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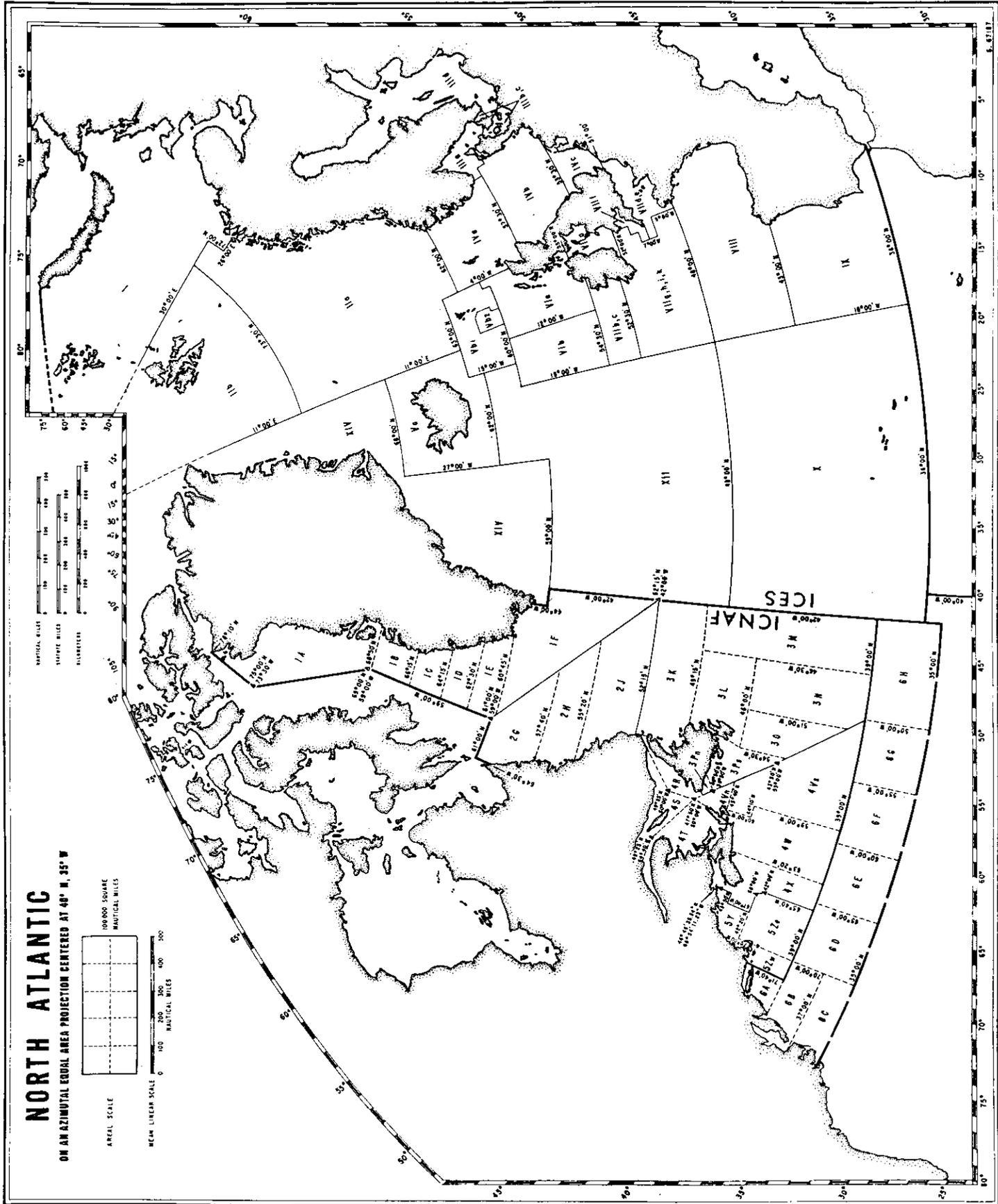
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NORTH ATLANTIC

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



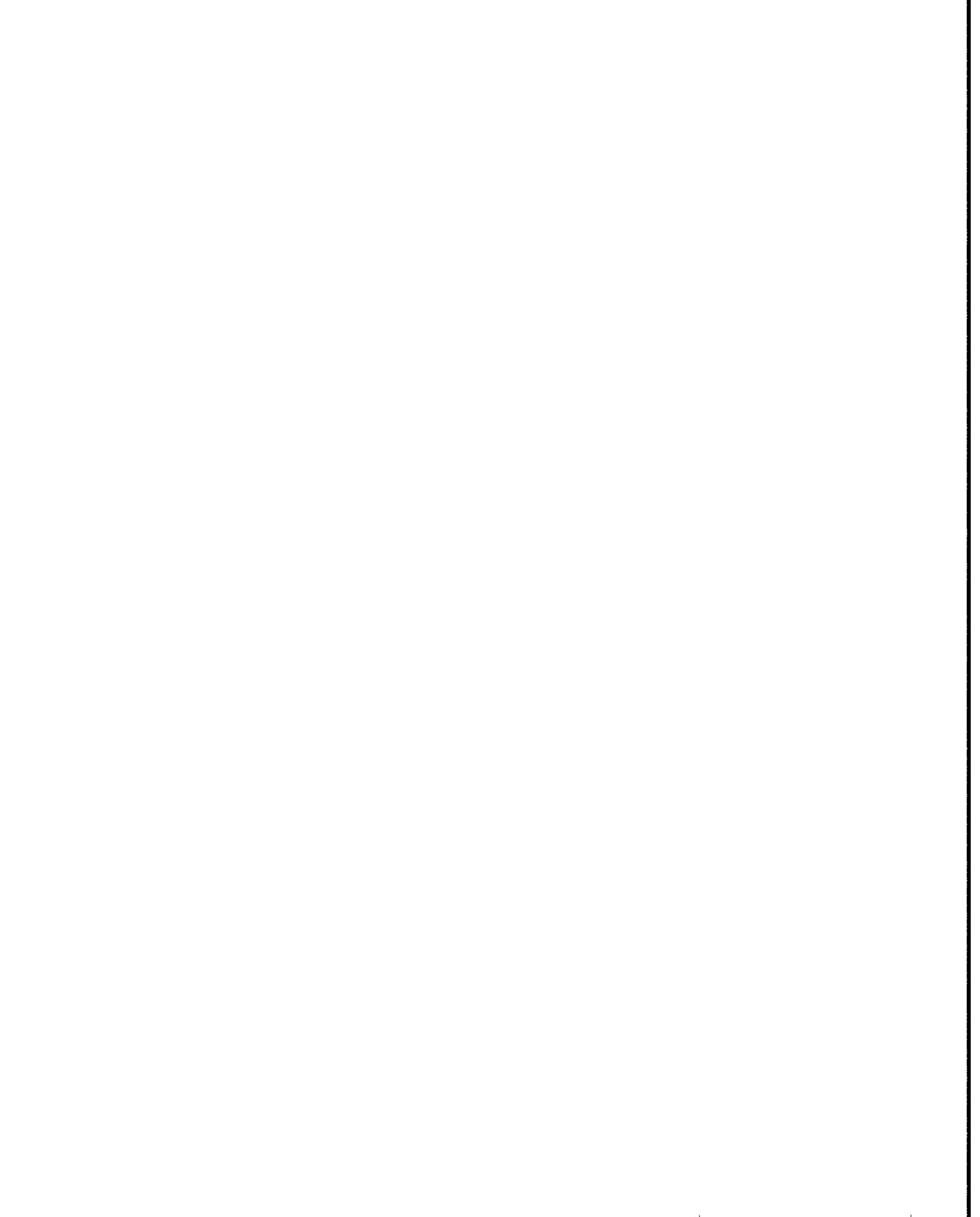
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Growth of Yellowtail Flounder, *Limanda ferruginea* (Storer), on Three New England Fishing Grounds

BY F. E. LUX¹ AND F. E. NICHY¹

Abstract

Length at age of yellowtail flounder, *Limanda ferruginea* (Storer), determined from scales, differs slightly on the three grounds off New England where the fish are caught commercially. The fish reach commercial size, about 30 cm, during their third or fourth year. Females grow faster than males and live longer. The growth rate from age 2 onward for males and females combined is estimated by the Bertalanffy growth equation

$$l_t = 500 (1 - e^{-0.335(t+0.26)})$$

where l is length in millimeters and t is age in years.

Introduction

The yellowtail flounder, *Limanda ferruginea* (Storer), an important flatfish in the New England otter-trawl fishery, has provided annual landings over the past 25 years ranging from a low of 6,000 metric tons in 1954 to a high of 35,000 tons in 1964 (Lux, 1964). The fishery, which began in the mid-1930's, is largely on three grounds off New England (Fig. 1): the southern New England ground (Subareas XXII-O, -Q, -S, and area XXIII, in depths of 25 - 55 m); Georges Bank (Subareas XXII-H, -M, and -N, in 45 - 75 m); and the Cape Cod ground (Subareas XXII-E and -G, in 10 - 65 m). About 90% of the landings are from the southern New England ground and Georges Bank.

Tagging experiments have shown that a relatively distinct group of yellowtail flounder occurs on each ground, but that a small amount of movement occurs between grounds (Royce, Buller, and Premetz, 1959; Lux, 1963). Fish from different grounds show no differences in finray counts (Lux, 1963).

Two previous studies contain information on the growth of yellowtail flounder. Scott (1954), using otoliths, determined length at age of yellowtail flounder off eastern Nova Scotia. He compared their growth with that of southern

New England fish, the latter based on a single collection of otoliths. He found that Nova Scotian fish grew faster than those from southern New England after age 7 but slower before age 7 and that females grew faster than males on both grounds. Royce *et al.* (1959), using scales, determined length at age of yellowtail flounder from the commercial catch on the southern New England ground; the findings agreed with those of Scott (1954) for this area.

As part of a study of the population dynamics of New England yellowtail flounder, the present paper reports length at age of fish before and after they reach the size of recruitment to the fishery, from scale samples collected in 1955-65 from the three New England grounds defined above.

Materials and Methods

Fish samples were obtained from commercial food fish landings at New Bedford, Massachusetts, USA, the largest yellowtail flounder port; industrial fish landings at Point Judith, Rhode Island, USA; and research vessel catches.

The commercial catch provided samples from all grounds. At New Bedford it is packed in boxes of 125 lb. (57 kg) of whole fish upon discharge from the fishing vessels. Only catches made on trips to a single fishing ground were sampled. Each sample consisted of one box of fish. (Repeated sampling within the same catch of a given vessel indicated that a single box gave a reliable measure of the length distribution of fish taken during the trip). The sample was separated into males and females (sex was determined externally — see Royce *et al.*, 1959), and scales were taken from a random sample of 25 fish of each sex.

The Point Judith industrial fish catch, made with small-mesh otter trawls, provided infrequent

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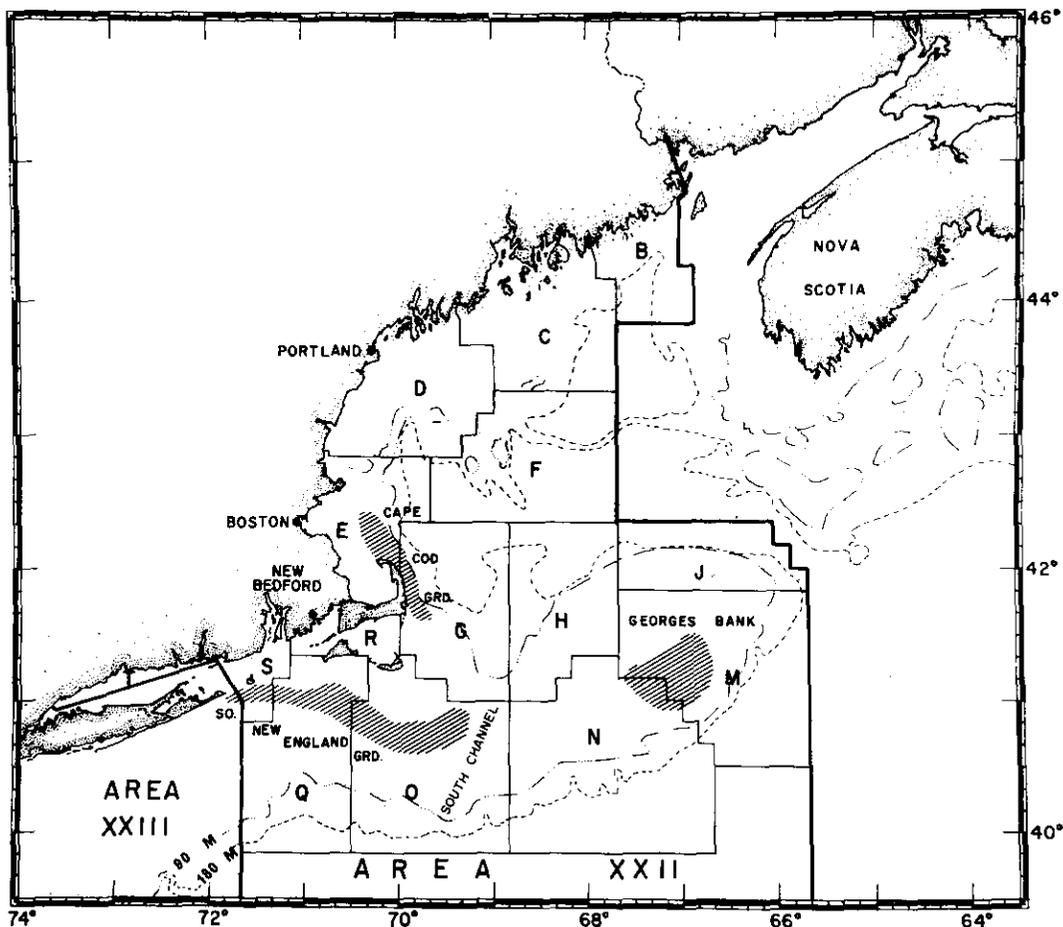


Fig. 1. Chart of New England fishing areas showing the three principal grounds where yellowtail flounder are caught. Grounds of greatest fishing effort are shaded. (The statistical areas are those defined by Rounsefell (1948). Area XXII is the equivalent of ICNAF Subarea 5; area XXIII is outside the ICNAF area.)

samples of 1- and 2-year-old fish from the southern New England ground. Samples were removed from the conveyer onto which vessels are unloaded. Scales were taken from all fish in each sample; sex was determined from internal examination.

Research vessel catches of yellowtail flounder were obtained sporadically from all three grounds in 1956-65. The otter trawls used had small-mesh codend liners which retained all sizes. Catches were separated by sex, and scales were taken from the entire catch or from representative subsamples.

Scales were removed from the eyed side of the fish along the lateral line in the area immedi-

ately anterior to the caudal peduncle. Length was recorded in millimeters for each fish. Impressions of the scales in cellulose-acetate strips were examined with a microprojector, at 40 X magnification, and the numbers of year marks (annual rings) were counted (Royce *et al.*, 1959).

Yellowtail flounder spawn in the spring. First-year growth is represented on the scale by a small, central zone of closely spaced circuli (Fig. 2a). The outer edge of this zone was taken to be the first year mark. In later years the annual growth on a scale is made up of a zone of widely spaced circuli formed during spring and summer, and a zone of more closely spaced circuli formed during autumn and winter (Fig. 2b).

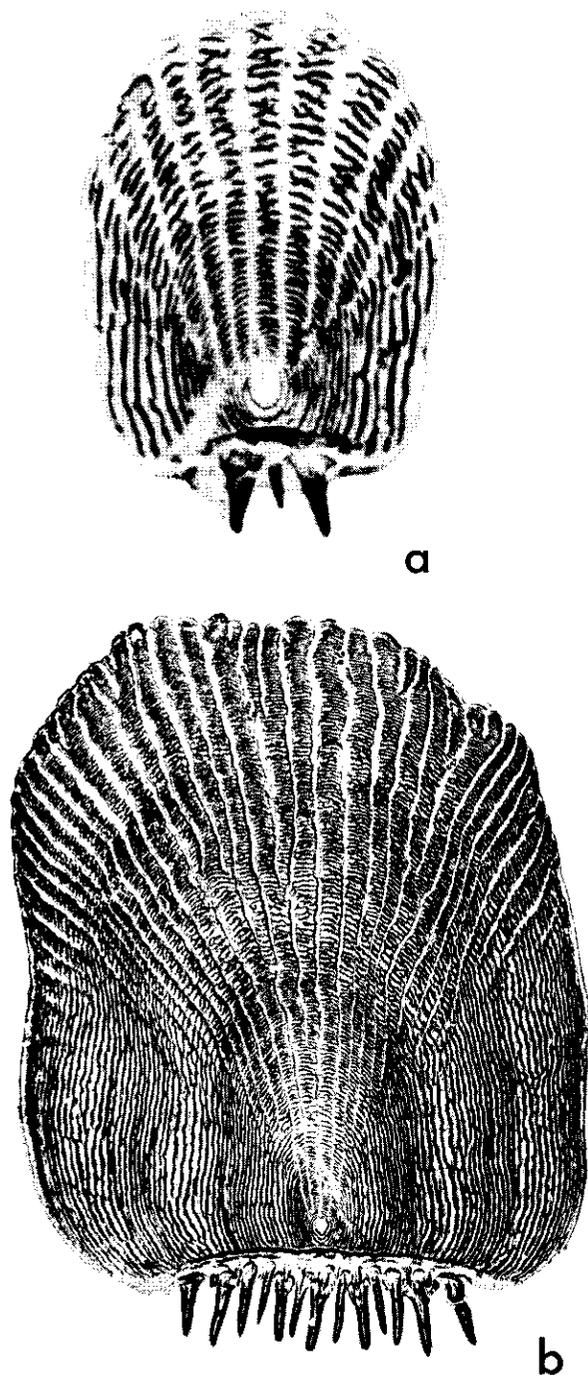


Fig. 2. Photographs of scale impressions of yellowtail flounder from the southern New England ground. (a) Scale from a 13-cm fish caught in March showing the completed first year, represented by a central zone of closely spaced circuli, and the beginning of the second year, represented by marginal, more widely spaced circuli. (b) Scale from a 41-cm fish (4 years old) caught in January showing four completed years.

The outer edge of the latter zone of circuli was taken to be the year mark. This zone was apparently completed by the end of the calendar year. For convenience, we have therefore used 1 January as the "birthday."

An accessory mark or check, appearing as a narrow zone of only a few closely spaced circuli not preceded by a gradual narrowing of circulus spacing, frequently was apparent in the spring and summer growth zone of the third year. These checks may be related to the approach of sexual maturity which usually occurs at age 3. Checks also occurred occasionally in other years without apparent pattern. All marks identified as checks were disregarded in assigning age.

Age assessment was more difficult in old fish because of narrowing of the growth zones. The authors, both of whom read the scales, frequently disagreed on the age for fish over age 5. When disagreement occurred, we re-read the scales and assigned an age to the best of our ability. Only those scales for which the recorded length obviously was in error or where abnormalities, such as regeneration, made them unreadable were discarded. These amounted to less than 1% of the total.

Table 1 shows ages assigned by each reader to 641 fish from the 1960 commercial catch on Georges Bank. For no scale was disagreement greater than 1 year, and agreement for all ages combined was 95%. This percentage approximated the agreement for other samples from commercial catches. Agreement was better for samples from industrial fishery landings and research vessel catches, which consisted largely of young fish.

Validity of the Scale Method for Determining Growth During the First Year

The growth of yellowtail flounder during their first year was estimated from average lengths of fish collected, by various methods, in different seasons (Fig. 3). Peak spawning occurs in mid-May (Bigelow and Schroeder, 1953). At hatching, which takes place in 5 days, the average length is 2.8 mm. Planktonic larvae and post-larvae collected in May and June on the southern New England ground and Georges Bank ranged from 4 to 14 mm in length and averaged 7 mm (Marak and Colton, 1961; Marak, Colton, and Foster, 1962 *a* and *b*).

TABLE 1. Comparison of numbers of yellowtail flounder that were assigned to various age groups on the basis of independent scale examinations by the two authors of this paper.

Age in years determined by Lux	Age in years determined by Niehy							Total
	2	3	4	5	6	7	8	
Males								
2	138							138
3	6	90	2					98
4		2	31					33
5			2	22				24
6								
Total	144	92	35	22				293
Females								
2	69	1						70
3		133	2					135
4		3	73	5				81
5			1	47				48
6				3	6			9
7					1	1		2
8						2	1	3
Total	69	137	76	55	7	3	1	348

Bigelow and Schroeder (1953) reported that metamorphosis is complete, and the fish move to the bottom, at a length of about 14 mm. In late August (1965) nine young of the year taken on the bottom in a naturalist dredge in Subarea XXII-O (*Albatross IV*, cruise 65-11) were 13-24 mm long and averaged 16 mm. In late September (1965) 33 young caught on the bottom in a ring net on Georges Bank (*Albatross IV*, cruise 65-13) were 13-41 mm long and averaged 24 mm. In early October (1955) 12 young taken in a Digby dredge in Subarea XXII-Q (*Albatross III*, cruise 67) were 25-31 mm long and averaged 28 mm.

Young-of-the-year yellowtail flounder first appeared in otter-trawl catches in the autumn. In early November (1965) seven fish caught in a trawl in Subarea XXII-O (*Albatross IV*, cruise 65-14) were 27-54 mm long and averaged 37 mm. Only closely spaced circuli were present on the scales. In mid-February (1964) 24 fish from trawl collections on the southern New England ground (*Albatross IV*, cruise 64-1) were 5-10 cm long and averaged 6.8 cm. Their scales had closely spaced circuli in the central zone and a few, more widely spaced, circuli at the margin. In late March (1962) seven young fish from trawl catches made by a chartered vessel in Subarea

XXII-S were 9-14 cm long and averaged 11.6 cm. The scales had closely spaced circuli in a central zone and several widely spaced circuli at the margin. We assume that the more widely spaced marginal circuli in the February and March fish reflected an increase in growth rate with the approach of spring (Fig. 2a); this increase apparently occurs earlier in the year in young fish than in older ones.

All of the foregoing information is evidence that only one growth zone, consisting of closely spaced circuli, is laid down on the yellowtail-flounder scale during the calendar year of hatching and that this zone is identifiable. We have defined the outer edge of this zone as the first year mark.

Validity of the Scale Method for Determination of Age Beyond the First Year

Verification of the defined scale marks as indicators of age for fish beyond their first year was obtained from three sources.

1) **Correspondence within each year between scale growth zones, scale size, and fish size**

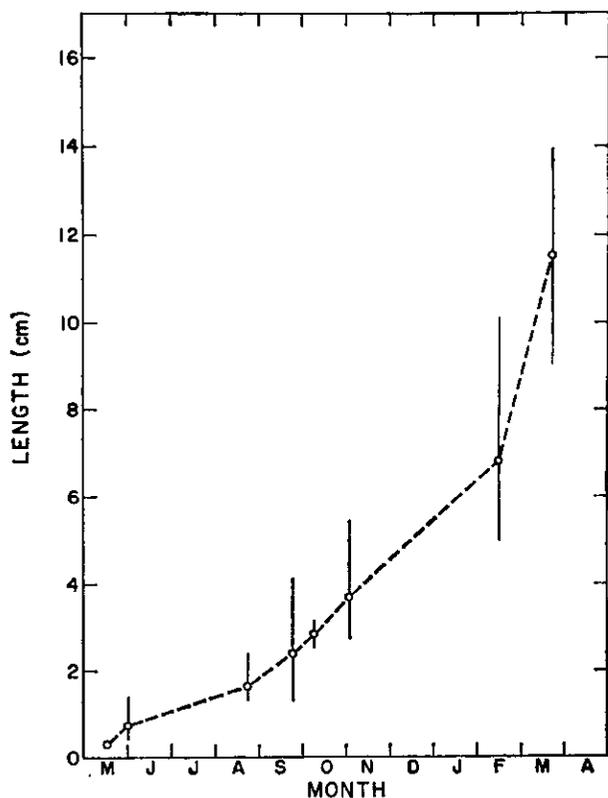


Fig. 3. Length at age of yellowtail flounder during the 10 months after hatching. Circles are mean lengths; vertical lines show length range.

Scales collected through the year showed that for fish of age 1 and over distinct growth zones were laid down in different seasons: a zone of

widely spaced circuli, corresponding with rapid growth, in spring and summer and a zone of closely spaced circuli, corresponding with slow growth, in fall and winter. As the zones were added, the average length of fish within an age group, and the size of their scales, increased. These observations indicated that the scale zones are laid down in a regular manner, that they are related to the growth of the fish, and that only one growth field is added each year.

2) Correspondence between size of fish and their age determined from counting year marks on scales

Royce *et al.* (1959) showed that the length of yellowtail flounder increased as the number of year marks on scales increased. Our data confirm this finding (Tables 2-10). In addition, we found that the modes in length-frequency distributions of small fish coincided with mean lengths of age groups as determined by counting the annual rings on scales (Fig. 4). These observations further indicate that age is related directly to the number of year marks.

3) Agreement between number of year marks added on scales of tagged fish and number of years at liberty

Fish having two or more annual rings were marked with numbered tags; length, sex, and scales were obtained at the time of marking. Length and scales of 35 of these were obtained when the fish were recaptured in 2-56 months after

TABLE 2. The relationship of number of year marks on scales to fish length for yellowtail flounder from autumn research vessel catches in two areas on the southern New England ground (*Albatross IV*, cruise 63-7).

	Number of year marks											
	Males					Females						
	1	2	3	4	5	1	2	3	4	5	6	7
Subarea XXII-O												
Number of fish	33	41	38	6	1	31	50	72	6	3	—	—
Mean length (cm)	25	33	36	36	41	26	35	38	42	43	—	—
Area XXIII												
Number of fish	62	29	18	21	—	75	76	29	51	8	1	1
Mean length (cm)	25	32	33	35	—	25	34	38	39	40	43	45

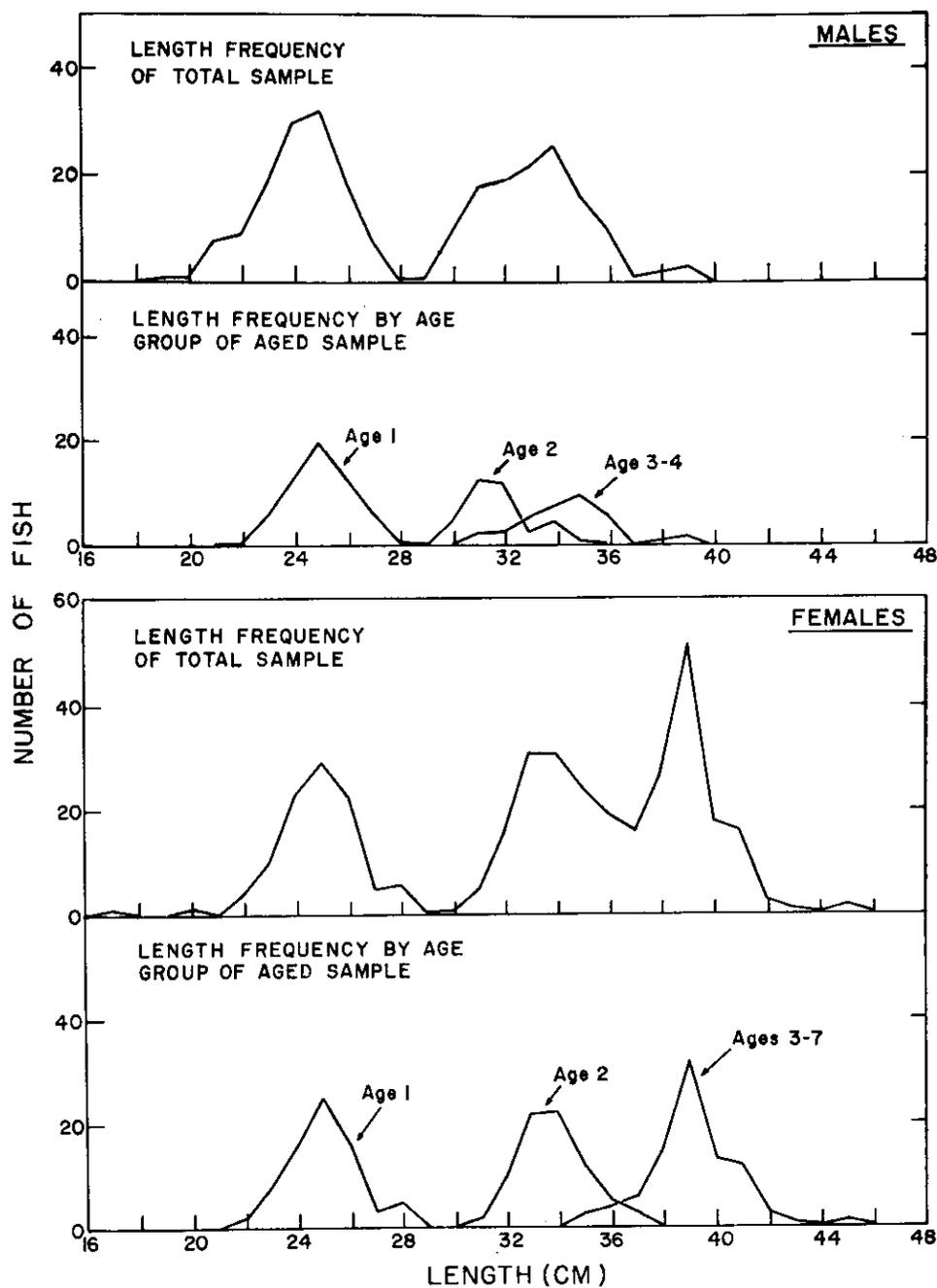


Fig. 4. Length frequency distributions of autumn research vessel catches of yellowtail flounder from area XXIII on the southern New England ground, and length frequencies by age-group for a sample from the same catches, aged by counting the number of year marks on scales. (*Albatross IV*, cruise 63-7. See Table 2 for mean lengths at age for this sample.)

tagging. The number of annual rings added to the scales between tagging and recapture corresponded, except in one fish, with the number of years the fish were at liberty (Table 3). In the one exception, a male with 3 year marks at tagging in February 1957 had 5 distinguishable year

marks at recapture 42 months later (Table 3). In the 42 months 3 year marks instead of 2 should have been added. We believe that one of the annual rings was obscured because of the slow growth of this fish after tagging (29 mm), resulting in an underestimation of age at recapture.

TABLE 3. Tagging and recovery information for 35 yellowtail flounder from which scales were obtained both at tagging and at recovery 2-56 months after tagging.

Tagging information				Recovery information			Months at liberty	Growth (mm)
Date	Sex	Length (mm)	No. of yr marks	Date	Length (mm)	No. of yr marks		
April 1965	—	360	3	Dec. 1955	384	3	7.5	24
"	♂	290	2	Jan. 1956	329	3	9.0	39
"	♀	375	3	Jan. 1957	404	5	20.5	29
May 1955	♀	365	3	Sep. 1956	415 ^a	4	16.5	50
"	♂	345	3	Dec. 1955	373 ^a	3	7.0	28
June 1955	♀	356	3	Sep. 1955	387 ^a	3	2.5	31
"	♂	325	3	Oct. 1955	335 ^a	3	4.0	10
"	—	410	3	Nov. 1955	425 ^a	3	4.5	15
"	♀	293	2	Nov. 1955	316 ^a	2	4.5	23
"	♀	373	3	Nov. 1955	409 ^a	3	5.0	36
"	♀	470	6	Dec. 1955	483 ^a	6	5.5	13
"	♂	353	3	Dec. 1955	364 ^a	3	5.5	11
"	♀	353	3	Dec. 1955	384 ^a	3	5.5	31
"	♀	410	4	Jan. 1956	412 ^a	5	6.5	2
"	♂	345	3	Feb. 1956	370	4	8.0	25
"	♀	383	3	Mar. 1956	414	4	8.5	31
"	♀	402	3	Apr. 1956	403	4	10.0	1
"	♂	316	3	May 1956	332 ^a	4	10.5	16
"	♀	364	3	Oct. 1956	419 ^a	4	15.0	55
"	♀	354	3	Jan. 1957	409 ^a	5	19.0	55
"	♀	354	3	Dec. 1958	441	6	29.5	87
Feb. 1957	♀	349	3	July 1957	364	3	4.0	15
"	♂	269	2	Aug. 1957	322	2	6.0	53
"	♀	267	2	Oct. 1957	326	2	7.0	59
"	♀	424	4	Oct. 1957	434	4	7.5	10
"	♂	272	2	Nov. 1957	335 ^a	2	9.0	63
"	♂	286	2	Jan. 1958	297	3	11.0	11
"	♀	255	2	July 1958	384	3	16.0	129
"	♀	290	2	Aug. 1958	400	3	18.0	110
"	♂	286	2	Dec. 1958	358	3	21.5	72
"	♀	300	2	May 1959	386	4	26.5	86
"	♀	366	3	Jan. 1960	425	6	35.0	59
"	♂	279	2	Jan. 1960	391	5	35.0	112
"	♂	350	3	Aug. 1960	379	5	42.0	29
"	♀	285	2	Aug. 1961	436	6	56.0	151

^aConverted from approximate length in inches and fractions of inches.

Lengths of all 35 fish increased, and the amount of the increment was related directly to time between tagging and recapture, sex of the fish and age at marking.

The evidence from tagging and recapture thus supports the thesis that length increases with number of annual rings and that only one annual ring is added to the scale each year.

Length at Age

Royce *et al.* (1959) showed that for yellowtail flounder of commercial size (over 30 cm long) the females grow faster than males. Our data, which include the entire size range of the fish, show that this relation holds for fish greater than age 2, but that growth rate up to age 2 is the same for both sexes. For estimating length at age we therefore separated sexes only for fish of age 2 and older.

Estimated lengths at age were obtained by combining data for fish from small-mesh nets and from commercial-otter-trawl samples. Since some fish of ages 1-3 are discarded by commercial vessels as undersized, commercial catch samples of these age groups were excluded from the summary.

The growth data indicated differences in mean lengths at age between grounds. We therefore have reported length at age separately for each ground.

Southern New England Ground

On the southern New England ground most yellowtail flounder are caught in Subareas O and Q, and lesser amounts are taken in Subarea S and area XXIII, to the west (Fig. 1). Length at age frequently was slightly greater in Subarea O than in the other subareas (Tables 4 and 5). These differences were too small, however, to be clearly defined by our data. Since we intend to treat the southern New England ground yellowtail flounder as a group for population studies, we combined material for all subareas there to provide a general estimate of length at age for the ground.

Since no differences were apparent in length at age between years (Table 5), we combined collections for all years.

Mean lengths at age for males and females by calendar quarter for age one and older fish are summarized in Table 6. These data and those for young-of-the-year (O-group) fish (Fig. 3) are graphed in Fig. 5. The fish reach a length of 26 cm in 2 years, but later growth is less rapid.

TABLE 4. Numbers of fish (n) and mean lengths in cm (cm) by age-group of yellowtail of flounder collected in small-mesh-otter trawls on the southern New England ground in 1955-64, calendar quarter.

Calendar quarter	Sex and age-group																								
	Male and female		Male						Female																
	n	cm	1	2	3	4	5	6	2	3	4	5	6	7											
Jan.-Mar.	18	7.0	147	26.5	173	33.0	53	35.7	16	36.2	3	39.3	142	26.7	200	34.7	45	39.0	26	41.7	10	42.7	--	--	
Apr.-June	46	11.6	59	25.4	30	31.9	1	32.0	--	--	--	--	76	26.6	29	34.3	3	38.0	1	46.0	--	--	--	--	
July-Sept.	164	18.5	14	28.7	3	33.3	--	--	--	--	--	--	31	30.6	3	36.3	--	--	--	--	--	--	--	--	
Oct.-Dec.	477	25.3	47	31.2	31	33.8	22	35.5	--	--	--	--	98	33.3	45	37.7	51	39.2	8	40.5	1	43.0	2	47.0	
													Subarea XXII-O and S, and area XXIII												
													Subarea XXII-O												
Jan.-Mar.	8	6.4	20	26.7	34	33.5	20	37.0	4	37.5	--	--	14	26.3	32	34.9	24	39.8	4	41.5	2	44.0	--	--	
Oct.-Dec.	113	25.8	46	33.4	49	35.8	6	36.5	2	39.0	--	--	51	34.9	73	38.6	11	42.0	5	43.4	--	--	1	47.0	

TABLE 6. Number of fish (n) and mean lengths in cm (cm) by age-group of yellowtail flounder (samples from small-mesh and commercial-otter trawls combined) from the southern New England ground in 1955-64, by calendar quarter. (Commercial samples were included only for fish of age 4 or older.)

Calendar quarter	Age-group															
	1		2		3		4		5		6		7		8&8+	
	n	cm	n	cm	n	cm	n	cm	n	cm	n	cm	n	cm	n	cm
Males																
Jan.-Mar.	26	6.8	167	26.5	207	33.0	464	36.1	136	38.3	19	40.1	4	40.8	1	39.0
Apr.-June	46	11.6	59	25.4	30	31.9	122	35.6	28	37.2	2	39.5	1	42.0	1	39.0
July-Sep.	164	18.5	14	28.7	3	33.3	66	36.7	9	38.3	6	39.7	2	39.0	—	—
Oct.-Dec.	590	25.4	93	32.3	80	35.0	196	37.4	24	38.8	2	40.5	—	—	—	—
Females																
Jan.-Mar.	26	6.8	156	26.7	232	34.7	582	39.5	313	42.4	85	44.5	28	46.2	10	48.2
Apr.-June	46	11.6	76	26.6	29	34.3	174	38.9	63	41.8	17	44.2	6	46.4	1	47.0
July-Sep.	164	18.5	31	30.6	3	36.3	144	40.3	52	43.3	17	44.1	3	43.0	—	—
Oct.-Dec.	590	25.4	149	33.8	118	38.3	293	41.0	76	43.3	23	45.9	12	47.2	5	47.0

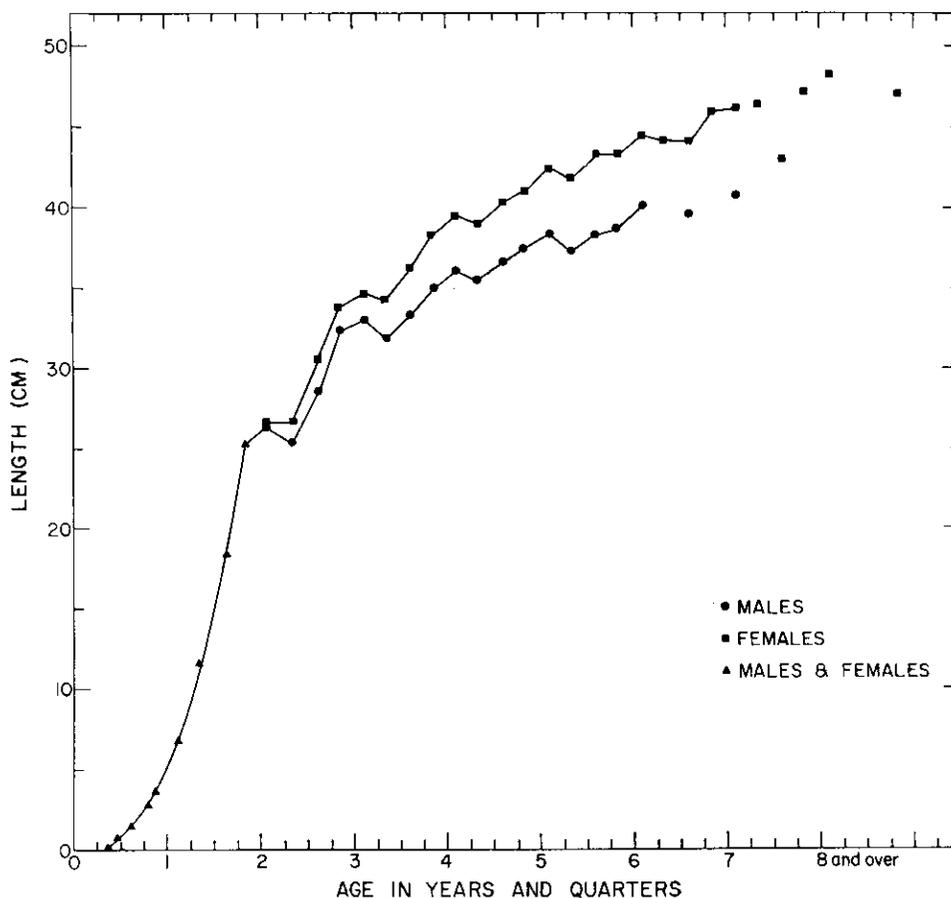


Fig. 5. Length at age of male and female yellowtail flounder on the southern New England ground, based on samples from small-mesh otter trawls through age 3 and from small-mesh and commercial otter trawls for age 4 and over. (Only lengths based on three or more age determinations are plotted.)

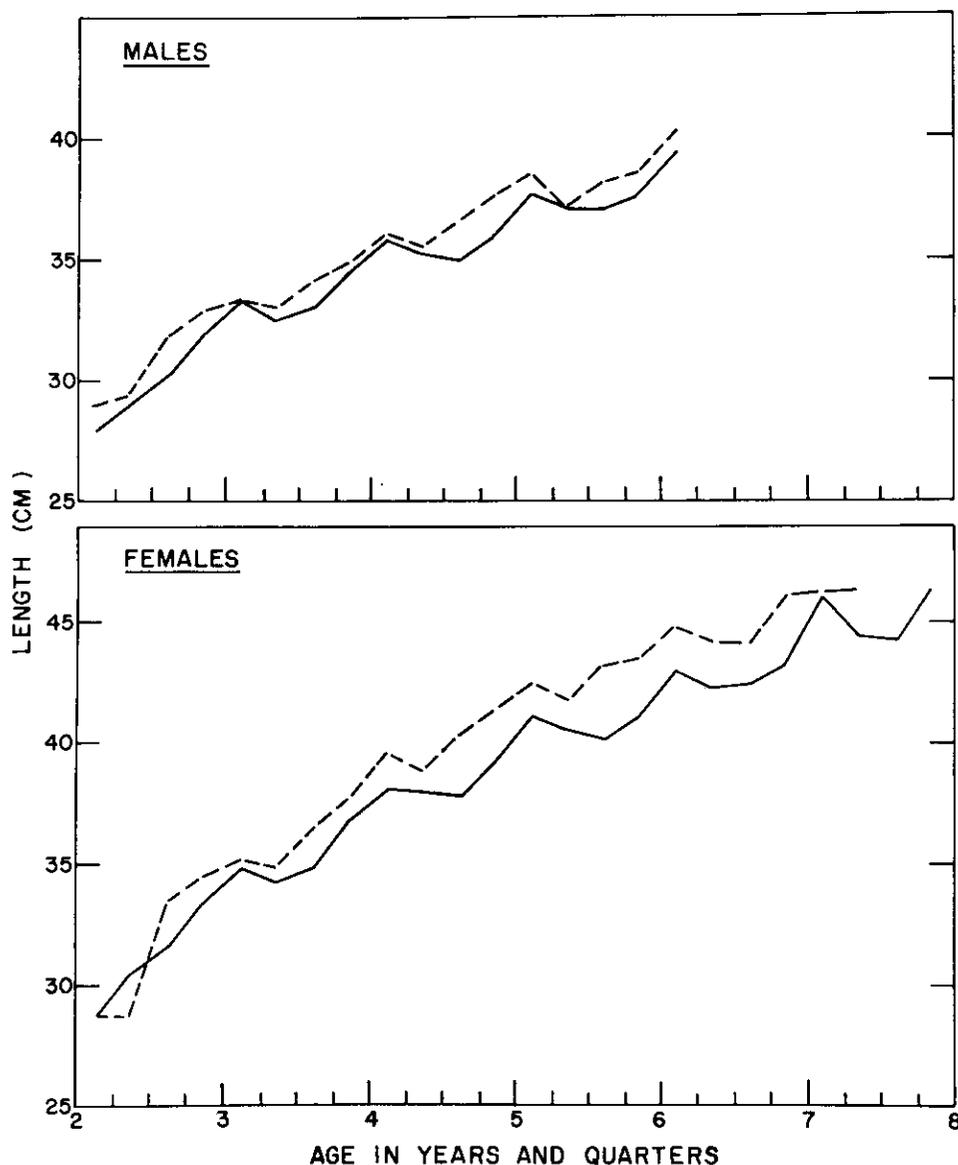


Fig. 6. Length at age for yellowtail flounder from the commercial catch on the southern New England ground in 1942-47 (solid line) and 1957-62 (broken line).

The females grow faster than males and live longer: few males older than 6 years were included in our samples, whereas 7-group females were not uncommon (Table 6).

The average length of age 2 and older fish was greater in the first quarter than in the second, rather than the reverse, as would result if size increased regularly with time (Fig. 5). The cause of this unexpected relation is not clear. Appar-

ently it is not due to a seasonal shift in fishing effort from one subarea to another where growth rate is different, because records for a single year and subarea, such as Subarea O, show the same pattern (Table 5).

Royce *et al.* (1959) suggested that the observed length differences stemmed from mixing in some seasons of yellowtail flounder of differing growth rates. Mixing between subareas within

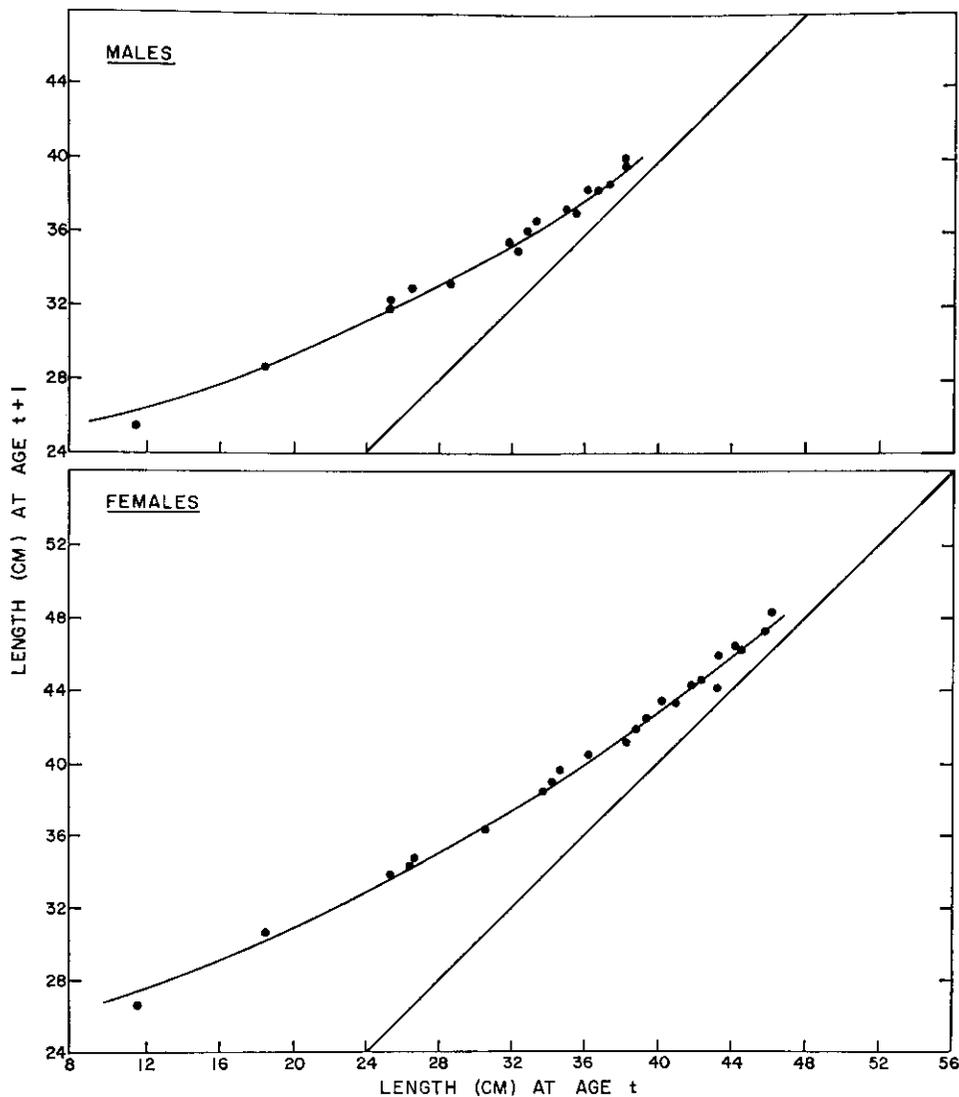


Fig. 7. Length at age t years plotted against length at age $t + 1$ years for yellowtail flounder from southern New England ground. (The curves were fitted by eye.)

the ground could have this effect on the western part of the ground. There is a westward movement in fall and winter of some fish from Subarea O, and a movement back towards the east in spring and summer. As an example, the mixing of faster growing fish from Subarea O with slower growing ones in Subarea S during the first calendar quarter would raise the average length of fish in Subarea S. Departure to the eastward of these fish in the second quarter would lower average length in Subarea S.

A further reason for the greater length of fish caught in the first quarter might be the winter

migration of fish from Georges Bank to the southern New England ground. Recoveries of marked fish show that about 5% of the fish from George Bank, where growth is faster, move to the southern New England ground in winter (Lux, 1964).

A comparison of lengths at age of fish from the commercial catch for 1942-47 on the southern New England ground (Royce *et al.*, 1959) with those for 1957-62 indicates that the 1957-62 fish were slightly larger for a given age (Fig. 6). This difference may have been due in part to an eastward shift in the distribution of fishing effort on the southern New England ground. From 1942

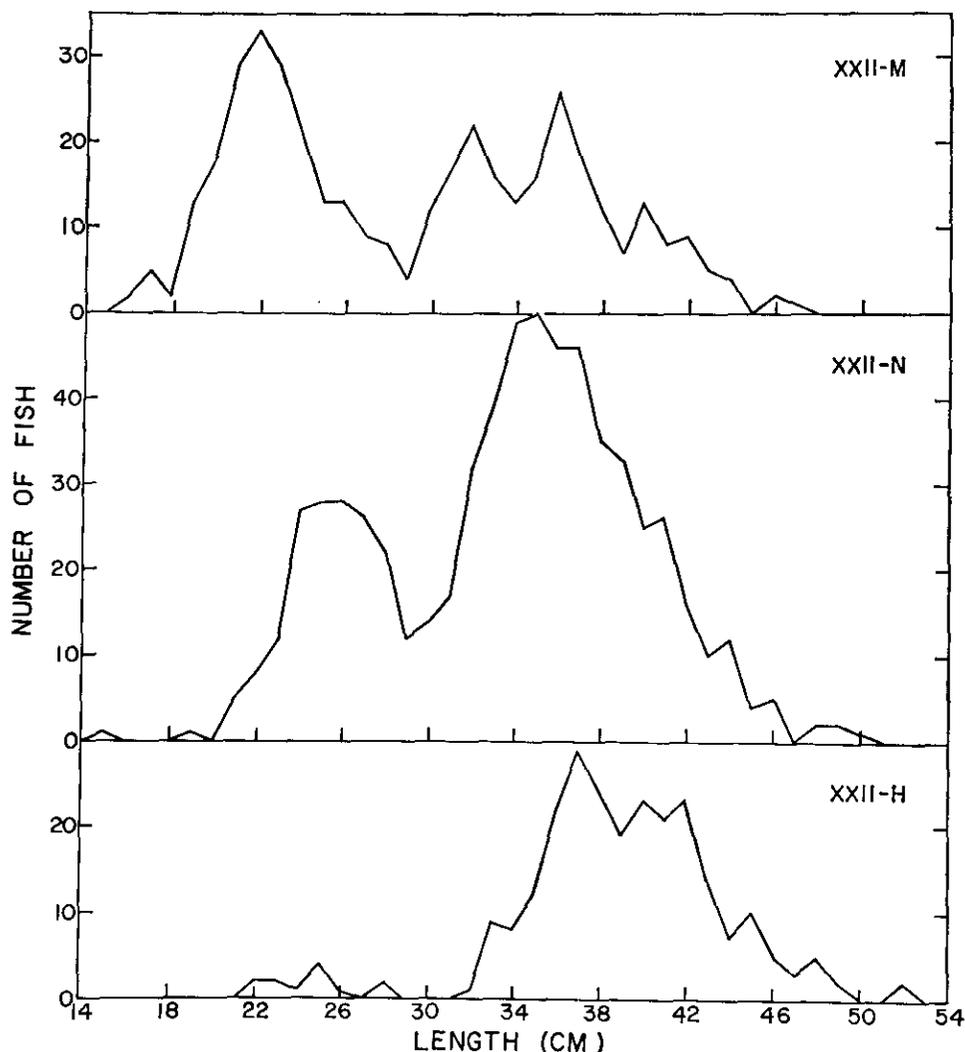


Fig. 8. Length frequency distributions by subarea for research vessel collections of yellowtail flounder (sexes combined) on Georges Bank in autumn 1963 and winter 1964.

to 1947 the percentages of landings by subarea were as follows (Royce *et al.*, 1959): Subarea O, 31%; Q, 44%; S, 18%; and area XXIII, 7%. From 1957 to 1962 they were as follows: Subarea O, 48%; Q, 37%; S, 14%; and area XXIII, 1%. Since commercial catch samples collected for growth studies were about proportional to catch in each area, greater representation was given to Subarea O in 1957-62, where growth apparently was slightly faster (Tables 4 and 5).

