International Council for the
Exploration of the Sea

https://doi.org/10.17895/ices.pub.9541

C.M.1973/F:3
Demersal Fish (Northern) Cttee.

REPORT OF THE NORTH-EAST ARCTIC FISHERIES WORKING GROUP

Charlottenlund Slot, 12 - 17 February 1973

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REPORT OF THE NORTH-EAST ARCTIC FISHERIES WORKING GROUP

1. Participation

Mr A Hylen, Chairman	Norway
Mr B W Jones	U.K.
Dr A Meyer	Germany (F.R.) and I.C.N.A.F.
Dr A I Treschev	U.S.S.R.

2. Terms of Reference

At the Statutory Meeting of ICES in 1972 the following Resolution (C.Res.1972/2:15) was adopted:

"It was decided, that:

the North-East Arctic Fisheries Working Group will meet 12 - 17 February 1973 at Charlottenlund with Mr A Hylen as Chairman to:

(a) continue assessments of the Arcto-Norwegian cod and haddock stocks,

(b) consider particularly the effects of increase in mesh size on those species for which sufficient data exist,

(c) consider the possibility of an estimation of the optimum size of the spawning stock of Arcto-Norwegian cod, and

(d) include in its study the Polar cod, owing to its increasing importance for the fisheries in the Barents Sea.

(e) Icelandic scientists will be invited to participate in the consideration of Item (b) above."

Icelandic scientists had been invited to participate in the consideration of Item b) above, but no one was able to attend the Meeting.

3. Preamble

In order that the Working Group can do worthwhile work, it needs reliable data, especially when predictions and recommendations for future fisheries have to be given. Final data for 1971 catches showed considerable differences from the provisional data on which the 1972 Report was based. The corrections concerned mainly the U.S.S.R. data as well as the data for "Other Countries" (France, DDR, Poland and Faeroes). Due to the fact that these countries fish mainly in the non-spawning areas (I and IIb), an error in the weight of the landings can lead to an even larger error in the numbers of fish in each age group. This is particularly so in the case of the recruiting year classes, and any error is carried all through subsequent calculations.

Even less basic material for 1972 were presented to this Meeting, and it was also more unreliable. The U.S.S.R. was able to present only very preliminary data concerning catches of cod and haddock, and age composition data of the Soviet cod and haddock landings were not available. Further, no catch figures from "Other Countries" could be obtained.

For the meetings of this Working Group it is especially important to have available precise information concerning the year classes entering the fishery as a basis for the assessments for recommendations for future management of the fishery.

On the basis of recent experience the Working Group is obliged to make the following strong recommendation: in future, this Working Group should meet only when sufficient data are available.

4. Status of the Fisheries

(i) Cod (Tables 1 - 4)

Provisional figures for the landings in 1972 were given by Norway, U.K. and the Federal Republic of Germany. U.S.S.R. was able to give only some indications of the size of their landings for 1972. No data for other countries were available, but estimates of their landings have been prepared on the assumption that they have changed in the same proportion as U.K. landings. The total landings in Sub-area I and Division IIb are, therefore, all very preliminary, but landings in Division IIa are reliable.

The preliminary figures for the landings in 1971 given in the last Report had to be increased by about 88 000 tons. This was due mainly to the poor initial estimate for Sub-area I. The final catch figure for 1971 was 705 000 tons, of which 48% was taken in Division IIa. According to the very preliminary figures total landings in 1972 decreased to 643 000 tons. The Norway coast fishery remained on much the same level as in 1971, being 350 000 tons compared with 336 000 tons in 1971. The very strong 1963 and 1964 year classes provided high catches again in the Norway coast fishery. The fishery at Bear Island and in the Barents Sea was relatively poor, owing to the series of weak year classes 1965-68. However, the recruiting year class 1969 apparently made up a bigger part of the catches in these areas than expected.

Fishing effort in the Barents Sea/Bear Island fishery appears to have been relatively stable during recent years, but the fishing effort in the Norway coast fishery has increased to some extent in 1972.

The catch per unit effort in the Barents Sea/Bear Island and Norway coast trawl fishery has decreased year by year since 1970. However, an increase in catch per unit effort has been observed in the Norway coast non-trawling fishery during the period 1968-71.

(ii) Haddock (Tables 5-7)

Provisional figures for total landings in 1971, given in the 1972 Report, were too high. This was caused by an overestimate of the preliminary figures for the Barents Sea. According to the preliminary figures for 1972 the total landings may have been as much as 166 000 tons, which is more than double the 1971 landings. Overall fishing effort deployed on haddock is thought not to have changed much since 1969. Catch per unit effort in 1972 in the Barents Sea was, therefore, about double that in 1971, while it decreased by 28% in Division IIa.

5. Fishing Mortality (Tables 8-9)

Provisional data for the age composition of the catches in 1972 were available only for Norway, U.K. and Federal Republic of Germany. No information of the age composition of the U.S.S.R. catches could be made available at this time of the year. In an attempt to construct an age composition of the total 1972 landings the U.K. age composition for Sub-area I and Division IIb was applied to landings of the U.S.S.R. and "Other Countries". Since the Soviet landings from these areas normally make up a great proportion of the total catch, it is important for the assessments that reliable U.S.S.R. data should be available. It must be appreciated that the age composition of the total landings used in the assessments could be unreliable, and particularly so for the estimates of catches of the 1969 year classes of both cod and haddock, which are critically important to the assessment. As a result estimates of the fishing mortality and the stock size in the recent years are very uncertain.

A number of approximate methods have been used to estimate fishing mortality in the most recent year. Estimates based on the trend in total mortality between years determined from catch per unit effort data were not valid this year, because the pattern of fishing appeared to have changed in 1972, compared with the previous year. It appeared that U.K. trawlers may have concentrated to some extent on the recruiting 1969 year class of cod, and catch rates on older age groups appear artificially low.

It was considered that the values of fishing mortality for fully exploited age groups assumed at the last Meeting for 1971 were too low, but the Group thought there had probably been little change from 1971 to 1972. Accordingly the initial values chosen to initiate the Virtual Population Analysis for 1972 were increased somewhat compared with those used last year.

Updated estimates of fishing mortalities for the years 1968-1971 are lower than given in the 1972 Report. This is to some extent caused by a correction introduced in the Virtual Population Analysis to compensate for the fact that the recent year classes in the stock have not completely passed through the fishery. This bias in the fishing mortalities gave estimates of stock size which were too small, with a consequent underestimate of predicted catches. At least some of the earlier discrepancies between the predicted catch, and that subsequently recorded, can be explained on this basis.

6. Growth (Table 10)

Estimates of mean weight at age of cod have been revised. The new data have been calculated from weight at age data determined separately for landings of U.S.S.R., Federal Republic of Germany, Norway and the U.K. In some cases length data were converted to age using the relationship $W = 1^3 \times 9 \times 10^{-6}$. An overall average was then calculated weighted by each nation's catch of each age group.

7. Recruitment (Tables 11 and 12)

For cod the abundance estimates of the 1965-1968 year classes derived from commercial landings have confirmed earlier estimates based upon pre-recruit surveys. They are all very weak. The 1969 year class was estimated in 1972 to be below average. The most striking point coming out of the V.P.A. is the very high estimate of the size of the 1969 year class present at the beginning of 1972. The present estimate of the size of the 1969 year class is four times that obtained at the last Meeting and is of the same magnitude as the 1964 year class at the same age. U.S.S.R. young fish surveys assessed the 1969 year class as very poor. However, the 0-group survey report indicated that this year class was only slightly less abundant than the 1963 and 1964 year classes. It is possible that previous estimates of the size of this year class adopted by the Working Group may have been too low. However, the current estimates are critically dependent on the number of the 1969 year class taken in the U.S.S.R. fishery in 1972, and this is still unknown. The 1970 year class is still expected to be rich. Based on the U.S.S.R. young fish survey the 1971 and 1972 year classes are estimated to be below average and poor, respectively, while they appeared from the 0-group surveys to be above average.

For haddock the 1969 year class appears in the present study to be stronger than expected and almost double the estimates given in 1972. This depends, as for cod, very much on the reliability of the age composition of the landings in 1972. However, the 0-group survey and the U.S.S.R. young fish surveys both indicated it to be very abundant. The abundance of the 1970 year class is probably a little less than the 1969 year class. The 1971 year class is less abundant than the two preceding ones, although still above average, but the 1972 year class appears to be of lower abundance than the 1969-1971 year classes.

8. Estimates of future catches (Table 13)

Estimates of catches have been prepared on the basis of the material available at the Meeting and on the assumption that the fishing mortality continues at the same level as estimated for 1972 (for fully recruited age groups). The expected catches have been divided between the Sub-area I/ Division IIb and the Division IIa fisheries on the basis of the ratios of catches of the different age groups in the regions in the period 1967-1971. These estimates for catches in Division IIa are not precise, but they are thought to give a realistic trend.

Estimates of future catches of haddock have been prepared on the assumption that fishing mortality remains at its 1972 level in 1973 and 1974. Since the stock of older age groups is so small, the future yield of haddock will be highly dependent on the abundance of newly recruiting age groups and especially the 1969 year class.

9. Mesh Change Assessments

Mesh assessments were made for North-East Arctic cod and haddock, but it was not considered possible to do this for redfish or saithe because of lack of data at the Meeting. It is hoped that an assessment for saithe will be made by the Saithe Working Group. Redfish assessments will be prepared by Dr A I Treschev. For the cod fishery at Iceland an assessment was prepared for the Meeting by the Chairman of the North-Western Working Group.

(i) Arcto-Norwegian Cod and Haddock (Tables 14-15)

The method of assessment adopted was the same as that previously used at the 1969 Working Group Meeting. The previous assessments had been done using a selection factor of 3.7 for cod (manila, without chafer) although there were some data to indicate that a lower value might have been more appropriate. The present Working Group had the benefit of advice from Dr H J Bohl, who suggested that the appropriate selection factors would be 3.2 for manila and 3.5 for polyamide for both cod and haddock. These values differ from the average values given in ICES Coop.Res.Report (No.25, 1971) so a range of selection factors is given in Table 14. Yield per recruit was calculated for ages at first capture ranging from 2.5 to 5 years. Growth data for cod in terms of length at age data correspond to the weight at age data given in Table 10. Haddock mean length at age data were based on U.S.S.R. observations. The relationship of fishing mortality with age used was that which was thought to represent the likely levels in the next two or three years. These data are summarised in Table 14. Yield per recruit for the total fishery was estimated and this was then subdivided to give estimates of yield per recruit in the Division IIa fishery and in the Sub-area I and Division IIb fisheries. This division was made on the basis of the average proportion (1967-1971) of the catch of each age group taken in the IIa fishery. Mature stock biomass was also calculated.

The results of the assessments are given in Table 15 and Figure 1. For haddock the estimated yields per recruit over the range of ages at first capture agree closely with the results of the 1969 assessment which shows increasing gains with increasing age at first capture over the whole range. Catches in IIa would benefit more than catches in I and IIb if the size at first capture was to be increased.

