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Gadoid Fish Committee
No. 3

Arctic Fisheries Working Group

Report of meeting in Hamburg, January 18th - 23rd 1965

1. Participants:

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D.J. Garrod	(England)
A. Meyer	(Germany)
A. Schumacher	(Germany)
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J.A. Gulland	(Secretary of Liaison Committee)

2. Introduction

The present group was set up by the Liaison Committee of ICES following a request by the North-East Atlantic Fisheries Commission to renew the activity of the Arctic Fisheries Working Group, which, on the basis of the scientific data then available and to be obtained, should submit a report through the Liaison Committee as soon as possible. Previous reports of the Arctic Fisheries Working Group have been made to the Permanent Commission through the Liaison Committee in 1960 and 1961 (documents PC 8/117 and PC 9/135). Other interim reports were made to ICES, in particular following the second meeting of the Working Group in Copenhagen in 1959.

A short meeting was held in Copenhagen during the 1964 ICES meeting, under the chairmanship of Mr. R.J.H. Beverton, during which agreement was reached on the preparation of statistical and biological data for the present meeting.

A preliminary analysis of the data, including work carried out by Mr. Hylen before the meeting, showed that there were considerable difficulties in the interpretation of the data. These difficulties included uncertainties regarding the quantities discarded, and about the effective selectivity of the present gear as used commercially, and especially the extent to which the decrease in the numbers of older fish in the trawl catches could be taken as a proper measure of the real mortality rate.

Though the Group reached some conclusions regarding these questions, they felt that much further considerations and analysis is neccessary. The present report is therefore essentially an interim report, pending such further research work. However, the Group has reached certain definite conclusions regarding the state of the stocks, (at least of cod and haddock) and the effect of fishing on these stocks, and has made some general assessments of the effects of changes in the selectivity of the gear at present used, and in the total amount of fishing on the stock.

3. C o d

3.1 Recent trends in the fishery:

The total landings of cod from the area are given in Table I (including the landings from each region) and shown in Figure I. Since 1946 the total landings have not changed much; there is a two-fold difference between the best year (1956 : 1343 thousand tons) and the worst (1960 : 638 thousand tons). Omitting the two outstanding years of 1955 and 1956 the fluctuations have been less than 20 % each side of the average landings of 780 thousand tons. There is no apparent trend in the total landings since 1946 - apart from 1955 and 1956 the two greatest landings were in 1947 and 1962.

The proportion of the total landings in the different regions has changed very greatly; as shown in Figure 2 the percentage of the total catch taken in Region IIa (Norwegian Coast), where the fisheries are predominantly on mature, spawning or pre-spawning fish has declined from over 40 % to only 15 %. The great majority of the total catch is now taken in the trawl fisheries in Region I (Barents Sea) and Region IIb (Bear-Island - Spitsbergen), which are predominantly on immature fish.

3.2 Effort

In contrast to the stability of total landings since 1946, the total fishing effort has increased greatly in the same period. In each region the effort by all countries combined, expressed in English units (i.e. the amount of fishing that English trawlers would have had to do to take the total catch in the region) has been calculated. These estimates of effort in each region have been added together to give the total effort, and this has been plotted in Figure 3. This shows that the effort has increased more than seven-fold since 1946.

3.3 Catch per unit effort

Data on the catches per unit effort are available for several fleets in the different regions - English and U.S.S.R. trawlers in Region I and IIb, and English trawlers and Norwegian gill-nets in Region IIa. These are given in Table 2. All show very great declines since 1946. For easier comparison of these data, which are on different scales, each has been expressed as a percentage of its 1946-63 average, and these are plotted in Figure 4. In Region I the U.S.S.R. catch per unit effort in the 1960's was about one-third of that in 1946 while the English is about one-quarter. In Region IIb the recent English catch per unit effort was about one-eight of the 1946 catch, while the U.S.S.R. was about one-quarter. The English data are of catches per hour trawling divided by the average tonnage of the trawlers, and therefore contain some correction for the increases in power and effiency of trawlers which have occurred since 1946. The U.S.S.R. data are of the catch per one hour trawling, and would be expected to increase with increased size or efficiency of the trawlers. It is therefore believed that the English data give a better measure of the abundance of the stocks.

In Region IIa the English and Norwegian catch per unit effort show a decline in catch per unit effort between 1946 and 1963 to about one-eighth and one-fourth reseptively.

3.4 Size and age composition

Since 1946 there have been great changes in the composition of the catches, particularly by the trawlers. The proportion of old and large fish has decreased, and in the English fishery, there has been a tendency to include smaller fish in the landings. These changes can be shown in various ways. Figure 5 gives the catches per unit effort of fish 10 years old and older in the two feeding areas. This show the very high abundance immediately after the war, and the rapid decline of these old fish after 1946. Some variations will be due to changes in year-class strength; in particular the figure in 1947 would be expected to be high due to the presence of the rich 1937 year-class, but the 10-years old and older fish were even more abundant in 1946, when no particularly good year-class was included.

The average numbers in each age-group caught per unit effort during different periods are shown in Figure 6 for each of the 3 main regions. This shows the virtual disappearance of fish older than about 8 years from the landings in Region I and IIb after 1959 and the increasing proportion of groups younger than 5 years.

In Figure 7 the length composition of English landings in 1950, and 1963 are compared. This shows both the great scarcity of big fish in 1963, and the substantial number of small fish, less than 50 cm included in the 1963 landings, although very few such small fish were kept on board in 1950. The same tendency towards keeping smaller fish has occurred in the German and Norwegian trawlers. Figure 7b shows the length composition of the catches of U.S.S.R. survey vessels in 1950 and 1963. In 1963 these vessels were using a much larger mesh than in 1950, which accounts for the absence of very small fish in the 1963 catches. In both the U.S.S.R. and English data the large fish above 60 cm are very much scarcer in 1963 than in 1950.

To summarise, the major trends in the cod fisheries since 1946 have been

1. Little change in total catch
2. A great increase in the total effort
3. A reduction in the proportion of fish taken in Region IIa
4. A fall in the catch per unit effort in all regions
5. A very big decrease in the catches of old and large fish
6. An increase in the landings of small fish

3.5 Mortality

The fishing rate on the Arctic cod is different for different ages of fish. In particular the important fisheries on the Norwegian Coast (Region IIa) are based almost entirely on mature fish - 8 years old and older. In the trawl fisheries in the feeding areas (Region I and IIb) the large and small fish are not uniformly distributed, the larger fish tending to be in deeper water, and the trawlers concentrate on the sizes of fish which are most abundant. There is good evidence that this concentration has changed since 1946 from the larger immature and mature fish (7-9 years old) to the smaller immature fish (4-6 years old). It has therefore proved difficult to obtain reliable estimates of mortality by the usual method of comparing the catches (or catch per unit effort) of successive age-groups. Other methods give estimates of the average percentage of the total stock dying each year during the most recent period. These increase from about 50 % among the immature fish to 60-65 % among the mature fish.

The present estimated mortality rates, particularly for the younger immature fish are much greater than the corresponding estimates for the period just after the war, and this increase corresponds very closely to the increase in the total fishing effort in the trawl fisheries. Fishing therefore is now the major cause of mortality, and probably accounts for two-thirds of the deaths among the immature fish, and rather more among the mature fish. (A more detailed description of the methods will be given later).

3.6 Year-classes

The varying strength of year-classes is a major cause of the variation of catches from year to year. Among recent year-classes those of 1948 and 1950 were outstanding and produced the very high catches in 1955 and 1956. Several measures of year-class strength are available, and are in good agreement concerning the relative strength of year-classes occurring during any one period. It has, however, not yet been possible to obtain a long series of estimates of year-class strength which are free from any possible bias; (for instance the catch per unit effort of four or five years old fish in the trawl catches may provide overestimates in recent years as the trawlers concentrate more on these ages of fish). In particular it has not been possible to compare very precisely the average strength of year-classes between 1938 and 1947, and since 1951. Thus it has not been possible to determine to what extent the failure of the catches since 1956 to increase above the 1946-54 average, despite the great increase in effort, was due to a lower average strength of year-class. However, the preliminary analysis of the data does not suggest that the most recent year-classes are, on average, substantially less strong than those between 1938 and 1947, and they may in fact be stronger.

Little is known about the causes of variation in year-class strength, though environmental factors during the first few months of life are believed to be critical. However, the strength of the spawning stock must have some influence, at least below some critical level, but the data examined by the Group were not sufficient to determine the relation between spawning stock and the average strength of the year-class produced.

3.7 The effect of changes in selectivity

During the meeting the Group became aware of certain deficiencies and uncertainties in the data available, and therefore found it difficult to express the expected results of any change in the selectivity in quantitative terms. They reached some definite conclusions, however, regarding the qualitative effect; that is, whether or not an increase in the selectivity (larger mesh size) would lead to a larger long-term catch.

The major uncertainties are

1. The proportion of small fish that are caught and rejected at sea.
2. The size composition of the catches of the U.S.S.R. commercial vessels.
3. The real selectivity of the gear in use, due to the effect of chafing-gear.

In their previous assessments, based on data up to 1960, the Group had made some reasonable assumptions concerning these uncertainties. Since 1960 there have been changes in the fishery, including an appearent increase in the use of chafers, and a greater market demand for small fish, and the Group felt that it could not make assumptions with the same confidence as previously.

3.8 Rejection

There is little direct information on the quantities of small fish rejected by the trawlers. The proportion would be expected to vary with the abundance of the youngest fish (e.i. due to year-class fluctuations) marked demand for small fish, and the selectivity of the gear in use. With the recent increase in the demand for small fish, and the increased legal mesh size it is probable the rejection is less than it was in the 1950's. One observation on the Norwegian trawler at Bear Island in November 1964 showed a rejection rate of four percent by numbers and about 2 % by weight, though the rejection by other trawlers, or by Norwegian trawlers at other times or places may be quite different from this. If the selectivity was increased to enable all the fish which would be rejected to be released, this would certainly give a long-term gain, of a magnitude rather less than the percentage rejected in terms of numbers. Thus, if the data above gave the real rejection rate for all trawlers, than the release of the rejected fish would give a long-term gain round about 3 %. It is, however, possible that the rejection rate is greater, in which case the gain in rate would be considerable. (For comparison the rejection rate used in the earlier assessments made by the Working Group in their 1961 report were, for English trawlers, 15 % by weight, and 30 % by numbers).

3.9 Size composition of U.S.S.R. catches

Up to 1963 the data presented by U.S.S.R. referred to catches by their scouting vessels. In the earlier assessments the catches by the commercial fleet was estimated by applying to these data the selection ratios of the mesh size in use by the commercial fleet. For recent years the mesh size used by the scouting vessels and the commercial fleet were the same. However, the scouting vessel data included a much larger number of small fish than would be expected from the selection characteristics of the mesh size used (110 mm Kapron). This is believed to be due to the areas fished, and to blocking of meshes by especially small flat-fish, and it was not known to what extent the same factors applied to the commercial fleet. Thus the number of small fish caught and hence the numbers expected to be released by any increase in mesh size, is unknown, and neither short-term losses nor long-term gain could be calculated. The Group took note of the fact that sampling on board U.S.S.R. commercial vessels started in 1964, and hoped that when the data from these observations are available proper quantitative assessments will be made.

3.10 Present selectivity

The Group noted from their personal knowledge of the fisheries, and from the replies to the Commission's request for information, that chafers are commonly used by many of the trawlers. The effective mesh size is therefore certainly not the Commission's legal size of 120 mm (110 mm nylon), but the Group could not determine precisely what the present effective selectivity is. Because of this and other uncertainties concerning the effective mesh size achieved by any given legal mesh size (see the Liaison Committee's report of the 1964 ICES meeting), the assessments in this report are given primarily in terms of the size of fish released, and these sizes are then compared with the 50 % point of meshes of different materials, with or without chafers.

