing to spawn for the first time, and these would thus spawn later than the period of peak spawning.

The absence of any significant variation in average egg diameter by area and month (except for Fortune Bay in May) reflects the absence of ovarian development during the winter months (January to April); the average diameter increased only slightly (0.67 to 0.71 mm) in Southwest Newfoundland from January to April, and remained the same (0.72 mm) in Placentia Bay herring between February and April. Only in Fortune Bay herring did the average diameter of eggs increase significantly (0.74 to 0.84 mm) between March and May, just prior to spawning. Surface to bottom water temperatures in the bays and fjords of southern and eastern Newfoundland are generally below 1°C during January to early April, after which there is gradual warming of the surface layer to 5° C or higher during spawning time in May and early June.

TABLE 5. The relationship between log fecundity and log weight for herring of four areas of southern and eastern Newfoundland, 1966.

Area	No. of fish	Regression coefficient, *n*	Intercept log *k*	Correlation coefficient, *r*
A. Southwest Nfld.	65	1.599	2.422	0.84
B. Fortune Bay	45	1.427	3.384	0.92
C. Placentia and St. Mary's Bays	61	1.235	4.431	0.86
D. Eastern Nfld.	64	1.244	4.671	0.92

TABLE 6. Computed fecundity values for selected weights as derived from the log fecundity-log weight regressions for Areas A, B, C, and D.

Fish weight (gm)	Fecundity ('000) predicted from curves			
	A	B	C	D
200	53	56	58	78
250	77	78	77	102
300	103	101	96	129
350	131	126	117	156
400	163	152	138	184

TABLE 7. Average diameter (mm) of herring eggs by fish length and by area and month of capture. (Number of specimens in parentheses.)

Total length (cm)	Southwest Newfoundland		Fortune Bay		Placentia Bay	
	January	April	March	May	February	April
27	–	0.45 (1)	0.51 (7)	0.80 (3)	0.63 (1)	0.45 (1)
28	0.62 (1)	–	–	0.59 (2)	0.45 (1)	0.45 (1)
29	–	0.62 (2)	–	0.80 (3)	–	0.64 (1)
30	0.68 (6)	0.77 (1)	–	0.75 (4)	–	0.58 (1)
31	0.69 (14)	0.61 (1)	–	0.89 (3)	–	0.69 (1)
32	0.68 (9)	0.73 (7)	0.68 (1)	0.88 (7)	0.67 (4)	0.64 (1)
33	0.65 (6)	0.74 (2)	0.80 (8)	0.87 (8)	0.76 (5)	0.64 (1)
34	0.64 (5)	0.79 (3)	0.71 (4)	0.82 (4)	0.75 (10)	0.77 (8)
35	0.67 (2)	0.77 (2)	0.77 (8)	0.88 (4)	0.71 (7)	0.75 (4)
36	0.60 (1)	0.41 (1)	0.79 (6)	0.94 (1)	0.77 (4)	0.69 (1)
37	0.71 (1)	–	0.87 (4)	–	0.74 (2)	0.79 (2)
38	–	–	0.77 (3)	–	0.74 (2)	–
39	–	–	0.72 (3)	0.99 (1)	–	0.81 (2)
40	–	–	0.77 (1)	–	–	0.82 (1)
Av.	0.67 (45)	0.71 (20)	0.74 (45)	0.84 (40)	0.72 (36)	0.72 (25)

Discussion and Conclusions

The fecundity of herring taken in Newfoundland coastal waters was found to vary at a rate proportional to about the 4.5 power of total length, the regression coefficents ranging between 4.0 and 4.9. These values of the exponent are generally in the upper part of the range of values reported by others for herring and for other species. Most authors of papers on fecundity of a variety of species have found that the exponent usually ranged between 3 and 5: values between 3 and 4 have been reported by Raitt (1933) for North Sea haddock, by Bagenal (1957) for long rough dab, by Botros (1962) for Baltic cod, by Pitt (1964) for American plaice of the Grand Bank and by May (1967) for cod off eastern Newfoundland, while values between 4 and 5 have been reported by Powles (1958) for Gulf of St. Lawrence cod and by Hodder (1963) for Grand Bank haddock. Fecundity has been extensively studied in herring of the Northeast Atlantic with exponent values generally ranging between 3.5 and 4.5 (Farron, 1938; Hickling, 1940; Baxter, 1959; and many others), and in herring of the Northeast Pacific by Katz (1947) who obtained a value of 4.7 and by Nagasaki (1958) who reported values generally between 3 and 4. Of the few fecundity studies previously reported for the herring stocks of the Northwest Atlantic, two authors applied the exponential relationship between fecundity and length: Barrett (MS, 1968) obtained an exponent of 2.36 for 51 specimens of spring spawners between 30 and 35 cm in total length from the southern Gulf of St. Lawrence, and Draganik and Rast (MS, 1970) obtained a value of 5.76 for Georges Bank autumn spawners in the length range of 26-35 cm. Perkins and Anthony (1969) give fecundity estimates for a total of 656 herring from Georges Bank, Gulf of Maine and Southwest Nova Scotia stocks, but they used the linear model without the logarithmic transformation. It appears, therefore, that for herring, as for other species of fish, fecundity varies with fish length at a rate greater than the cube of the length and that the exponent may vary between fairly wide limits for different stocks and areas.

Comparison of the correlation coefficients for the relationships of fecundity to length and to weight separately (Tables 3 and 5) indicates that fecundity is slightly better correlated with weight than with length. Similar observations were made by Hodder (1963) for Grand Bank haddock and by May (1967) for East Newfoundland cod, and Botros (1962) concluded that the fecundity-weight relationship provided the best description of the egg production of Northeast Atlantic cod. However, length measurements are usually more easily and more accurately obtained during field sampling than weights, and with the rather insignificant difference between the correlation coefficients of the fecundity-length and fecundity-weight relationships, the egg production of herring in the Newfoundland area may be considered to be adequately described by fecundity-length relationships of the form used in the present analysis.

Casual examination of the exponential relationships for the Newfoundland herring fecundity data does not reveal any obvious differences between the stocks; yet the fecundity estimates for autumn spawners of eastern Newfoundland are approximately 50% higher than the estimates for spring spawners (in the same length groups) of the three south coast areas. This confirms the generally accepted view that autumn spawners are more fecund than spring spawners; for example, Hickling (1940) and Baxter (1959) have shown that in fish of the same size there are significant differences in the egg production of winter and spring spawners on the one hand and summer and autumn spawners on the other, with the latter types being the more fecund. Also, Parrish and Saville (1965) observe that differences in fecundity between stocks seem to be governed by the level of first spawning rather than by differences in the rate of change in fecundity with length.

A comparison of available fecundity values by length for autumn and spring spawning stocks of herring in the Northwest Atlantic is provided in Table 8. Considered over the same length range (27-33 cm), the fecundity values for eastern Newfoundland autumn spawners agree reasonably well with those reported by Perkins and Anthony (1969) for autumn spawners of the Georges Bank, Gulf of Main, and Southwest Nova Scotia stocks. However, fecundity values reported by Draganik and Rast for Georges Bank herring, taken in 1968, are considerably less than values given for the same stock by Perkins and Anthony, based on samples collected in 1963 and 1964. The difference between the two sets of data for Georges Bank herring is greater than one would expect to attribute to sampling error or even to differences in counting techniques, but it could be due to increased growth rate or delayed maturation or a combination of both factors during the period between 1963 and 1968. If the two sets of data are really representative of the fecundity of the Georges Bank herring stock in the two different periods, the value of fecundity studies as a characteristic suitable for differentiating between stocks would have to be questioned, and even the importance of fecundity as a parameter in determining the relation between spawning potential and recruitment, as postulated by Draganik and Rast (MS, 1970), would be minimized, unless the fecundity of the stock is monitored regularly.

Herring, which inhabit the fjords of Southwest Newfoundland in winter (December-April), migrate there from the southern Gulf of St. Lawrence where they spend the rest of the year (Hodder, 1969, 1971; Hodder and Parsons, 1971; Winters, MS, 1971). Thus the fecundity estimates reported in this paper for spring spawners taken in the fjords of Southwest Newfoundland in winter should be comparable with data reported by Barrett (MS, 1968) for spring spawners taken in the southern Gulf of St. Lawrence in the spring of 1967. However, his fecundity values (49,600-61,400 eggs for herring in the length range of 30-34 cm) are not much more than one-half of the range of values presented in this paper (61,300-106,700 eggs) for the same groups. A plausible explanation for the difference is that Barrett's samples were taken near the end of the spawning period and that his specimens were partially spent when captured. Messieh and Tibbo (1971) reported that the peak period of spawning in the southern Gulf of St. Lawrence (Bay of Chaleur area) varied from 3 to 17 May for spring spawners in the years 1966 to 1969. In 1967

TABLE 8. Fecundity data by length for herring stocks of the Northwest Atlantic (derived from the curves reported by various authors).

Length group (cm)	Autumn spawners					Spring spawners			
	Georges Bank[a]	Georges Bank[b]	Gulf of Maine[b]	Southwest Nova Scotia[b]	East Nfld[c]	Gulf of St. Law.[d]	Southwest Nfld.[c]	Fortune Bay[c]	Placentia Bay[c]
25	–	28.0	17.5	28.0	–	–	–	22.0	–
26	24.7	41.0	33.0	39.5	–	–	–	27.0	–
27	30.7	54.5	48.5	51.5	59.1	–	38.5	32.3	43.7
28	37.9	67.5	63.5	63.5	68.9	–	45.2	38.8	50.5
29	46.6	80.5	79.0	75.5	80.1	–	52.8	46.4	58.0
30	56.3	93.5	94.5	87.5	91.7	49.6	61.3	55.0	66.4
31	62.1	106.5	110.0	99.5	105.1	52.3	70.9	64.9	75.5
32	81.6	120.0	125.0	111.5	120.1	55.2	81.6	76.2	85.7
33	97.6	133.0	141.0	123.0	136.4	58.5	93.5	89.1	96.8
34	115.9	–	–	–	154.6	61.4	106.7	103.6	108.1
35	137.0	–	–	–	174.5	–	121.3	120.0	122.2
36	–	–	–	–	196.3	–	137.1	138.4	136.6
37	–	–	–	–	220.1	–	155.2	159.0	152.4
38	–	–	–	–	246.1	–	–	182.0	169.4
39	–	–	–	–	274.4	–	–	207.7	187.8
40	–	–	–	–	305.1	–	–	236.1	207.7

[a] Draganik and Rast (MS, 1970). [b] Perkins and Anthony (1969). [c] Hodder (This paper). [d] Barrett (MS, 1968).

spawning was reported to be at its peak on 17 May, but Barrett's samples were taken during 30 May - 5 June.

