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RECENT EVENTS IN THE HADDOCK FISHERY OF THE EASTERN SCOTIAN SHELF

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INTRODUCTION

The eastern Scotian Shelf (ICNAF Divisions 4V-W) has long supported an important haddock fishery. Distribution, tagging, and meristic studies have shown that the haddock of Div. 4V-W and of 4T (southern Gulf of St. Lawrence) are closely interrelated and probably belong to a single major stock (Clark & Vladykov, 1960; McCracken, 1963, 1965). Traditionally, this fishery has been prosecuted mainly by Canada on the winter and spring concentrations of large fish found in the Emerald Bank-Western Bank region (western 4W).

In the 1958-1968 period landings from this stock averaged 27,500 metric tons annually, reaching a maximum of 55,518 metric tons in 1965 and a minimum of 10,912 tons in 1967 (Table 1). (Haddock landings quoted are from ICNAF Statistical Bulletins, Vol. 8-17, and ICNAF Res. Doc. 69/21.) The 4T fishery, prosecuted almost entirely by Canadians, was insignificant during these years falling to less than 1,000 tons from 1964 onwards. Landings from 4V averaged almost 4,500 tons, taken mainly as by-catches in the predominantly cod and flatfish fisheries of Spain and Canada. Canadian landings from 4W reached a peak of 22,000 tons in 1961, then declined rapidly to about 7,500 tons in the 1965-68 period. Spain consistently landed around 2,000 tons each year incidentally to the 4W cod fishery. The USSR first landed small quantities of haddock from 4W in 1961 and continued to do so in subsequent years until 1965, mainly as a by-catch in the summer silver hake fishery. However, in 1965, particularly in July and August, the USSR prosecuted an intensive haddock

fishery, landing almost 43,000 tons in that year. Soviet vessels took a further 10,000 tons from 4W in 1966, but their landings in 1967 and 1968 were negligible.

Previous assessments of this stock were based on 1949-58 Canadian data (Beverton and Hodder, 1962, Beverton, 1965). More recently, McCracken (1968) described size and age compositions of Canadian landings and discussed recruitment variations and total mortality rates over the period 1948-65. The present document updates McCracken's work to 1968 and presents a preliminary stock assessment based on 1958-68 data. Data collection and processing methods are those of McCracken, unless otherwise stated.

LENGTH AND AGE COMPOSITION OF CANADIAN LANDINGS

Canadian landings in the 1958-68 period were composed mainly of haddock 4-7 years old, the greatest contribution in terms of numbers normally being made at age 5 and in terms of weight at ages 5 and 6 (Table 2). Fish 40-60 cm formed the bulk of the catch (McCracken, 1968). In the years 1966-68, a slightly higher proportion of fish under 40 cm were landed, forming 7-12% of the catch by numbers compared with less than 2.5% prior to 1966.

ABUNDANCE

Most Canadian haddock landings were by side otter trawlers of 151-500 gross tons. Thus, the catch per hour of these vessels was taken as a measure of haddock availability in each month, and the annual average of the monthly catch per unit effort (cpe) values was taken as a measure of average abundance in that year. Too little data were available for 4T to calculate cpe values. However, in the 1958-68 period this fishery was insignificant and can reasonable be ignored in this and following sections.

The 4V and 4W abundance indices followed similar trends (correlation = 0.78) (Fig. 1). However, these indices are not directly comparable, as haddock is seldom the species sought in fishing operations in 4V, while it frequently is in 4W. As 4V data are also scanty, a combined 4V-W index would possibly be less accurate an estimate of stock abundance than the 4W value alone. Thus, the 4W index was taken as representative of stock abundance in the whole area of distribution, the assumption being that relative stock distribution was the same in all years.

The cpe of 4W haddock is not negatively correlated with that of 4W cod between 1954 and 1968, when both are calculated in the above manner (correlation = -0.18). Therefore, this method of calculation removes, at least partly, the major objection of Dickie (1965) to the use of these data as abundance estimates.

Haddock abundance increased from 1954 to 1957 due to recruitment of the extremely abundant 1952 year-class (McCracken, 1968), and then declined with minor fluctuations, reaching the lowest values for the 15-year period in 1967 and 1968.

McCracken (1968) found that the average year-class strength (mean numbers per hour fished at ages 5 and 6), over the 18 year-classes 1942-59 was 95.5 fish. This index calculated for the 1952-63 year-classes and adjusted to be comparable to McCracken's, showed that all four of the 1960-63 year-classes were below the long-term average year-class strength at ages 5 and 6 (Fig. 2).

TOTAL MORTALITY

There were large variations in survival rates between calendar years (Table 3) calculated from abundance indices of each age group in each year (Table 2). They showed, however, that recruitment to the fishery was complete by age 6 and that the average instantaneous total mortality rate (Z), assumed constant with age, was approximately 0.70.

Estimates of Z calculated for individual year-classes from catch curves (Fig. 3) declined fairly regularly from 0.93 for the 1952 year-class to 0.61 for the 1960 year-class, as follows:

Year-class:	'52	'53	'54	'55	'56	'57	'58	'59	'60
Z:	.93	.92	.87	.86	.80	.85	.68	.61	.61

McCracken found that Z lay between .50 and .70 for the 1945-50 year-classes, increasing to .80 to 1.05 for those of 1951-55. Thus, total mortality was highest for the extremely abundant 1952 year-class and those year-classes associated with it in the fishery.

NATURAL MORTALITY

From the relationship between total mortality and fishing effort between 1949 and 1958, Beverton and Hodder (1962) estimated natural mortality (M) of this stock to be 0.20.