Substantial increases to the mature stock size would be expected to result if size at first capture was increased to the upper limit used in the calculation.

For cod the calculated yields per recruit are slightly higher than in the previous assessment and there is no significant change in yield over the range of age at first capture. Mature stock biomass per recruit increases with increasing size at first capture.

The results of this method of assessment will depend to a large extent on the values that are adopted for the fishing mortality coefficients. If the fishing mortality on the young age groups is small in relation to that on the older age groups, the gains likely to result from an increase in mesh size will be less than if the mortality on the younger age groups was relatively high. This is illustrated to some extent in the present examples where the fishing mortality on the younger age groups of haddock is relatively higher than in the case for cod, and the gains for increased mesh sizes are correspondingly larger. From the present assessments it must be concluded that, provided the values of fishing mortality used correctly represent the future fishery, an increase in mesh size could not be expected to give significant increases in yield per recruit except in the case of haddock where, if the mesh was increased to the upper limit used in the present study (156 - 174 mm polyamide) an increase in yield of about 16% could result. With the present assessment the main gain from a mesh size increase would be an increase in the size of the mature stock.

Differences between this assessment and the one made at the 1969 Meeting result from the different values of fishing mortality adopted. Also in the present assessment the mesh sizes corresponding to the various ages at first capture differ from the earlier report because of the differing selection factors used.

The computer simulation in the Appendix paper also gives some indications of the benefits which might result from mesh increases to 145 mm and 160 mm. In this case the expected gains are greater than in the above assessment, but the simulation used a different relationship of fishing mortality on age. The relatively higher mortality on the younger age groups in the simulation would be expected to give greater benefits from increases in mesh size.

(ii) Redfish Selection

Treschev's method gives a value for the selection factor for redfish of 2.9 for double manila. However, Bohl (1964) has shown that the selection factor decreases with increasing size of catch, and that in big catches there is nearly no selection.

The meshing of redfish is a further problem. Bohl found in mesh selection experiments on East Greenland redfish (Sebastes marinus) that:

a) the number of meshed redfish increases with the size of the catch, and

b) the number of meshed redfish depends on the mesh size and the length composition in the catches.

There is no meshing of redfish in the codends with very small mesh sizes. However, the number of meshed redfish increases with increasing mesh size up to the size which corresponds to the most frequent length. If the mesh size is further increased the number of meshed fish decreases. Soviet investigations (Treschev, 1964) have shown, however, that meshing of redfish takes place mainly during the hauling of the trawl.

If the findings off East Greenland hold true for all other regions where there is fishing for Sebastes marinus it can be deduced from Tables 16 and 17 that the meshing in Division IIa is at its greatest with the mesh size now in force and a modal length of Sebastes marinus of 40.6 cm. Further increases in mesh sizes in Division IIa would therefore decrease the rate of meshing. In all other areas an increase in mesh size will tend to increase somewhat the rate of meshing. Nothing can be said about the alteration of the rate of meshing of Sebastes mentella when the mesh size is increased.

(iii) Iceland Cod (Table 18)

Dr A Schumacher (Germany), the Chairman of the North-Western Working Group, presented to the Meeting a mesh assessment on Iceland cod for an increase in mesh size from 130 mm to 140 mm (Table 18). These assessments (Gulland, 1961) based on the length composition of the 1971 and the length-weight relation calculated from Icelandic data show that the English fishery, which mostly is engaged in the non-spawning fishery, would have the highest immediate losses (7.2%) and would also suffer a long-term loss (2% or less). All other fisheries, especially the Icelandic spawning fishery, would have a long-term gain of 5.5 to 7.1%. It is known that mature East Greenland cod join the Icelandic spawning stock from year to year in varying proportions. These immigrants could not be eliminated from the length composition of the total spawning stock off Iceland. Therefore, the long-term gain in the catches of cod of Icelandic origin is greater than estimated (Table 18). In 1971 the proportion of East-Greenland immigrants in the total spawning stock at Iceland was relatively high and thus tended to underestimate the long-term gain.

An increase in mesh size from 130 to 140 mm in the Icelandic area would, in the long term, result in an increase in the total international output of the Icelandic stock of cod, but the allocation of the total catch between the various fisheries would be changed.

10. The Optimum Size of the Arcto-Norwegian Cod Spawning Stock

In its 1972 Report the Working Group pointed out that the present size of the spawning stock is very low, and is expected to decline still further into the mid-1970's. It was considered that when the spawning stock is at a low level there are increased risks of poor recruitment. The Group recommended that steps should be taken to reduce these risks. So far no progress has been made in this direction.

At the present meeting the Group was asked to estimate the optimum size of the Arcto-Norwegian cod spawning stock. A paper on this subject was prepared in advance of the meeting by D J Garrod and B W Jones of the Fisheries Laboratory, Lowestoft, to provide a basis for discussion. This paper entitled "Stock and recruitment relationship in the North-East Arctic cod stock and the implications for management of the stock" is included as an Appendix to this Report. Figure 1 of the Appendix shows clearly how low the mature stock size has become compared with earlier years, and by 1976 it is expected to be only 1/40 of the mature stock size observed in the mid-1940's. The stock/recruitment relationship which was fitted to the observed data indicates that the optimum stock size would be equivalent to that which prevailed in the stock in the early 1950's when, according to the fitted stock/recruitment relationship, an average of about 1200 million 3-year-old recruits might be expected, although the normal fluctuations in year class strength about this mean value must be expected. If the spawning stock was allowed to build up to the optimum size an average annual yield from the fishery in excess of 800 000 tons could be expected while maintaining the stock in equilibrium. The fishing mortality required to harvest the equilibrium catch while maintaining the stock size at the optimum level has been determined in terms of the total fishing mortality (ΣF) on each cohort of fish throughout its life up to the mean age of the mature stock. For the optimum stock size this has been estimated as $\Sigma F = 1.8$. If the selection pattern in the fishery is known, ΣF can be expressed in terms of annual fishing mortality on the fully recruited age groups. The selection pattern used at the 1972 Working Group meeting was as follows:-

Age	Proportion of F on fully recruited age groups
3	.30
4	.60
5	.90
6	1.00

For this selection pattern $\Sigma F = 1.8$ corresponds to an annual fishing mortality rate on the fully exploited age groups of $F = 0.26$. The average annual yield in these circumstances would be expected to be just over 800 000 tons. It is probable that this selection pattern is not the optimum one for the fishery, and it is likely that even greater yields could be obtained if the selection pattern was changed, for example by reducing the fishing mortality on the younger age groups. If ΣF is maintained for a long period at a value greater than $\Sigma F = 2.5$ (equivalent to an annual $F = 0.43$ with the selection pattern given), the stock would be expected to decline towards extinction.

The Appendix paper includes a computer simulation which provides some indication of the yields which might be expected from the stock from 1971 onwards if fished at a range of values of F which were held constant for 25 years. The selection pattern used in the simulation is that given above. The recruitment data used were the year class strength estimates given in the 1972 Working Group Report up to the 1971 year class. Subsequently recruitment for the model is determined from the mature stock size using the stock/ recruitment relationship. Again the results indicate that for annual fishing mortality rates in excess of $F = 0.4$ the long-term trend is one of declining yields. At lower values of F the yield tends to increase. No attempt was made to estimate the size of the mature stock in each year of the simulation. It is possible that for some values of F this might increase above the optimum. It is likely that a constant low level of fishing mortality would not give the greatest possible yield or the most rapid rate of recovery of the fishery. Better yields and a more rapid recovery rate might be obtained with a different selection pattern and/or variation of fishing mortality according to year class strength.

With the present very low stock size and the prospect of further decline before some recovery can be expected, the Working Group once again wishes to stress the increased risks of poor recruitment. The Group emphasizes the need for immediate measures designed to permit the spawning stock to increase. At the present time there is the prospect of a series of above average year classes recruiting to the fishery. The 1969 year class may be better than earlier estimates indicated, and the 1970 and 1971 year classes are both expected to be good. A small sacrifice at the present time, by reducing the amount of fishing on these recruiting year classes at the youngest ages, could make a significant contribution to the future size of the spawning stock and would also be expected to increase the overall yield from these year classes.

11. Polar Cod (Tables 19 and 20)

The Polar cod, Boreogadus saida, is a circumpolar species. Besides its commercial importance, the species forms an important link in the food web in Arctic waters. It is distributed in the eastern and northern parts of the Barents Sea and around Spitsbergen. The distribution of the O-Group Polar cod suggests that there are two separated spawning areas in the Barents Sea (Benko et al. 1970). One area is situated in the south-eastern part of the Sea. The exact locality of the other one is not known, but it may be to the east of Spitsbergen.

The following observations relate to the southeastern Barents Sea. The Polar cod spawn for the first time at 3-4 years old. They are first exploited at an age of 2 years, but the main part of the catch is taken as 4 and 5 year olds (Table 19). On the basis of data from a Norwegian echo survey in the eastern Barents Sea in August 1972, the stock was estimated to be about 4 million tons. However, Polar cod were also present outside the area investigated and the stock was definitely greater than 5 million tons (Gjøsæter, 1973).

The Polar cod have been subject to increasing exploitation during the last years by U.S.S.R. and Norway. The main part of the catches is taken by bottom trawl and only small quantities by purse seine and pelagic trawl. The fishery takes place from April to December, but the main season is in November and December. The catch per hour trawling for all categories of Soviet trawlers was 3.4 tons in 1972.

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Table 1. COD. Total nominal catch by fishing areas (metric tons).

Year	Sub-area I	Division IIb	Division IIa	Total
1960	380 962	94 599	155 116	630 677
1961	409 694	222 451	149 122	781 267
1962	548 621	222 611	138 396	909 628
1963	547 469	113 707	116 924	778 100
1964	202 566	126 029	108 803	437 398
1965	241 489	103 407	99 855	444 751
1966	292 244	56 568	134 664	483 476
1967	322 781	121 050	128 729	572 560
1968	642 449	268 908	162 472	1 073 829
1969	670 158	266 117	254 985	1 191 260
1970	551 015	85 423	240 150	876 588
1971	311 788	56 907	336 269	704 964
1972x)	244 287	47 856	350 497	642 640

x) Provisional figures.

Table 2. COD. Nominal catch (in metric tons) by countries (Sub-area I and Divisions IIa and IIb combined).

Year	England	Germany	Norway	U.S.S.R.	Others	Total	Coastal Cod Norway
1960	141 175	9 472	231 997	213 400	34 633	630 677	43 092
1961	157 909	8 129	268 377	325 780	21 072	781 267	32 359
1962	174 914	6 503	225 615	476 760	25 836	909 628	29 596
1963	129 779	4 223	205 056	417 964	21 078	778 100	40 405
1964	94 549	3 202	149 878	180 550	9 219	437 398	46 100
1965	89 874	3 670	197 085	152 780	1 342	444 751	23 786
1966	103 012	4 284	203 792	169 300	3 088	483 476	27 800
1967	87 008	3 632	218 910	262 340	670	572 560	33 102
1968	140 054	1 073	255 611	676 758	333	1 073 829	47 212
1969	231 066	5 434	305 241	612 215	37 287	1 191 260	52 416
1970	179 562	9 451	377 606	276 632	33 337	876 588	49 000
1971	78 160	9 726	407 044	144 802	65 232	704 964	
1972x)	55 633	3 382	392 525	142 000	49 100	642 640	

x) Provisional figures.

