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Report of the ICES/ICNAF Working Group on Cod Stocks in the North Atlantic
Charlottenlund, 8-14 March 1972

NOTE:

At the 1970 Annual Meeting of ICNAF, Panel 1, in discussing Subarea 1 cod assessments, noted the close association between the cod fisheries in ICNAF Subareas 1, 2, and 3 and also those in neighbouring areas of the Northeast Atlantic and drew attention to the importance of extending the assessments to cover the other cod stocks in the North Atlantic, especially those in Subareas 2 and 3 and in the northern part of the Northeast Atlantic.

At its 1970 Annual Meeting ICES supported the idea and proposed that ICNAF be approached with a view to convening a joint ICES/ICNAF Working Group to study the effects of increases in and massive re-deployments of fishing effort on the cod stocks and on fishery management in the North Atlantic.

At the 1971 Annual Meeting of ICNAF the Standing Committee on Research and Statistics, supporting the proposal by ICES, recommended (ICNAF Redbook 1971, Part I, p. 13)

(i) that the Commission accept the invitation of ICES to convene a meeting of a joint ICES/ICNAF Working Group on Cod Stocks in the North Atlantic, and

(ii) that the Executive Secretary and the Chairman of the Assessments Subcommittee consult with the Chairman of the ICES Liaison Committee concerning the composition of the Working Group so that appropriate experts are invited to meet at the time of the mid-term meeting of the Assessments Subcommittee.

The change in timing for the Meeting of the Joint Working Group and the terms of reference, as given at the beginning of the Report, were established by ICES at its 1971 Annual Meeting.

28 April 1972 Office of the ICNAF Secretariat

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REPORT OF THE ICES/ICNAF WORKING GROUP ON COD STOCKS IN THE NORTH ATLANTIC

Section I. Introduction

1. Terms of reference

The Group was convened with the following terms of reference (C.Res.1971/3:2):-

"It was decided, that:

(a) the Joint ICES/ICNAF Working Group on Cod Stocks in the North Atlantic meet in Copenhagen for one week in March 1972 to summarise existing assessments concerning cod stocks in the North-East Arctic, Icelandic and East Greenland Waters, as well as the West Greenland, Labrador and Newfoundland cod stocks, and to examine in general terms the effects of possible regulatory measures, with particular emphasis on the interaction between fisheries on different stocks,

(b) Mr D J Garrod will be Chairman of the Working Group."

2. Participants

A Pinhorn	(Canada)	R Hennemuth	(U.S.A.)
Sv Aa Horsted	(Denmark)	D J Garrod, Chairman	(U.K.)
A Schumacher	(Germany, F.R.)	B W Jones	(U.K.)
A Meyer	(Germany, F.R.)	J Møller Christensen	(ICES)
S Schopka	(Iceland)	V Hodder	(ICNAF)
A Hylen	(Norway)	L Boerema	(FAO)
E Stanek	(Poland)	J Gulland	(FAO)

The Group wishes to acknowledge the computer programming assistance by Mr J G Pope (Lowestoft, U.K.) and Mr K Lassen (Denmark).

3. Stocks considered

1.	Barents Sea/Bear Island (non-spawning)	Arcto-Norwegian	ICES Subarea I and Div. IIb
2.	Norway Coast (spawning)		ICES Div. IIa
3.	Iceland (non-spawning)	Iceland/Greenland complex	ICES Div. Va
4.	Iceland (spawning)		" " "
5.	Greenland, East and South-West		ICES Subarea XIV and ICNAF Div. 1E and 1 F
6.	Greenland West		ICNAF Div. 1 A-D
7.	Labrador/East Newfoundland		ICNAF Div. 2G - 2J, 3K - 3L
8.	Flemish Cap		ICNAF Div. 3M
9.	Grand Bank		ICNAF Div. 3N and 3 O
10.	St Pierre Bank		ICNAF Div. 3P (south)
11.	West Newfoundland		ICNAF Div. 3P (north) and 4R, 4S
12.	Southern Gulf of St Lawrence		ICNAF Div. T and 4V (north)
13.	Banquereau		ICNAF Div. 4V(south) and 4W
14.	Brown's Lahavre		ICNAF Div. 4X
15.	George's Bank		ICNAF Subarea 5

Information available for stocks 1-7, 9, 10 and 12 enabled these to be incorporated into a model of the total North Atlantic cod resource to examine the interactions between fisheries. Figure 1 illustrates the geographical distribution of these stocks. Recent assessments of resources 13-15 are reviewed. Resources located in other parts of the ICES area have been excluded from detailed analysis because they are exploited by trawlers using smaller mesh sizes than elsewhere and further research is necessary to determine comparabilities between these and vessels fishing the stocks specified in the terms of reference.

Section II. The present status of the North Atlantic cod fisheries

1. Conclusions

(i) Increasing range and mobility of the fleets fishing for cod in the North Atlantic has increased their efficiency and their ability to concentrate on those stocks that happen to be most productive at a particular time.

(ii) For virtually all the stocks considered the current fishing mortality has reached the level where further increases in fishing will at best produce very small increases in yield per recruit, and in some stocks will actually decrease the yield per recruit.

(iii) There is a probability that spawning stocks as low, or lower than the present could lead to a recruitment failure and consequently to a very large drop in total catch. Taking this into account, and to some extent the economic benefits implied by an improved catch per unit effort, a desirable level of fishing mortality (effort) would be approximately half the present level. This would not affect the average long-term yield.

(iv) If such a reduction were achieved in a single year, then, given average recruitment, the cod catch would recover close to the current level after a transitional period of five years.

(v) The same benefit could be achieved by a phased reduction involving less immediate disturbance to the catch though it would take perhaps ten years to realise the full benefits.

(vi) If the displaced fishing effort remained fishing and could be redeployed on other lightly exploited species there would be an increase in the total catch of all species and a less severe immediate loss.

2. The main features of the cod fisheries 1960-1970

2.1 Trends in the fishery

The changes in total cod catch from the North Atlantic are summarised in Tables 1-3. During the period 1955 to 1970 the total catches have fluctuated about a level of some 3 million tons, with a peak of nearly 4 million tons in 1968. On the surface, therefore, the state of the Atlantic cod fisheries appears to be satisfactory. But despite the relatively constant value of total catch, both overall and by country, there have been great changes in the fishery and the stocks.

At the beginning of the 1960's the north-east Atlantic resources were already fully exploited but the north-west Atlantic resources less so; and the development of the highly mobile international fleet of 901 + GRT freezer and factory trawlers had scarcely begun. About that time a decline in catches and catch per unit effort in the northeast caused some countries to extend their activities westward. On these stocks, which were relatively lightly fished stocks at that time, they achieved high catches a part of which represented accumulated biomass.

Countries also began to expand their fleets of larger vessels to improve economic performance on grounds at long range but sufficient fishing was maintained in the northeast to fully exploit those stocks. The expansion of fishing effort to the northwest Atlantic and the development of the 901 + GRT vessel class reached an initial peak in 1967/68. (Tables 4 and 5). This coupled with favourable recruitment in several stocks, particularly in the Arcto-Norwegian, led to very high catches in 1968/69, well above any sustainable long-term average yield. Thus now, by the early 1970's, all stocks are fully exploited; there are no lightly fished stocks to sustain the high productivity of fishing operations when, as now, several stocks suffer poor recruitment, either through natural causes and/or the effects of stock/recruitment relation.