For the 1958-68 period Z values were calculated from age 6 onwards. Thus, it was with the effective effort on fish age 6 and older that particular Z's were associated. Although Soviet and Spanish landings made up 35% of the total in the 1958-68 period, age compositions of their catches were not available. Spanish catches, being taken incidentally to the cod fishery, were probably similar in age composition to Canadian catches. Soviet catches, however, were partly incidental to the small-mesh silver hake fishery, and were taken mainly in 4W in summer. Haddock populations in 4W in summer normally consist almost entirely of fish smaller than 40 cm and younger than age 5 (McCracken, 1965). Thus, the age composition of the Soviet catch was probably very different from that of other countries, consisting mainly of young fish. Taking alternative hypotheses, firstly that the age composition of Soviet catches was identical to that of Canadian catches, secondly that no fish age 6 and over were contained in Soviet catches, Z for each year-class 1952-60 was plotted against the average estimated effective effort which effected this mortality (Fig. 4). A line was fitted to both data sets by the method of Paloheimo (1961).

When it was assumed that age compositions of Soviet and Canadian catches were the same, there was no significant correlation of Z and estimated effort (Fig. 4A). The estimate of M from Paloheimo's linear formula was 0.78, which is obviously erroneous. The alternative hypothesis that Soviet catches contained no haddock age 6 and over gave effort values which were correlated with Z (correlation coefficient = 0.88, significant at 1% level) and gave an estimate of M = 0.20 (95% confidence intervals $\pm$ 0.29) (Fig. 4B). This value of M is acceptable and identical to the value given by Beverton and Hodder (1962).

It is shown below that Soviet catches probably contained small quantities of haddock older than age 5. This would cause effort estimates from the latter hypothesis to be biased downwards in the years of greatest Soviet haddock catches, i.e. 1965 and 1966. This would tend to bias M upwards (Fig. 4). Thus, the true value of M is possibly less than 0.20.

GROWTH

The von Bertalanffy growth equation was fitted to length and age data from Canadian 1st quarter commercial samples for each year 1958-68, by the method of Allen (1966). Estimates of L_{∞} varied between 66.7 cm and 99.3 cm, of K between 0.07 and 0.33, and t_o between -5.79 and +2.22. Means of the annual estimates of the parameters were as follows:

$$L_{\infty} = 77.5 \text{ cm}$$

$$K = 0.15$$

$$t_o = -0.84$$

These are close to the values of $L_{\infty} = 75$ cm and $K = 0.20$ used by Beverton (1965).

A value of $W_{\infty} = 11.1$ lb was obtained by substituting the value of L_{∞} in the length-weight equation.

LENGTH AND AGE AT ENTRY TO THE EXPLOITED PHASE

The majority of Canadian otter trawlers fishing haddock in Subarea 4 use polypropylene codends, but a substantial number use codends of polyethylene, polyester, and polyamide fibres (Canadian Department of Fisheries, unpublished data). Haddock selection factors for these different materials were recommended by the Joint ICES/ICNAF Working Group on Selectivity Analysis (MS 1969). Haddock mean selection lengths were calculated for each material by multiplying the appropriate selection factor by the average mesh size for that material in the Canadian fleet in 1968 and 1969, measured by Fisheries Officers of the Canadian Department of Fisheries. A mean selection length for the fleet was calculated by taking the mean of the selection lengths for each material, weighted by the proportion of the fleet using that material. This gave a mean selection length for haddock of 38 cm. Substituting this value in the von Bertalanffy growth equation gave a mean selection age of 3.7 years.

MAXIMUM YIELD FROM THE TRADITIONAL FISHERY

The simple Beverton and Holt equation (Beverton and Holt, 1957) giving yield per recruit was calculated for the Canadian fishery for various levels of F, using the values determined above for the other parameters:

$M = 0.20$

$W_\infty = 11.1$ lb

$K = 0.15$

$t_o = -0.84$

$t_p = 1.0$ year (= age at recruitment to the fishing area)

$t_p' = 3.7$ years (= age at recruitment to the exploited phase)

$t_\lambda = 12$ years (= maximum age of significant contribution to the fishery)

A long-term average value of $Z = 0.70$ is indicated from the results of both Beverton and Hodder (1962) for the 1947-58 period, and the present author for the 1958-68 period. With $M = 0.20$, the average value of F would be 0.50, i.e. the value of fishing mortality giving maximum yield (Fig. 5A). If $M = 0.15$ ($F = 0.55$), yield would increase slightly with a decrease in effort of one-quarter. If $M = 0.25$ ($F = 0.45$) yield would increase only slightly with an increase in effort. Thus, in none of these circumstances would increased effort result in substantially increased yield.

It is possible that the value of t_p' used here is too low, perhaps due to the ability of the fleet to concentrate its activities on large fish. Beverton (1965) took a mean selection length of 43 cm equivalent to a $t_p' = 4.6$ years. It is unlikely, from examination of length and age compositions of Canadian catches, that t_p' is greater than this. Taking $t_p' = 4.6$ years does not greatly affect the conclusions drawn earlier on the state of the fishery (Fig. 5B). If $M = 0.15$, the average fishing intensity was close to the optimum, if $M = 0.20$, the yield would have increased only slightly with increased effort, if $M = 0.25$, the yield was 93% of the maximum value.

Thus, the average fishing intensity was apparently close to that producing maximum yield. Only if M was considerably higher than indicated by the data presented here and by Beverton and Hodder (1962), could an increase in effort have produced a substantial increase in yield.

SOVIET CATCHES: POSSIBLE AGE AND LENGTH COMPOSITIONS, AND EFFECT ON THE TRADITIONAL FISHERY

In 1965, the USSR landed 42,876 tons of haddock from 4W, 30,675 tons of this taken in July and August (ICNAF Statistical Bulletin, Vol. 15). This raised haddock landings from the eastern Scotian shelf in 1965 to over twice the long-term average landings. Nevertheless, there was no marked increase in the mortality of haddock over age 6 resulting from this sharp increase in effort. Neither did Canadian statistics show any increase in abundance in that year of haddock aged 4-12 (the ages on which the Canadian fishery is based).