Plots of length at age t against length at age $t + 1$ of the data in Table 6 indicate that the relationship for yellowtail flounder is a curved one, rather than a straight line which Walford (1946)

found to be common among fishes (Fig. 7). We therefore infer that the rate of change in length increment is not constant over any part of the range of lengths covered, although it approaches constancy in later years.

The maximum attained length (l_{∞}) may be estimated from observed lengths rather than the Walford plots. Maximum lengths of fish in samples on the southern New England ground were 44 cm for males and 54 cm for females.

Georges Bank

Fishing effort for yellowtail flounder on Georges Bank is limited by abundance of fish to

TABLE 7. Numbers of fish (n) and mean lengths in cm (cm) by age-group of yellowtail flounder from commercial catches on three Georges Bank subareas in spring (April-June) and summer (July-September) in 1957-62.

Subarea	Calendar quarter	Age-group													
		2		3		4		5		6		7		8&8+	
		n	cm	n	cm	n	cm	n	cm	n	cm	n	cm	n	cm
Males															
XXII-M	Apr.-June	142	32.0	318	34.7	74	37.1	25	39.0	1	39.0	3	41.0	—	—
	July-Sep.	561	32.2	709	35.2	164	37.4	20	38.8	10	39.7	2	42.5	—	—
XXII-N	Apr.-June	23	31.6	83	34.2	28	36.8	7	37.7	2	39.5	1	42.0	—	—
	July-Sep.	98	32.8	74	35.2	31	36.8	3	39.3	1	41.0	1	42.0	—	—
XXII-H	Apr.-June	11	32.1	260	35.0	161	37.3	52	38.3	12	39.2	1	43.0	1	40.0
	July-Sep.	36	33.3	77	35.2	28	38.0	9	39.4	—	—	—	—	—	—
Females															
XXII-M	Apr.-June	36	33.1	366	37.9	179	41.7	63	44.1	22	45.3	10	47.3	5	49.2
	July-Sep.	326	34.2	918	38.4	266	41.7	101	44.4	32	45.9	7	47.4	5	50.6
XXII-N	Apr.-June	7	33.9	94	36.5	33	40.3	7	43.3	5	44.2	1	46.0	2	50.5
	July-Sep.	81	34.0	105	38.2	26	41.9	21	44.3	11	45.1	3	48.3	2	50.0
XXII-H	Apr.-June	3	34.3	202	37.2	139	41.0	62	43.5	44	45.5	20	46.8	15	47.8
	July-Sep.	30	35.5	75	38.6	16	41.8	16	43.2	5	45.4	1	46.0	2	49.5

Subarea H, M, and N. About 75% of the catch there in 1956-62 came from Subarea M. Size composition differs with subarea. The smallest fish are caught in Subarea M, those of intermediate size in Subarea N, and the largest in Subarea H, as length frequency distributions from research vessel catches show (Fig. 8). Length distributions of commercial catches are similar to those of Fig. 8 except that fish smaller than 30 cm are missing.

Lengths at age by subarea for the commercial catch in spring and summer, the seasons when the catch of yellowtail flounder on Georges Bank is highest, indicated no marked differences between subareas (Table 7). The data for the 3 subareas therefore were combined to provide an estimate of growth on all of Georges Bank for each year (Table 8). These data indicated that year to year differences in size for a given age, if present, were small. Growth information for all years therefore was combined.

The growth data for males and females, by calendar quarter, for the combined collections from small-mesh nets and commercial catches for 1-group and older fish are given in Table 9. These data and the growth of 0-group fish are graphed in Fig. 9. Growth was similar to that on the southern New England ground, but the proportion of older fish was greater on Georges Bank.

Yellowtail flounder of age-group 3 and older usually were slightly longer in the first quarter than in the second (Fig. 9), as was true for fish on the southern New England ground (Fig. 5). Age 4 fish from the second quarter 1962, for example, were shorter than those from the first quarter (Table 8). Such differences may have stemmed from seasonal within-group or between-group movements of fish of differing growth rates, as we suggested for the southern New England ground, but present information is insufficient to identify causes.

TABLE 8. Numbers of fish (n) and mean lengths in cm (cm) by age-group of yellowtail flounder from the commercial catch on Georges Bank in 1957-62, by calendar quarter and year.

Calendar quarter and year	Sex and age-group																												
	Male							Female																					
	2	3	4	5	6	7	8 & 8+	2	3	4	5	6	7	8 & 8+															
n	cm	n	cm	n	cm	n	cm	n	cm	n	cm	n	cm	n	cm														
Jan.-Mar.																													
1959	—	9	35.0	1	40.0	1	42.0	—	—	9	38.3	10	40.9	2	41.5	2	45.5	1	45.0	—	—								
1960	1	31.0	3	35.3	10	38.3	10	38.7	—	—	—	—	5	41.8	10	44.6	7	46.1	3	47.0	—	—							
1961	1	33.0	43	35.4	9	36.5	14	39.1	7	40.5	1	41.0	—	—	22	38.4	5	40.0	10	43.2	17	44.9	8	49.3	12	49.0			
1962	2	31.5	90	34.6	98	37.6	27	40.0	12	40.2	4	42.2	1	43.0	1	31.0	74	37.3	89	41.4	36	43.4	21	46.2	19	47.6	10	50.1	
Total or mean	4	31.8	145	34.9	118	37.6	52	39.6	19	40.3	6	42.0	1	43.0	1	31.0	105	37.6	109	41.3	58	43.5	47	45.7	31	47.9	22	49.5	
Apr.-June																													
1957	9	32.3	3	34.0	2	38.0	—	—	—	—	—	—	—	—	8	33.0	14	38.9	10	41.5	4	44.0	—	—	—	—	—	—	
1958	25	32.7	132	34.4	35	37.4	14	39.8	1	39.0	1	42.0	—	—	5	33.0	147	37.2	56	41.5	16	43.9	11	45.3	6	47.5	2	50.5	
1959	45	31.7	63	35.4	99	36.8	19	37.3	3	38.3	—	—	—	—	4	35.0	79	38.3	132	41.1	20	43.2	14	45.7	8	46.7	5	48.2	
1960	64	31.8	55	35.1	36	37.8	26	39.1	1	39.0	1	43.0	1	40.0	20	33.2	78	37.9	56	42.1	54	44.2	9	45.2	3	46.7	2	47.5	
1961	26	32.0	215	35.0	26	37.9	10	37.8	4	39.7	—	—	—	—	5	33.0	202	37.5	38	41.5	20	44.4	17	45.8	7	46.6	8	48.1	
1962	7	30.1	163	34.6	65	37.0	15	38.1	6	39.5	3	41.0	—	—	3	33.7	142	37.0	79	40.8	18	42.4	20	44.8	7	47.1	5	48.4	
Total or mean	176	31.9	631	34.8	263	37.2	84	38.5	15	39.2	5	41.6	1	40.0	45	33.3	662	37.5	351	41.3	132	43.8	71	45.3	31	46.9	22	48.4	
July-Sept.																													
1957	86	32.1	37	35.9	1	40.0	—	—	—	—	—	—	—	—	82	34.0	118	38.2	43	42.1	11	44.5	1	47.0	1	51.0	—	—	
1958	111	32.5	191	34.8	20	37.5	3	39.7	2	43.5	—	—	—	—	33	33.7	246	38.3	44	41.4	17	45.3	9	44.7	—	—	—	—	
1959	82	31.7	76	35.4	56	36.4	1	41.0	—	—	1	44.0	—	—	47	33.6	106	38.8	64	41.8	18	44.5	8	45.8	4	48.2	—	—	
1960	145	32.6	89	35.2	35	37.7	14	39.3	—	—	—	—	—	—	112	34.3	106	38.7	41	42.5	34	44.0	2	47.0	—	—	3	49.7	
1961	122	32.8	214	35.5	23	38.0	5	39.4	5	37.6	—	—	—	—	88	34.7	228	39.0	22	42.3	21	44.9	11	45.5	3	47.0	1	49.0	
1962	149	32.3	253	35.2	88	37.6	9	38.1	4	40.8	2	41.5	—	—	75	34.6	294	38.0	94	41.2	37	43.6	17	46.0	3	46.0	5	50.8	
Total or mean	695	32.4	860	35.2	223	37.4	32	39.1	11	39.8	3	42.3	—	—	437	34.2	1098	38.4	308	41.7	138	44.3	48	45.7	11	47.5	9	50.2	
Oct.-Dec.																													
1957	8	32.8	14	35.6	3	38.7	—	—	—	—	—	—	—	—	8	34.4	10	39.2	6	42.7	1	41.0	—	—	—	—	—	—	
1958	43	33.0	77	35.9	20	38.4	5	40.4	—	—	—	—	—	—	30	35.8	77	39.4	16	43.5	16	45.4	3	46.3	1	51.0	1	51.0	
1959	24	31.9	17	34.4	9	37.6	—	—	—	—	—	—	—	—	9	33.9	23	39.2	16	41.9	2	46.0	—	—	—	—	—	—	
1960	103	33.6	47	36.5	12	38.5	6	39.3	—	—	—	—	—	—	91	35.9	47	39.7	21	43.1	9	45.1	1	50.0	—	—	—	—	
1961	88	33.3	86	36.0	19	37.4	5	40.4	2	38.0	—	—	—	—	73	35.4	82	39.8	23	42.4	12	46.0	6	46.3	—	—	2	48.5	
1962	62	33.6	68	35.6	16	38.2	2	42.0	1	43.0	1	45.0	—	—	56	35.6	64	38.8	16	42.6	10	45.1	1	47.0	2	47.0	1	51.0	
Total or mean	328	33.3	309	35.8	79	38.1	18	40.2	3	39.7	1	45.0	—	—	267	35.6	303	39.4	98	42.7	50	45.4	11	46.7	3	48.3	4	49.8	

TABLE 9. Numbers of fish (n) and means lengths in cm (cm) by age-group of yellowtail flounder (samples from small-mesh and commercial-otter trawls combined) from Georges Bank in 1957-64, by calendar quarter. (Commercial samples were included only for fish of age 4 or older.)

Calendar quarter	Age-group																	
	1		2		3		4		5		6		7		8		8+	
	n	cm	n	cm	n	cm	n	cm	n	cm	n	cm	n	cm	n	cm	n	cm
Males																		
Jan.-Mar.	1	7.0	4	25.5	12	33.4	135	37.3	55	39.6	21	40.2	6	42.0	1	43.0	—	—
Apr.-June	—	—	—	—	—	—	263	37.2	84	38.5	15	39.2	5	41.6	1	40.0	—	—
July-Sept.	75	18.1	48	30.2	37	34.9	244	37.4	39	39.1	11	39.8	4	42.7	—	—	—	—
Oct.-Dec.	285	22.8	74	32.1	110	35.8	97	38.1	25	40.6	3	39.7	1	45.0	—	—	—	—
Females																		
Jan.-Mar.	1	7.0	4	23.0	5	36.4	135	41.3	63	43.6	48	45.7	32	47.9	15	49.0	7	50.6
Apr.-June	—	—	—	—	—	—	351	41.3	132	43.8	71	45.3	31	46.9	14	47.7	8	49.5
July-Sept.	75	18.1	41	30.6	27	37.5	330	41.7	143	44.3	48	45.7	13	48.2	5	49.4	4	51.2
Oct.-Dec.	285	22.8	56	34.7	108	39.7	121	42.6	55	45.3	14	46.9	7	47.7	4	50.0	1	48.0

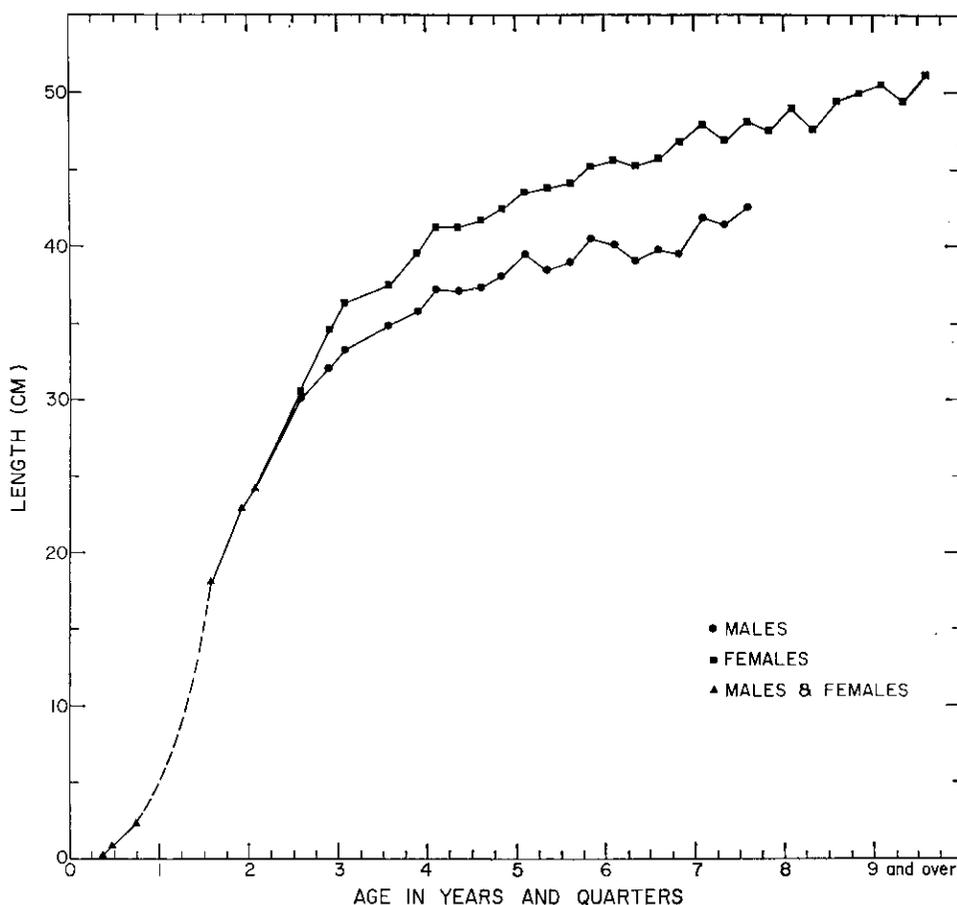


Fig. 9. Length at age of male and female yellowtail flounder on Georges Bank based on samples from small-mesh otter trawls through age 3 and small-mesh and commercial otter trawls for age 4 and over. Only lengths based on three or more age determinations are plotted. Part of the growth curve for the second year (broken line) was estimated from the growth on the southern New England ground, in lieu of data for Georges Bank.

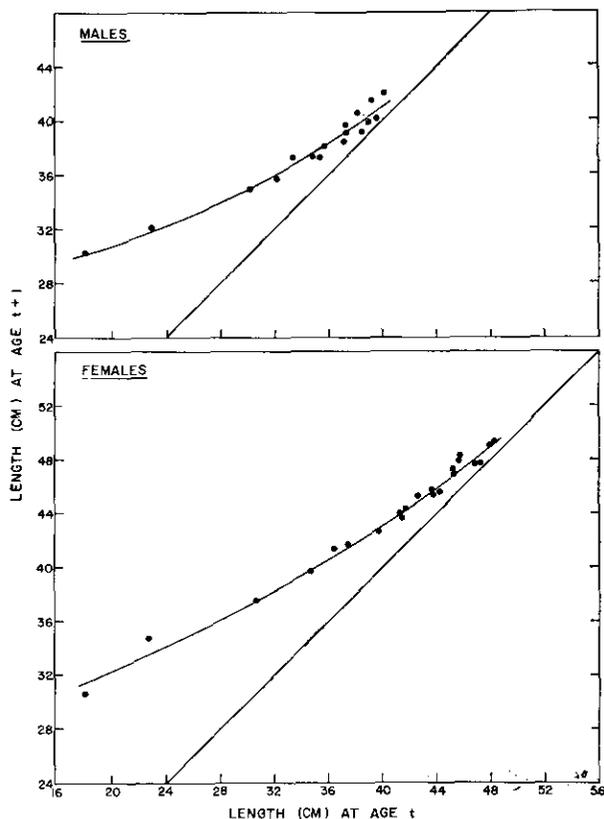


Fig. 10. Length at age t years plotted against length at $t + 1$ years of yellowtail flounder from Georges Bank. (The curves were fitted by eye.)

The relationship between length at time t and at time $t + 1$, as on the southern New England ground, is represented by a curved line (Fig. 10). Approximations of l_{∞} , based on maximum observed lengths, were 45 cm for males and 56 cm for females.

Cape Cod Ground

The yellowtail flounder catch from the Cape Cod ground in 1956–62 was less than 10% of the total catch of this species, and fishing effort there has been correspondingly low. We therefore have obtained few samples from the commercial catch and have had to rely largely on research vessel samples for growth information.

The Cape Cod ground has two yellowtail flounder fishing areas. The first of these, which supplies about 75% of the catch, extends along the outer face of Cape Cod in water 10–65 m deep

from Pollock Rip lightship on the south ($41^{\circ}32'N$) to Race Point on the north ($42^{\circ}05'N$). The other area is Stellwagen Bank, a small shoal ground whose southern edge is about 5 miles north of Race Point. Our growth information applies to the first area and particularly to the part that lies in Subarea G (Fig. 1).

We combined growth data for all years to obtain average lengths at age for each calendar quarter (Table 10). These averages are graphed in Fig. 11. Differences in growth of males and females were similar to those for fish from the other grounds; however, the data were insufficient to show if there was a seasonal pattern in length at age here as was indicated on the other two grounds.

Estimates of l_{∞} from maximum lengths observed in regular catch samples were 47 cm for males and 54 cm for females. The longest yellowtail flounder that we have seen, however, brought to our attention by fishermen, came from this ground. Three of these, all females, exceeded 60 cm in length; the largest was 64 cm long and weighed 2.4 kg. The age of this fish was estimated (from scale examination) to be 14 years.

Growth Comparisons

Curves fitted by eye to the growth data presented in the preceding sections give the approximate relative rates of growth of yellowtail flounder on the 3 grounds (Fig. 12). The southern New England fish were slightly larger than those from Georges Bank from about $1\frac{1}{2}$ to $2\frac{1}{2}$ years of age. After the middle of the third growing season the Georges Bank fish were larger.

On the Cape Cod ground, yellowtail flounder apparently grew slower than on the other grounds in early years and faster in later years (Fig. 12). More rapid growth in later life is consistent with our earlier observation that the largest yellowtail flounder are found on the Cape Cod ground.

The Growth Rate Equation

We estimated the growth rate for the most intensively fished part of the New England yellowtail flounder population by combining lengths at age for the first calendar quarter for the southern New England ground with those for the third quarter for Georges Bank (Tables 6 and 9). Fishing effort is relatively high during these quarters

TABLE 10. Numbers of fish (n) and mean lengths in cm (cm) by age-group of yellowtail flounder (samples from small-mesh and commercial-otter trawls combined) from Cape Cod ground in 1957-64, by calendar quarter (commercial samples were included only in the summary of age 4 and older fish).

Calendar quarter	Age-group																	
	1		2		3		4		5		6		7		8		9	
	n	cm	n	cm	n	cm	n	cm	n	cm	n	cm	n	cm	n	cm	n	cm
Males																		
Jan.-Mar.	4	9.0	126	23.4	87	33.5	56	37.8	6	40.3	—	—	—	—	—	—	—	—
Apr.-June	—	—	—	—	—	—	13	37.2	3	39.7	3	41.3	—	—	—	—	—	—
July-Sep.	8	15.3	—	—	—	—	2	36.5	—	—	—	—	—	—	—	—	—	—
Oct.-Dec.	249	21.4	209	31.0	32	35.4	40	38.7	8	41.2	—	—	—	—	—	—	—	—
Females																		
Jan.-Mar.	4	9.6	109	23.4	44	33.8	74	40.2	22	41.8	4	46.8	—	—	—	—	—	—
Apr.-June	—	—	—	—	—	—	35	41.2	7	43.9	5	45.5	1	46.0	1	46.0	—	—
July-Sep.	8	15.3	—	—	—	—	19	41.3	1	45.0	—	—	—	—	—	—	—	—
Oct.-Dec.	249	21.4	126	31.9	47	38.9	86	42.7	43	45.6	13	47.0	4	47.2	3	49.0	1	50.0

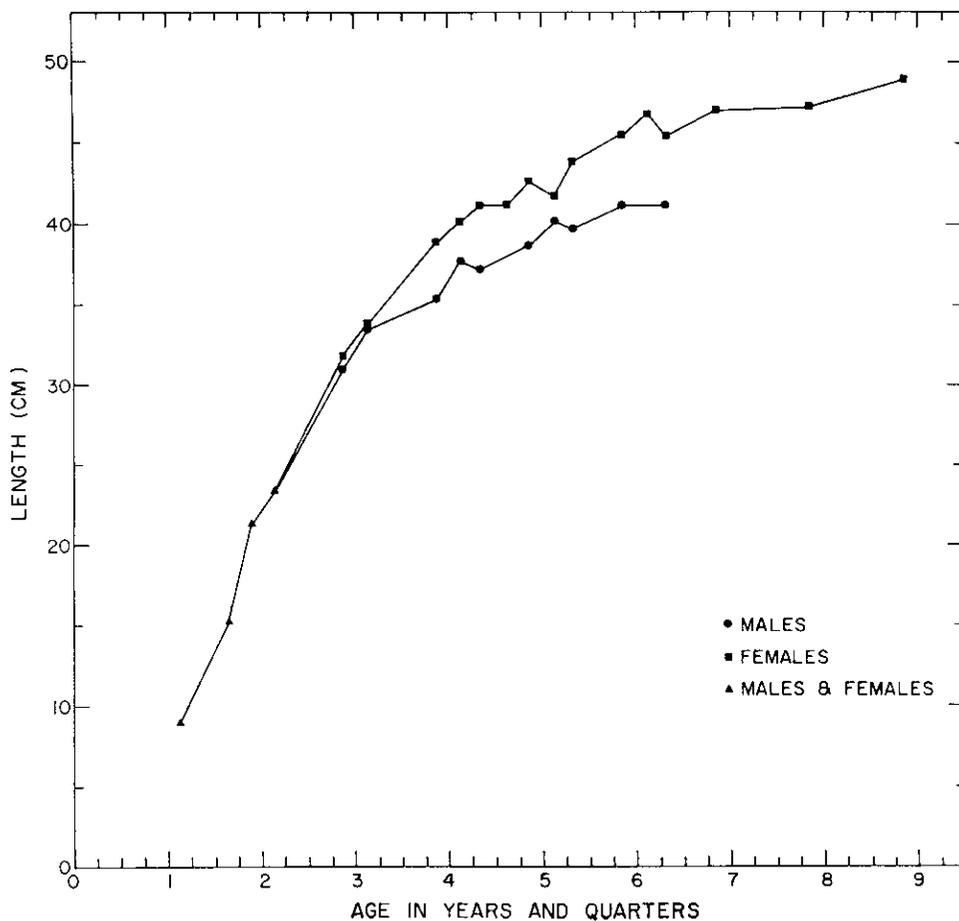


Fig. 11. Length at age of male and female yellowtail flounder on the Cape Cod ground. Data for fish through age 3 were from small-mesh otter trawl samples; for older fish, samples from small-mesh and commercial otter trawls were combined. (Only lengths based on three or more age determinations are plotted.)

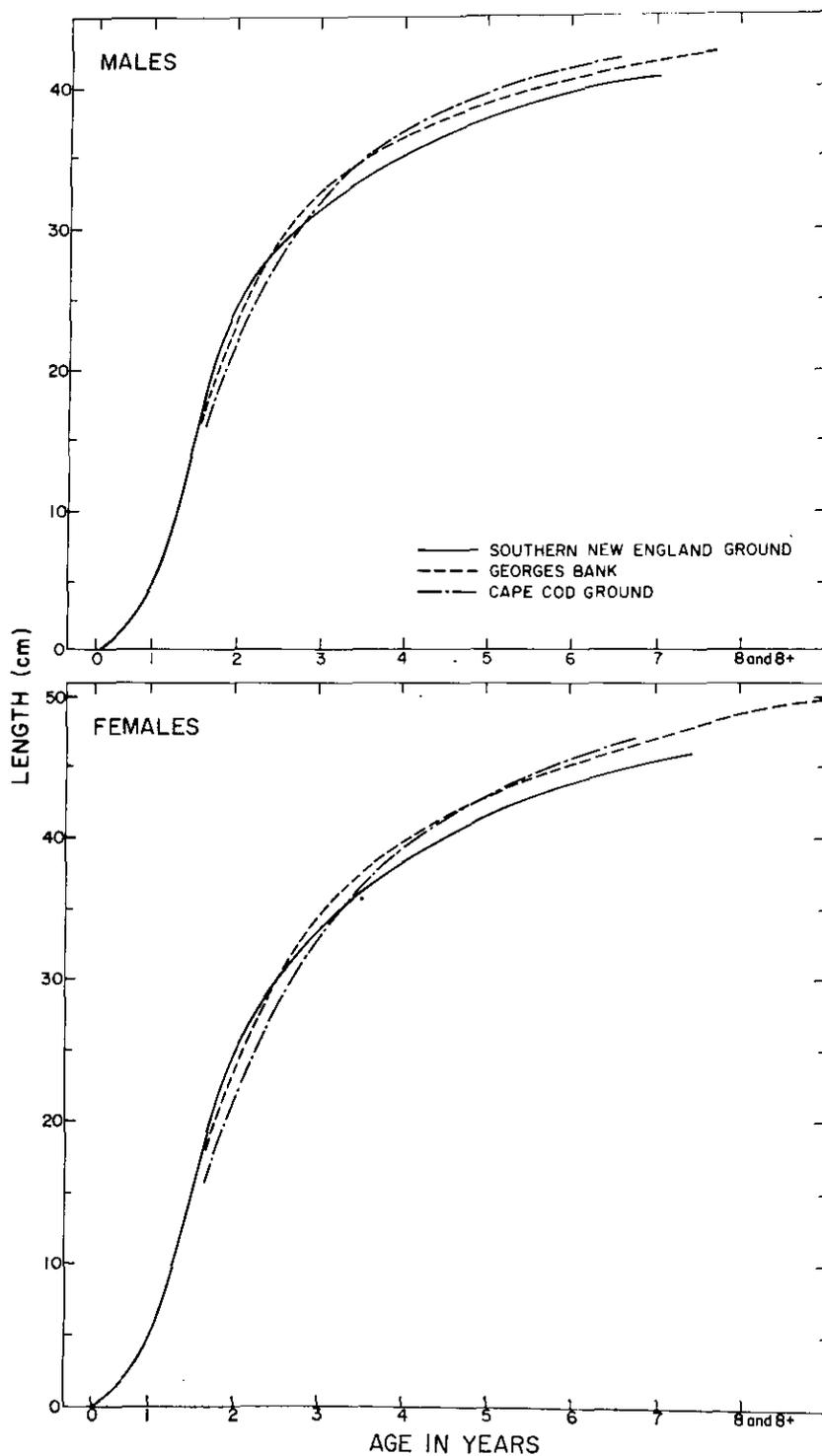


Fig. 12. Growth curves for yellowtail flounder on the southern New England ground, Georges Bank, and the Cape Cod ground. (The curves were fitted by eye to data from Figs. 5, 9, and 11.)

on the respective grounds (Lux, 1964). Growth data for males and females from each ground, adjusted by the sex ratio of fish in commercial catches, were combined to give length at age for the population as a whole. The plotted data followed a smooth curve (Fig. 13).

A Bertalanffy growth equation of the form

$$l_t = l_\infty (1 - e^{-K(t-t_0)})$$

in which l is length in millimeters, t is age in years, and K is a constant determining the rate of change in length increment was fitted, by the method of Ricker (1958), to the part of the curve for fish of commercial size (age 2 and older). The resulting equation

$$l_t = 500 (1 - e^{-0.335(t+0.26)})$$

fits the empirical points well over the range of ages considered (Fig. 13).

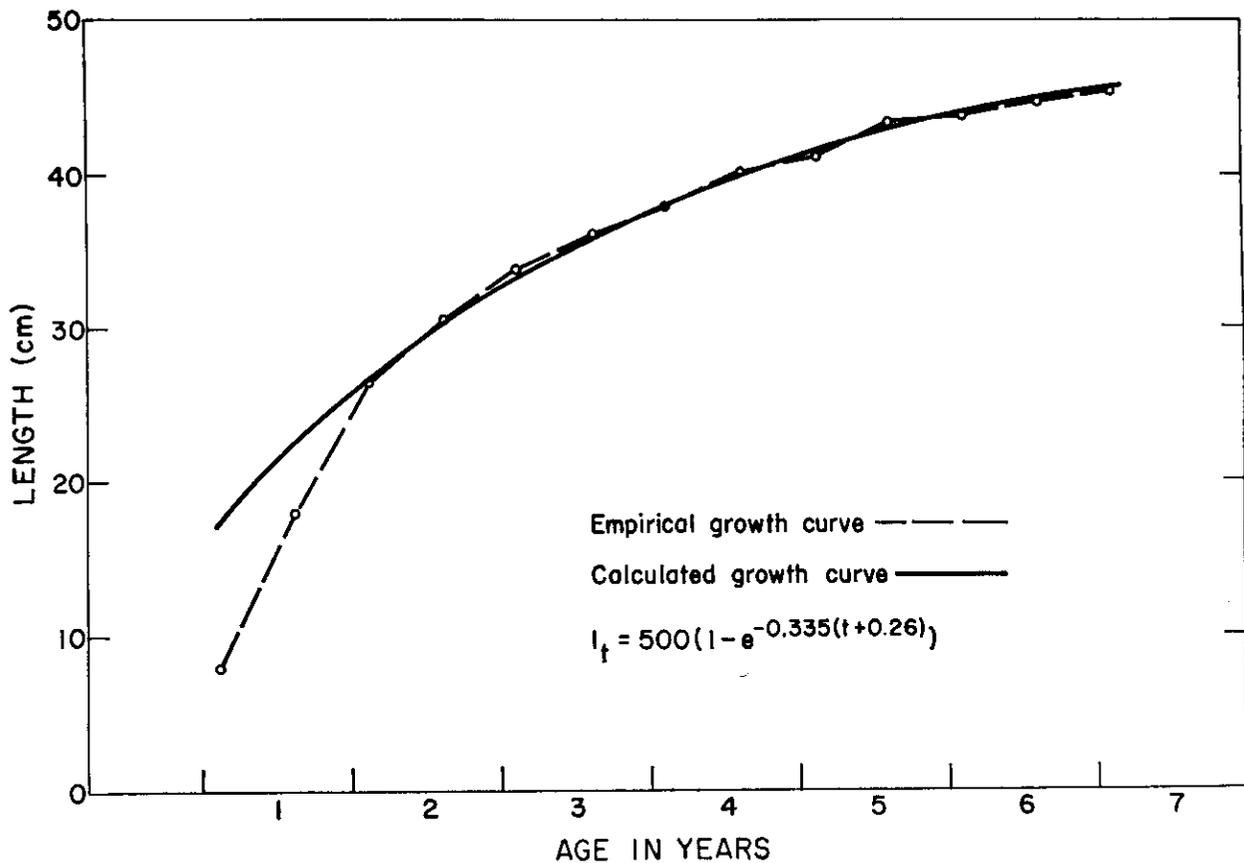


Fig. 13. Empirical growth curve for yellowtail flounder, sexes combined, for the southern New England ground (first calendar quarter) and Georges Bank (third calendar quarter) and the graph of the fitted Bertalanffy growth equation for fish beyond age 2.

Summary

Seasonal growth marks on yellowtail flounder scales permit accurate assessment of age of the fish. Length at age was determined from scales of fish from the three New England grounds where most of the catch is made. Scales were obtained from catches by the commercial fishing fleet and research vessels. Rate of growth differs slightly from ground to ground. Females grow faster than males and live longer. Growth, particularly in early years, is rapid; length at age for combined sexes is 8 cm at age 1, 26.5 cm at age 2, 34 cm at age 3, 38 cm at age 4, and 41 cm at age 5. Length from age 2 onward is represented by the Bertalanffy growth equation

$$l_t = 500 (1 - e^{-0.335(t+0.26)})$$

in which l is length in millimeters and t is age in years.

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Empirical Assessments of Catch/Effort Relationships in North Atlantic Cod Stocks

BY D. J. GARROD¹

Abstract

The empirical relationships between catch per unit effort and fishing effort have been compared for seven major cod stocks in the North Atlantic, using generalized indices of stock abundance and fishing intensity. The comparisons show that these cod stocks have broadly similar yield/intensity curves and that the overall level of fishing them is adequate to secure the maximum sustainable yield. There is no clear indication for any one stock that the present level of fishing is well beyond the optimum; this conflicts with previous evidence based on more rigorous analysis.

Introduction

It is obviously desirable to base stock assessments upon critical analyses of the parameters influencing population size in particular stocks. For the most part these studies have in the past depended upon catch per unit effort/effort analysis, or more recently, upon 'virtual population' analysis, as extended by Gulland (1965), which overcomes in some measure the inherent variability of catch per unit effort data. The use of this technique has recently led to a substantial modification of the assessment of the Iceland cod stock based upon the catch per unit effort data (ICES, 1968*a*), and it seems possible that analogous studies of the Northwest Atlantic cod stocks will also be hampered by the difficulties of constructing an adequate series of consistent data. Therefore, it is relevant to seek confirmation of the analytical models by the alternative, but less rigorous, approach developed by Schaefer (1954) and extended by Gulland (1961). This method does have the advantage that its generality includes the variations in absolute yield which are generated by density dependent changes in the fundamental population parameters and which are in practice excluded from most analytical assessments to date, owing to the difficulty of defining these factors with any degree of precision. More-

over, the method facilitates rapid comparison of data from different fisheries and enables one to draw upon the effects of fishing in stocks that have been exploited intensively for a longer period than the Northwest Atlantic stocks, which have been subjected to a rapid increase in fishing only in recent years.

Method

Once recruitment is complete the abundance of an exploited fish population is for the most part determined by the amount of fishing to which the constituent age groups have been exposed. However, in all exploited cod stocks it is easy to identify a number of age groups which contribute the major proportion of the abundance of the exploited stock in any year, and so, as an approximation, it can be said that the abundance in that year is determined by the fishing effort to which these age groups have been exposed. Most of the cod stocks of the North Atlantic make their major contribution as 5-, 6- and 7-year olds, so the measured abundance would include primarily the effects of recruitment, and of fishing during the year of sampling and the preceding 2 years.

If the abundance is measured as the numbers of fish caught per unit effort, then provided recruitment remains constant, this index will decline exponentially with increasing fishing effort. However, data for a series of years during which effort has changed considerably are necessary to detect the effect of increasing effort upon the abundance of the stock, and at the present time only the landed weight per unit effort is available for the necessary period for most stocks. The relationship between the landed weight per unit effort and increasing effort is mathematically more complex; in fact at high levels of effort this relation would be rather lower than one based on numbers, owing to the lower mean weight of fish caught at high levels of exploitation. Conversely one can argue that this tendency would be offset by

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TABLE 1. Basic catch statistics of North Atlantic cod stocks. Catch—thousands of tons round fresh; Effort—equivalent UK hours fishing by 760 ton side trawler; Catch per unit effort (C.P.U.E.)—tons per hour UK 760 ton side trawler.

Year	Barents Sea			Bear Island			Iceland			Faroe		
	Catch	Effort	C.P.U.E.	Catch	Effort	C.P.U.E.	Catch	Effort	C.P.U.E.	Catch	Effort	C.P.U.E.
1946	200	88	2.32	210	31	6.95	279	161	1.76	30	39	0.80
1947	341	136	2.55	165	51	3.32	306	230	1.35	31	53	0.59
1948	407	207	1.98	131	52	2.58	322	281	1.16	21	52	0.41
1949	485	227	2.15	127	45	2.88	362	344	1.06	28	53	0.54
1950	356	322	1.12	164	84	1.98	362	404	0.90	36	73	0.50
1951	408	418	0.99	140	97	1.45	347	399	0.87	35	86	0.42
1952	524	549	0.97	106	72	1.48	401	477	0.85	34	86	0.39
1953	443	527	0.85	104	76	1.40	523	515	1.03	27	70	0.40
1954	598	564	1.07	99	72	1.38	545	587	0.94	36	74	0.49
1955	831	731	1.15	153	86	1.79	537	561	0.97	39	78	0.50
1956	787	838	0.95	324	178	1.83	482	513	0.95	28	76	0.36
1957	400	612	0.66	257	251	1.03	457	613	0.75	31	81	0.40
1958	388	621	0.63	229	251	0.92	520	706	0.74	28	101	0.28
1959	323	472	0.69	243	267	0.92	460	745	0.62	26	105	0.25
1960	380	702	0.55	102	129	0.80	474	899	0.53	39	160	0.25
1961	408	714	0.58	222	229	0.98	383	895	0.43	27	170	0.16
1962	540	789	0.69	223	223	1.01	388	844	0.46	24	129	0.19
1963	540	855	0.64	116	157	0.74	412	875	0.49	24	113	0.21
1964	203	539	0.43	126	109	0.69	435	109	0.42	25	96	0.27
1965	241	415	0.49	107	100	0.81	394	922	0.43	27	102	0.27
1966	289	519	0.56	55	93	0.59	357	787	0.46	23	82	0.28

Year	West Greenland			Labrador			Newfoundland		
	Catch	Effort	C.P.U.E.	Catch	Effort	C.P.U.E.	Catch	Effort	C.P.U.E.
1954	297	125	2.38	22	7	3.07	472	384	1.23
1955	268	123	2.18	26	10	2.69	429	394	1.09
1956	322	131	2.45	34	10	3.36	390	342	1.14
1957	269	155	1.73	32	12	2.78	449	420	1.07
1958	320	200	1.60	40	21	1.92	294	330	0.89
1959	233	204	1.14	60	29	2.08	425	373	1.14
1960	236	231	1.02	150	58	2.60	470	465	1.01
1961	348	247	1.41	265	109	2.44	461	387	1.19
1962	451	228	1.98	255	106	2.40	389	357	1.09
1963	396	285	1.39	216	85	2.53	466	324	1.44
1964	350	248	1.41	213	102	2.09	581	421	1.38
1965	358	298	1.20	332	193	1.72	496	517	0.96
1966	366	248	1.47	338	181	1.87	499	466	1.07

density dependent changes in the stock, or by a reduction in the rate of discarding on board the fishing vessels. Consequently, it is meaningful to approximate the relationship between catch weight per unit effort and effort by the logarithmic regression that would be applied to catch numbers, plotting the logarithm of the catch per unit effort against the mean fishing effort in the year of sampling and the preceding 2 years.

This technique has been applied to data for the following cod fisheries: Barents Sea; Bear Island; Iceland; Faroe; West Greenland; Labrador; Newfoundland; and is shown in Table 1. There are difficulties in this area breakdown, because each area does not necessarily support one

unique unit stock. The Barents Sea/Bear Island fisheries are part of the Arcto-Norwegian stock complex, so that the exclusion of the Norway coast fishery, which also exploits the same stock, will lead to an underestimate of effort. This is perhaps not important in this context, because the abundance of the stock in these two fisheries depends on the abundance of the immature cod, and at this stage of life the two stocks are independent (Garrod, 1967). At Faroe two stocks—the plateau and the bank—are included in the one set of data (Jones, 1966). At Iceland the stock situation is not as well understood as had been thought, for it has become evident that the catch per unit effort given is not a measure of the total

abundance of the stock; however, it does measure a part of it, in the same way as the Barents Sea and Bear Island data measure a part of the Arcto-Norwegian stock. To this extent the estimates of catch per unit effort are valid, but the total international effort is certainly overestimated (ICES, 1968*a*). The distribution of the Northwest Atlantic cod stocks was described by Templeman (1962); from his analysis, and subsequent national research reports (ICNAF, 1962-67), and the work of Hodder (1965) it is clear that the Labrador stock extends into Subarea 3, and even excluding this the consideration of the statistics from Subarea 3 as a single unit clearly includes data from more than one other stock.

To facilitate the comparison between stocks the catch per unit effort data for the seven areas shown in Table 1 have been reduced to a standard unit, i.e. the catch per hour of a 760 ton English distant-water side trawler. For the Northeast Atlantic fisheries this is available directly from national data and has been taken from the reports of various ICES Working Groups in recent years (ICES, 1967, 1968*a*, 1968*b*). For the Northwest Atlantic stocks some conversion device has been necessary. For West Greenland cod the basic catch per unit effort is the mean of the index recorded by three groups of Portuguese dory vessels, Portuguese side trawlers (901-1800 ton), Spanish side trawlers (901-1800 ton), and German side trawlers (501-900 ton), expressed relative to the index of abundance that these groups recorded in 1954. This follows a procedure adopted by the West Greenland Working Group (ICNAF, 1966). Data for the Labrador stock have been derived from those given by Hodder (1965) for Portuguese trawlers from January to June, and for Newfoundland the basic unit is the mean of the catch per unit effort of French, Portuguese, and Spanish trawlers derived in a manner analogous to that for the West Greenland stock (ICNAF 1954-67). These various units of effort have then been converted to the English unit by appropriate conversion factors based on the comparisons of fishing between the various fleets in recent years, when the English vessels have fished these Subareas to a greater extent. In fact, provided that this conversion has remained constant its accuracy does not matter, because the subsequent treatment of the data depends on the relative changes in catch per unit effort within, rather than between, stocks.

The total international effort has been estimated in the conventional way from the total

catch and the English catch per unit effort. This method was used in order to obtain comparable data for a wide selection of cod stocks, but it does in itself create some error in subsequent analysis because the regression variables are not independent. The data were adequate to satisfy this criterion for only two fisheries (Barents Sea and Bear Island), using USSR estimates of abundance and estimates of effort based on UK data.

Results

The regression equations of the catch per unit effort/effort relationships are given in Table 2, giving the intercept as an estimate of the initial abundance of the unexploited stock, and the regression coefficient as a measure of the effect of fishing effort. This table also contains, in parentheses, the parameters for the Barents Sea and Bear Island fisheries estimated from truly independent variables. Those for the Bear Island fishery are very similar to those estimated from the non-independent variables, and for the Barents Sea fishery a part of the increased variation has been caused by a shift in the objectives of the USSR fleet from cod to redfish in the late 1950's, resulting in underestimates of the abundance of cod. The general conformity of the two sets of estimates indicates that the use of partially independent variables has not biased the general interpretation of the relationships to a great extent.

The correlations are good for the Northeast Atlantic stocks, showing that despite the theoretical shortcomings the relation between catch and effort is adequately described by the technique used. Variability about the regression can be ascribed to variation in year-class strength, and sampling errors. If the errors in the treatment of data are comparable between stocks, then the greater variability of the regression for the West Greenland and Labrador stocks can be attributed to proportionately greater fluctuations in year-class strength or availability. There is ample evidence of this in more rigorous studies of those fisheries (Horsted, 1967; May, 1966). There is no regression for the Newfoundland fishery, owing to its stability during the period for which data are available.

The regression coefficient is a measure of the effect of the unit of effort chosen, and clearly this generates a greater effect on some stocks. But fishing mortality is more correctly related to fishing intensity. If a constant fishing intensity

TABLE 2. Regression equations of \log_e catch, in tons per hour, against international fishing effort, in standard UK trawler units, for North Atlantic cod stocks. (Figures in parentheses are the parameters estimated from truly independent variables.)

Fishing area	Regression intercept	Regression slope coefficient	SE of R	Correlation coefficient	Ratio of R (Bear Island) to R (stock)	Area of stock ('000 of square nautical miles)	Ratio of stock area to Bear Island area
Barents Sea	+0.734	-0.00173 (-0.00106)	0.00035 (0.00052)	-0.766 (-0.489)	2.693	210	4.04
Bear Island	+0.803	-0.00466 (-0.00551)	0.00113 (0.00138)	-0.705 (-0.738)	1.000	52	1.00
Iceland	+0.508	-0.00152	0.00027	-0.805	3.065	51	1.00
Faroe	-0.125	-0.01081	0.00115	-0.916	0.431	6	0.12
West Greenland	+0.893	-0.00235	0.00139	-0.492	1.982	81	1.56
Labrador	+0.975	-0.00213	0.00105	-0.561	2.187	149	2.63
Newfoundland	—	-0.00209 ^a	—	—	2.230	111	2.13

^aEstimated value only.

generates a constant fishing mortality, i.e. if the reaction of cod to fishing gear is constant, then the difference between the regression coefficients reflects the greater effort required to generate equivalent fishing intensity in the different stocks, which itself might be expected to be related to differences in the areas occupied by them (see Appendix and Fig. 3). The fishing effort on each stock has therefore been weighted to give a fishing intensity equal to that on the Faroe stock (that with the smallest area), using the ratios of the regression coefficients.

Similarly, although the absolute magnitudes of these stocks are different they can be generalized by measuring the proportional decline from the original unexploited stock size in relation to increasing fishing effort. The data in this form are plotted in Fig. 1. The linear regression is an adequate expression of these data. It should perhaps be slightly concave downward, and this would flatten a derived yield curve, but it has no bearing on the relative positions of the various stocks on this curve, which is the object of this contribution.

This generalized yield curve and 'Schaefer plots' are given in Fig. 2. The implication of this technique is that all the North Atlantic cod stocks

have identical relative yield curves. This is not unacceptable when one considers the logical conclusion of the constant parameter model as developed by Beverton and Holt (1964). The values of M/K can be presumed to be nearly constant, except for Faroe cod and, for practical purposes, the ratio L_0/L_∞ is also approximately constant between stocks, since comparable mesh sizes are in use throughout the areas, and the asymptotic lengths are not very different, within the accuracy of existing data, except for the Labrador stock.

Discussion

The present level of exploitation of the various fisheries in these terms is added to Fig. 2, showing the present level below the function, and, where relevant, the peak reached in earlier years above it.

The Barents Sea fishing reached a peak fishing intensity beyond the optimum in 1961-63; this happened at Bear Island in 1957-59. Since then effort has declined, especially at Bear Island. Recent analytical assessment of the Arcto-Norwegian stock as a whole showed that the maximum yield would be achieved by a 25% reduction in effort (ICES, 1968b). It should be recalled that

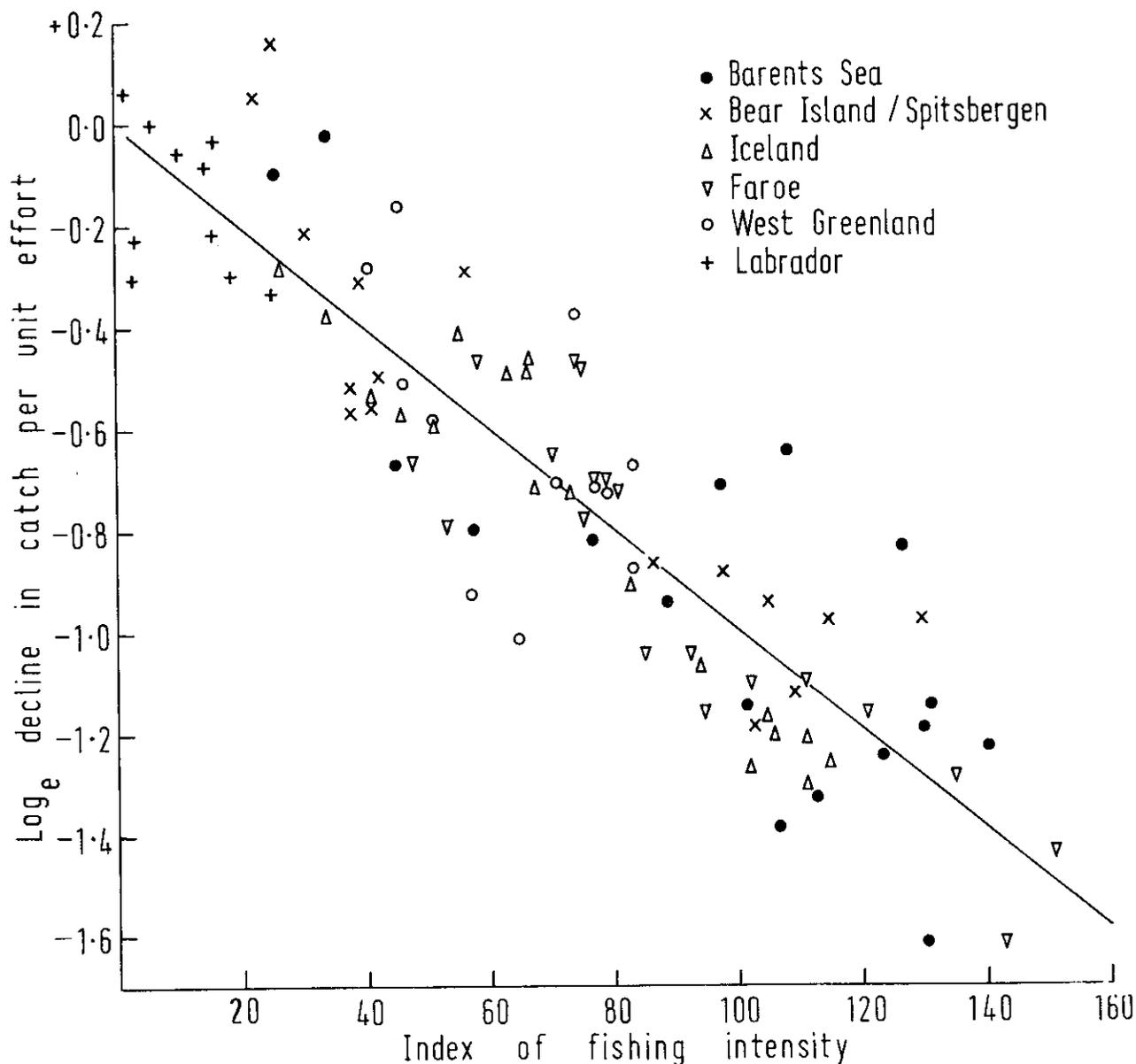


Fig. 1. The regression of catch per unit effort against international fishing effort, generalized for some North Atlantic cod stocks.

this present result excludes the effort in the Norway coast fishery, and to a large extent the contribution of mature fish to the yield. So, while the present levels of effort may well relate to the potential yield of individual fisheries as indicated, this cannot be directly equated with the requirements of the entire stock. In fact the yield curve of Arcto-Norwegian cod under the present conditions of exploitation is flatter than that shown in

Fig. 2, with a maximum at a lower level of fishing intensity than this scale.