Note: Estimates of coastal cod landed by Norway in 1971 and 1972 are not complete.

Table 3. COD. Estimates of total international fishing effort in Sub-area I and Divisions IIa and IIb.

Year	Sub-area I				Division IIb				Division IIa			
	National Effort		Total International Effort		National Effort		Total International Effort		National Effort		Total International Effort	
	UK 1)	USSR 2)	UK Units	USSR Units	UK	USSR	UK Units	USSR Units	UK	Norway 3)	UK Units	Norwegian Units
1960	95	43	512	91	42	11	97	34	39	10	252	26
1961	94	53	518	109	51	22	173	39	30	9	255	20
1962	93	61	590	94	51	16	168	29	34	10	210	21
1963	78	62	635	91	45	9	120	22	29	7	176	19
1964	42	30	351	55	49	17	136	32	36	6	157	17
1965	42	25	367	62	37	11	95	4	33	5	150	16
1966	63	33	387	69	23	16	71	29	46	5	199	15
1967	51	30	395	61	10	12	110	13	50	5	261	22
1968	86	45	584	67	9	24	151	26	52	6	288	15
1969	115	45	593	72	24	19	197	26	73	5	272	18
1970	122	35	573	77	24	15	122	27	55	5	346	16
1971	82	23	576	74	4	27	79	34	48	5	523	14
1972 x)	73	20	546	49	8	25	116	30	35	6	623	21

1) Hours fishing x average tonnage x 10^{-6} = millions of ton-hours.

2) Hours fishing (catch/catch per hour fishing) x 10^{-4}

3) Number of men fishing at Lofoten x 10^{-3}

x) Provisional figures.

Table 4. COD. Catch per unit effort (metric tons, round fresh).

Year	Sub-area I		Division IIb		Division IIa	
	UK[1)]	USSR[2)]	UK	USSR	UK	Norway[3)]
1960	0.075	0.42	0.105	0.31	0.067	3.0
1961	0.079	0.38	0.129	0.44	0.058	3.7
1962	0.092	0.59	0.133	0.74	0.066	4.0
1963	0.085	0.60	0.098	0.55	0.066	3.1
1964	0.058	0.37	0.092	0.39	0.070	4.8
1965	0.066	0.39	0.109	0.49	0.066	2.9
1966	0.074	0.42	0.078	0.19	0.067	4.0
1967	0.081	0.53	0.106	0.87	0.052	3.5
1968	0.110	1.09	0.173	1.21	0.056	5.1
1969	0.113	1.00	0.135	1.17	0.094	5.9
1970	0.100	0.80	0.100	0.80	0.066	6.4
1971	0.056	0.43	0.071	0.16	0.062	10.6
1972	0.044	0.50	0.043	0.16	0.056	

1) UK data - tons per 100 ton-hours fishing

2) USSR data - tons per hour fishing

3) Norwegian data - tons per gill net boat week at Lofoten.

Table 5. HADDOCK.Total nominal catch by fishing areas (metric tons).

Year	Sub-area I	Division IIb	Division IIa	Total
1960	125 675	1 854	27 925	155 454
1961	165 165	2 427	25 642	193 234
1962	160 972	1 727	25 189	187 888
1963	124 774	939	21 031	146 744
1964	79 056	1 109	18 735	98 900
1965	98 505	939	18 640	118 079
1966	124 115	1 614	34 892	160 621
1967	108 066	440	27 980	136 486
1968	140 970	725	40 031	181 726
1969	88 960	1 341	40 208	130 509
1970	59 493	497	26 611	86 601
1971	56 300	435	21 567	78 302
1972[x)]	145 620	3 165	17 432	166 217

x) Provisional figure.

Table 6. HADDOCK. Nominal catch (in metric tons) by countries (Sub-area I and Divisions IIa and IIb combined).

Year	England	Germany	Norway	U.S.S.R.	Others	Total	Coastal Haddock Norway
1960	45 469	5 597	47 263	57 025	100	155 454	5 943
1961	39 625	6 304	60 862	85 345	1 098	193 234	4 031
1962	37 486	2 895	54 567	91 940	1 000	187 888	3 293
1963	19 809	2 554	59 955	63 526	900	146 744	4 285
1964	14 653	1 482	38 695	43 870	200	98 900	6 460
1965	14 314	1 568	60 447	41 750	-	118 079	6 217
1966	27 723	2 098	82 090	48 710	-	160 621	5 223
1967	24 158	1 705	51 954	57 346	1 323	136 486	3 181
1968	40 102	1 867	64 076	75 654	27	181 726	2 766
1969	37 234	1 490	67 549	24 211	27	130 509	2 120
1970	20 344	2 119	36 716	26 802	620	86 601	
1971	15 605	896	45 715	15 778	308	78 302	
1972x)	16 792	1 656	46 169	101 000	600	166 217	

x)Provisional figures.

Table 7. HADDOCK. Catch per unit effort and estimated total international effort.

Year	Catch per Effort (UK) Kilos/100 ton-hours			Estimated Total International Effort in UK Units
	Sub-area I	Divisions IIa	Divisions IIb	Total catch in tons x 10^{-6} / tons/100 ton-hours Sub-area I
1960	33	34	2.8	4.7
1961	29	36	3.3	6.7
1962	23	42	2.5	8.2
1963	13	33	0.9	11.2
1964	18	18	1.6	5.5
1965	18	18	2.0	6.6
1966	17	34	2.8	9.4
1967	18	25	2.4	7.6
1968	19	50	1.0	9.6
1969	13	42	2.0	10.0
1970	7	31	1.0	12.4
1971	8	25	3.0	9.8
1972	15	18	22.0	11.1

Table 8. Fishing mortality 1968-1972. Estimated by Virtual Population Analysis.

Year / Age	COD (M = 0.30)					HADDOCK (M = 0.20)				
	1968	1969	1970	1971	1972	1968	1969	1970	1971	1972
3	0.02	0.02	0.04	0.00	0.06	0.06	0.18	0.16	0.04	0.20
4	0.17	0.22	0.12	0.14	0.22	0.43	0.23	0.48	0.26	0.39
5	0.33	0.41	0.38	0.25	0.32	0.62	0.57	0.36	0.50	0.62
6	0.41	0.45	0.45	0.29	0.38	0.50	0.66	0.62	0.30	0.65
7	0.35	0.69	0.48	0.45	0.50	0.80	0.46	0.65	0.60	0.65
8	0.48	0.83	0.73	0.66	0.63	0.73	0.64	0.49	0.56	0.65
9	0.70	1.10	0.83	0.93	0.63	0.47	0.51	0.57	0.40	0.65
10	0.68	0.89	1.03	0.74	0.63	0.58	0.43	0.45	0.69	0.65
11	0.50	1.12	0.62	0.92	0.63	0.41	0.26	0.42	0.44	0.65
12	0.26	0.76	0.48	0.54	0.63	1.05	0.30	0.25	0.70	0.65
13	0.57	0.48	0.50	0.81	0.63	0.20	0.35	0.73	0.44	0.65
14	0.42	0.22	0.32	0.61	0.63	0.72	0.03	1.05	0.11	0.65
15	0.63	0.63	0.63	0.63	0.63	0.65	0.65	0.65	0.65	0.65

Table 9. Stock size 1968 - 1972 (Millions of fish).

Year / Age	COD (M = 0.30)					HADDOCK (M = 0.20)				
	1968	1969	1970	1971	1972	1968	1969	1970	1971	1972
3	198	135	180	376	1691	13	10	167	59	602
4	1305	143	98	128	278	210	10	7	116	46
5	1087	818	85	64	82	97	111	7	4	73
6	363	577	402	43	37	22	43	51	4	2
7	103	178	274	190	24	31	11	18	23	2
8	49	53	66	126	90	11	11	6	8	10
9	26	23	17	24	48	2	4	5	3	4
10	8	10	6	6	7	0	1	2	2	2
11	2	3	3	1	2		0	1	1	1
12	1	1	1	1	0			0	0	1
13	0	0	0	0	1					0
14	0				0					
15										

Table 10. Mean weight at age data for COD and HADDOCK used in the assessments in this Report.

Age	Mean Weight in Kilos Cod	Haddock
2	0.45	0.25
3	0.65	0.41
4	1.00	0.62
5	1.55	0.97
6	2.35	1.59
7	3.45	2.33
8	4.70	2.72
9	6.17	3.56
10	7.70	4.41
11	9.25	5.40
12	10.85	6.70
13	12.50	7.40
14	13.90	8.00
15	15.00	-

Table 11. COD. Arctic Cod. Year class strength. The number per hour fishing for U.S.S.R. young fish survey is the mean of 2- and 3-year old fish.

Year class	USSR Survey, No/hour of fishing			USSR Assessment	0-Group Survey	Virtual Population No. of 3 year olds 10^{-6}
	Subarea I	Div. IIb	Mean			
1956	12	24	15	-average		914
1957	10	15	11	-average		1 028
1958	10	20	14	+average		1 233
1959	12	13	12	+average		1 034
1960	6	13	10	poor		693
1961	2	2	2	poor		513
1962	6	5	5	poor		1 117
1963	14	84	46	rich		2 111
1964	51	39	45	rich		1 458
1965	<1	<1	<1	very poor	very low abundance	198
1966	<1	<1	<1	very poor	very low abundance	135
1967	1	<1	<1	very poor	below average	180
1968	4	<1	2	very poor	v.low abundance	(376)
1969(1+2)	3	1	2	very	x)	(1 691)
1970(1)	23	64	44	rich	xx)	(1 700)
1971			8	-average	xxx)	(1 200)
1972			4	poor	xxxx)	(1 000)

x) Abundance may not be so abundant as the 1963 and 1964 year classes.

xx) More abundant than the 1964-69 year classes.

xxx) Above average abundance.

xxxx) Above average abundance.

Table 12. HADDOCK. Arctic Haddock. Year class strength. The number per hour fishing for U.S.S.R. young fish survey is the mean of 2- and 3-year old fish.

Year class	USSR Survey No. of fish/hour fishing Sub-area I	0-Group Survey	Virtual Population No. of 3-year olds 10^{-6}
1956	23		326
1957	12		241
1958	4		109
1959	25		239
1960	56		270
1961	42		307
1962	3		93
1963	10		223
1964	14		255
1965	<1	Very low abundance	13
1966	<1	Very low abundance	10
1967	10	Average abundance	167
1968	8	Very low abundance	59
1969(1+2)	50	Most abundant recorded in the period 1965-69	(602)
1970(1)	(10)	Probably lower abundance than 1969 but second in strength in the period 1965-70	(275)
1971	3	Less abundant than 1969-70, but more abundant than 1965-68	(200)
1972	3	Less abundant compared with the 1969-71 year classes	(100)

Table 13. Estimates of nominal catches of COD and HADDOCK at selected levels of fishing mortality.