2.2 Fleet mobility

The changes in the fleets have been twofold:

(a) an increase in the efficiency of their operations with the use of improved fishing gear (e.g. mid-water trawls) and electronic apparatus for navigation and fish detection;

(b) increasing flexibility in their operations, with increased ability to move from one stock to another in response to short-term fluctuations in fishing prospects.

This second change is reflected in Table 4 which, for the two categories > 501 GRT shows a 25% decrease in units of the 501-900 GRT class counterbalanced by a doubling in the number of the larger, and operationally more flexible 900 + GRT class. Overall, however, the number of equivalent fishing units appears to have remained fairly stable through the 1960's; the change has been in the scope of their fishing operations. The changes in efficiency are difficult to quantify; to allow for it we have assumed, on the basis of trends in catchability, that an hour of fishing in 1970 was 30% more effective than in 1960 but this must vary; for example there has been a change in catchability with time at West Greenland.

In addition, the higher operating costs of the larger vessels causes them to seek out more dense concentrations of fish (higher catch rates). This, combined with the depletion of resources, which has in itself forced fleets to concentrate on area or fisheries where the availability of fish is high, has gradually altered the seasonal pattern of fisheries. Now more than ever fishing concentrates on seasonal aggregations of fish in different stocks, further increasing the efficiency of the fleets as a whole.

2.3 Trends in fishing effort and stock abundance

The changes in fleet efficiency make it difficult to calculate the real changes in the amount of fishing effort over the past ten years, and also make it difficult to estimate the changes in the abundance of the stocks, at least in terms of catch per unit effort. Estimates that have been made are given in Table 5.

These reflect the switch which began in 1955 from fishing in the north-east Atlantic (as represented by the NEAFC area) to the north-west (ICNAF), but it appears that in 1963/64 a proportion of the fishing effort was taken out of the cod fisheries in the NEAFC area and redeployed, presumably on other species, e.g. hake, haddock and herring in the ICNAF area.

The redistribution of fishing effort in the decade 1960-1970 is also evident in the distribution of catches by vessel categories in Table 6. Catches by the fleet of vessels < 500 t are fairly uniformly distributed through all stocks. Unless used with support craft, or as pair trawlers, this group may be regarded as 'non-mobile' in the sense that their range is very limited. The 501-900 GRT group has a degree of mobility, but their operational range is limited and vessels of this class fishing the north-east Atlantic are, for the majority, unable to fish the north-west Atlantic profitably, and vice versa. The 900 + GRT class developed through the decade has, in 1970, taken most of their catch at Greenland, Labrador and Newfoundland. Of the total catch in 1970 the non-mobile fleet took 40%, the intermediate 501-900 GRT group 30%, and the fully mobile 901 + GRT fleet 30%. This is roughly equivalent to the distribution of their effective (but not actual) fishing time in the units used here (Table 7).

The abundance of stocks in the north-east Atlantic, which were already fully exploited prior to 1960 has shown no trend since that time, mainly because the total stock estimates are heavily influenced by the abundance of recruit year classes. There have been changes in the abundance of some north-west Atlantic stocks since 1966, particularly at West Greenland, Labrador and Grand Bank. The decrease in population at West Greenland is also apparent in a decline in the population biomass as calculated by a different method (see Table 12).

2.4 Present status of the stocks

In 1960 the north-east Atlantic stocks were fully exploited but the north-west Atlantic less so. The developments through the 1960's reduced this 'imbalance'. Prior to 1960 there had always been one or more stocks which were relatively lightly fished and which could absorb, at least temporarily, fishing effort diverted from other areas. Even in the late 1960's as all stocks came to be fully exploited, good year classes have occurred in one or more stocks to permit good fishing. Exceptionally, as in 1968, good year classes have occurred in more than one stock resulting in short-term catches well in excess of the level that may be expected as a long-term average, even under management.

The general increase in level of exploitation for approximately the same level of effort reflects an improvement in overall harvest efficiency of the fleets as a whole, but it has reduced the average age of fish in the stocks making short-term fishing prospects over the whole Atlantic cod resource more dependent upon the strength of new year classes and, when these appear, they attract the mobile fleet causing 'pulse fishing'. (The peak in catches in ICNAF Div. 3NO 1967/68 is a classic example). But this overexploits the older part of the stock as well as the young fish that attracted the fishing, and when the fleet moves on it leaves behind a stock severely depleted throughout its age range.

The available estimates of the abundance of recent year classes which will enter the commercial fisheries 1972-1975 are summarised in Table 8. The most reliable of these indicate good recruitment to some of the ICNAF stocks (but not West Greenland) which will recruit to those fisheries from 1972, and a very strong 1970 year class in the Arcto-Norwegian stock which will recruit to the Barents Sea/Bear Island fishery in 1973. It is very likely that fishing effort will concentrate on this last year class.

The best available guide to short-term fishing prospects on an Atlantic wide basis is given by a simulation (see Section III, 3.4). This indicates a prospective yield of 2 million tons from the selected stocks in 1973, if the 1970 level of fishing is continued. This, and the expected average long-term catches under management is well below the peak catch of 3 million tons in 1969.

3. Stock assessments

Detailed assessments of the state of individual stocks have been presented by various Working Groups and Sub-Committees of ICES and ICNAF, and much of the basic material has been summarised in Section III of this Report. Since the relation between adult stock and subsequent recruitment has not been established for any cod stock, it is not possible to state definitely the relation between the amount of fishing and long-term yield. Calculations have been made of fishing mortality in relation to yield per recruit, identifying two critical values of fishing mortality:

(a) F_{max}, corresponding to the maximum yield per recruit, which gives the absolute upper limit to the amount of fishing that should be allowed, and

(b) F_{opt}, calculated following the usage of the 1972 ICNAF mid-term assessment report, as the level at which the marginal yield (the net addition to the total catch produced by an additional unit of effort) is one-tenth of the catch per unit in a very lightly exploited stock.

For each stock for which sufficient data are available estimates of recent fishing mortality (1966-1970) in Table 9 have been related to F_{max} and F_{opt} in Table 10. In nearly every case it exceeds F_{opt} and in several cases F_{max} as calculated from the present pattern of fishing over all age groups.

Recognition of F_{opt} as a criterion has become necessary because as the level of exploitation has increased and with it the need to locate the best concentrations of fish, so fishing mortality has become more age specific. In some years fishing concentrates on young age groups, in others the older age groups are most attractive. The precise location of F_{max} is sensitive to these changes and may vary over a wide range whereas F_{opt} is more stable. Moreover if recruitment is influenced by the level of fishing mortality this implies that at the moderately high levels of fishing represented by most values of F_{max}, the recruitment could be decreased, and that the maximum total yields would be likely to occur at somewhat lower levels of fishing, perhaps around the values of F_{opt}.

Since increasing fishing mortality beyond the level of F_{opt} will only increase the yield per recruit by an amount that is small compared with the increase in effort, and could well decrease the total yield, it is suggested that, pending further analysis, the estimate values of F_{opt} should serve as target figures for the fishing mortality to be achieved on each stock. For most stocks this would imply a sharp decrease in the amount of fishing from current levels without great change in the yield per recruit.

The scale of decrease in fishing mortality that would lead to F_{opt} is given below together with the long-term yield that could be expected under past average recruitment conditions. This compares with the average yields for each stock 1966-1970 in Table 3.