3.11 Theoretical considerations

The direction (gain or loss) of the effect of releasing fish of a given size can be determined by comparing the weight when released with the average weight of fish in the catches above the size at release (i.e. the potential growth in weight). For the Arctic cod this potential growth is very large, so that there will be a benefit even if the proportion of the released fish which will be recaptured (=E) is quite small. Using the data on the sizes of fish caught in 1963, the following are estimates, for various values of E, of the corresponding sizes of fish which if released would be expected to provide long-term gain:

E = 0.3	gain in releasing fish up to 42 cm
E = 0.4	" " " " " " 50 cm
E = 0.5	" " " " " " 70 cm
E = 0.6	" " " " " " 85 cm

The estimate of E varies with the size of fish, increasing with the age of fish, but even for the young fish the best estimate is 0.6 or higher. Thus a long term gain may be expected from releasing fish very much larger than those in the selection range of the present mesh (30 - 50 cm). This method, however, can not give any measure of the quantitative effect of the change in selectivity.

An alternative method was based on calculations of growth, mortality etc. This method gives quantitative measures, but is only correct if the mortality rates do not change with age. Probably the fishing mortality is rather less on the smallest fish, and this will tend to make the method provide over-estimates of the magnitude of the effect of selectivity, although it should not change the direction (gain or loss). These calculations were made for a range of values of the present effective size of first capture, natural mortality, and fishing mortality.

Two values of the present effective selection size were used - 34 cm, and 44 cm -, and for any likely set of values of fishing and natural mortality an increase in selection size above these sizes up to at least 60 cm will give long-term gains. The range of probable values of these gains are given in the table below.

New effective selection length (cm)	Percentage increase in total catch, selection length changing from		Mesh size with corresponding 50% selection length			
			No chafer		Chafer*	
	34 cm	44 cm	Manila	Nylon	Manila	Nylon
60	40-90	15-35	162	147	194	171
55	30-70	12-25	149	134	177	157
49	25-55	7-12	133	120	158	140
44	15-40	-	119	107	142	126
39	8-20	-	105	95	126	111
34	-	-	92	83	110	97
Selection factor used			3.7	4.1	3.1	3.5

* A reduction of about 20 % in selectivity due to the use of a chafer was assumed.

3.12 Changes in total effort

As shown in earlier sections, a striking feature of the fisheries since 1946 has been the fact that the average annual landings have changed little despite an increase in the amount of fishing of more than three-fold from the 1946-48 average. Because of year-class fluctuations the relation between average landings and the effort would be established more clearly if a correction could be made for the strength of the year-classes, and the landings expressed as landings from a year-class of average strength. Though the neccessary quantitative measure of year-class strength was not available to the Group, it seems probable that (omitting the very good 1948-50 year-classes) the average strength has not greatly decreased, and may have increased. Therefore the landings from a year-class of average strength has not greatly increased and may have decreased.

This conclusion based simply on the statistics of landings and fishing effort, that the increased effort gave no increase in landings, is confirmed by theoretical calculations. In the time available it has not been possible to make these in as much detail as is desirable, and in particular no allowance has been made for the variations of fishing mortality with age of fish. Taking the mortality rates as being constant with age, and using reasonable values of these, the growth rate, and the effective selectivity, the relation between yield per recruit and fishing effort was calculated. This is shown in Figure 8; in this figure the present level of total effort is indicated. The figure also shows, as a dotted line, the changes of catch per unit effort with effort. This shows that halving the effort would result in a long-term increase in catch around a maximum about 10 % higher than that applying at present. At this level of effort the catch per unit effort will be twice the present catch per unit effort.

These calculations were repeated for other combinations of mortality rates and effective selectivity, and within the likely range the conclusions were qualitative the same - that any moderate reduction of effort would give an increase in the total catch, and a substantial increase in the catch per unit effort.

These conclusions are strictly true only if the reduction in fishing effort gave a proportional reduction in the fishing mortality on all ages of fish. This will not in general be true; thus the increase in total effort since 1946/48 of more than 3-fold was mainly by the trawlers fishing in the feeding areas on small or medium fish. Whereas the fishing mortality among the adults has no more than doubled that on the younger fish has probably increased by 4 or 5 times, to reach a level not much less than that on the adults. If the decrease in total effort mainly reduces the mortality on the younger fish, then the increase in total catch will be greater than expected from a uniform decrease in mortality; this is because such a change will tend to have the same beneficial effect as an increase in selectivity.

The Group considered briefly the possible effect of large changes in fishing mortality on different age. Because of the very large potential growth in weight of cod - over 10 times between 3 years old and 10 years old - it is probable that the greatest catch would be taken by catching only the larger fish. If the present average fishing mortality, of about 30 - 40 % per year, was applied only to fish greater than about 70 cm, then the catch would almost certainly be at least 20 % greater than at present, and might, particularly if the present effective selectivity is low, be more than twice the present yield. Such a mortality could be achieved, with a total effort, in terms of days fishing with a standard vessel, considerably less than the present effort effort.

4. H a d d o c k

The total haddock landings from the area are shown in Table 3 and Figure 9. There are marked fluctuations which can be ascribed to outstanding year-classes; the 1950 year-class gave good catches in 1955 and 1956, and the 1956 and 1957 year-classes good catches in 1961 and 1962. Apart from these fluctuations there appears to have been some increase in the average annual catches, from about 110 thousand tons in 1946 to 160 thousand tons in 1963, i.e. by about 40 - 50 %.

The increase in total effort has been much greater than this. In the most important region for haddock (Region I) the effort is estimated to have increased nearly 10-fold since 1946, and is now some 5 times the 1946-48 average. The best estimates of catch per unit effort show corresponding large decreases - to about one-seventh of the 1946 level in Region I, and to probably less than one-tenth in Region IIa. The decrease is most marked among the older fish. The proportion of fish 10 years old and older in the U.S.S.R. catches in Region I has decreased from over one-third in 1948 to less than one percent in the 1960's - even the outstanding 1950 year-class made up only 0.6 % of the total catch when 10 years old. This decrease in older fish can be closely related to the amount of fishing. At the present level of fishing about 70 % of the haddock die each year, and rather more than three-quarters of these deaths are due to fishing.

4.1 Changes in selectivity

Similar difficulties were experienced in assessing the effects of fishing to those found for cod. Using similar methods it was found that there would be a benefit from releasing fish up to 50 cm of E = 0.5, up to 60 cm if E = 0.6, and up to 70 cm if E = 0.7. Theoretical calculations confirm these conclusions that there would be an increase in catch by releasing fish up to at least 55 cm. A length of 55 cm corresponds to the 50 % length of a manila cod-end without chafers of 160 mm.

4.2 Changes in effort

The history of the fishery suggests that further increase in effort would not give much increase in catch and that in fact an increased yield might be obtained by decreasing the effort. Theoretical calculations suggest that with the present selectivity the greatest catch would be taken with a fishing effort around half the present and with this effort the catch from a year-class of average strength would be about 10 % above the catch taken with the present effort.

5. Future work

The Working Group hope these interim results will be of value, but recognize that some further consideration and analysis are necessary in order to give more definite conclusions regarding the effects of changes in the selectivity of the gear at present used and in the total amount of effort on the stocks. Attention should specially be drawn to the following subjects:

1) Changes in mortality with effort and age
2) Changes in year-class strength
3) Changes in availability of the fish according to changes in environmental conditions in the feeding areas

For providing a more precise basis for a rational exploitation of the fisheries the Group wishes to recommend that the countries concerned should provide more data according to:

1) The rate of discards made by the trawlers including fish used for meal

2) Length measurements of the landings of commercial trawlers

3) The effective selectivity of the gear in use

On behalf of

Arctic Fisheries Working Group

Arvid Hylen.

(15th February 1965)

Table I. Arctic cod. Total landings for each region 1930 - 1963 in metric tons round fresh weight.

Year	Region I	Region II b	Region IIa	Total
1930	83 466	72 013	282 163	437 642
1931	96 884	64 266	172 010	333 160
1932	118 681	52 761	220 922	392 364
1933	133 118	53 270	172 448	358 836
1934	183 977	58 773	188 134	430 884
1935	223 253	116 778	151 801	491 832
1936	369 574	186 182	190 148	745 904
1937	431 514	167 960	285 847	885 321
1938	314 075	215 913	259 309	789 297
1939	-	137 133	352 282	-
1940	137 394	20	244 699	382 113
1941	102 714	-	207 498	310 212
1942	25 462	-	177 814	203 276
1943	32 506	-	136 118	168 624
1944	39 281	-	180 094	219 375
1945		50 000	151 958	-
1946	199 640	210 443	295 917	706 000
1947	340 758	164 879	376 380	882 017
1948	406 620	130 831	236 844	774 295
1949	484 942	127 103	188 077	800 122
1950	356 474	163 783	211 725	731 982
1951	407 989	140 493	278 698	827 180
1952	524 160	105 860	246 775	876 795
1953	442 839	103 616	149 091	695 546
1954	597 534	98 663	129 824	826 021
1955	830 694	153 437	163 710	1147 841
1956	787 070	323 834	232 164	1343 068
1957	399 595	256 504	136 458	792 557
1958	388 067	229 115	152 131	769 313
1959	322 798	242 762	179 047	744 607
1960	380 488	101 591	155 654	637 733
1961	407 699	222 451	148 886	779 036
1962	539 785	222 611	138 186	900 582
1963	540 057	116 494	116 788	773 339

Table 2. Arctic cod. Catch per unit effort in Regions I, IIa and IIb 1946 - 1963 in metric tons round fresh weight.

Year	Region I England	Region I USSR	Region IIa England	Region IIa Norway	Region IIb England	Region IIb USSR
1946	0.305	1.13	0.647	13.589	0.915	1.70
1947	0.335	1.02	0.381	13.027	0.437	0.87
1948	0.261	0.98	0.290	7.914	0.339	1.11
1949	0.283	0.95	0.296	8.580	0.379	0.92
1950	0.147	0.84	0.140	6.181	0.261	1.29
1951	0.130	0.82	0.143	6.805	0.191	1.25
1952	0.127	1.05	0.116	5.872	0.195	0.98
1953	0.112	0.95	0.117	5.166	0.184	1.19
1954	0.141	1.19	0.099	2.700	0.182	1.56
1955	0.151	1.42	0.104	4.623	0.236	1.64
1956	0.125	1.04	0.139	4.797	0.241	1.71
1957	0.087	0.51	0.112	2.801	0.136	0.84
1958	0.083	0.46	0.087	3.833	0.121	0.69
1959	0.091	0.44	0.084	5.531	0.121	0.55
1960	0.075	0.42	0.067	3.013	0.105	0.31
1961	0.079	0.38	0.058	3.701	0.129	0.44
1962	0.092	0.59	0.066	4.044	0.133	0.74
1963	0.085	0.60	0.066	3.113	0.098	0.55

Notes: (1) English fisgures are $\frac{\text{tons(fish landed)}}{\text{100 hours fishing x average tonnage (ships)}}$

(2) Norwegian figures are tons per vessel per week of the gill net fishery in Lofoten.

(3) USSR figures are tons per 1 hour trawling.

Table 3. Arctic haddock. Total landings for each region 1930 - 1963 in metric tons round fresh weight.