The recent assessment of the Iceland stock showed that, at the most realistic assumptions about the rate of natural mortality, the present yield is close to the maximum, though there is some doubt as to the correct measure of effort. In this examination of the data this has been overcome by the adjustment of effort to a common

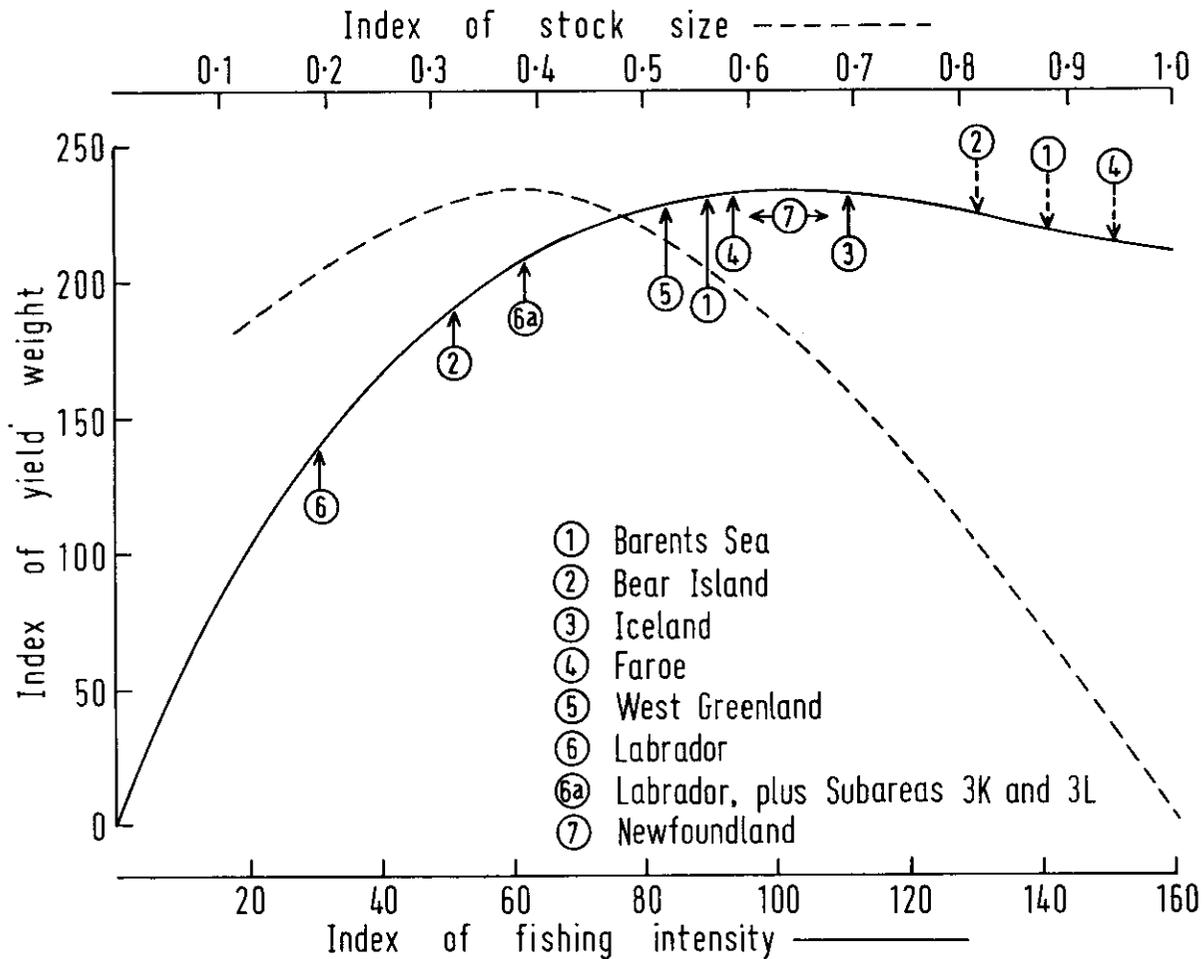


Fig. 2. The generalized yield curve for some North Atlantic cod stocks, and 'Schaefer plots' derived from the catch per unit effort/effort relation.

base, using the assumption that a common fishing intensity will generate the same proportional decline in stock abundance.

The Faroe fishery reached a peak fishing intensity in 1960-62, from which the level of exploitation has returned to something close to the optimum, though the stock has not yet returned to its equilibrium level.

In the Northwest Atlantic this treatment implies that the level of fishing at West Greenland has reached the optimum. This is in broad agreement with Gulland's conclusion (Gulland, 1967) "that the 1965 level of effort is not substantially below the level giving the maximum sustained yield, and may well be above it". Gulland was clearly inclined to the latter view but this was

based on estimates of mortality derived ultimately from the age composition of research vessel samples. Wherever virtual population analysis has been used in conjunction with catch per unit effort analysis (e.g. for the Arcto-Norwegian and Iceland stocks) it has shown the catch per unit effort analysis to overestimate mortality. This is understandable, since the size-group objective of a fishery will decrease as fishing becomes more intense. In view of this the conclusion that the level of fishing at West Greenland is close to an optimum is not unrealistic.

The position of the Labrador fishery is less certain, owing to the limitations of the data at hand, particularly the exclusion of landings from Subareas 3K and 3L. The indication from this analysis—that the level of exploitation is probably

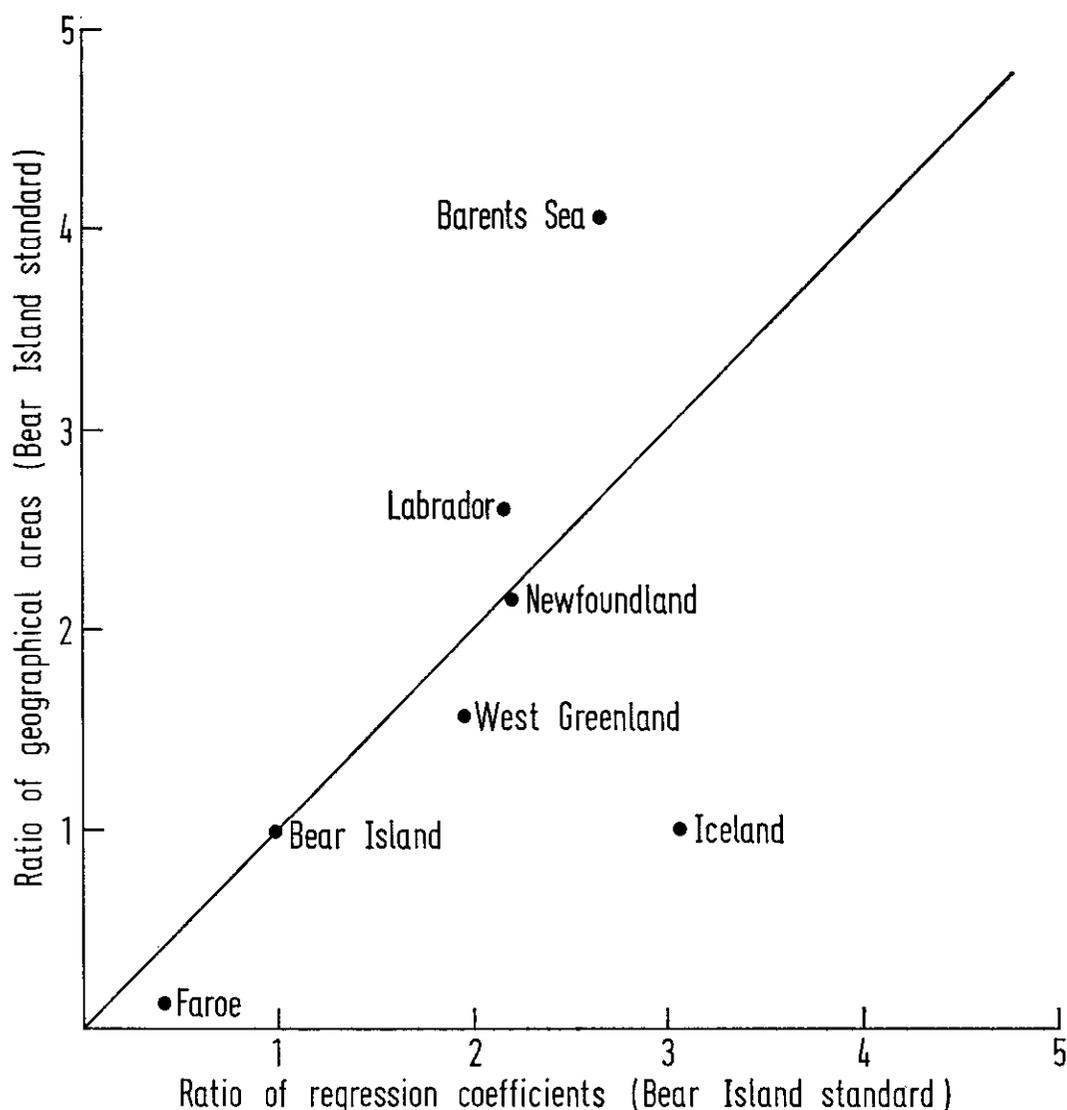


Fig. 3. The relation between fishing effort and fishing area in the North Atlantic. The ratio of regression coefficients represents the ratio of fishing effort required to generate a given proportional decline in stock abundance.

to the left of the optimum (Fig. 2)—conflicts with the conclusions drawn by May (1967). His estimate of F/M chosen for entry into the tables of yield functions was deduced from age composition data (May 1966), and it is worth noting that it is rather higher (4.5) than Gulland's estimate (3.5) for the West Greenland stock, which one might expect to be the more heavily exploited of the two by virtue of its greater accessibility. The general logic of the position given for Labrador in Fig. 2 can be seen by comparison of this fishery with that of the Barents Sea. In the latter area a fishing

effort of 520 units (Table 1) is adequate to reach a point close to the optimum. The Labrador fishery in Subareas 2G, 2H, and 2J occupies an area equivalent to about one half that of the Barents Sea fishery, so one would expect about 250 units of effort to reach the same level of exploitation at Labrador. The present level is about 180 units. However, if Subareas 3K and 3L are included the area of the Labrador fishery becomes almost equivalent to that of the Barents Sea, and if the effort at Labrador is weighted up by the catches in these Subareas, then the Labrador

fishery will also lie closer to the optimum level, at the alternative position (6a) shown in Fig. 2.

The only justifiable conclusion from this is that the proportional decline in catch per unit effort at Labrador has been less than that observed elsewhere in securing the optimum level of fishing. Moreover, recruitment to this stock is apparently less variable than elsewhere, so that the observed maintenance of the catch rates in that area is less likely to be caused by a favourable variation in recruitment.

In the recent data for the Newfoundland stock the trend in effort is not sufficient to permit the calculation of a meaningful regression; there are signs of an increase in the last 2 years, but on the whole the fishery has remained remarkably stable since 1950. Its present position in Fig. 2 has been estimated from data given by Beverton and Hodder (1962). In their figure 6.1 the catch per unit effort of trawl landings is given as about 35 for the period 1935-45, and about 22 for the period 1950-56, and there is no evidence to show that it has changed significantly since then. The corresponding effort figures for these periods are 7 units and 16 units respectively. Thus the change from 7 to 16 units generated a 37% decline in stock abundance, and on the logarithmic scale this can then be related to the abundance of the unexploited stock. The proportional decline to the present stock abundance can then be traced on Fig. 1 and related to a level of effort for entry on to Fig. 2. Similarly a regression coefficient can be estimated for entry in Table 2. This implies that the level of exploitation in Subarea 3 is in the region of its optimum, or slightly beyond it if the true yield curve is flatter than that shown.

Conclusions

For an area such as the Northwest Atlantic, where very rapid changes in fishing intensity have recently taken place, it is difficult to estimate the population parameters vital for critical stock assessment, but there is something to be gleaned from comparisons with other stocks for which more consistent data are available.

The methods used in this paper are obviously very approximate, and the paper is contributed not as a definitive statement but to stimulate a critical appraisal of catch and effort analysis before drawing far-reaching conclusions on the present levels of exploitation in the Northwest Atlantic, or

for that matter the North Atlantic as a whole. Although the precision of the present approach is not high the results do indicate that the level of fishing in the Northwest Atlantic is probably very close to the optimum required to secure a yield close to the potential maximum, and certainly not a long way beyond this level. This points to the need to stabilize fishing effort at its present level, rather than to reduce the existing fleet capacity.

Appendix

The relationship between fishing effort, fishing intensity and the geographical area of distribution of the exploited stocks.

From basic theoretical concepts, and using the international notation

$$Y_N = \frac{FN}{Z} (1 - e^{-Z});$$

N here represents the initial abundance of the unit stock, and in the relative terms of this inter-stock-comparison it is unity, i.e. $N = N^1 = N^2 \dots$, so that

$$Y_N = F \frac{(1 - e^{-Z})}{Z}.$$

More precisely, $F = qf/A$, where A is the area of the stock, i.e. F is proportional to fishing effort per unit area, and the fishing intensity $f/A = (f/A)^1$ etc. Hence

$$Y_N = \frac{qf}{A} \frac{(1 - e^{-Z})}{Z}$$

and

$$\frac{AY_N}{f} = q \frac{(1 - e^{-Z})}{Z}.$$

With the exclusion of the effect of area size upon catchability, the coefficient q now has the narrower sense relating to the response of fish to fishing gear, and the relative distributions of fish and fishing with time. These can also be assumed constant within the species. Hence when the proportional decline in abundance of two stocks N and N^1 is equal

$$q \left(\frac{1 - e^{-Z}}{Z} \right) = \left[q \left(\frac{1 - e^{-Z}}{Z} \right) \right]^1$$

$$\frac{AY_N}{f} = \frac{(AY_N)^1}{(f)^1}$$

and

$$\frac{Y_N f^1}{Y_{N1} f} = \frac{A^1}{A}$$

Furthermore, at this equal level of depletion the yield will be an equal proportion of the initial stock, so that $Y_N = Y_{N1}$ and $f^1/f = A^1/A$.

The fishing effort required to generate the equivalent decline in the two stocks will be proportional, and the relative catch per unit effort will be inversely proportional to their respective areas. Similarly the regression coefficient relating the change in catch per unit effort to increasing fishing effort will be inversely proportional to this area. Consequently, if the theoretical concept that fishing mortality is proportional to fishing intensity is valid, then a plot of the ratio of the regression coefficients against the ratio of geographical areas, both referred to a standard, will also be proportional.

The ratios of the regression coefficients and the geographical areas are given in Table 2, using the data for Bear Island as standard. The geographical area has here been defined as the number of nautical square miles lying between the coastline and the 200 fathom isobath circumscribing the known distribution of the stock, and limited, where necessary, by the boundaries of the Statistical Divisions from which the data have been taken. This assumes that any unaccounted area of distribution beyond the 200 fathom isobath will be proportional to the area within. Although necessarily approximate this measure is adequate to indicate the relative sizes of the areas occupied by the stocks considered here.

The relationship between these ratios is a measure of the increase in effort required to maintain an equivalent fishing intensity in each area. This is illustrated in Fig. 3, showing also the bisector. There is a substantial anomaly for the Iceland fishery. It suggests that the derivation of a figure for the total international effort at Iceland from the statistics of the English fishery has led to a serious overestimate. Subsequent investigation has confirmed this; the English fishery is based mainly on immature cod, but some 50% of the international catch is composed of mature fish which are barely represented in the English catch per unit effort data. The method of derivation of the international effort figure thus leads to 'double counting'.

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Diurnal Variation in Availability of Different Sizes of Redfish, *Sebastes mentella*

BY E. J. SANDEMAN¹

Abstract

During a series of alternate haul mesh selection experiments directed at redfish on the eastern part of the Grand Bank of Newfoundland, continuous fishing at the one position depleted the local population to a sufficient extent to allow DeLury estimates of the initial population to be made. With estimates of the initial population available it was possible to examine, for different size groups, the proportion of total fish present which were caught at the different time periods throughout the experiments.

The results indicated very great (and statistically significant) differences in availability between the time periods. Furthermore, it was apparent that, within the limits imposed by the selection factor of the gear, the smaller commercial-sized redfish were caught two or three times more effectively than were the larger fish. This differential fishing mortality rate with size may present an additional complicating factor in attempts at managing a fishery and assessing the effects of mesh size regulation.

Introduction

In recent years attention has been increasingly focussed on the different types of bias which may affect the use of catch per unit of effort in providing efficient indices of abundance of different fish stocks. One of the aspects which may generate such bias is concerned with changes in the vulnerability of the fish to the fishing gear. This vulnerability is a function of the fishing gear (in the broadest sense) and of the behaviour of the species of fish. The latter, which reveals itself both in the intrinsic behaviour pattern of the fish species in relation to the environment and in its behaviour towards the fishing gear, is likely to change with respect to time, and these changes may give rise to cyclical changes in availability, and to changes in availability related to the physiology of the fish and particularly the ageing process. The latter may be manifested in different degrees of availability for different sexes and size groups.

Cyclical changes in availability of different fish stocks have been the subject of many investigations and correlations between fish abundance and different cyclically varying factors are numerous (Gulland, 1955, provides a general discussion and more recently the ICES symposium on "The Measurement of Abundance of Fish Stocks" has served to direct attention to some of these). One of the most widespread of these cyclical changes in availability is that associated with the diurnal change between daylight and darkness. Although diurnal variations in catches have been reported for most of the major marine commercial fish species as caught by many different fishing gears, data on diurnal variation of the different size groups making up the catch are not so frequently documented.

Diurnal variations in the catches of *Sebastes* are well known to every redfish fisherman and these may on some occasions and at some localities be so extreme as to necessitate a switch to another target species or even a complete cessation of fishing activities during the hours of darkness when the redfish are generally least available to the otter-trawl gear.

The phenomenon has been documented for redfish by the following authors: Steele (1957); Konstantinov and Scherbino (1958); Templeman (1959); Von Seydlitz (1962); and Beamish (1966).

Materials and Methods

The results presented here could perhaps be regarded as part of a fortuitous bonus arising from two cruises of the research vessel *A. T. Cameron* in which the purpose was to compare the selectivity of No. 41 otter trawl manila nets having different mesh characteristics. The main characteristics of the four nets used (B, C, D, and E) are summarized in Table 1.

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TABLE 1. General specifications of manila nets used during experiments (a = number of meshes. Forward end/After end; b = numbers of meshes long; c = dry manufacturers mesh size [between knot centres] in inches; d = Runnage/Ply of twine. All single twine except where indicated).

	Net B				Net C				Net D				Net E			
	a	b	c	d	a	b	c	d	a	b	c	d	d	b	c	d
Upper wing	10/75	85	5	100/3									10/70	78	5½	100/3
Lower wing	33/45	130	5	100/3									30/42	120	5½	100/3
Square	220/170	30	5	100/3	As Net B				As Net B				202/156	27	5½	100/3
Belly	170/170	20	5	100/3									156/38	35	5½	100/3
	170/60	70	5-3¼	100/3	170/42	20	5	100/3	170/38	20	5	100/3		35	5½	75/4
Lengthening piece	60/60	105	3½	75/4	42/42	75	4½	50/4	38/38	66	5¼	50/4	38/38	60	5½	50/4
Codend	60/60	90	3¼ (2.0) ²	75/4 ¹	42/42	58	5½ (3.4) ²	50/4 ¹	38/38	52	5½ (4.1) ²	50/4 ¹	38/38	48	6¼ (4.5) ²	50/4 ¹

¹Double twine.²Internal mesh size inches, wet after at least five sets (Westhoff gauge 10 lb. pressure).

During these two cruises, three different experiments were undertaken. In each experiment fishing was carried out at a single location, and was continued with one set every 3 hr for several days. The position was maintained constant by use of a Decca Navigator Track Plotter to ensure that the ships track did not deviate from the narrow corridor used during all the sets of the experiment.

Each day (24 hr) was divided into eight, 3-hr-time periods and care was taken to ensure all sets (of 1 hr duration) occurred within these time periods. It is convenient to label or code each time period and this has been done according to the scheme below:

Time period	
1	00.00 hr to 02.59 hr
2	03.00 " to 05.59 "
3	06.00 " to 08.59 "
4	09.00 " to 11.59 "
5	12.00 " to 14.59 "
6	15.00 " to 17.59 "
7	18.00 " to 20.59 "
8	21.00 " to 23.59 "

The plan of the experiment was such that in a block of 32 sets each net should have been used once in each time period. While this condition was enforced during Experiments II and III, in Experiment I occasional damage to the gear necessitated some modifications which resulted in each net being used twice in each time period during the 64 sets which comprised the experiment rather than the once in 32 used in the later experiments.

The dates and locations (all eastern edge of the Grand Bank) of the Experiments are summarized below.

For each set the catches of redfish were separated and the quantity of fish taken measured in baskets. When catches were small the total catch was weighed in baskets before being measured. Large catches were sampled by a random process of selection with the sampled baskets being weighed and measured and the sample weight and frequency subsequently multiplied to the total catch.

Redfish measurements were all of fork length (from the anterior tip of the lower jaw with the mouth closed to the most distal portion of the median caudal rays) made to the nearest centimeter; however, for most of the subsequent analysis these lengths were later combined into 2-cm groups. All redfish were sexed by internal examination of the gonads. Examination during the measuring operation revealed only four *marinus* redfish in the total of 31,352 fish measured during Experiment I, seven out of 24,247 and 11 out of 17,438 in Experiments II and III respectively.

With fishing continuing at the one position for a protracted period of time a marked decrease in availability of redfish could be noted from the beginning to the end of each experiment. Although considerable variation exists with the different nets used during the different time periods, the trend was clear and was sufficient to allow estimates of the initial population to be made by a method similar to that described by DeLury (1951) (Method 1).

Experiment No.	Dates (1961)	No. of sets	N lat	W long	Depth (fathoms)
I	11-21 July	64	46°39'	47°21'	185-170
II	30 July to 3 Aug.	32	46°58'	47°26'	170-180
III	4-8 Aug.	32	47°11'	47°25'	170-185
			to 47°08'		

The model is of a closed system and it is assumed that there is no exchange of fish with the area outside the system for the duration of the experiment and that there is no mortality acting apart from that due to the removal of fish by the fishing gear.

N_o = Number of fish present in the closed system before the start of the experiment.

N_t = Number of fish remaining in the system after t sets.

C_t = Number of fish removed during set t .

$$N_t = N_o - \sum_1^t C_t \quad (1)$$

The otter-trawl sets were all of 1 hr duration and the usual assumption is made that the number of fish caught in a given set is proportional to the number of fish present before the start of that set

$$C_t = K N_{t-1} \quad (2)$$

where K is the constant of proportionality. Combining the above equations we have

$$C_t = KN_o - K \sum_1^{t-1} C_t \quad (3)$$

A plot of C_t against $\sum_1^{t-1} C_t$ should thus be a straight line and a least squares fit should allow estimates of both K and N_o . The value of K can be considered as the average proportion of fish present taken during each set. The actual value of K in each set will fluctuate quite widely depending on the particular net in use and the time period when the set in question was made.

This method of estimating (N_o) was used in the two smaller experiments each of which consisted of 32 sets. For Experiment I the procedure was modified (Method 2). In this experiment a

total of 64 sets was made and each net was used twice in each time period. Also, although each net was not used an exact equal number of times nor each time period fished an exact equal number of times within each period of 16 sets, this was nearly so. Thus variations due to either the net or to the time period will likely be averaged out within each successive block of 16 sets. If this is so then for the block of first 16 sets the relationship (2) above can be written

$$\sum_0^{16} C_t = K \sum_0^{15} N_t$$

and similarly for the second and subsequent blocks using the requisite values of t for the block in question. As before K is a constant which represents the average proportion of fish caught under average conditions of availability to an average net.

Under these conditions when the summed catch of the sets in each block is proportional to the summed total fish present before each set, it is evident that the instantaneous decrease of the population is proportional to the number present or

$$\frac{dN}{dt} = -qN$$

which yields on integration

$$N_t = N_o e^{-qt} \quad (4)$$

where N_t represents the number of fish remaining after t sets have removed from the initial population of N_o fish. Thus from equations (1) and (4)

$$N_o - \sum_1^t C = N_o e^{-qt}$$

$$\text{whence } \sum_1^t C = N_o (1 - e^{-qt})$$

By substituting $t + 1$ for t in the above equation and subtracting the resulting equation from it, the following may be obtained (analogous to the Ford-Walford transformation):

$$\sum_1^{t+1} C_t = N_0 (1 - e^{-q}) + \sum_1^t C_t e^{-q} \quad (5)$$

With N_0 and q constants a straight line will be obtained from which estimates of these values may be obtained. As we have seen, the value of q is not constant but varies according to the time of day and the net used; however by using blocks of 16 sets the variations can be averaged out or at least minimized. The equation (5) above becomes in this case

$$\sum_2^4 B_R = N_0 (1 - e^{-q}) + \sum_1^3 B_R e^{-q}$$

where

$$B_1 = \sum_1^{16} C_t, \quad B_2 = \sum_{17}^{32} C_t, \quad B_3 = \sum_{33}^{48} C_t,$$

$$B_4 = \sum_{49}^{64} C_t$$

and estimates of q and N_0 determined from the least squares fit to a three point line.

Both of the two methods described above yield estimates of the initial population of redfish present within the assumed closed system prior to the start of each experiment. With estimates of the number of fish of different sizes present at the start of each experiment it is immediately possible to obtain estimates of the proportion of the total fish present that were taken during each set and to compare the amounts of fish of different sizes caught at different time periods and by the different nets.

Results

Estimates of N were obtained for each of the length groups for each sex and each experiment. As has been stated previously, two methods have been used to derive the estimates of N_0 and Fig. 1 shows the two methods as applied to the 36 and 37 cm males from Experiment I. N_0 as computed here by least squares fits to each line using Method 1 was: 5,550 fish; and by Method 2 the value of 6,060 fish was obtained.

With a total of 128 sets in the complete series of experiments, each net was fished in each time period four times and thus four different values of the proportion of the total fish of each size group caught are available for each combination of net and time period. It is convenient to label these proportions and they are called here availability factors. It was apparent from even a cursory examination of these availability factors that the catchability of the redfish in these experiments varied with size and that greater proportions of the smaller redfish were being caught than of the larger.

The size distribution of the estimated redfish population before and after these experiments is shown in Fig. 2. This figure while it does not show any clear difference in catchability between large fish and small fish or between the sexes, does show the size distribution of the population being examined.

When the percentage of fish caught of the total present before the start of fishing is examined for each different length group (Fig. 3) it is at once apparent that these percentages were greater for the small fish taken during these experiments than they were for large fish. This is all the more striking when one considers that included in these results are the catches of large-meshed nets D and E, which can be expected to catch very few of the smaller fish in any case. Indeed, when the proportion of fish caught in each size group at each time period are examined for each net separately (Fig. 4), it is clear that for the smaller-meshed nets B and C the availability factors of the smaller fish were considerably larger than those of the bigger fish. In Fig. 3 there are indications that the behaviour of the two sexes does not differ very much, and analysis of variance confirms there were no differences between the availability factors of males and females of a given size group (Table 3). Thus it is valid to combine the sexes as has been done in Fig. 4.

In order to examine the relative importance of the different time periods and different nets in affecting the availability, a series of analyses of variance were computed. These so-called availability factors are actually ratios and this suggests that the requirements of homogeneity of variance and additivity might better be met by applying a suitable transformation to the data. Preliminary analyses in which the inverse sine transformation was applied (the availability factors transformed to the angle whose sine is the square root of each

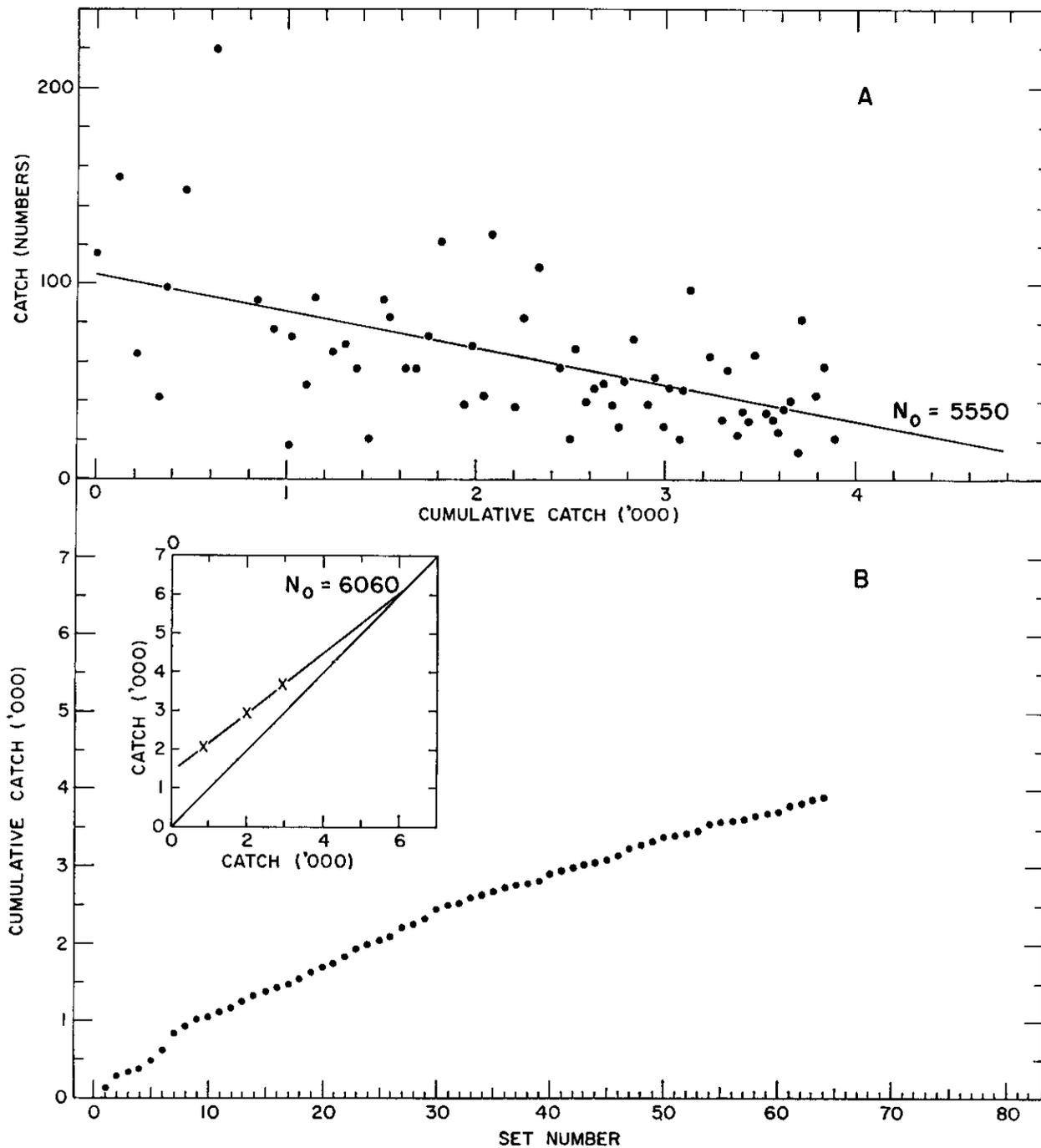


Fig. 1. Example of two methods used in deriving estimates of N_0 (36- and 37-cm males). (A) Method 1. Plot of numbers of fish caught in each set against cumulative catch in numbers before it. (B) Method 2. Plot of Cumulative catch in numbers against time (set number). The inset shows the catch in numbers obtained in a block of 16 sets plotted against that obtained in the previous block of 16 sets.

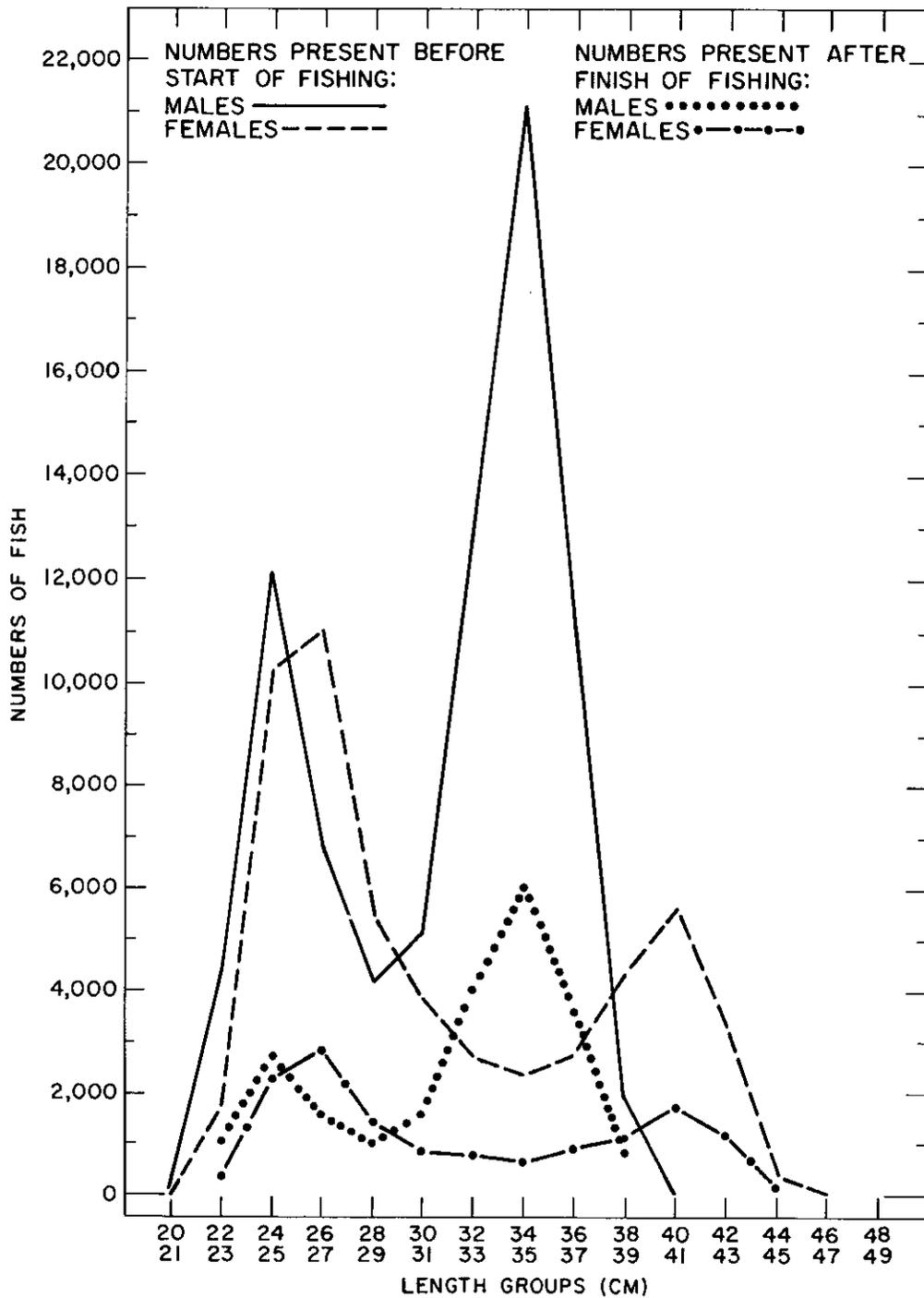


Fig. 2. Calculated numbers present at each length group before and after the experiment.

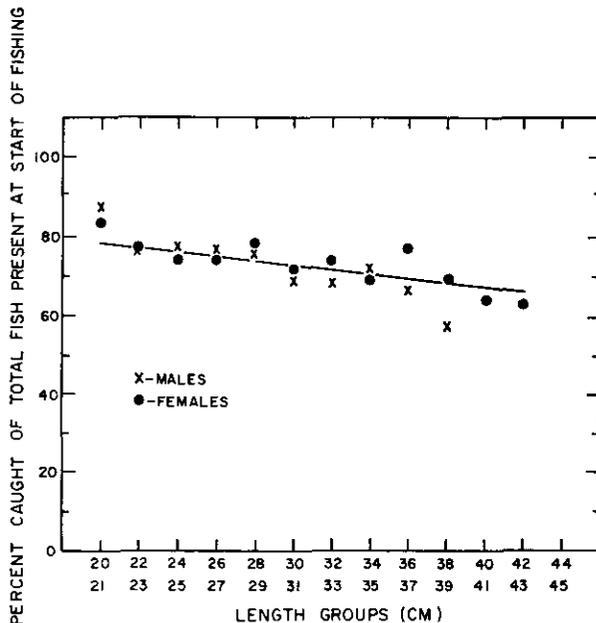


Fig. 3. Percentage of fish caught of the total calculated present before the start of fishing for each length group.

factor) indicated a more normal-like frequency distribution of the data and tests on part of the data revealed an improvement in additivity (Tukey, 1949), and in the main analyses that followed the data were all transformed using this transformation.

In the first series of analyses of variance the data for each sex and length group were examined with respect to differences between nets and time periods. It was evident from this analysis (Table 2) that interaction between the two sources of variation was negligible and that, apart from the single instance of the 20- and 21-cm-males group, the difference between time periods was always highly significant. With regard to differences between nets, both for males and females at the length group of 36 and 37 cm and for sizes above this, the action of the nets could be considered similar and only on sizes smaller than this could differences between nets be considered real.

In the second series of analyses of variance differences between sexes and time periods were examined for each length group and net. Following the conclusion above that interaction was negligible, the assumption was made that here also interaction would likely be negligible and in this

series of analyses (as also in the ones that follow) mean values of the transformed data were used. It is evident (Table 3) that differences between time periods are significant while those between sexes in general are not. In spite of this and because it is customary to separate the sexes for biological reasons, the sexes were treated separately in the next stage of the analysis when the proportion of fish of each sex and length group caught by one net were examined against that taken by each other net at each time period.

It is customary when comparing the selectivity of different nets to compare the results of comparative fishing by selection ogives of the different nets being tested. In doing this it is usually assumed that the small-meshed net provides a sample of the total population and the catches of the large-meshed nets are expressed as percentages of this small-meshed net at corresponding length groups. With estimates on hand of the average proportion of total fish present (availability factors), it is possible to compare these proportions in a like manner and derive selection ogives and the other statistics pertaining to them. This has been done in Fig. 5 and included in this figure are the results of the analyses of variance summarized in Table 4 which indicate where differences between the nets may be considered significant or not.

Probably the most significant result from these experiments is to be found in the results obtained when all time periods are combined and the availability factors of the length groups examined for each net. The experiments were designed to compensate for differences between time periods just to allow such a combination of time periods in order to effect a comparison between the nets independently of the variation due to diurnal movements. The results of this analysis are shown in Fig. 6.

The different proportions of fish caught by the different nets can very easily be seen, and whereas for the larger fish the four nets caught the same proportion of fish present (males about 2%, and females about 3-4%) at the smaller lengths the fish were much more available to the nets which could catch them with the small-mesh net B (2-inch-mesh size internal, wet after use) catching about 7% of the available fish of 24-25 cm in length and net C (3.4-inch mesh size internal, wet after use) about 5.5% of the available fish.

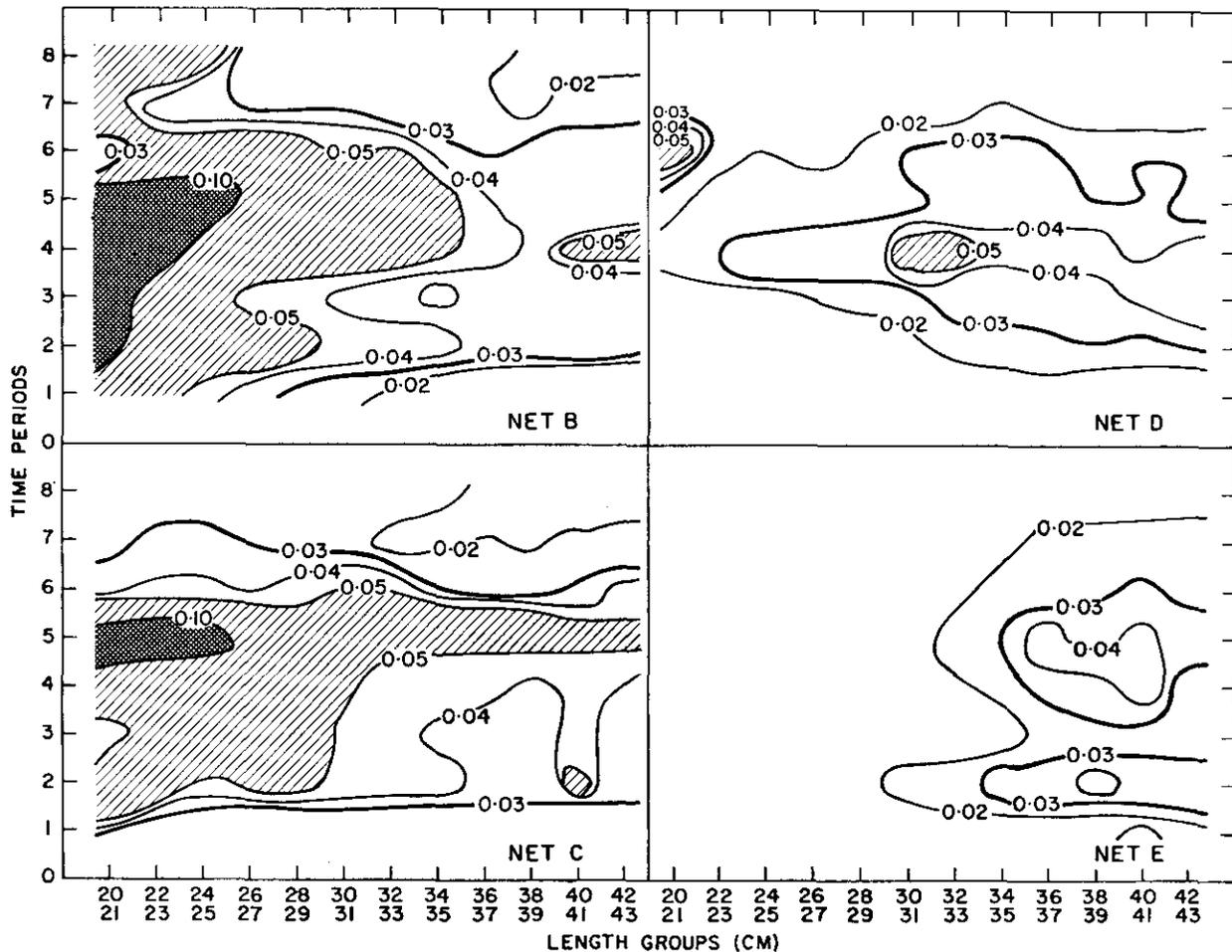


Fig. 4. Availability factor isopleth diagrams for the four nets used. In each diagram the mean availability factors for each length group and time period have been plotted, and isopleths drawn joining points at which the availability factors were the same.

Discussion

The results examined above are all based on one important assumption; namely that the system was a closed one and that during the experiment the only removal of fish was by the fishing operation itself. While it might be quite realistic to assume the normal processes of natural mortality to be negligible during the relatively short period of the experiment, it is much more difficult to believe that there would be no migration of fish from the area which is being stirred up by repeated sets of the otter trawl. Furthermore even though the fish may not actually leave the area, it is quite conceivable that they could become less available to the net because they remained away from the bottom and did not foray to the less attractive disturbed area close to the bottom; in this case the effect would be the same as leaving the area.

It is important to examine what effects emigration might have on the results obtained during these experiments. If emigration takes place so that a constant proportion (p) of the total fish present become permanently unavailable to the net, the basic equation (1) can be altered with the incorporation of an additional term to account for this steady removal of fish by a means other than the fishing operation itself.

$$N_t = N_o - \sum_1^t C_t - p \sum_o^{t-1} N_t$$

and substituting as before this reduces to

$$C_t = KN_o - (K + p) \sum_1^{t-1} C_t$$

which of course is similar to the equation used (3)

TABLE 2. Results of analyses of variance: differences between nets and time periods are here examined for each length group (sexes separate).

Length group (cm)	Males			Females		
	Between time periods	Between nets	Interaction	Between time periods	Between nets	Interaction
20 and 21	NSD	**	NSD	—	—	—
22 and 23	**	**	NSD	**	**	NSD
24 and 25	**	**	NSD	**	**	NSD
26 and 27	**	**	NSD	**	**	NSD
28 and 29	**	**	NSD	**	**	NSD
30 and 31	**	**	NSD	**	**	NSD
32 and 33	**	**	NSD	**	**	NSD
34 and 35	**	**	NSD	**	**	NSD
36 and 37	**	NSD	NSD	**	NSD	NSD
38 and 39	**	NSD	NSD	**	NSD	NSD
40 and 41	—	—	—	**	NSD	NSD
42 and 43	—	—	—	**	NSD	NSD

** = significant difference at 0.01 probability level.

NSD = no significant difference.

— = data not analyzed because of lack or paucity of data.

TABLE 3. Results of analyses of variance: differences between sexes and time periods examined for each length group and net.

Length group (cm)	Differences between sexes				Differences between time periods			
	B	C	D	E	B	C	D	E
20 and 21	—	—	—	—	—	—	—	—
22 and 23	NSD	NSD	NSD	NSD	**	**	**	NSD
24 and 25	NSD	**	NSD	NSD	**	**	**	**
26 and 27	NSD	NSD	NSD	NSD	**	**	**	*
28 and 29	NSD	NSD	NSD	NSD	**	**	**	*
30 and 31	NSD	NSD	NSD	NSD	*	**	**	**
32 and 33	NSD	NSD	NSD	NSD	**	**	*	*
34 and 35	NSD	NSD	NSD	NSD	*	**	**	**
36 and 37	NSD	NSD	NSD	NSD	NSD	*	**	*
38 and 39	*	**	*	*	NSD	NSD	*	NSD
40 and 41	—	—	—	—				
42 and 43	—	—	—	—				

* = difference at 0.05 probability level.

** = difference at 0.01 probability level.

NSD = no significant difference.

— = data not analyzed because of lack or paucity of data.

TABLE 4. Results of analyses of variance between pairs of nets.

Length group (cm)	Nets	Female			Male		
		Nets			Nets		
		C	D	E	C	D	E
22	B	NSD	**	**	*	**	**
	C		**	**		**	**
	D			**			*
24	B	*	**	**	**	**	**
	C		**	**		**	**
	D			**			NSD
26	B	NSD	**	**	*	**	**
	C		**	**		**	**
	D			**			*
28	B	NSD	**	**	NSD	**	**
	C		**	**		**	**
	D			**			*
30	B	NSD	*	**	NSD	**	**
	C		*	**		**	**
	D			*			**
32	B	NSD	NSD	**	NSD	NSD	**
	C		NSD	**		*	**
	D			**			**
34	B	NSD	NSD	**	NSD	NSD	**
	C		NSD	**		NSD	**
	D			NSD			**
36	B	NSD	NSD	*	NSD	NSD	NSD
	C		NSD	*		NSD	*
	D			NSD			NSD
38	B	NSD	NSD	NSD	NSD	NSD	NSD
	C		NSD	NSD		NSD	NSD
	D			NSD			NSD
40	B	NSD	NSD	NSD			
	C		NSD	NSD			
	D			NSD			
42	B	NSD	NSD	NSD			
	C		NSD	NSD			
	D			NSD			

** = significant difference ($P < 0.01$).

* = significant difference ($0.05 > P > 0.01$).

NSD = no significant difference ($P < 0.05$).

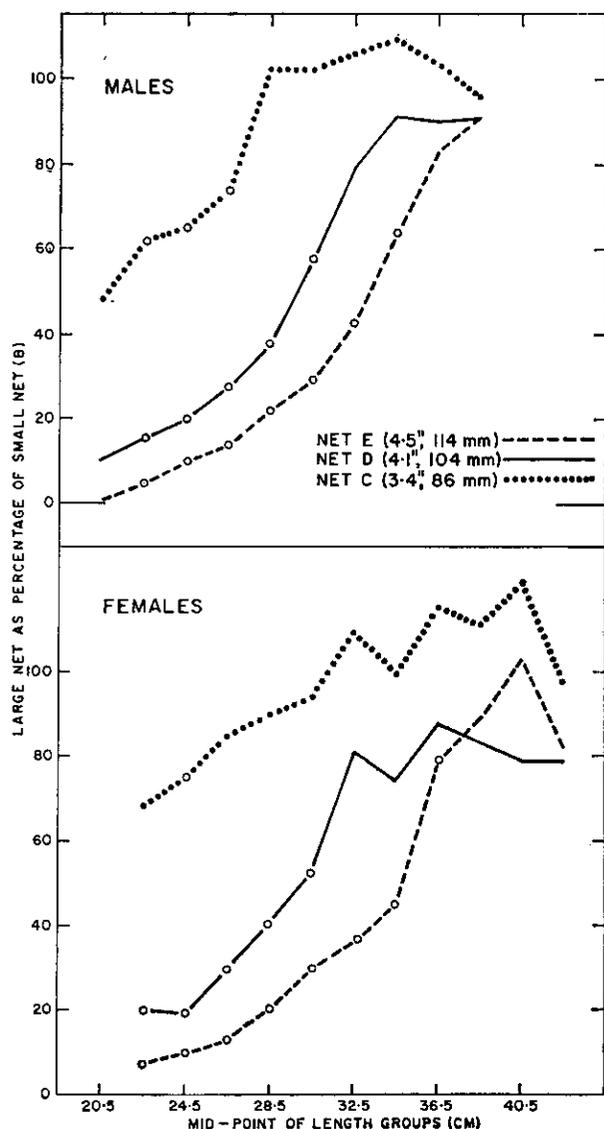


Fig. 5. Selection ogives obtained from availability factors. The points shown by open circles indicate that the large and small nets were significantly different ($P < 0.05$) at these points. Where no open circles are drawn the small and large net may be considered essentially the same.

except that the slope is increased by the amount p , and being unable to separate K and p we have no means of estimating N_0 .

An examination of the values obtained for the slopes ($K + p$) in the two experiments in which this method was used for estimating N_0 showed that there was no obvious correlation between either the slope and the intercept or between the slope and the length groups in three of the four possibilities examined. (In the males for one ex-

periment an inverse correlation was evident between the slope and the length groups). With the assumption of no emigration we have considered the slope $(K + p) = (K)$ and if the value of p is positive and significantly different from zero we will obtain estimates of N_0 which are too small and hence the individual estimates of the availability factor for each net and time period will be too large. To negate the results shown here, p would have to be different for each length group being considerably greater for the larger fish and not so great for the smaller fish.

The whole analysis would have been much simplified had only a single net been used in the course of the experiments. With one of the sources of variability removed there should be much less scatter of data points and better estimates of N_0 should result. The method appears to be suitable for general application provided the condition of a closed system or controlled migration is satisfied and provided the density of fish is such that continuous fishing will cause a marked diminution in the catches.