	STOCK							
	NEAFC Area			ICNAF Area				
	I + IIB, IIA	VA	XIV + ICNAF 1E,F	1A-D	2G-3L	3NO	3Ps	4T-4Vn
Maximum long-term catch (000 t per year)	800	390	100	230	800	?	60	100
Surplus F in 1966-1970[1]	38	53	NIL	50	62	75	67	NIL

[1] Defined as the surplus of F in 1966-1970 over F_{opt} as a percentage of F in 1966-1970 and calculated as

$$100 \left(\frac{F66\text{-}70 - F_{opt}}{F66\text{-}70}\right) \text{ i.e. } 100 \left(1 - \frac{F_{opt}}{F66\text{-}70}\right).$$

4. Economic opportunities

The ICNAF Bio-Economics Working Group estimated in 1967 that the amount of fishing on cod and haddock could be reduced by 10-20%, leading to potential annual savings in costs of $ 50 - 100 million. The present analyses suggest that the amount of fishing could be reduced by considerably more than 10-20%, with opportunities for commensurate reduction in costs.

5. The effect of regulatory measures

5.1 Control of the size at first capture

Previous assessments have pointed out the benefits in most of the North Atlantic cod stocks that would arise from an increase in the size at first capture, as might be achieved by the use of a larger mesh size. No new quantitative assessments of the effects of mesh changes were made by the present Group. It should be pointed out that the greater mobility of many fleets, and their increased ability to concentrate on a strong year class as soon as the fish reach a commercial size, probably combined in the immediate future with a lack of good alternative supplies of larger cod, will tend to an increase in the relative fishing mortality on the smaller fish (below the optimum size at first capture). In turn, this would increase the need for, and potential benefits from, appropriate control of the size at first capture.

5.2 Control of fishing intensity

Whatever action may be taken to control the size at first capture, it can provide only a partial solution to management of the Atlantic cod stocks. Some control of the amount of fishing has become necessary. Ideally, for optimum biological management, such control should be applied to each stock separately. Some of the practical problems involved have been discussed (ICNAF Bio-Economics Assessment Report).

An alternative, the implementation of an Atlantic wide regulation of fishing effort has herebeen examined using a simulation model as an example of this technique and as an initial study of the effect of such a regulation on the distribution of fishing effort and catches, incorporating the interaction between fisheries caused by the mobility of fleets.

Details of this model, produced in the Lowestoft Laboratory, are given in Section III of this Report. The accuracy of simulation achieved for the period 1960-1970 is illustrated in Figure 3. It should be stressed that this model does not attempt to produce a complete description of the fishery, nor a detailed prediction of future events. It should, however, provide some measure of the relative effects of, for example, two different management actions. The particular model described did not, as employed this time, include any provision for a possible relation between stock and recruitment. Therefore, on the one hand it may underestimate the benefits from reducing the amount of fishing (and hence increase the spawning stocks), and on the other hand it ignores the possibility of some spawning stocks becoming so low that there is a recruitment failure.

Amongst a number of possible management actions considered four important strategies were identified:

Strategy 1 (Run 3)	To stabilise fishing effort (i.e. mortality) at its 1970 level.
Strategy 2 (Run 6)	To decrease fishing effort to a level that could in total generate F_{opt} on all stocks, but with no restriction on mobility.
Strategy 3 (Run 8)	To allow fishing effort to increase 50% above the present level.
Strategy 4 (Run 7)	As (2) but effort reduced 10% per year over 5 years.

The consequences of these strategies are illustrated in Figure 4. Predictably strategy 2 would cause a substantial immediate loss of catch, and strategy 3 an immediate gain. However, in all four cases the long-term yield following a period of readjustment would be much the same despite retention of the mobility of fleets, although the apparent stability under 3 conceals increased variability in the catches of individual stocks. There would, however, be some changes in the catches from different stocks and, by implication, by some countries. Equally important the strategies imply substantial changes in stock abundance (c.p.u.e.) with implied benefits from strategy 2 to both commercial catch rates and to the spawning stock size and so, more problematically, to long-term catches.

These results refer only to consequential catches of cod. In the event of a reduction in cod fishing effort it may be presumed that the surplus effort could be diverted to other species. If such alternatives exist in the form of lightly exploited stocks, either in the North Atlantic (e.g. for grenadiers), or outside (e.g. hake in the south Atlantic), it seems reasonable to assume, that the immediate return (catch value per day fishing) on these stocks is somewhat less than for cod (otherwise the vessels would already be fishing there). Extra fishing on these stocks would be expected to increase the total yield from them. A diversion of part of the effort away from cod would therefore in the long term increase the total fish catch, though the catch from the particular vessels diverted would drop slightly. This possibility is illustrated in Figure 5A for two hypothetical levels of catch per unit effort for fishing effort diverted on to non-cod stocks.

The change in total catch of cod and alternative species taken by the present cod fleets is impossible to forecast, as it depends on the uses to which the surplus effort is put. Some vessels may be scrapped, or used for non-fishery purposes, thus reducing the total costs of fishing, but it is likely that most would be employed on other stocks. The total catch might then drop in the first year, but would recover, and soon (probably in the second or third year) rise above the present level.

Achievement of an immediate 50% reduction of fishing effort would involve disturbance of a large proportion of the fleet and would be impracticable. An alternative would be a phased reduction such as the

10% reduction phased over 5 years as illustrated in Figure 5B. In fact other sources of annual variation in catches are such that a 5% reduction per year phased over 10 years would cause still less disturbance to catch levels.

This maintenance of the overall catch would only be possible if the alternative stocks are not too heavily exploited. However, their exploitation is rapidly increasing, and opportunities for relatively painless diversion of the surplus and effort may not last much longer.

This summary of the effects of four possible management strategies on the North Atlantic cod fisheries indicates an approach to the study of the interactions between fisheries. The implications of other strategies e.g. the regulation of fishing effort or catch can be studied in a similar way provided the intended strategy is carefully defined.

Section III. Data and Methods: Supplementary Information

1. Analysis of catch and effort statistics

1.1 Catches by stocks

Table 1 shows the total catches of cod in the North Atlantic, by stocks, for the period 1955-1970. During most of this period the total catch of all stocks has fluctuated around a level of roughly 2.7 million tons, but substantially higher catches were made in 1968 and 1969 with the 1968 catch reaching nearly 4 million tons. There was a rapid decline to 3 million tons in 1970.

The table identifies at the top eight major stocks for which data were adequate for detailed assessments. These represent 75-85% of the total catch of Atlantic cod. Adequate data were not available for the remaining stocks which are mostly located in the southern part of the ICNAF and ICES areas; the catches for these are given as "Other ICNAF Stocks" and "Other ICES Stocks" in Table 1. The trend in total catch for the principal stocks is similar to that mentioned above for all North Atlantic cod stocks.

Of the eight stocks given above, four have contributed the major part of the cod catches. The catch in the Arcto-Norwegian stock has generally fluctuated around an average level of about 800 000 tons annually, with catches greater than one million tons in 1955/56 and again in 1968/69, but low catches around 450 000 tons in the 1964/65 period. The 1970 catch was nearly 880 000 tons. In the Iceland area the catches showed a slow but fairly consistent decline from about 500 000 tons in 1955/56 to about 350 000 tons in 1966/67, but increased steadily to 470 000 tons in 1970. The catches in West Greenland (Div. 1A-1D) fluctuated irregularly between 180 000 and 290 000 tons in the 1955-61 period, between 270 000 and 360 000 tons during 1961-68, and declined rapidly to 67 000 tons in 1970. In the Labrador-East Newfoundland area the catches increased steadily from about 300 000 tons in the 1955-58 period to nearly 700 000 tons in 1967, jumped to 900 000 tons in 1968, and declined thereafter to 560 000 tons in 1970.