Year	Region I	Region II a	Region II b	Total
1930	91 042	2 834	8 479	102 355
1931	69 958	4 596	6 162	80 716
1932	40 912	4 910	8 432	54 254
1933	41 399	3 434	3 497	48 330
1934	44 658	10 062	4 596	59 316
1935	52 667	18 411	5 388	76 466
1936	73 046	21 462	3 924	98 432
1937	102 583	27 973	7 391	137 947
1938	167 741	30 384	14 202	212 327
1939	106 139	17 050	5 748	128 937
1940	88 835	1 981	15	90 831
1941	68 115	2 577	-	70 692
1942	21 030	2 191	-	23 221
1943	47 798	1 747	-	49 545
1944	55 734	1 145	-	56 879
1945	21 171	1 023	-	22 194
1946	59 166	26 799	8 245	94 210
1947	94 329	36 258	5 603	136 190
1948	79 423	37 785	7 373	124 581
1949	115 574	24 953	9 626	150 153
1950	90 517	30 010	11 206	131 733
1951	86 735	27 758	5 564	120 057
1952	103 662	20 334	3 664	127 660
1953	105 416	15 605	2 426	123 447
1954	125 681	22 096	8 671	156 448
1955	157 098	34 693	10 954	202 745
1956	163 720	40 935	8 624	213 279
1957	86 986	24 658	11 061	122 705
1958	78 112	29 391	5 169	112 672
1959	58 734	26 415	3 030	88 179
1960	121 160	26 302	2 336	149 798
1961	159 728	25 642	7 864	193 234
1962	159 172	25 189	3 527	187 888
1963	123 356	21 471	1 091	145 918

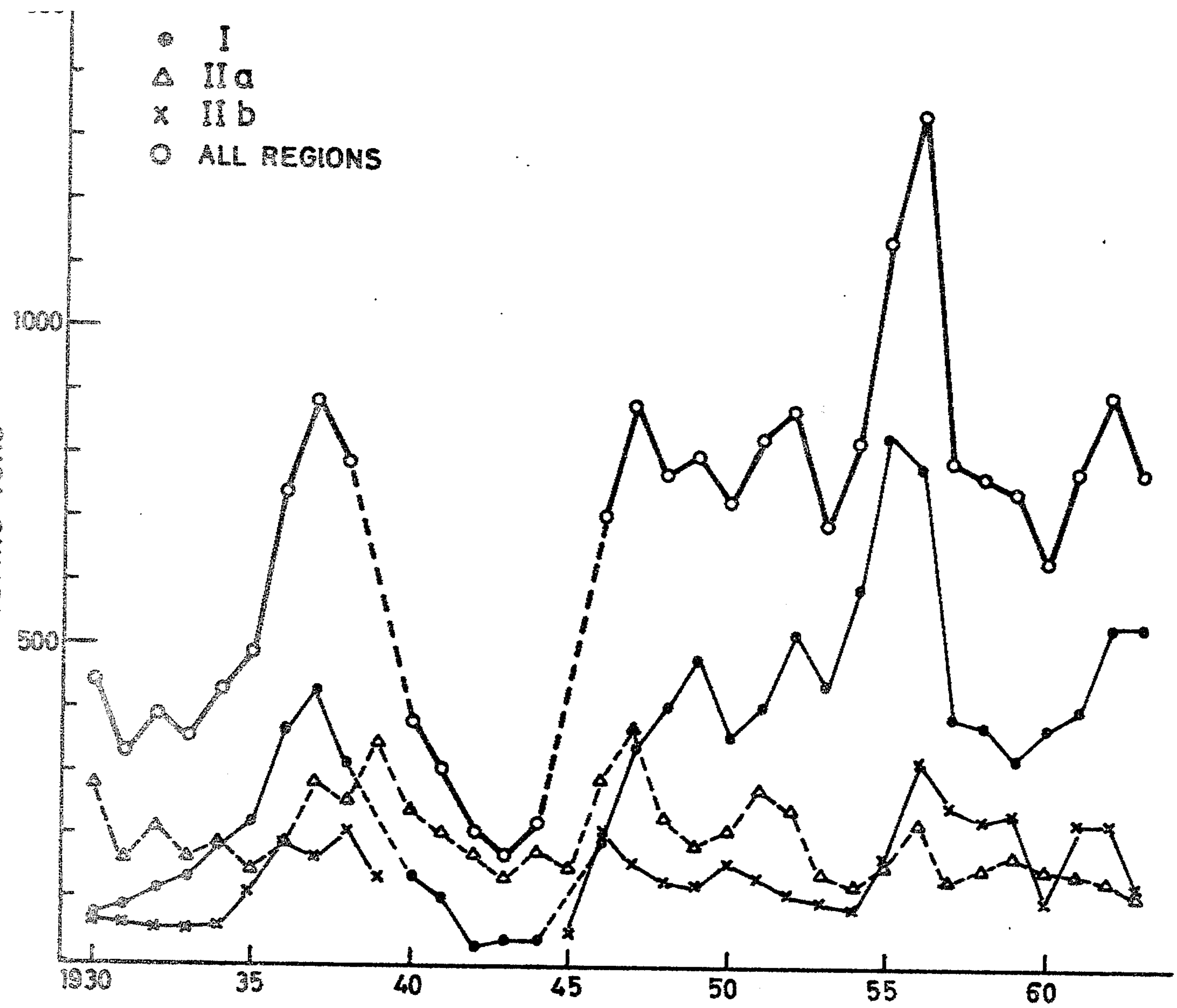

Figure 1. Arctic cod. Total landings from each region (see Table 1).

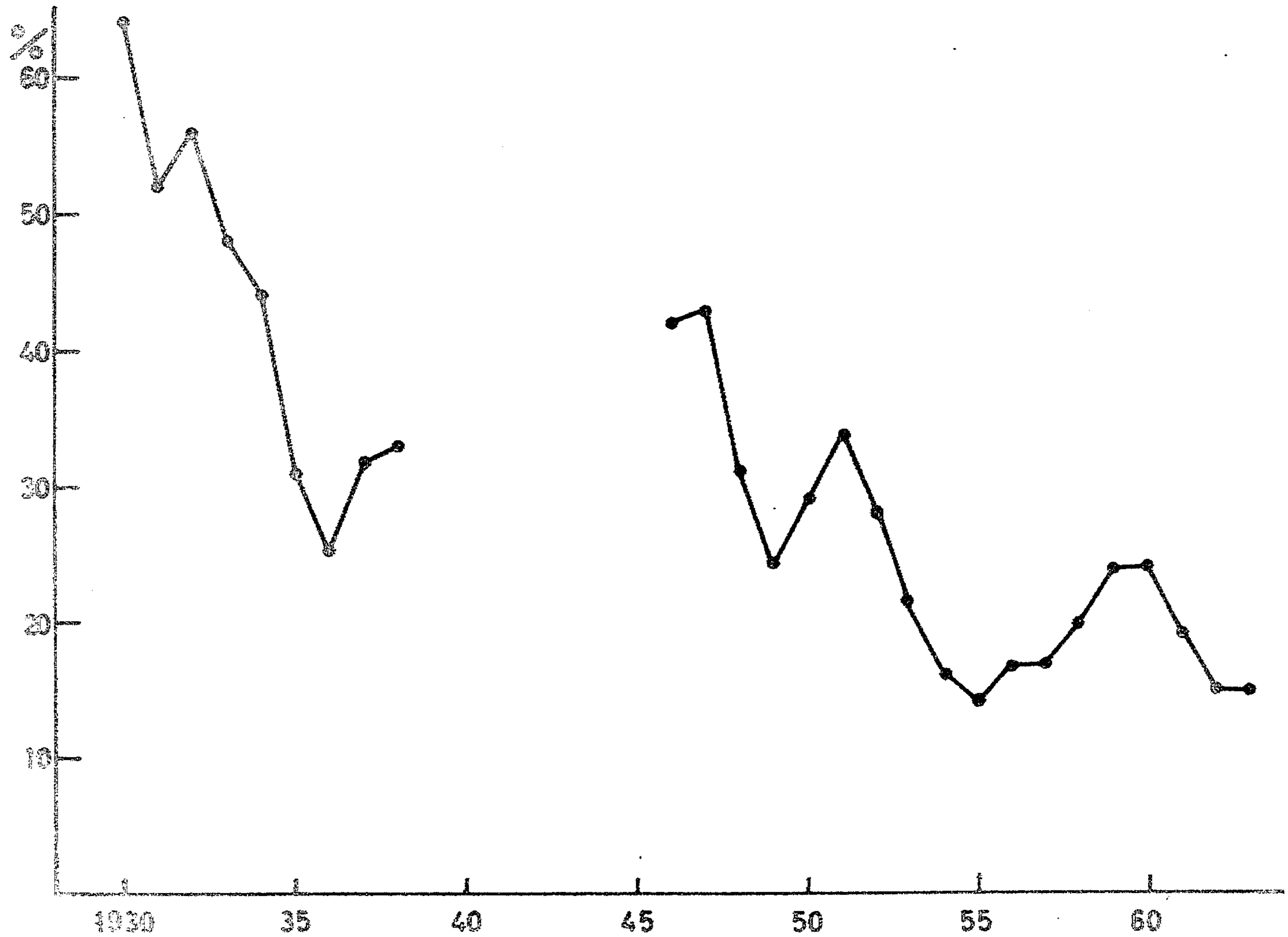

Figure 2. Arctic cod. Total landings in Region IIa as percentage of total landings from all regions.

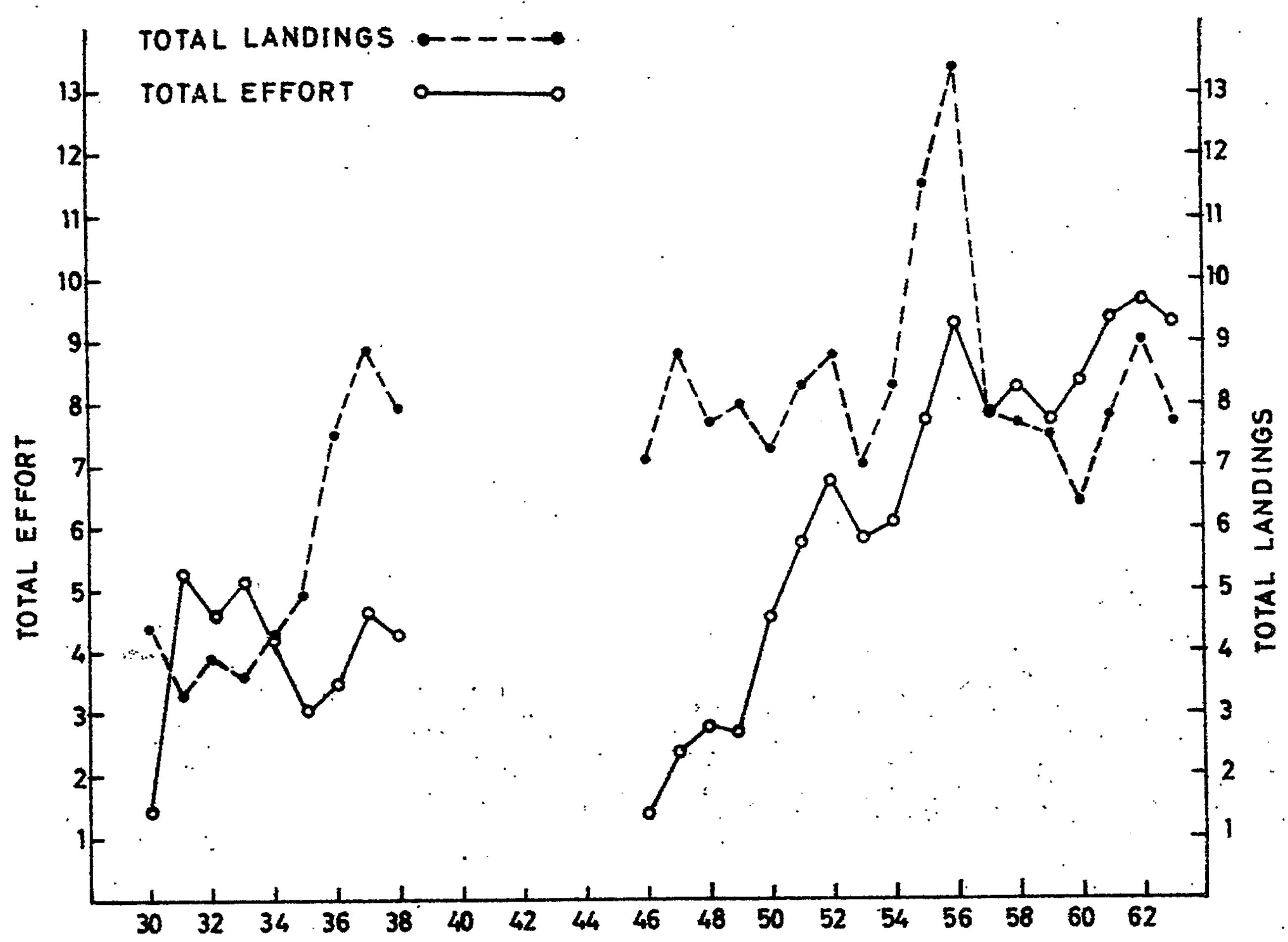

Figure 3. Arctic cod. Total landings in 100000 metric tons and total effort in English units (ton-hours 10^{-8}).