Within the limitations of the model, these experiments have yielded two general results. The first allows 50% selection lengths and selection factors to be obtained. These net selection parameters obtained using the availability factors show satisfactorily close agreement with those obtained by the usual methods (Table 5). Furthermore, as is usual in redfish selection experiments, the selection lengths of the females were higher than those of the males for the same net.

TABLE 5. Comparison of net selection parameters obtained by the usual method and from availability factors.

Net	Sex	Standard method		From availability factors	
		50% point	Selection factor	50% point	Selection factor
		<i>cm</i>		<i>cm</i>	
D	♂	30.0	2.88	29.7	2.86
D	♀	30.6	2.94	30.1	2.89
E	♂	33.4	2.93	33.0	2.93
E	♀	33.7	2.96	34.6	3.03

The second and far more significant result is the very great difference in availability of the small and large redfish to the net. The principle that small fish are more easily caught than the larger fish (provided the mesh size is large enough

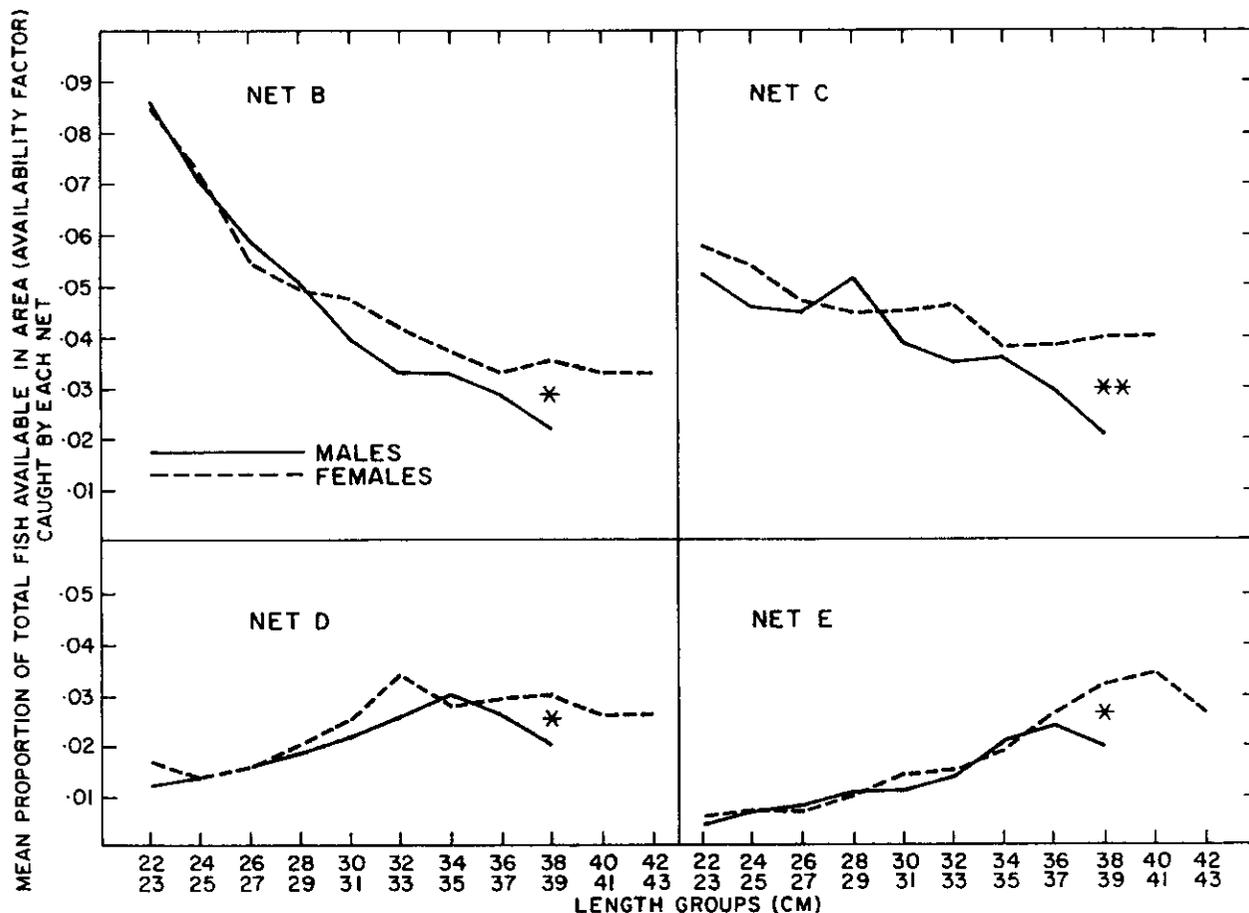


Fig. 6. Mean proportions of total fish in area (availability factor) obtained at each length group for each net.

to retain them) is common and expected. However, that a net can catch the smaller commercial sized fish between two and three times more effectively than the same nets or indeed larger-meshed nets, can catch the larger fish creates a situation in which a differential fishing mortality rate with size might present an additional complicating factor in our attempts at managing the fishery and assessing the likely effects of mesh-size regulation.

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Landings per Unit of Effort, Age Composition, and Total Mortality of Yellowtail Flounder, *Limanda ferruginea* (Storer), off New England

BY F. E. LUX¹

Abstract

Abundance of yellowtail flounder off New England (ICNAF Subarea 5) increased during 1960-63 because of high recruitment from the 1958, 1959, and 1960 year-classes. Subsequent year-classes have been smaller, and abundance in 1964-66 has decreased. The commercial landings consist of fish in the 2-9 age-groups; fish of ages 2-5 make up most of the catch. The annual total mortality rate, estimated from catch per day by age-group in 1960-65, was about 64%. Limited information on natural mortality indicates that it is 20% per year or less.

Introduction

Yellowtail flounder are caught on three grounds off New England: the southern New England ground, Georges Bank, and the Cape Cod ground (Lux, 1963). Each ground supports a relatively separate group of fish. The southern New England and Georges Bank groups, for which estimates of abundance, age composition, and mortality are given below, supply about 90% of the catch.

Otter-trawl codends used for yellowtail-flounder fishing usually are of 114-mm mesh (internal, stretched measure). This mesh retains yellowtail flounder below the minimum acceptable market size, which in recent years has been about 30 cm (225 g). Undersized fish, which sometimes make up more than half of the total catch by weight, are discarded at sea. These discarded flounders include nearly all of the 1-group fish retained by the net and many of the 2- and 3-group fish. My limited information on the survival of discards, obtained by placing discarded yellowtail flounder in tanks of running seawater aboard commercial trawlers, suggests that about 25% live. Survival, however, probably varies widely, depending on length of tow, amount of catch, other species present, and season.

Yellowtail flounder grow rapidly, reaching lengths of 26 cm at age 2, 33 cm at age 3, and 38 cm at age 4 (Lux and Nichy, 1969).

Abundance

Apparent abundance, measured by average landings per day of fishing (Lux, 1964), has varied widely in the period over which records have been obtained. It generally decreased between 1943 and the mid-1950's, then increased up to 1963, and decreased again in 1964-66 (Table 1). Numbers of fish landed per day by age-group in 1960-65, estimated according to the method used by Hennemuth, Grosslein, and McCracken (1964), are given in Tables 2 and 3 and Fig. 1. These data show that yellowtail flounder begin to enter the landings in strength at age 2 and make their peak contribution at age 3. They also show that high recruitment from year-classes spawned in 1958, 1959, and 1960 contributed greatly to the high abundance of the early 1960's.

Fishing effort increased with increasing abundance in 1960-63 (Table 1). When abundance decreased in 1964-66, however, effort, instead of decreasing as well, continued to increase and reached its highest level for the entire period of record in 1966.

Total Mortality

Yellowtail flounder are fully recruited at age 4. Year-to-year survival from age 4 onward may therefore be estimated from numbers caught per day for each age-group. Level of recruitment, however, has varied widely with year-class (Fig. 2). Survival rates for ages 4-7 in 1960-65 therefore were estimated within each year-class from the ratio of abundance in a given calendar quarter to that of the same quarter of the previous year (Ricker, 1958). Ratios were computed for the

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TABLE 1. Landings, landings per day, and days fished for yellowtail flounder on the southern New England ground and Georges Bank in 1943-66 (landings and landings per day are in metric tons).

Year	Southern New England			Georges Bank		
	Total landings	Landings per day	Days fished	Total landings	Landings per day	Days fished
1943	18,039	3.17	5,681	1,262	6.37	198
1944	10,615	2.55	4,164	1,664	7.66	217
1945	10,368	3.63	2,852	1,356	4.81	282
1946	10,824	3.01	3,596	868	3.75	232
1947	12,111	2.66	4,550	2,257	4.70	480
1948	9,919	1.96	5,047	5,656	5.04	1,122
1949	4,673	1.44	3,248	7,300	2.93	2,493
1950	4,709	1.54	3,062	3,892	2.38	1,636
1951	2,786	1.48	1,889	4,311	2.68	1,611
1952	2,989	1.26	2,364	3,651	2.29	1,596
1953	1,976	1.37	1,442	2,897	2.33	1,241
1954	1,515	1.26	1,200	2,886	2.08	1,385
1955	2,180	1.42	1,529	2,945	2.39	1,234
1956	3,541	1.54	2,297	1,594	2.02	790
1957	5,440	2.30	2,396	2,301	2.80	821
1958	8,905	2.43	3,666	4,533	3.24	1,400
1959	7,737	1.58	4,904	4,130	2.10	1,969
1960	7,842	1.77	4,439	4,446	2.20	2,018
1961	11,630	2.48	4,686	4,247	2.34	1,816
1962	17,765	3.30	5,383	7,767	3.31	2,347
1963	24,295	4.06	5,976	10,990	4.56	2,409
1964	20,753	3.70	5,613	14,910	4.20	3,552
1965	20,338	3.06	6,644	14,244	3.18	4,486
1966	14,904	2.06	7,247	12,076	2.00	5,463

first, third, and fourth quarters on the southern New England ground and for the second and third quarters on Georges Bank. The fishing effort on the respective grounds was comparatively high in these quarters. The survival ratios for the 1954-60 year-classes, and geometric means of the ratios are given in Table 4.

The mean survival ratios of 0.36 and 0.37 for the southern New England ground and Georges Bank, respectively, are nearly identical. They indicate that the annual total mortality of groups 4-7 was about 64% ($Z = 1.02$). This level of mortality would generally be considered high in flatfish fisheries.

The high fishing effort of recent years presumably increased total mortality over that of previous years. Mortality in 1960-65 was higher, for example, than the 54% per year ($Z = 0.78$) which was estimated (Lux, unpublished) from the data of Royce, Buller, and Premetz (1959) for age-

groups 4-6 in 1943-47 on the southern New England ground.

Natural Mortality

Insufficient data are available for a good estimate of the natural mortality rate; generally, however, it appears that losses of adult flatfish from natural causes are small. For example, natural mortality of the European plaice, a species that is similar to the yellowtail flounder, has been estimated by Beverton and Holt (1957) to be 10% per year ($M = 0.10$).

Predation by other fish apparently is not a significant cause of mortality in yellowtail flounder; analyses of stomach contents of all species of fish caught in New England groundfish surveys aboard *Albatross IV* in 1963-66 indicated that few yellowtail flounder were eaten.

Further information on natural mortality was obtained from results of marking experiments.

TABLE 2. Estimated numbers by age-group of yellowtail flounder landed per standard day fished on the southern New England ground in 1960-65.

Year and quarter	Age-group								Total
	1	2	3	4	5	6	7	8+	
1960									
Jan.-Mar.	—	67	503	689	830	111	22 ^a	—	2,222
Apr.-June	—	942	684	502	422	21 ^a	59 ^a	40 ^a	2,670
July-Sept.	18 ^a	2,748	829	667	320	65 ^a	—	—	4,647
Oct.-Dec.	4 ^a	4,523	663	533	148	36 ^a	—	—	5,907
1961									
Jan.-Mar.	—	55	3,702	328	278	150	27	9 ^a	4,549
Apr.-June	—	256	3,032	217	256	116 ^a	—	—	3,877
July-Sept.	—	2,486	3,388	260	227	110	13 ^a	—	6,484
Oct.-Dec.	—	3,682	3,690	626	200	100	33 ^a	17 ^a	8,348
1962									
Jan.-Mar.	—	95	3,948	1,621	161	67	13 ^a	10 ^a	5,915
Apr.-June	—	260	5,208	1,158	161	19 ^a	14 ^a	2 ^a	6,822
July-Sept.	—	1,301	5,052	1,644	62	33 ^a	14 ^a	—	8,106
Oct.-Dec.	—	3,938	8,005	1,510	278	55 ^a	22 ^a	20 ^a	13,828
1963									
Jan.-Mar.	—	34 ^a	4,880	3,775	803	147	15 ^a	—	9,654
Apr.-June	—	96	4,748	3,156	530	109	28 ^a	—	8,667
July-Sept.	—	1,241	5,592	3,723	618	30 ^a	27 ^a	—	11,231
Oct.-Dec.	18 ^a	3,239	5,352	1,862	399	4 ^a	17 ^a	—	10,891
1964									
Jan.-Mar.	—	11 ^a	2,203	3,000	1,536	306	8 ^a	6 ^a	7,070
Apr.-June	—	149	1,283	1,178	1,322	—	168 ^a	—	4,100
July-Sept.	—	1,644	2,383	2,462	2,649	129	47 ^a	—	9,314
Oct.-Dec.	16 ^a	2,931	1,916	2,134	1,165	264	15	8 ^a	8,449
1965									
Jan.-Mar.	—	95	2,952	1,795	1,385	558	114	8 ^a	6,907
Apr.-June	—	159	2,105	812	962	580	73	6 ^a	4,697
July-Sept.	—	1,705	3,356	902	982	551	39 ^a	4 ^a	7,539
Oct.-Dec.	—	3,383	2,395	1,057	595	203	55 ^a	—	7,688

*Estimates based on fewer than six age determinations in all samples combined.

TABLE 3. Estimated numbers by age-group of yellowtail flounder landed per standard day fished on Georges Bank in 1960-65.

Year and quarter	Age-group							Total
	2	3	4	5	6	7	8M	
1960								
Apr. - June	501	921	646	573	81	33 ^a	25 ^a	2,780
July - Sept.	2,384	1,788	697	431	16 ^a	—	—	5,316
1961								
Apr. - June	130	2,554	747	225	170	55	71	3,952
July - Sept.	1,398	3,091	304	227	103	26 ^a	10 ^a	5,159
1962								
Apr. - June	69	2,821	1,361	332	235	100	38 ^a	4,956
July - Sept.	1,498	3,889	1,235	338	139	37 ^a	16 ^a	7,152
1963								
Apr. - June	40 ^a	3,730	1,613	746	90	31 ^a	27 ^a	6,277
July - Sept.	805	8,091	2,025	380	98	14 ^a	22 ^a	11,435
1964								
Apr. - June	100	2,328	3,676	649	106	50	11 ^a	6,920
July - Sept.	851	3,108	3,695	785	88	95 ^a	7 ^a	8,630
1965								
Apr. - June	50	2,197	1,317	1,103	227	66	29 ^a	4,989
July - Sept.	328	3,188	1,630	966	210	50 ^a	24 ^a	6,396

^aEstimates based on fewer than six age determinations in all samples continued.

The total return rate of tagged yellowtail flounder in the late 1950's usually ranged from 20 to 40%, over a period of about 3 years. The rate, presumably, was low because of loss of tags from tagging mortality, tag detachment, non-reporting of recovered tags, and movement of fish out of fishing areas. However, in 1957 aboard a research vessel during a southern New England experiment, seven fish were tagged and all were returned within 56 months (Table 5).

For these seven fish the upper limit of natural mortality can be estimated by using the average time at liberty, 22 months, and calculating the probability, through binomial expansion, of no losses from natural mortality in this period at various assigned values of natural mortality. If the natural mortality rate is assumed to be 20% per year ($M = 0.22$), for example, the probability of no losses through natural causes in 22 months is 0.04. For an assumed mortality of 15% ($M = 0.16$), the probability is 0.10. From these calculations it is suggested that natural mortality was 20% per year or less.

TABLE 4. Annual survival ratios in 1960-65 for yellowtail flounder of age-groups 4-7 from the 1954-60 year-classes. (The ratios were computed from data of Tables 2 and 3; all values used were based on six or more determinations for all samples combined.)

Calendar quarter	Survival ratio			Geometric mean
	Age-group			
	4 - 5	5 - 6	6 - 7	
Southern New England Ground				
Jan. - Mar.	0.442	0.340	0.338	0.370
July - Sept.	0.518	0.220	—	0.338
Oct. - Dec.	0.396	0.331	—	0.362
Geometric mean	0.449	0.291	0.338	0.356
Georges Bank				
Apr. - June	0.380	0.328	0.606	0.423
July - Sept.	0.339	0.295	—	0.316
Geometric mean	0.359	0.311	0.606	0.366

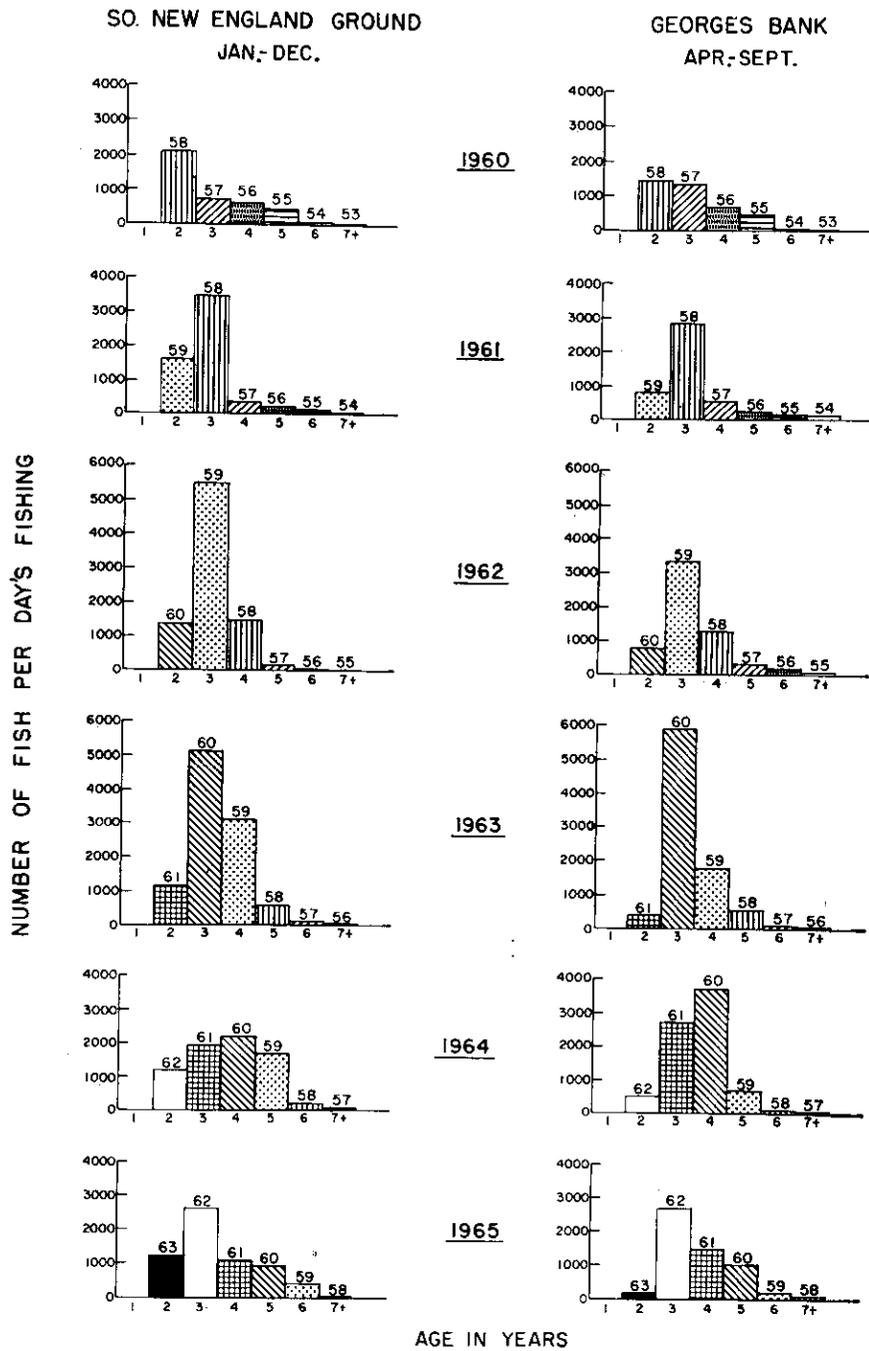


Fig. 1. The age compositions of yellowtail flounder landings on the southern New England ground and Georges Bank in 1960-65. (Numbers at tops of bars indicate year-classes.)

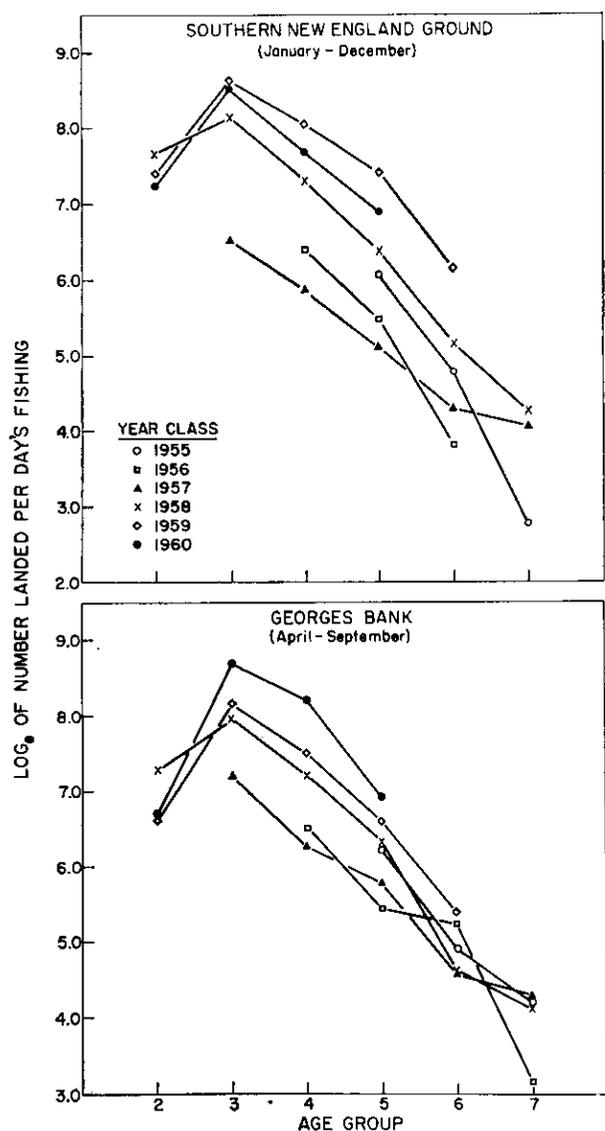


Fig. 2. Catch curves for yellowtail flounder for the 1955-60 year-classes on the southern New England ground and Georges Bank.

TABLE 5. Recovery dates and lengths and ages at tagging of seven yellowtail flounder tagged in February 1957 on the southern New England ground.

Recovery date	Length at tagging (cm)	Age at tagging (years)	Months at liberty
July 1957	34	3	5
Sept. 1957	34	3	7
Nov. 1957	27	2	9
Aug. 1958	29	2	18
Apr. 1959	30	2	26
Jan. 1960	37	3	35
Oct. 1961	28	2	56

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Experimental Snella Fishing for Cod, *Gadus morhua* L., on West Greenland Bank, August 1965, and Comparison of a Snella and an Otter-Trawl Catch of Cod from the Same Locality of Store Hellefiske Bank

BY WILFRED TEMPLEMAN¹

Abstract

An experiment was carried out on the West Greenland banks in August 1965 to compare the numbers, weight, and length of cod, *Gadus morhua* L., caught by the three sizes of hooks, No. 10, 11, and 12, used as part of the snella rubber bait handline gear. Number 10, the smallest hook, gave the greatest numbers and total weights but the differences were not as a rule statistically significant. There was also no significant difference in the average lengths of fish caught by the three hook sizes. The catch of a line with three hooks produced less numbers and weight than lines with six hooks but the differences were not significant.

An otter-trawl and a snella catch of cod in the same area of Store Hellefiske Bank on the same day showed significantly longer fish caught by the snella gear, when the catch of the otter trawl with the codend lined by small mesh was modified for selection by meshes of approximately 130-mm-double manila, but the actual differences were small—about 2 cm.

In snella fishing, cod catches were much less at temperatures of 1.25° to 2.2°C than at 2.4° to 5.3°C.

Introduction

In recent years snella fishing originating in Norway has become a common method of handlining cod and other fishes in Norway, the Faroes, Iceland, and Greenland. The snella is a hand reel, the line is monofilament nylon with usually a leader of somewhat smaller monofilament nylon. A lead or iron weight of 1.4–1.8 kg is used and, above this, hooks with rubber-worm baits.

According to Nordafar, the Norwegian-Danish-Faroese Fish Company at Faeringehavn, West Greenland, for their smaller boats the snella is the best gear. In the commercial Faroese fishery in West Greenland seven hooks are used with assorted colours of rubber. There were

three sizes of hooks available at Nordafar—No. 10, 11, and 12, of which No. 10 is the smallest and No. 12 the largest.

Snella gear is figured and the gear and its operation are briefly described by Devlin (1963). Devlin's article was also presented by Anon. (1963). For an earlier variation of the method see Anon. (1954).

I am indebted to Mr Steinar Olsen for an explanation of the various forms of Norwegian words which are used at times in relation to the snella operation: snelle = reel; snella = the reel; sneller = reels. I have preferred to use "snella" but either of the other two words could equally well have been used.

Methods and Materials

During the cruise of the *A. T. Cameron* to West Greenland in July–August 1965 with the author as scientist-in-charge, the main trawl winch failed in the middle of the cruise and samples of cod were collected on the West Greenland banks by snella fishing. The reels and equipment were obtained from the Nordafar Company at Faeringehavn.

For the gear obtained at Faeringehavn and used on the *A. T. Cameron* see Fig. 1–5.

Each reel was rigged with a monofilament line 1.5 mm in diam. The monofilament nylon leader to which the six hooks were attached, each pair 1 m apart, was 1.2 mm in diam.

An experiment was run to compare cod catches on hooks of sizes No. 10, 11, and 12. (See Table 1 and Fig. 6 for hook sizes and measurements.)

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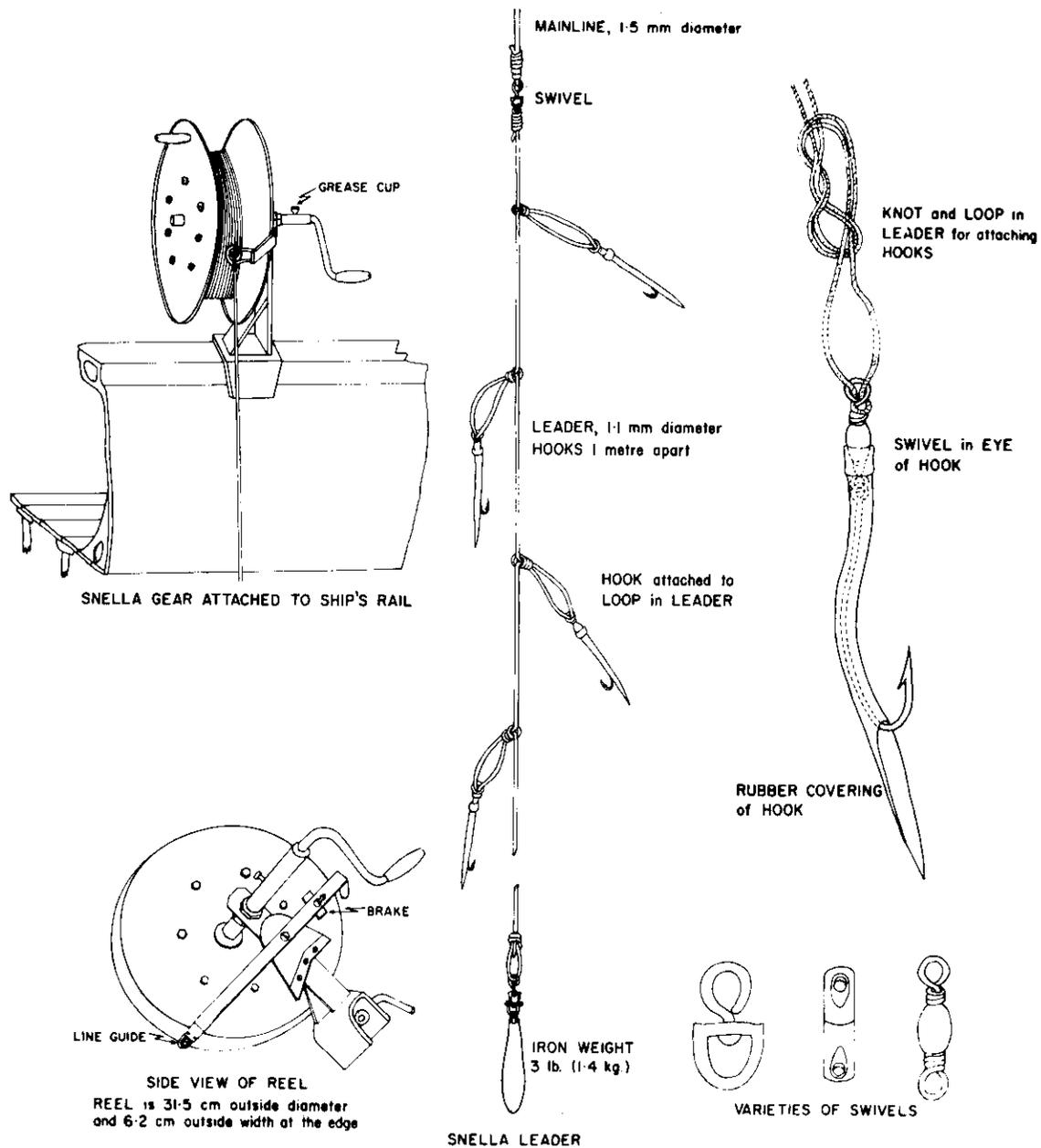


Fig. 1. Drawing of snella gear as used by the *A. T. Cameron* on West Greenland banks, August 1965.

TABLE 1. Measurements of hooks used in snella fishing, West Greenland, August 1965. (For A, B, and C refer to Fig. 6.)

	Length of shaft or shank (A)			Depth of bend (B)			Width of bend (throat) (C)		
	No. 10	No. 11	No. 12	No. 10	No. 11	No. 12	No. 10	No. 11	No. 12
Hooks measured (No.)	9	9	9	9	9	9	9	9	9
Range of dimensions (mm)	94-96	102-103	109-110	25-28	28-31	33-35	26-27	28-31	34-35
Average of dimensions (mm)	96	103	110	26	30	34	26	30	34
Diameter of wire in hook (mm)	2.4	2.7	3.0						

Rubber bait colours were, red, yellow, black, green, and white. It was impossible to obtain the same colours for the different sizes of hooks, consequently the experiment which follows takes no account of colours.

Three reels were arranged along one side of the *A. T. Cameron* (Fig. 2), the vessel drifted over the ground and, when the fishing failed, steamed back to drift over the ground again. In some areas and on some days a drift of as great as 3 nautical miles could be made with fishing successful along the whole drift. In other areas and depending on rapidity of change in depth and temperature and on the direction of drift the distance which could be successfully fished was much shorter.

The reels were each rigged with six rubber bait hooks and each reel had only one type of hook, either No. 10, 11, or 12. The operation began at the same time with a fisherman at each reel (Fig.

2). Each fisherman fished a particular reel or hook size for 10 min, then progressed along the rail to the next reel and hook size and a new man began at the first reel aft. Usually five fishermen were available at a time on 6-hr shifts, but the fishing period was usually shorter than this, the men were relatively fresh, interest was high and retrieval relatively rapid for men unskilled at this operation but used to hand-line fishing in Newfoundland.

At intervals during the fishing, the positions of the reels containing the different sized hooks were interchanged along the rail so that effects due to differences in position could be equalized.

In fishing, the sharply bent shaft and bend of the hooks (Figs. 4 and 5) and the movements of the free tail of rubber produced wiggly motions of the hooks which attracted the fish, and the cod apparently took hold as they would on ordinary bait. They were typically caught with the hook

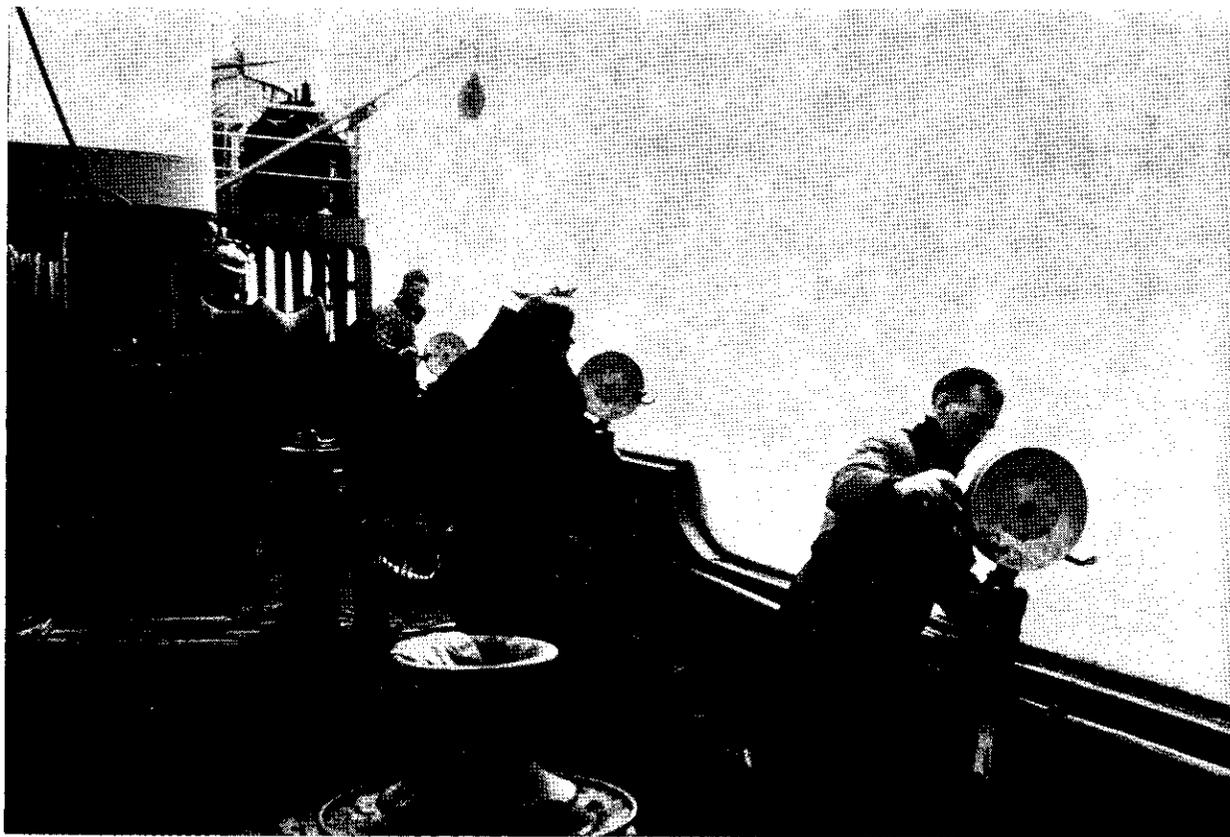


Fig. 2. Snella gear on the *A. T. Cameron* in West Greenland, August 1965.

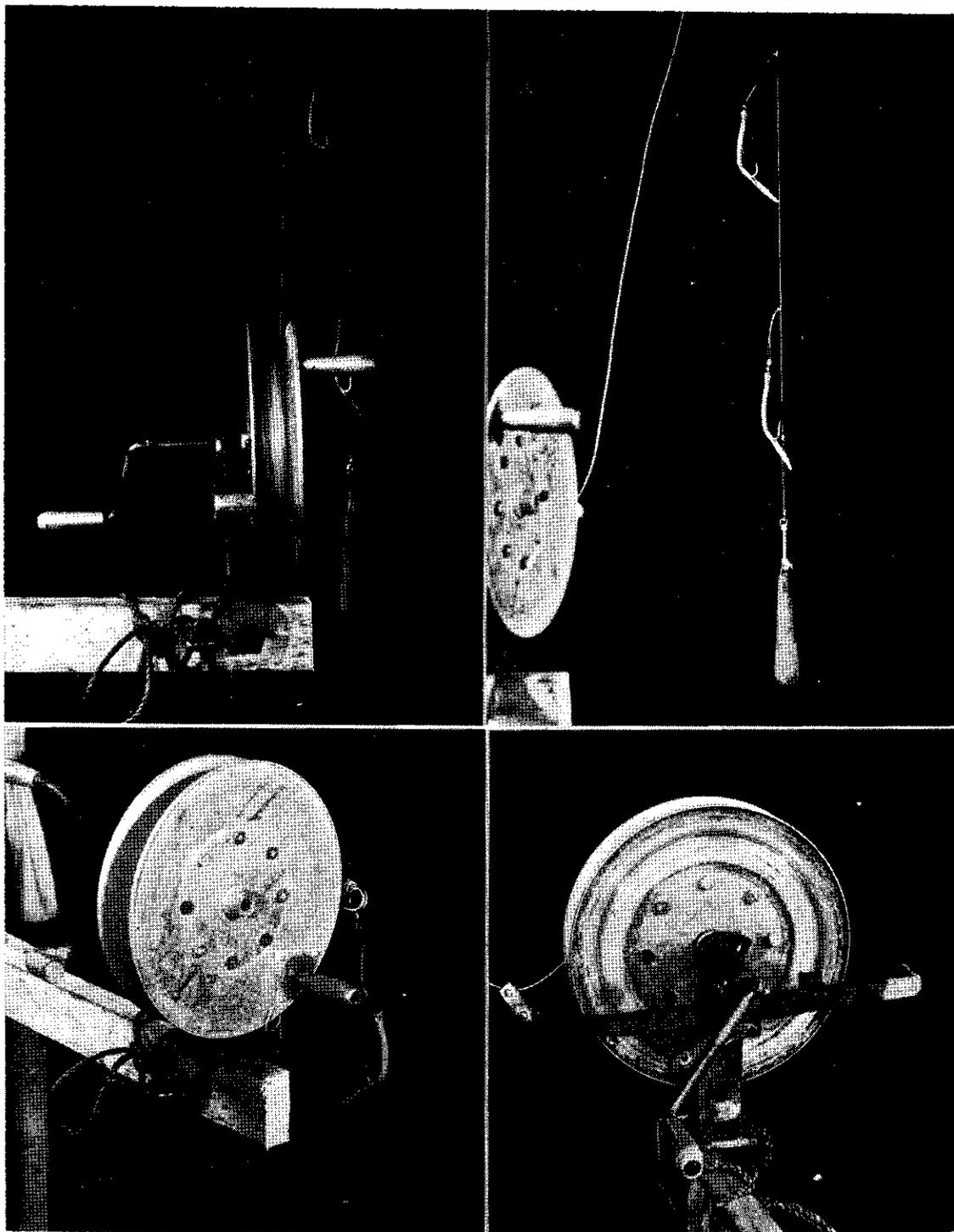


Fig. 3. Various views of snella gear used by the *A. T. Cameron* on West Greenland banks, August 1965.

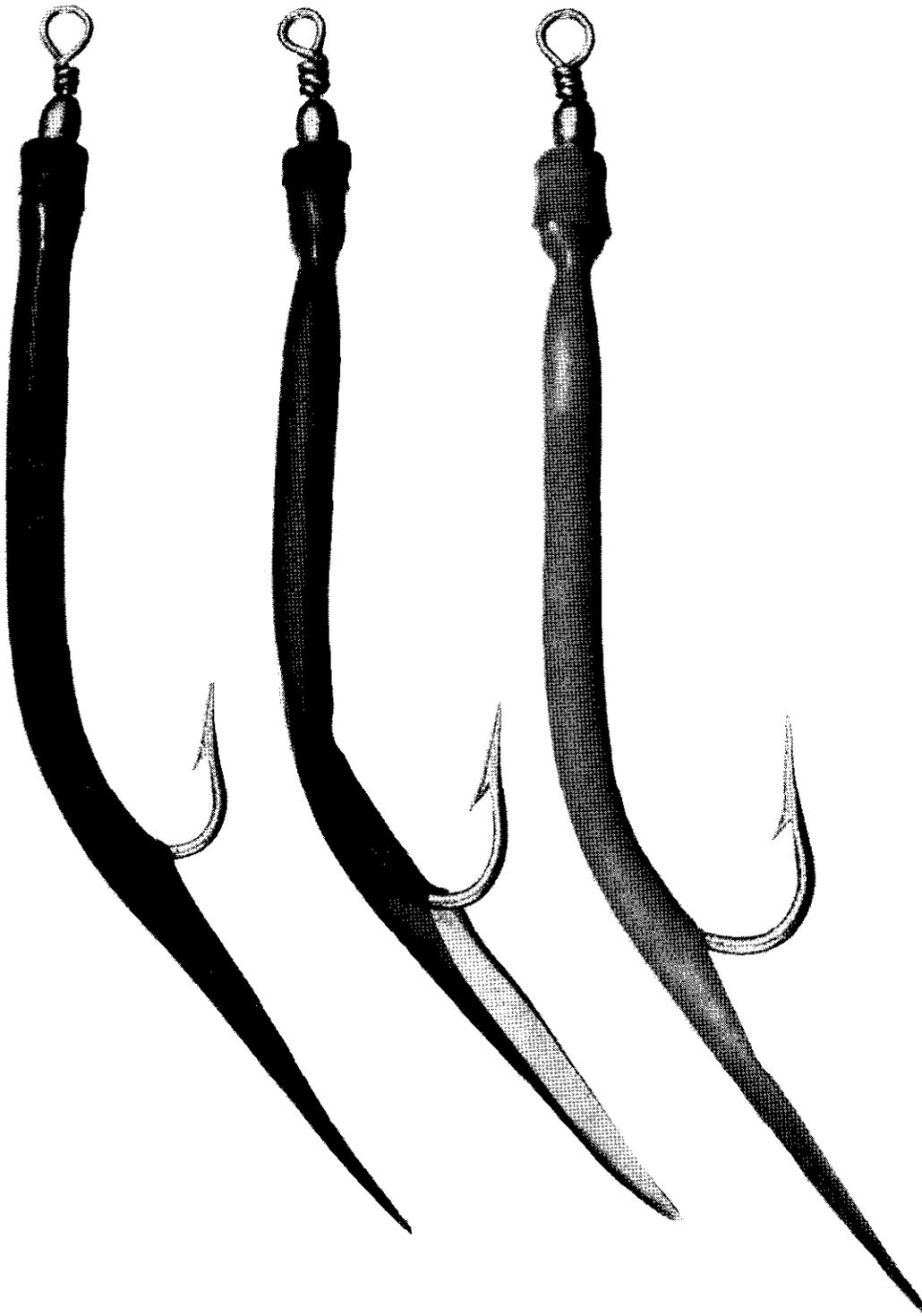


Fig. 4. No. 10, 11, and 12 snella hooks, natural size.

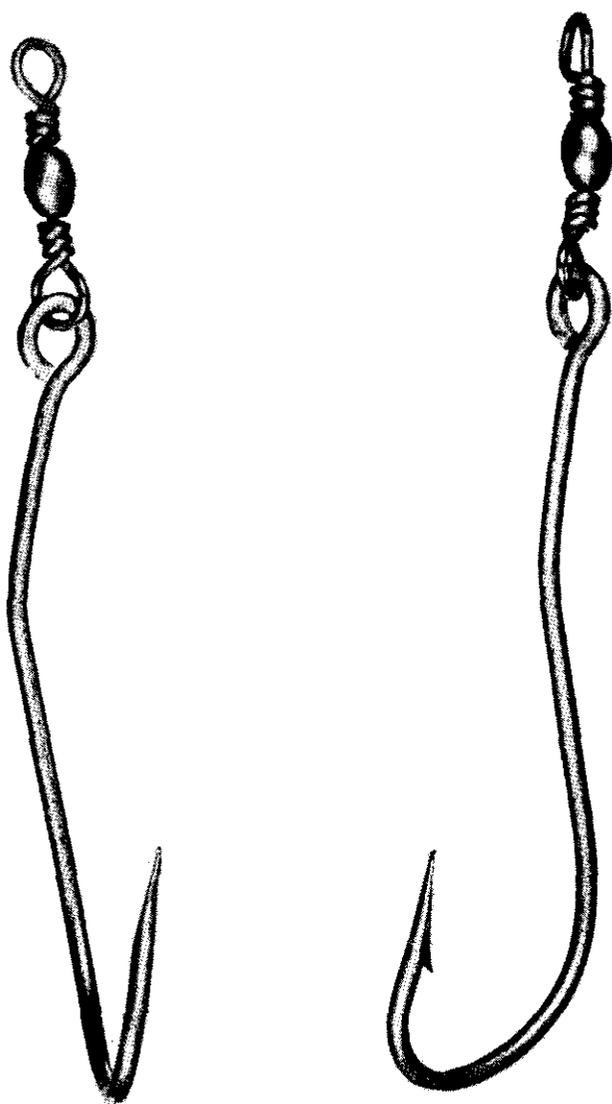


Fig. 5. Two views of a No. 12 snella hook with the rubber removed, natural size.

in the mouth. It was unnecessary to jig, merely to move the line up and down to keep the hooks moving and sometimes to set the hook when the fish bit. When one cod was hooked, the motions imparted to the hooks seemed to be favourable to the attachment of more cod and often three, four, or five fish were caught in one return of the hooks. This could happen when the first cod was being reeled back, but the fishermen often deliberately moved the line up and down and hooked several cod one after the other before retrieving the line.

The *A. T. Cameron* fishing was in relatively shallow water on the tops of the banks and fishing

was done near bottom, the lead was allowed to strike and pulled up about 2 m before fishing. As the ship drifted and the hooks came off bottom it was necessary to lower them again. Mid-water-snella fishing is also often successful in West Greenland especially in August when large quantities of cod are off bottom and relatively near the surface over deep water (Rasmussen, 1957).

Results

Comparative catches on No. 10, 11, and 12 hooks

In fishing with six hooks on each line, No. 10 hook produced a greater catch (352 cod, 1,213 kg) than No. 11 (310 cod, 1,034 kg) or No. 12 (296 cod, 1,048 kg) (Table 2). Including, also, two other sets in which there were six hooks on No. 11 and 12 but not on No. 10, catches of the No. 11 and 12 hooks were approximately equal, 484 cod, 1,345 kg for No. 11 and 471 cod, 1,375 kg for No. 12 hook.

In Sets 241 and 248, in which for half (Set 241) and the whole (Set 248) of the fishing period No. 10 had only three hooks and No. 11 and 12, six hooks, the No. 10 hook caught less cod than the larger hook sizes (Table 2).

There was no consistent difference in the average length and weight of cod caught by the three different sized hooks (Tables 2 and 3).

Comparison of sizes of cod caught by otter trawl and snella

At the time of the cruise to West Greenland, ICNAF had under consideration the proposal of Denmark to ban otter trawl and allow only hook (handline and longline) fishing on Store Hellefiske Bank because of the large numbers of small cod on this bank.

Plans had consequently been made to try snella and otter-trawl fishing in the same areas of the bank. The main winch of the *A. T. Cameron* ceased to operate after one pair of these comparative sets but since as far as we know nothing else of this nature is available for this area it may be worthwhile to present this small result.

The otter trawl was the usual *A. T. Cameron* No. 41 otter trawl, 24.1-m-head rope, 30.5-m-foot rope with 127-mm wing and anterior-belly meshes declining to 89-mm mesh in the after belly and codend and with the codend lined with 29-mm-nylon mesh. The net itself was of manila and was towed at about $3\frac{1}{2}$ knots.

TABLE 2. Catches and sizes of cod in experimental snella fishing by the A. T. Cameron, West Greenland banks, August 1965.

Area	Set	Date 1965	Range of depths fished	Range of bottom temperatures	Time each hook fished	Catch of cod on hooks						Average sizes of cod caught on hooks No. 10, 11, and 12								
						No. 10			No. 11			No. 12			No. 10		No. 11		No. 12	
						No.	No.	No.	No.	No.	No.	No.	No.	No.	kg	cm	kg	cm	kg	cm	kg	cm
N. peak of Store Hellefiske Bank	238	5 Aug.	22-24	5.27 (24)	117	83	67	57	121	93	82	52.7	51.8	52.1	1.5	1.4	1.4			
	241	6 Aug.	24-31	4.98 (29)	90	57*	68	71	115	152	150	57.4	59.8	57.9	2.0	2.2	2.1			
Lille Hellefiske Bank	248	9 Aug.	27-70	3.42 (66)	205	90*	106	105	155	159	177	55.3	54.0	55.3	1.7	1.5	1.7			
Dana Bank	271	18 Aug.	64-73	2.96 (66) to 3.49 (60)	268	93	89	84	300	304	261	68.7	71.9	68.4	3.2	3.4	3.1			
	274	19 Aug.	64-73	3.34 to 3.60 (60)	240	83	71	61	401	312	298	79.7	77.6	80.4	4.8	4.4	4.9			
Total with six hooks on each line for No. 11 and 12 hooks and three hooks for all or half of the set on No. 10	275	19 Aug.	60-64	2.42 (58) to 3.02 (60)	300	93	83	94	392	325	406	75.2	73.3	75.7	4.2	3.9	4.3			
	241-248	6-9 Aug.	24-70	3.42 (66) to 4.98 (29)	295	147	174	176	270	311	327	56.1	56.2	56.3	1.8	1.8	1.9			
Total Dana Bank (six hooks on each line)	271-275	18-19 Aug.	60-73	2.42 to 3.60 (58-66)	808	269	243	239	1093	941	965	74.7	74.0	74.3	4.1	3.9	4.1			
Total all sets with six hooks on each line	238, 271-275	5-19 Aug.	22-73	2.42 to 5.27 (24-66)	925	352	310	296	1213	1034	1048	69.5	69.2	70.1	3.4	3.3	3.5			
Total all sets for No. 11 and 12 hooks, six hooks on each line	238-275	5-19 Aug.	22-73	2.42 to 5.27 (24-66)	1220	.....	484	471	.....	1345	1375	.....	64.6	64.9	.....	2.8	2.9

*Sets 241 and 248 had only three hooks on No. 10 instead of usual six—in Set 241 for half the fishing time and in Set 248 for the full period fished.

TABLE 3. Total length frequencies of cod caught by the A. T. Cameron on hooks No. 10, 11, and 12 in snella fishing, West Greenland, August 1965. (Total length = snout to end of caudal fin in the mid line. The frequencies have been adjusted for small differences in actual times fished by the various hook sizes, hence the fractional numbers. Sheppard's correction has been used.)