	1972			1973			1974		
	F	Yield		F	Yield		F	Yield	
		Total	IIa		Total	IIa		Total	IIa
COD	0.63	643	350	0.63	500	(140)	0.63	650	(115)
HADDOCK	0.65	166	17	0.65	125		0.65	150	

Table 14. Data used for the mesh assessments for COD and HADDOCK.

Age at First Capture (Years)	F	Age at Mean Selection (Years)	Mean Length at Mean Selection (mm)	Mesh Size (mm) Manila S.F. = 3.2-3.4	Mesh Size (mm) Polyamide S.F. = 3.5-3.9
COD					
2.0	0	3.5	452	141-132	129-116
2.5	0.01	4.0	481	150-141	137-123
3.0	0.02	4.5	515	161-151	147-132
3.5	0.03	5.0	556	174-164	159-143
4.0	0.08	5.5	639	200-188	183-164
4.5	0.12	6.0	680	213-200	194-174
5.0	0.45	6.5	726	227-214	207-186
6.0	0.60				
7.0	0.65				
8.0	0.70				
				S.F. = 3.2-3.3	S.F. = 3.5-3.8
HADDOCK					
2.0	0	3.5	420	131-127	120-108
2.5	0.01	4.0	462	144-140	132-118
3.0	0.04	4.5	500	156-152	143-128
3.5	0.06	5.0	529	165-160	151-136
4.0	0.17	5.5	569	175-172	160-146
4.5	0.23	6.0	590	184-179	169-151
5.0	0.55	6.5	610	191-185	174-156
6.0	0.65				

Table 15. Results of mesh assessments for COD and HADDOCK.

Age at First Capture (Years)	Yield per Recruit (kg)			Mature Stock Biomass[1] (kg per Recruit)
	I + IIb	IIa	Total	
COD				
2.5	.492	.096	.588	.310
3.0	.492	.096	.588	.314
3.5	.494	.097	.591	.319
4.0	.496	.099	.595	.330
4.5	.499	.103	.602	.356
5.0	.489	.110	.599	.402
HADDOCK				
2.5	.397	.138	.535	.444
3.0	.398	.139	.537	.448
3.5	.403	.144	.547	.466
4.0	.407	.151	.558	.496
4.5	.421	.167	.588	.587
5.0	.421	.200	.621	.741

1) Assuming for cod 50% of 7 year-olds and all older fish are mature, and for haddock 50% of 6 year-olds and all older fish.

Table 16. Relation between mesh size and modal length of East Greenland REDFISH.

Mesh Size of Perlon Codend (mm)	Length of Most Frequent Meshed Redfish (cm)
121.3 ± 0.1	40.8 ± 0.2
131.0 ± 0.2	42.0 ± 0.1
138.8 ± 0.2	45.3 ± 0.2
145.7 ± 0.2	46.0 ± 0.3

Table 17. Modal Length of REDFISH in German research and commercial catches in 1971 and 1972 in different regions.

Region	Species	Number of Samples	Mean Modal Length (cm)	Range
IIa	S. marinus	22	40.6	37.5 - 43.5
Va, SW	S. marinus	19	42.8	37.5 - 46.5
Va, SW	S. mentella	28	42.8	38.5 - 46.5
Va,Rosengarten	S. mentella	25	44.1	40.5 - 47.5
XIV	S. marinus	10	46.7	45.5 - 49.5
West Greenland	S. marinus	4	45.3	40.5 - 49.5

Table 18. ICELAND COD. Percentage change in yield per recruit for increase in mesh size from 130 to 140 mm. M = 0.20. A selection factor of 3.2 and a range of 140 mm.

Fishery	E	Immediate Loss	Long-Term Gain
England	.7	7.2	-2.0
	.8		-1.3
	.9		-0.01
Germany	.7	0.56	5.0
	.8		5.7
	.9		6.5
Iceland non-spawning	.7	2.5	2.9
	.8		3.7
	.9		4.5
Iceland spawning x)	.7	-	5.5
	.8		6.3
	.9		7.1

x) Calculated from the total spawning fishery (including immigrants).

Table 19. Percentage age compositions of landings of POLAR COD from Sub-area I.

Year	Country	Age						
		2	3	4	5	6	7	8
1971	U.S.S.R	1.3	11.3	44.2	35.0	6.0	1.5	0.7
1970	Norway	1	23	62	12	2		
1971		4	21	42	29	4		
1972		3	13	41	34	9	1	

Table 20. Total landings (tons) of POLAR COD from Sub-area I.

Year	Norway	U.S.S.R.	Total
1969	18 182		
1970	8 948	116 550	125 498
1971	16 483	330 680	347 163
1972	3 878	139 130	143 008

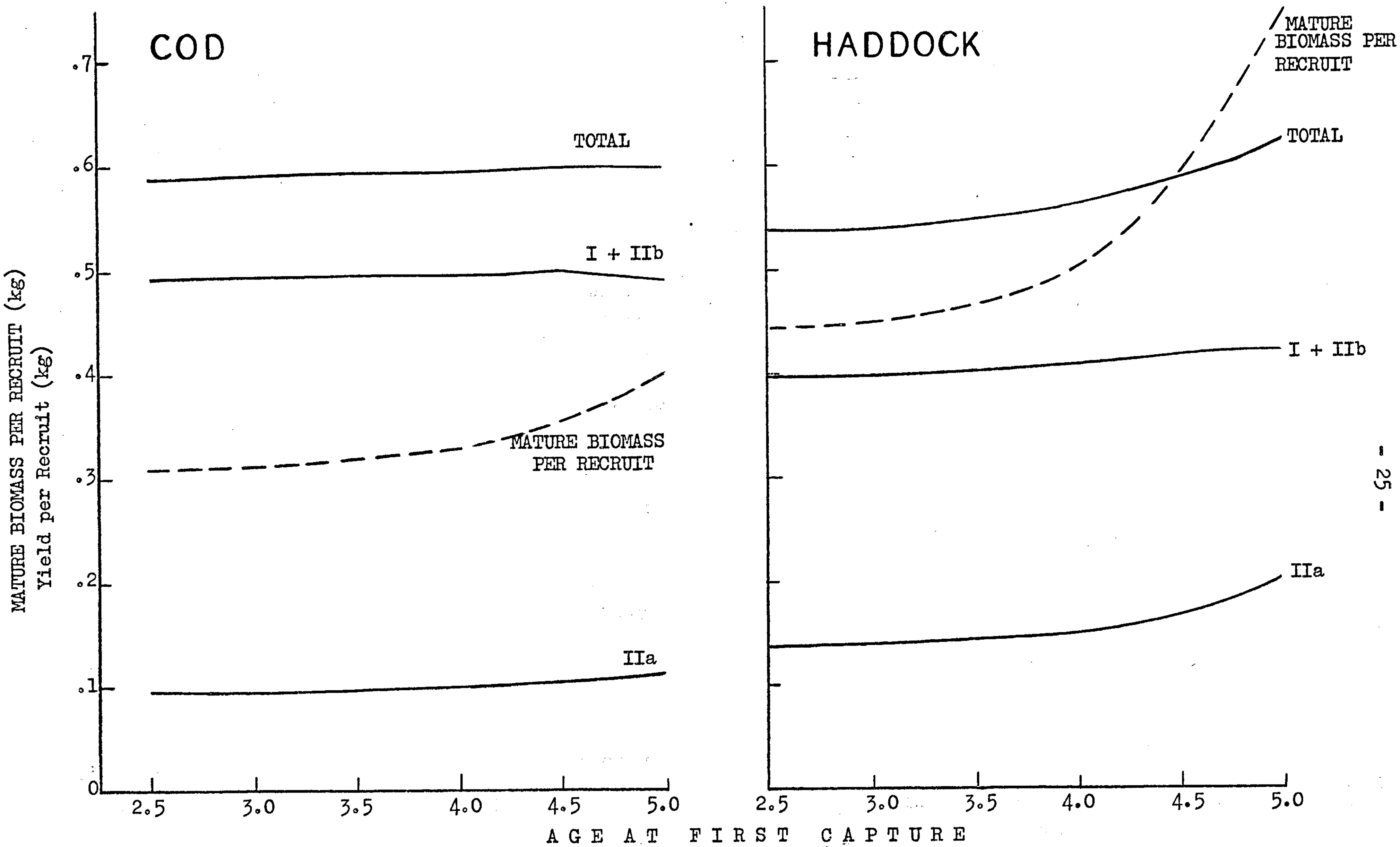

Figure 1. Mesh assessments for COD and HADDOCK.

APPENDIX TO THE REPORT OF THE NORTH-EAST ARCTIC FISHERIES WORKING GROUP

Stock and recruitment relationship in the North-East Arctic cod stock and the implications for management of the stock

by

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Introduction

Since 1969 the annual reports of the ICES North-East Arctic Fisheries Working Group have expressed concern at the declining size of the spawning stock of the Arcto-Norwegian cod. In its 1972 Report the Group pointed out that the spawning stock would become very small indeed by the mid-1970's. The Working Group considered that at low levels of spawning stock the risk of poor recruitment was increased. The terms of reference for the 1973 Meeting of the Working Group include a request "to consider the possibility of an estimation of the optimum size of the spawning stock of Arcto-Norwegian cod". In this paper we have calculated a stock-recruitment relationship for the Arcto-Norwegian cod stock, and using this relationship we have shown what size of catch can be expected at any equilibrium level of stock size, and the level of fishing mortality to take this catch has been estimated. Using this stock-recruitment relationship the optimum stock size has been calculated together with the yield that can be expected from it. Using a computer simulation the trend in catches to be expected over the next 25 years has been calculated if the stock is exploited at a range of constant values of fishing mortality. Similar catch trends have been calculated at the same levels of fishing mortality assuming exploitation with minimum trawl cod-end mesh sizes of 145 mm and 160 mm.

The stock-recruitment relationship

Estimates of parent stock in each year have been derived as follows:-

1. The age composition of the stock was derived for the beginning of each year from the Virtual Population Analysis
2. The mature stock was then calculated assuming 50% of seven year old fish were mature and all fish of eight years or older were mature. From this the annual IIa catch was deducted on the assumption that the majority of fish in the IIa catch are taken in the pre-spawning fishery and are therefore effectively lost to the spawning stock.
3. Mature stock biomass was estimated by multiplying the number of mature fish of each age group by the average weight at each age and summing for all age groups. The weight/age data used was the average weight at age in the English catches from Division IIa.
4. The mature biomass was then converted into eggs assuming a production of 400 eggs per gm of mature biomass (based on Botros, 1962).

   The number of resultant 3 year old recruits was taken from the Virtual Population Analysis. Estimates of the number of recruits are independent of estimates of mature stock size.

A Ricker stock-recruitment curve was fitted to the resultant data for the years 1942-1968. The equation of the curve was:

$$R = a\,S\,e^{-bS}$$

where
- R = number of recruits
- S = parent stock size
- a = coefficient of density independent mortality
- b = coefficient of density dependent mortality.