Barrett (MS, 1968), in explaining the very low value of the exponent (2.36) in his fecundity-length data compared with values reported for European herring, suggested that his samples consisted of fish which were becoming senile and thus their reproductive capacity was declining rapidly. This view was expressed by Raitt (1933) who found that for haddock the increase in fecundity with age gradually declined and ceased when the age was reached at which all specimens of an age-class were spawners. Although the phenomenon of declining reproductive potential is not apparent in the Southwest Newfoundland data for herring up to 37 cm in length (Fig. 1), some evidence of it is indicated for the larger fish (> 36 cm) in the other three areas.

In the interpretation of differences in fecundity between spawners of different stocks, both genetic and environmental factors have variously been emphasized, and a review of the problem is given by Parrish and Saville (1965). Parsons and Hodder (1971), in their analysis of meristic differences between spring- and autumn-type spawning herring which intermix during the over-wintering period in the fjords of Southwest Newfoundland, attribute the observed differences in fin-ray and gillraker numbers to differences in developmental rates of spring- and autumn-hatched larvae due to increasing and decreasing water temperatures respectively. In the Newfoundland area spawning generally occurs in May for spring-spawners and in late August-September for autumn spawners. By December, when the herring have migrated into the fjords, the ovaries of spring spawners have developed to maturity stage 4 while those of autumn spawners are in stage 8 condition. Further gonadal development is retarded (Table 7) due to the scarcity of food and the low water temperatures (< 1° C) which prevail during January to early April. During the winter, as revealed by the examination of thousands of stomachs over several years of sampling, herring feed very little if at all, and this is verified by a substantial decrease in their fat content between December and April (Hodder and Parsons, unpublished manuscript). Hodder and Parsons (MS, 1972) even report a small decrease in weight from January to April. Although there is little or no evidence to indicate that follicular atresia plays a very significant role in the fecundity of marine fishes, it is possible that severe food restriction during the winter months immediately preceding spring spawning may induce reabsorption of eggs. Vladykov (1956) for wild speckled trout, *Salvelinus fontinalis*, in Quebec lakes reported that an abundant food supply during several months preceding spawning resulted in higher fecundity at spawning time, while Scott (1962), who carried out experimental diet restriction on rainbow trout, *Salmo gairdneri*, found that starvation preceding spawning increased the rate of atresia. If these observations are considered relevant to herring, the very significant difference in fecundity between spring and autumn spawners (Fig. 2) could be attributed largely to the very different environmental conditions existing in the months preceding the spawning periods.

Acknowledgements

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References

BAGENAL, T. B. 1957. The breeding and fecundity of the long rough dab (*Hippoglossoides platessoides* Fabr.) and the associated cycle in condition. *J. mar. biol. Ass.* U.K., **36**: 339-375.

BARRETT, B. E. MS, 1968. The fecundity of Canadian Atlantic herring. *Annu. Meet. int. Comm. Northw. Atlant. Fish., 1968*, Res. Doc. No. 62, Serial No. 2046 (mimeographed).

BAXTER, I. G. 1959. Fecundities of winter-spring and summer-autumn herring spawners. *J. Cons.*, **25**: 73-80.

BOTROS, G. A. 1962. Die fruchtbarkeit des dorsches (*Gadus morhua* L.) in der westlichen Ostsee und Westnorwegischen Gewässern. *Kiel. Meeresforch.*, **18**: 67-80.

BOYAR, H. C., and R. A. CLIFFORD. 1967. An automatic devise for counting dry fish eggs. *Trans. Amer. Fish. Soc.*, **96**: 361-363.

DRAGANIK, B., and B. RAST. MS, 1970. The fecundity of Georges Bank herring. *Annu. Meet. int. Comm. Northw. Atlant. Fish. 1970*, Res. Doc. No. 63, Serial No. 2404, (mimeographed).

FARRON, G. P. 1938. On the size and number of ova of Irish herrings. *J. Cons.*, **13**: 91-100.

HICKLING, C. F. 1940. The fecundity of the herring of the southern North Sea. *J. mar. biol. Assoc. U.K.*, **24**: 619-632.

HODDER, V. M. 1963. Fecundity of Grand Bank haddock. *J. Fish. Res. Bd. Canada*, **20**: 1465-1487.

1969. Herring landings and distribution of catches in Newfoundland, 1967-68. *Fish. of Canada*, **22**(4): 3-6.

1971. Status of the southwest Newfoundland herring stocks, 1965-70. *Int. Comm. Northw. Atlant. Fish., Redbook 1971*, Part III: 105-114.

HODDER, V. M., and L. S. PARSONS. 1971. Comparison of certain biological characteristics of herring from Magdalen Islands and southwest Newfoundland. *Res. Bull. int. Comm. Northw. Atlant. Fish.*, No. 8, p. 59-65.

HODDER, V. M., and L. S. PARSONS. MS, 1972. Length, age and weight of herring in the Southwest Newfoundland winter fishery from 1965-66 to 1970-71. *Fish. Res. Bd. Canada, Tech. Rep.* (In press).

ICNAF. 1964. Report of Standing Committee on Research and Statistics. App. I. Report of ad hoc group on herring and other pelagic fish. *Int. Comm. Northw. Atlant. Fish., Redbook 1964,* Part I: 23-30.

KATZ, M. 1947. The fecundity of herring from various parts of the North Pacific. *Trans. Amer. Fish. Soc.,* **75**: 72-76.

MAY, A. W. 1967. Fecundity of Atlantic cod. *J. Fish. Res. Bd. Canada,* **24**: 1531-1551.

MESSIEH, S. N., and S. N. TIBBO. 1971. Discreteness of Atlantic herring (*Clupea harengus harengus*) populations in spring and autumn fisheries in the southern Gulf of St. Lawrence. *J. Fish. Res. Bd. Canada,* **28**: 1009-1014.

NAGASAKI, F. 1958. The fecundity of Pacific herring (*Clupea pallasi*) in British Columbia coastal waters. *J. Fish. Res. Bd. Canada,* **15**: 313-330.

PARRISH, B. B., and A. SAVILLE. 1965. The biology of the Northeast Atlantic herring populations. *Oceanogr. Mar. Biol. Ann. Rev.,* **3**: 323-373.

PARSONS, L. S., and V. M. HODDER. 1971. Meristic differences between spring- and autumn-spawning Atlantic herring (*Clupea harengus harengus*) from southwest Newfoundland. *J. Fish. Res. Bd. Canada,* **28**: 553-558.

PERKINS, F. E., and V. C. ANTHONY. 1969. A note on the fecundity of herring (*Clupea harengus harengus* L) from Georges Bank, the Gulf of Maine and Nova Scotia. *Int. Comm. Northw. Atlant. Fish., Redbook 1969,* Part III: 33-38.

PITT, T. K. 1964. Fecundity of American plaice, (*Hippoglossoides platessoides* Fabr.), from Grand Bank and Newfoundland areas. *J. Fish. Res. Bd. Canada,* **21**: 597-612.

POWLES, P. M. 1958. Studies on reproduction and feeding of Atlantic cod (*Gadus callarias* L.) in the southwestern Gulf of St. Lawrence. *J. Fish. Res. Bd. Canada,* **15**: 1383-1402.

RAITT, D. S. 1933. The fecundity of the haddock. *Fish. Bd. Scotland Sci. Invest. 1932.* No. 1, p. 1-42.

SCOTT, D. P. 1962. Effect of food quantity on fecundity of rainbow trout (*Salmo gairdneri*). *J. Fish. Res. Bd. Canada,* **19**: 715-731.

SIMPSON, A. C. 1951. The fecundity of the plaice. *Fish. Invest. Lond.* (2), **17**(5): 1-27.

SNEDECOR, G. W. 1956. Statistical methods (fifth edition). Iowa State College Press, 534 pp.

VLADYKOV, V. D. 1956. Fecundity of wild speckled trout (*Salvelinus fontinalis*) in Quebec lakes. *J. Fish. Res. Bd. Canada,* **13**: 799-841.

WIBORG, K. F. 1951. The whirling vessel. *Fiskeridir. Skr. Havundersøk.,* **9**(13): 1-16.

WINTERS, G. H. MS, 1971. Migrations of the southwest Newfoundland stock of herring as indicated by tag recaptures. *Annu. Meet. int. Comm. Northw. Atlant. Fish. 1971,* Res. Doc. No. 108, Serial No. 2591 (mimeographed).

YUDANOV, I. G. 1966. Fecundity and efficiency of spawning of Atlantic herring in the Gulf of Maine. *Trudy PINRO* **17**: 249-262.

Growth and Mortality of Atlantic Argentine, *Argentina silus* Ascanius, on the Nova Scotia Banks

By C. Zukowski[1]

Abstract

Studies on the age, length, rate of growth, and mortality of argentine, *Argentina silus* Ascanius, were carried out between 1964 and 1968 on the Nova Scotia Banks. Results show that argentine can attain great ages. Growth in length is rapid up to first sexual maturity at 7-8 years of age. Total mortality rate is low. However, it may easily be affected by an increase of fishing effort and therefore subject to overfishing.

Introduction

Among the publications on Atlantic argentine, *Argentina silus* Ascanius, the most noteworthy are those by Borodulina (1964), Emery and McCracken (1966), Keysler (1968), and Wood and Raitt (1968). All of these papers deal intensively with the biology and distribution of this species.