A Canadian research ship survey cruise in 4W between July 29 and August 8, 1965, gave a good indication of what sizes of haddock were available to a commercial otter-trawl fishery in these months. Forty-three tows were made at depths of 19 to 205 fath with a #41 otter trawl with 1 1/4-inch mesh liner in the codend and lengthening piece. Part of this survey was undertaken in an area west of Sable Island being fished by an estimated 40 Soviet vessels. Haddock were abundant between 19 and 30 fath around Sable Island and moderately abundant between 65 and 100 fath, at temperatures of 4.0 to 11.8 C, but very scarce in 40 to 55 fath where temperatures were 1.4 to 3.4 C, and also scarce at depths greater than 100 fath. The length compositions of the shallow and deeper haddock concentrations were closely similar. Thus, the length frequencies of all tows were combined to give one length composition representative of the whole area (Fig. 6A). The length range was 15-73 cm, with 87% of the catch less than 40 cm.

Taking the Canadian research vessel catches as representative of the population, the catch of an otter trawler using regulation codend mesh was calculated, using a selection ogive for 4½-inch double manila. Such a catch would be composed mainly of fish 25-50 cm (average = 40.1 cm), 52% being less than 40 cm (Fig. 6C).

The 4W haddock stock was sampled in August 1965 by a Polish research vessel also (ICNAF Sampling Yearbook Vol. 10). These data give an independent estimate of the haddock length composition in the catch of a vessel using 114 mm (4½-inch) codend mesh. Polish catches were mainly of fish 16-55 cm (average = 36.2 cm), 70% being less than 40 cm. (Polish data are converted to fork lengths from total lengths for direct comparison with Canadian data.)

Polish data also include an age-length key, whereas none of the haddock taken on the Canadian research cruise were aged. Unfortunately, Polish age readings are very different from those to be expected from Canadian experience of aging fish from this stock. Thus, apparently important differences in aging technique exist between the two countries. It was preferred, therefore, to estimate the age structure of Canadian 1965 catches using a Canadian age-length key for 4W haddock. A key based on data collected in July 1960 was used as there are no indications from commercial samples of appreciable changes in growth rate between 1960 and 1965. This method indicated that, with a 1 1/4-inch mesh codend, 84% of the catch was composed of age groups 1-3, only 3% being age 6 and over (Fig. 6B). The age composition of the estimated catch of a vessel using 4½-inch mesh, was dominated by age groups 3 and 4, those age 6 and over composing 12% of the catch (Fig. 6D).

The Soviet silver hake fishery in Subarea 4 in 1965 was conducted with 40 mm (1.6 inch) mesh liners in the trawl codends (L.R. Day, personal communication). It is unlikely that gear rigged in this way has selection properties greatly different from those of the research vessel trawl with 1.25 inch mesh liner. Thus, any Soviet haddock catches made with this gear would have age and length compositions closely similar to those of research catches.

The Soviet silver hake fishery in 4W in 1965 was substantial, amounting to over 49,000 metric tons, and concentrated mainly in the same summer months as the haddock fishery. Large by-catches of haddock in this small-mesh fishery most likely occurred. Research vessel catches in the vicinity of the Soviet fleet in July and August took silver hake and small haddock in a ratio of approximately 4:1 by volume. Thus, it is a reasonable deduction that a considerable proportion of the Soviet haddock catch was taken with small-mesh liners in the codend. As this proportion cannot be ascertained at present, two extreme cases were considered, i.e. that all

the haddock were taken with 4½-inch mesh nets, and alternatively, that all were taken with small-mesh nets. The length and age compositions shown in Fig. 6, C and D, were taken as representative of the catch with 4½-inch mesh, those in Fig. 6, A and B, of that with small mesh. (Polish length-frequency data were not used because of the difficulties in converting from total length.)

If the entire Soviet haddock catch of 42,876 tons in 1965 was taken with 4½-inch mesh nets, the average fish weight would have been 1.65 lb giving numbers caught as 57,000,000 fish. Contribution by numbers and weight of each age group are given below. Also given are the potential yields had they survived this fishery to be caught at ages 4–12 in the traditional fishery.

Age	Numbers caught	Weight caught (metric tons)	Potential yield (metric tons)
1	300,000	30	100
2	2,000,000	500	1,400
3	22,000,000	9,400	16,000
4	19,000,000	13,400	17,500
5	6,000,000	6,000	6,300
6+	8,000,000	13,600	10,600
Total	57,000,000	42,900	51,900

Loss in yield = 9,000 metric tons

Potential yields were calculated using the Beverton and Holt yield equation with t_p = 1.5, 2.5, 3.5 years etc. as appropriate, t_p' = 3.7 years, M = 0.20, F = 0.50, and other values as before.

If the entire Soviet catch was taken with small-mesh nets, the average fish weight would have been 0.72 lb giving numbers caught as 131,000,000 fish. Contributions by numbers and weight of each age group and potential yields to the traditional fishery were:

Age	Numbers caught	Weight caught (metric tons)	Potential yield (metric tons)
1	40,000,000	3,400	19,100
2	22,000,000	3,800	12,700
3	48,000,000	15,500	34,500
4	14,000,000	9,400	13,000
5	3,000,000	3,400	3,700
6+	4,000,000	7,400	5,800
Total	131,000,000	42,900	88,800

Loss in yield = 45,900 metric tons

The potential yields were calculated as before.

The actual situation in 1965 most probably lay somewhere between these two extremes. The intensive fishery for young fish resulted in an overall loss in yield to the eastern Scotian Shelf haddock fishery of between 9,000 and 46,000 metric tons (from above tables). The bulk of this loss (7,600—41,600 tons) was from the 1962-64 year-classes at ages 1—3 respectively.

SUMMARY AND DISCUSSION

The decline in the 1960's in Canadian landings from, and effort on, the haddock stock of the eastern Scotian Shelf, reflected a decline in abundance of haddock aged 4 and over. Abundance indices in 1967 and 1968 were the lowest on record. On average, over the last 10 years, fishing mortality caused by the traditional fishery was close to that giving maximum yield. The recent decline in stock abundance was apparently due to a recruitment failure to the traditional fishery, the 1959 year-class being the only moderately good one (at ages 5 and 6) between 1958—63.