Of the four smaller stocks, the catches in the South and East Greenland area have fluctuated around an annual average of about 80 000 tons with catches greater than 100 000 tons in 1962-64 and again in 1967-68; the Grand Bank stock yielded catches which fluctuated around 70 000 tons up to 1965, increased rapidly to 220 000 tons in 1967 and declined again to 100 000 tons in 1970; the St Pierre Bank and South Gulf of St Lawrence stocks each yielded catches which fluctuated around an annual average of about 65 000 tons over the 1955-70 period.

It is apparent from the above synopsis that the catches from the individual cod stocks show very different trends and fluctuations, but together, however, they have varied very little over the 1955-70 period, except in 1968 and 1969 when the exceptionally high catches were associated with the recruitment of very good year classes in the Arcto-Norwegian and Labrador-East Newfoundland stocks. A typical example of 'pulse fishing' is to be seen in the rapid doubling of catches in Div. 3NO in 1966/67.

1.2 Catches by countries from the selected stocks

The cod catches by countries for the whole Atlantic in Table 2b relate to all stocks in Table 1 and are included here for reference only. In Table 2a the catches by country from "Other ICNAF" and "Other ICES" stocks have been excluded to isolate the national catches from the stocks here selected for detailed study i.e. those grouped in the first part of Table 1. For these selected stocks the major cod-fishing countries, in order of importance, are Norway (17% of 1970 catch), USSR (15%), Iceland (12%), UK (12%), Spain (11%), Canada (10%), Portugal (6%) and Germany (6%).

During the 1955-70 period the catches by Canada (180 000 - 290 000 tons), Iceland (200 000 - 320 000), Norway (200 000 - 420 000), Portugal (140 000 - 220 000) and UK (270 000 - 390 000 tons) have remained relatively unchanged except for annual variations as indicated by the ranges of catches given in parantheses. However, the catch by Germany increased from about 100 000 tons in the late 1950's to just over 200 000 tons in 1967 and 1968, and the catches by Spain increased more markedly over the same period from 90 000 to 250 000 tons. During most of the 1955-70 period the USSR catch fluctuated between 250 000 and 580 000 tons, but in 1968 and 1969 catches of 920 000 and 800 000 tons were taken. The cod fishery by France yielded catches between 120 000 and 160 000 tons during the 1955-68 period, but there was a substantial decline to 35 000 tons in 1970. The Danish cod fishery by Faroes and Greenlanders increased from about 100 000 tons in 1955-60 to nearly 150 000 tons in 1962, but declined steadily to less than 80 000 tons by 1970. The catches given for "Others" in Table 2a and 2b represent mostly the catches by the German Democratic Republic.

1.3 Catch by country and stock

Table 3 gives the average catch by each country from individual stocks in the period 1966-70. In the Arcto-Norwegian area the USSR catch was about 48% of the total with Norway (33%) and UK (17%) taking most of the remainder. At Iceland the Icelandic cod catch accounts for about 60% and UK about 25%. The Fed. Republic of Germany takes about 50% of the cod catch off South and East Greenland. At West Greenland, F.R. Germany, Denmark and Portugal have taken the greatest share and likewise the 2G-3L stock is exploited by most countries in varying degrees, with Portugal, Canada and Spain having taken the three highest catches. The 3 NO stock has been fished almost exclusively by Spain and USSR, the 3P south stock equally by Canada and Spain and the small 4T-4V north stock mostly by Canada.

While many of the European countries exploit most of the stocks on both sides of the North Atlantic in varying degrees, France, Portugal, Poland and Spain have fished for cod almost exclusively in the Northwest Atlantic. The two North American countries fish exclusively on the cod stocks which are adjacent to their coasts. This also applies to the cod fisheries by Denmark (G) in West and South Greenland, by Iceland on the Icelandic cod stock, and partly by Norway on the Arcto-Norwegian stock.

1.4 The fleet

Statistics of the number of vessels that have caught cod in the North Atlantic in the specified areas were returned by all countries except Faroe, U.S.A. and U.S.S.R. These are summarised in Table 4. The returns account for 80% of the total catch of cod in 1970. The figure for the category < 150 GRT are very imprecise because such fleets are typically very heterogeneous and vessels may not necessarily fish full time. The category 151-500 GRT shows an increase of some 25% in the countries sampled during the period. Except for such vessels of Faroe, Spain and USSR, these categories are henceforward taken to represent 'non-mobile' effort, i.e. fishing effort whose operation is restricted to resources in the immediate vicinity of the home-country. Categories 501-900 GRT and 901+ GRT are here combined to represent the 'mobile' fleet capable of redeployment from one part of the North Atlantic to another, though the 501-900 GRT group has only a limited mobility between a few resources. In these classes a decrease in the number of 501-900 GRT of the sampled countries has been balanced by an increase in the number of 901 + GRT units.

An index of the total number of equivalent fishing units has been calculated for all 501 + GRT vessels as described in the footnote to Table 4. In these terms the size of fleet fishing for cod appears not to be increasing at the present time but this ignores the increases in efficiency of vessels due to their improved range and performance characteristics.

1.5 Fishing effort and catch per unit effort

The fishing effort and catch per unit effort values, given in Table 5, are derived from several sets of national fishing effort data, one or more for each stock, and converted to the equivalent of hours fishing by English trawlers.

In the Arcto-Norwegian and Iceland non-spawning stocks effort data (hours fishing) for English (501-900 GRT) trawlers were used. No time series of fishing effort data is available for the Iceland spawning fishery. For the South and East Greenland stock English hours fishing for all trawler categories was used and for West Greenland A-D F.D.R. German effort data of days fished were converted to an English equivalent with a conversion factor 11.51.

The comparability of fishing effort units between fleets fishing the stocks mentioned above and fleets fishing the remainder of the ICNAF area is difficult to determine because of lack of overlap between fleets. The available statistical evidence indicates that otter trawler hours fished for Portugal, Spain and UK are approximately equivalent and they have been taken as such. For the 2G-3L stock (Labrador-East Newfoundland) Portuguese otter trawl data (hours fished) were taken as being directly equivalent to UK hours fished. For the 3N-O, 3Ps and 4T-Vs stocks Spanish pair-trawl data were taken as being equivalent to Portuguese effort data and consequently equivalent to UK effort unit as used for the North-East Atlantic stocks. Using 1961 as the base year the effort values for the various stocks were raised by 3% per year from 1961 yo 1970 in order to provide for a slow but gradual increase in efficiency which must undoubtedly have occurred especially for the mobile fleets.

As indicated above for the catches in Table 1, the effort values for the various stocks (Table 5 a) show different trends and fluctuations. The Barents Sea/Bear Island stock had high effort levels in the early 1960's and also during 1968-70 with a low level during 1964-65. In contrast, the Labrador-East Newfoundland stock was subjected to almost continuously increasing effort from about 300 000 hours during 1960-63 to nearly 600 000 hours in 1969. Both the East and West Greenland stocks had relatively high effort levels during 1961-64 and in both areas the effort had by 1970 declined to not much more than one-third of the 1961-64 levels.

The catch per unit effort values, given in Table 5 b, are relatively stable for some stocks (e.g. Arcto-Norwegian and Iceland) over most of the 1960-70 period, while for others they fluctuate greatly (e.g. 3N-O, 4T-4Vn and 3Ps). In South and East Greenland the catch per unit effort steadily increased between 1960-61 and 1968-69 with a slight decline in 1970. In West Greenland there was a steady rise from 1962 to 1966 and a steady decline thereafter. In the Labrador-East Newfoundland area there was a steady decline from a high level during 1960-63 to a relatively low level by 1970.