Length, 3-cm groups	Set 238			Total Sets 241 and 248			Total Sets 271-275			Total Sets 238, 271-275			Total Sets 238-275	
	No. 10	No. 11	No. 12	No. 10	No. 11	No. 12	No. 10	No. 11	No. 12	No. 10	No. 11	No. 12	No. 11	No. 12
27-29	.....	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
30-32	.....	.....	.....	.....	.....	1.1	.....	.....	.....	.....	.....	.....	.....	1.1
33-35	.....	.....	1	1	1	.....	.....	.....	.....	.....	.....	1.0	1	1.0
36-38	1	4	.....	2	1	2.3	.....	.....	.....	1	4	.....	.....	5
39-41	3	2	1	2	5	3.3	.....	.....	.....	3	2	1.0	7	4.3
42-44	4	9	9	11	10	12.8	.....	.....	.....	4	9	9.0	19	21.8
45-47	13	6	2	13	18	19.5	.....	.....	.....	13	6	2.0	24	21.5
48-50	13	11	9	22	21	16.4	7	2	7.3	20	13	16.3	34	32.7
51-53	14	5	16	14	17	26.0	9	5	7.2	23	10	23.2	27	49.2
54-56	12	10	3	13	22	14.3	14	13	14.4	26	23	17.4	45	31.7
57-59	4	8	8	16	23	19.3	10	20	13.3	14	28	21.3	51	40.6
60-62	10	6	1	19	16	14.0	16	16	13.3	26	22	14.3	38	28.3
63-65	8	2	5	6	16	21.4	20	19	13.4	28	21	18.4	37	39.8
66-68	1	3	2	10	3	7.3	17	14	9.2	18	17	11.2	20	18.5
69-71	.....	1	.....	5	10	4.4	13	11	10.3	13	12	10.3	22	14.7
72-74	.....	.....	.....	3	1	2.1	15	13	14.3	15	13	14.3	14	16.4
75-77	.....	.....	.....	3	3	2.1	16	22	21.5	16	22	21.5	25	23.6
78-80	.....	.....	.....	3	3	1.0	23	25	26.5	23	25	26.5	28	27.5
81-83	.....	.....	.....	1	.....	1.0	30	15	27.6	30	15	27.6	15	28.6
84-86	.....	.....	.....	.....	1	4.4	32	28	17.4	32	28	17.4	29	21.8
87-89	.....	.....	.....	1	.....	2.1	18	14	18.3	18	14	18.3	14	20.4
90-92	.....	.....	.....	.....	2	1.0	15	15	9.3	15	15	9.3	17	10.3
93-95	.....	.....	.....	1	1	.....	6	6	8.2	6	6	8.2	7	8.2
96-98	.....	.....	.....	.....	.....	.....	4	3	5.1	4	3	5.1	3	5.1
99-101	.....	.....	.....	.....	.....	.....	1	2	2.0	1	2	2.0	2	2.0
102-104	.....	.....	.....	.....	.....	.....	3	.....	.....	3	.....	.....	.....	.....
Total	83	67	57	147	174	175.8	269	243	238.6	352	310	295.6	484	471.4
Average length (cm)	52.69	51.78	52.11	56.10	56.24	56.34	74.66	74.04	74.34	69.48	69.23	70.05	64.56	64.94
Standard deviation	6.90	8.10	7.16	10.72	10.33	10.92	12.78	12.24	12.79	14.94	14.68	14.80	14.66	15.04
Standard error	0.76	0.99	0.95	0.88	0.78	0.82	0.78	0.79	0.83	0.80	0.83	0.86	0.67	0.69

*Only 3 hooks instead of the usual six for half of Set 241 and the whole of Set 248. See Table 2.

The otter-trawl set was made in the shallow water on the northern peak of Store Hellefiske Bank on 5 August, 0600-0630 hr, and the snella comparison taken immediately afterward, 0735-0937 hr, on the same day, and in approximately the same position. Since the snella set was by drifting, it was not possible to hold exactly the same depths but only to drift approximately over the otter-trawled area, the otter-trawl set averaging 1.5 m deeper.

The cod caught by the otter trawl with the lined codend were considerably smaller than those taken by snella. When, however, the otter-trawl length frequency obtained from the lined codend was treated for selection by a 119.8-mm-mesh polypropylene monofilament codend as in Bohl (1967b), and for 132- and 138-mm-double manila as in Anon. (1965), the cod sizes caught by the A. T. Cameron's otter trawl, although somewhat

smaller, are little different from those caught by the snella gear (Table 4).

The cod selection data used were all from side trawlers, but the cod selection factor (3.26) for the polypropylene monofilament net operated by the side-trawler *Anton Dohrn* in Southwest Greenland (Bohl, 1967b) was very similar to that (3.22) obtained by the larger stern trawler *Walther Herwig* for the same kind of twine and approximately the same sized mesh on the southern slope of Store Hellefiske Bank in 1965 (Bohl, 1967a).

Temperature and snella catches

Although there was no deliberate and systematic attempt to compare snella catches of cod at different temperatures, some records made during fishing trials show an indication of better catches at higher temperatures (Table 5). At temperatures of 1.2° to 2.2°C, catches were much less than

TABLE 4. Comparisons of frequencies of cod from snella and otter-trawl catches.

Length 3-cm groups	Total frequencies		Calculated No. retained in codend in <i>A. T. Cameron</i> otter-trawl Set 237 after application selection for			Percentage of total			
	<i>A. T. Cameron</i>		<i>Anton</i> <i>Dohrn</i> ^b	<i>Ernest</i> <i>Holt</i> ^c	<i>Anton</i> <i>Dohrn</i> ^d	<i>A. T.</i> <i>Cameron</i>	<i>Anton</i> <i>Dohrn</i> ^b	<i>Ernest</i> <i>Holt</i> ^c	<i>Anton</i> <i>Dohrn</i> ^d
	Snella Set 238 22-24 m 117 min	Otter trawl ^a Set 237 22-27 m 30 min	119.8-mm- poly- propylene codend	132-mm- manila codend	138-mm- manila codend	1965 snella	1966 119.8-mm poly- propylene	1962 132-mm- double manila	1962 138-mm- double manila
21-23	0	3	0	1	0	0	0	0.4	0
24-26	0	1	0	0	0	0	0	0	0
27-29	0	4	0	1	1	0	0	0.4	0.4
30-32	0	7	0	2	2	0	0	0.9	0.9
33-35	1	7	1	3	2	0.5	0.4	1.3	0.9
36-38	5	20	6	10	7	2.4	2.5	4.3	3.1
39-41	6	18	10	11	9	2.9	4.2	4.7	4.0
42-44	22	42	31	29	28	10.6	13.0	12.3	12.4
45-47	21	47	41	36	36	10.1	17.2	15.3	15.9
48-50	33	45	41	37	38	15.9	17.2	15.7	16.8
51-53	35	35	34	31	32	16.9	14.2	13.2	14.2
54-56	25	31	31	30	28	12.1	13.0	12.8	12.4
57-59	20	18	18	18	17	9.7	7.5	7.7	7.5
60-62	17	13	13	13	13	8.2	5.4	5.5	5.8
63-65	15	5	5	5	5	7.2	2.1	2.1	2.2
66-68	6	3	3	3	3	2.9	1.3	1.3	1.3
≥ 69 ^e	1	5	5	5	5	0.5	2.0	2.0	2.2
Total	207	304	239	235	226	99.9	100.0	99.9	100.0
Average length (cm)	52.23	47.78	50.48	49.83	50.23				
Standard deviation	7.35	...	7.02	7.97	7.58				
Standard error	0.51	...	0.45	0.52	0.50				

^a*A. T. Cameron*, No. 41 trawl, codend lined with 29-mm-mesh nylon. See text.

^b*Anton Dohrn*, polypropylene monofilament, 119.8-mm-codend mesh, average total codend catch of cod per set, 622 kg, selection factor (cod) 3.26, West Greenland, ICNAF Division 1F, 27 September-30 October 1966 (Bohl, 1967b).

^c*Ernest Holt*, double manila, 132-mm-codend mesh, average total codend catch per set, 2,640 kg, selection factor (cod) 2.8, North Iceland, 24-25 July 1962 (Anon., 1965).

^d*Anton Dohrn*, double manila, 138-mm-codend mesh, average total codend catch per set, 555 kg, selection factor (cod) 2.9, N and NW Iceland, 9-14 July 1962 (Anon., 1965).

^e≥ 69 has been treated as an average of 70.

Sheppard's correction has been used.

at temperatures of 2.4° to 5.3°C. On the Dana Bank on 19 August, in Set 275 with low bottom temperatures of 1.57°C in 60 m toward the eastern part of the bank, cod were scarce but by passing westward to 64 m and 2.50°C excellent cod fishing by snella was obtained.

Discussion and Conclusions

Differences in numbers and total weight of cod caught by snella hooks No. 10, 11, and 12

In spite of the apparent differences, chi-square tests based on the hypothesis that the same

TABLE 5. Cod catches near bottom by snella gear at various bottom temperatures.

Set	Date 1965	Time (Greenland standard)	Bank area	Bottom	Time	Cod catch		Remarks
				temp °C	fished min	No.	kg	
238	5 Aug.	0735-0935	N peak of Store Hellefiske Bank	5.27 (24 m)	117	106	152	
241	6 Aug.	1830-2100	S edge of Store Hellefiske Bank	4.98 (29 m)	90	131	278	Temp. at 36 m = 5.2°C
248	9 Aug.	1200-1620	Lille Hellefiske Bank	3.42 (66 m)	205	84	137	Temp. at 75 m = 3.4°C
249	9 Aug.	1925-1955	Banana Bank	1.49 (48 m)	30	2	0.8	Temp. at from 37 to 53 m = 1.5°C
250	9 Aug.	2100-2115	Banana Bank	1.83 (93 m)	15	0	0	Temp. at 70 m = 1.5°C, and at 103 m = 1.8°C
252	10 Aug.	0915-0935	Fyllas Bank	1.80 (35 m)	20	3	6	Temp. at 43 m = 2.1°C
254	12 Aug.	1920-1940	Fyllas Bank	2.20 (40 m)	20	6	9	Temp. at 32 m = 2.5°C
255	12 Aug.	2045-2115	Fyllas Bank	1.30 (75 m)	30	14	18	Temp. at 65 m = 1.5°C
270	18 Aug.	0650-0720	Dana Bank	1.19 (51 m)	30	20	60	
271	18 Aug.	0835-1300	Dana Bank	3.49 (60 m) 2.96 (66 m)	268	59	194	Temp. at 77 m = 3.50°C
274	19 Aug.	0623-1132	Dana Bank	3.60 (60 m) 3.34 (60 m)	240	54	253	Temp. at 64 m = 3.74° and 3.64°C
275	19 Aug.	1155-1945	Dana Bank	2.42 (58 m) 3.02 (66 m)	300	54	225	

numbers of cod (Table 2) are caught by the different hook sizes, and the numbers caught with each hook size compared in each case in a 3-class table, show no significant differences in numbers of cod caught by the three different sized hooks for Set 238, Store Hellefiske Bank, P between 0.10 and 0.05; for the total of Dana Bank Sets 271-275, P between 0.5 and 0.3; or for the total of Set 238 and Dana Bank, P between 0.10 and 0.05. When numbers caught by individual hooks are compared by chi-square, the differences between hooks No. 11 and No. 12 are never close to significance. The greater differences between numbers caught by hooks No. 10 and 11 are also not significant: for Set 238, Store Hellefiske Bank, $P = 0.20$, for the Dana Bank total, $0.30 > P > 0.20$, and for the total of Sets 238 and Dana Bank, $P = 0.10$.

For the somewhat greater differences between the numbers caught by hooks No. 10 and 12: for Set 238, Store Hellefiske Bank and also for the total of Set 238 and Dana Bank the differences are significant $0.05 > P > 0.02$; for the total of Dana Bank the differences are not significant $P = 0.20$.

The chi-square comparison of differences in numbers caught by each of the three hook sizes in the total of Sets 241 and 248 in which there were only three hooks on No. 10 for half or the whole of the set and six hooks on each of No. 11 and No. 12, showed no significance, $P = 0.20$. Similarly, for the individual Sets 241 and 248, there were no significant differences in the numbers caught by different hooks in the individual sets; for both Set 241, and for Set 248, $0.50 > P > 0.30$.

The only significant difference, therefore, between the catches by the three hook sizes is between those for No. 10 and 12 for Set 238 because the significance of the total of Set 238 and Dana Bank for these two hook sizes is due to differences between these catches in Set 238 on Store Hellefiske Bank rather than to differences between the larger catches on Dana Bank which are not significant. Because the much greater numbers for Dana Bank show no significant differences between hook sizes, this difference between the small numbers caught on hooks 10 and 12, though statistically significant, cannot be given much weight and it is concluded that no real differences

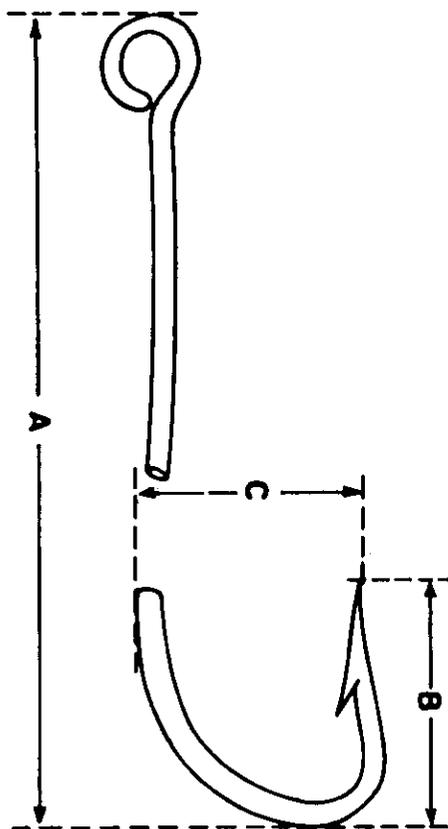


Fig. 6. Parts of hook measured for Table 1: (A) length of shaft; (B) depth of bend; (C) width of bend.

have been shown between the numbers of cod caught by the different hook sizes.

Because, also, the small differences in sizes caught by the different hooks have been shown later not to be significant, it may be assumed that the differences in quantities shown as caught by the three hook sizes in Table 2 are also not significant.

Differences in sizes of cod caught by snella hooks No. 10, 11, and 12

Some of the length frequencies of Table 3 are bimodal but moderately well balanced and of the same shape relative to one another and with fairly large numbers in the samples, and it is allowable in view of the central-limit theorem to apply the usual statistical tests (Snedecor, 1956).

None of the differences in average lengths of cod caught by the different hook sizes within the experiments or combinations of experiments shown in Tables 2 and 3 approach statistical significance.

The lack of difference in average length of the cod caught on the three hooks of different sizes is unexpected and is different from McCracken's

(1963) results from longline catches in which considerably greater numbers of small cod were caught on smaller than on larger hooks. In longline catches the cod must hook themselves whereas there is some effect of the fisherman's hooking the fish in the snella fishery.

Actually as may be seen in Fig. 4, in spite of the considerable differences in the overall proportions of the actual hooks (Table 1; Fig. 4), the rubber lengths were variable and did not necessarily correspond in relative size to the hook sizes. Thus, because the rubber was more visible than the hook, the overall appearance of hooks of sizes 10-12 often differed little. Snella hooks, measured overall between perpendicular planes in their natural shape between the extreme ends of the swivel and rubber, had lengths as follows, each of these lengths representing averages of usually 10 hooks as bought in bundles of 10 from Nordafar: No. 10—18.4, 18.3, 18.7; No. 11—18.6, 19.1; and No. 12—18.7, 18.8, 19.0. This lack of considerable differences in overall appearance very likely contributed to the lack of considerable differences in the quantities and sizes caught.

General

Although the cod caught in the Newfoundland hand-line fishery are rather small, the hooks used (with about 31-33 mm width of bend and approximately similar in size to the larger snella hooks) are much larger than those (only 20-21 mm width of bend) used in the longline fishery and evidently must be efficient for catching the smaller as well as the larger commercial sizes of cod present, or presumably they would not be used. For the sizes of cod fished in West Greenland, the ease of taking the smaller hook or of getting hooked more deeply by this hook in the snella fishery, which resulted in the catching of more cod and a greater weight of cod by the smaller hook, must have extended approximately equally throughout the size range of cod taken by the hooks.

The work described is a first approach whose imperfections were largely due to its ad hoc nature with a resulting lack of a completely adequate range of hook sizes and colours.

The differences shown, however, in the numbers and weights of cod caught on the different hooks during the experiment are worthy of further investigation with greater numbers of fish (which if the same relative level of numerical difference were maintained would raise the level of significance), a wider range of hook sizes, and with rubber baits of the same colour and of the same length,

and in another experiment of lengths proportional to hook sizes. The Manager of Nordafar at Faeringehavn said that their fishermen usually buy No. 10 and 11 hooks. Thus, in spite of the lack of significance in the present tests, the capture of more cod by the No. 10 hook may have some reality. The effects that the use of different colours with the same size of hook would have on the catch would also be worth investigating.

Differences between otter-trawl and snella catches

The 1.8–2.4 cm smaller average sizes of the otter-trawl catch, when transformed by selection corresponding approximately with that of 130-mm-double manila, are highly significantly different (statistically) from the snella catch in the same area of Store Hellefiske Bank (Table 4). However, the actual differences are small and indicate that the effects on cod selection of the 130-mm-(manila) mesh regulation for West Greenland proposed by ICNAF (1966) might not be greatly different from selection by the No. 10–12 hooks of the snella gear.

Cod and temperature in West Greenland

I have found no record of comparative temperature relationships to cod catches by snella gear. However, for pelagic longline cod fishing in the Holsteinborg Deep, Anon., actually Rasmussen, (1953) showed reasonably good catches for 0.6°–1.0° to 4.1°–4.5°C, with better catches for 1.6° to 4.0°C and the peak catches at 2.1° to 2.5°C. For cod fishing by longline on Disko Bank, Rasmussen states that in some places the bank was covered with water of temperatures below 1°C and here the fishery mostly gave poor results. Fishing was best where the transition layer of 4° to 2°C touched the bottom. Rasmussen (1955) for pelagic longlining in Holsteinborg Deep shows the best catches of cod in 1953 at 2.2°C and in 1954 at 0.8° to 0.9°C.

Bratberg and Hylén (1964) in a summary of Norwegian longline cod catch and temperature observations off West Greenland show best catches between about 1.8° and 3°C with moderate but declining catches down to 0.5° or 0°C with occasionally excellent catches between 1.0° and 1.5°C.

It has been recorded (Lee, 1952) that when concentrations of food animals such as capelin which prefer low temperatures are available, cod, feeding on them, will be found at lower temperatures than usual. The longline fishing recorded above appears to be relatively more productive at

temperatures below 2.0°C than our few records for snella gear and it may be that there is a different temperature relationship to catches by the two gears which is worthy of further investigation.

Acknowledgements

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Reassessment of the Cod Stocks at West Greenland (ICNAF Subarea 1)

BY SV. AA. HORSTED¹

Abstract

Population studies on Greenland cod are reviewed and parameters on growth, mortality, and selectivity are revised. Yield per recruit is assessed on the basis of the constant parameter model for various combinations of parameters and effort.

Introduction

The cod in Greenland waters has been studied by Danish fisheries investigators since the early 1900's. The most comprehensive work on the biology of the Greenland cod was by Hansen (1949) who reviewed all work completed to 1947.

Since the establishment of the International Commission for the Northwest Atlantic Fisheries (ICNAF) in 1952, intensive studies on the Greenland cod stocks have been carried out by scientists of various ICNAF member countries. The first assessment of the cod stocks in the West Greenland waters (ICNAF Subarea 1) was made by the ICNAF Working Group of Scientists on Fishery Assessment in Relation to Regulation Problems (The Assessment Group) in 1960 and 1961 (Beverton and Hodder, [ed.] 1962). From 1962 to 1965 no reassessment of Subarea 1 cod was made. Each year, however, the ICNAF Assessment Subcommittee reviewed the development of the fishery and the research carried out.

At the 1965 Annual Meeting of ICNAF, Denmark proposed that Store Hellefiske Bank (ICNAF Division 1B) be closed to trawling in order to protect small cod. The ICNAF Greenland Cod Working Group was established to review this proposal and the whole problem of the desirability of protecting small cod at West Greenland. The Working Group met twice in 1966. The reports of the Working Group and some of its working documents are published in Section A of Part III of the ICNAF Redbook 1966.

The effects of possible conservation actions on West Greenland cod were studied by the ICNAF Working Group on Joint Biological and Economic Assessment of Conservation Actions in 1966 and 1967 (Gulland, 1968). At the same time, Meyer (1967) made an analysis of the efficient use of West Greenland cod, while Horsted (1967*b*) provided quantitative estimates of the abundance and fluctuations of the cod year-classes.

In 1967, ICNAF established its new Standing Committee on Regulatory Measures. At its first meeting in January 1968, the Committee posed a number of questions to the Standing Committee on Research and Statistics. Part of the answer to these questions is a reassessment of the various ICNAF fish stocks. In the present paper the author has tried to revise the parameters for the cod stocks in Subarea 1 and, insofar as some of these parameters differ from those used in earlier assessments, to reassess the Subarea 1 cod.

Review and Revision of Parameters

Growth parameters, K and L_{∞}

Since 1924 when data became available on the length and age of Greenland cod these have shown fluctuations in the growth rate (Hansen and Hermann, 1965). Horsted (1967*a*) and Meyer (1967) have shown that from 1953 to 1959 the growth rate of cod was slower than in the period 1960-65. The values for the growth parameters, K and L_{∞} , used in this paper were obtained from Horsted (1967*a*, table 2) by plotting yearly increments in length against initial length, thus giving a straight line of slope $e^{-k}-1$ and an intercept on the X-axis of L_{∞} (Fig. 1). Table 1 shows that the growth parameters used in earlier assessments correspond rather closely to those used in the present paper.

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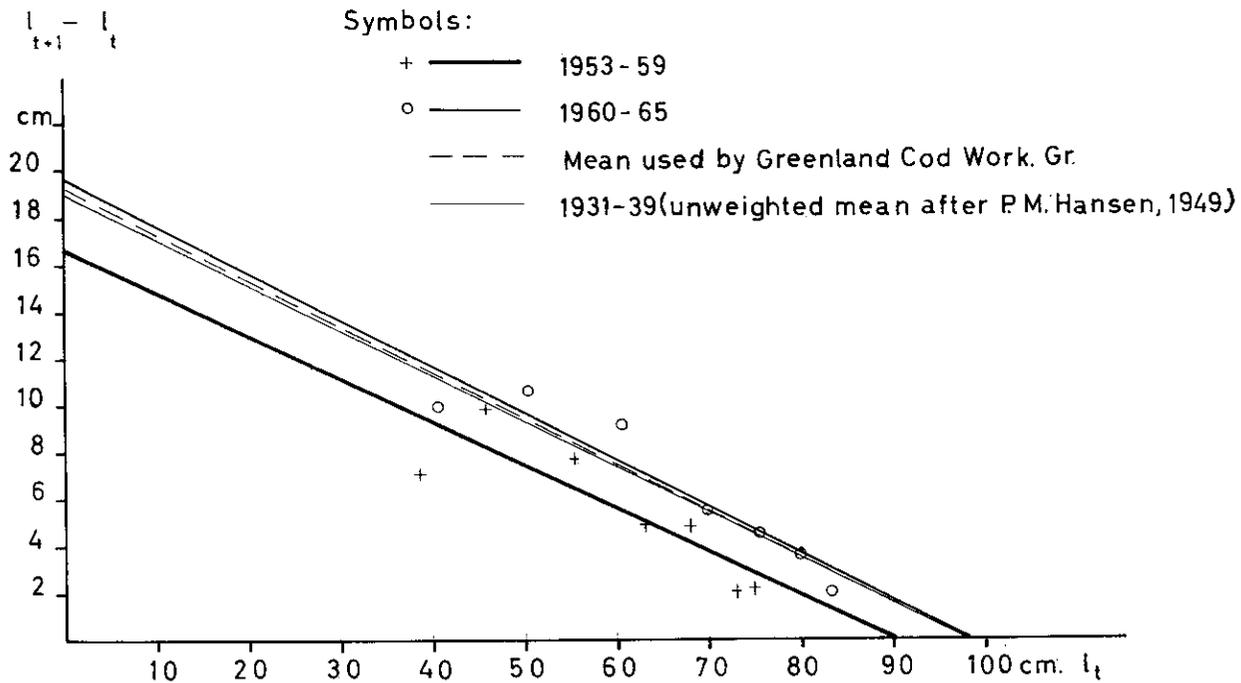


Fig. 1. Growth rates of cod at West Greenland.

TABLE 1. Growth parameters (symbols according to the Beverton and Holt /von Bertalanffy model).

Growth parameter	Unweighted mean of values for 1931-39 (Hansen, 1949)	Assessment Group	Greenland Cod Working Group (Gulland, 1967)	Bio-economic Working Group (Gulland, 1968)	Present paper	
					min.	max.
K	.21	—	.22	.25	.20	.22
L_{∞} (cm)	98	—	97	90	90	98

Mortality coefficients, Z, F, and M

Total mortality, Z, has been estimated from recaptures from Danish tagging experiments. Details of these experiments are given in Table 2. Plots of the natural logarithm of returns (as a percentage of the releases) in the first to fourth calendar years after year of tagging are shown in Fig. 2. The period to which the values of Z estimated from recaptures are referred is taken as the last year in the tagging period plus the following

year, e.g. for the tagging period 1955-59, the period of recaptures is taken as 1959-60. The slopes of the regression lines in Fig. 2 give the values of Z shown in Table 3. Values of Z obtained in this way may tend to be somewhat underestimated since the fishing intensity is increasing steadily throughout each period. Less biased values, obtained by taking the natural logarithm of the ratio of numbers caught in the second year to those caught in the first year, are also given in Table 3.

TABLE 2. Cod tagged by Denmark and recaptured in ICNAF Subarea 1, 1946-63. Only cod > 50 cm in length when tagged are included. Data from taggings carried out in fjords are not included.

Year	No. tagged	No. recaptured		Recaptures in first four calendar years after year of tagging (in numbers and as a percentage of the releases)				
				1st	2nd	3rd	4th	Total
1946-49	3,109	376	No.	115	65	62	38	280
			%	3.60	2.04	1.94	1.19	9.01
1950-54	9,270	1,403	No.	495	294	180	94	1,063
			%	5.34	3.17	1.94	1.01	11.47
1955-59	10,966	2,366	No.	1,044	480	245	99	1,868
			%	9.52	4.38	2.23	0.90	17.03
1960-63	12,988	2,267	No.	1,076	458	249	not yet	1,783
			%	8.28	3.53	1.92	complete	13.73

TABLE 3. Estimates of mortality rates used in earlier assessments and as found from Fig. 2.

	Values	Year				
		1949-50	1954-55	1959-60	1963-64	1965
Assessment Group, 1960-61 (Beverton and Hodder [eds.] 1962)	Z		.35			
	M		.15 - .20			
	F		.20 - .15			
Greenland Cod Working Group, 1966 (fig. 7 in Gul- land [ed.] 1967a)	Z	.45	.56	.62		
	M	.15 - .20	.15 - .20	.15 - .20		
	F	.30 - .25	.41 - .36	.47 - .42		
Bio-Economic Working Group, 1967 (Gulland, 1968)	Z					.63 - 1.00
	M	Figures based on those of the Greenland Cod Working Group				.15 - 0.20
	F					.48 - 0.80
Present paper Fig.2	Regression year 1 to 4	Z	.34	.55	.68	.73
		M	.20	.20	.20	.20
	Relation 2nd: 1st year of recapture	Z	.14	.35	.48	.53
		M	.57	.52	.78	.85
		M	.20	.20	.20	.20
		F	.37	.32	.58	.65

The fishing mortality, F , could not be determined from these tagging experiments because all recaptures were not reported. Instead an estimate of the natural mortality, M , is obtained. All previous assessments on Greenland cod have estimated M to be between 0.15 and 0.20. Recaptures from cod tagged in the period 1935-39 were made, in part, during the war when fishing effort was low. Therefore, plotting recaptures from these taggings in the same way as for the

taggings given in Table 2 should give a line with a slope close to the natural mortality. This line is shown in Fig. 2. Since the value of Z from the 1935-39 experiments is 0.28, it may be assumed that M is close to 0.20. This value of M is used in the present paper. Subtracting $M = 0.20$ from Z gives the value of F . This is shown in Table 3 which also shows the F values used in earlier assessments.

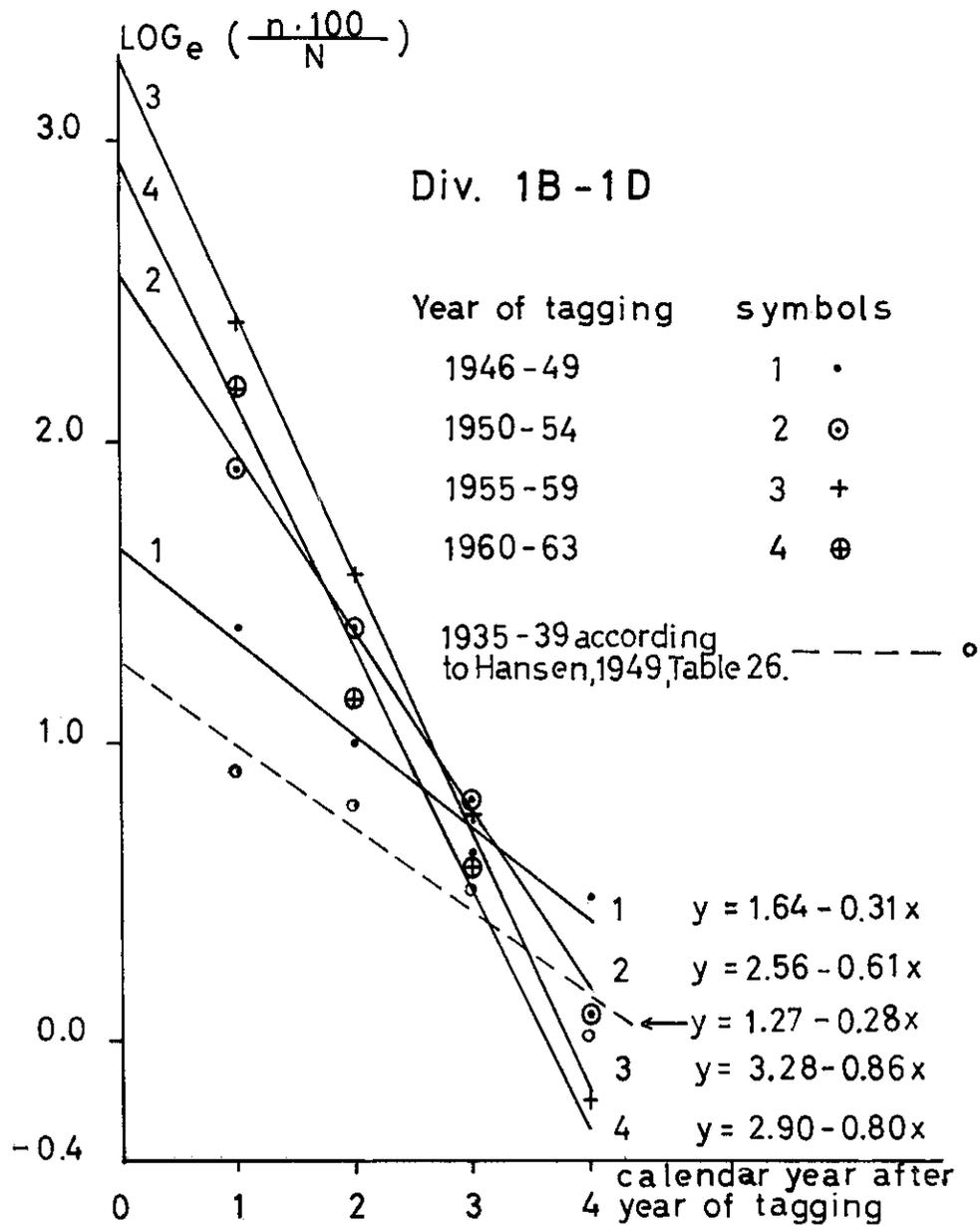


Fig. 2. Analysis of West Greenland cod tagging experiments to give estimates of total mortality rate, Z .

There is obviously good agreement between the mortality estimates used in earlier assessments and those found in the present study. Although the estimate of F for the northern stock (Div. 1B-1D) was found to be somewhat higher than that for the southern stock (Div. 1E and 1F), for the purpose of this study the West Greenland cod stocks may well be regarded as a unit.

Estimating mortalities from tagging experiments makes it impossible to obtain up-to-date values. Indeed, the reported increase in fishing activity means that the value of F is at present higher than the latest values shown in Table 3. A total mortality, Z , of 1.00 may be close to the actual present day value (fishing mortality, $F = 0.80$; exploitation rate, $E = 0.80$) with upper and lower limits of 1.20 and 0.80 respectively.

Length at first capture, l_c

In this study, length at first capture, l_c , is considered the same as the 50% retention length of the trawl-caught cod, it being understood that length at recruitment, l_r , is less than l_c .

The Bio-Economic Assessment Group (Gulland, 1968) used an l_c value of 50 cm. The Assessment Group (Beverton and Hodder [ed.] 1962) estimated l_c to be 53 cm at a mesh size of 114 mm.

The Assessment Group and the Greenland Cod Working Group used a selection factor of 3.7. Recent experiments (Bohl, 1967*a* and *b*) show, however, that the selection factor is close to 3.3. However, Meyer (1967) reports that the effective mesh sizes in use on some factory trawlers are less than those assumed in earlier assessments. The uncertainty in estimating l_c in previous assessments is due, in part, to lack of information on discards. The recent experiments mentioned above do, however, suggest that the values of l_c used previously are too high and that a value of 35-40 cm is more realistic. Danish trawling experiments on Fyllas Bank in 1968 and the recent German experiments (Meyer, 1967; Bohl, 1967*a* and *b*) indicate that the value of l_r remains less than the proposed value of l_c .

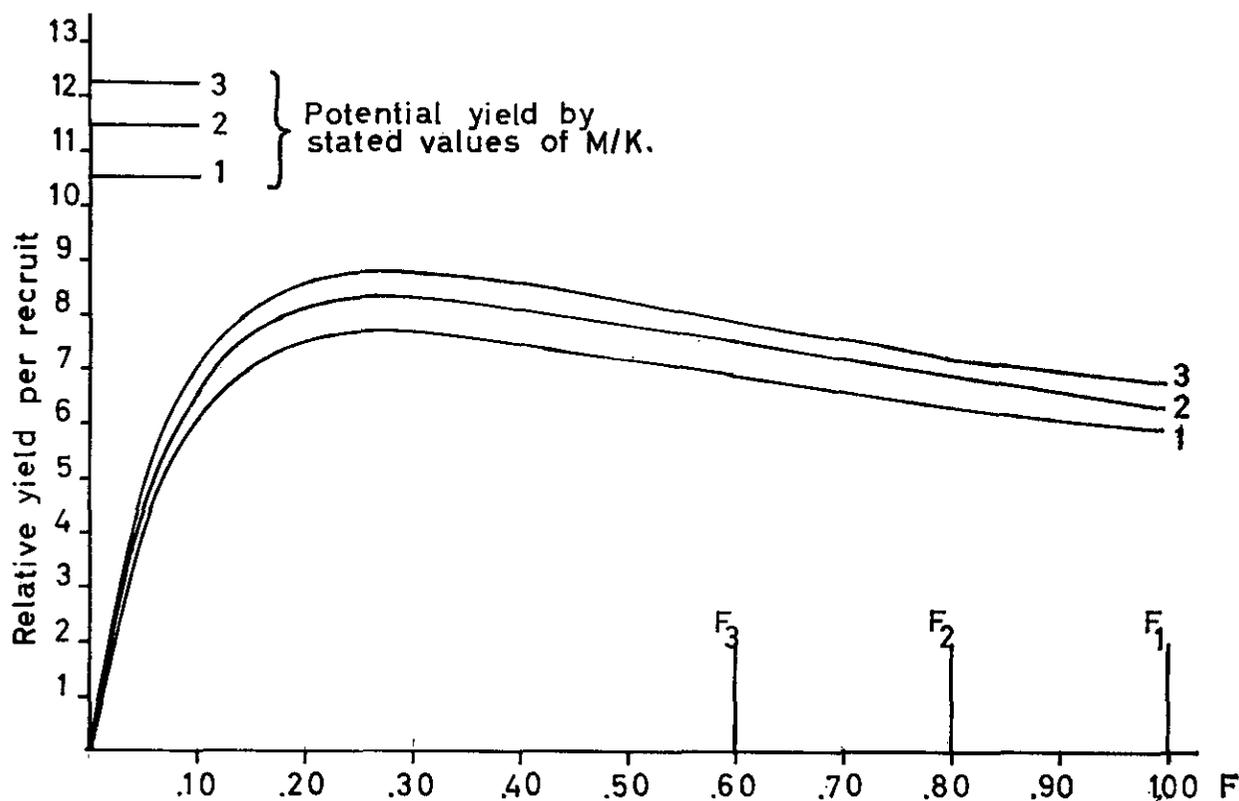


Fig. 3. Yield/effort curves for the three examples in Table 4.

TABLE 4. Parameters and corresponding yield per recruit of Subarea 1 cod. (Symbols according to FAO Yield Tables.)

Example:	1	2	3
	Upper limit of effort Lower limit of growth Lower limit of l_c	Possible medium values	Lower limit of effort Upper limit of growth Upper limit of l_c
F	1.00	.80	.60
M	.20	.20	.20
Z = F+M	1.20	1.00	.80
F/M	5.00	4.00	3.00
E = F/Z	.83	.80	.75
K	.20	.21	.22
M/K	1.00	.95	.91
L_∞	90 cm	94 cm	98 cm
l_c	35 cm	38 cm	40 cm
$c = l_c/L_\infty$	.39	.40	.41
Relative yield per recruit	060	070	082
% of potential maximum yield	57%	61%	67%
l_c and c unchanged:			
maximum yield	077 (= +28%)	084 (= +12%)	090 (= +10%)
corresponding E	.57	.60	.60
corresponding F	.26 (= -74%)	.30 (= -62%)	.30 (= -50%)
F and L_∞ unchanged:			
maximum yield	103 (= +72%)	111 (= +59%)	116 (= +41%)
corresponding c	.70	.71	.69
corresponding l_c	63 cm	67 cm	68 cm
$l_c = 45$ cm			
other parameters unchanged:			
relative yield	.081 (= +35%)	085 (= +21%)	090 (= +10%)
$l_c = 45$ cm			
change of F to give maximum yield:			
relative yield	087 (= +45%)	092 (= +31%)	095 (= +16%)
corresponding E	.65	.65	.65
corresponding F	.37 (= -63%)	.37 (= -54%)	.37 (= -39%)
Potential relative yield by stated values of M/K	105	115	123

Conclusions and Discussion

Using the parameters with the values established in the preceding sections, the yield per recruit can be estimated from the FAO Yield Tables (Beverton and Holt, 1964). Three sets of parameters are used (Table 4) to give upper, medium and lower limits of the state of the cod stock and fishery. Yield per effort curves for the three examples are shown in Fig. 3.

The examples show that either the present effort is too high or the mesh size which determines l_c is too small or both. In the optimum case,

example 3 of Table 4, 67% of the potential maximum yield is obtained, while in the other two examples only 57-61% of the potential yield is obtained. If the present effort is maintained, the values of l_c must be changed to 63-68 cm in order to get maximum yield in terms of weight. These l_c values correspond to mesh sizes of 190-205 mm and the corresponding increases in yield per recruit would be 41-72%. However, reduction of effort, although it results in a smaller increase in weight than does increase in mesh size, has obvious economic advantages in cost saving which are not obtainable by increasing mesh size

alone. Obviously a combination of reduction in effort and increase in mesh size has the greatest advantages.

Introduction of the 130 mm mesh size proposed by ICNAF for Subarea 1 (in force from 21 September 1968) should mean that l_c will be close to 45 cm. This parameter combined with the other parameters in Table 4 gives an increase in present yield of 10-35%. However, a further 6-10% increase in yield to 16-45% could be obtained by combining this mesh size with a 39-63% reduction in effort resulting in great economic advantages.

The conclusions reached above are only as reliable as the values established for the parameters used in the assessments. Despite the fact that the best possible values have been established, they are subject to further improvement.

Also, the assessments are based upon the constant parameter model which may provide a good idea of the state of the stock and the fishery, but which, on the other hand, is too simple to give a more definitive answer. The same problem that is dealt with in this paper has been attacked by Garrod (1969) who, using a "Schaefer-type" model on the catch/effort relationship, concluded that the level of fishing at West Greenland is close to the optimum. This is a more optimistic conclusion than that reached in this paper. However, Garrod's methods are also very approximate and he emphasizes that his paper "is contributed not as definitive statement but to stimulate a critical appraisal. . . before drawing far-reaching conclusions. . ." The same holds true for this paper.

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Spiny Dogfish Tagging and Migration in North America and Europe

BY ALBERT C. JENSEN¹

Abstract

The spiny dogfish is a valued food fish in Europe but in North America it has little or no economic value and is considered a nuisance species by commercial fishermen. Possible increased use of dogfish in North America, as a food fish and for fish protein concentrate, will require more biological information that can be used as a basis for sound management of the species.

Successful tagging experiments off the North American West Coast and in European waters have yielded information about the migrations and relative abundance of the dogfish. However, tagging experiments in the ICNAF areas off the USA and Canada have been hampered by fishery practices and the lack of readily recognizable tags.

Previous tagging studies are reviewed and the tags and their relative successes are discussed. Details of recent taggings off the New England and Middle Atlantic states are described and possible dogfish migration routes in these waters are mentioned.

Petersen disc tags, attached dorsally or through the snout, gave good returns over periods of up to 7 years. Streamer tags or spaghetti tags apparently are abraded by the rough skin of the dogfish and thus lost. The best return of tags came from fisheries that sought the dogfish either for food or as an industrial species.

The pattern of tag recoveries in ICNAF waters suggests there are more or less resident groups of dogfish and migratory groups that move at least between Virginia and Newfoundland. A few trans-Atlantic recoveries of tagged individuals suggest that the dogfish off the coast of North America may be related to the dogfish off the Scottish-Norwegian coasts.

Introduction

At the present time, the spiny dogfish, *Squalus acanthias* L., in the Northwest Atlantic has little economic value. It does, however, constitute a nuisance to fishermen. During certain times of the year, especially during the early spring and late autumn, it may quickly fill the nets of trawlers. A catch per tow then of 5,000–10,000 lb. is not unusual.

This situation is in contrast to that in European waters where the spiny dogfish is sought after as a valued food. The Norwegian fishery, for example, in 1964 landed 48 million pounds of dogfish for food, mostly for the British market (Aasen, 1964a). Other European nations, that same year, landed nearly 21 million pounds of dogfish for food.

The complaints of North American fishermen about the spiny dogfish and the possibility that we soon may want to manage and conserve the species indicate the need for information about the status of the dogfish populations in the Northwest Atlantic. It is my purpose here to summarize dogfish tagging experiments relative to success of tag types, and dogfish populations and migrations. This report will describe some of the tags used, their relative successes, and, particularly, experiments carried on during the past 10 years in the ICNAF waters off New England.

Tagging Experiments

One of the earliest dogfish tagging experiments was reported by Clemens (1932) in which the fish were marked with aluminum strap tags attached to the caudal fin. The dogfish were marked incidentally during a salmon tagging program off British Columbia and only one fish (1.5%) was recaptured. There is little other information available about the experiment. Since that time, however, many thousands of the species have been tagged off both coasts of North America and in the Northeast Atlantic. These experiments are summarized in Table 1.

The choice of tag and its place of attachment on the fish have varied from experiment to experiment. Most taggers, however, have favored Petersen discs, or an Atkins-type tag, attached through, or at the base of, the first dorsal fin. (See Rounsefell and Kask, 1945, for detailed

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TABLE 1. A historical summary of dogfish tagging experiments.

Tag	Gear	Number		% Recaptured	Area	Reference
		Tagged	Recaptured			
Aluminum strap (caudal)	Salmon troll	66	1	1.5	Off British Columbia	Clemens (1932)
Atkins-type (dorsal)	Gill net	279	15	5.4	Off Newfoundland	Templeman (1944, 1954, 1958)
Petersen (dorsal)	Otter trawl and trap	9,705	653	6.7	Vancouver Island	Bonham <i>et al.</i> (1949); Kauffman (1955); Holland (1957)
Atkins-type (dorsal)	Danish seine	75	2	2.7	Irish Sea	Beverton <i>et al.</i> (1959)
Lea-type (dorsal)	Longline	8,122	881	10.8	North of Scotland	Aasen (1960, 1964b)
See below ^a	See below ^b	844	17	2.0	Off New England	Jensen (1961, 1966)
See below ^c	Otter trawl	1,438	32	2.2	Northeast of Scotland	Holden (1965)
Petersen (dorsal)	Otter trawl	5,830	346	5.9	North of Scotland	Holden (1965)
Petersen (dorsal)	Longline	2,890	515	17.8	North of Scotland	Holden (1965)
Rototags (dorsal)	Longline	111	2	1.8	Off New England	Casey (pers. comm.)

^aPetersen discs on snout; Petersen discs on dorsal fin; combination spaghetti-Petersen disc on dorsal fin; spaghetti on dorsal fin.

^bOtter trawl, longline, trap, hook and line.

^cPetersen discs on dorsal fin; plastic flag on braided nylon loop through dorsum; plastic flag on wire bridle through dorsum; plastic flag in body cavity.

descriptions of types of tags.) Templeman (1944, 1954, 1958) used an Atkins-type tag on dogfish tagged near Newfoundland and on the Grand Bank. It was made of red plastic, 32 mm long and 8 mm wide, attached to the first dorsal fin with a nickel wire. Even after more than 10 years on a fish (Templeman, 1958) the plastic tag "... was in excellent condition and would probably have been in good enough condition to remain on the fish for another 10 years or more." The nickel wire, however, "... was somewhat eroded and reduced in size in the area where it was twisted tightly to attach the tag to the wire and probably would not have lasted more than a year or two longer." It had become brittle and broke at the eroded sections when handled.

In an extensive tagging experiment off the state of Washington, nearly 10,000 dogfish were marked and released (Bonham *et al.*, 1949; Kaufmann, 1955; and Holland, 1957). The fish were marked with Petersen discs attached to the base of the first dorsal fin with a nickel pin. The discs held up well but the pins tended to corrode internally and were weakened although two tagged dog-

fish were recaptured after 8 years and one after 10 years at liberty.

Beverton *et al.* (1959) tagged 75 dogfish in the Irish Sea incidentally during a hake, *Merluccius merluccius*, tagging experiment. The mark used was the so-called Lowestoft tag, an Atkins type with a soft plastic tab attached with a braided nylon loop through the base of the first dorsal fin. After 2 months, two tagged dogfish (2.7%) were recaptured but no tag deficiencies were reported.

One of the largest number of dogfish tagged in European waters was the group marked and released by Aasen (1960, 1964b) near the Shetland Islands, north of Scotland. He marked 8,122 and as of 1964, 881 (10.8%) had been recaptured. The tag was a Lea-type capsule attached with a stainless steel bridle anterior to the first dorsal fin. The capsule is formed from a strip of plastic 4 cm wide and 13 cm long imprinted with a message to the finder. The strip is wound about a bobbin and sealed in clear plastic. No tag deficiencies were noted and it seems to be a very successful tag. It should be noted here that the area in which the tagging experiment took place is the site of an

intensive summer fishery by English and Welsh trawlers.

British interest in dogfish tagging experiments was sparked by their food fishery for the species in the waters around the British Isles. Holden (1965) summarized their experiments since 1960 and in a personal communication (1967) outlined some of the tag failures.

In the otter-trawl fishery for dogfish north of Scotland, 5,830 dogfish were tagged by the British (5.9% recaptured). In 1960, four tags were used; the Lowestoft tag mentioned above (Beverton *et al.*, 1959); Petersen discs attached to the base of the first dorsal fin; plastic flags on a stainless steel wire bridle in the musculature between the dorsal fins; plastic flags inserted in the body cavity. (The tags are described in detail by Williams, 1963.) There is no breakdown of percentage returns by tag type but Holden (1965) reports 2.2% returns (through 1963) with the Petersen discs giving the highest rate. In 1961, the fish were tagged mostly with Petersen discs; a few fish smaller than 60 cm long were marked with the flags on wire bridles. The total recaptures were 7.8%. In 1962, Petersen discs only were used and yielded 2.3% returns after 1 year.

In the line-trawl fishery in the southern and middle North Sea, 2,890 dogfish were tagged by the British with 17.8% returns (Holden, 1965). Petersen discs attached to the first dorsal fin were used almost exclusively in this experiment; a few Lowestoft tags were used very early in the marking experiment.

Holden (personal communication) reports that the Lowestoft tag was rapidly lost; "... after about a year fish which had been double tagged with this type and a Petersen disc were being recaptured with only the latter still attached." He concluded that the nylon was chafed by the dogfish's rough skin and eventually broke. It is not known for certain why the flags on the wire bridles gave such poor results, but he suspected the bridle was too large and tore out. The internal tags also gave poor returns and two factors are suggested here. One is that some fish may have died as a result of inserting the tag in the body cavity. The second is that in those fish that survived and were recaptured the tags were not seen when the fish were dressed for market.

Some dogfish had been tagged with plastic "spaghetti" tubing sewn through the dorsal musculature between the first and second dorsal fins.

In a comparison between dogfish tagged with Petersen discs and spaghetti tags, Holden (personal communication) reports the return rate for the Petersen discs was four times that for the spaghetti tags. He could offer no explanation for the poor return rate of the spaghetti tags.

In the waters off New England, nearly 1,000 spiny dogfish were tagged incidental to the tagging of other species (Jensen, 1961, 1966). Four different tags were used on 844 fish. The tags were Petersen discs attached to the first dorsal fin; Petersen discs attached to the snout; a combination tag with a Petersen disc attached with yellow "spaghetti" tubing to the first dorsal fin; and yellow spaghetti tubing only through the first dorsal fin. All disc tags were attached with stainless steel pins (Jensen, 1958). Seventeen tagged dogfish (2%) were recovered. Later, 63 more dogfish were tagged with Petersen discs through the snout bringing the total of marked fish to 907. To date, 27 tagged fish (2.9%) have been recovered (Table 2).

The Petersen discs through the first dorsal fin yielded the highest rate of returns (10%) but only 20 fish had been tagged and this is not really a fair trial of the tag. Petersen discs on the snout were used on 442 fish and 22 (4.9%) were recaptured. The fewest tagged fish recaptured (0.7%) were those marked with either the combination disc-spaghetti tag or the spaghetti alone, although 151 and 294 dogfish, respectively, had been marked with these tags.

None of the returned tags bore any sign of more than minor structural failures. A few of the Petersen discs had slightly separated laminations but were otherwise intact. Some on the underside of the fish's snout were scratched as though the fish had "rooted" in the bottom. The stainless steel pins were sound and intact even after 6½ years on the fish. The spaghetti tags were slightly darkened where they had been in contact with the fin tissue but the tubing was not abraded or weakened.

The most recent tagging experiments are underway in a cooperative program between the U.S. Bureau of Sport Fisheries and Wildlife, Narragansett, Rhode Island, and a graduate student at the University of Rhode Island (John G. Casey, personal communication). In 1966, 111 dogfish were marked with Rototags, a plastic bachelor button-type tag attached to the first dorsal fin. To date, two fish (1.8%) have been

TABLE 2. A summary of US dogfish tagging experiments, 1956-64.

Tag	Number		% Recovered
	Tagged	Recovered	
Petersen discs (dorsal fin)	20	2	10.0
Petersen discs (snout)	442	22	4.9
Combination (dorsal)	151	1	0.7
Spaghetti (dorsal)	294	2	0.7
Total	907	27	2.9

recaptured, one after 28 weeks, 300 miles from the point of release, the other after 96 weeks, 287 miles from the point of release. More than 1,000 additional dogfish have been tagged with the Rototag. The results are to be analyzed and reported elsewhere.