The present paper contributes more information on the biology of argentine and furnishes further data for estimation of the abundance of the stocks. Since there was only limited exploitation of this species between 1964 and 1968, fundamental parameters of its rate of growth and total morality can be established.

Materials and Methods

Materials were collected from otter trawl catches made on Sable Island Bank, Emerald Bank, Sambro Bank, and Browns Bank from 1964 to 1968. A total of 10,651 fish were measured. Detailed analysis was performed on 1,915 individuals of which 1,760 were examined for age. Back calculations for the rate of growth were made from the otoliths from 479 individuals.

Measurements included body length to the nearest centimeter. Ages were estimated using reflected light from the concave surface of unpolished otoliths immersed in 1:1 mixture of ethyl alcohol (96%) and glycerin. Back calculations for rate of growth were based on otolith readings. This served as a basis for calculation of theorectical growth by means of the von Bertalanffy equation.

Mortality coefficient, corresponding to the slope of the straight line, has been calculated by the method of least squares. Samples were taken from catches made with trawls which were adapted to eliminate, as far as possible, the effect of selectivity.

Extensive sampling of the fishery in 1964-68 was carried out at the same depth range which should take care of the possibility of the fish size increasing with depth as recorded by Chrzan and Zukowski, 1965 and Emery and McCracken, 1966.

Results

Age

The results of investigations on age in the years 1964-68 are given in Fig. 1.

In 1964 the most abundant fish were 4 and 5 years old, born in 1960 and 1959 respectively. Their total number in the catches exceeded 45%. The proportion of 3-year-old fish and 6- to 11-year-olds amounted in total to about 50%. Only a small number of individuals were older.

In 1965 the 4-, 5- and 6-year-olds were dominant. Hence it may be concluded that the 1959 and 1960 year-classes were abundant. The proportion of fish older than 8 years was comparatively small.

In 1966, the 1959 and 1960 year-classes, as 6- and 7-year-old fish, were still dominant. However, fish of ages 4 to 13 years were abundant in the sampled catches.

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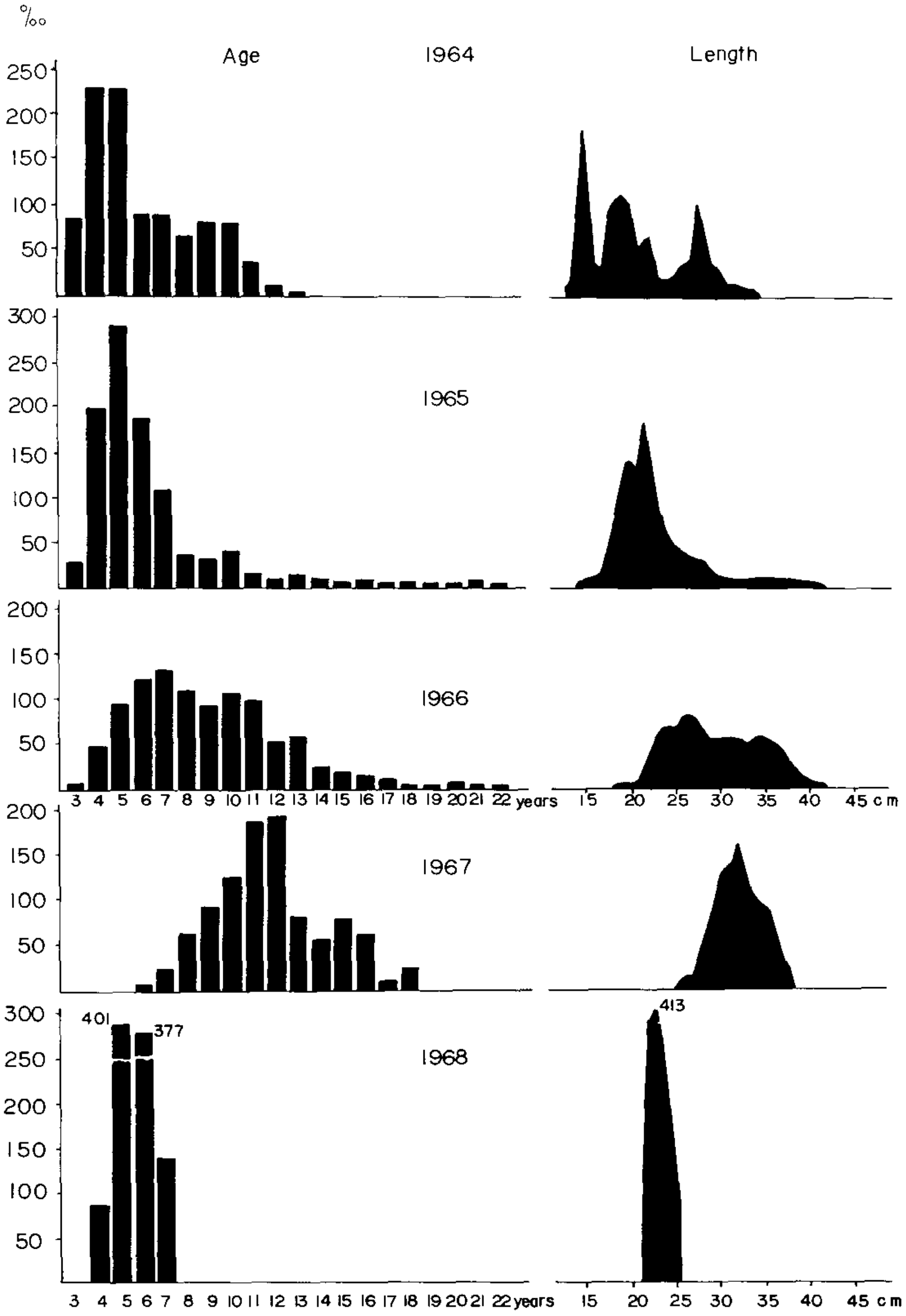

Fig. 1. Age and length of argentine in the catches made on the Nova Scotia Banks from 1964 to 1968.

In 1967, older fish, of the 1956 and 1955 year-classes, of 11 and 12 years of age were predominant. The proportions of 8 to 10 and 13 to 16 year old fish were also high.

In 1968 the samples were made up of much younger fish, 4 to 7 years of age, than in previous years. These were presumably concentrations of juvenile fish which do not occur with the adult fish and are found in different localities.

Length

The results of length measurements for the years 1964-1968 are given in Fig. 1.

A number of distinctly marked peaks may be noted in 1964. They were the 15-, 19- and 28-cm length-classes. It may be assumed that the presence of three predominant length-classes was connected with the occurrence of a number of strong year-classes.

In 1965 fish from 19 to 23 cm in length were most abundant. The modal length-class was 22 cm. Fish ranged in length from 14 to 42 cm. Similarly, some increase of mean length was noted from the preceding year (Table 1).

TABLE 1. Mean length of argentine off Nova Scotia, 1964-68.

	♂		♀		♂+♀	
Year	n	cm	n	cm	n	cm
1964	99	23.8	112	22.4	211	23.0
1965	257	23.3	243	25.5	500	24.3
1966	455	28.3	440	31.0	895	29.6
1967	173	30.5	78	32.0	251	30.9
1968	30	22.6	30	23.0	60	22.8

In 1966 the abundance of particular length-classes was not appreciably different. However, a slight predominance of fish in the length-class 26-27 cm was noted.

In 1967 the majority of fish ranged in length from 30 to 35 cm with a peak at 32 cm.

In 1968 the length of fish was confined to the 21-25 cm range with a distinct predominance of the 23-cm length-class.

From 1965 there is a tendency for the annual modal length to shift towards the right-hand side of the graph, i.e., towards the range of larger fish. This tendency persists to 1967.

The decrease in length in 1968 is based on comparatively little material, collected only in the first quarter of the year.

Rate of growth

Borodulina (1964), Emery and McCracken (1966), and others determined the rate of growth of argentine on the basis of mean lengths of fish in particular age-groups.

In the present paper in order to obtain more representative data, particularly for the youngest and oldest age-groups, it was decided to determine the rate of growth also by the method of back calculation using otoliths. To adopt this method the relationship between rate of growth of fish and length increase of its otolith was determined. In the literature this problem is dealt with by Ketchen (1964), Jensen (1938), Trout (1954), and Cieglewicz, *et al.* (1969). Depending on the fish species and the section plane of the otolith, the ratio of fish length to otolith radius may be depicted either by a curve or by a straight line. Since this problem has not been considered previously for argentine, the above ratio was examined in detail before back calculation was attempted.

Measurements of the otolith radius along the axis connecting the nucleus with the edge of rostrum and the nucleus with the edge of antirostrum showed that the former axis is more suitable for back calculation of growth rate for the following reasons:

1) For the same length of fish any error in the measurement of the shorter radius affects the final result to a greater extent;
2) The zones (rings) of annual length increment on the rostrum show more contrast and therefore can be measured with more accuracy;
3) The distribution of the points in the graph, showing the relation between the rostrum radius and the fish body length is rectilinear (Fig. 2).

On the basis of empirical data the following linear equation was derived:

$$R = 0.168L + 0.14$$

where

R = the length of otolith radius in mm,
L = the length of fish body in cm.