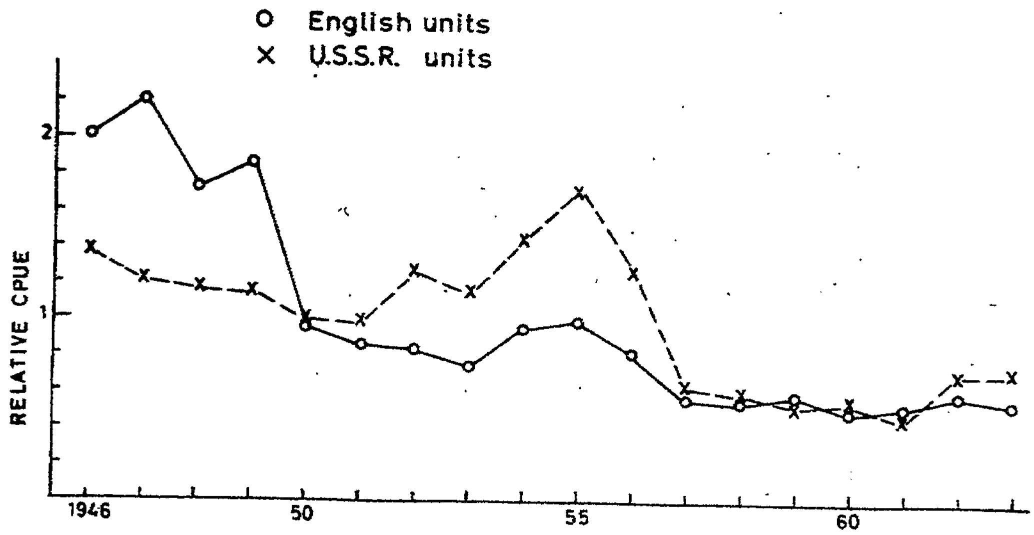

Figure 4a. Arctic cod. Region I. Catch per unit of effort, relative to the mean in a) English and b) USSR units.

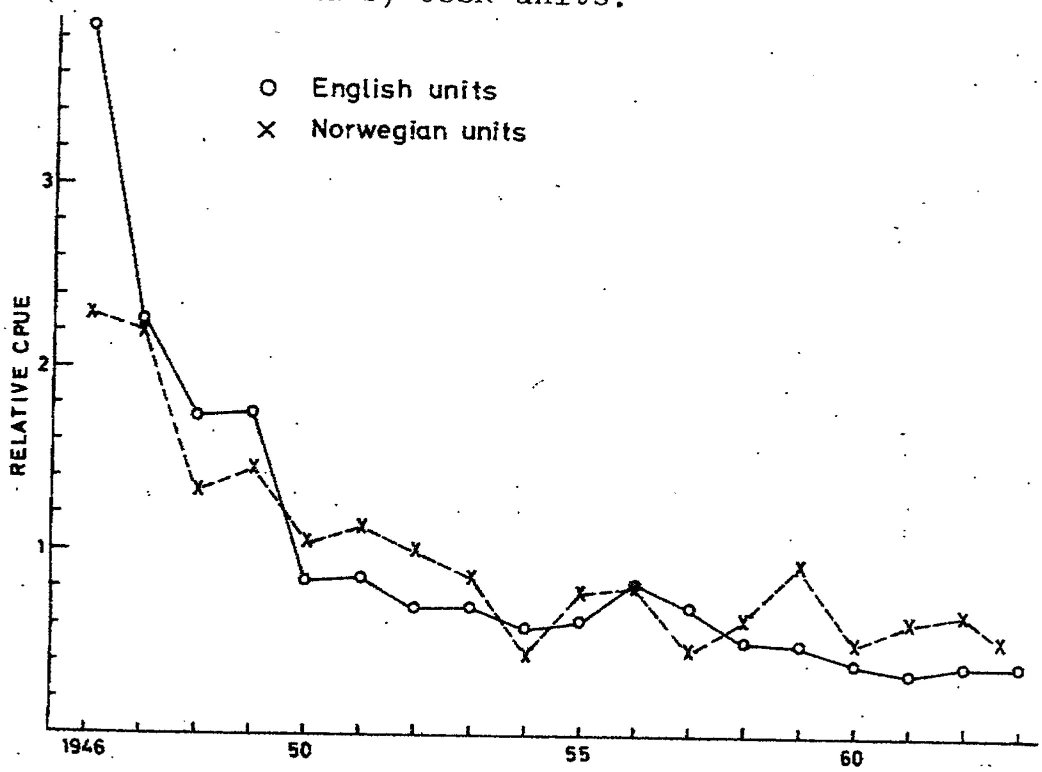

Figure 4b. Arctic cod. Region IIa. Catch per unit of effort, relative to the mean in a) English units and b) catch per vessel per week of the gill net fishery in Lofoten.

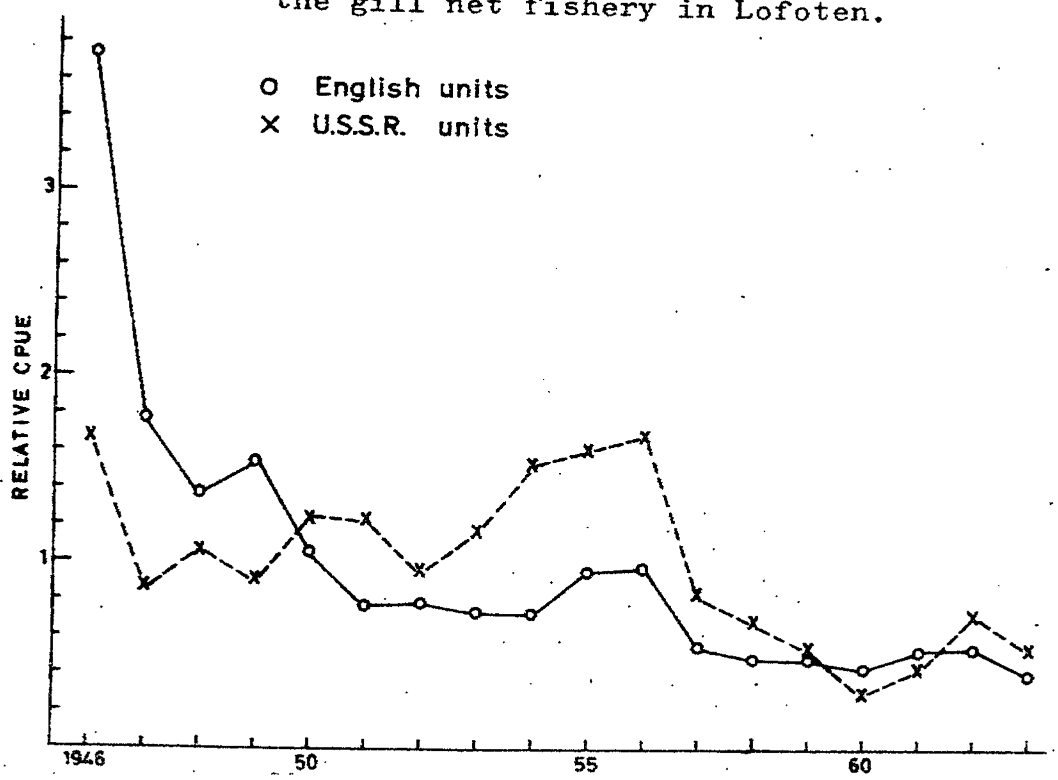

Figure 4c. Arctic cod. Region IIb. Catch per unit of effort, relative to the mean in a) English and b) USSR units.

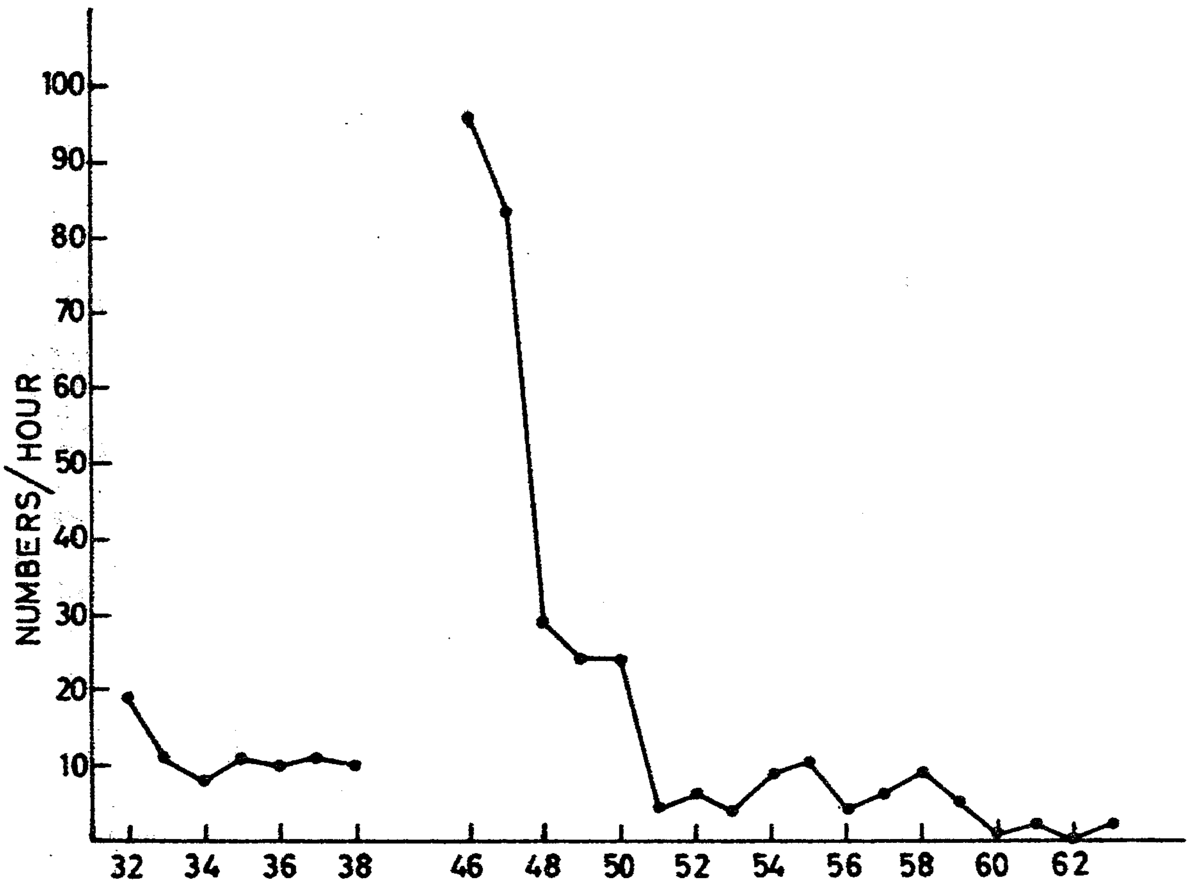

Figure 5a. Arctic cod. Region I. USSR landings of 10 years old and older per unit of effort.