The large Soviet haddock catch of 1965 was undoubtedly an event of considerable importance in the history of this fishery. Unfortunately, the effects can only be determined in general terms as data on length and age compositions of the Soviet catch are unavailable, and estimates of these parameters from Canadian research vessel data must be used. It is likely that the Soviet catch contained substantial numbers of young, immature fish. This reduction of the age at recruitment to the fishery probably resulted in a loss in yield to the eastern Scotian Shelf haddock fishery of 9,000–46,000 metric tons. A further substantial Soviet fishery of 10,500 tons, prosecuted under similar circumstances in 1966, was not considered here.

Practical measures to aid the recovery of this fishery might be to prevent further reduction of the spawning stock on the unproven but reasonable hypothesis that very low adult stock densities reduce the likelihood of good recruitment. Thus, any substantial increase in effort in the immediate future would be undesirable. Significant fisheries on young immature fish are also undesirable, in that they reduce both yield and recruitment to the spawning stock.

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Table 1. Haddock landings from the eastern Scotian Shelf stock, 1958-68. (metric tons round fresh)

Year	All countries			Total All countries 4T-V-W Combined	Divisions 4T-V-W			
	4T	4V	4W		Canada (M & Q)	Spain	USSR	Other
1958	2750	4586	19,592	26,928	23,336	3087	-	505
1959	3061	8259	26,600	37,920	29,153	3643	-	5124
1960	2041	6552	21,244	29,837	24,636	5047	-	154
1961	1572	3483	23,908	28,963	25,184	3287	151	341
1962	1142	3416	21,408	25,966	18,853	4315	2,567	231
1963	1065	5369	20,138	26,572	14,157	7853	3,301	1261
1964	462	3816	19,016	23,294	11,613	5001	4,391	2289
1965	438	3593	51,487	55,518	8,799	3362	42,876	481
1966	150	3300	20,199	23,649	9,838	2856	10,501	454
1967	121	2101	8,690	10,912	8,156	1920	554	282
1968	149	3094	10,066	13,309	9,710	3230	254	115

Table 2. Numbers at age by year-class of 4V-W haddock per 100 hours fished by Canadian side otter trawlers of 151-500 gross tons, and the percentage contribution to Canadian landings (by numbers and weight) of each age group, averaged for the 1958-68 period. (Age composition representative of 4V-W. Catch/effort for 4W taken as representative of whole area.)

Year-class	Age 2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1944													47	-	3
1945												-	3	-	-
1946											109	-	10	6	-
1947										330	23	89	11	5	-
1948									473	23	82	64	2	-	-
1949								1438	282	247	128	12	6	-	-
1950							1388	311	155	89	38	-	5	-	-
1951						2030	321	479	220	54	2	7	-	-	-
1952					13402	4928	2475	915	242	22	22	5	7	-	-
1953				3848	3183	3210	1284	370	55	87	16	16	-	-	
1954			4953	7257	4050	1429	996	203	123	84	14	14	5		
1955		3032	10931	11743	5927	2121	841	703	194	43	7	23			
1956	81	5485	8760	11798	8101	3736	3011	852	264	116	86				
1957	-	402	5408	9669	7419	5243	2162	822	349	117					
1958	-	505	1535	3555	3562	1486	1079	433	232						
1959	120	393	4338	8644	4961	3518	1201	681							
1960	-	95	2055	2370	1937	961	609								
1961	-	623	2746	5812	2360	1223									
1962	-	647	8066	5772	3923										
1963	-	876	4283	5117											
1964	126	1380	2966												
1965	215	597													
Av. contribution by numbers (%)	0.2	5.4	21.4	28.8	22.4	11.4	5.9	2.7	1.0	0.5	0.3[1]				
Av. length (cm)	35.7	40.6	43.7	47.1	50.9	54.4	57.4	60.9	62.4	64.4	66.5				
Wt/individual (lb)	1.01	1.51	1.89	2.39	3.03	3.72	4.40	5.27	5.68	6.26	6.92				
Av. contribution by weight (%)	0.1	2.9	14.5	24.7	24.3	15.2	9.3	5.1	2.0	1.1	0.7				

1/ Age 12 and over.

Table 3. Total survival rate of 4V-W haddock.

Years	Age groups 2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	$\Sigma^{7-12}/\Sigma^{6-11}$
1958-59	67.72	3.61	1.47	0.83	0.37	0.16	0.22	0.20	0.05	0.07	0.31
1959-60	-	1.60	1.01	0.56	1.01	0.50	1.49	0.50	0.88	3.57	0.73
1960-61	-	13.45	1.35	0.50	0.35	0.40	0.37	0.46	0.57	0.52	0.38
1961-62	3.28	3.04	1.79	0.69	0.36	0.70	0.29	0.26	0.25	0.43	0.39
1962-63	-	11.04	2.32	0.77	0.46	0.40	0.20	0.15	0.09	0.04	0.41
1963-64	-	21.63	1.99	1.00	0.71	0.81	0.84	0.61	1.58	1.00	0.75
1964-65	-	4.41	1.15	0.57	0.42	0.41	0.28	0.28	0.68	0.18	0.38
1965-66	-	12.47	2.12	0.82	0.71	0.73	0.38	0.31	0.22	0.17	0.59
1966-67	10.95	4.89	0.72	0.41	0.50	0.34	0.40	0.42	0.44	0.16	0.40
1967-68	2.78	2.15	1.19	0.68	0.52	0.63	0.57	0.54	0.34	0.74	0.54
Average	21.18	7.83	1.51	0.68	0.54	0.51	0.50	0.37	0.51	0.69	0.49