This equation shows that the application of the Lea formula (Walus-Karpinska, 1961) gives the results of back calculation with a slight error only. An ideal equation for the above relation should have the parameters: $b = 0$, $y = ax$. The value of $b = 0.14$ in the

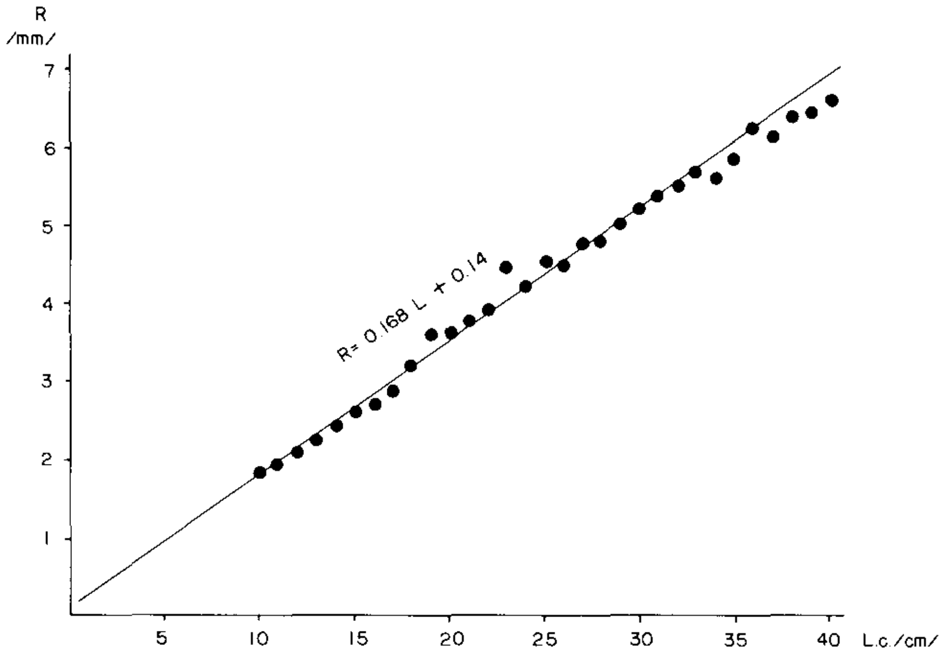

Fig. 2. Relationship between the length body (L.c.) of argentine and the longer radius of its otolith (R).

above equation might be due either to inadequate data or to slight disproportion between the growth of otolith and the length increase of fish body. For practical purposes, it was assumed that both these characteristics are directly proportional.

The growth of argentine was finally characterized on the basis of back calculations by means of the von Bertalanffy equation:

$L_t = L_\infty (1 - e^{-K(t - t_o)})$ (Beverton and Holt, 1957)

Where

L_t = length of fish in cm at age t,

L_∞ = asymptotic length of the fish,

e = the base of natural logarithm,

t_o = arbitrary origin of growth curve,

K = the rate at which length reaches the asymptote.

Methods of calculating the above parameters have been described in detail in papers by Allen (1966), Cieglewicz, *et al.* (1969), and Ketchen (1964-66). For this reason, only their values are given in Table 2 and graphic presentation of the rate of growth plotted on the basis of above equation.

TABLE 2. The parameters for the von Bertalanffy equation.

	L_∞		K		t_o	
Region	♂	♀	♂	♀	♂	♀
Nova Scotia	37.9	41.4	0.145	0.129	–0.75	–0.75

Since the empirical data and the data calculated on the basis of parameters (L_∞, K, t_o) agree closely, adoption of the von Bertalanffy equation for the determination of the characteristics of the rate of growth of argentine seems justified (Fig. 3).

The data show that, in the region off Nova Scotia, argentine from 1 to 8 years of age increase in length from 4.0 to 1.8 cm annually. Over 8 years of age the increase drops markedly to within a range of 1.5 to 0.5 cm annually (Fig. 3).

Figure 4 shows that male and female argentine increase in length at about the same rate up to 8 years of age. From this age onward the length increase is greater in females than in males.

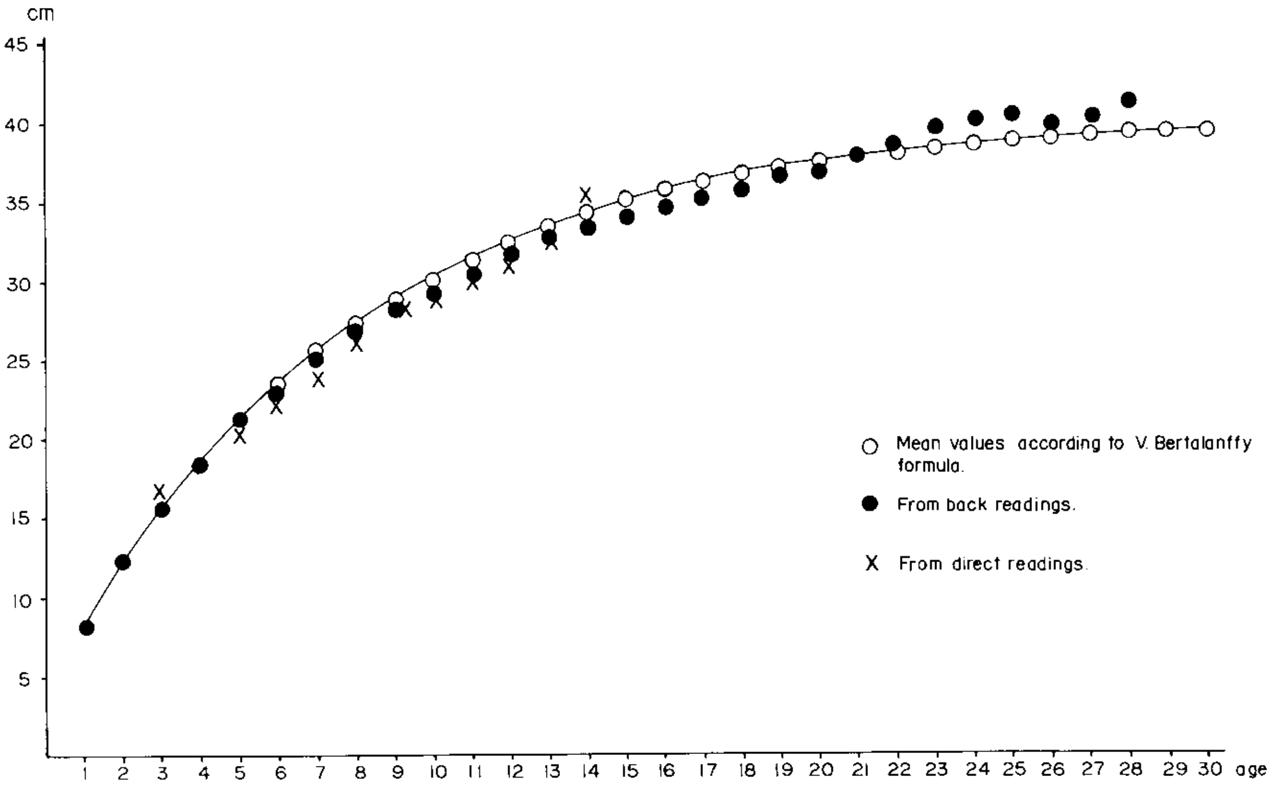

Fig. 3. Curve of growth for argentine, plotted according to von Bertalanffy formula.

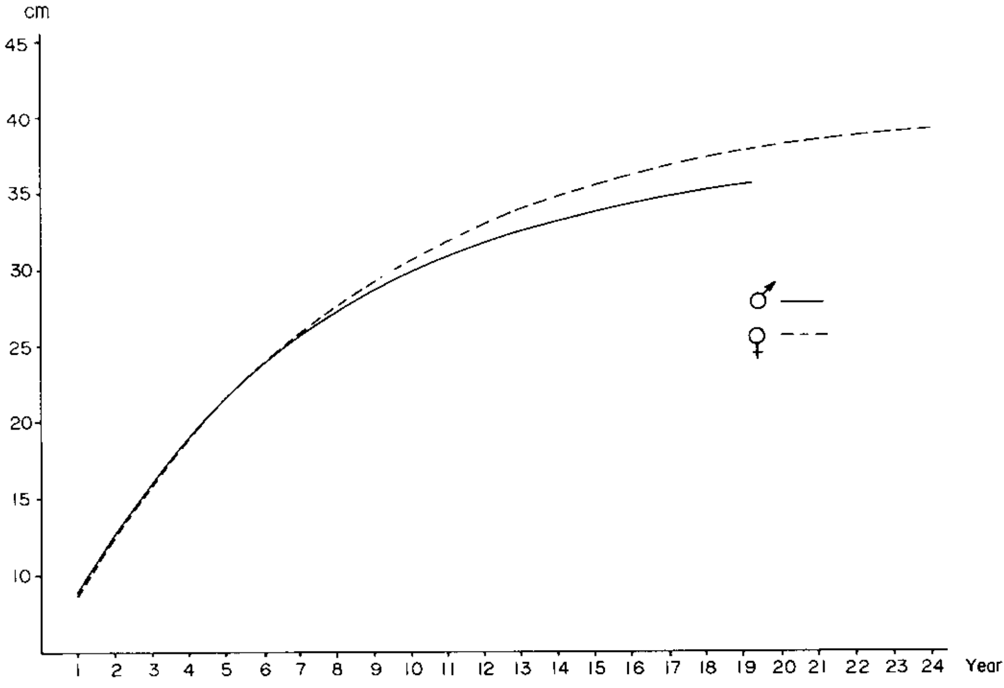

Fig. 4. Curves of growth for males and females of argentine plotted according to the von Bertalanffy formula.

Mortality

Age composition data were used to determine the coefficient of total mortality (Z). This coefficient may be calculated by means of the equation:

where

N_o = abundance of fish at time t_o,

N_t = abundance of fish at time t_1.

However, the application of this formula requires further data on the catch per unit of effort in numbers of age-groups in consecutive years. Hence, in addition to the age composition of the catches it is necessary to have detailed statistical data on the catches. Since such statistics are not available, determination of the index of total mortality was based on age composition.

If we assume the mortality of fish of different ages to be similar, then the index, according to Ricker (1958), may be calculated from the catch curve.

When the proportion of particular age-groups is expressed in logarithms ($\log_e$), the right-hand section of the curve obtained becomes approximately linear. Assuming that the abundance of the stock in the region of Browns Bank has not been subject to any considerable fluctuations in recent years, the slope of this straight line may be interpreted as the coefficient of total mortality.