The curve was fitted by the method of least squares to minimise $\Sigma(R - aSe^{-bS})^2$. The calculated curve is shown in Figure 1 of the Appendix with 95% confidence limits of the curve. The parameters of the curve are:

a = 3.8981

b = 0.1122

where R is measured as numbers x 10^{-8} of 3 year old recruits and S as eggs x 10^{-14}.

Alternatively recruitment can be expressed in the same units as parent stock by calculating the potential egg production of the recruit (filial) generation assuming they are subject, throughout their life, to natural mortality only (10^8 3 year old recruits ≡ 3.12 x 10^{14} eggs). The stock-recruitment curve tranformed in this way is defined by $R = 12.1640Se^{-0.1122S}$ where R and S are both measured as eggs x 10^{-14}. This curve is plotted in Figure 2.

If parent stock and recruits are measured in the same units the stock will replace itself when R = S. If R > S recruits are produced in excess of the number required to replace the stock and the surplus can be harvested. The degree of surplus can be expressed as the ratio $\frac{R}{S}$ or in the inverse form $\frac{S}{R}$ it represents the extent to which R can be depleted and still provide replacement of the parent stock. Thus if R = 100 and S = 10, $S/R = 0.1$ and 90% of R can be removed leaving R = S. The logarithm of this ratio $\log_e (S/R)$ is plotted against stock (S) as the points in Figure 3. The fitted line is that given by the Ricker stock-recruitment curve $R = 12.1640S\,e^{-0.1122S}$. Also plotted in Figure 3 is the $\log_e$ reduction in potential egg production per unit of fishing mortality plotted against annual fishing mortality on fully exploited age groups. It can be shown that $\log_e$ reduction in potential egg production per unit of F is equivalent to ΣF up to mean age of mature stock. Thus by relating the two lines plotted in Figure 3 it is a simple matter to determine the level of annual fishing mortality required to harvest the surplus production at any stock level. (For the purposes of this paper recruitment to the exploited stock is considered complete at 6 years of age. Proportional recruitment for younger age groups has been taken as 3 years = 0.3, 4 years = 0.6 and 5 years = 0.9, as adopted at the 1972 meeting of the North-East Arctic Fisheries Working Group).

Interpretation of the stock-recruitment curves

In Figures 1 and 2 the points for each year are identified. The curve has been fitted to the points for 1942-1968 for which estimates of 3 year old recruits are available from Virtual Population Analysis. Points are also plotted in Figure 1 for the years 1969-71 using recruitment data estimated from pre-recruit surveys. Also indicated in Figure 1 are the estimates of mature stock size for the years 1972-77. It will be seen that the present very low size of the mature stock is expected to decline still further, probably reaching a minimum level in 1975-76.

The stock-recruitment curve is more easily interpreted when stock and recruitment are plotted in equivalent units as in Figure 2. In this figure the 45° replacement line is drawn. Recruitment above this line under the dome of the stock-recruitment curve is recruitment in excess of that required to provide a replacement stock, and this represents the amount which can be harvested if the stock is maintained in equilibrium. Where the lines intersect, at a stock size of 22.3×10^{14} eggs, the stock will just replace itself in the absence of fishing. To the right of this point recruitment is less than the parent stock and there is no surplus production of recruits. The maximum number of recruits is produced from a stock size of 8.9×10^{14} eggs. Maximum surplus production is obtained with a stock size of 7.3×10^{14} eggs (indicated by the arrow in Figure 2) when the number of recruits produced is equivalent to 39.2×10^{14} eggs of which 31.9×10^{14} are surplus to that required for replacement. The optimum stock size of 7.3×10^{14} eggs is equivalent to the observed stock size in the early 1950's.

In the alternative plot in Figure 3 the stock-recruitment curve has been plotted as log $(^{S}/R)$ against S and in this form it is a straight line. At the point at which the stock just replaces itself in the absence of fishing log $(^{S}/R) = 0$ and $R = S = 22.3 \times 10^{14}$ eggs, and this is indicated by the broken line. In the absence of fishing the stock will tend to stabilise at this level under the influence of natural mortality only. At stock levels below the replacement level there is surplus production of recruits. If, for any size of stock, the whole surplus is removed by fishing the stock will remain in equilibrium. Using Figure 3 the amount of fishing mortality which has to be applied to remove the surplus production can be determined as follows:

For any given stock size read the value of log $(^{S}/R)$ from the graph of log $(^{S}/R)/S$. This value is numerically equal to $-\Sigma F$ (or the log reduction in potential egg production per F) and the annual value of F on the fully recruited age groups is read from the graph $-\Sigma F/F$. Eg. For a stock size of 10×10^{14} eggs the value of log $(^{S}/R) = -1.38$ can be read from the graph of log $(^{S}/R)/S$. Then from the graph of $-\Sigma F/F$, $-\Sigma F = -1.38$ can be seen to be equivalent to an annual $F = 0.205$. This value of annual F is based on the pattern of recruitment to the exploited stock as defined on page 27.

The following conclusions can be made from Figure 3.

(i) At each stock size up to the replacement point there is an appropriate level of fishing mortality which will remove surplus production and maintain the stock in equilibrium. This value of F is greatest at low stock levels and decreases to zero at the replacement point.

(ii) If ΣF is greater than 2.5, equivalent to an annual F of 0.43 the stock will inevitably tend to extinction because losses by fishing exceed the surplus generated when density dependent mortality is at a minimum.

(iii) The maximum catch is obtained with a stock size of 7.3×10^{14} eggs exploited with an annual fishing mortality of 0.26.

(iv) There is a clear increase in variance, i.e. population instability, about the stock-recruitment curve at low levels ($< 6 \times 10^{14}$ eggs).

In Figure 4 the annual fishing mortality appropriate to maintain the stock in equilibrium is plotted against stock size. The resultant equilibrium catch is also plotted in the figure. Exploited at the optimum level the Arcto-Norwegian cod stock would give an annual yield of over 800 000 tons.

<u>Computer simulation</u>

A version of the computer simulation program described by Clayden (1972) was used to predict catch trends from the Arcto-Norwegian cod stock, if, starting from the stock situation as in 1971, the stock was exploited over a period of 25 years at a range of values of fishing mortality which remained constant over the whole period. Three runs were made; the first with the selection pattern as at present and the other two with selection patterns equivalent to the use of 145 mm and 160 mm mesh sizes. Comparisons of the yields given by runs 1 and 2, and 1 and 3 provide estimates of the benefits to be derived from the introduction of larger minimum mesh sizes.

The computer model works as follows:- The initial stock is subjected to natural and fishing mortality. The numbers at each age removed from the stock by fishing mortality are multiplied by the appropriate weight at age and the products summed to give the catch for the year. The survivors at the end of the year are carried forward as the stock for the next year and their ages are incremented by 1. The estimates of 0-group recruits are added to this stock. Recruitment is calculated from the size of the mature stock in the previous year and the stock-recruitment relationship. This cycle is then repeated 25 times to simulate 25 years fishing. The data used in this model are summarised in Annex 1.

The results of the three runs are given in Figures 5-7. The initial fluctuations result from the year class strengths as estimated from Virtual Population Analysis or 0-group surveys up to 1971. The initial decline in catches is due to the strong 1963 and 1964 year classes fading out of the fishery. The subsequent upsurge results from the recruitment of the good year classes of 1969-1971. After the 1971 year class recruitment is determined by the stock recruitment relationship and the fluctuations are gradually damped out. Figure 8 provides a comparison of yields at selected values of fishing mortality for changes of mesh to 145 mm and 160 mm.

Conclusions from the computer simulation

With the present mesh size and selection pattern (Figure 5) it can be seen that a constant level of F greater than F = 0.3 results in a trend of declining catches. If larger mesh sizes were to be used (Figures 6 and 7) fishing mortality could be increased to about F = 0.4 (145 mm mesh) or F = 0.5 (160 mm mesh) without causing a long-term downward trend. Figures 5-7 also provide some indication of the rate at which the fishery might be expected to recover if fishing mortality was to be stabilised at adequately low levels. From Figure 8 it is clear that mesh size increases up to at least 160 mm would give a long-term improvement in yields for all levels of F above F = 0.2 after an initial period of reduced yields. The long-term gain is greater at higher levels of fishing mortality.

Summary

1. A Ricker-type stock-recruitment curve has been fitted to observed data of parent stock size and the size of the resultant recruitment. The data covered the period 1942-1968.

2. A relationship was derived between stock size and the level of annual fishing mortality required to harvest the production in excess of that required to maintain the stock in equilibrium, assuming the selection pattern would be the same as at present.

3. The optimum size of the mature stock, in the units used, would be 7.3×10^{14} eggs. This corresponds to the observed size of the mature stock in the early 1950's. At this stock size, and with the present selection pattern, the optimum level of fishing mortality would be F = 0.26 when an average annual yield of over 800 000 tons could be expected. It is possible that by changing the selection pattern an even greater yield might be obtainable.

4. The size of the mature stock is presently at a very low level and is expected to decline still further before showing some recovery after the mid-1970's. The present management strategy for the immediate future should be to reduce fishing to a level where the harvest is less than the surplus production allowing the difference to go towards building up the size of the mature stock to the optimum level.

5. The computer model gives an indication of how the fishery could be expected to recover if fishing mortality was to be stabilised, assuming a selection pattern as at present or for modified selection patterns as might result from the adoption of larger minimum mesh sizes. It is not intended to suggest that a constant low level of fishing mortality would give the most rapid rate of recovery or would give the greatest possible yield during the period required for the stock to build up to its optimum size. It would be more efficient to vary fishing mortality according to the size of the year classes in the fishery with the aim of producing each year a spawning stock of optimum size but no larger or smaller. This would be very difficult or impossible to achieve in practice.

6. The conclusions in this paper are based on the assumption that the size of recruiting year classes would be determined from the spawning stock according to the calculated stock-recruitment relationship. The stock-recruitment curve would be expected to represent the average relationship between stock and recruitment but individual annual values would be expected to show the same variance about the curve as has been the case for the observed data for past years.

References

BOTROS, A. G., 1962. Die Fruchtbarkeit des Dorsches (Gadus morhua L.) in der westlichen Ostsee und den westnorwegischen Gewässern.

CLAYDEN, A. D., 1972. Simulation of the changes in abundance of the cod (Gadus morhua L.) and the distribution of fishing in the North Atlantic. Fish.Invest., Lond., Ser.2, 27, 58 pp.

Data used in computer model

1. Age composition of stock: 1971 stock as estimated at the 1972 N-E Arctic Fisheries Working Group meeting. This includes estimates of recruitment for the 1969-71 year classes based on 0-group and pre-recruit surveys. The capacity of the model permits only age groups 0-11 to be used in the calculations. When older age groups constitute a significant proportion of the stock the model will tend to give an underestimate of the catch and of the mature stock size.