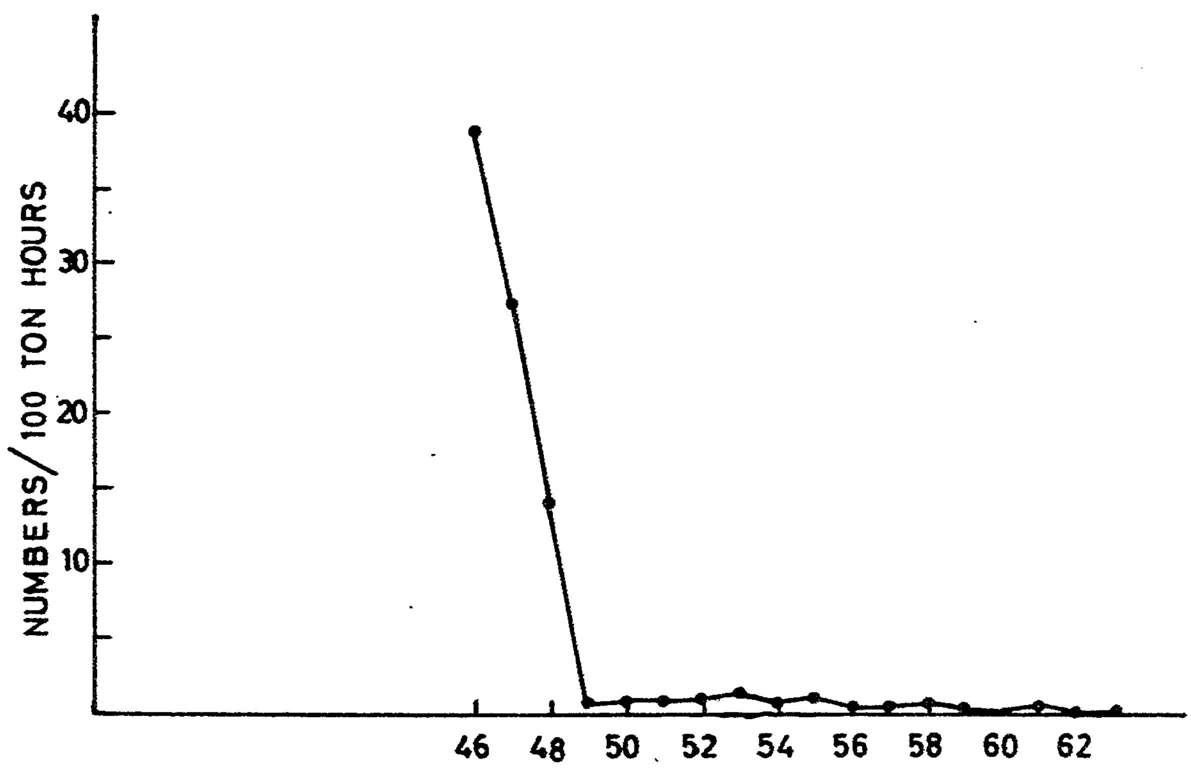

Figure 5b. Arctic cod. Region IIb. English landings of 10 years old and older per unit of effort.

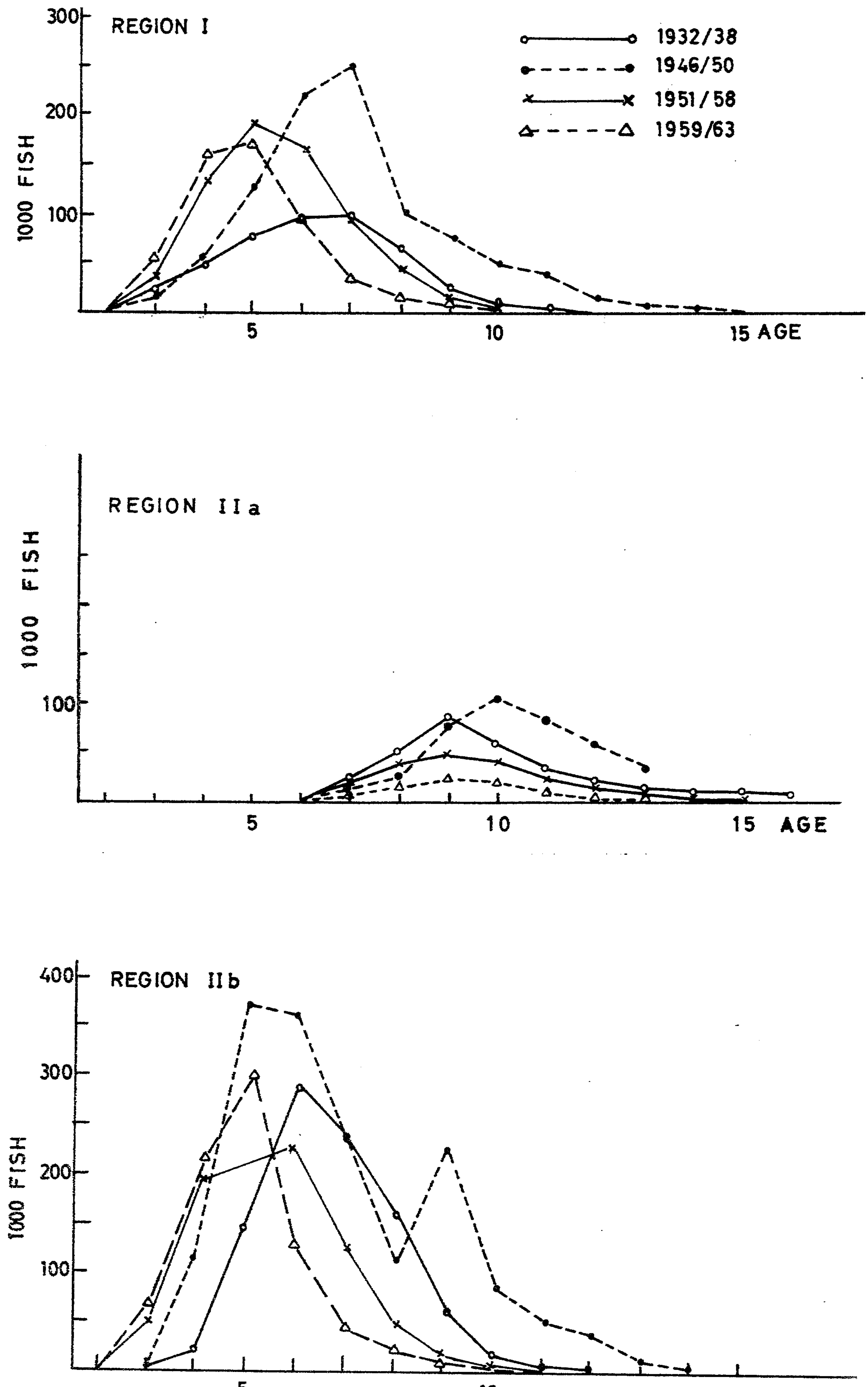

Figure 6. Arctic cod. Number of each age-group caught per unit effort, for each region in different periods. [illegible] units.

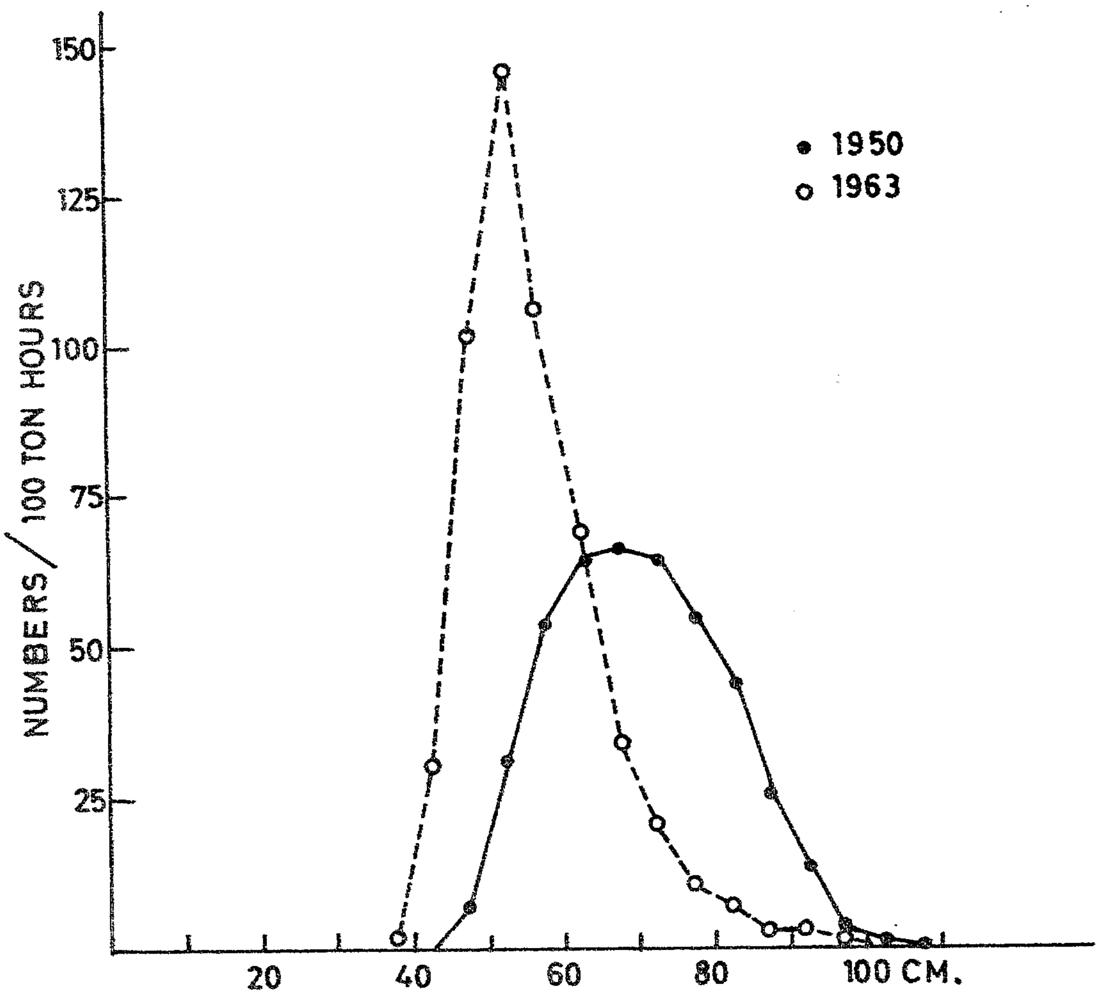

Figure 7a. Arctic cod. Region I. Length composition of English landings.