Factors That May Affect the Rate of Return of Tags

Probably the one factor that contributes most to success in any fish tagging program is to tag the fish in an area where there is an active fishery for the species, especially a food fishery where each fish is individually handled. Thus, a tag on an individual is more likely to be noticed. This is certainly true of the spiny dogfish. The other factors considered here (fishing gear, season of capture) vary so much that it is difficult to try to separate them. Dogfish caught on hook and line gear — long lines, angling — tend to yield a higher rate of returns than dogfish caught in otter trawls or other trawl-net gear. A review of the literature suggests dogfish caught for tagging during the warm months (hence in shoal water?) tend to yield a higher rate of returns than dogfish caught in the cold months (in deep water?). A noticeable exception, however, is the extensive tagging by Aasen that was done mostly in the winter months. These dogfish, however, were caught on long lines.

How soon a tag is detected is an extremely important factor. In the absence of other evidence I suspect the snout tags (Jensen, 1961, 1966) were more easily and quickly noticed aboard ship. It may seem odd that a relatively small disc on the snout of a dogfish could be more visible than a yellow plastic loop in the dorsal fin. However, this same sort of differential rate of returns was noted in tagged haddock (Jensen, 1963). More

haddock with Petersen discs on the operculum were found aboard ship compared to haddock with spaghetti tags attached dorsally. Some of the spaghetti tags escaped detection until the fish were bought by retail customers.

It was believed the dorsal spaghetti tag on the haddock was not noticed by the fishermen who routinely hold the fish belly up when dressing it aboard ship. In the case of the dogfish, it may be that the snout is more easily noticed aboard a trawler. This line of reasoning, admittedly, is weak but at the moment no other logical explanation is forthcoming. Since the dogfish is unwanted by US fishermen in the Northwest Atlantic, it is discarded at sea as quickly as possible. In the Pacific Coast, Canadian, and European fisheries, however, the dogfish was or is a wanted species and each fish received more or less individual attention. Thus, there was a greater likelihood of a tagged fish being seen and recovered from the catch.

Stocks and Migrations of Spiny Dogfish

Some of the several dogfish tagging experiments reviewed here have reported the existence of local as well as far-ranging dogfish stocks. Off the Pacific Northwest (Holland, 1957); the tagging data yielded evidence of an indigenous population in Puget Sound and the Strait of Georgia. There is also a migratory population off the coast that ranges at least from Baja California north and west to Japan. Holland suggests further separation between the dogfish in the Strait of Georgia and the dogfish in Puget Sound.

Holden (1965) reports three stocks of dogfish around the British Isles. One is the Channel Stock that overwinters in the English Channel and spends the summer between England and the Low

Countries. The second is the Scottish - Norwegian Stock that overwinters in the deep waters between Scotland and Norway and in the summer concentrates around the Shetland and Orkney Islands. The third is the Atlantic Stock that overwinters off the Brittany Coast or farther south off the French coast and migrates north, possibly to the Barents Sea, in the summer. There may be further subdivisions between these stocks.

Two long-distance migrations are reported for the Scottish-Norwegian stock (Holden, 1967). One was a dogfish tagged north of Scotland in 1962 that was recaptured in 1966 just south of Newfoundland. Another dogfish from this stock, also tagged north of Scotland in June 1961, was recaptured in October of that year west of Iceland.

Returns from Canadian and USA dogfish tagging experiments (Templeman, 1954, 1958; Jensen, 1961, 1966) have done little to indicate the presence of definitive stocks in the Northwest Atlantic. Dogfish tagged in the Newfoundland area were recaptured mostly in the local waters or off the Maritimes. Two of the fish, however, were caught off Gloucester, Massachusetts, and one was caught off Cape Henry, Virginia. Templeman

(1954) postulated a southward movement in the late autumn and a northward movement in the spring and early summer. There is evidence also of the presence of dogfish that overwinter in the deep water of the Gulf of St. Lawrence. Templeman (1958) later reported a dogfish which was tagged off Newfoundland and recaptured off Iceland 10 years later.

Returns from dogfish tagged in the Gulf of Maine came mostly from nearby waters. Some of these have already been reported (Jensen, 1961; 1966). Later returns are listed in Table 3.

Two of the tagged fish had been at liberty for more than 6 years but were recovered only a few miles from the tagging location. While we have no idea where they went during that period of time it seems likely they followed some regular seasonal migration and returned to the same general area at about the same season of the year.

A possible path of migration is suggested by seven tag returns from the 13 June 1961 experiment on Stellwagen Bank. If we overlook the years involved in the returns and consider only the month, we can trace what may have been the path

TABLE 3. Returns of dogfish tagged in the Gulf of Maine and recaptured after June 1962.

Date and location		Time at liberty (weeks)	Distance (miles)
Tagging	Recapture		
8 July, 1956; Cape Ann, Mass. (42°48'N - 70°15'W)	8 Oct., 1962; Portland, Me. (43°31'N - 70°00'W)	326	60
14 Oct., 1957; Browns Bank (42°36'N - 65°46'W)	1 July, 1964; Browns Bank (42°41'N - 66°07'W)	350	16
13 June, 1961; Stellwagen Bank (42°25'N - 70°21'W)	15 July, 1962; St. Johns Bay, Me. (43°53'N - 69°33'W)	57	106
13 June, 1961; Stellwagen Bank (42°25'N - 70°21'W)	23 June, 1963; Gurnet Pt., Mass. (42°02'N - 70°33'W)	106	25
13 June, 1961; Stellwagen Bank (42°25'N - 70°21'W)	22 July, 1963; Harpswell, Me. (43°44'N - 70°00'W)	109	85
13 June, 1961; Stellwagen Bank (42°25'N - 70°21'W)	15 Oct., 1963; Shinnecock Inlet, N.Y. (40°40'N - 72°16'W)	111	154
13 June, 1961; Stellwagen Bank (42°25'N - 70°21'W)	7 Nov., 1963; Nantucket Shoals (41°05'N - 69°55'W)	178	80
13 June, 1961; Stellwagen Bank (42°25'N - 70°21'W)	9 Dec., 1965; Indian River Inlet, Del. (38°35'N - 75°00'W)	234	320
22 July, 1961; Cape Ann, Mass. (42°44'N - 70°36'W)	24 Dec., 1962; Cape Elizabeth, Me. (43°21' - 70°12'W)	74	60
22 July, 1961; Cape Ann, Mass. (42°44'N - 70°36'W)	18 Sept., 1963; Ipswich Bay, Mass. (42°40'N - 70°41'W)	113	6

taken by the tagged individuals. In June and July, the fish frequented the waters off New England. With the coming of autumn and a cooling of the offshore waters, the fish moved southward, moving onto Nantucket Shoals, to the offing of Long Island, New York, and in December to off Delaware. Presumably these fish belong to the same group tagged by Templeman (1954) or mingle with them in the southern waters. Thus, they may have continued their journey southward to Virginia to overwinter.

I have already discussed the reproductive activity and movements of the overwintering populations (Jensen, 1966). Evidently the female dogfish that move to the waters off Delaware and Virginia give birth to the pups there. This may take place in deep water, although, as shown in other studies (Ford, 1921), some pregnant females move inshore to deliver. The Delaware-Virginia offshore area also may represent a nursery area for the young dogfish. There is strong evidence of such areas for other sharks (Springer, 1967). During a cruise of the R/V *Albatross IV* in the Middle Atlantic Bight in October 1967, hundreds of spiny dogfish 35–40 cm long were trawled 35 miles off the mouth of Delaware Bay. Edwin B. Joseph (personal communication) reports that research vessels from the Virginia Institute of Marine Science have caught up to 3,000 lb. of spiny dogfish 35–40 cm long in the deep water of Norfolk Canyon in the summer through the autumn. These fish would be about 1–2 years old. (Holden and Meadows, 1962).

The recaptures, however, also include fish such as the one that was tagged off Cape Ann, Massachusetts in July 1961, and was recaptured off Cape Elizabeth, Maine, in December of the following year. This fish may be one of the group that overwinters in the deep water off the Gulf of Maine or off the Continental Shelf (Jensen, 1966).

Conclusions

The choice of an efficient tag for the spiny dogfish seems to be limited to a tag attached dorsally, preferably through a dorsal fin, or a tag attached through the snout. Both have yielded

fair to good rates of returns. Streamers — nylon loops or plastic tubing — may be easily abraded by the rough hide of the dogfish and thus lost. Leatype tags on wire bridles have been used successfully. But, in tests of several kinds of dorsal tags, the Petersen disc gave the best results.

In general, dorsal tags hold the most promise in experiments carried out in areas where there is a specific fishery for dogfish. In areas where the dogfish is unwanted and is discarded at sea as quickly as possible, the tag must be attached on the dogfish where it is readily noticed. In the usual fishing operation, whether otter trawling or some kind of hook and line fishery, the fish's snout is quickly and easily noticed. Thus, the best choice in a non-dogfish fishery is the Petersen disc tag attached to the snout.

The recaptures of tagged spiny dogfish in the Northwest Atlantic are too few to permit any but speculative remarks about their possible migrations. A north-south, coastal migration at least between Canada and Virginia seems evident.

We could consider the few east and west trans-Atlantic migrants simply as stragglers, but I prefer to believe that they do indeed represent a percentage of the population that makes a journey across the North Atlantic. Thus, the dogfish in the Northwest Atlantic, off Canada and the USA, may be related to, or at least mingle with, the dogfish from the Northeast Atlantic, the Scottish-Norwegian stock.

Evidence for a migration offshore in the winter is even less positive, but the few tagged fish that were recovered in the winter not far from the area of tagging may be part of a relatively non-migratory group or groups.

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Age Determination and Growth Rate of Redfish, *Sebastes* sp., from Selected Areas Around Newfoundland ¹

BY E. J. SANDEMAN ²

Abstract

Ages have been determined from the otoliths of *mentella* redfish from Hermitage Bay, the southwest slope of the Grand Bank, the Gulf of St. Lawrence, Flemish Cap, and Hamilton Inlet Bank and of *marinus* redfish from the latter two areas. Empirically, growth of both *marinus* and *mentella* redfish from these areas was found to be well represented by the von Bertalanffy equation and the parameters of this equation were obtained by least squares fit to the mean length at age values for males and females from each of the areas examined.

A comparison of ages obtained by two independent readers revealed that although considerable differences were apparent in the estimates for individual fish, when the

results were expressed as growth curves these were virtually identical.

Differences in growth rate between sexes, between the different areas and, for samples from Hamilton Inlet Bank, between depths were examined using plots of instantaneous growth rate against time. In the latter study the redfish, *mentella*, from the deeper waters were found to grow faster after an age of about 10 years than those of the same age which had been obtained in the shallower waters.

The order of the growth rates found in this study resembles that obtained by recent authors from the USA and USSR, however, it was noted that the resemblance to the work of those authors who used otoliths was closer than to those who used the scale method for estimating ages.

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Introduction

Redfish of the genus *Sebastes* are widely distributed in the North Atlantic. In northeastern Atlantic waters they range from the Barents Sea and Norway to the waters off Iceland and eastern Greenland, while in the Northwest Atlantic commercial quantities are to be found south from Davis Strait to the Gulf of Maine, as well as along the coast of West Greenland (Templeman, 1959). The area referred to here as the Northwest Atlantic may be defined as the Convention Area of the International Commission for the Northwest Atlantic Fisheries (Fig. 1). The eastern boundary line of the Convention Area which, except near Cape Farewell, Greenland, extends along the 42°W long line, divides this defined Northwest Atlantic area from the Northeast Atlantic.

Taxonomic position

The taxonomic position of the various members of the genus *Sebastes* in the North Atlantic is rather confused. At present the following different forms of redfish can be considered to exist in the area:

Northeastern Atlantic—*Sebastes viviparus*, *Sebastes marinus*, *Sebastes mentella*; Northwestern Atlantic — *Sebastes mentella*, *Sebastes marinus*; Bathypelagic stock—*Sebastes mentella*

Some of these different forms are no doubt similar enough to be considered the same species (*S. marinus* of the Northwest and Northeast Atlantic); others however show differences which suggest that they may not be as similar as would appear from a superficial external examination. Thus until the taxonomic position is clarified it is probably better to consider the forms from the northeastern Atlantic separately from those from the northwestern Atlantic.

The species which are considered in this paper are *S. mentella* and *S. marinus* from the northwestern Atlantic.

Age and growth studies on redfish

From the first information on the likely growth rate of redfish by Jensen (1922) many persons have attempted to age various members of the genus *Sebastes*. A review of many of the papers pertaining to age and growth studies can be found in a paper by Kelly and Wolf (1959). Validation studies by Bratberg (1955, 1956a and b) for redfish from the coast of Norway, by Perlmutter and Clark (1940), Kelly and Wolf (1959), and

Sandeman (1961) have shown that redfish grow very slowly and that during their first 10 years of life, one and only one annulus (hyaline layer on the otolith) is laid down. After the age of about 10 years, redfish otoliths and scales become more and more difficult to read, but in spite of this it is possible to obtain age estimates as has been done by many authors amongst whom were Kelly and Wolf (1959), Surkova (1961, 1962), Zakharov (1962), Savvatimksy and Sidorenko (MS, 1965). These authors all supported the slow growth hypothesis rather than the fast growth hypothesis as put forward by Kotthaus (1949, 1952, 1958).

Methods

The general areas where the samples of fish used in this study were obtained, are shown in Fig. 1. At some of these localities the samples were taken at a single position and depth whereas at others fish from several depths and positions have been combined to provide an adequate sample. At each locality redfish were obtained by otter trawling, the required samples separated from the catch by a sampling procedure and the individual fish examined at sea or at the Biological Station, St. John's, Newfoundland. In most cases the length, sex, and maturity were recorded, and the otoliths were removed for subsequent examination.

All fish lengths reported here are "fork lengths", the measurements being taken from the anterior tip of the lower jaw, with the mouth closed, to the end of the median caudal rays.

This study is based on the examination of otoliths, with the exception of data from Hermitage Bay where scales were also used for ageing redfish up to about age 5. It is considered that following the work of Kelly and Wolf (1959) and Sandeman (1961) that the validity of the otolith method as applied to the ageing of Northwest Atlantic redfish, *mentella*, is established. Kelly and Wolf (1959) refer to the Gulf of Maine redfish as *Sebastes marinus marinus*. However, it seems clear that these fish are in fact what are being called in this paper North American *mentella* redfish.

The techniques used for "reading" the otoliths and the estimation of age on a calendar year basis were the same as was previously reported by Sandeman (1961).

With the exception of otoliths from the Gulf of St. Lawrence and Hamilton Inlet Bank, which

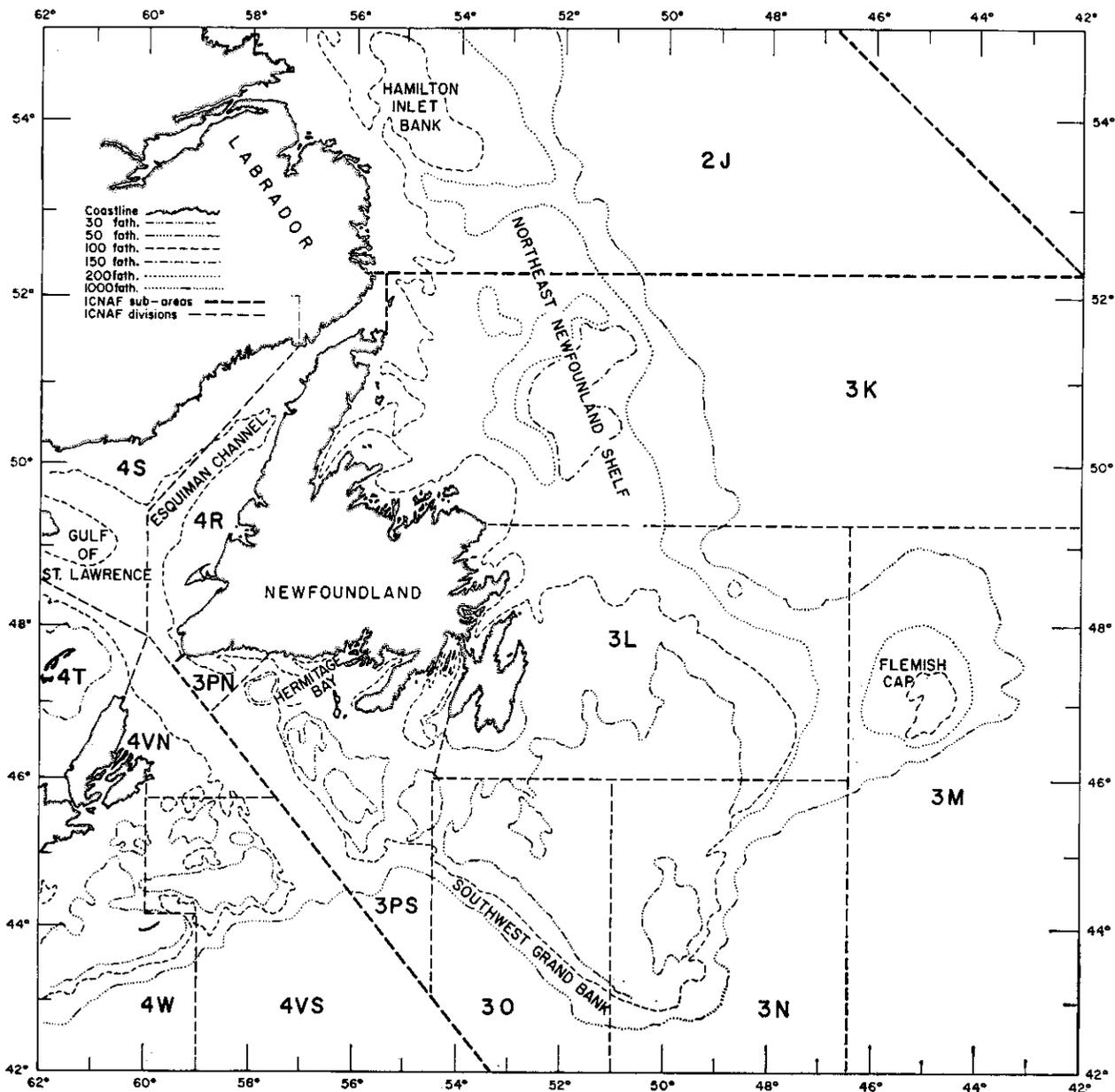


Fig. 1. Map of general Newfoundland area.

were read by E. Squires, age determinations were by the author.

Empirically, growth of both *marinus* and *mentella* redfish may be quite well represented by the inverse exponential equation, and the parameters of the von Bertalanffy form of this equation (Bertalanffy, 1938) were obtained by a least squares fit to the mean length at age values for males and females from each of the areas examined.

The form of the Bertalanffy growth in length curve which is used in this paper is:

$$l_t = L_{\infty} (1 - e^{-K(t-t_0)})$$

where l_t = The length of the fish (cm), at age t (years);

L_{∞} = Theoretical maximum length (asymptotic length);

K = Constant expressing the relative rate of approach to L ;

t_0 = The theoretical age at which $l_t = 0$.

The general method described by Tomlinson and Abramson (1961) has been used for fitting the Bertalanffy growth curves to the length at age data. This method has the advantage that it is more objective than the methods which are usually used (Beverton and Holt, 1957; Ricker, 1958) and at the same time it provides estimates of the variance of the parameters. The method as described requires equal sized random samples to be selected from each age-group containing a sufficient number of observations. As this would occasion very small samples at each age and the discarding of data (a most undesirable requirement in the light of the tremendous variation in the age estimates), it was apparent that much better use of the material available would result from a least squares fit to data consisting of single points at each age and that these points should be mean length values.

Thus for most of the data here, Bertalanffy growth curves were fitted to smoothed mean length values at even ages (2, 4, 6, etc.) between stated upper and lower limits. These limits were determined by the range of data available for the fit, bearing in mind that the method as described by Tomlinson and Abramson (1961) requires that there be no gaps in the consecutive ages used, and that the tables only allow a total of 18 age-groups to be used in this fit. Smoothing was accomplished by the use of the formula

$$\bar{l}_t = \frac{1}{2}(l_{t-1} + l_t + l_{t+1})$$

where \bar{l}_t is the smoothed mean length at the even age t and l_t is the observed mean length at the same age. Occasionally, where there were gaps in the unsmoothed data, the formula was suitably modified to provide the requisite interpolation.

Where growth curves are presented in figures, the thicker line shows the range of ages to which the curve was fitted, while the thinner line indicates the extrapolated curve.

The growth rate, which in a plot of age against size is represented by the slope of the curve at each instant of its generation is, in Bertalanffy type growth, continually changing and is directly proportional to the length of the organism.

$$\frac{dl}{dt} = KL_{\infty} - Kl$$

To obtain the growth rate in terms of time rather than length, the original Bertalanffy equation may be differentiated to yield

$$\frac{dl}{dt} = KL_{\infty} e^{-K(t-t_0)}$$

In both these equations $\frac{dl}{dt}$ represents the instantaneous growth rate. The above equations provide a convenient means of comparing the growth rates of two or more populations having different parameters K , L_{∞} and t_0 . Using the former equation, a plot of $\frac{dl}{dt}$ against l_t results in a straight line having the intercept on the y axis of KL_{∞} and on the x axis of L_{∞} . Similarly a semi-logarithmic plot of $\frac{dl}{dt}$ against t for the latter equation can be used for comparing growth rates and how they change with age, viz.

$$\log \frac{dl}{dt} = \log K + \log L_{\infty} + Kt_0 - Kt$$

Although the former plot is very much simpler, it is deceptive in that it is more customary to think of growth rate in terms of age rather than length. Consequently in the comparisons of growth rates presented here it will be most often the latter equation that will be used.

Materials

Hermitage Bay

This area has been of particular interest because in 1953 an isolated year-class of fish in their first year of life was found, and with a relative failure of adjacent year-classes it has been possible to follow this dominant 1953 year-class during several succeeding years (Sandeman, 1957, 1958, 1961). This has allowed a useful check on the validity of the otolith and scale methods of age determination as applied to North American *mentella* redfish and it has been established in Hermitage Bay that, at least to age 10, in each successive year a further pair of zones, a hyaline and an opaque, are laid down on the surface of the otolith.

The otoliths used in this study and the derived age at length data are the same that were reported previously (Sandeman, 1961). The fish, which were likely all *mentella*, were obtained at the one position (Fig. 1) and from a limited depth range of 120–180 fathoms (220–330m).

Southwest slope of the Grand Bank

The fish on which this study is based were obtained in 1947 during several sets in the general area indicated in Fig. 1. Although the data from this rather wide area have been combined to provide an adequate sample for ageing, the depth variation in these sets was not very great and all the fish were obtained in the rather shallow (for redfish) depth range of 45-115 fathoms (82-210m).

The samples were not examined for the presence of *marinus*, but it is most unlikely, from our subsequent knowledge of the numbers of these fish in the area, that more than the occasional *marinus* fish was caught and the growth curves presented here can thus be considered as those of North American *mentella* redfish.

Gulf of St. Lawrence

The majority of otoliths used in this study were obtained from 1947 to 1949 from redfish in the area of the Esquiman Channel (Fig. 1). Occasional samples of otoliths obtained during the same period, but from other areas in the northern part of the Gulf of St. Lawrence, have also been included and, because of the complete dearth of small redfish in the samples obtained during this period, a more recent sample containing some small fish has also been added.

Recent surveys for *marinus* and *mentella* redfish in the Gulf of St. Lawrence have revealed only the very occasional *marinus* specimen and the otoliths considered here can be regarded as from *mentella* redfish.

Flemish Cap

The fish were all caught on the northern slope of Flemish Cap. Otoliths for growth study were obtained from small samples of fish used for detailed studies and because of small number, data from all depths of 150-300 fathoms (274-548m) are combined.

In addition the samples were selected to provide fish only at each length group of 5 cm or multiple thereof. Although this will, of course, affect the calculation of mean length at age, it is considered that the data are adequate for providing at least a preliminary examination of growth rate.

Enough specimens of *marinus* redfish were obtained in the Flemish Cap area to allow a consideration of the growth rate of these fish, as well

as that of the more common and deeper living *mentella*.

Hamilton Inlet Bank

The otoliths examined from the area of Hamilton Inlet Bank were all taken from fish caught in August 1960. Fishing was carried out on a line across the slope at the northern part of Hamilton Inlet Bank (Fig. 1), and otoliths were obtained as shown in the table below.

Depth		<i>Mentella</i>		<i>Marinus</i>	
fath	m	males	females	males	females
140	256	...	...	47	19
150	274	7	9	34	48
175	320	61	47	....	....
200	366	76	37	....	....
250	457	54	54	....	....
300	549	61	41	....	....
400	732	4	11	....	....
Total		263	199	81	67

Results

The growth curves of *mentella* redfish from the Hermitage Bay area are shown in Fig. 2B. These curves and the Bertalanffy parameters describing them (Table 1) are based on the same length at age data that were reported in a previous paper (Sandeman, 1961) when frechand curves were drawn to the data from 366 males and 332 females. As the dominant 1953 year-class appears to have shown unusually fast growth during the first 4 years, and its numbers are so great (205 fish) relative to the other fish, these fish have been considered separately (Fig. 2A) and are not included in the mean growth curves for the area shown in Fig. 2B.

The very high standard errors in L_{∞} and K that were obtained for the 1953 year-class data result from the absence of data for the older ages where the average lengths approach the asymptotic values.

The data from the southwest slope of the Grand Bank have been used to compare the growth curves obtained by two different age readers using the same basic age reading methods on *mentella* otoliths (Table 1, Fig. 3).

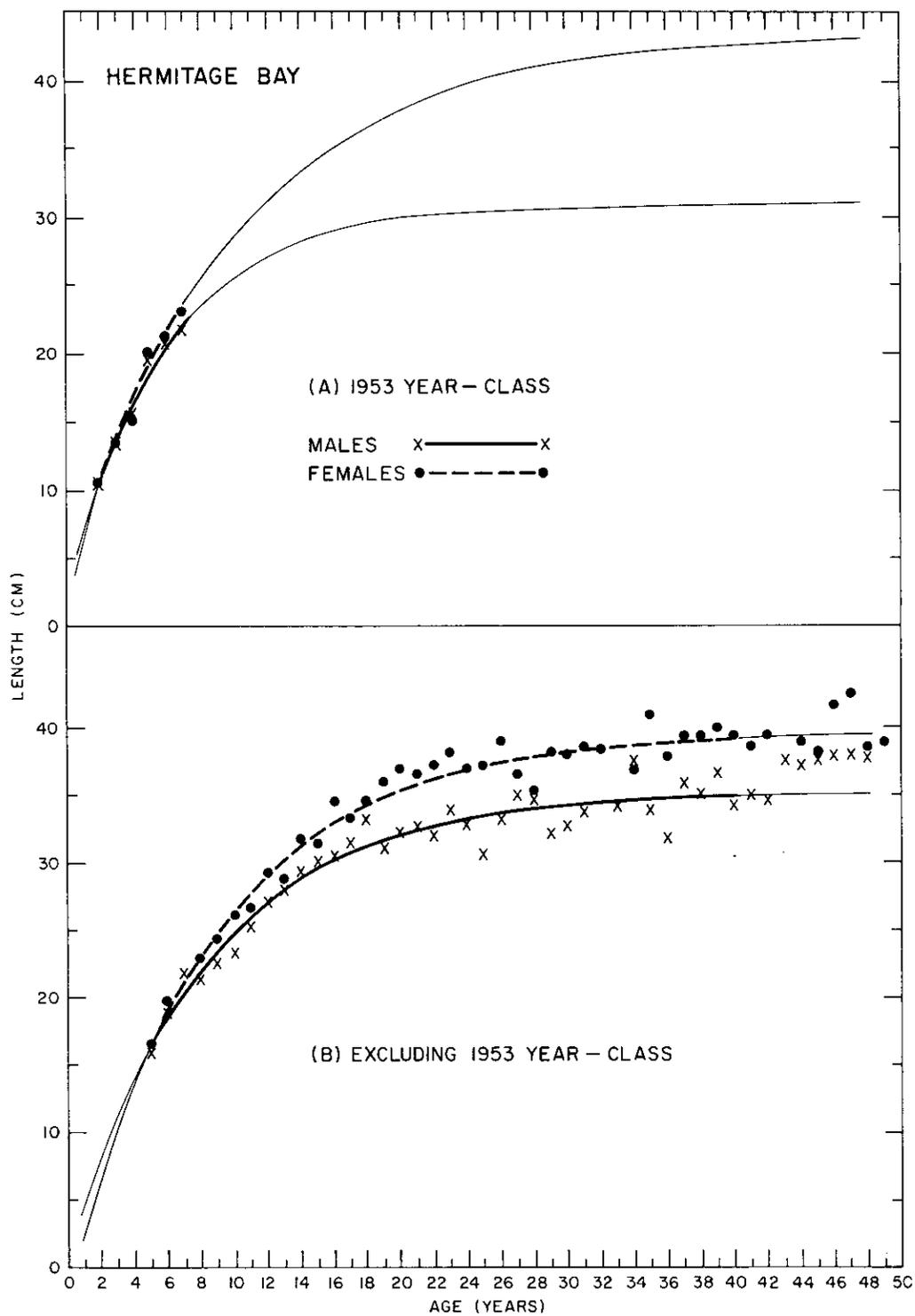


Fig. 2. Growth curves of *mentella* redfish from Hermitage Bay: (A) 1953 year-class (B) All data, 1953 year-class excluded. In this and in subsequent figures showing growth curves and their derivatives, the thicker part of the line shows the range of ages to which the curve was actually fitted while the thinner part of the line indicates the extrapolated curves.

TABLE 1. Summary table showing the Bertalanffy parameters and their standard errors.

	K	L_{∞}	t_0	Fitted years	No. of fish
<i>Mentella</i> redfish					
Hermitage Bay (excluding 1953 year-class)					
^a Males	0.119 ± 0.028	35.2 ± 1.0	- 0.3 ± 1.6	6 - 40	336
^a Females	0.113 ± 0.019	39.7 ± 0.9	0.2 ± 1.0	6 - 40	332
Hermitage Bay (1953 year-class)					
^a Males	0.17 ± 0.35	31.0 ± 28.0	- 0.4 ± 1.6	2 - 7	310
^a Females	0.10 ± 0.37	43.0 ± 95.0	- 0.7 ± 1.7	2 - 7	333
Southwest Grand Bank					
Sandeman					
^a Males	0.05 ± 0.05	33.0 ± 6.0	-20 ± 6	8 - 34	164
Females	0.13 ± 0.05	34.2 ± 1.4	- 0.7 ± 3.0	8 - 32	281
Squires					
^a Males	0.06 ± 0.04	30.6 ± 2.3	-17 ± 5	8 - 34	164
^a Females	0.13 ± 0.07	33.3 ± 2.0	- 1 ± 5	8 - 34	284
Gulf of St. Lawrence					
^a Males	0.06 ± 0.04	36.0 ± 13	- 5 ± 18	12 - 46	265
^a Females	0.13 ± 0.04	38.4 ± 1.2	4.4 ± 2.0	12 - 46	314
Flemish Cap					
^a Males	0.17 ± 0.05	34.4 ± 1.2	0.1 ± 1.2	4 - 30	53
^a Females	0.15 ± 0.06	38.5 ± 1.4	0.6 ± 2.5	6 - 40	62
Hamilton Inlet Bank					
All depths					
^a Males	0.16 ± 0.05	38.5 ± 1.0	- 0.1 ± 1.6	6 - 38	261
^a Females	0.11 ± 0.04	44.8 ± 2.1	0.0 ± 3.1	8 - 40	199
175-200 fathoms					
Males	0.21	36.5	2	10 - 22	142
Females	0.16	41.5	2	7 - 20	92
250-300 fathoms					
Males	0.02	93.0	-14	10 - 22	115
Females	0.08	52.0	1	11 - 22	95
<i>Marinus</i> redfish					
Flemish Cap					
^a Males	0.07 ± 0.10	45 ± 14.0	- 5.0 ± 8	6 - 34	33
^a Females	0.13 ± 0.03	47.8 ± 1.4	1.9 ± 1.3	6 - 40	57
Hamilton Inlet Bank					
^a Males	0.05 ± 0.06	55 ± 9.0	- 9.0 ± 14	18 - 42	80
^a Females	0.10 ± 0.12	60 ± 6.0	4.0 ± 18	18 - 42	66

^aDenotes when fit was made to smoothed data for even years.

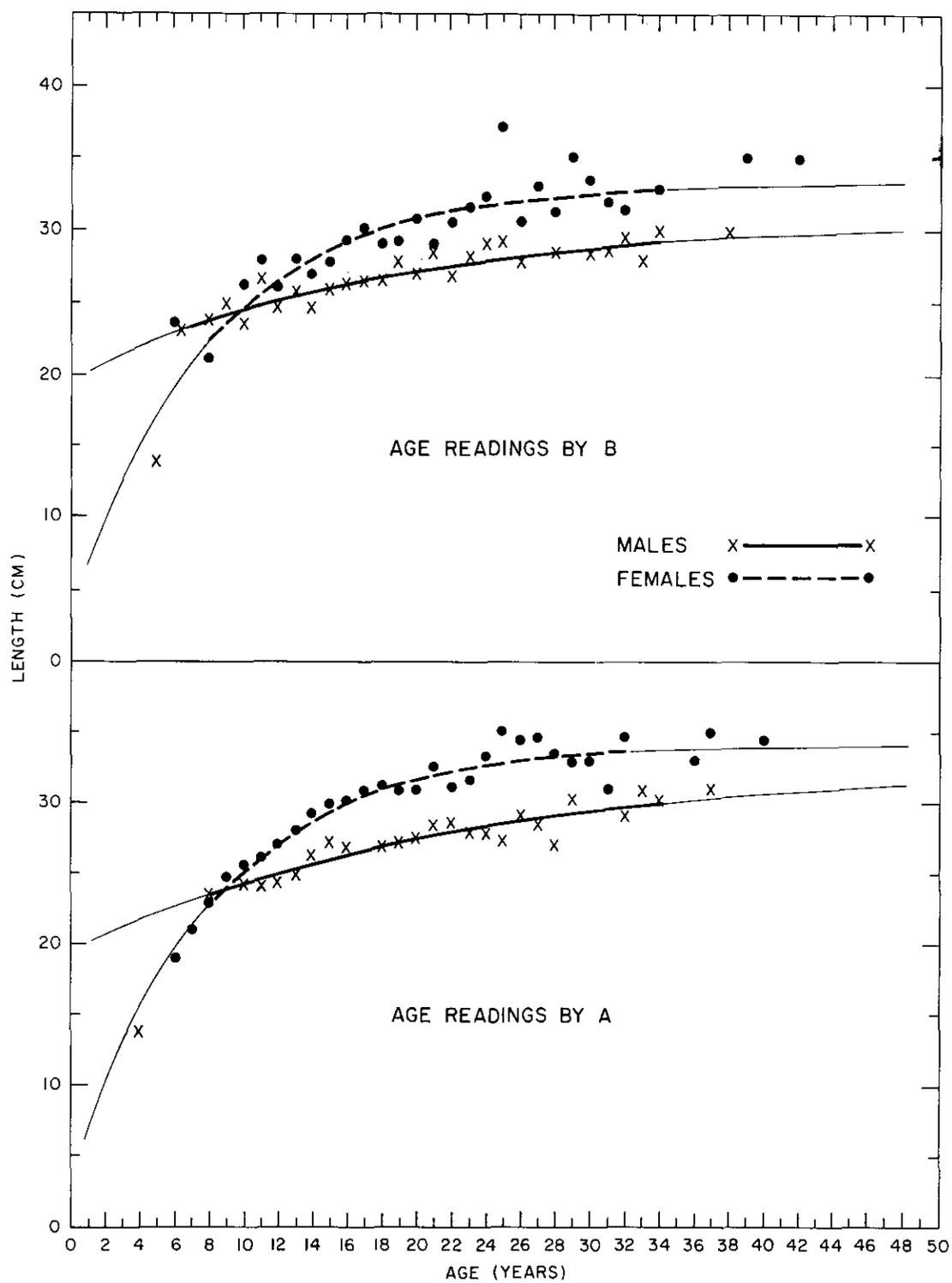


Fig. 3. Growth curves of *mentella* redfish from Southwest Grand Bank as derived from the otolith age estimates of two different persons.

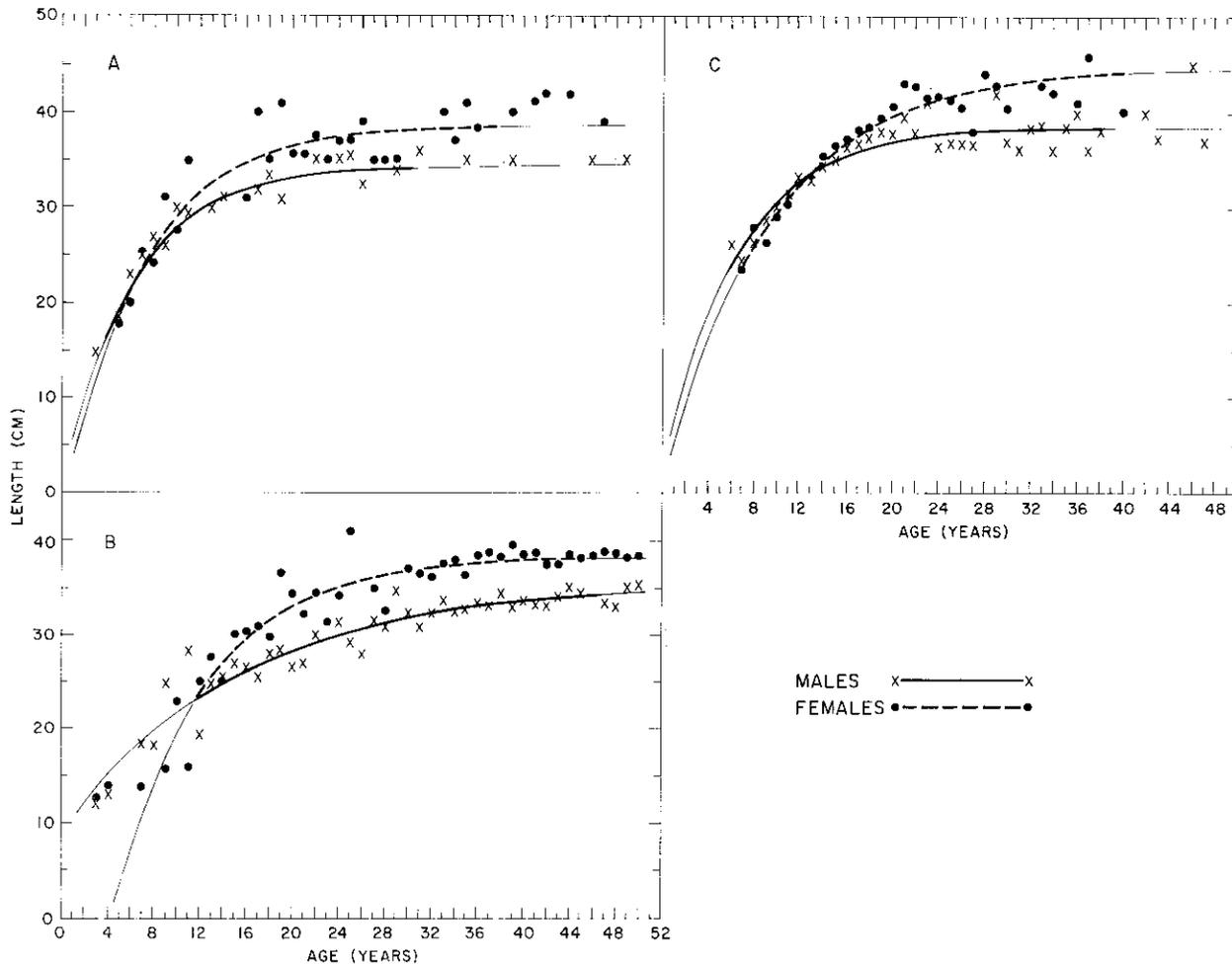


Fig. 4. Growth curves of *mentella* redfish: (A) Flemish Cap; (B) Gulf of St. Lawrence; (C) Hamilton Inlet Bank.

Growth curves for *mentella* redfish from the Gulf of St. Lawrence, Flemish Cap and Hamilton Inlet Bank are shown in Fig. 4 and the parameters of the fitted Bertalanffy equations, years fitted, and number of otoliths read are to be found in Table 1.

Growth curves for *marinus* redfish from Hamilton Inlet Bank and Flemish Cap are presented (Fig. 5) as are also the parameters of their least squares fits (Table 1).

Discussion

Comparisons of ages and growth rates as determined by two different persons

The otoliths from the southwest slope of the Grand Bank were examined and ages estimated by

two different persons, the author (A) and technician E. Squires (B). This provides an opportunity to examine the variation occurring between the results obtained by the two age readers who are attempting to determine the ages, using the same basic method. Agreement in age assignment is seldom obtained from otoliths of fish above age 10 (agreement was obtained in only 43 of 444 such readings in the present study).

Table 2 shows the number of times in which agreement or disagreement occurred between the two age readers. It is evident from this table that there is a wide variation between the ages as determined by these two readers. Furthermore, the spread of the data on the upper side of the diagonal of complete agreement indicates that the ages estimated by B are on the average, higher

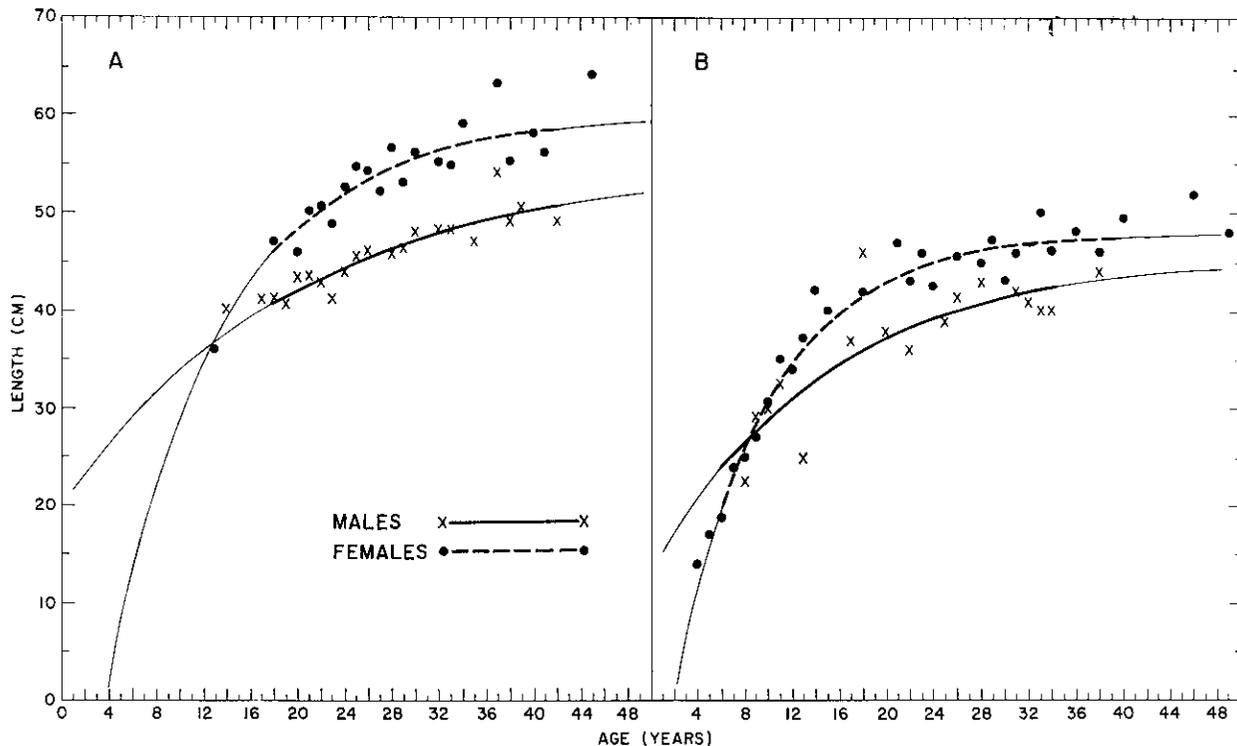


Fig. 5. Growth curves of *marinus* redfish: (A) Hamilton Inlet Bank; (B) Flemish Cap.

than those estimated by A. This may perhaps be better seen by examining the frequency of agreement or disagreement without reference to the actual ages at which the agreement and disagreements occurred (Fig. 6). The shape of the histogram approximates to a normal curve and indicates a rather large random error but also because the curve is skewed to the right, it indicates that B on the average obtains age estimates that are higher than those of A.

Comparison of the age frequencies obtained by the two readers using χ^2 tests indicates that both for males and females no significant difference exists between the age frequencies obtained by the two readers. (The difference between the two frequencies for the males could be expected to occur with a probability > 0.99 and thus, the frequencies are striking in their similarity, whereas that for the females showed a probability of occurrence of between 0.10 and 0.20). However, in dealing with growth curves it is really the differences between the respective mean lengths at each age that should be considered, and a paired comparisons test between these mean lengths at each age would perhaps be more appropriate.

Paired comparison tests indicated that for the males the mean difference between the mean length at age values was not significantly different from zero ($0.90 > P > 0.80$) whereas the mean difference for the females was different from zero. ($0.02 > P > 0.01$).

The values for mean length at each age, as calculated from the age estimations of A and B for males and females separately, are shown in Fig. 3. Also shown are the least squares Bertalanffy curves fitted to the smoothed mean length at age data for ages 8-34 (because of the lack of data at age 33, 34, and 35 for females in A's data, this curve was fitted to the smoothed data for ages 8-32). The curves derived from the age estimations of these two different persons appear so similar in this figure that it is difficult to see any difference at all.

Although the difference between the age estimation of the two readers was found to be significantly different at the 5% probability level when the mean lengths at each age of females are compared, it is apparent (Fig. 3) that many of the mean length at age data occur at ages greater than

TABLE 2. Table showing the frequency of agreement and disagreement between two persons in estimating ages from the same otoliths of male and female fish from the southwest slope of the Grand Bank. The **bold type** denotes the frequency of perfect agreement at each age.

		Age readings by (B)																														
		4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	>30			
Age readings by (A)	4	1																												1		
	5																															
	6									1																					1	
	7					1																									1	
	8						2			2		4			1																9	
	9			1			1	2	2	2	3						1														12	
	10						2			1	3	1	3		1	1		1	2					1							16	
	11				1		2	2	5	1	6	3		1	4	3	1	1													30	
	12				1		2		3	3	5	1		1	1	3	1	1	1												23	
	13					1			3	5	2	4	3		1	1	1	1		1		2		1							26	
	14				1	1			3	5	5	2	2		1	5	4	4	2	3	1		1								40	
	15					2	1	1		1	3	3	3		3		2	2	1		1		1								23	
	16					2	2		3	6	2	4	2		3	2	2	3	1				1								32	
	17					1	1	1	2	7	4				3	2	3	2					1					1			28	
	18						1		2		3	4	5	2			3	1	1	4							1	1	1		29	
	19							1	3	2		3	2	2	5		2	1	2	1	2	1	2	2	2		2				30	
	20								1		1		2	2	2	1	2	5	1	1	2	1	1	1	1		1			1	24	
	21									2	2	2		2	2	8	3	1	1	3		2		1		1				1	26	
	22												1	5	2	3	2		1	2		1	1		1		1			1	19	
	23												2	1	2	1		2	3	2		1		1		1				1	15	
	24								1	1						1		3	1	1			2							1	12	
	25															1				1		2									4	
	26																2	2				2	1	2		1					10	
	27																				1		2			1				1	5	
	28																1			1		1	1			1				1	5	
	29																	1				1	1		1		2			4	10	
	30																											1		1	2	2
	>30																				1	1		2	1	1				6	12	
			1			3	1	10	8	22	22	32	30	32	31	29	34	33	29	22	24	25	7	18	2	6	3	6	15	445		

about 15 when the asymptotic part of the curve is being approached and when the total average change in length represents only about 5 cm over a period of 20-25 years. When the variability of the smoothed mean length of age values from the results of both age readers are examined in the light of this, and when Bertalanffy curves are fitted to the data, it is not surprising that the differences between the parameters are small. It is evident from the considerable overlap in the confidence limits of all the parameters (Table 1) that, for both males and females, the growth curves derived from the age estimates of A and B can be considered similar.

Differences in growth rate with depth

When the growth curves for male and female *mentella* redfish from the Hamilton Inlet Bank area (Fig. 4) are compared with the data points from which they are derived, they do not seem to fit the data very well. This is particularly so for the males, where ages 7-10 lie well below the fitted line and ages 16-21 lie above it, all of which would seem to indicate a steeper slope at this section of the curve. As data from widely different depths have been combined it is proper that the data should be examined for differences in growth rate with depth.

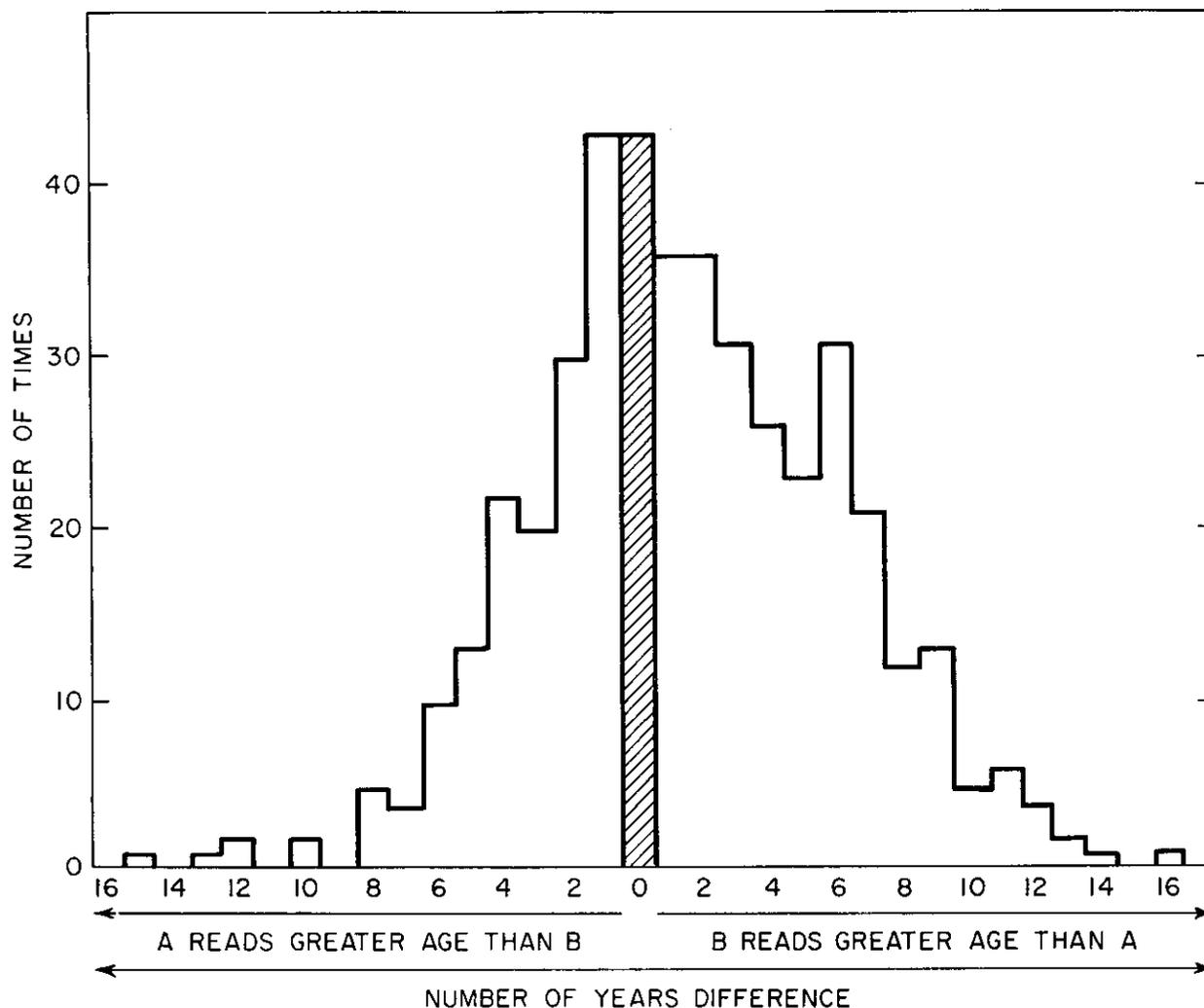


Fig. 6. Agreement-disagreement frequency histogram. Comparison of otolith age estimates by two different persons.