Total instantaneous mortality = 0.71

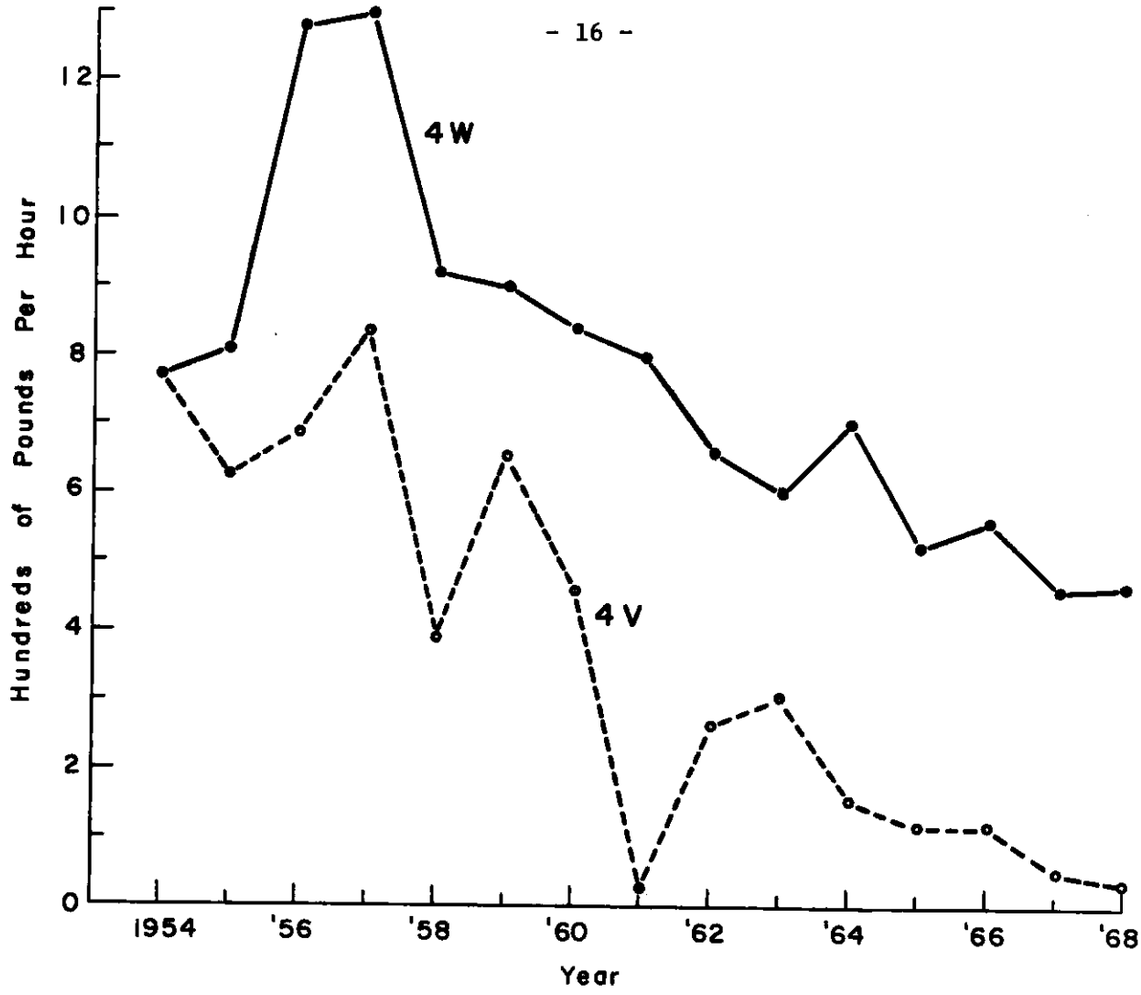

Fig. 1. Abundance indices of haddock in 4V and 4W, 1954-68. (Annual value, weighted by month, of lb/hr fished by Canadian side otter trawlers 151-500 gross tons).