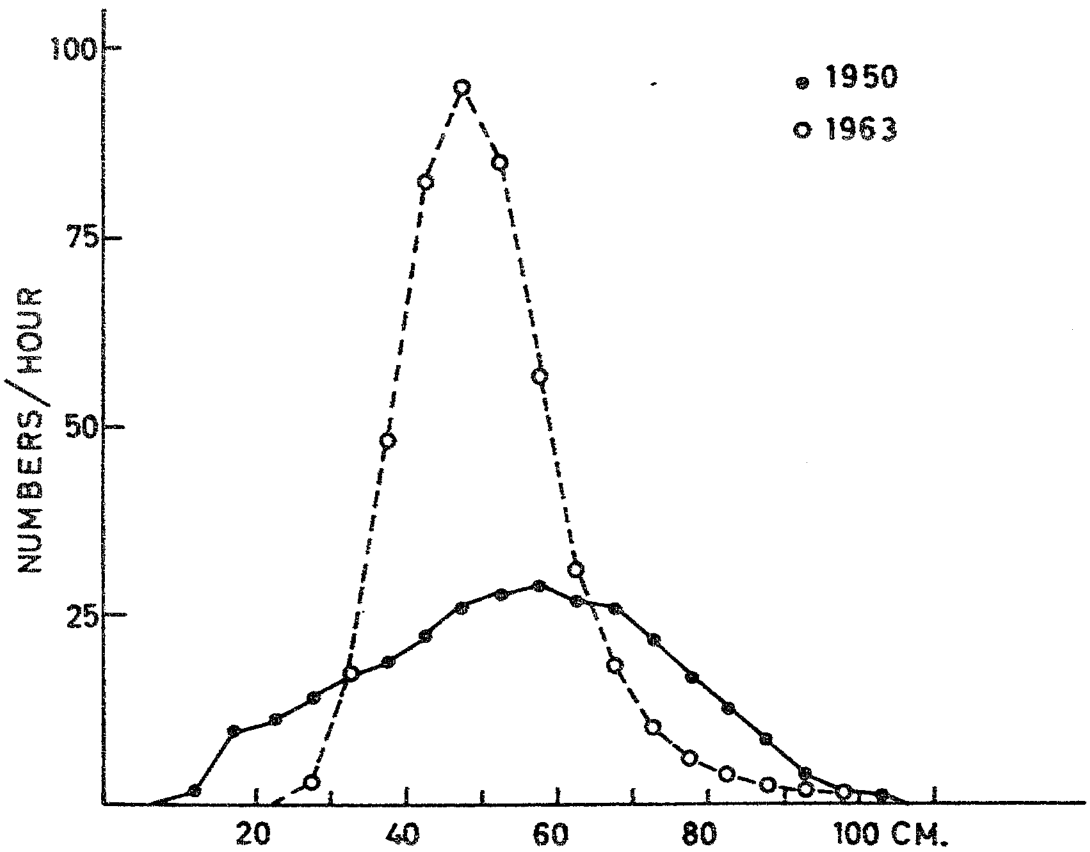

Figure 7b. Arctic cod. Region I. Estimated length composition of USSR landings, based on length composition from USSR survey vessels.

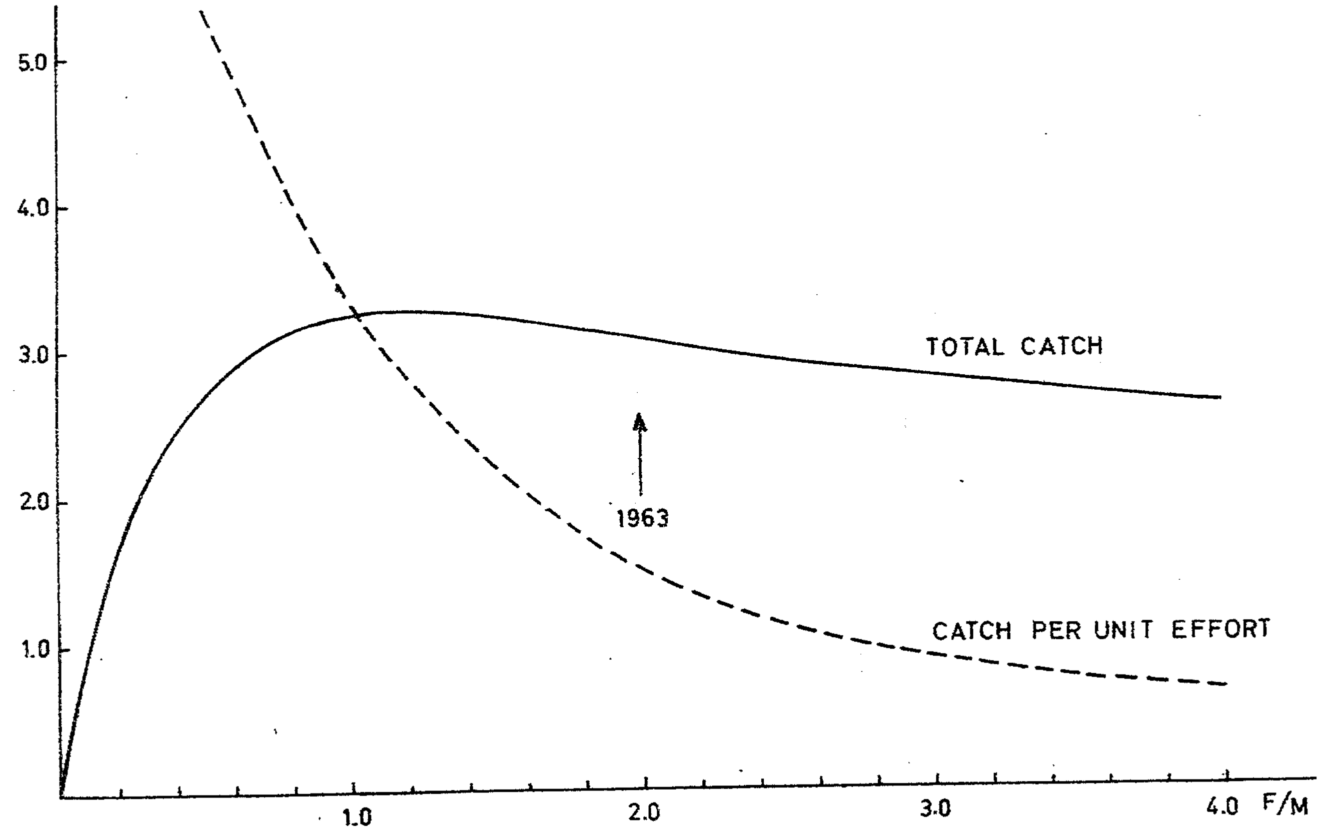

Figure 8. Arctic cod. Relation between theoretical yield per recruit and fishing effort. Parameters used: M/K = 1.75 c = 0.32 (l_c = 44 cm, mesh size 120 mm manila without chafer).

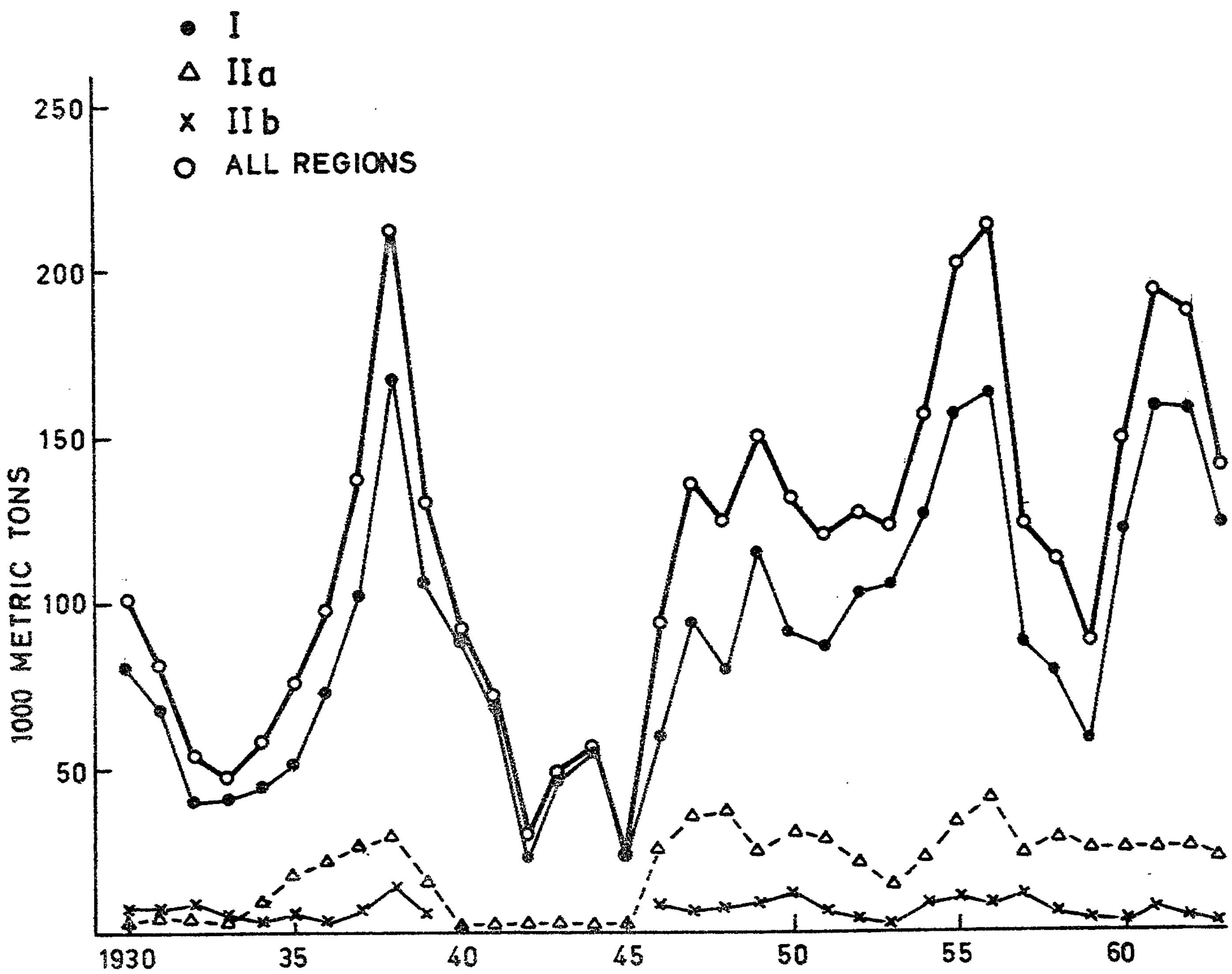

Figure 9. Arctic haddock. Total landings from each region (see Table 3).

ANNEX

Estimation of Mortality Rates

Introduction

In the previous analysis of the Arctic cod, as presented in the second progress report of the Working Group at ICES in 1959, mortality rates had been estimated in the usual manner as the ratio of the catches per unit effort of the same year-class (or year-classes) in successive years.

As shown in the Figures 15 and 16 in the report, this method gave some extremely variable estimates, though an attempt was made to reduce the variance by omitting certain years where the estimated mortality appeared to be too high. More seriously the method, at least in the simple form, depends on fishing mortality being constant with age. This is clearly not true for the trawl fisheries; thus the 1959 report estimated the fishing mortality (for all gears combined) to be about the same, or even higher, for the immature fish as for the mature fish. As the majority of the mature fish are caught outside the feeding areas, mainly by gears other than trawl, the fishing mortality on mature fish caused by trawlers in the feeding area must be quite small, and certainly much smaller than the corresponding mortality on young fish. Such a change in fishing mortality with age will bias, possibly quite seriously, the estimates of mortality rate.

The present Working Group therefore considered that other methods of estimating mortality should be considered. The method of virtual populations (Fry, 1949; Ricker, 1958) was used. This appears to reduce fluctuations due to changes in availability, and the known catches in the mature fisheries provide useful upper estimates to the fishing mortality in the immature fisheries. Also, using methods analogous to those of Jones (1964) preliminary estimates of natural mortality, and of total mortality among the oldest fish, were used to obtain unbiased estimates of the true mortality among the younger fish.