In order to apply this method, data have been compiled on mean age composition, from which it appears that starting with the fifth year of life the rate of mortality is greater than the rate of recruitment. This mean age composition was expressed in logarithms ($\log_e$). The right-hand slope of the curve is presented as a straight line by means of the method of least squares.

The curve for the age composition of the catches, plotted from 1964 to 1967 data may not be sufficiently representative. It presents, however, a preliminary estimation of the mortality for that period when the intensity of fishing is still very low. In such a case the calculated total mortality might have a value similar to that for natural mortality.

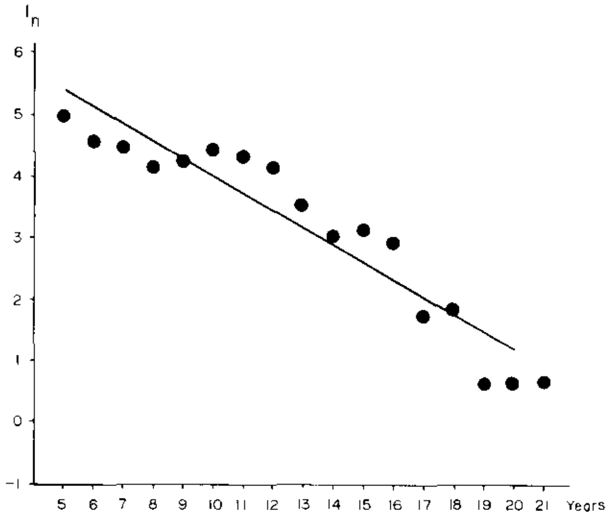

Fig. 5. Mortality of argentine expressed in l_n plotted against age.

The slope of the straight line for 5- to 20-year-old fish calculated by means of least squares is 0.28 (Fig. 5). This parameter is also the coefficient of total mortality (Z) for a period of one year and points to the reduction of the populations by 24% per annum.

From this value, we may conclude that the stock of argentine has at present a low total mortality rate.

Summary

Investigations of argentine on the Nova Scotia Banks from 1964 to 1968 showed that the 1959 and 1960 year-classes were the most abundant. The age of fish in the catches ranged from 3 to 29 years, their lengths from 13 to 42 cm. Larger fish, up to 52 cm in length, occurred sporadically.

Growth rate was relatively rapid up to 7-8 years of age. In general, females grew faster than males. This difference increased with age.

Natural mortality was found to be low and the coefficient of total mortality – 0.28. Thus an increase in fishing effort may affect the state of the stock and excessive fishing intensity may lead to rapid decrease in the stock size. In view, however, of the present low exploitation of argentine some expansion of the fisheries for this species is undoubtedly possible.

References

ALLEN, K. RADWAY. 1966. A method of fitting growth curves of the von Bertalanffy type to observed data. *J. Fish. Res. Bd. Can.*, 23(2).

BEVERTON, R. J. H., and S. J. HOLT. 1957. On the dynamics of exploited fish populations. *Fish. Invest., Lond. (2).*

BORODULINA, C. D. 1964. Some data on the biology of the argentine, *Argentina silus* Ascanius. *Vop. Ikhtiol.* 4(1): 68-81. (Translation prepared by C. A. McLean, Fisheries Laboratory, Lowestoft, Suffolk)

CIEGLEWICZ, W., B. DRAGANIK, and Cz. ZUKOWSKI. 1969. Charakterystyka wzrostu storni, *Platichthys flesus* L., i skarpia, *Scophthalmus maximus* L. za pomoca rownania v. Bertalanffy ego. *Prace MIR*, Tom 15, Seria A, Wyd. Mors. Gdansk.

CHRZAN, F., Cz. ZUKOWSKI. 1966. Some characteristics of Argentine, *Argentina silus* Ascanius, occuring in the region off Nova Scotia. *Res. Bull. int. Comm. Northw. Atlant. Fish.*, No. 3, p. 81-85.

EMERY, A. R., and F. D. McCRACKEN. 1966. Biology of the Atlantic argentine, *Argentina silus* Ascanius, on the Scotian Shelf. *J. Fish. Res. Bd. Can.*, 23(8).

JENSEN, A. I. C. 1938. Factors determining the apparent and the real growth. *Rapp. Cons. Explor. Mer*, 108.

KARPINSKA-WALUS, B. 1961. Wzrost ploci, *Rutilus rutilus* B., w jeziorach okolic Wegorzewa. *Roczn. Nauk rol. (B)*, Zeszyt Zootechn. No. 2, PWR i L.

KETCHEN, K. S. 1964. Preliminary results of studies on growth and mortality of Pacific cod, *Gadus macrocephalus*, in Hecate Strait, British Columbia. *J. Fish. Res. Bd. Can.*, 18(4): 513-558.

KETCHEN, K. S., and C. R. FORRESTER. 1966. Population dynamics of the Petrale sole, *Eopsetta jordani*, in waters of western Canada. *Bull. Fish. Res. Bd. Can.*, No. 153.

KEYSLER, H. D. 1968. Investigations on the stocks of *Argentina silus* in the waters off Norway, Iceland and Newfoundland. *Rapp. Cons. Explor. Mer*, **158.**

RICKER, W. E. 1958. Handbook of computations for biologic statistics of fish populations. *Bull. Fish. Res. Bd. Can.*, No. 119.

TROUT, G. C. 1954. Otolith growth of the Barents Sea cod. *Rapp. Cons. Explor. Mer*, **136**: 89-102.

WOOD, R. I., and D. F. S. RAITT. 1968. Some observations on the biology of the greater silver smelt, particularly in the northeastern Atlantic Ocean. *Rapp. Cons. Explor. Mer*, **158.**

A Yield Assessment of the Eastern Scotian Shelf Cod Stock Complex

By R. G. Halliday[1]

Abstract

Landings of cod from ICNAF Subdivision 4Vs and Division 4W fluctuated between 50,000 and 80,000 metric tons, averaging 62,205 tons, in 1960-71. Canada and Spain were the main exploiters, and over 90% of catches were by otter and pair trawls. Removals from the stock were predominantly fish 40-70 cm long and 4-6 years of age. Numbers removed annually varied between 23 and 42 million fish. Recruitment to the fishery occurred between 3 and 6 years of age, the 50% recruitment age being 4.2 years. Fishing mortality was fairly constant in 1960-69, averaging $F = 0.49$ on fully recruited age-groups (when natural mortality is assumed to be $M = 0.20$). This is close to that giving maximum yield-per-recruit. An increase in long-term yield-per-recruit is predicted to result from increase in the age at recruitment, and substantial economic benefits are predicted from a reduction in fishing mortality. Analysis of likely biases in the data implies that the estimates of benefits are conservative.

Introduction

The cod fishery on the eastern Scotian Shelf (ICNAF Subdivision 4Vs and Division 4W) is based on a complex of cod stocks (Templeman, 1962; Martin and Jean, 1964). However, considerable mixing takes place among adults of these stocks and possibly also among the pelagic egg and larval stages. Thus, in the present state of knowledge, it is practical to consider this complex as a unit for assessment purposes.

The only previous assessments of this stock were made in connection with studies on the effects of changes in trawl mesh size reported on by Beverton and Hodder (eds., 1962). In the 1947-58 period when landings averaged 38,000 metric tons, instantaneous total mortality, Z, was 0.50 on fully recruited age-groups.

This paper describes size and age composition of landings, stock abundance, and mortality in the 1960-71 period, and the relationship of yield-per-recruit to mortality rate and age at first capture.

Landings

Landings fluctuated between approximately 50,000 and 80,000 metric tons in the 1960-71 period, averaging 62,205 metric tons (Table 1). Almost equal quantities were taken from Subdivision 4Vs and Division 4W. Spain was the principal exploiter of the stock, taking 63% of the catch in the 12-year period. Canada was the only other country taking substantial quantities from the Stock (28% of the catch). Canada has taken 75% of her catch from Div. 4W, whereas Spain has taken 60% of her catch from Subdivision 4Vs.

On average, 70% of Canadian landings were caught by otter trawlers. The remaining 30%, amounting to 4,000-7,000 metric tons annually, was taken predominantly inshore. Up to 1,000 tons were taken annually by gillnets, seines, and traps, and the remainder by handline and longline gear. All non-Canadian landings were taken by otter trawlers or pair trawlers, except for small catches by Portugese dory vessels in 1960-62.

Size and Age Composition of Catches and Landings and Numbers Removed from the Stock

Biological sampling of this fishery has been extremely poor (Table 2) and well below minimum ICNAF requirements as set out in the Assessments Subcommittee report for 1970. This analysis is based predominantly on samples of Canadian landings which represent only 28% of total landings, but includes the few Spanish and French samples available from ICNAF Sampling Yearbooks. French length-frequency samples represent total lengths measured to the centimetre below, whereas Canadian and Spanish sampling conforms to the ICNAF convention of measuring fork length to the nearest

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TABLE 1. Subdivision 4Vs and Div. 4W cod: Nominal catches. (From ICNAF Statistical Bulletins for 1960-70.)

Year	Canada	France	Portugal	Spain	USSR	Others	Total	Subdivision 4Vs	Div. 4W
1960	18,390	1,018	1,720[a]	29,391	–	126	50,645	27,689	22,956
1961	19,697	3,252	2,321[a]	40,884	113	42	66,309	34,237	32,072
1962	17,579	2,645	341[a]	42,146	2,383[a]	60	65,154	26,350	38,804
1963	13,144	72	617	44,528	9,505	307	68,173	27,566	40,607
1964	14,330	1,010	–	39,690	7,133	1,094	63,257	25,496	37,761
1965	23,104	536	88	39,280	7,856	124	70,988	36,713	34,275
1966	17,690	1,494	–	43,157	5,473	356	68,170	27,163	41,007
1967	18,464	77	102	33,934	1,068	512	54,157	26,607	27,550
1968	24,888	225	–	50,418	4,865	29	80,425	48,781	31,644
1969	14,188	217	–	32,305	2,783	664	50,157	22,309	27,848
1970	11,818	420	296	41,926	2,521	446	57,427	28,632	28,795
1971[b]	17,064	. . .	. . .	30,864	. . .	(3,672)	51,600	. . .	. . .