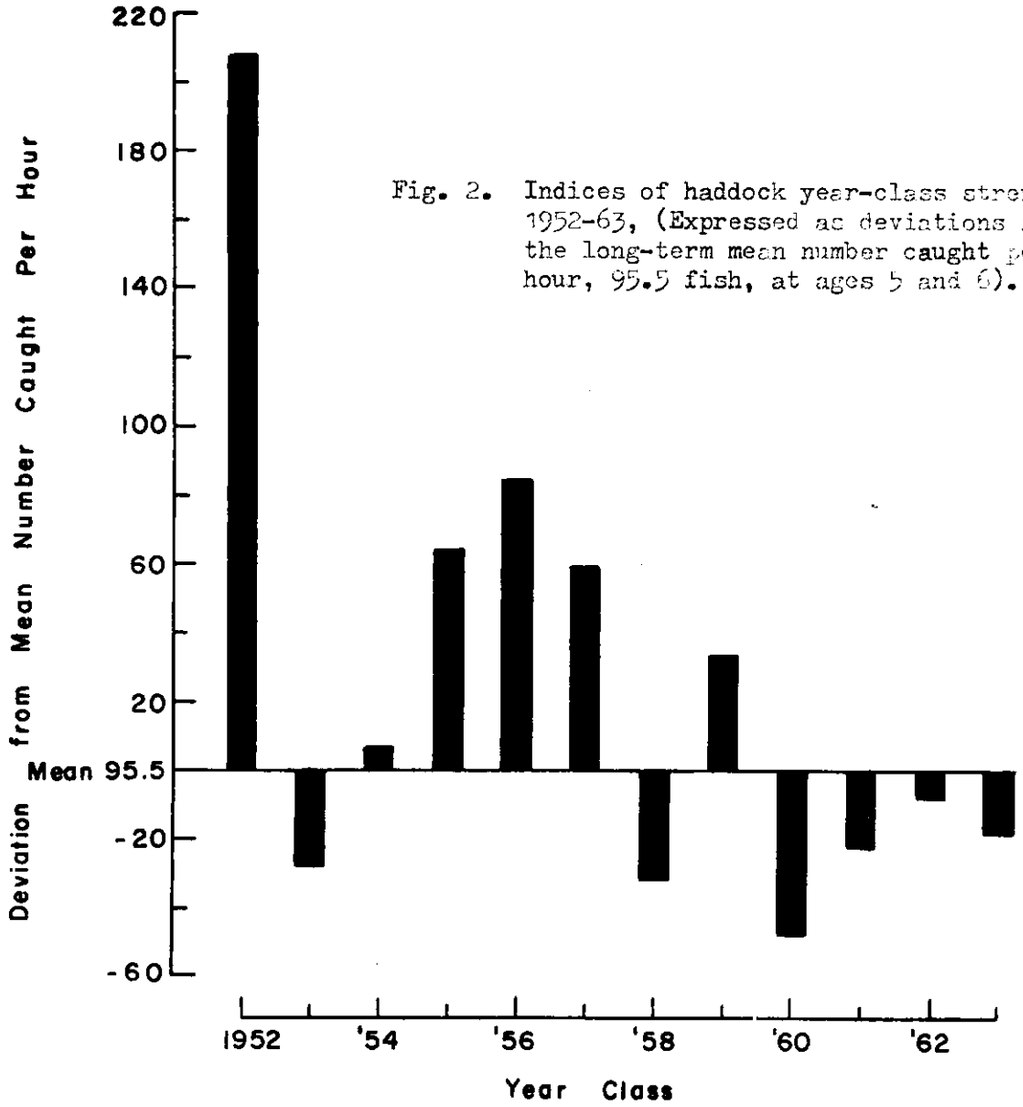

Fig. 2. Indices of haddock year-class strength, 1952-63, (Expressed as deviations from the long-term mean number caught per hour, 95.5 fish, at ages 5 and 6).

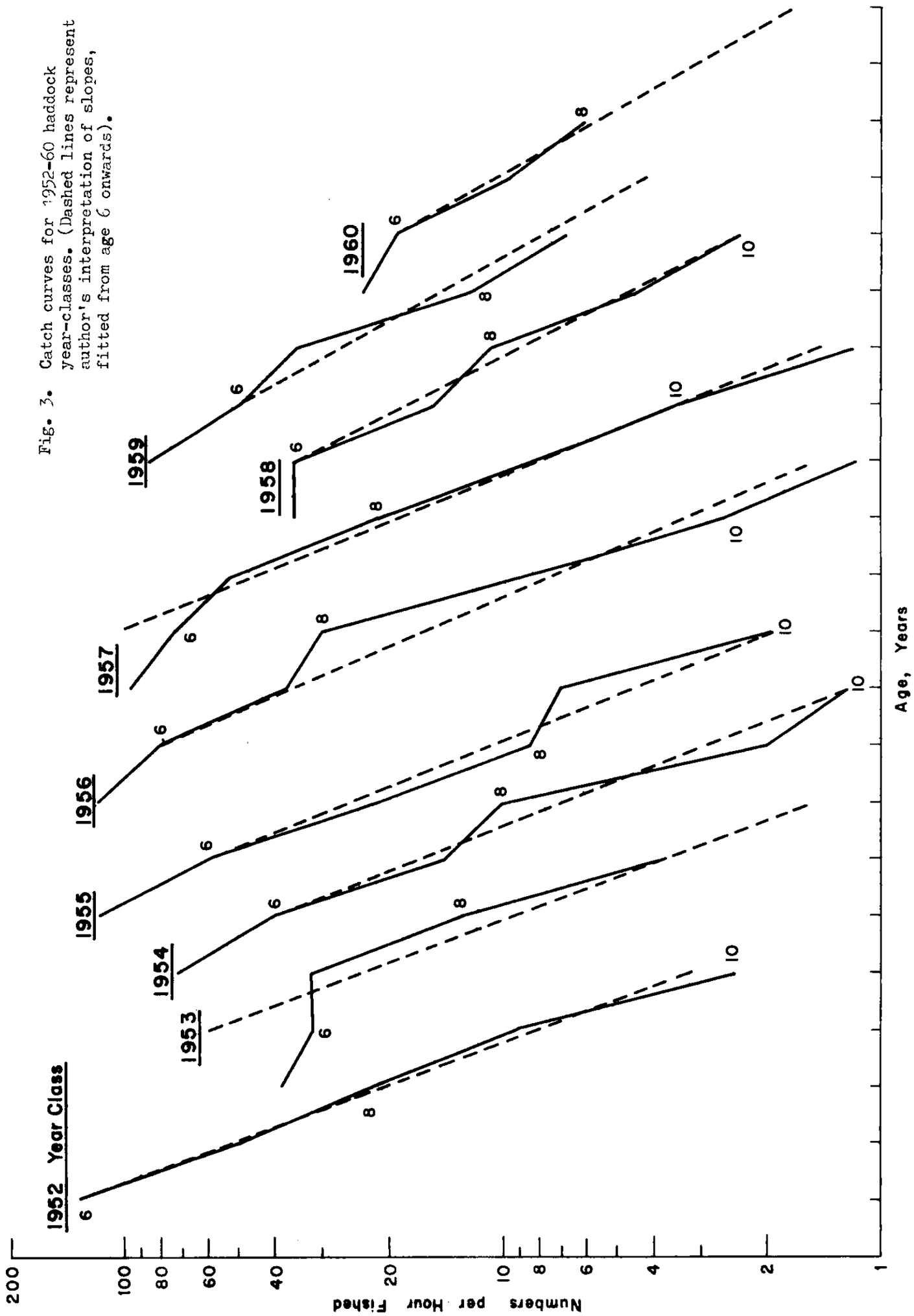

Fig. 3. Catch curves for 1952-60 haddock year-classes. (Dashed lines represent author's interpretation of slopes, fitted from age 6 onwards).