During the period under consideration significant changes have taken place in the patterns of fishing on some of the stocks. For example, it is well known that in the Labrador-East Newfoundland area there has been a major shift from mostly autumn fishing, in the early years, to mostly winter and spring fishing on spawning concentrations in the latter years. Because of such changes in the seasonality pattern of fishing, the catch per unit effort values of Table 5b may not reflect reliable changes in stock abundance.

1.6 The allocation of catches and fishing effort between different sectors of the total fleet

The proportion of the catch in 1970 taken by each category and on each ground is summarised in Table 6. Though the 900 + GRT group takes the greater part of the catch from resources most distant from centres of population, overall the greatest part of the catch is taken by the < 500 GRT sector of the international fleet.

The allocation of catch between vessel categories is used in Table 7 to allocate the available fishing effort, i.e. the national units of English hours fishing adjusted for a 30% increase in efficiency 1960-70. The uncorrected number of hours fished has been related to the number of hours fished per day of German 501-900 GRT trawlers giving an estimated 170-190 days fishing per year per vessel. This is realistic and since the estimate of vessels and hours fishing have been derived independently the comparison adds credibility to the estimate of trend in fleet structure summarised in Table 4.

2. Review of stock assessments

2.1 Arcto-Norwegian. ICES I, IIa, IIb (North-East Arctic Fisheries Working Group Report, ICES, 1970)

The exploitation rate on this stock reached a very high level in the early 1960's, and then declined as mobile fleets transferred their activity to other stocks when the abundance of the Arcto-Norwegian resource fell in 1964. A period of lower exploitation followed until 1968 when the recruitment of two successive strong year classes, 1963 and 1964, increased the relative attraction of this area to the mobile fleet. Catches and the exploitation rate were very high in 1968-1970, and the stock again became overexploited at that time with regard to the long-term yield. The 1963/64 year classes are being followed by a series of weak year classes and in 1971 fishing mortality has fallen to a level of $F = 0.5$, and may decline further. The fluctuations in the fishery have been primarily due to fluctuations in recruitment, which, for a period, attracted excessive fishing effort. These factors leave, in 1972, a stock which contains old fish surviving from the good year classes and one strong recruit year class of 1970 which will enter the fishery in 1973.

The evidence that recruitment is related to spawning stock size is the strongest for all cod stocks in this Arcto-Norwegian stock. The North-East Arctic Fisheries Working Group is of the opinion that the long-term future of the resource as a whole depends largely on the fate of the recruiting 1970 year class. Fishing mortality should be held as low as practicable in order to ensure an increase in the stock.

2.2 Iceland. ICES Va (Northwest Arctic Fisheries Working Group, ICES, 1971)

The fishery for cod at Iceland can be divided into two components:-

Spawning fishery: a fishery in the spring off the south-west corner of Iceland for mostly spawning cod carried out by Icelandic vessels exclusively. This fishery, which accounts for about 46% of the total catch of cod in the Icelandic waters, is based mainly on the spawning stock of cod of Icelandic origin but supported by a component of mature cod immigrating from Greenlandic waters. The proportions of those immigrants probably differs from year to year, and may have a substantial influence onthe results of this fishery.

Non-spawning fishery: a general fishery for cod around the whole Icelandic coast at all times of the year. This fishery is mostly for immature cod and is prosecuted mainly by English, German and Icelandic vessels. Immigrants from Greenland which survive from the Icelandic spawning fishery appear to stay at Iceland and are at least partially available to capture in the non-spawning fishery.

The catch: during the period 1964 to 1967 the catch of cod at Iceland declined to 345 000 tons in 1967 due to lack of good year classes in the spawning fishery, but since 1968 a part of the strong year classes 1961, 1962 and 1963 which originated at Greenland migrated to Iceland and raised the catches again to a high level (471 000 tons in 1970). Previous assessments indicate that an increase in fishing mortality would not result in a further increase in a yield per recruit so this stock can be considered as being fully exploited.

2.3 Iceland-Greenland interrelationship. Methods of calculation

No migration of adult cod from Iceland to Greenland has been observed in the last decades, whereas migration of mature cod from West Greenland to East Greenland /Iceland and from East Greenland to Iceland is known to take place. Results of tagging experiments make it reasonable to neglect the small-scaled migration from Div.1A-1D and to treat the IE-IF and East Greenland cod as a unit stock for assessment purposes.

On the basis of tagging experiments the Northwestern Working Group estimated the actual proportion of mature fish at Greenland emigrating to Iceland as about 25% per year. A new attempt to estimate the migration has been made, using the virtual population technique. Back-calculations to age 3 of mature age groups (i.e. 7+) from the total catch at Iceland and back-calculations from the catches of immature age groups only, to age 3, reveals two different figures. The difference between these is regarded as the number of 3 years old fish in the IE-IF, East Greenland stock which will ultimately migrate to Iceland at maturity.

The stock size at 3 years of age of fish of Greenland origin which will remain at Greenland was back-calculated from the catches of all age groups taken at Greenland. The stock size of fish which would remain at Greenland can be added to the size of the stock of 3 years old ultimately providing the migrants to give the total stock size of all fish of Greenland origin. The migrant stock size can then be expressed as a proportion of the total stock of Greenland origin.

The results indicate that migration may fluctuate between years and year classes, but generally it takes place from age 7-8 and onwards by an average proportion of 24% which is comparable to the findings of the Northwestern Working Group. For simplification in the present analysis, the migration is regarded as an extra natural mortality in the Greenland stock equal to a coefficient of 0.15 and the corresponding number of fish is added to the mature stock at Iceland for each year and age group.

2.4 Greenland. (ICNAF Assessments: Mid-term Report, 1972)

South and East Greenland (ICNAF Div.1E-1F, ICES Subarea XIV)

In the last decade catches have fluctuated between 82 and 131 thousand tons, highest in 1968. The originally mixed fishery (cod plus redfish) is gradually directed more and more towards cod especially fished when concentrating during and around the spawning season. Catch per unit effort has, therefore, been increasing during the decade but this cannot be taken as an index of increased abundance of cod. Rather can it be taken as a sign of increased fishing mortality on older age groups.

Emigration of mature cod from this area to Iceland is mentioned above.

West Greenland (ICNAF Div. 1A-1D)

Catches between 1955 and 1968 fluctuated between 180 and 360 000 tons, highest in 1962. Recent poor recruitment and adverse physical fishing conditions has made 1969 and 1970 catches decline to 141 and 67 thousand tons, respectively. The remaining effort has tended to concentrate more on relatively old fish probably maintaining a relatively high F on these age groups. Prospect for recruitment up to the mid-1970's is bad, and a catch level of not more than 100 000 tons is likely.

The ICNAF Assessment Committee 1972 has concluded that the cod stock of ICNAF Divisions 1A-F is at least fully exploited.

2.5 Labrador - East Newfoundland (ICNAF Div. 2G-3L)

(Pinhorn, 1970; Pinhorn and Wells, 1970)

The fishery on this stock increased steadily from a level of about 300 000 tons during 1955-1959 to about 700 000 tons in 1967, then increased strongly to 900 000 tons in 1968 and 831 000 tons in 1969, but fell to 561 000 tons in 1970 (Table 1). Fishing mortality estimates fluctuated in the vicinity of F_{max} of 0.4 during 1960-66 (0.3-0.6) but were well in excess of the maximum during 1967-69 (0.6-0.75), decreasing to F_{max} of 0.4 in 1970 (Table 12).

Total stock size of fish older than 3 years fluctuated between 2 500 and 5 000 million during 1960-1970 in response to fluctuations in recruitment, while the numbers of fully recruited fish older than 6 years decreased from about 650 million in 1961 to 365 million in 1969 with an increase to 470 million in 1970. Population biomass decreased from 3.5 million tons in 1960 to 2.6 - 2.7 million tons in 1969-1970.