[a] Landings reported as Div. 4V assigned as in ICNAF Res. Doc. 72/57.

[b] Spanish and Canadian landings as reported to ICNAF Secretariat, landings of other countries estimated from 1969-70 landings.

TABLE 2. Subdivision 4Vs and Div. 4W cod: Commercial samples (trawl gear only).

		Div. 4W			Subdivision 4Vs		
Year	Country	No. of samples	No. of lengths	No. of ages	No. of samples	No. of lengths	No. of ages
1960	Canada	5	2,365	493	2[a]	550	110
	Spain	1	258	–	–	–	–
1961	Canada	7	2,326	398	–	–	–
	France (M)	–	–	–	16	606	–
	Spain	–	–	–	3	878	–
1962	Canada	4	916	223	1	395	70
	Spain	17	2,320	–	3	398	–
1963	Canada	4	1,098	341	1	375	47
1964	Canada	2	298	213	1	330	59
	Spain	–	–	–	3	654	–
1965	Canada	8	3,101	631	3	1,092	123
1966	Canada	6	2,245	304	2	590	121
1967	Canada	3	857	197	6[b]	1,841	188
1968	Canada	8	2,717	354	5[c]	1,443	184
1969	Canada	3	960	130	–	–	–
	France (S.P.)	–	–	–	3	4,264	–
1970	Canada	5	1,626	212	3	928	139
1971	Canada	2	711	92	10	3,178	467

[a] Includes one sample from 4Vs-W combined. [b] Includes two samples from 4Vs-W combined. [c] Includes one sample from 4Vs-W combined.

centimetre. In cod, fork and total length are virtually equivalent so French sampling technique results in a length frequency displaced 0.5 cm toward zero in comparison with that of Canada and Spain. This cannot be readily corrected for with data summarized in 3 cm groups, and the French samples are used without adjustment in the belief that the increased information they provide outweighs the slight error introduced.

Canadian and French samples in 1969 are of landings after discard. French samples in 1961 and almost all Spanish samples are of catches, presumably before discard. However, Spanish discards have been negligible (ICNAF, MS, 1966-67; 1968-71) and catches and landings are virtually synonymous. There are no accurate data on Canadian discards. Substantial biases in collection methods make Canadian discard submissions to ICNAF unreliable. However, it is known that discards of cod by Canadian vessels in the 4Vs-W area have been very low. It is assumed therefore that discards by Canada and Spain have been zero between 1960-71 in this fishery, and that available samples are representative of both landings and removals from the stock.

As there is inadequate material to treat the two areas (4Vs and 4W), different countries, or different seasons separately, annual landings are weighted by all otter and pair trawl samples available for that year. The fishery by other gears, due to its insignificance and the virtual absence of samples from it, is ignored. The major assumption here is that samples from Canadian landings are also representative of Spanish catches. Only for 1962 is it possible to make a comparison of the age and length composition of Spanish catches and Canadian landings (Fig. 1). In that year Spanish catches contained a substantially higher proportion of smaller, younger fish. This may indicate that Canadian discards were not negligible as assumed, or it may be a result of poor sampling. Alternatively, it may reflect a real difference in size and age composition of removals. It is impossible, with the information currently available, to distinguish among these possibilities. It is almost certain, however, that whatever biases are in the data tend to underestimate the quantities of small fish removed from the stock.

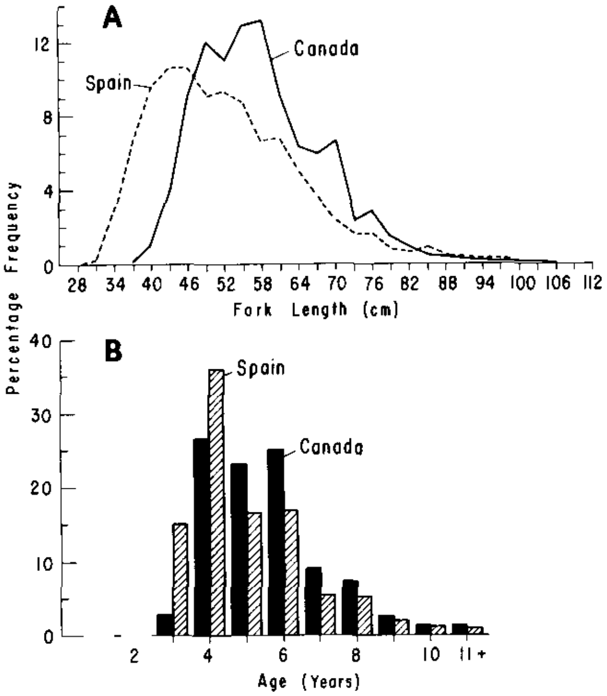

Fig. 1. Subdivision 4Vs and Div. 4W cod: Spanish catches and Canadian landings in 1962, A – size composition, B – age composition.

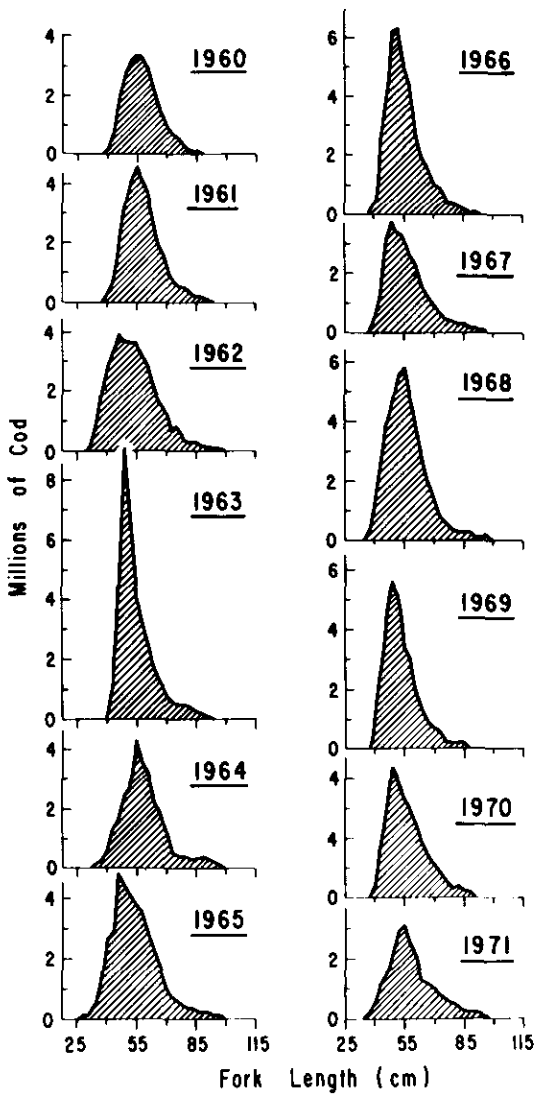

Fig. 2. Subdivision 4Vs and Div. 4W cod: length composition of removals, 1960-71.

The available sampling data indicate that most removals from the stock were of fish 40-70 cm long (Fig. 2), mean lengths of annual removals varying between 54 cm and 59 cm (Table 3). Ages 4, 5, and 6 predominated numerically (Fig. 3), average age varying between 5.2 years and 6.1 years. Mean weight of fish varied from 1.6 to 2.2 kg. Estimated numbers removed from the stock varied between 23 and 42 million without major trend (Table 4), averaging 32.3 million.

TABLE 3. Subdivision 4Vs and Div. 4W cod: Annual mean length, weight and age of removals from the stock.

Year	Mean length (cm)	Mean weight (kg)	Mean age (yrs)
1960	58.1	2.04	5.83
1961	59.0	2.17	5.87
1962	53.8	1.73	5.30
1963	55.4	1.78	5.49
1964	59.2	2.24	5.99
1965	54.5	1.79	5.42
1966	55.3	1.75	5.19
1967	57.1	2.00	5.58
1968	56.6	1.93	5.37
1969	53.9	1.62	5.15
1970	57.0	1.97	5.63
1971	58.9	2.22	6.12

Abundance

Catch-per-unit-effort

Two data series on catch-per-unit-effort (cpe) are available as indicators of abundance changes of the stock; that of Spanish pair trawlers of 151-500 gross tons and that of Canadian side otter trawlers of 151-500 gross tons.

The cpe of Spanish pair trawlers in Subdivision 4Vs has been similar to that in Div. 4W (Fig. 4) with apparent abundance being slightly higher in Subdivision 4Vs in the 1962-67 period. Canadian cpe in the two areas is also similar from 1961 onwards with indications that abundance was slightly higher in 4Vs that in 4W in the 1963-65 period. Therefore, for each country the cpe was averaged for the two areas in each year to give abundance indices for the entire stock.

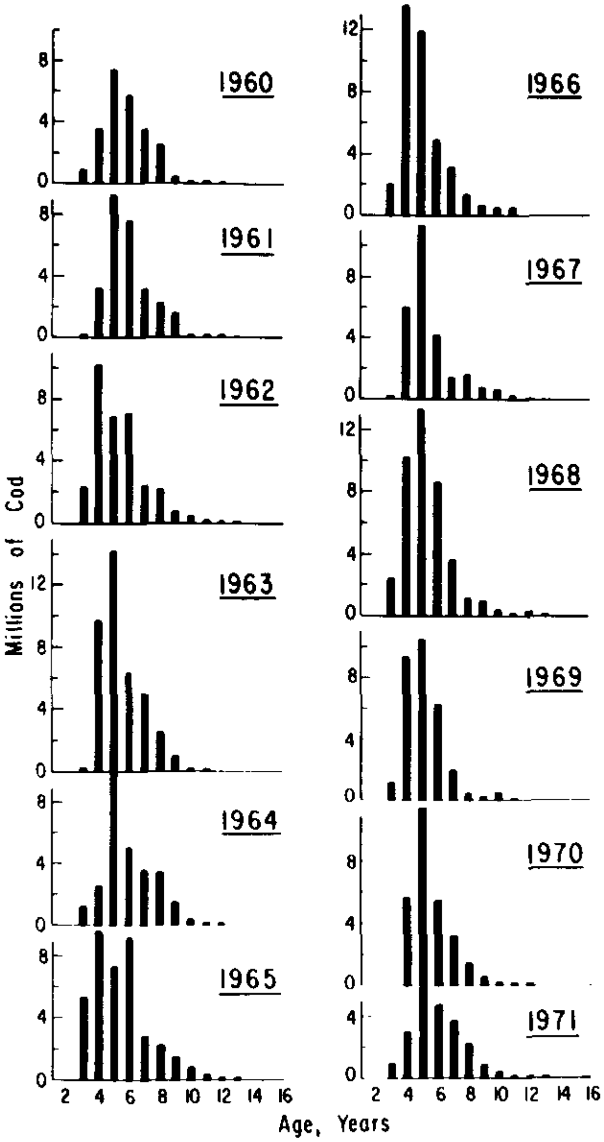

Fig. 3. Subdivision 4Vs and Div. 4W cod: age composition of removals, 1960-71.