Very few age data are available from 150 and 400 fath and when these are included with the data from 175 and 300 fathoms respectively, we have the equivalent of four different depth levels: 175 and shallower, 200, 250, and 300 fathoms and deeper.

Bertalanffy curves have been fitted to the unsmoothed mean length at age data for each of these depth zones. In each case the curves were fitted to the range of data in which there were data for consecutive ages. These were:

Depth		Males	Females
fath	m	years	years
175	320	6-22	7-20
200	366	10-27	10-20
250	457	9-20	11-21
300	549	13-25	14-26

These curves are shown in Fig. 7. Apparently the growth patterns of the fish from 175 and 200 fathoms are rather similar, and that these

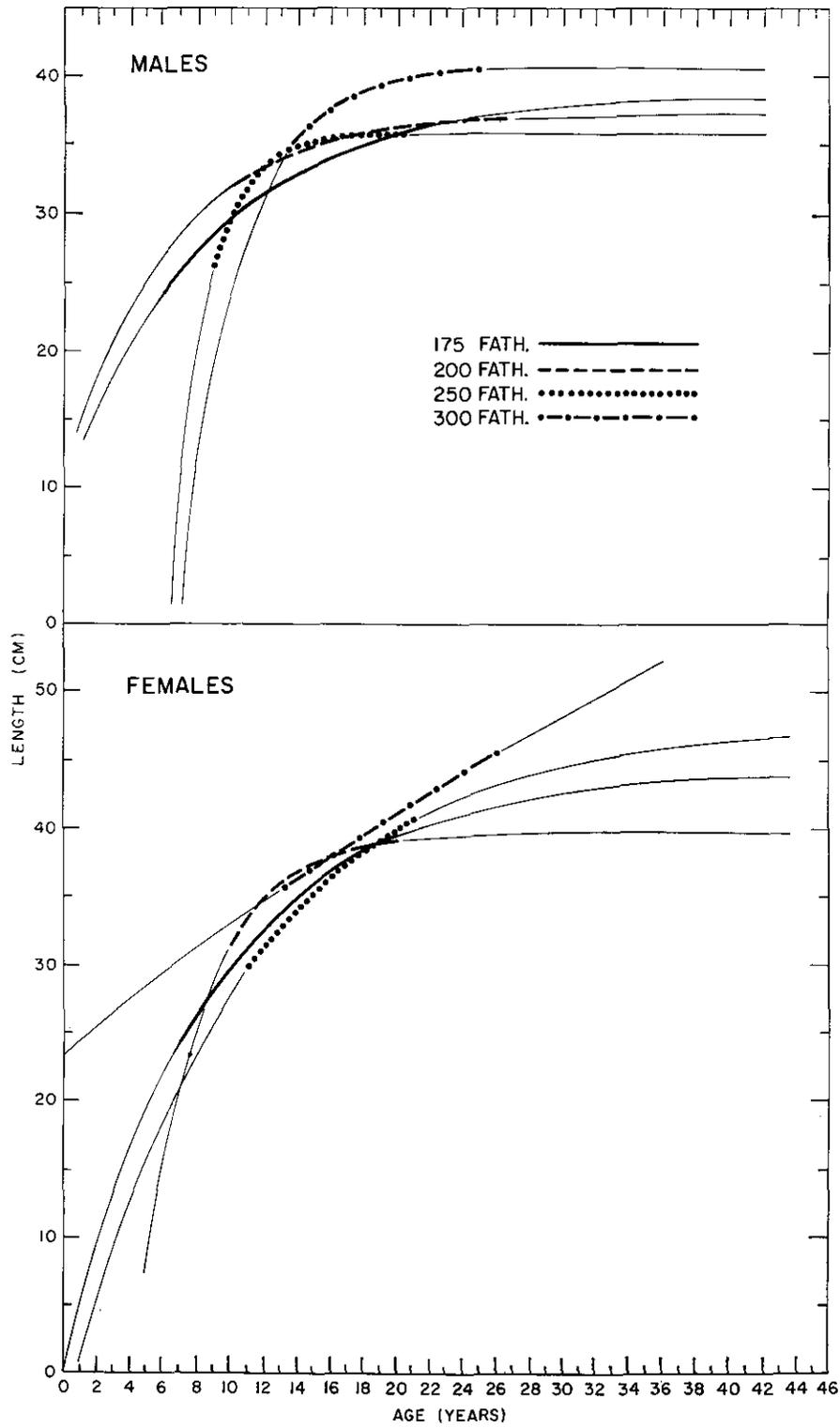


Fig. 7. Growth curves of *mentella* redfish from different depths Hamilton Inlet Bank.

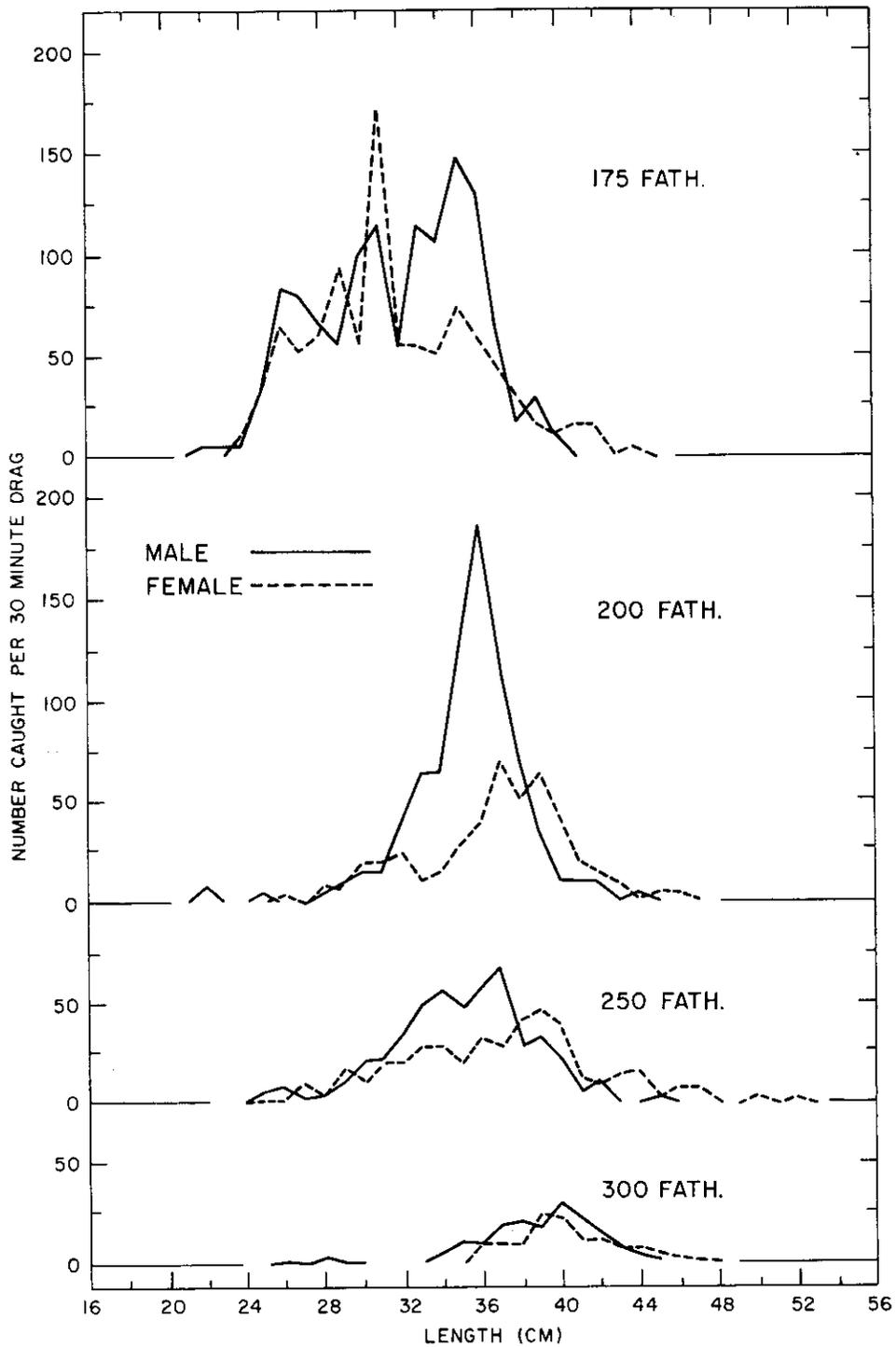


Fig. 8. Length frequencies of *mentella* redfish from different depths Hamilton Inlet Bank.

fish from the shallower depth ranges differ somewhat from those obtained from the deeper zones.

A perusal of the length-frequency distribution of the catches at the different depths shows a general trend of increase in size with increase in depth (Fig. 8). This trend, which is apparent at several localities in the Newfoundland area, and the lack of smaller fish from the greater depths, lead quite naturally to the hypothesis that the fish gradually move deeper as they grow larger and older.

However, when the age frequency distribution of the catches at the different depths is examined (Fig. 9), it is apparent that, although there is a decline in the number of the youngest ages present from the shallow to the deep water, for both the males and females, there is also a scarcity of the oldest males in the deeper levels. This scarcity of older males at the 250- and 300-fathom levels is not

reflected in the age distribution of the females, but in these frequencies an even more dramatic phenomenon may be noticed, namely that at the deepest levels almost all the females are immature. These characteristics of the male and female redfish from the deeper levels suggest that separate populations may exist at these different depth levels and that such a division might occur between the 200- and 250-fathom levels.

With this hypothesis in mind, the data from 175 and 200 fathoms have been combined as have also those from 250 and 300 fathoms. The growth curves for the combined data, the parameters of which are listed in Table 1, were fitted to the unsmoothed data for all available consecutive ages at each depth zone (Fig. 10).

It is evident from this figure that the fitted curve for the male redfish from the deeper depth strata does not fit the data points very well in the

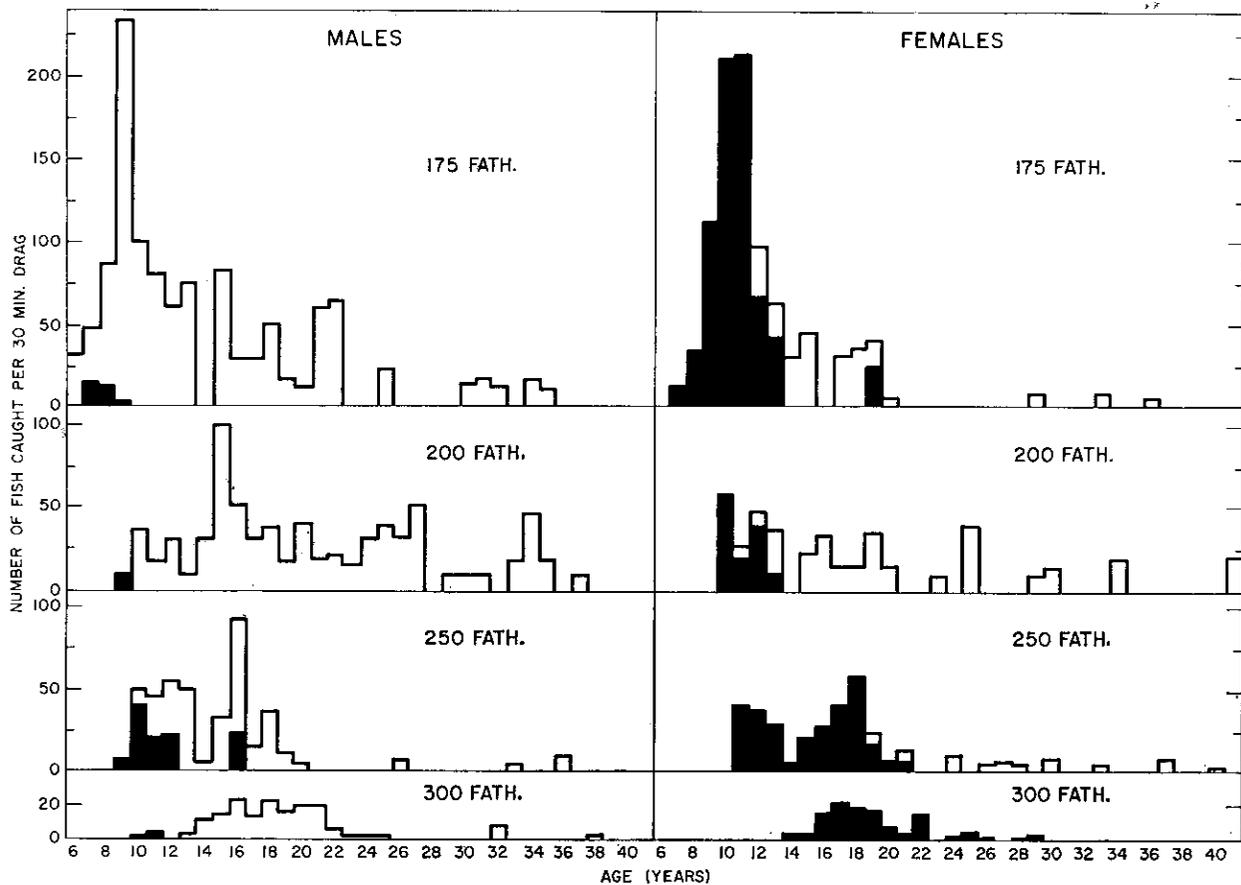


Fig. 9. Age frequencies of *mentella* redfish from Hamilton Inlet Bank (Shaded portion shows immature fish, unshaded mature).

region of extrapolation beyond the maximum age used in the fitting process (age 22). This results not only in a high value for L_{∞} but also a rather extraordinary value for t_0 . Extending the range of the fitting process to higher ages would not alter the parameters to any great degree as the 11 age groups above age 22 include only 12 fish. The results suggest that there are separate populations of redfish which, although they originate from the same shallow water population of young fish, have become separated from each other at an age of about 10–12 years to form a shallow-water stock of slow-growing fish and a deep-water stock of fast-growing fish. With male redfish attaining maturity at an age several years younger than the females, it seems likely that most fish in the deep-water population become separated at an age between that at which the males and that at which the females attain sexual maturity.

Although the hypothesis above suggests the existence of two stocks of redfish having different growth and maturity characteristics, these stocks need not remain separate at all stages of their annual cycle. The hypothesis, based as it is on growth and differences in growth rate, requires a separate identity to the stocks only during the period of active growth, and does not preclude a mixing of stocks or change in depth level of either stock at any time of the year when growth and presumably also active feeding, are not taking place.

From the growth curves shown in Fig. 10 some idea can be obtained of the growth rates prevailing in the catches at the two depth zones and their respective rates of decrease. However, the direct comparison of the different growth rates can most easily be accomplished graphically by the plot of instantaneous growth rate dl/dt against either fish length (l_t) or time (age). This has been done to compare the growth rates at the two depth zones for males and females separately in Fig. 11. It is clear from these plots that, both for males and females, the growth rate is higher for the younger ages at the shallower depths, whereas the older fish show faster growth in the greater depths. It is also evident that, if the theoretical curves provide reasonable expectations of growth, and provided other things remain equal, maximum growth rates will be obtained if the males migrate from shallow to deep water at about their eleventh year and females at about their ninth year.

In general a difference in growth rate between the deep and shallow depth zones might be due to

either or both of two basic types of causes, the one consisting of factors of the fish themselves, and the other of factors stemming from the environment.

It has already been noted that one of the main features indicating the differences in growth pattern between the depth zones was that of maturity. In particular the age at first maturity was considerably delayed in the deeper zone so much so in the females that no mature fish were found in depths of 300 fathoms or deeper.

Thus, it is possible that the change in growth rate between the two zones is not so much an increase in growth rate as the fish change from one form of Bertalanffy growth to another, but rather a decrease in growth rate in the shallow zone. This might be caused by the larger and older fish attaining maturity, and devoting much of their growth energy to the exigencies of reproduction, while their relations, who emigrated to the deeper zone, continue to live and grow as adolescents.

However, it is evident from the maturity pattern of the males (Fig. 9) that, in spite of maturity being attained in the deeper water, growth continued at the fast rate that prevailed before maturity. In Fig. 9 most of the males in depths of 250 and 300 fathoms have been recorded here as mature, some doubt exists as to whether or not these were actually so. At depths of 200 fathoms and shallower, the testes of all the fish with lengths greater than about 25 cm were obviously mature. These fish had large, creamy white testes and milt could easily be seen in the vas deferens. At the 250-fathom level and even more so at the 300-fathom level, greater numbers of the fish had rather small testes which, although they were large enough to be producing viable sperm, were not creamy white in colour and no milt was visible in the vas deferens. These testes were grey in colour and appeared as if they had produced milt previously but had recovered. The above description is taken from notes made by W. Templeman who examined the fish in the field and indeed there was enough doubt about them that he made rather complete notes about their peculiarities and only called them mature in a very tentative manner.

The environmental temperature has a very close relationship with metabolism and growth. The prevailing temperatures however, in these waters of 175 fathoms or deeper, remain very stable from depth to depth, and indeed also from year to year, and thus could not really be expected to affect the growth rate. However, the closer

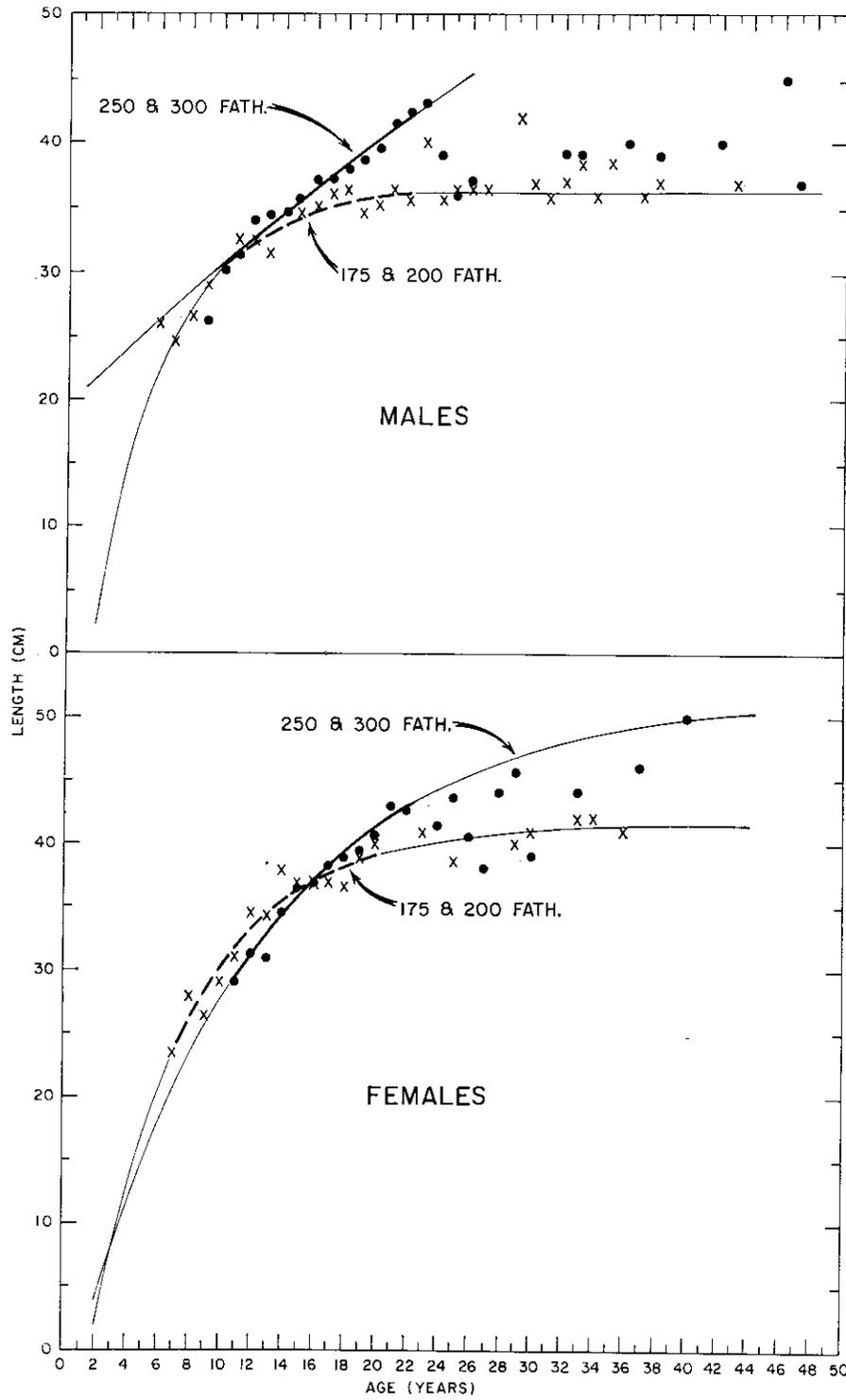


Fig. 10. Growth curves of *mentella* redfish from Hamilton Inlet Bank. The data from 175 and 200 fathoms have been combined as have the data from 250 and 300 fathoms.

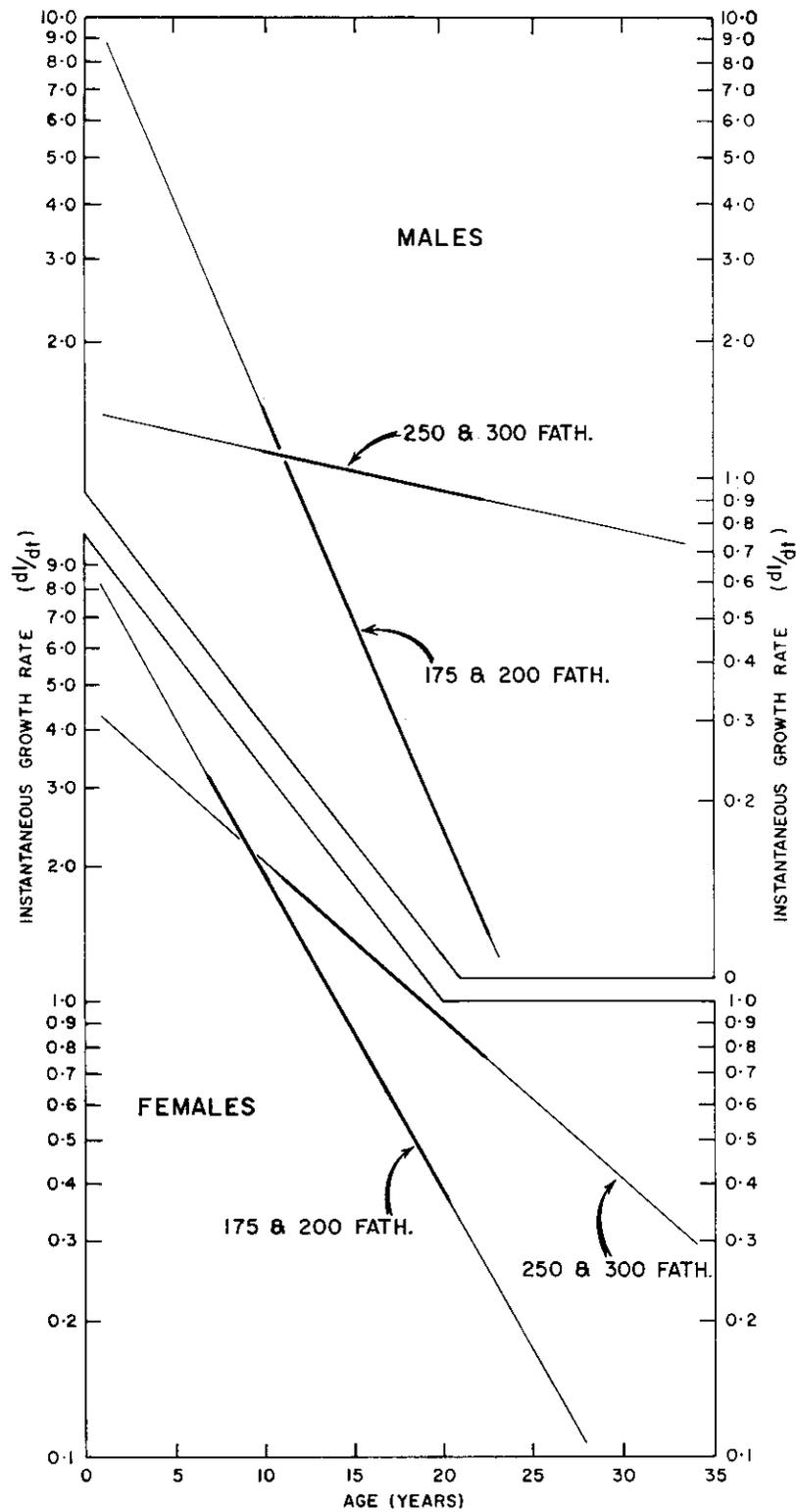


Fig. 11. Plots of growth rate against age for male and female *mentella* redfish from the shallower (175 and 200 fathoms) and deeper (250 and 300 fathoms) zones of Hamilton Inlet Bank.

proximity of the cold water layers to the shallower depth zone could limit the foraging area, and the pelagic feeding habits of these fish have not the scope and range that is available to the fish from the deeper zone.

The most likely cause of the faster growth rate in deep water is probably to be found in the interplay of environment and fish physiology that occurs in the process of feeding. Here, unfortunately, we have very little data, although it seems clear that with increase in depth redfish tend to eat more and more fish as opposed to the smaller invertebrates which make up the greatest part of their diet in shallow water (Yanulov, 1962; Rees, MS, 1962, 1966).

Comparison of redfish growth rates in the Newfoundland area

Differences between males and females

Mentella redfish. The data presented indicate a striking difference in growth pattern between the sexes. The total growth of the females is nearly always greater than that of the males, and at any of the older ages the females are on the average very much larger than the males. The parameters of the fitted Bertalanffy curves (Table 1) in conjunction with the confidence limits indicate that the main difference between the growth of the sexes lies not so much with the parameter K , but with L_{∞} . At Hermitage Bay, Flemish Cap, and Hamilton Inlet Bank the confidence limits of L_{∞} for the males and females do not overlap, and this indicates that the differences are likely to be real. In the areas of the Gulf of St. Lawrence and Southwest Grand Bank, the difference between the L_{∞} values for the males and females is not so clear, but in both these areas the growth curves of the males are rather aberrant, as in each we have a rather large negative t_0 value. This results in a very much lower than usual K value and a slightly higher value for L_{∞} .

The difference in growth rate between males and females is probably not so much the result of the environment, as of the genetics which determine the behaviour and physiology of the fish. The males mature at considerably smaller sizes and ages than do the females (in Hermitage Bay on the average, males mature at about 20 cm at which time they are about 6 years old, whereas females mature at about 30 cm or 10–12 years of age). This suggests that the males will start earlier the processes associated with maturity, namely the

pre-spawning reduction in feeding (Yanulov, 1962) and the diversion of energy to the formation of sexual products, with the probable result that less total energy is available for growth. With the reproductive season of the males as well as the pre-spawning season of fast coinciding with the latter part of the season of greatest potential growth, the actual growth season of mature males could be effectively shortened in comparison to that of the immature portion of the stock. Yanulov (1962) has presented evidence to show that the intensity of feeding of mature individuals changes with season and for both males and females it decreases abruptly in April and May. Females begin to feed again in June–July and by August are feeding heavily whereas the males appear to delay active feeding till later and it was not till about October–November that 60% of the fish taken were found to be actively feeding. Rees (MS, 1962) presents some further data on the feeding of redfish, and while he found a different pattern of feeding throughout the year in Hermitage Bay to that found by Yanulov (1962) in the areas he examined, both these authors and Kashinksev (1962) agree that there is a period of pre-spawning fast.

Marinus redfish. The difference in growth pattern between the sexes of *marinus* redfish resembles that observed for the *mentella* of the Southwest Grand Bank and the Gulf of St. Lawrence. The males in these two areas and the *marinus* males from both Flemish Cap and Hamilton Inlet Bank show Bertalanffy growth patterns involving fairly high t_0 values and low values for K (Table 1). In both these areas the females show higher growth rates than the males during the younger years but, after about age 21 at Flemish Cap and age 33 at Hamilton Inlet Bank, the males exhibit faster growth (Fig. 15).

Differences between areas

The Bertalanffy equation has been found to describe adequately the growth pattern of many species of fish, and several authors have examined the relations of the parameters of this equation to each other and to various environmental factors (in particular Beverton and Holt, 1959; Taylor, 1958, 1959 and 1960). Of the relations between the parameters themselves, K and L_{∞} have been found and, indeed, may a priori be expected to show an inverse correlation with each other (Knight, MS, 1962). When t_0 has values which depart from zero, it will likely also be inversely correlated with K .

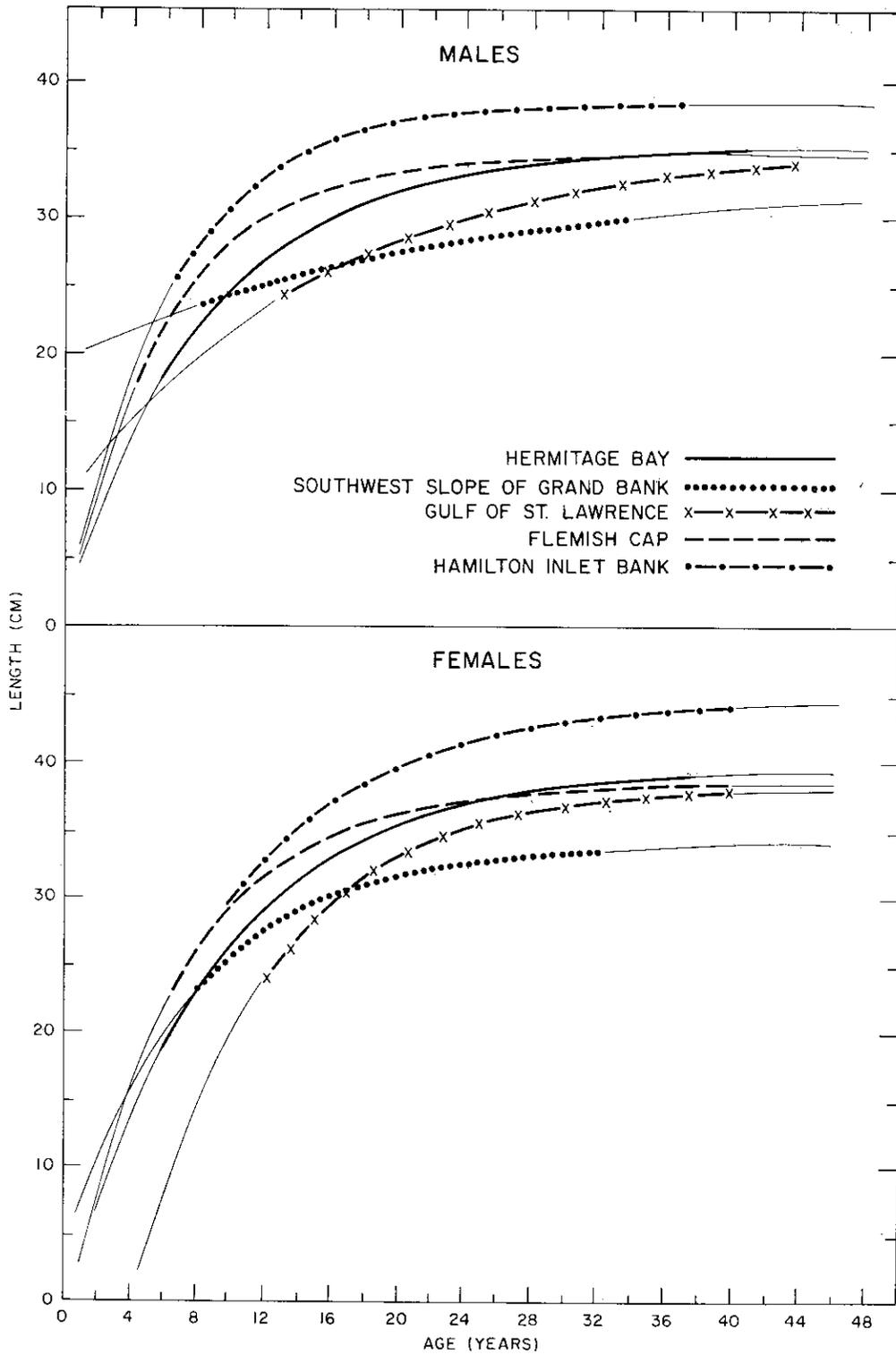


Fig. 12. Growth curves of *mentella* redfish from five different areas around Newfoundland plotted on the same coordinate system.

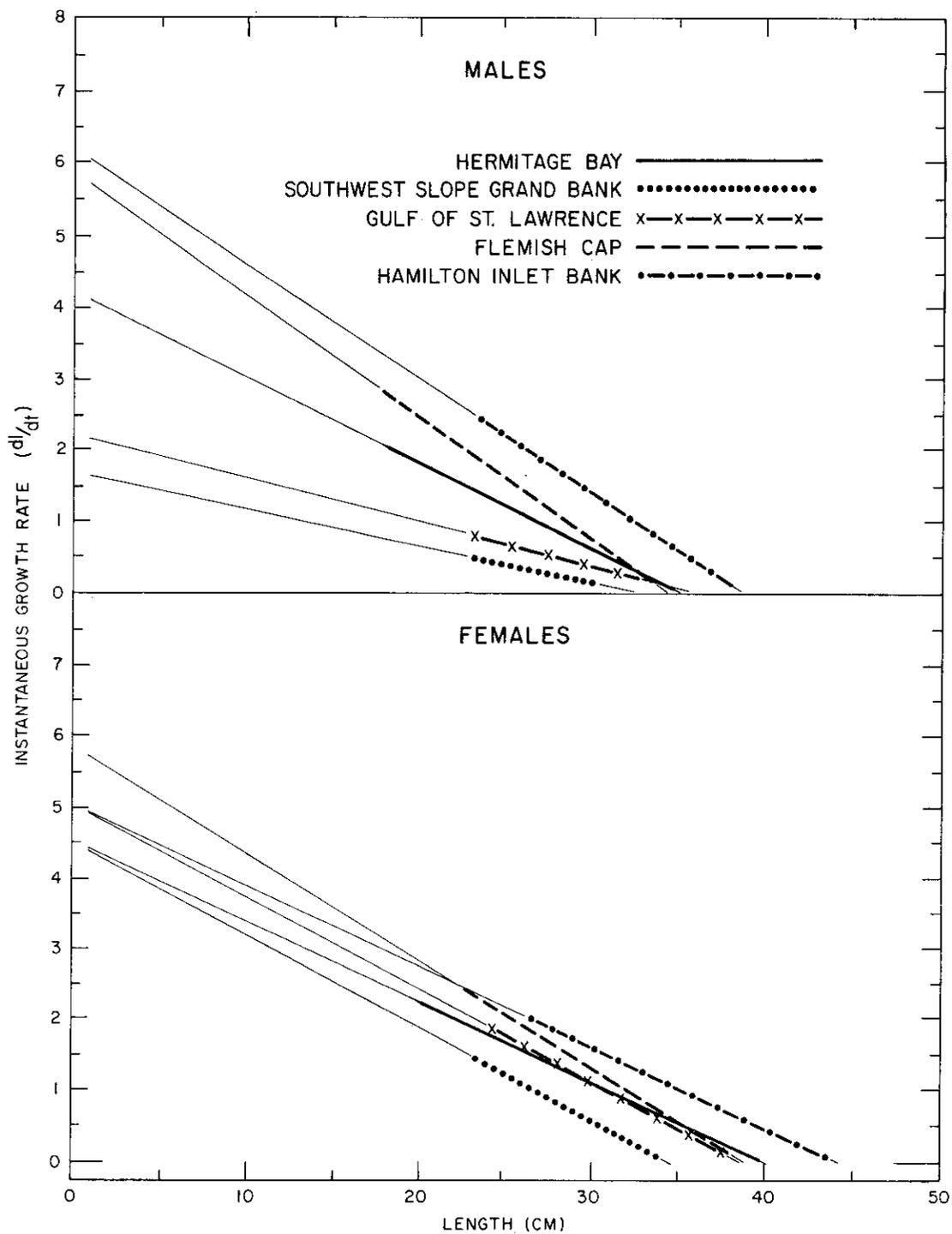


Fig. 13. Growth rate plotted against length for male and female *mentella* redfish from five areas around Newfoundland.

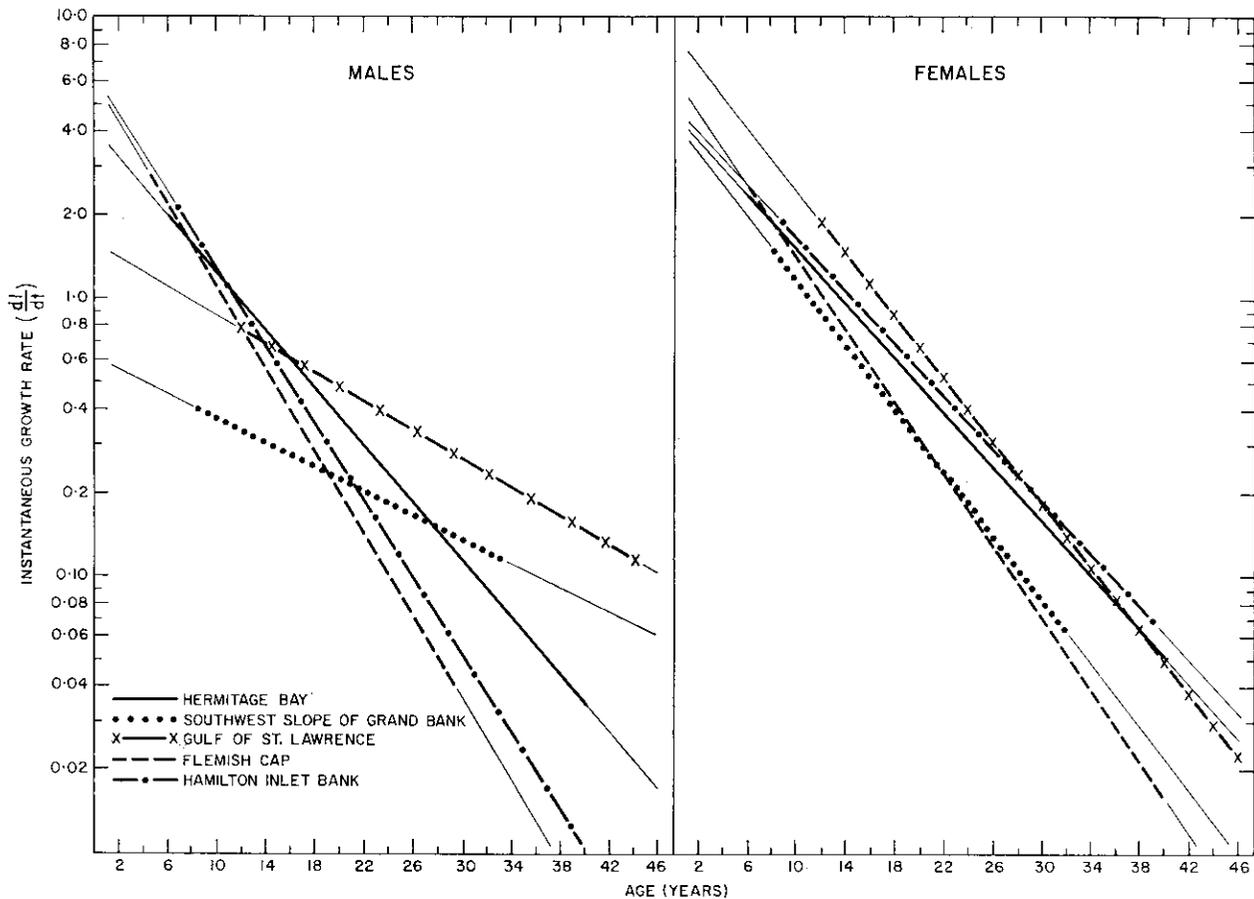
Because studies in which the Bertalanffy parameters have been correlated with various environmental factors have often yielded rather contradictory results, it seems preferable to avoid, for the time being at any rate, any possible physiological connotation which might be placed on these parameters, and to treat this equation in a purely empirical manner. The equation provides a good fit to the age at length data for redfish, as well as a convenient mathematical summary from which age and length values and growth rates can be extracted with ease by simple calculation.

In examining the differences in growth patterns between areas, discussions are here limited to a consideration of how the growth rates vary from area to area.

Growth rates of male *mentella* redfish. The Bertalanffy growth curves of male redfish from five areas around Newfoundland are plotted on the same coordinate system in Fig. 12. The para-

meters of these curves are shown in Table 1. The growth curves shown for Flemish Cap and Hamilton Inlet Bank represent the data from several widely separated depths, whereas the curves for the Southwest Grand Bank are derived from fish obtained in depths of less than 110 fathoms and those from Hermitage Bay and the Gulf of St. Lawrence from 140 and 129-142 fathoms respectively.

The male *mentella* of Hamilton Inlet Bank seem to have a much faster growth rate, and those of the southwest slope of the Grand Bank a slower growth rate than those of the other areas. This is confirmed when the growth rates are compared by length (Fig. 13). Until about a length of 32 cm, the growth rates at any length are in the order of highest to lowest: Hamilton Inlet Bank, Flemish Cap, Hermitage Bay, Gulf of St. Lawrence, and Southwest Grand Bank. In terms of age (Fig. 14), the Hamilton Inlet Bank fish have fastest



[Fig. 14. Growth rate plotted against age for male and female *mentella* redfish from five areas around Newfoundland.

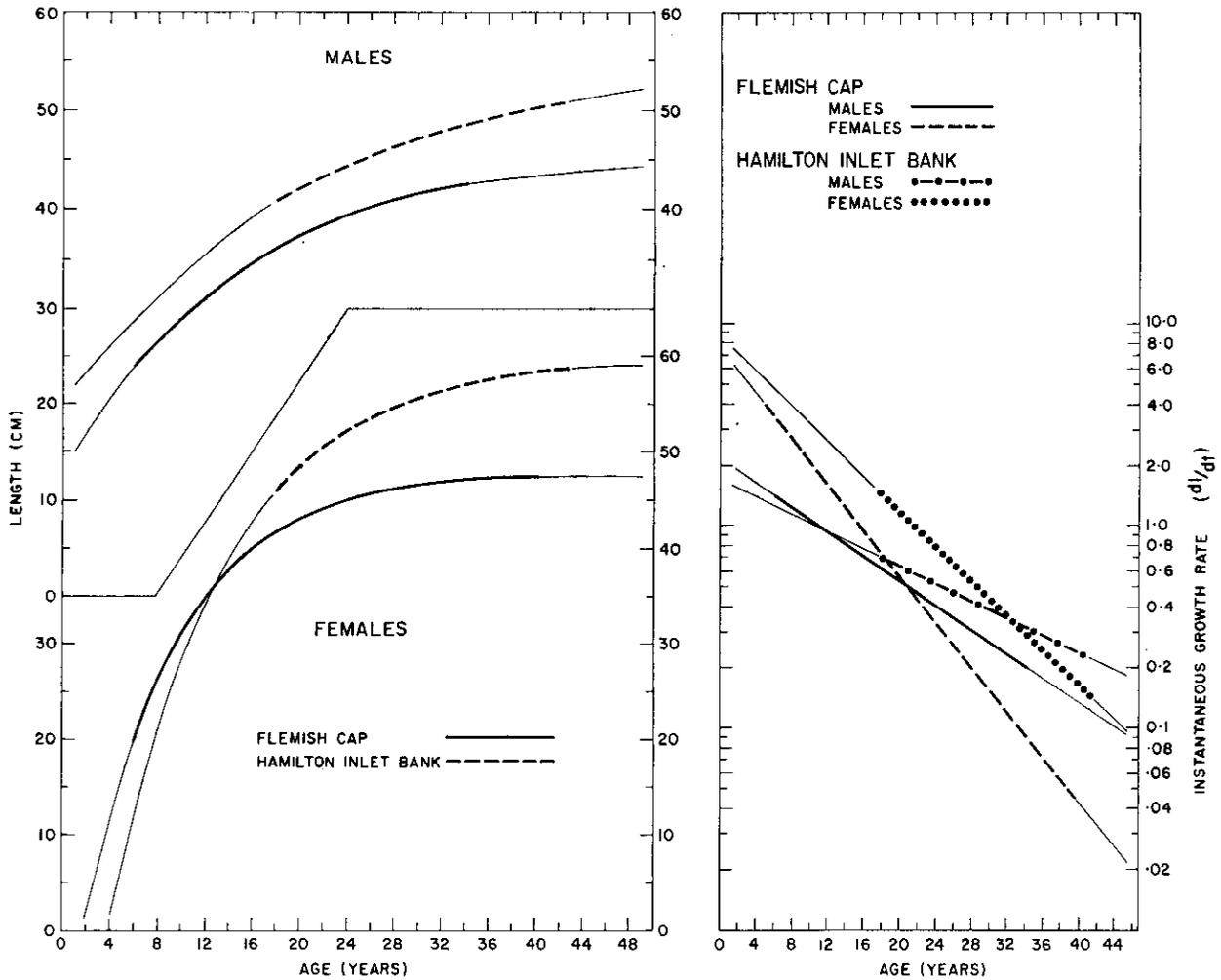


Fig. 15. Growth curves and plots of growth rate against age for male and female *marinus* redfish from Flemish Cap and Hamilton Inlet Bank.

growth to about the age of 10, but at greater ages the fish from Hermitage Bay grow faster and, after the age of about 15 the fish of the Gulf of St. Lawrence show the fastest growth. Apart from the Southwest Grand Bank fish, after about age 12 those from Flemish Cap show the slowest growth.

An examination of the Bertalanffy parameters and their confidence limits indicates a complete overlap by K and t_0 for all areas, and L_∞ for Southwest Grand Bank and Gulf of St. Lawrence with the other areas. Hamilton Inlet Bank can be considered different from Hermitage Bay and Flemish Cap in the maximum length to which fish from these areas may attain.

Growth rates of female *mentella* redfish. The area differences in growth pattern for female

mentella parallel rather closely those of the males (Fig. 12). Over the range of lengths corresponding to the ages for which we have fitted the Bertalanffy curves, there are, relative to length (Fig. 13), three main groups of growth rate: the fish from Hamilton Inlet Bank, which show a fast growth rate, and those from Hermitage Bay and the Gulf of St. Lawrence which show a medium growth rate, and those from the southwest slope of the Grand Bank which show a slow growth rate.

When the growth rate is considered with respect to age (Fig. 14), the Gulf of St. Lawrence fish grow fastest till about the age of 28, and apart from these fish, Hamilton Inlet Bank fish grow fastest followed closely by those from Hermitage Bay.

An examination of the Bertalanffy parameters and their confidence limits shows that the K and t_0 may overlap from all areas, but that L_∞ provides a likely separation of three differing growth patterns: Hamilton Inlet Bank having a high L_∞ ; Flemish Cap, Hermitage Bay, and the Gulf of St. Lawrence having a medium L_∞ ; and the southwest slope of the Grand Bank having a low value for L_∞ .

Growth rates of *marinus* redfish. As *marinus* were available from only two areas, area and sex differences are considered together. The fish from Hamilton Inlet Bank are larger than those from Flemish Cap (Fig. 5). Although the Flemish Cap males show a faster growth rate to about age 18 than the Flemish Cap females or Hamilton Inlet Bank males, after this age both the males and females from Hamilton Inlet Bank display a faster growth rate than the fish from Flemish Cap (Fig. 15).

Comparison of redfish growth curves as derived by different authors

North American mentella redfish

Very little age-length data have been published for redfish of the ICNAF Area. Some data are available from the ICNAF Sampling Yearbooks but only from Russian sources. Data to 1960 are summarized in a paper by Surkova (1962). More recently Savvatimsky and Sidorenko (MS, 1965) have presented growth data for *mentella* redfish from Hamilton Inlet Bank and the Northeast Newfoundland Shelf.

Perlmutter and Clarke (1949) were concerned primarily with immature redfish and, because much of their market sampling was aimed at these smaller fish, the values for mean length at age for the older fish in their samples are likely to be biased, with lower mean lengths and a flatter growth curve resulting.

Kelly and Wolf (1959) show growth curves of redfish from the Gulf of Maine for the years 1951-53. While Kelly and Wolf recognize the rather uncertain taxonomic position of the North American form of redfish, they class the Gulf of Maine redfish, in their final table, as *Sebastes marinus marinus*. It is the author's opinion and that of Templeman (1959) that the Gulf of Maine redfish belong to the common North American *mentella*-type.

Canadian and USA length measurements are made to the nearest centimetre, from the anterior

tip of the lower jaw, with the mouth closed, to the end of the mid-fork of the caudal fin. The Russian measurements, however, were of total length (to the tip of the caudal fin - Surkova, 1962) and presumably also made to the nearest centimetre. Because of this difference in the basic dimension measured, the Russian measurements will be larger than those of the USA and Canada. The difference will increase with size of fish and, according to Templeman (1959), should be about 1-1½ cm for redfish in the 30-to 40-cm-length range.

The method of age estimation also differs between the USA and Canada on the one hand, whose biologists use otoliths, and Russian biologists who rely almost entirely on scales. In many species of fish, although scales and otoliths agree and provide good age estimates for the younger fish, for the older fish which are forming very little new scale tissue annually, it becomes very difficult to distinguish between the winter and summer growth zones. This often results in an underestimation of the age of old fish by the scale method, as compared with the otolith method.

Gulf of Maine. Bertalanffy growth curves have been fitted for male and female redfish from the data of Kelly and Wolf (1959) for all samples collected in the Gulf of Maine in 1951-53. The curves were fitted to the unsmoothed length at age data for ages 1-18, for both males and females. These curves, together with the mean length at age values to which they were fitted, are shown in Fig. 16. It is unfortunate that we have no age estimations for this area, but included in the figure are our Bertalanffy curves for Hermitage Bay. It is evident, both from the parameters of the fitted curves (table below) and the curves themselves, that differences are not very great.