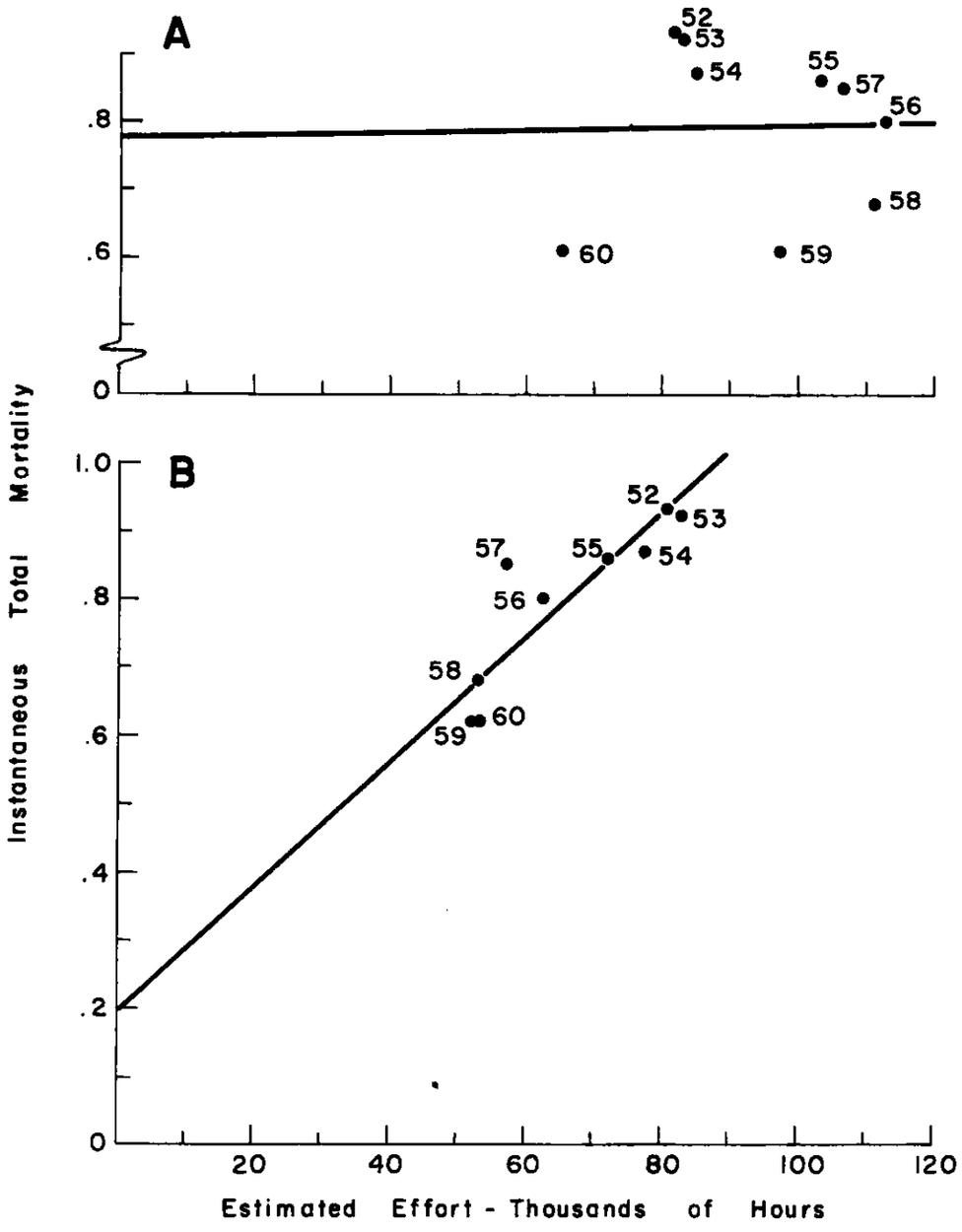

Fig. 4. Relationship of instantaneous total mortality (Z) to estimated effective effort on the 1952-60 haddock year-classes. A - assuming age composition of Soviet and Canadian catches identical, B - assuming Soviet catches contained no haddock age 6 and over.