Canadian and Spanish cpe for 4Vs-W have little in common (Fig. 5). Canadian data indicate that population abundance, which was fairly stable in the 1960-67 period, was considerably lower in 1968-71. Spanish data indicate a gradual increase in abundance from 1958-67, a sharp increase in 1968, and moderate declines in 1969-70.

The Canadian fishery in 4Vs-W has been a mixed one with haddock a prime species and flounders also of importance. Canadian cpe data may therefore be a poor reflection of cod abundance due to interactions between the cod and other fisheries. The Spanish fishery, which had cod as its prime species, is likely to give the more accurate indication of cod abundance.

TABLE 4. Subdivision 4Vs and Div. 4W cod: Numbers removed from stock at age ($\times 10^{-3}$).

	Year											
Age	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971
2	–	–	–	–	136	35	–	–	79	–	–	117
3	889	242	2,339	337	1,337	5,435	1,972	285	2,379	1,277	81	1,080
4	3,569	5,260	12,072	9,681	2,598	9,573	13,496	6,020	10,300	9,426	5,699	2,975
5	7,364	9,345	6,922	13,246	9,788	7,261	12,027	11,409	13,379	10,508	11,631	5,960
6	5,737	7,507	7,152	6,372	5,088	9,176	4,915	4,254	8,637	6,198	5,572	4,831
7	3,623	3,174	2,458	5,134	3,603	2,960	3,225	1,389	3,624	2,066	3,341	3,776
8	2,633	2,340	2,188	2,602	3,401	2,199	1,401	1,624	1,098	513	1,517	2,317
9	454	1,659	841	505	1,475	1,532	748	802	990	278	578	931
10	166	185	494	207	426	819	508	709	437	537	210	408
11	202	190	216	155	206	289	519	356	251	101	221	241
12	116	144	94	63	102	170	60	120	371	34	171	174
13	6	131	97	35	66	112	7	22	100	14	45	187
14	20	8	–	–	–	51	–	15	50	–	59	83
15	–	–	3	–	–	74	4	17	4	–	38	31
16+	9	18	2	6	49	23	3	5	8	–	14	103
Total	24,786	30,203	34,878	38,343	28,274	39,709	38,886	27,026	41,705	30,952	29,179	23,211

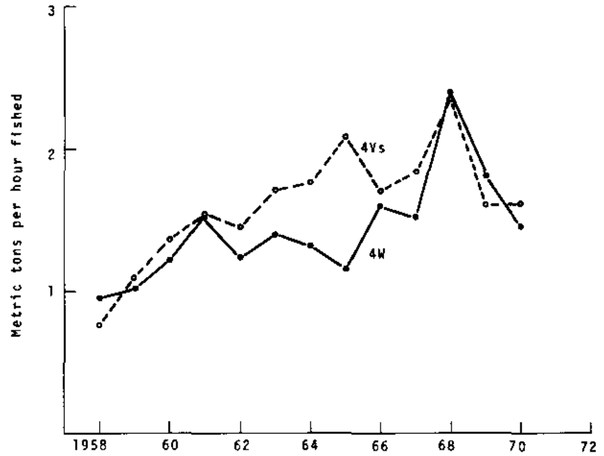

Fig. 4. Subdivision 4Vs and Div. 4W cod: catch-per-unit-effort of Spanish pair trawlers 151-500 gross tons (February to April inclusive), 1958-70.

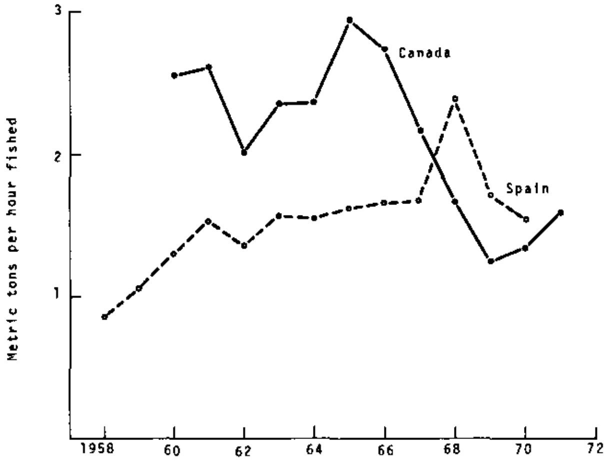

Fig. 5. Subdivision 4Vs and Div. 4W cod: catch-per-unit-effort of Canadian side otter trawlers and Spanish pair trawlers, 151-500 gross tons, 1958-71. (Canadian cpe × 10, Spanish cpe for February-April inclusive.)

Population estimates

An independent check on abundance changes is provided by population abundance estimates from cohort analysis (Pope, 1972). Numbers removed at age (Table 4) are used with an assumed natural mortality of M = 0.20 and, after several trials, an assumed fishing mortality for the oldest age-groups of F = 0.50, to give population numbers at age (Table 5).

The population has remained stable over the 1960-69 period, numbers of 3-11 year olds fluctuating close to the mean of 186 million fish. The numbers of the older, fully recruited (see below) age groups 6-11 years old have also remained stable, although in the most recent years 1966-69 their abundance has been below the average of 39 million fish.

TABLE 5. Subdivision 4Vs and Div. 4W cod: Population numbers ($\times 10^{-3}$) per age-group, 1960-69 from Pope's cohort analysis.

	Year										
Age	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	Mean
3	55,783	68,669	72,113	37,070	60,025	78,843	70,154	68,518	60,307	38,056	60,954
4	57,265	44,867	56,002	56,925	30,046	47,935	59,633	55,653	55,840	47,222	51,139
5	36,788	43,655	31,975	34,927	37,846	22,248	30,584	36,612	40,117	36,398	35,115
6	17,510	23,456	27,286	19,915	16,610	22,129	11,645	14,157	19,652	20,739	19,310
7	10,016	9,145	12,411	15,868	10,539	8,996	9,815	5,087	7,742	8,274	9,789
8	6,953	4,922	4,615	7,937	8,346	5,369	4,687	5,118	2,908	3,059	5,391
9	1,440	3,310	1,912	1,799	4,144	3,756	2,406	2,569	2,720	1,387	2,544
10	684	768	1,209	804	1,015	2,058	1,689	1,293	1,378	1,331	1,223
11	620	409	461	542	471	446	944	923	417	733	597
Σ6-11	37,224	42,010	47,894	46,865	41,125	42,754	31,196	29,147	34,817	35,523	38,856
Σ3-11	187,060	199,201	207,984	175,787	169,042	191,780	191,567	189,930	191,081	157,199	186,063

Estimates of "available biomass" were obtained from population numbers and mean weight at age, adjusting for partial recruitment, giving:

Year	"Available biomass" (metric tons $\times 10^{-3}$)	
1960	169	
1961	193	
1962	225	Mean = 191
1963	186	
1964	180	
1965	158	
1966	157	
1967	158	Mean = 161
1968	175	
1969	157	

These data should be more comparable than population numbers to catch-per-unit-effort data which are also expressed in terms of weight.

While confirming the general conclusion from cpe data that abundance has not changed greatly between 1960 and 1969, these data are in contrast with Spanish cpe data in indicating a lower abundance in the 1965-69 period than in 1960-64 by about 16% on average.

Recruitment

The mean recruitment to the stock at age 3 in the 1960-69 period was 61 million fish, showing only moderate variation between 37 million and 79 million fish (Table 5). The 1959 and 1962 year-classes were good while those of 1960 and 1966 were poor.

Three-year olds are only slightly recruited to the fishery, ages 4 and 5 are about 40 and 80% recruited to the fishery respectively, and full recruitment occurs at age 6 (Table 6). A graphical estimate from these data give an age at 50% recruitment of 4.2 years.

TABLE 6. Subdivision 4Vs and Div. 4W cod: Instantaneous fishing mortality (F) per age-group, 1960-69, from Pope's cohort analysis.

	Year											
Age	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	Mean 1960-69	% recruit-ment
3	0.02	0.00	0.04	0.01	0.02	0.08	0.03	0.00	0.04	0.04	0.03	6
4	0.07	0.14	0.27	0.21	0.10	0.25	0.29	0.13	0.23	0.25	0.19	39
5	0.25	0.27	0.27	0.53	0.34	0.45	0.57	0.42	0.46	0.38	0.39	80
6	0.45	0.44	0.34	0.44	0.41	0.61	0.63	0.40	0.66	0.40	0.48	100
7	0.51	0.48	0.25	0.44	0.47	0.45	0.45	0.36	0.73	0.32	0.45	100
8	0.54	0.75	0.74	0.45	0.56	0.60	0.40	0.43	0.54	0.20	0.52	100
9	0.43	0.81	0.67	0.37	0.50	0.60	0.42	0.42	0.51	0.25	0.50	100
10	0.31	0.31	0.60	0.33	0.62	0.58	0.40	0.93	0.43	0.59	0.51	100
11	0.45	0.72	0.73	0.38	0.66	1.26	0.93	0.56	1.09	0.17	0.70	100
Mean 6-10	0.45	0.56	0.52	0.41	0.51	0.57	0.46	0.51	0.57	0.35	Overall mean, ages 6-10 = 0.49	

Mortality

Estimates of fishing mortality (F), obtained from cohort analysis, averaged 0.49 for fully recruited age groups for the 1960-69 period (Table 6). There was little year-to-year variation.