2. Age/maturity relationship: 0% mature up to age 7, 7 year olds 50% mature, 8 and older 100% mature. No allowance has been made for the deduction of each year's IIa catch from the mature biomass estimated as at the beginning of each year as was done in fitting the stock recruitment curve. A correction was made for this in some later computer runs but the difference in the results was quite small.

3. Selection pattern: the values of F referred to are those relating to the fully exploited part of the stock. The proportion of the given value of F acting on partially selected age groups are as follows:

Age	Proportion of F		
	Present mesh	145 mm mesh	160 mm mesh
3	0.30	0.14	0.04
4	0.60	0.43	0.24
5	0.90	0.76	0.56
6	1.00	0.94	0.82
7		0.96	0.89
8		1.00	0.96

The proportions for the 145 mm and 160 mm mesh sizes were calculated from selection ratios for each age for 130/145 mm and 130/160 mm mesh changes based on a selection factor of 3.6.

4. Weight at age: as given in the 1971 Report of the North-East Arctic Fisheries Working Group.

5. Instantaneous coefficient of natural mortality: M = 0.3.

6. Stock-recruitment relationship: as developed in this paper.

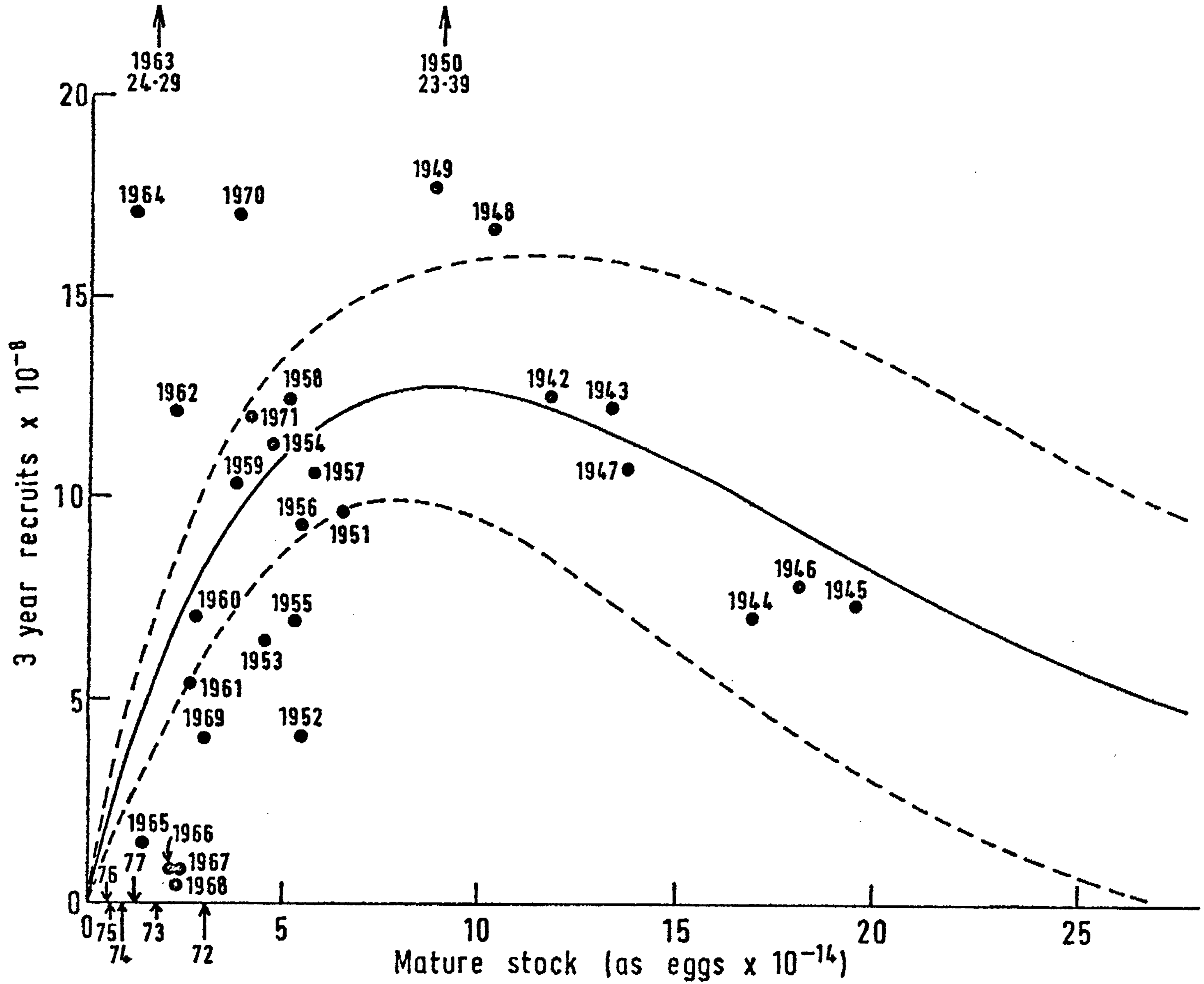

Figure 1 Stock-recruitment curve for the Arcto-Norwegian cod. $R = 3.8981\,S e^{-0.1122S}$. The curve is fitted to the points for 1942-68. The broken lines indicate 95% confidence limits of the curve.

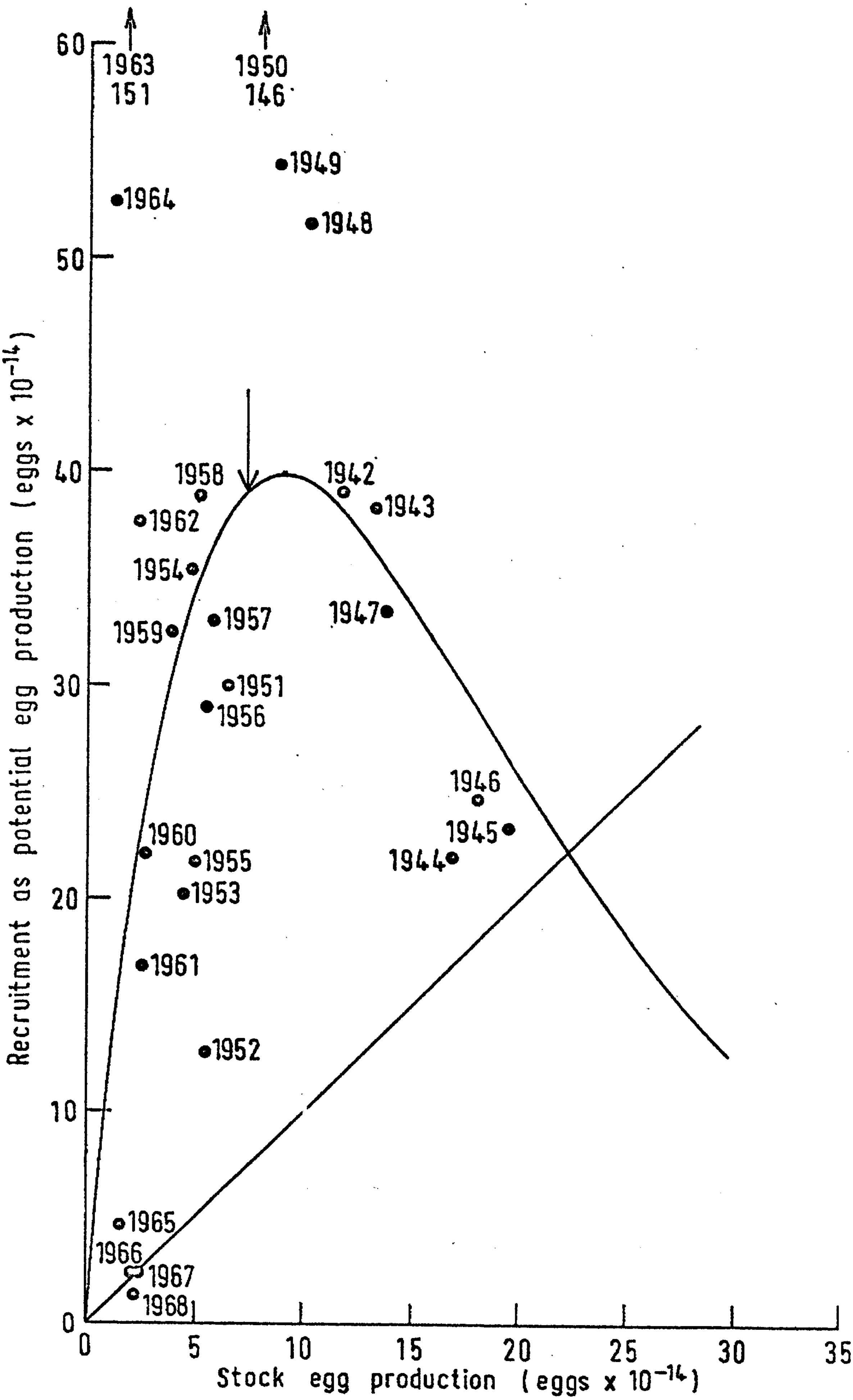

Figure 2 Stock-recruitment curve for Arcto-Norwegian cod. Recruits and stock measured in the same units. $R = 12.164Se^{-0.1122S}$. The arrow indicates the point of maximum surplus production.