2.6 Grand Bank (ICNAF Div. 3NO)

(Pinhorn and Wells, 1970)

The fishery on this stock fluctuated between 34 and 78 000 tons during 1956-1964 increasing to 96 000 tons in 1965 and 106 000 tons in 1966. The catch more than doubled to 222 000 tons in 1967, decreasing to 110 000 tons in 1968 and 104 000 tons in 1970 (Table 1). The sharp increase in landings in 1967 was a reflection of the entrance of the very strong 1964 year class as 3 year olds and the reduction to the 1966 catch level in 1969 indicates that this year class only contributed significantly to the fishery for two years as ages 3 and 4. The characteristics of the present stock status indicates that the fishery is heavily dependent on individual recruiting year classes and with such a fast growth rate in this area, the long-term yield from a year class is greatly reduced by heavy fishing at an early age.

Catch/effort assessments for 1963-1966 indicated F to be at or beyond the F_{max} of 0.2 during the early 1960's. With increased catch and effort since 1966 F of fully recruited age groups is almost certain to have been well beyond the F_{max} since 1966.

2.7 St Pierre (ICNAF Div. 3Ps)

(Pinhorn, 1972)

The fishery on this stock fluctuated only between 50 000 and 80 000 tons during the entire 1955-1970 period (Table 1). Fishing mortalities for the 1960-1970 period varied between 0.30 and 0.55 and were thus somewhat beyond the F_{max} of 0.30 for this stock for the entire period (Table 12). Total stock size of fish older than 3 years decreased from 225 million in 1960 to 150 million in 1963 and then increased to 325 million in 1970, in response to variations in recruitment. Numbers of fully recruited fish older than age 6 decreased from 30 million in 1960-1961 to 14 million in 1967 and then increased to slightly over 20 million in 1969-1970.

Population biomass decreased sharply from 270 000 tons in 1960 to 180-190 000 tons in 1962-1965, and then increased slowly to 220 000 tons in 1968 and 1969 and 290 000 tons in 1970.

2.8 Southern Gulf of St Lawrence (ICNAF 4T-4Vn)

(Halliday, 1972)

Landings declined from the peak of 110 000 tons in 1964 to 41 000 tons in 1967, but increased again to 64 000 tons in 1970. The most recent increase was due to the mobile fleet effort in Div. 4Vn. Most of the catch is now taken by otter trawls but gill net effort has increased.

Assessment of the effect of fishing on this stock is complicated by density-dependent changes in growth rate and recruitment which, in turn, have caused changes in the rate of recruitment to the fishery and in age at first exploitation. As a result it is difficult to assess an optimum value of F. The recent increase in trawl catches probably increased F only to about 0.3 on 7-10 year olds as stock abundance had increased at the same time. This is lower then the F in 1960-1966 of 0.35-0.60. Thus the stock appears to be in a relatively good state, with some increase in fishing still possible.

2.9 Brown's Lahavre, George's Bank (ICNAF Div. 4X and 5)

Complete assessments for these stocks are not yet available; however, the stocks appear to be rather heavily exploited. For Div. 4X in fact the present F is about twice the value corresponding to maximum-yield-per-recruit. Recent pre-recruit year classes are known to be poor from research vessel surveys.

For Subarea 5, the present effort is somewhat higher than the level corresponding to the maximum sustainable catch and it was considerably higher in the previous six years.

Thus, although these stocks are not included in the model, <u>they will not support additional effort,</u> and, in fact, <u>the effort should be decreased somewhat.</u> The maximum yields from both stocks are probably less than 50 000 tons and a large share of the present effort is non-mobile.

3. Biological characteristics of the stocks incorporated in the simulation model

3.1 Initial stock composition and biomass estimates

The majority of estimates of fishing mortality described in this Report have been derived by virtual population analysis. This method also provides estimates of the size of each stock in terms of millions of fish in each age group at the beginning of each year. The stock structure in a particular year is necessary to initiate a simulation run. For the validation of the model and data the simulation was initiated in 1960; the appropriate data are at Table 11. Subsequent experimental runs were based on analogous stock estimates for 1970.

Though not used explicitly in the model, estimates of biomass were derived by multiplying the estimates of standing stock in numbers per age group from the virtual population analyses by the mean weight per fish which was obtained from various sources (see Table 16). They represent the biomass of the stock of fish aged three and older and are given in Table 12.

The three largest stocks - Arcto-Norwegian, Iceland and Labrador/Newfoundland - amount to 2.1, 2.9 and 2.7 million tons, respectively. For these the biomass has been rather stable since 1960, although the Arcto-Norwegian stock is rather lower than average in 1970. The other stocks are all about 0.3-0.4 million metric tons, and excepting 3Ps, have all declined since 1960. The West Greenland stock in 1970 was only about $\frac{1}{4}$ of its size in 1960.

For most of the stocks, the catch in 1970 was 20-25% of the biomass. It was somewhat lower for the Iceland stock (Σ 16%), and much higher for the Arcto-Norwegian stock (41%).

3.2 Fishing mortality and the catchability coefficient, q

Values for F (Table 9) were taken directly from the virtual population analyses, except for 3NO, where a value of q was estimated and applied to the estimates of effective fishing effort.

The tabulated values represent fishing mortality on fully recruited and, in most cases, the mature stock (ages 7-12).

There are no consistent time trends in F, except that more of the higher values appear in the later years. The estimated F in 1970 dropped for most stocks, after some large increases in 1968-1969 in the Iceland, West Greenland and Labrador stocks.

It is important, however, to relate the F's to those applicable to the younger, recruiting age groups. In many areas the two segments of the stock are fished separately, and a high F on the younger age groups could occur with a low F on the mature stock.

In Table 13 estimates of F (from Table 9) have been used with the independently determined estimates of fishing effort (Table 5) to estimate the catchability coefficient q. The estimates of fishing effort include an adjustment for increases in efficiency with time and for most stocks the implied value of q shows little trend. However, the value of q for the Greenland stock in Div. A-D has increased considerably in recent years: this is thought to reflect concentration of the fleet on a shrinking stock during the spawning season with more efficient fishing gear (midwater trawls).

3.3 Seasonality and seasonal variations in the catchability coefficient

Table 14, the monthly percentage variation in CPUE, gives a picture of the different availability of the fish in the course of the year. It shows the concentration of cod during the first half of the year mainly due to the formation of spawning shoals (pre-spawners, spawners, post-spawners) and partly also due to environmental factors. During the second half of the year the cod are on feeding migration and thus widely spread (horizontally and vertically) and less available to the gears (slack period). The higher summer catches in 4T-4Vn are due to profitable fishing on cod returning from 4Vn to the Gulf of St Lawrence.

Whilst up to the beginning of the 1960's off Greenland and in 2G-3L the fishery of the mobile fleet was mainly carried out during summer and autumn or over the whole year's period, the modern factory trawlers are now fishing for cod mostly only during the first half of the year, when dense concentrations allow profitable catches. During the uneconomic slack period, this fleet goes for other species (e.g. herring).