Growth

There were no consistent trends in mean length at age among commercial landings in the 1960-71 period.

A von Bertalanffy growth curve fitted to data for ages 6-10, i.e. those fully recruited age groups best represented in the fishery, gives the following estimates of growth parameters:

$K = 0.14$
$t_o = 0.07$
$L_\infty = 105$ cm

The length-weight relationship:

$$\log W = 3.0748 \log L - 2.1571$$

obtained for this stock on a July 1971 research vessel survey, gives a value of $W_\infty = 11.41$ kg by substituting the above value of $L_\infty = 105$ cm.

Yield-Per-Recruit

The values of parameters derived in earlier sections are substituted in the Beverton and Holt constant parameter yield-per-recruit model as follows to estimate yield-per-recruit:

$K = 0.14$
$t_o = 0.07$
$W_\infty = 11.41$ kg
$t_o = 3.0$ yrs (= age at recruitment to the fishing area)
$t_\rho{}^1 = 4.2$ yrs (= age at recruitment to the exploited phase)
$t_\lambda = 13$ yrs (= maximum age of significant contribution to the fishery)

Instantaneous natural mortality, M, is not known for this stock. However, in those cod stocks in the Northwest Atlantic for which M has been estimated, the value obtained has been close to 0.20. The values 0.10, 0.20 and 0.30 are used in the yield equation giving the results shown in Fig. 6.

Assuming $M = 0.20$, maximum yield-per-recruit is obtained from this stock at $F = 0.45$, slightly lower than current values of F (0.49).

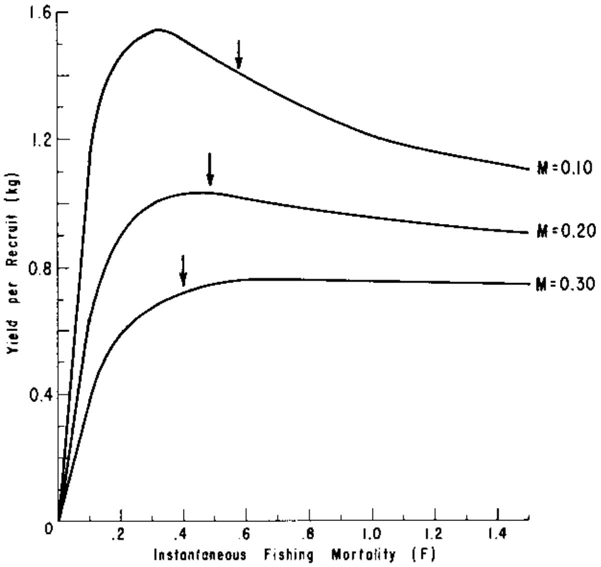

Fig. 6. Subdivision 4Vs and Div. 4W cod: yield-per-recruit. (Arrows indicate average 1960-69 position on the curves.)

If $M = 0.10$, the stock is considerably over-exploited, and if $M = 0.30$, the present yield-per-recruit is slightly below the maximum (95% of maximum).

Discussion

The present analysis suggests that the 4Vs-W cod fishery was moderately stable over the period of investigation. Size and age compositions of removals and quantities landed did not vary greatly and recruitment, abundance and mortality have also remained fairly constant. However, there are some inconsistencies in the results, presumably due to the inaccuracy of some of the assumptions it has been necessary to make.

Spanish cpe data indicate that stock abundance gradually increased from 1960-67 and increased substantially in 1968. Abundance estimates from cohort analysis, which are independent estimates based only on age compositions and total removals, suggest a lower abundance in 1965-69 than in 1960-64. Thus, the assumption that Canadian samples adequately represent Spanish catches is apparently inaccurate. The discrepancy could be explained by an increasing tendency by Spain to catch smaller cod resulting in small increases in cpe even though abundance of larger cod, on which the Canadian fishery was based, was declining.

The 49% increase in Spanish landings in 1968 was accompanied by a 43% increase in cpe, indicating that virtually all of the increase in landings was due to increased cpe and not to increased effort. The increased cpe may reflect an increase in the catchability coefficient rather than a real increase in abundance, but the consistency of the other cpe data in the series suggest that such a substantial change is unlikely. If a real increase in abundance occurred, it implies that a strong year class entered the Spanish fishery and was heavily exploited at an age younger than that normally fished by Canadians.

If Spain has removed fish significantly smaller than Canada, and if there is an increasing tendency to fish small cod, this is equivalent to lowering the mean selection age with a resultant loss in yield-per-recruit. The Beverton and Holt model predicts increases in yield-per-recruit at F = 0.50 up to an age at recruitment to the exploited phase of about 6 years (Fig. 7).

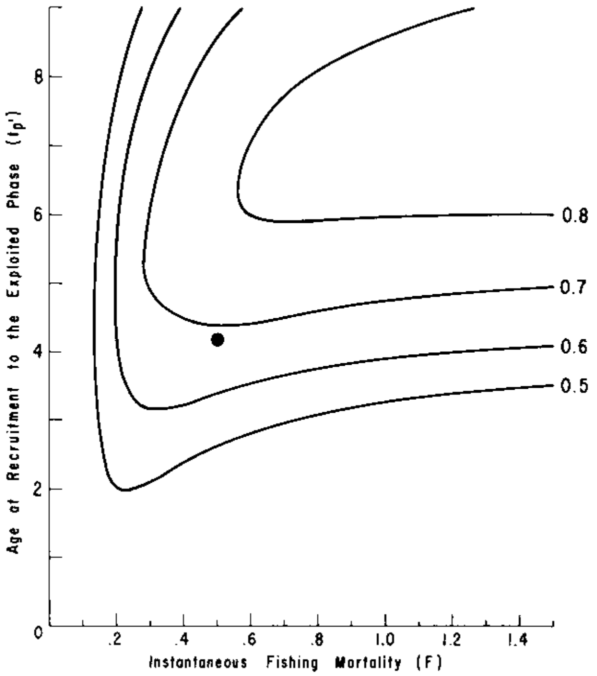

Fig. 7. Subdivision 4Vs and Div. 4W cod: yield isopleth diagram. Dot indicates average 1960-69 position. Values on right define isopleth yields per recruit in kg (K = 0.14; t_0 = 0.07; W_∞ = 11.41; t_ρ = 1 yr; t_λ = 13 yrs; M = 0.20.)

Thus, the incomplete information available on the 4Vs-W cod stock indicates that the stock is stable and being exploited close to the maximum-yield-per-recruit. However, substantial economic benefits could be obtained by a reduction in fishing mortality – 95% of the maximum yield-per-recruit would be obtained at F values of 55% of the present level (i.e. F = 0.28). Increased long-term yield-per-recruit is likely to accrue from increased age at recruitment to the fishery. If, as appears to be the case, the number of young fish removed from the stock is underestimated, then the greater are the benefits likely to be of reduced fishing mortality and increased size at first capture.

These results are not directly comparable with those of Beverton and Hodder (eds., 1962). In the 1947-58 period, the fishery was prosecuted predominantly by hook and line and although Z on fully-recruited age groups age 10 and over was 0.50, Z on all age-groups age 6 and older must have been considerably less. This value is not available to compare with current estimates.

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References

BEVERTON, R. J. H., and V. M. HODDER. eds. 1962. Report of working group of scientists on fishery assessment in relation to regulation problems. Supplement to *Annu. Proc. int. Comm. Northw. Atlant. Fish.*, **11**: 81 p.

ICNAF. 1966-71. Summary of statistics on discards (whole fish returned to the sea), 1964-69. *Annu. Meet. int. Comm. Northw. Atlant. Fish. 1966*, Res. Doc. No. 10, Serial No. 1664; *1967*, Res. Doc. No. 7, Serial No. 1786 (mimeographed). *Int. Comm. Northw. Atlant. Fish. Redbook*, Part III: *1968* (p. 29-36); *1969* (p. 115-123); *1970* (p. 181-188); *1971* (p. 297-302).

MARTIN, W. R., and Y. JEAN. 1964. Winter cod taggings off Cape Breton and on offshore Nova Scotia Banks, 1959-62. *J. Fish. Res. Bd. Canada*, **21**: 215-238.

POPE, J. G. 1972. An investigation of the accuracy of virtual population analysis using cohort analysis. *Res. Bull. int. Comm. Northw. Atlant. Fish.*, this volume, p. 65-74.

TEMPLEMAN, W. 1962. Division of cod stocks in the northwest Atlantic. *Int. Comm. Northw. Atlant. Fish. Redbook 1962*, Part III: 79-123.

International Commission for the Northwest Atlantic Fisheries

The Commission in Brief

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

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

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c) Prepare and submit the original and two carbon copies of the text and at least two sets of illustrations.

d) Number all pages of the manuscript consecutively with Arabic numerals in the centre of the top margin space.

e) Start a new page for each of the following sections with appropriate headings and sub-headings: (1) title, name and address of author, list of contents (if applicable); (2) abstract of the paper; (3) text; (4) references to literature; (5) tables; (6) legends for figures and (7) figures.

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g) Wherever practical the text should be subheaded into Introduction, Materials and Methods, Results, and Discussion. Authors must provide a Summary which lists one by one the principal facts and conclusions of the paper. Acknowledgements should be placed immediately after the Summary.

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j) Only those words to be printed in italics should be underlined.

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Each manuscript should have an abstract not to exceed 3% of the length of the text or 200 words whichever is the smaller. For position of the abstract in the manuscript see (e) above. The abstract should summarize the contents and conclusions of the paper, point to new information in the paper and indicate the relevance of the work.

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