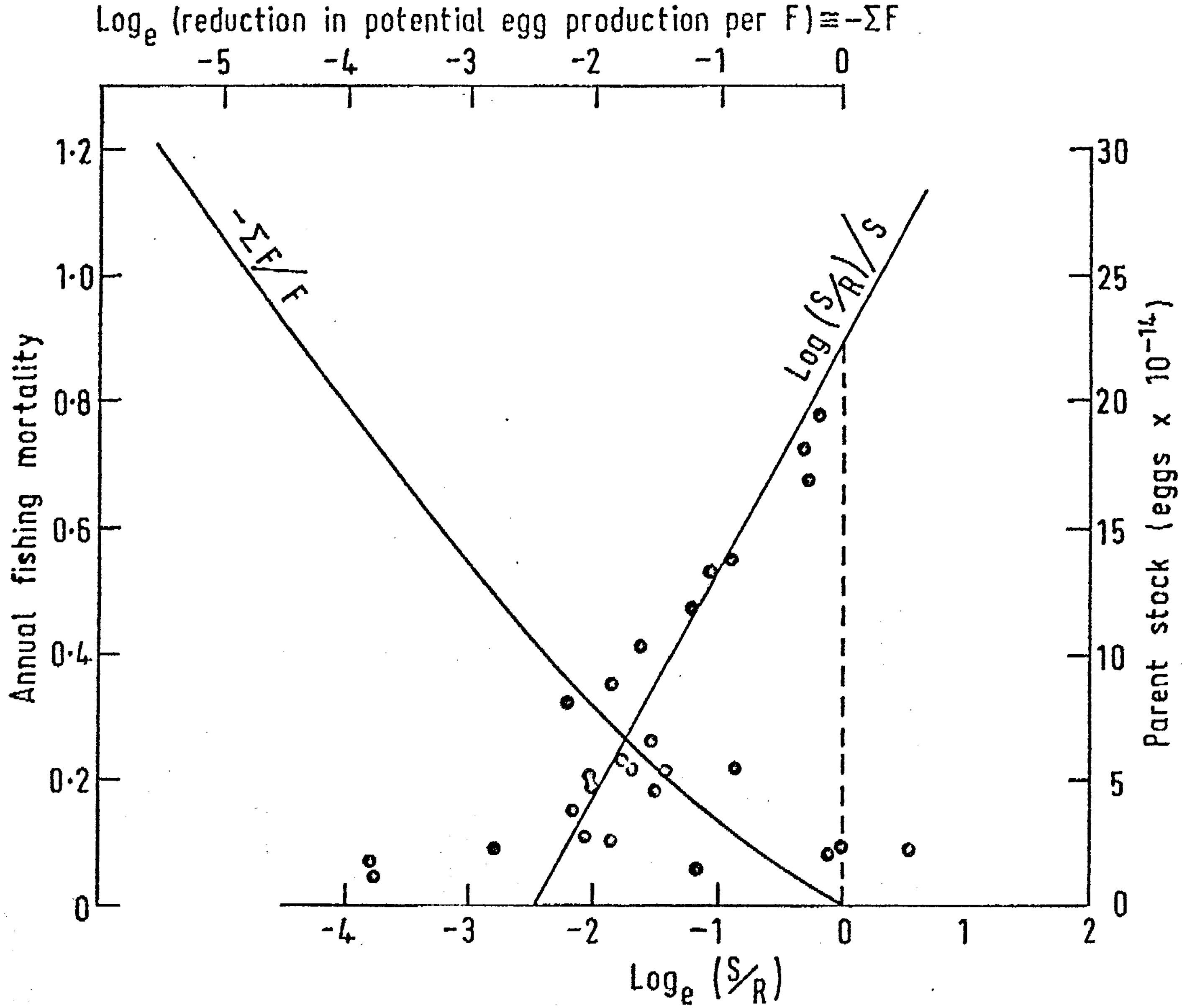

Figure 3 Plot of log$_e$ (Stock/Recruit) against Stock. The observed points for years 1942–68 are shown and the line represents the fitted stock-recruitment curve. Plot of cumulative fishing mortality on mean age in mature stock against annual fishing mortality coefficient.

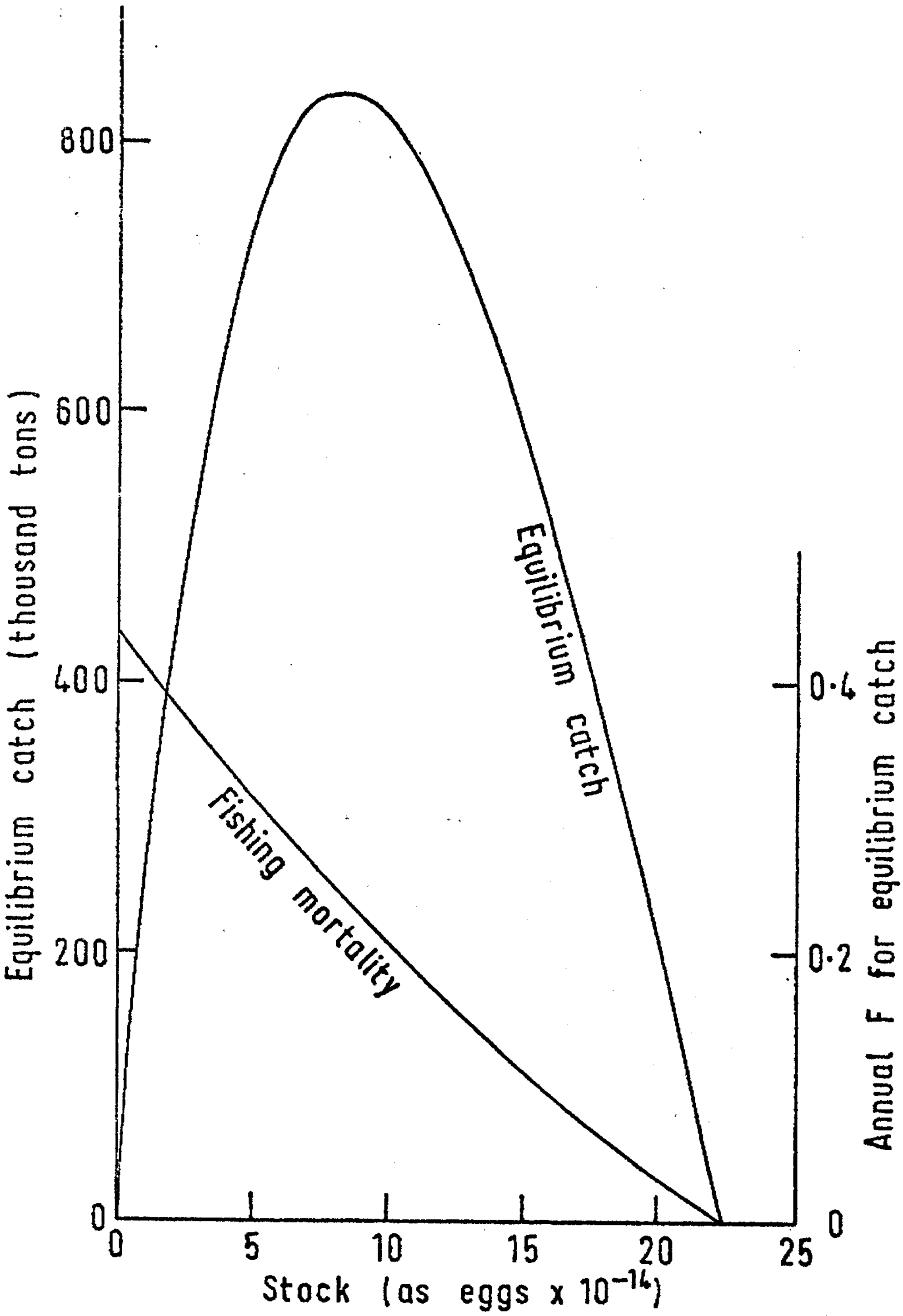

Figure 4 Equilibrium catch against stock size, and the annual fishing mortality required to achieve equilibrium catch.

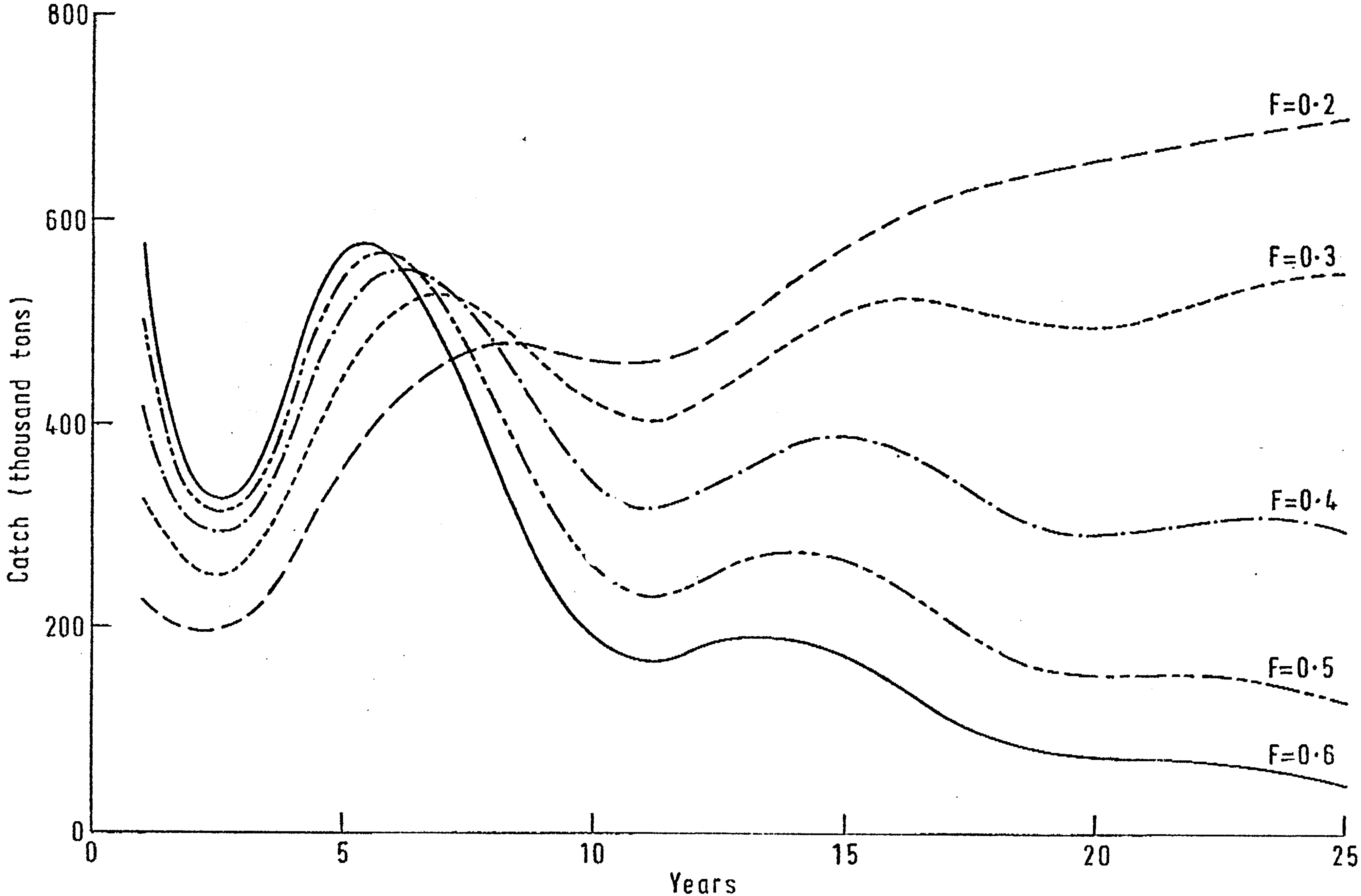

Figure 5 Catch predictions for exploitation at constant levels of fishin_ mortality. 1971 stock composition used as initial stock.