3.4 Recruitment (Table 8)

For the North Atlantic cod stocks for which recruitment data were available, recruitment of 3 year olds has varied considerably, both in absolute size, in corresponding year classes between stocks (cf. Barents Sea/Bear Island with Iceland) and in the degree of fluctuations of successive year classes within each stock (cf. Barents Sea/Bear Island with 2G-3L) (Table 8). The Icelandic, 2G-3L, 3Ps and 4T-Vn stocks show only moderate fluctuations in year class strength, whereas in the East and West Greenland and 3NO stocks, fluctuations are greater. The Barents Sea/Bear Island stock demonstrated reasonably stable recruitment up to the 1964 year class after which recruitment from the 1965-1968 year classes was only about 5%, the previous level. Similarities evident in recruitment patterns between stocks include the importance of the 1963 year class in the Barents Sea/Bear Island, East Greenland, E and F and 2G-3L, the importance of the 1961 year class from Iceland and East and West Greenland stocks and the similarity of recruitment trends in the Barents Sea/Bear Island and 2G-3L stocks up to the 1965 year class.

3.5 Partial recruitment to the exploited stock

Table 15 gives the pattern of recruitment to each stock in terms of the partial fishing mortality of each age group as a proportion of fishing mortality on fully recruited age groups. It is derived from the mortality analysis and represents the combined effects of biological recruitment to the area of each fishery and selection of the fishing gear in use.

3.6 Growth

The growth rate data (weight at age) in Table 16 are collected from different sources. Data for the Arcto-Norwegian and Icelandic stocks are taken from Working Group reports (ICES, 1971a, b), respectively. The growth data for the 2G-3L and 3Ps stocks are derived from curves of growth in length combined with a length-weight relationship given in papers by May et al. (1965) and Wells and Pinhorn (1970). The growth data for the 3NO stock was derived from data submitted to the meeting by Pinhorn (pers.comm.). The 4T-4Vn stock data are from a paper by Halliday (1972).

4. Interaction between fisheries

In order to examine the interaction between fisheries that follows from the redeployment of fishing effort from one resource to another in response either to the natural fluctuations in the stocks, or to regulation of individual stocks, the data summarised have been incorporated in a simulation model of the total cod resource complex. This model is described by Clayden (1972). A simplified flow diagram showing the relationships between the basic parameters and the resulting computations is at Figure 2. The results of the first control simulation to validate the model are illustrated in Figure 3. This was achieved by restricting the observed fishing effort on each stock to fish only that stock.

This simulation is not perfect. There are differences between actual and simulated catches in most stocks. In general, these can be attributed either to inevitable simplification of reality in the model, or to poor data. The accuracy is considered sufficient to demonstrate that this fishery system can be described by the parameters chosen, and that our estimates of these parameters must be close to the truth.

Having established the validity of the model, the interactions between fisheries were examined for a number of assumptions related to possible changes in fishing effort deployed on these North Atlantic cod resources. This was achieved by allocating the available fishing effort to different sectors of the fleet (Table 7). The effort capacity of the < 500 GRT class was regarded as being restricted to the stocks in the vicinity of its origin, e.g. Norwegian effort < 500 GRT could only fish Barents Sea or Norway Coast. Fleets of this class which do have a degree of mobility were assigned to mobile categories as appropriate. Thus Spanish pair trawlers were assigned to 501-900 GRT class capacity fishing the Northwest Atlantic; Faroese vessels and USSR vessels working with support craft, which may fish both in the north-east and in the north-west Atlantic, were assigned to the 901+GRT class. The 501-900 GRT class has limited range over resources on one side of the Atlantic or the other, but not over all resources. It was divided in two parts according to the 1970 pattern of activity and each part was allowed to fish only stocks in the North-East Atlantic, or stocks in the North-West Atlantic. The 901+ GRT group was permitted to fish any stock. Within the model the fishing effort of the three mobile groups was allowed to fish any stock in its range according to their relative abundance in each month.

In the time available, it was only possible to investigate a small number of possible patterns of interaction, and it has not been possible to consider the redeployment of effort on to species other than cod.

In considering these results it is important to remember that such a model cannot and does not attempt to predict reality because data on future recruitment and on fishing effort cannot become available. The model is a research tool that enables us to investigate interactions over a time period based on the assumption that recruitment will fluctuate as it has in recent years. The relative yields between different strategies will be valid for any level of recruitment, but actual catches would not.

Starting from a 1970 stock situation, and recycling recruitment from 1957 as representing realistic natural fluctuations in stock, five runs were made to study the effect of possible changes in the pattern of fishing on average catches over a 10-year period.

Strategy 1	(Run 3)	Effort kept constant at the 1970 level.
Strategy 2	(Run 6)	Effort reduced in Year 3 and later years to half the 1970 level (= F_{opt} overall).
Strategy 3	(Run 8)	Effort increased in Year 3 and later years to 50% above the 1970 level.
Strategy 4	(Run 7)	Effort reduced by 10% per year between Years 4-8 and thereafter kept constant.
Strategy 5	(Run 4)	Effort increasing at 5% per year over the 10-year period.

The summary results of these runs are given in Table 17. Figure 4 gives the changes in total effort, total catch, and overall catch per unit effort over the 10-year period. In Year 3, the first year of major changes in fishing effort, the catches vary widely, but by the end of the 10-year period the catches from different runs have converged close to the same quantity. The exception is for strategy 4 (Run 7) for which the catches are still in a transitional state at the end of the period, but could be expected also to converge to the common value in later years.

The catches per unit effort shown at the bottom of the figure are very different for different runs. By the tenth year the catch per unit effort for strategy 2 (Run 6) is three times that for strategy 3 (Run 8).

The differences between some runs are shown in Figure 5. In this Figure an attempt has been made to estimate the effects on total catches taken by the present fleets, i.e. including the likely catches taken by the surplus effort diverted to other stocks. The present catch per unit effort on cod is about 0.65 and two values of the catch per unit effort on alternative stocks were assumed - 0.2 and 0.4. Figure 5A shows that if there were a 50% cut in the effort on cod, the cod catch would drop by about 850 000 tons (i.e. a little under 50%), increasing thereafter, but recovering close to the catch taken with the original effort 5 years later. However, the total catch (including catches from stocks to which surplus effort had been diverted) will be considerably higher. At the more conservative estimate of the productivity of the alternative stocks (rather less than one-third that of the cod stocks) the total catch following the reduction of cod effort will be equal to that of the unregulated fleets after four years. On the assumption that the alternative stocks are about two-thirds as productive as cod, there will be a loss only in the first year, and by the seventh year the total catch will be over half a million tons higher.

Similar results are obtained from a phased reduction in effort. There will be a reduction on cod catch over the short period considered, but the total catch will increase and on the more optimistic estimates of catches from alternative stocks the initial decrease will be insignificant.