Methods

The following notation will be used:-

${}_xC_n$ = catch in numbers, during year n, of the year-class born in year x;

${}_xV_n$ = virtual population in year n of the x year-class;

i.e. ${}_xV_n$ = the total number of fish of the x-year-class which will be caught in the year n or later;

${}_xN_n$ = total number of fish of the x-year-class alive at the beginning of year n;

then ${}_xV_n = {}_xE_n \cdot {}_xN_n$, where

${}_xE_n$ = "exploitation ratio", i.e. the proportion of the fish of the x-year-class alive at the beginning of year n which will, at some time, be caught.

(In the simple constant parameter case ${}_xE_n$ = constant = $E = F/_{F+M}$)

In these definitions suffices have been used to denote different years, and prefixes denote different year-classes. In the following symbols it is more convenient to use prefixes for different age-groups, though retaining suffices for years;

${}_tF_n$ = fishing mortality coefficient on fish of age t in year n;

f_n = fishing effort in year n;

${}_tq_n$ = catchability coefficient for fish of age t in year n;

M = natural mortality coefficient (assumed constant).

A first estimate of the survival during year n is given by the ratio of the virtual populations of a year-class at the beginning and end of the year, i.e.

$${}_xS_n = {}_xV_{n+1}/{}_xV_n$$

which if all the mortalities are constant reduces to

$${}_xS_n = E_xN_{n+1}/E_xN_n = e^{-(F+M)}$$

The virtual population also provides, in all situations, an upper limit to the rate of exploitation ("u" in Ricker's notation; $\frac{F}{F+M}(1-e^{-F+M})$),

as the rate of exploitation =

$${}_xC_n/{}_xN_n > {}_xC_n/{}_xV_n$$, and this upper limit may not infrequently be useful.

More precisely, the catch during any year can be expressed as a function of the fishing and natural mortality rates during the year, and of the population at the end of the year. Thus, in a manner similar to that of Jones (1964), if it is assumed that natural mortality is constant, and some value of fishing mortality among the very old fish is assumed, it is possible for each year-class to proceed year by year backwards from old to young fish estimating the fishing mortality in each year.

Assuming that year-class x is t years old in year n,

let $${}_xr_n = {}_xN_{n+1}/{}_xC_n$$

i.e. r is the population at the end of the year, expressed as a proportion of the catch during the year (thus r can be greater or less than unity)

then $${}_xr_n = \frac{{}_xN_{n+1}}{{}_xC_n} = \frac{{}_xN_n\, e^{-(F+M)}}{{}_xN_n \frac{F}{F+M}(1-e^{-(F+M)})}$$

where for convenience F has been written for ${}_tF_n$.

Thus ${}_xr_n$ is a simple function of ${}_tF_n$ and M, and if given M, the function

$$\frac{(F+M)\ e^{-(F+M)}}{F(1-e^{-F+M})}$$ is tabulated for a range of values of F, then once ${}_xr_n$ is

determined, ${}_tF_n$ can be at once read off from this table.

Now $${}_xr_n = {}_xN_{n+1}/{}_xC_n = \frac{{}_xV_{n+1}}{{}_xE_{n+1}\cdot {}_xC_n}$$

$$= \frac{1}{{}_xE_{n+1}}\left(\frac{{}_xV_{n+1}}{{}_xV_n - {}_xV_{n+1}}\right) = \frac{1}{{}_xE_{n+1}}\left(\frac{{}_xS_n}{1 - {}_xS_n}\right)$$

i.e. ${}_xr_n$ is a simple fraction of the apparent survival during year n (as estimated from virtual populations) and the exploitation ratio ${}_xE_{n+1}$, applicable to the fish of the x-year-class alive at the end of year n.

The exploitation ratio, ${}_xE_n$, applicable to the fish at the beginning of year n will be the sum of the proportions of fish alive at the beginning of the year caught during the year, and caught later, i.e.

$${}_xE_n = \frac{{}_tF_n}{{}_tF_n + M}\left(1 - e^{-({}_tF_n + M)}\right) + e^{-({}_tF_n + M)}\ {}_xE_{n+1}$$

Thus, if values of M and ${}_xE_{n+1}$ are assumed, estimates can be observed in succession of ${}_xr_n$, ${}_tF_n$, ${}_xE_n$, ${}_xr_{n-1}$, ${}_{t-1}F_{n-1}$ ..... etc. The actual steps in the calculation of mortality rates for the 1948 year-class are set out in Table 1 (values of M = 0.20, and E at the 15th birthday of 0.8 were taken).

Table 1. Calculation of true mortality rates for the 1948 year-class.

Age	S	Z'	$\frac{S}{1-S}$	E	r	F	Z	$\frac{F}{Z}(1-e^{-Z})$	Ee^{-Z}
14	.37	.99	.588	.8	.735	.79	.99	.501	.298
13	.39	.94	.640	.799	.801	.75	.95	.484	.309
12	.45	.80	.818	.793	1.03	.62	.82	.423	.349
11	.48	.74	.923	.772	1.20	.56	.76	.392	.361
10	.40	.92	.667	.753	.886	.70	.90	.462	.306
9	.49	.70	.961	.768	1.25	.54	.74	.382	.366
8	.42	.87	.724	.748	.968	.65	.85	.438	.319
7	.51	.67	1.04	.757	1.38	.50	.70	.360	.376
6	.68	.39	2.13	.736	2.89	.27	.47	.215	.460
5	.70	.36	2.33	.675	3.45	.23	.43	.187	.439
4	.78	.24	3.55	.626	5.67	.15	.35	.127	.441
3				.568					

The right-hand columns are determined quickly, using tabulations, for a range of F, of r, $\frac{F}{Z}(1-e^{-Z})$, and e^{-Z}. Included in the table are the values of Z', (= $-\log_e$ S), the first estimate of the total mortality coefficient. In fact, for much of the table Z' is close to the corrected value, Z, though fluctuating rather more widely, and being a distinct under-estimate of Z for the youngest fish.

Results

Table 2 shows Z', the mortality estimated as the ratio of virtual populations at the beginning and end of the year for fish between 4 and 14 years old for the years 1946-1962. (The figures are based on preliminary data on the total catches of each age-group, which have since been revised. It is believed that there revision will not alter the estimates of mortality appreciably). Compared with the estimates obtained from catch per unit data these are much less variable; from the method used no negative values can occur, and for fish less than 10 years old the greatest value is only 1.13. Examination of the table suggests, as does the catch per unit effort data, that the fish are not fully recruited until they are six years old; from eight years old there is some recruitment to the mature fisheries, so that an increasing part of the total fishing mortality occurs outside the feeding areas. Accordingly a first estimate of the division between fishing and natural mortality was obtained by relating the apparent mortality Z' among 6 and 7 years old fish to the total effort in the feeding area (Regions I and IIb). There is no direct estimate of the combined effort in the two regions. The estimate used was the sum of the total international effort in each area, expressed in English units (millions of ton-hours). Alternatively, because the catch per ton-hour is higher in Region IIb than in Region I, by an average factor of 1.5, a better estimate might be

Effort = (Effort in I) + (Effort in IIb) x 1.5.

However, as the trends in effort in the two regions have been similar it is probable that the results would be the same.

Figure 1 shows the plot of apparent mortality of 6 (below) and 7 (above) year old fish against effort; the correlation is very good. As the method tends to under-estimate the mortality when this is low, the total mortality at low levels of effort, and hence the intercept on the y-axis (the estimate of natural mortality) will tend to be low. In Figure 1 the intercepts on the y-axis are 0.05 (for 6 year olds) and 0.20 (for 7 year olds): as these are under-estimates a first estimate of 0.2 for natural mortality was used to calculate by the methods outlined above, better estimates of Z. These are given in Table 3.

Using these estimates, further plots of total mortality against effort are shown (Figure 2). For both ages the correlation is slightly improved: intercepts (i.e. the estimate of M) are 0.21 and 0.40 for 6 and 7 year olds respectively. The confidence limits of the two estimates of M are 0.15-0.27 and 0.30-0.50, suggesting that there are some real differences in the mortality/effort relation for the two ages. Though the agreement between the estimates from the two ages is not too good, they suggest that M is between 0.2 and 0.4.

A nearly independent estimate can be obtained from the ratio of the catches per unit effort of certain year-classes in the Barents Sea and (four years later) on the Norway coast; the calculations of this ratio were made in the 1959 report(Table 18 and Figures 18a and b). The value of this ratio depends on the effort units used in the two areas as well as on the mortality between the times when the catches per unit effort are measured (4-7 years old in Region I, and 8-11 years old in Region IIa). However, if the effort units remain the same then changes in the ratio will be related directly to changes in the mortality. Figure 18b suggests that at the present high levels of effort the logarithm of the ratio is about 2.0 greater than when fishing was zero, i.e.

$$4\,\overline{F} = 2.0 \qquad \overline{F} = 0.5$$

where $\overline{F}$ is the average fishing mortality between 4 and 11 years old. The average total mortality over the main ages (4-10) and years concerned (1953-57) was 0.71; subtracting an F of 0.5 gives an estimate of natural mortality of 0.21.

Comparison with previous results

The total mortality rates obtained here are, for the immature fish (under say 10 years old) considerably smaller than those given in the previous report. This is due to the real decrease with age in the fishing mortality in the trawl fisheries. The decrease can be estimated by dividing the total fishing mortality on each age into that occurring in the spawning area (Region IIa) and in the feeding areas (Regions I and IIb) in the ratio of the catches in the two areas. That is F^1, the fishing mortality in the trawl fisheries is given by

$$F^1 = F \times \frac{\text{Catch in I and IIb}}{\text{Total catch}}$$

The relevant calculations for the 1948 year-class between 4 and 11 years old is given in Table 4. F^1 increases between 4 and 7 years old, and then decreases. These estimates of F^1 cover the years from 1952 to 1959, during which the effort has changed, and the more important measure is the changes with age of q^1,

wh[illegible] $F^1 = q^1 \; f, \quad \text{or } q^1 = F^1/f$

The mortality estimated from catch per unit effort data may differ from the true mortality during the year for two reasons: the decrease in catchability, q, with age, and any change in true mortality rates. The magnitude of these effects can be determined from the equation

$$\log_e {}^{n_t}/_{n_{t+1}} = Z_t + \log_e \frac{Z_{t+1}(1-e^{-Z_t})}{Z_t\,(1-e^{-Z_{t+1}})} + \log {}^{{}_tq}/_{{}_{t+1}q}$$

where n_t, n_{t+1} are the catches per unit effort of a given year-class in successive years, and ${}_tq$, ${}_{t+1}q$ are the values of q for that year-class in the two years

or $$\log_e {}^{n_t}/_{n_{t+1}} = Z_t + A + B$$

where A = correction for changes in mortality

B = correction for changes in q.

Table 5 shows these corrections, the resulting expected value of the apparent total mortality based on catch per unit effort data, and also the observed apparent mortalities in Regions I and IIb. These last are each the average of the estimates based on English and on U.S.S.R. data. Though the agreement between expected and observed apparent mortalities is not complete, it is reasonably good.