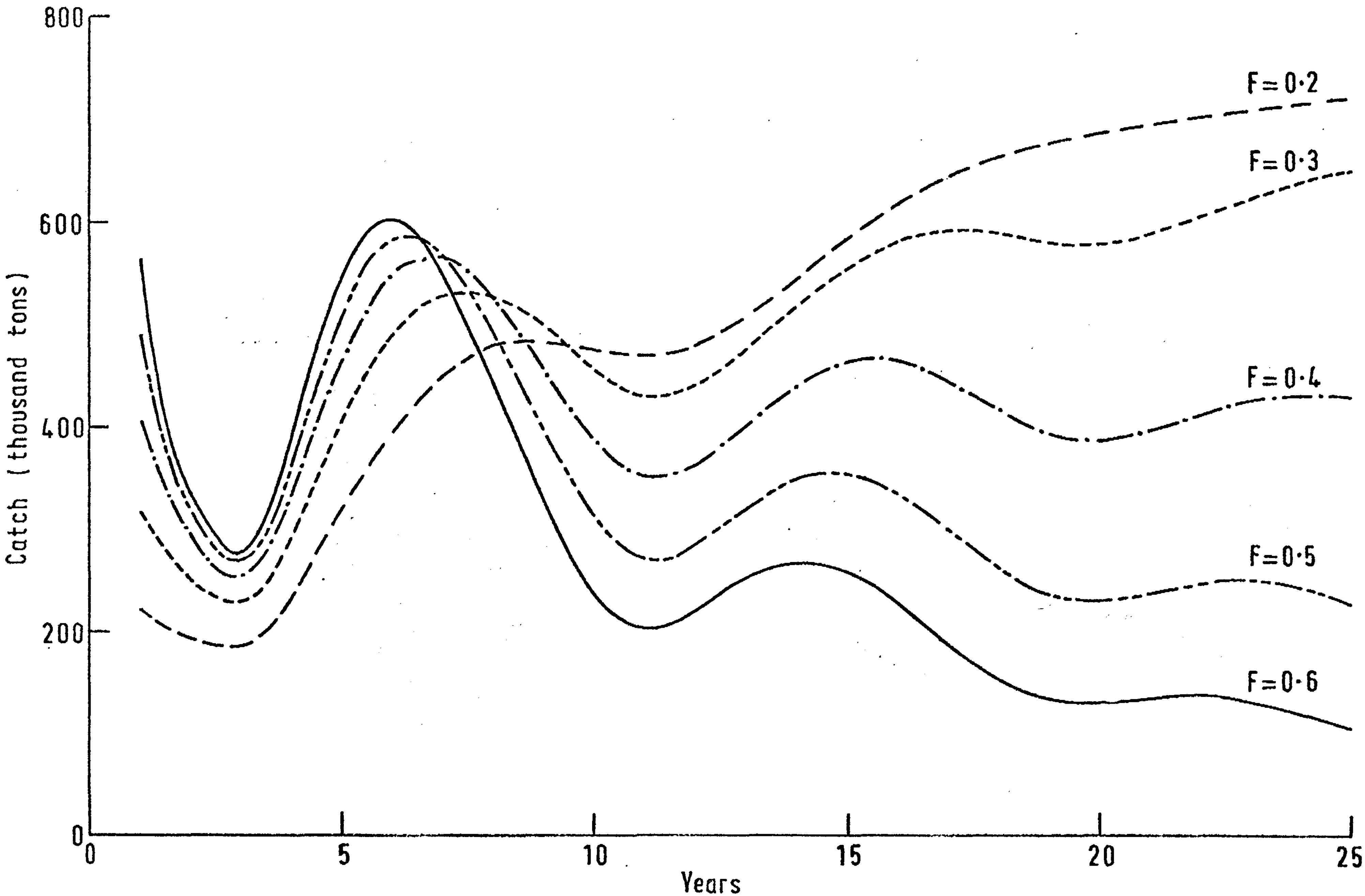

Figure 6 Catch predictions as in Figure 5 but allowing for the use of a 145 mm mesh size throughout.

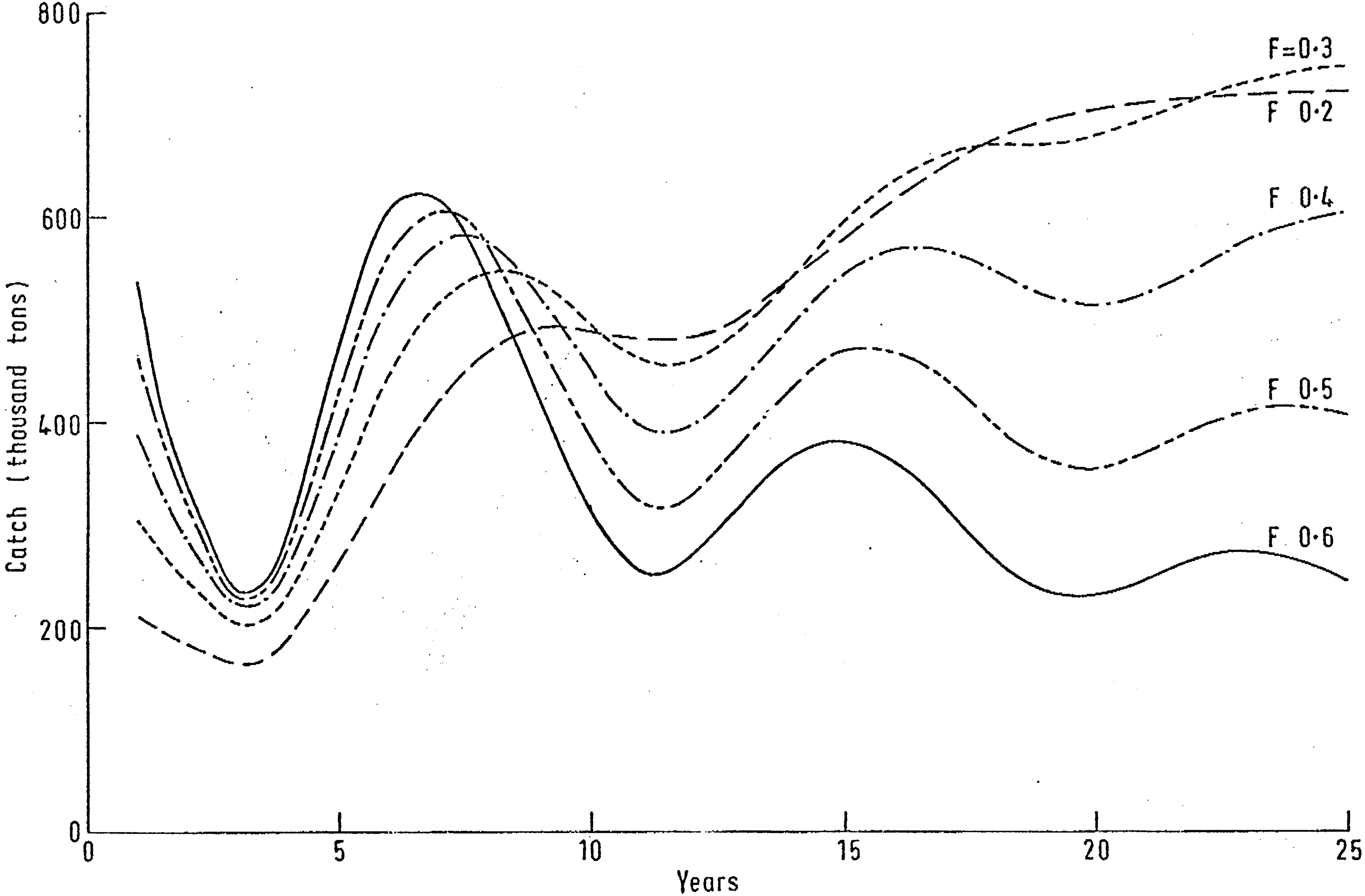

Figure 7 Catch predictions as for Figure 5 but allowing for the use of a 160 mm mesh size throughout.

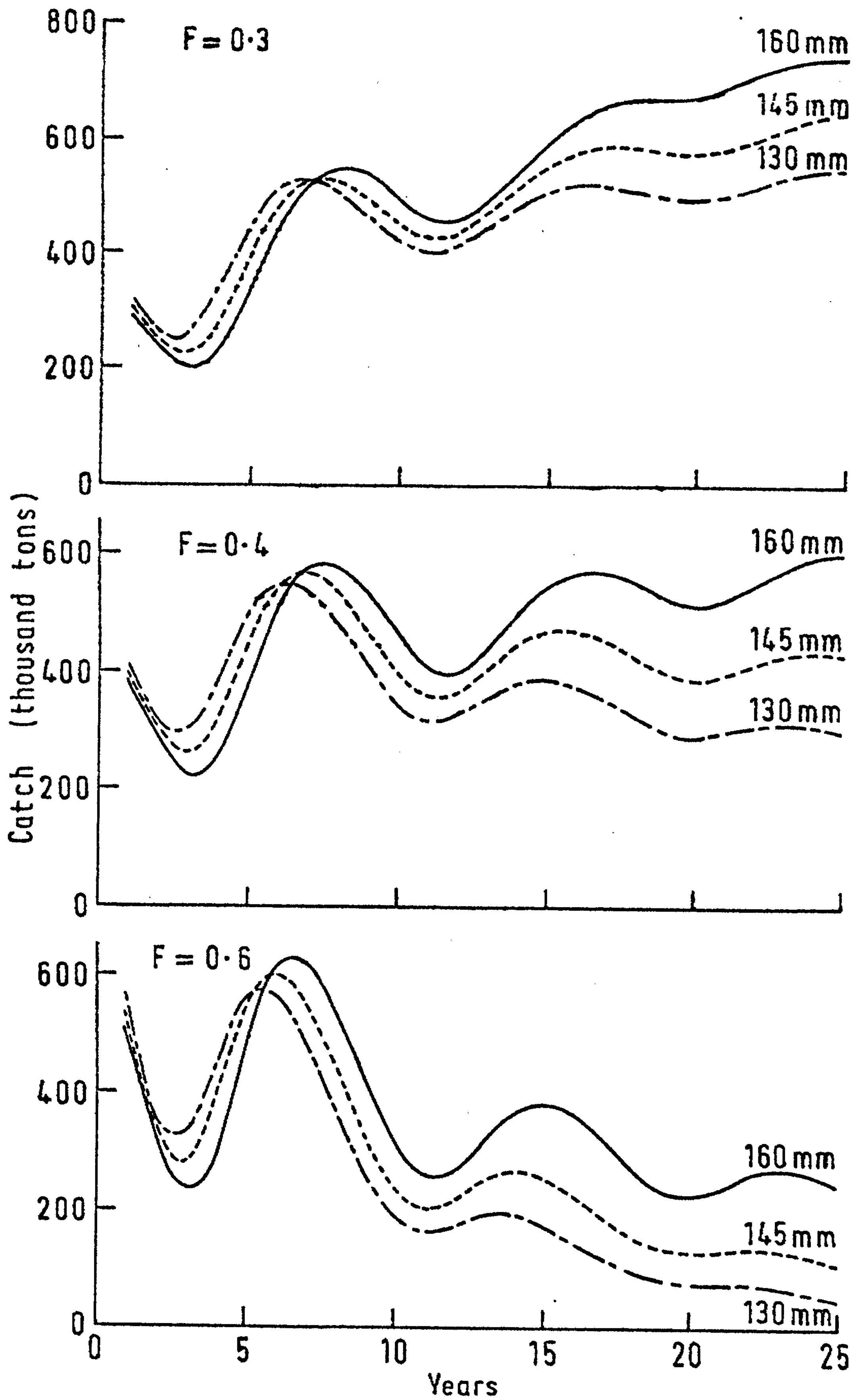

Figure 8 Comparison of yields for minimum mesh sizes of 130, 145 and 160 mm, at selected constant values of fishing mortality.