	Gulf of Maine		Hermitage Bay	
	Males	Females	Males	Females
L_∞	33.4	44.3	35.2	39.7
K	0.13	0.09	0.12	0.11
t	-0.5	-0.6	-0.3	0.3

The curves for the males are practically coincident to an age of about 14 years, after which the slightly higher value of L_∞ for the Hermitage Bay curve exerts its influence, and causes the

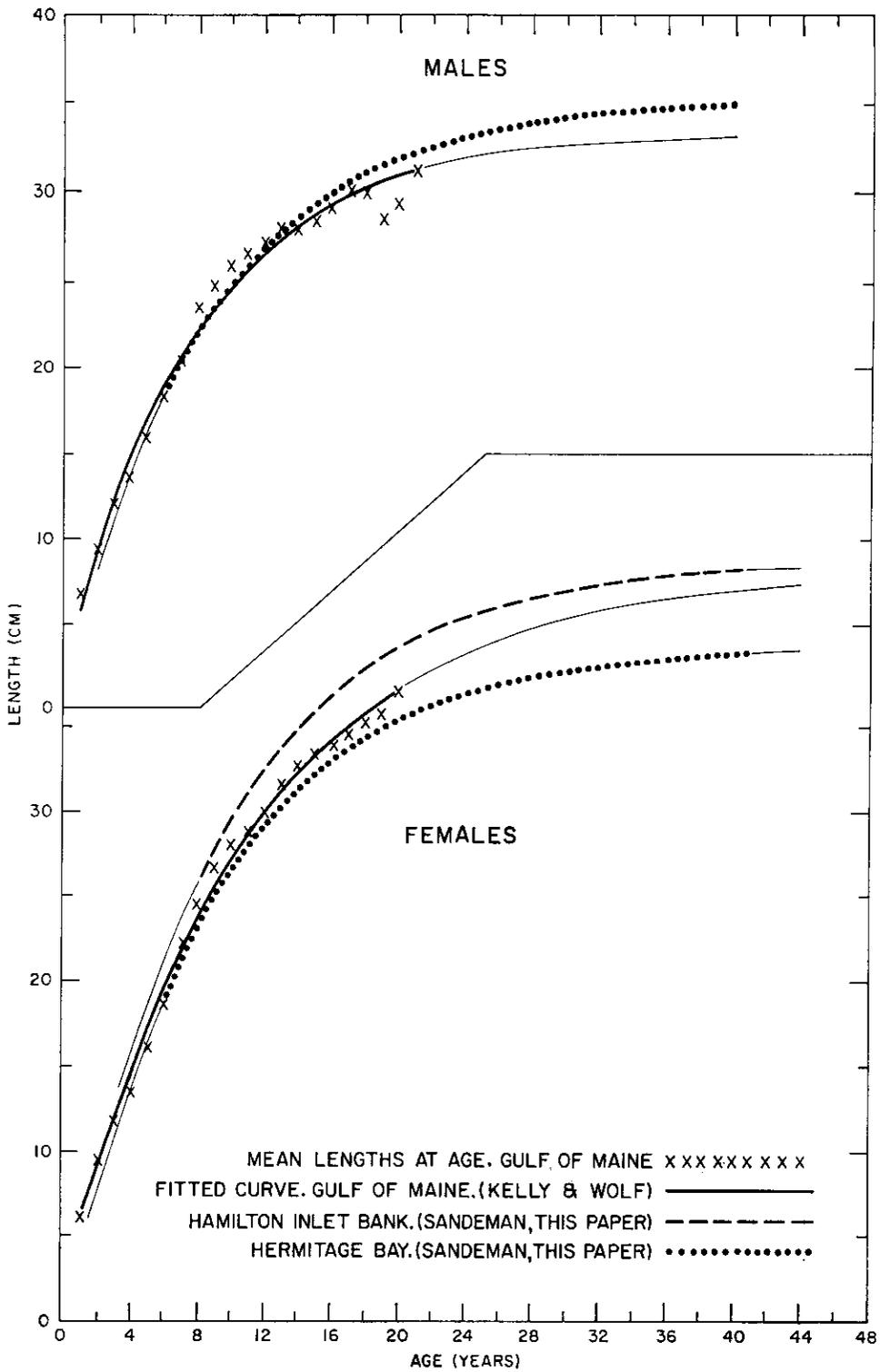


Fig. 16. Growth curves of *mentella* redfish from the Gulf of Maine (Kelly and Wolfe, 1959) compared with *mentella* from Hermitage Bay and also for the females from Hamilton Inlet Bank.

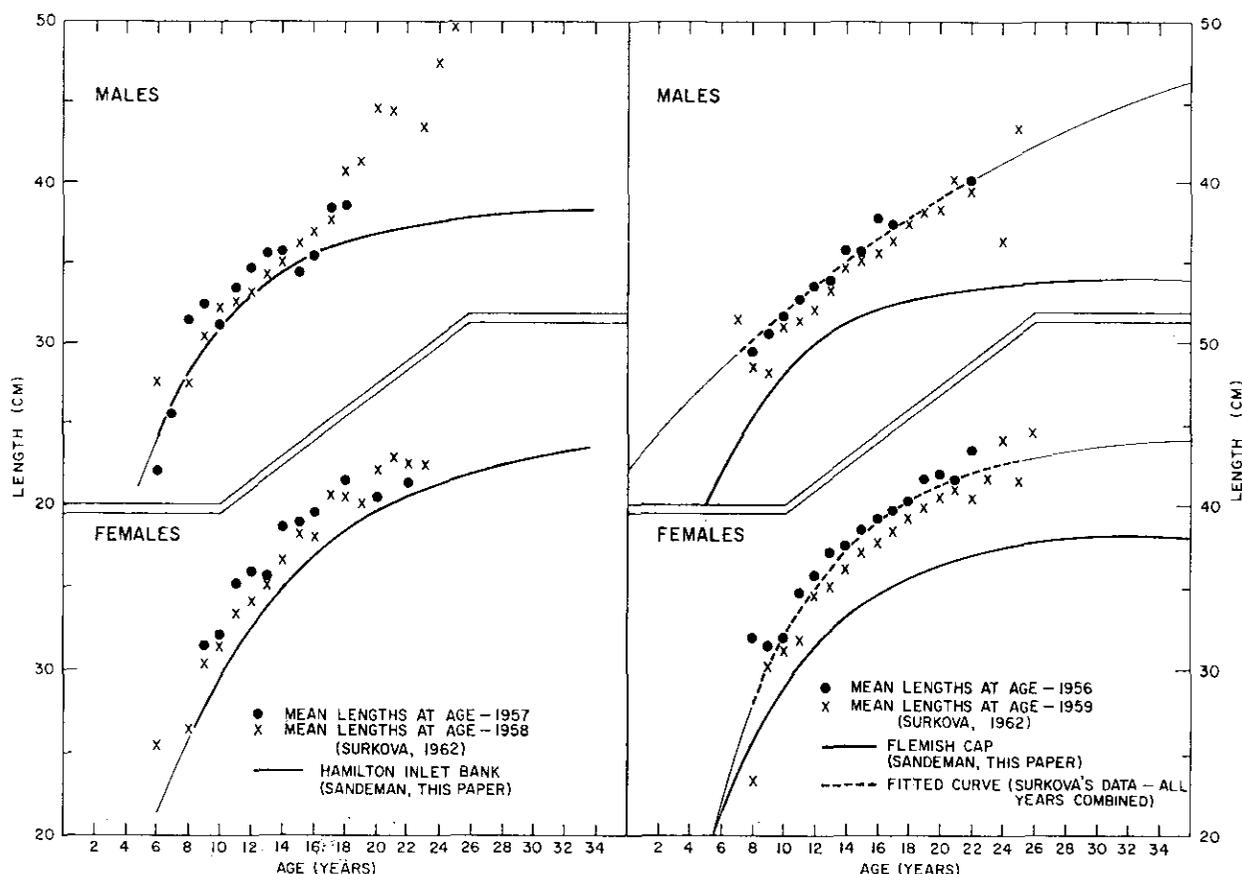


Fig. 17. Growth curves of *mentella* redfish from Hamilton Inlet Bank (left) and Flemish Cap (right). In each the mean lengths at age by Surkova (1962) are compared with the fitted curve obtained by the present author for the area in question.

curves to gradually diverge. The curves for the females do not appear quite so similar as those for the males, but the difference in mean length at each age is still less than 1.5 cm up to the age of 18, the largest age to which the curve was fitted. The Bertalanffy curve for the females of Hamilton Inlet Bank is also shown, to indicate how the curve for the data of Kelly and Wolf lies relative to the curves we have derived for various areas around Newfoundland.

ICNAF Subareas 2 and 3. Surkova (1962) has presented age at length data for ICNAF Divisions 2J, 3M, 3O, and 3P which may be compared with the growth data in this paper from Hamilton Inlet Bank, Flemish Cap, Southwest Grand Bank, and Hermitage Bay respectively. The curves for the area of best agreement—Labrador, and worst agreement—Flemish Cap are shown in Fig. 17.

Surkova's data for ICNAF Division 2J were obtained in 1957 and 1958. In the former year the data were based on one rather small sample of fish taken in the same area as was our own, whereas in the latter they were from several samples most of which were obtained in the southern part of ICNAF Division 2J.

When these data points are compared with our fitted curves for the Hamilton Inlet Bank line (Fig. 17) and allowance is made for the mean lengths of Surkova's data being about 1 – 1½ cm higher, except for the few very large males, the agreement between the growth curves is quite close. Why the large males in Surkova's data should diverge so greatly from the general trend is not known. Possibly scales have been used to obtain the age estimates, or, alternatively some fish from the deeper fast-growing population could have been mixed with samples obtained mainly

from shallower water. It is to be noted that these large fish occurred only in the 1958 samples.

Surkova's data for the Flemish Cap area are for the years 1956-60, but only her mean age at length data for 1956 and 1959, the years from which our samples were obtained from the area of Flemish Cap, have been plotted (Fig. 17). Also shown are the Bertalanffy curves fitted to our own data, and fitted to Surkova's data combined and averaged over the 5 years (unweighted).

The two sets of curves are quite different, with Surkova's data showing by far the faster growth rate.

Although differences are apparent between the age estimations of Surkova and the author, they are not of the order found between those who favour the slow growth and those who subscribe to the fast growth hypotheses for redfish. However, a lack of agreement is apparent and it seems unlikely that this could have been caused by between sample differences such as might exist due to the samples being obtained in diverse depths or localities. It is, in fact, difficult to evade the conclusion that the differences found between the results of these authors are due mainly to a difference in the basic method of age estimation. Thus, with otoliths being used by the one worker and scales by the other, the difference reduces to the much-discussed controversy of scales versus otoliths in age determination.

Just as the lack of agreement between the growth curves of Surkova and the author emerges so clearly from the comparisons, so also does the presence of agreement between the curves of Kelly and Wolf (1959) for the Gulf of Maine and those of the author for Hermitage Bay. Although the curves are for redfish from two different areas, it seems highly probable that the close agreement between the growth curves reflects a real agreement with regard to the basic method of age determination. The most striking difference between the data presented by Kelly and Wolf (1959) and

our data is the lack in the Gulf of Maine of the large, very old fish which seem so common in the samples from the Newfoundland area in 1947-53. It is probable that the high sustained fishing pressure to which the Gulf of Maine has been subjected has resulted in the relative absence of the large very old fish. A similar scarcity of these large old fish has been noted from the Gulf of St. Lawrence in recent years.

North American marinus redfish

Unfortunately very little data have been published for *marinus* redfish in the ICNAF Area. Some age frequencies are shown in the ICNAF Sampling Yearbooks, and Zakharov (1962) shows a table of age and mean length for *marinus* redfish from ICNAF Subarea 1. Zakharov's ages were determined from scales and although he is evidently extremely proficient at reading scales (he is able to read age to as many as 39 years), the growth curve he derives is typical of those obtained from scales. Travin's (1962) age frequency data also show ages to 35 years, with five fish being classed as older than 35. In view of the basic discrepancy between growth curves as derived from scales and otoliths of *mentella* redfish from the same area, little is to be gained by comparing between different areas, *marinus* growth curves which have been derived from otoliths and from scale age determinations. As the available detailed data on age and growth from both *mentella* and *marinus* of the Northeast Atlantic (with the exception of Bratberg, 1955, 1956a and b, and Trout, 1961 who worked only with rather young fish; and Kotthaus, 1949, 1952, and 1958) were all from scale readings, it is unlikely that comparisons will be of any real value.

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Growth Patterns on Otoliths from Young Silver Hake, *Merluccius bilinearis* (Mitch.)

BY FRED E. NICHY¹

Abstract

Otoliths of silver hake, *Merluccius bilinearis* (Mitch.), caught off southern New England and in the Gulf of Maine were studied to validate age assessment. Hyaline zones were formed during the pelagic, larval, and juvenile stages before formation of the first winter hyaline zone, and also frequently during the subsequent spring season. These ancillary zones complicate age assessment, particularly in young fish. Fish reached a modal length of 8-9 cm off southern New England and 12 cm in the Gulf of Maine at the time of formation of the first winter zone. Females grew faster than males.

Introduction

Silver hake, *Merluccius bilinearis* (Mitch.), are abundant off New England and are heavily exploited. To understand the dynamics of this stock or stocks, it is important to be able to estimate the age composition and growth rate.

This paper reports on the first study of age validation for this stock of fish. The growth rate of silver hake in the New York Bight area was studied by Schaefer (1960), but nothing is known about their growth on other important fishing grounds on Georges Bank and Gulf of Maine. Our first attempts at age determination of silver hake from New England waters were frustrated by the variable position of the first annulus and the presence of other zones in the center of the otoliths. A study of first-year growth was therefore undertaken to investigate this period of otolith development.

Data Collection

Material and data used in this report were obtained during seasonal survey cruises of the research vessels *Albatross III* and *Albatross IV*, Bureau of Commercial Fisheries, Woods Hole, Massachusetts, USA, and *Dolphin*, Bureau of Sport Fisheries and Wildlife, Sandy Hook, New Jersey, USA. Gear used on the *Albatross IV*

included otter trawls, Isaacs-Kidd midwater nets, and plankton nets. The otter-trawl codend was lined with $\frac{1}{4}$ -inch-mesh net (bar measure). The Isaacs-Kidd midwater net was lined throughout with $\frac{3}{8}$ -inch-mesh and had a fine-mesh codend of 1 mm² aperture. Plankton tows were made with nets of various mesh size, all with apertures less than 1 mm². *Albatross III* data consisted of only Isaacs-Kidd net catches made in 1957 and 1958. Collections from *Dolphin* were made with a Cobb midwater net reduced to one-third the size of the standard net; the codend was lined with $\frac{1}{4}$ -inch mesh. *Dolphin* collections were only from southern New England waters during 1966. *Albatross IV* cruises were from 1963 to 1966 and ranged on the continental shelf from the Hudson Canyon northward to the Bay of Fundy. About 175 stations were occupied during each survey cruise of *Albatross IV* over a period of about 1 month. An average of about 6,000 silver hake of all sizes was caught during each of the survey cruises.

Methods

Otoliths were stored in 60% glycerine with thymol added as a preservative. The otoliths were examined by placing them on a black surface and illuminating the broad surface of the whole otolith. The winter, or hyaline growth, then appeared as darkened rings and summer, or opaque growth, appeared white.

Measurements were made with an ocular micrometer in a stereoscopic microscope, at a magnification of 7X. Cross-sections of fractured otoliths were examined but offered no advantage over whole otoliths.

Figure 1 shows the lengths of otoliths plotted against fork length of fish up to 65 cm. Since the relation appears to be reasonably close to a straight line through the origin, all back calculations were made by direct proportion.

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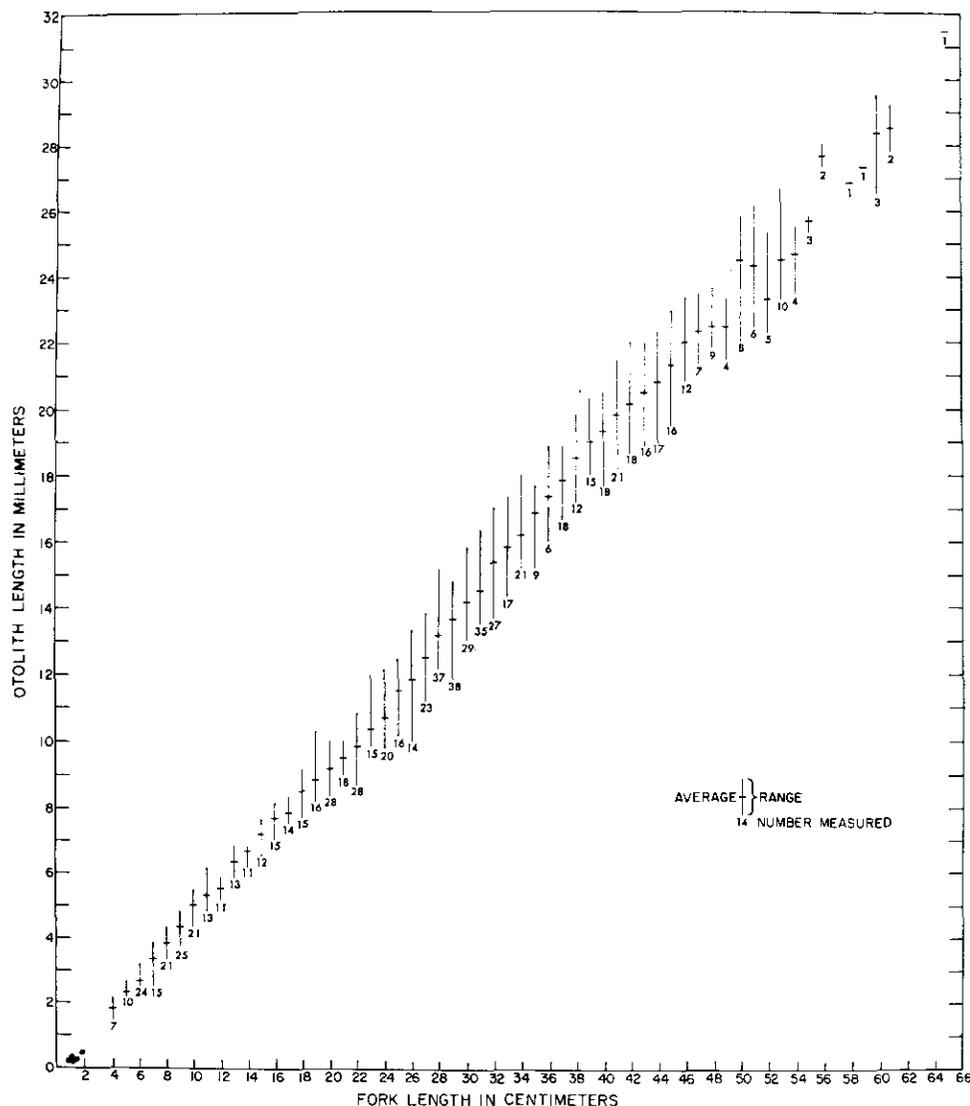


Fig. 1. Otolith length-fish length relationship. Measurements of silver hake under 2 cm were not summarized.

Growth of Silver Hake Caught in Different Areas and by Different Gears

Collections with otter trawls in two areas

Preliminary examination of otoliths indicated a difference in zonal formation between the fish in the Gulf of Maine and those on southern New England grounds. Length-frequency data for the areas north and south of $41^{\circ}30'N$ lat were therefore examined separately. This line of division was chosen because it passes through an area where the abundance of silver hake is lower than in areas to the north and south.

The most extensive series of length-frequency data for young-of-the-year silver hake were obtained from otter-trawl catches from *Albatross IV* survey cruises. Data from nine cruises, three winter, three summer and three autumn, undertaken between July 1963 and February 1966 are summarized in Fig. 2. Young-of-the-year silver hake were caught in the summer cruise of only 1 year; in the other years they first appeared in the autumn surveys. They are marked "0" in Fig. 2, or "1" at the change of the calendar year when they become, by convention, 1-year-olds.

In the southern area, the modal length of young silver hake was 6 cm during the surveys

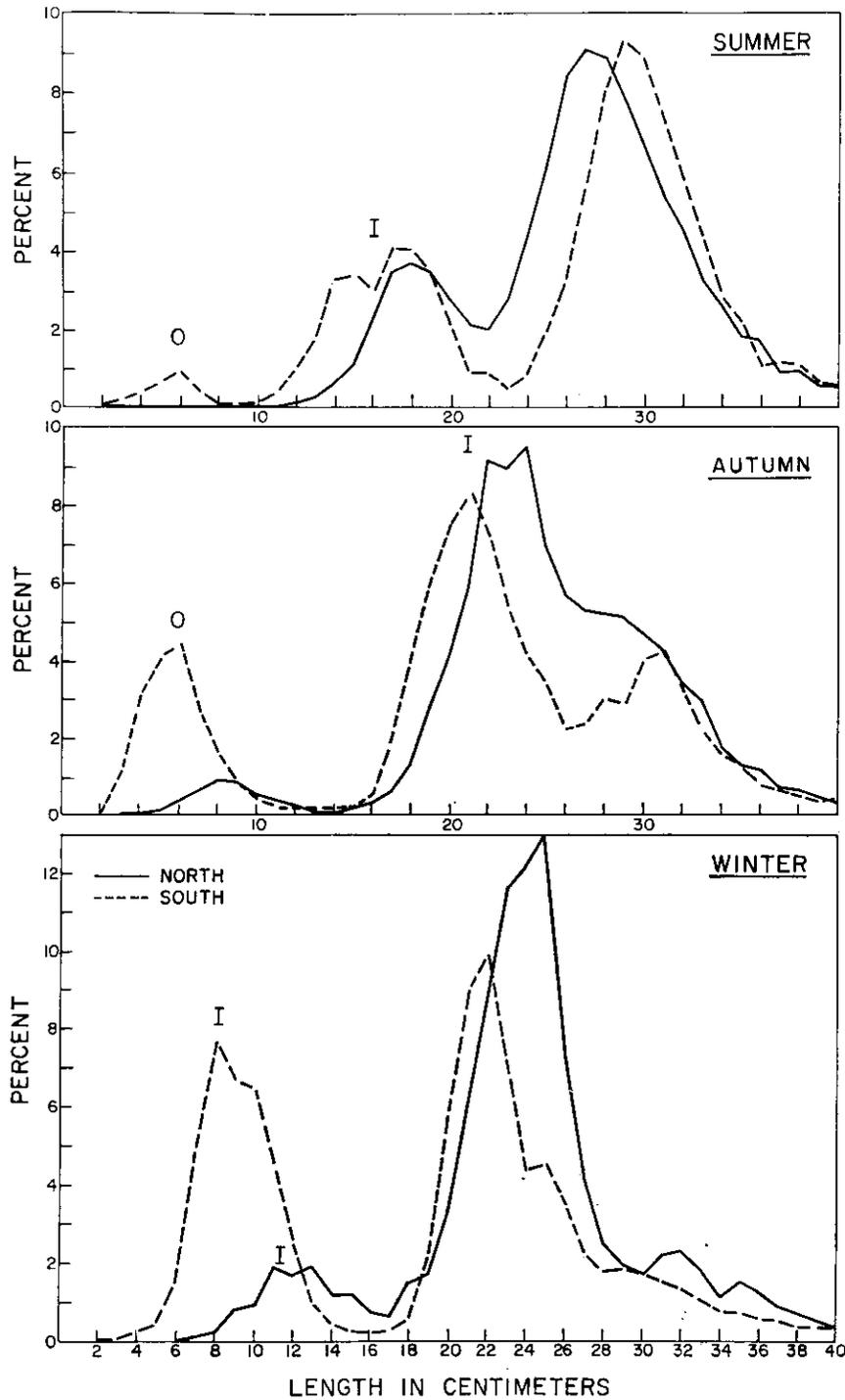


Fig. 2. Summary of silver hake length frequencies by per cent including fish up to 40-cm length from nine *Albatross IV* survey cruises. North (solid line) includes all silver hake taken north of 41°30' (Gulf of Maine), and south (broken line), below 41°30' (southern New England).

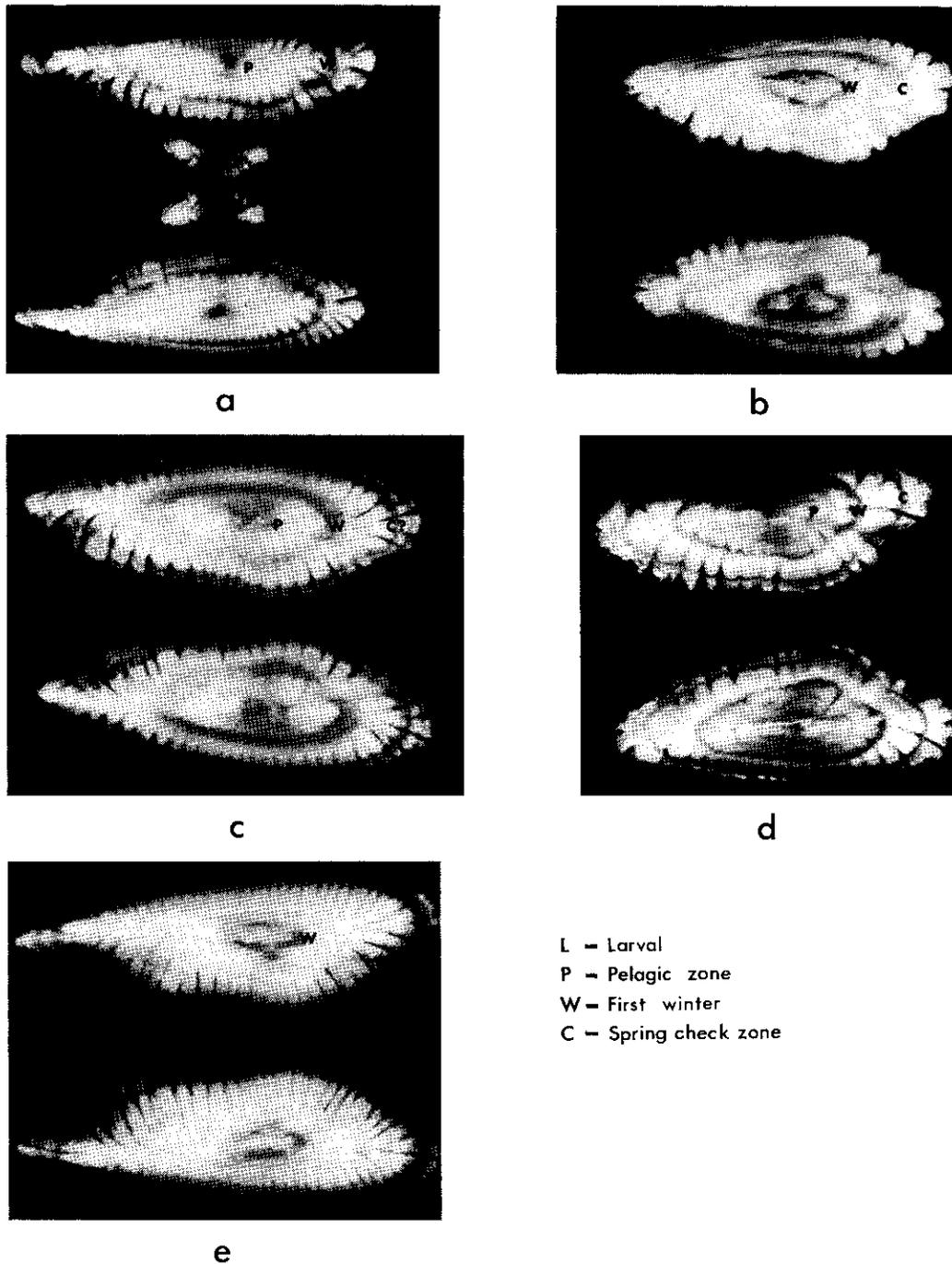


Fig. 4. Comparison of center growth in otoliths of silver hake.

- (a) Cheeky hyaline in center of small otolith is the pelagic ring; small dark center zone is first zone to occur. Large otoliths are from 29-cm female captured in the autumn, small otoliths from 9.5-cm silver hake, immature, captured in winter.
- (b) Type having small first winter zone and a spring check, 14.1 cm, immature, caught August.
- (c) Type with large first winter and possible spring check or annulus. Zone was called an accessory ring here. This type was found difficult to age. Length 22 cm, captured in winter.
- (d) Type having a large first winter and the spring check nearby. Pelagic zone is indicated by weak checks emanating from center. Length 18.5 cm, immature, captured in August.
- (e) Type having the first winter zone in the center of otolith, 29-cm female, caught in August.

in both the summer and autumn, but the range of lengths changed from 2-9 cm to 2-13 cm, indicating some growth. By winter, the modal length had risen to 8 cm. In the northern area, the autumn modal length was 8 cm, 2 cm larger than in the southern area. In winter, the mode in the northern area was 12 cm, 4 cm larger than in the southern area.

In summary, the data of Fig. 2 show that young silver hake were between 2 and 18 cm long during the period when the first winter zone could be expected to form on the otoliths. At this time silver hake were about 4 cm larger in the Gulf of Maine than off southern New England.

Collections with midwater gear

Young silver hake were first collected in July and early August at lengths between 0.5 and 4.0 cm (Table 1). In September, large numbers of silver hake from 1 to 7 cm long were caught. In October and November very small silver hake were usually still present in midwinter. The modal lengths of silver hake from individual survey cruises and midwater collections are plotted in Fig. 3 to compare the trawl and midwater catches. The plots show that lengths of silver hake caught with midwater gear were consistently smaller than those in otter-trawl catches during the summer and autumn. It was not possible to

TABLE 2. Back calculations of fish length at time of pelagic zone formation, and otolith edge condition of first-year silver hake.

Cruise	Month	No. examined	Back calculated length at pelagic zone		Edge condition S—summer W—winter
			Av. length of hake cm	length at pelagic zone cm	
Samples from the Gulf of Maine					
<i>Albatross IV—65-14</i>	Oct.—Nov.	4	5.3	3.7	3—S, 1—W
<i>Albatross IV—65-2</i>	Jan.—Feb.	17	11.2	4.8	3—S, 14—W
<i>Albatross IV—64-1</i>	Jan.—Feb.	10	11.7	4.3	7—S, 3—W
Total:		31			
Average:		Autumn:	5.3	4.3	Autumn: 3—S, 1—W
		Winter:	11.4		Winter: 10—S, 17—W
Samples from southern New England					
<i>Albatross IV—65-14</i>	Oct.—Nov.	33	5.7	4.2	25—S, 8—W
<i>Albatross IV—64-13</i>	Oct.—Nov.	18	5.0	4.4	16—S, 2—?
<i>Albatross IV—63-7</i>	Oct.—Nov.	21	7.7	5.7	21—S, 0—W
<i>Albatross IV—66-1</i>	Jan.—Feb.	50	8.6	4.0	6—S, 43—W, 1—?
Total:		122			
Average:		Autumn:	6.8	4.6	Autumn: 62—S, 8—W, 2—?
		Winter:	8.6		Winter: 6—S, 43—W, 1—?

determine from these data whether midwater or bottom-trawl catches were more representative of the young silver hake populations. I assume that all young of the year were available to otter trawls by the time of the winter surveys.

Zonal Formation on Otoliths

The first zone to appear on the otoliths is hyaline, and is considered to represent the larval phase of growth. The length of the otolith at this time is 0.3 to 0.6 mm. This larval zone can be seen in the otoliths of fish smaller than 10 cm, but frequently disappears as the otolith thickens with age. In Fig. 4a this zone appears as a dark point in the center of the smaller pair of otoliths.

The next hyaline zone on young-of-the-year silver hake is considered to represent the pelagic phase of growth. Otoliths from 10 fish, 2.5–4.5 cm long, taken in the autumn in a midwater-plankton tow all had this zone developing, indicating that it was formed before the fish descended to the bottom. It is normally composed of a series of thin hyaline checks starting from the very small, central hyaline zone mentioned earlier. Figure 4a shows the pelagic zone (labeled P) on otoliths from a 9-cm silver hake taken in the winter. An otolith from a larger fish (29 cm) shows the same structure now somewhat obscured by further growth. Back calculations made on otoliths from young-of-the-year silver hake taken in the otter trawl in autumn and winter cruises showed that the pelagic zone formed when they averaged about 4.5 cm long (Table 2).

The next hyaline zone to occur was interpreted as the first-year annulus. This zone was observed forming on the edge of silver hake otoliths collected in the winter. The varying amount of opaque material laid down just inside this zone created difficulties in its detection as a first annulus. Generally, the width of the opaque "summer" zone tended to decrease from the Gulf of Maine southward. The photographs of otoliths in Fig. 4a, c, and e show this transition from a large amount of opaque growth between the pelagic zone and first annulus to almost none. Otoliths in Fig. 4e were taken west of the Hudson Canyon. In a sample of 24 one-year old hakes taken off Chesapeake Bay, Maryland, all had early growth generally similar to Fig. 4e.

The first winter ring, even when small, was usually stronger in appearance than the pelagic zone. The presence of substantial opaque "summer" growth before the occurrence of the ring was influential, however, in judging whether or not this zone was the first-year annulus.

Investigation of the early growth of silver hake is further complicated by the presence of a check or accessory ring, which forms after the winter annulus, and which may be mistaken for an annulus. It is most likely to be confusing in otoliths from 1-year-old silver hake, i.e., those for which the second annulus has not yet formed. Examples of this type of mark are labeled with a "C" in the photographs in Fig. 4b, c, and d. These examples show well-developed accessory rings; usually the accessory ring is weaker than the annulus.

TABLE 3. Average length, from back calculations, of the pelagic and first winter ring, and spring check (accessory ring). Samples were taken in midwater.

Cruise	Month	No. examined	Av. length of hake	Back calculated length			Edge condition S—summer W—winter
				At pelagic zone	At winter zone	At spring check	
			cm	cm	cm	cm	
<i>Albatross IV</i> —66-4	April	33	7.7	3.5	7.2	—	24—S, 6—W, 3—?
<i>Dolphin</i> —66-5							
Off Atlantic City, N. J.	May	10	13.5	2.8	7.4	10.8	10—S, 0—W
Off Delaware Bay, Del.	May	18	13.8	3.4	6.2	11.4	18—S, 0—W

TABLE 4. Length-frequency distribution of male and female silver hake of different ages from the Gulf of Maine, based on calculated lengths from otoliths ("0" ring is the pelagic zone.)

Length <i>cm</i>	Age																			
	Males						Females													
	0	1	2	3	4	5	0	1	2	3	4	5	6	7	8	9	10	11	12	
2	2						4													
3	8						12													
4	20						21													
5	16						21													
6	3						12													
7							1													
8	2	1					3	7												
9	1	6					1	5												
10		3						2												
11		4						4												
12		10						7												
13		5						7												
14		5						8												
15		9						10												
16		4						8												
17		1	1					8												
18		2	2					3												
19		2	1					2												
20		5						2												
21		9						4												
22		8						8												
23		2						7												
24		10						12												
25		10						10	1											
26		4	6					14	4											
27		10		1				7	2											
28		3	2					4	7											
29		1	3	2				4	14	1										
30		4	2					4	7	1										
31		1	4			2		9	3	3										
32			1			2	1	2	5	8										
33						2	3	1	5	2	4									
34							1	1	3	6	5									
35								2	3	3	3									
36								1	6	3	2	1								
37								1	3	1	2									
38								1	3	3		1								
39								1	1	4	2									
40									2	4	1									
41									1	2	3									
42									2	1	2									
43									1	1	3									
44									2	2	1									
45									3	1	1									
46									1	1	1									
47									1	1	1									
48									1	1	1									
49									1	4	1									
50									1	2	1									
51										1	1									
52										1	1									
53										1	3									
54																				
55																				
56																				
57																				
58																				
59																				
60																				
Totals:	52	52	51	33	13	8	3	75	78	77	63	43	38	30	16	9	4	2	1	
Av. Length:	4.4	14.0	23.2	27.0	30.2	31.7	32.3	4.6	14.2	25.4	30.4	35.1	38.6	42.6	46.7	50.1	54.5	53.0	55.0	56.0

TABLE 5. Length-frequency distributions of male and female silver hake from southern New England waters based on calculated lengths from otoliths ("0" ring is the pelagic zone).

Length	Age													
	0	1	2	3	4	5	0	1	2	3	4	5	6	7
	Males						Females							
<i>cm</i>														
2						1								
3	3						6							
4	15						29							
5	14						19	2						
6	9						16	2						
7	6	3					6	3						
8	4	3					4	8						
9		4						13						
10		6						18						
11		8						8						
12		11						8						
13		9						8						
14		7						6						
15		4						5						
16								2						
17								4						
18			1					1	2					
19			1						3					
20			4						4					
21			5						3					
22			1						2					
23			2						9					
24			3	1					11	1				
25			3	2					9	1				
26			4	2					3	1				
27			1	3					9	4				
28				3	2				6	4				
29				6					3	1				
30					2				2	6				
31				1	3	1			2	7	1			
32					2	1			4	4				
33						1				5	1			
34						1				8	10			
35										2	2			
36										2	2	1		
37											2	1		
38										1		4		
39										1		3		
40											1		2	
41												1		
42											1	1		1
43														
44													1	
45														
46													1	
47														1
Totals:	51	55	25	18	9	4	81	88	72	48	20	11	4	2
Av. Length:	5.2	11.6	22.7	27.6	30.3	32.5	5.0	11.0	25.0	31.3	35.1	38.6	42.5	44.5

The accessory ring is believed to form sometime in the spring. Otoliths from hake collected in midwater in early April off southern New England had the first winter zone completed, and most of them had started summer growth but did not show the accessory ring. These fish averaged 7.7 cm when captured. Fish in samples from a *Dolphin* cruise made in late May, however, had developed the accessory ring with various degrees of intensity. They averaged 11.1 cm when the accessory ring formed, and 13.6 cm at capture (Table 3). It is evident from the length-frequency data that this accessory zone forms at a length significantly smaller than the modal size of fish in their second winter (see Fig. 2).

A series of otoliths from larger fish were back calculated to determine their length at formation

of the first winter and pelagic zones. These data are presented in Tables 4 and 5 for the Gulf of Maine and southern New England grounds. The average length at which the first winter zone occurred in both areas was similar to the modal length in the winter length-frequency compositions (Fig. 2). These results support our interpretation of the pattern of otolith growth during the first year. Further studies validating adult growth and resolving the problems encountered in adult fish are necessary before ageing this species can be considered a routine procedure.

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Length-Weight Relationship of Commercial-Size Greenland Halibut, *Reinhardtius hippoglossoides* (Walbaum)

Introduction

Length and weight data for Greenland halibut, *Reinhardtius hippoglossoides* (Walbaum), were collected to describe the relationships between whole and gutted weights and lengths, and to determine the factor for conversion of gutted to whole weights. In order to say definitely that one conversion factor can be used for the whole length range of commercially exploited fish, one must compute length-weight equations using whole and gutted weights. If the slopes of both gutted and whole weight curves are not significantly different, then it is reasonable to assume that one conversion factor can be used in conversion of commercial landings.

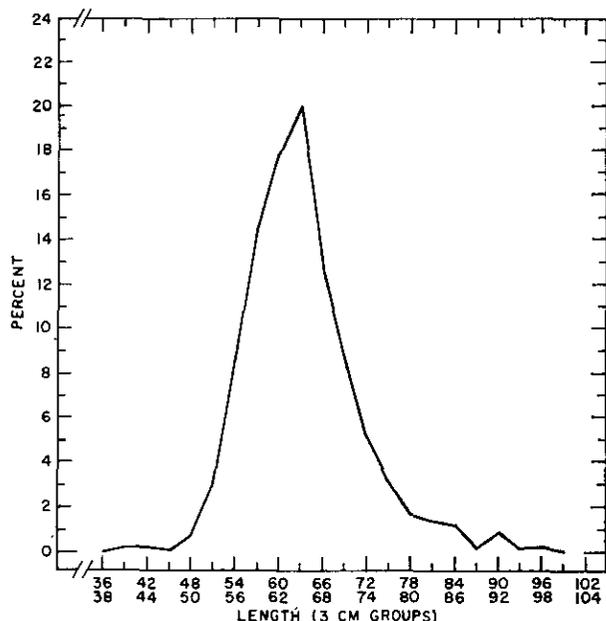


Fig. 1. Length distribution of commercial-size Greenland halibut (573 fish) used in computing length-weight curves.

Materials and Methods

The length-weight equations were computed using 573 Greenland halibut lengths and weights from catches of commercial fishermen in Trinity Bay, Newfoundland (ICNAF Division 3L).

The fish were measured to the nearest centimetre and fork lengths ranged from 41 to 97 cm with a mean length of 64.2 cm (Fig. 1). Weights were taken in pounds to the nearest ounce. The length-weight curves were obtained by using the equation $W = cL^b$ in which W = weight, L = length and c and b are constants. The least squares regression of the logarithmic transformation

$$Y = a + bX$$

in which $Y = \log_{10} W$; $a = \log_{10} c$; and $X = \log_{10} L$ was used for estimating values of c and b , (Snedecor, 1956).

The conversion factors were obtained by using four methods as follows:

1. Since the same fish were used to calculate both the round and gutted weight curves, the round and gutted weight totals were divided to give appropriate conversion factors.
2. The condition factor c of each length-weight curve was obtained by using the perfect cube or $b = 3$ in the equation $W = cL^b$. The condition factors were then divided to give appropriate conversion factors. (Hile, 1936).
3. The slope b of the round weight curve was substituted into the gutted weight curve so that two curves again had the same slope. The condition factors were then divided to give appropriate conversion factors.
4. The slope b of the gutted weight curve was substituted into the round weight curve and appropriate conversion factors calculated as before.

Results

The equation of the whole weight versus length is $8.702 \times 10^{-6} L^{3.2303}$ and for the gutted weight versus length curve is $8.712 \times 10^{-6} L^{3.2114}$ (Fig. 2). The conversion factors from the four methods are all very similar (Table 1).

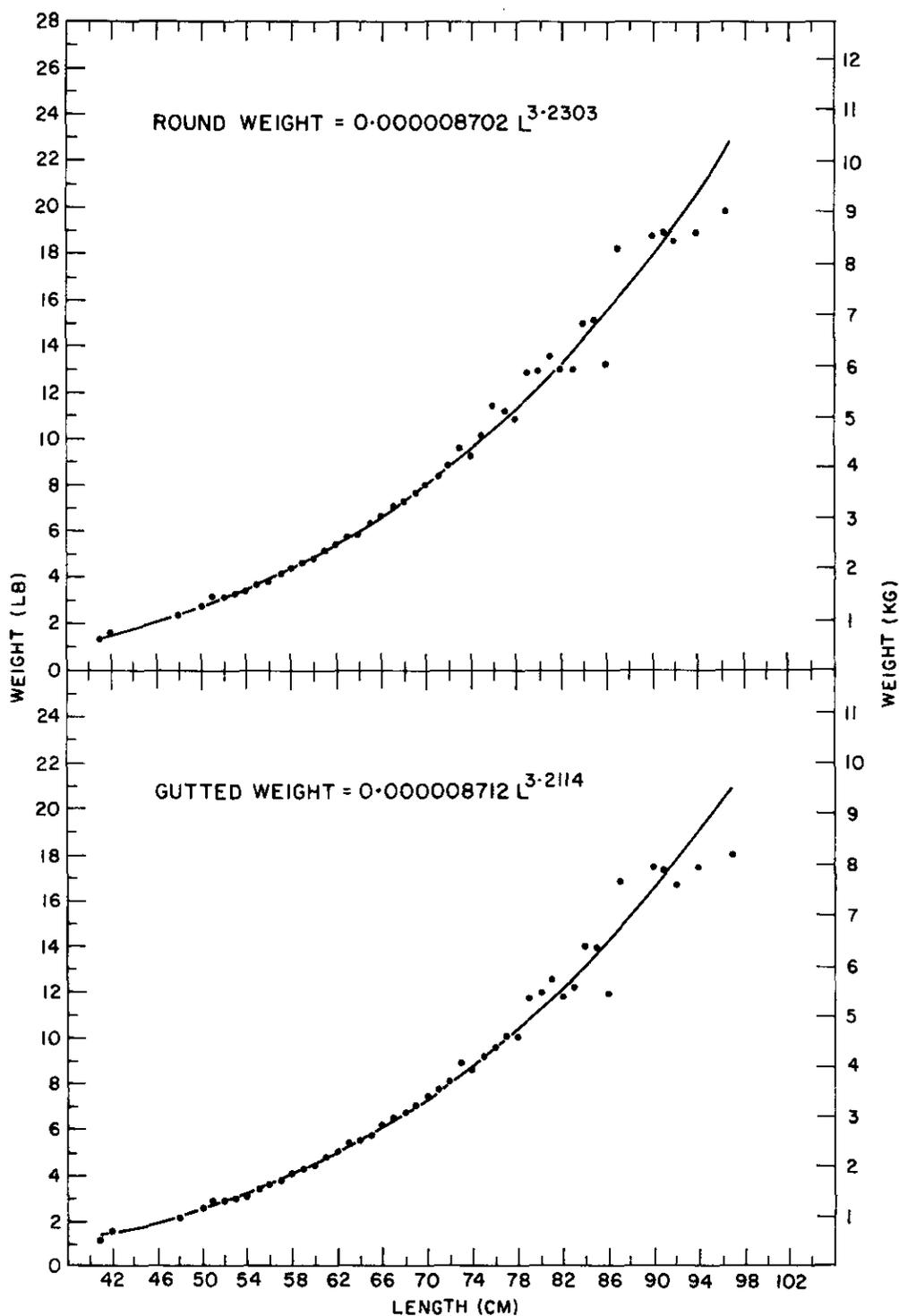


Fig. 2. Length-weight curves of commercial-size Greenland halibut. Above: Length-whole weight curve. Below: Length-gutted weight curve. The points represent average weights at each centimetre size.

TABLE 1. Conversion factors from whole to gutted weight and gutted to whole weight by four different methods.

Method	Conversion factor (whole weight to gutted weight)	Conversion factor (gutted weight to whole weight)
1	0.9256	1.0804
2	0.9217	1.0844
3	0.9244	1.0818
4	0.9245	1.0816

For converting commercial landings from whole to gutted weight, it would be reasonable to use a conversion factor of 0.9. For converting gutted weight to whole weight, a conversion factor of 1.1 would be a good approximation.

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W. H. Lear.

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 Canada, Denmark, France, Federal Republic of Germany, Iceland, Italy, Norway, Poland, Portugal, Romania, Spain, Union of Soviet Socialist Republics, United Kingdom, and United States of America.

Research Bulletin of ICNAF

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

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

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

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

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

Refereeing. To maintain a high standard of publication each contribution will be submitted by the Editor to one or more referees from a panel of experts appointed for that purpose. On the advice of the referee(s), the Editor will request the author to make such amendments to his manuscript as will help to avoid error or misunderstanding and add strength to his presentation or will reject the manuscript. Referees will remain anonymous and will treat all manuscripts as confidential.

Preparation of Manuscripts. To achieve maximum conformity of presentation by authors and to minimize typing and other editorial work, the Commission's Secretariat has prepared the following aid.

Instructions to Authors for the Preparation of Manuscripts Intended for Publication in the Research Bulletin of ICNAF

Text

- (a) Manuscript should be type-written, *double-spaced*, and on one side only of good quality white bond quarto paper, size $8\frac{1}{2} \times 11$ inches (220×280 mm).
- (b) Leave all margins 1 inch (25mm) to $1\frac{1}{2}$ inches (38 mm) for editorial marks and queries.
- (c) Prepare and submit the original and two carbon copies of the text and at least two sets of illustrations.
- (d) Number all pages of the manuscript consecutively with Arabic numerals in the centre of the top margin space.
- (e) Start a new page for each of the following sections with appropriate headings and sub-headings: (1) title, name and address of author, list of contents (if applicable); (2) abstract of the paper; (3) text; (4) references to literature; (5) tables; (6) legends for figures and (7) figures.
- (f) Please *double-space everything*—Text, quotations, footnotes, tables and table headings, legends, references to literature, and use even greater spacing where helpful (particularly around equations and formulae).
- (g) Wherever practical the text should be subheaded into Introduction, Materials and Methods, Results, and Discussion. Authors must provide a Summary which lists one by one the principal facts and conclusions of the paper. Acknowledgements should be placed immediately after the Summary.
- (h) All measurements, linear, weight, and time, should be given in numerals (not words) in the metric system. The Celsius scale should be used as a standard. When other units of measure are preferred, authors should include equivalents in metric units.
- (i) Footnotes should be avoided as far as possible, but if necessary they must be numbered consecutively in the text and typed under a horizontal line at the foot of the page concerned.
- (j) Only those words to be printed in italics should be underlined.

Abstract

Each manuscript should have an abstract not to exceed 3% of the length of the text or 200 words whichever is the smaller. For position of the abstract in the manuscript see (e) above. The abstract should summarize the contents and conclusions of the paper, point to new information in the paper and indicate the relevance of the work.

Tables

- (a) Tables should be carefully constructed so that the data presented may be easily understood.
- (b) Tables should be set out on separate sheets following the references.
- (c) Position of the tables in the text should be indicated clearly.
- (d) Each table should be provided with a descriptive heading which, together with the column headings, makes the table intelligible without reference to the text.
- (e) Tables should be numbered consecutively with Arabic numerals, e.g. Table 1, 2, 3, etc.

Figures

- (a) All illustrations, whether black-and-white drawings, graphs, photographs, or tone drawings, are to be considered as figures.
- (b) Each figure should be mentioned and described in the text.
- (c) A legend should be provided for each figure; the legends should all be typed together on a separate sheet or sheets attached to the manuscript following the tables.
- (d) Figures should be numbered consecutively with Arabic numerals, as Fig. 1, 2, 3, etc.
- (e) Figures should be set out on sheets preferably the same size as the text pages and in any case should not require a printer's reduction to less than one-third. Small figures can be arranged in groups on sheets the same size as the text pages.
- (f) For guidance in preparing figures, the size of the printed area of the *Research Bulletin* page is 21 × 17 cm. The *Bulletin* will have a two-column format, each column 8 cm wide.
- (g) Photographs presented as figures should be high contrast, glossy prints, about 5 × 7 inches (1251 × 75 mm) in size and should be shipped flat protected by stout cardboard.
- (h) Each illustration should be identified by marking on the back lightly in soft pencil on the margin the figure number and the author's name.

Bibliographic Style

- (a) References to literature in the text should be by the author-date system, for example

It was reported that (Collins, 1960) the . . .
In examining the situation, Rossini (1959) felt that. . .

Where more than one paper by the same author(s) have appeared in one year, reference should be given as follows:

Osborne and Mendel (1914a); Osborne and Mendel (1914b)
or Osborne and Mendel (1914a and b); (Barnet and Robinson, 1942; King and Pierce 1943a, 1954)

Reference to material not yet submitted for publication should be written into the text e.g. "Harvey, in an unpublished manuscript. . ." or "Harvey, in a letter. . ."

- (b) All references cited by the author-name system in the text should be listed alphabetically by the surname of the first *author* at the end of the paper. Year of publication follows the authorship. Then give the full *title* of the paper. This should be followed by the abbreviated name of the *periodical* with the *volume* and *pages* in Arabic numbers (e.g. : 2 : 120-136). For abbreviations of periodicals follow the "Word List of Scientific Periodicals". An issue, number, supplement or other part within a volume is shown in parentheses only when paged independently (e.g.: 2(4) : 1-56; 34 (Suppl. 2) : 1-26). Any special Series (Ser 3, III, or C) precedes the volume number. In *book citations* after the title, there appears the edition, the publisher's name, place of publication, and the number of pages if one volume, but the number of volumes if more. Reference to material submitted but not yet published should be referred to in the list of references as "in press" or "Submitted for publication" followed by the date of submission.

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