<u>Table 2.</u> Total mortality coefficients "Z" as estimated from the ratio of ~~initial~~ virtual populations at the beginning and end of each year

Age	1946	1947	1948	1949	195o	1951	1952	1953	1954	1955	1956	1957	1958	1959	196o	1961	1962
14			.304	.575	.861	1.185	1.086	.708	1.184	.886	1.020	.815	.174	.409	.787	1.514	.992
13		.638	.525	.835	.866	.945	1.073	.824	.863	.836	1.140	1.135	.491	.476	.51o	.943	.762
12	.536	.769	.705	.743	1.134	.869	1.659	.824	.884	.818	1.194	.928	1.070	.823	.800	1.108	1.342
11	.504	1.006	.720	.802	1.142	.883	1.207	.892	.924	1.110	1.077	.968	.921	.742	.935	1.128	1.191
1o	.500	.643	.550	.625	.582	.710	.952	.671	.839	.954	.882	.735	.924	.940	.898	.979	.889
9	.425	.616	.615	.506	.578	.701	.750	.542	.518	.736	.885	.705	.565	.796	.565	.817	1.13o
8	.234	.239	.435	.424	.523	.564	.581	.467	.524	.727	.874	.839	.572	.597	.580	.793	.919
7	.221	.329	.651	.487	.500	.651	.724	.425	.487	.669	.798	.719	.691	.601	.591	.664	.790
6	.156	.195	.274	.462	.348	.452	.691	.450	.391	.716	.906	.666	.742	.602	.717	.638	.881
5	.067	.182	.107	.276	.124	.355	.499	.362	.370	.408	.621	.288	.472	.568	.533	.586	.666
4	.033	.072	.018	.101	.031	.219	.241	.210	.206	.138	.283	.149	.350	.294	.305	.359	.366
3	.013	.009	.005	.022	.002	.055	.034	.063	.034	.029	.053	.035	.109	.060	.065	.133	?

Table 3. Corrected estimates of total mortality coefficient, assuming M = 0.2

Age	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963
14									1.15	.91	1.02	.85	.32	.51	.81	1.45	.99	
13								.86	.89	.87	1.11	1.02	.55	.55	.61	.95	.79	
12							1.62	.84	.90	.85	1.14	.85	1.01	.83	.82	1.07	1.28	
11						.93	1.15	.90	.92	1.10	1.02	.95	.90	.76	.95	1.14	1.19	
10					.65	.76	.94	.72	.87	.94	.90	.74	.90	.94	.92	.99	.93	
9				.57	.65	.73	.77	.61	.58	.76	.88	.74	.63	.83	.64	.85	1.12	
8			.49	.66	.59	.61	.62	.53	.59	.75	.85	.83	.64	.64	.64	.86		
7		.41	.66	.54	.54	.66	.71	.50	.56	.70	.80	.72	.70	.63	.66			
6	.29	.33	.38	.51	.43	.50	.67	.50	.47	.73	.88	.68	.74	.64				
5	.24	.31	.26	.37	.28	.44	.52	.43	.46	.49	.63	.40	.53					
4			.23	.26		.34	.35	.33	.34	.29	.38	.29						

Table 4. Estimation of fishing mortality in feeding areas.

Age	Year	Total F	Numbers caught x 10^{-6}			Trawl F = F^1	Effort	$_tq$
			I + IIb	Total	% Trawl			
14	1962	.79	57	315	18.1	.143	758	.189
13	1961	.75	285	542	52.6	.394	691	.571
12	1960	.62	363	1,859	19.5	.121	609	.199
11	1959	.56	1,307	3,715	35.2	.197	556	.354
10	1958	.70	3,785	10,772	35.1	.246	657	.374
9	1957	.54	10,297	18,619	55.3	.299	649	.461
8	1956	.65	34,532	50,473	68.4	.445	764	.582
7	1955	.50	78,636	82,534	95.3	.476	616	.773
6	1954	.27	80,382	80,811	99.5	.269	479	.562
5	1953	.23	109,197	109,197	100	.230	455	.505
4	1952	.15	98,068	98,068	100	.150	456	.329

Table 5. Estimation of the apparent total mortality rate in the feeding areas, and comparison with observed values in I and IIb.

Ages	$_tq/_{t+1}q$	B	Z_t	A	Apparent Z	Observed Z	
						I	IIb
8-9	1.263	0.23	.85	- .05	1.03	1.42	1.46
7-8	1.328	0.28	.70	+ .06	1.04	1.12	.82
6-7	.727	- 0.32	.47	+ .10	.23	.44	.73
5-6	.899	- 0.11	.43	+ .02	.34	- .12	.33
4-5	.651	- 0.43	.35	+ .03	- .05	- .33	.05

Note: A = correction for change in mortality = $\dfrac{Z_{t+1}\,(1 - e^{-Z_t})}{Z_t\,(1 - e^{-Z_{t+1}})}$

B = correction for change in catchability = $\log\, {_tq}/{_{t+1}q}$

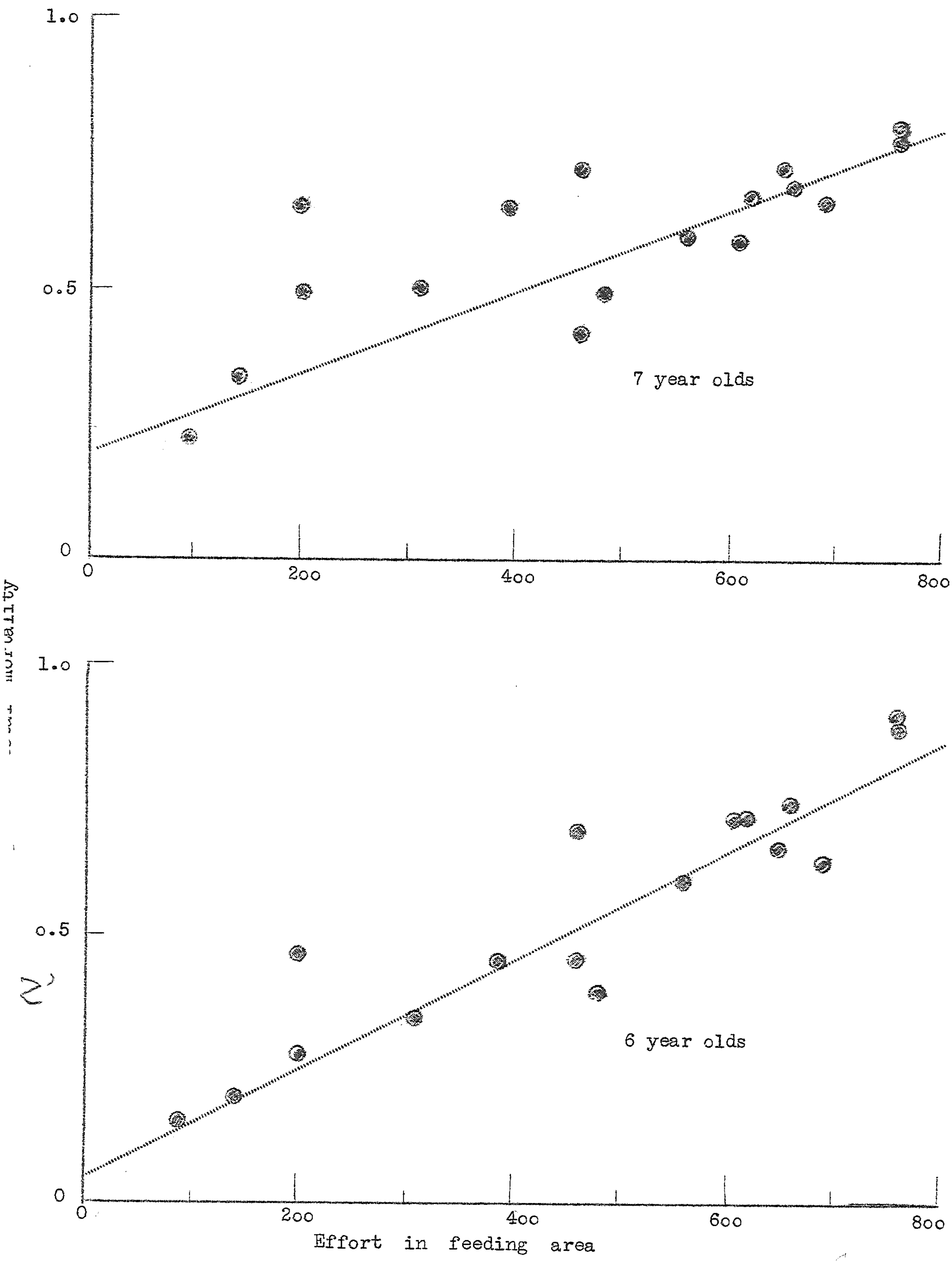

Figure 1. The relation between apparent total mortality and effort in the same year.

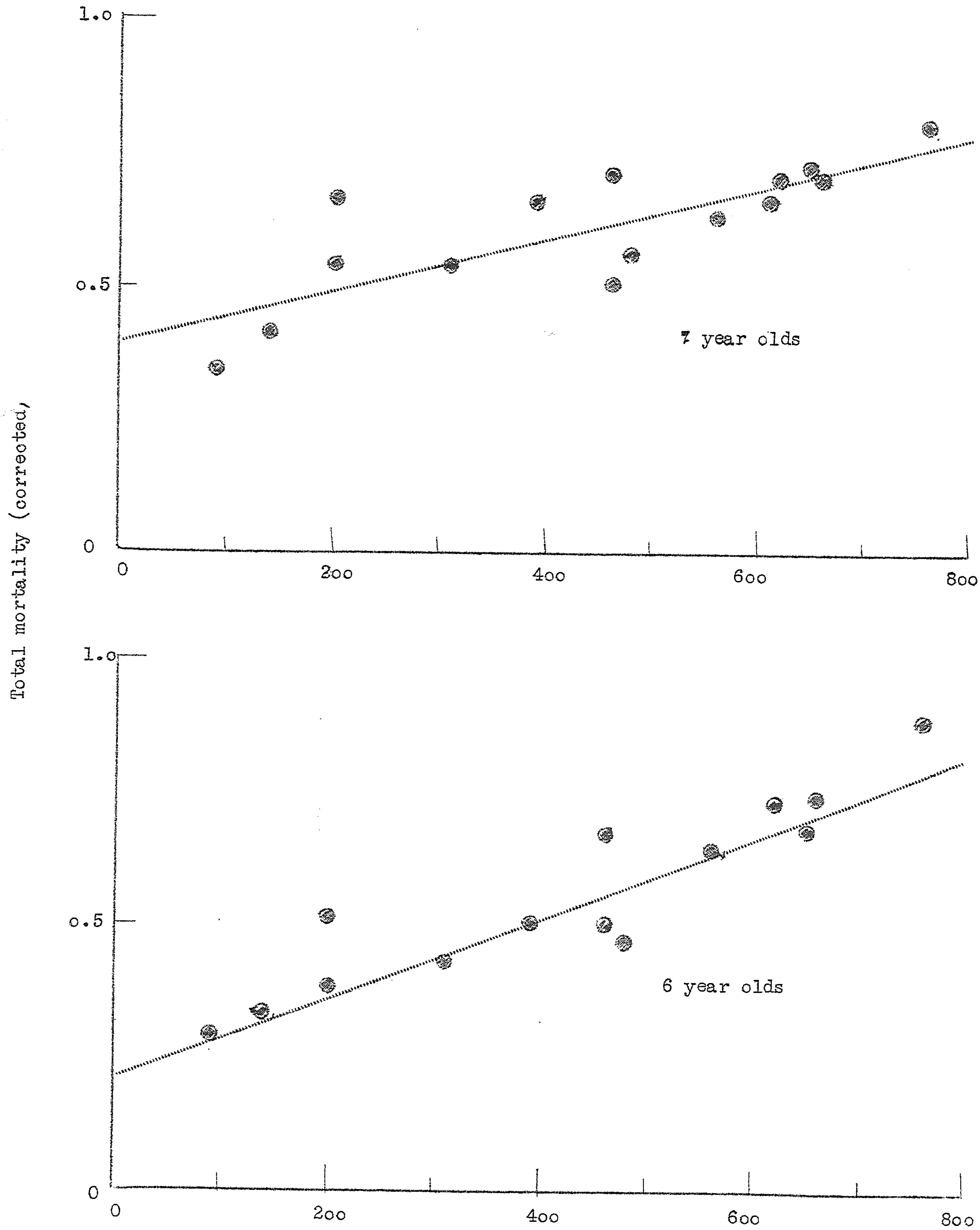

Figure 2. The relation between the corrected estimates of mortality and effort.