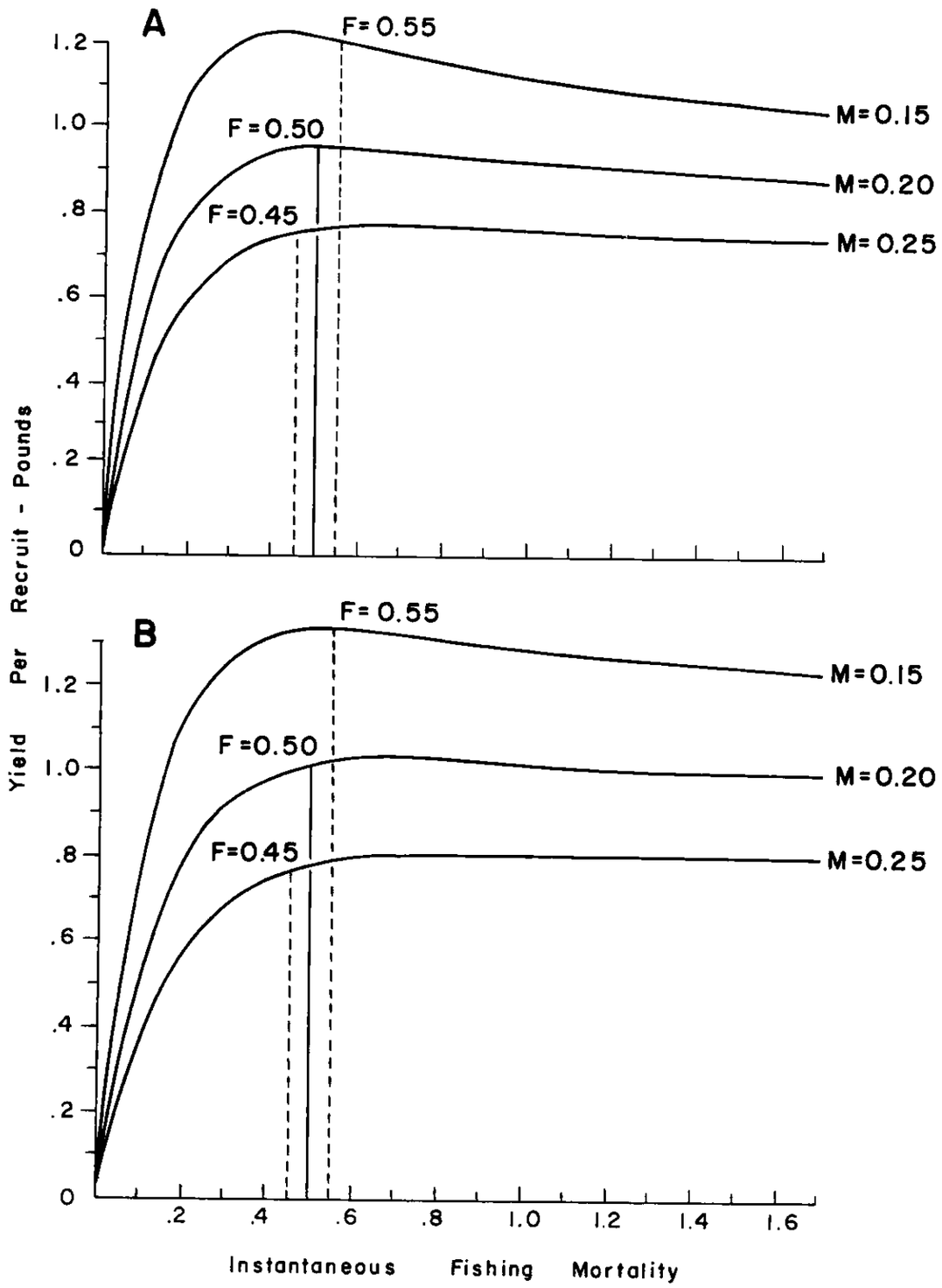

Fig. 5. Relationship of yield per recruit of haddock to instantaneous fishing mortality (F) at different levels of natural mortality (M), A - when age at entry to the exploited phase (t_ρ') is 3.7 years, B - when t_ρ' is 4.6 years.

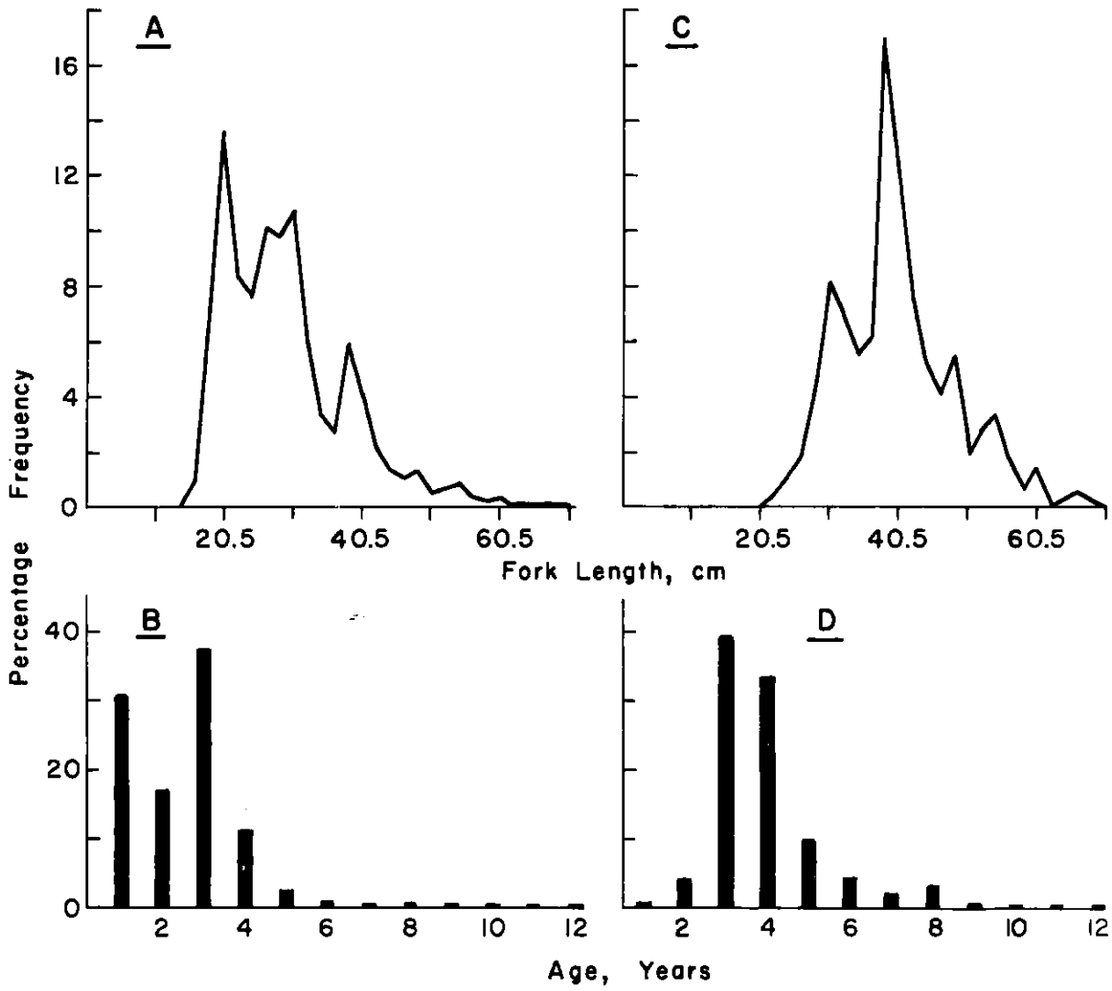

Fig. 6. Length (A) and estimated age composition (B) of Canadian research vessel haddock catches in 4W in July-August 1965, and estimated length (C) and age composition (D) of the catches of a vessel fishing this population with a 4 1/2-inch codend mesh.