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TABLE 1. Total nominal catch of COD in the North Atlantic, by stocks, 1955-1970 ('000 tons)

Stocks and areas	Footnotes	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971
Barents Sea/Bear Island ICES I + IIb	1	985	1 112	657	611	566	468	632	771	661	329	345	349	444	911	923	636	
Norwegian Sea, ICES IIa	1	164	233	137	153	180	155	149	138	117	109	100	135	129	163	255	240	
Iceland grounds, ICES Va	2	538	481	452	509	453	465	375	386	402	429	394	357	345	381	406	471	
Greenland East and South ICES XIV + ICNAF 1 E-F	3,4	30	51	77	82	73	86	92	108	130	116	82	90	111	131	90	72	
Greenland West, ICNAF 1 A-D	3	244	294	203	249	180	181	272	360	322	268	296	291	344	279	141	67	
Labrador/Newfoundland East ICNAF 2 G-3 L	3,5	275	311	307	235	351	482	513	513	512	627	619	626	678	906	831	561	
Grand Bank, ICNAF 3 N-O	3	113	65	86	46	62	78	71	34	68	62	96	106	222	160	110	104	
St Pierre Bank, ICNAF 3 Ps	3,6	76	56	78	50	71	73	84	49	47	52	50	64	61	74	59	71	
Southern Gulf of St Lawrence, ICNAF 4T-Vn	3,7	40	68	67	69	62	73	71	76	78	72	75	64	49	54	57	74	
Total in model (A)		2 465	2 671	2 064	2 004	1 998	2 136	2 259	2 435	2 337	2 064	2 057	2 082	2 383	3 059	2 872	2 296	
% (A/B)		85	85	80	76	80	80	81	82	81	78	76	75	76	78	80	76	
Other ICES stocks ICES III, IV, VI, VII & Vb	8,10	300	318	374	337	319	350	295	311	327	329	395	462	414	565	475	475	
Other ICNAF stocks ICNAF 3M, 3Pn-4s,4Va-W, 4X & 5	3,11	132	146	153	166	175	186	219	216	226	240	263	250	244	290	223	236	
Total all stocks (B)	9	2 897	3 135	2 591	2 507	2 492	2 672	2 773	2 962	2 890	2 633	2 715	2 794	3 141	3 914	3 570	3 007	

1) From Reports of the North-East Arctic Fisheries Working Group, 1965-1972
2) From Report of the North Western Working Group, 1970
3) From ICNAF Statistical Bulletins
4) From Meyer and Horsted
5) Denmark (F), Norway and non-member catches not reported by Subareas or Divisions are assigned to stock 2G-3L
6) 3Pn included prior to 1960
7) 4Vn excluded prior to 1960
8) From Bulletin Statistique
9) Do not include catch of Norwegian Fjord cod, fluctuating between 30-50 000 tons annually
10) Other ICES stocks are caught in the Baltic, Skagerrak, North Sea, S and W of the British Isles and Faroe Islands
11) Other ICNAF stocks are Flemish Cap, West Newfoundland, Barquereau, Brown's Lahavre and George's Bank

<u>Table 2 a</u> Total nominal catch of COD in the North Atlantic (Table 1, Group A) (excluding other stocks), by countries, 1955-1970 ('000 tons)

Countries	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971
Belgium	9	8	7	10	5	6	5	8	-	-	4	3	2	3	3	5	
Canada (M)	65	85	85	76	70	56	54	63	60	57	59	56	46	49	53	50	
Canada (N)	192	205	197	146	200	206	161	176	187	175	160	165	148	159	146	103	
Denmark (F)	78	76	70	69	60	75	78	110	100	94	85	82	82	67	66	56	
Denmark (G)	20	21	24	27	28	29	35	36	24	23	25	30	29	22	25	21	
France (M)	160	148	143	117	132	137	147	160	121	136	112	125	127	129	77	35	
France (SP)	5	7	5	3	5	4	5	3	3	4	5	5	3	2	3	2	
Germany F.R.	89	130	81	96	82	103	142	181	191	152	182	176	204	228	188	151	
Iceland	324	302	257	298	292	305	248	223	240	281	244	228	204	234	286	313	
Italy	10	9	7	3	5	2	3	1	-	-	-	-	-	-	-	-	
Japan	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	
Netherlands	-	-	-	1	-	-	-	-	-	-	2	-	-	-	-	-	
Norway	319	383	293	332	321	271	319	264	246	194	237	246	278	331	357	421	
Poland	-	-	-	-	1	1	2	3	9	10	20	36	54	88	76	53	
Portugal	190	215	195	161	147	169	176	202	211	192	182	183	218	200	173	140	
Romania	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	3	
Spain	87	99	100	88	102	120	137	139	152	170	180	172	220	252	236	240	
U.K.	361	394	312	312	307	273	274	310	292	265	260	264	282	299	336	310	
U.S.A.	+	+	+	+	+	+	+	+	+	+	+	+	+	+	1	1	
U.S.S.R.	552	585	285	269	243	365	471	558	476	268	265	254	416	917	799	390	
Others	-	-	-	1	+	1	+	+	1	44	51	62	70	82	55	17	
Total	2 461	2 667	2 061	2 009	2 000	2 123	2 257	2 437	2 313	2 065	2 073	2 087	2 383	3 062	2 883	2 311	

The slight discrepancies between these total and those in Table 1(A) are due to the inclusion of some catches which were not allocated to stocks for Table 1.

Table 2 b Total nominal catch of COD in the North Atlantic (Table 1, Group B) by countries, 1962 - 1970 ('000 tons)

Countries	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971
Belgium	15	12	10	18	21	22	28	17	12	
Canada (M)	115	112	112	124	120	110	122	115	110	
Canada (N)	206	222	204	190	188	176	201	179	153	
Denmark (M)	63	69	68	79	90	93	107	94	97	
Denmark (F)	116	106	103	95	90	90	81	87	71	
Denmark (G)	36	24	23	25	30	29	22	25	21	
Finland	+	+	+	+	+	+	+	+	+	
France (M)	188	145	178	168	174	187	207	135	141	
France (SP)	3	3	4	5	5	3	2	3	2	
Germany F.R.	200	208	176	210	208	239	274	223	185	
Iceland	223	240	279	244	232	204	234	286	308	
Ireland	1	1	2	2	2	3	3	3	3	
Italy	1	-	-	-	-	-	-	-	-	
Japan	-	-	-	-	-	-	-	+	+	
Netherlands	8	8	11	22	24	27	31	20	25	
Norway	290	277	224	262	290	298	354	430	458	
Poland	47	58	54	67	105	116	155	146	126	
Portugal	218	231	210	197	202	237	219	182	163	
Romania	-	-	-	-	-	-	-	3	4	
Spain	199	212	222	226	234	280	330	287	268	
Sweden	36	33	25	26	28	30	31	25	23	
U.K.	386	385	362	380	388	421	447	456	414	
U.S.A.	20	18	17	16	17	20	22	26	24	
U.S.S.R.	609	537	340	344	357	532	986	818	449	
Others	+	1	44	51	62	71	82	55	17	
Total	2 980	2 902	2 668	2 751	2 867	3 188	3 938	3 615	3 074	

The slight discrepancies between these totals and those in Table 1 (B) are due to the inclusion of some catches which were not allocated to stocks for Table 1.

TABLE 3. Average annual catch of COD 1966-1970 by country and stock ('000 tons)

Stocks and areas	Belgium	Canada		Denmark			Finland	France		Germany (FR)	Iceland	Ireland	Japan	Nether-lands	Norway	Poland	Portugal	Romania	Spain	Sweden	UK	USA	USSR	Others	Total
		(M)	(N)	(M)	(F)	(G)		(M)	(SP)																
ICES I + IIb	-	-	-	-	-	-	-	+	-	2	-	-	-	-	141	1	-	-	-	-	109	-	399	-	652
ICES IIa	-	-	-	-	10	-	-	+	-	3	-	-	-	+	131	-	-	-	-	-	39	-	-	-	183
ICES Va	3	-	-	-	3	-	-	+	-	20	247	-	-	+	+	+	-	-	-	-	117	-	1	-	391
ICES XIV + ICNAF 1 E-F	-	-	+	-	13	10	-	3	-	48	7	-	-	-	8	+	3	-	1	-	5	-	+	4	102
ICNAF 1 A-D	-	-	-	-	29	15	-	29	-	59	+	-	-	-	25	+	36	-	14	-	6	+	1	9	223
ICNAF 2G-3L	-	2	111	-	15	-	-	60	+	58	+	-	+	-	21	59	126	1	101	-	21	+	89	46	710
ICNAF 3 N-O	-	1	4	-	-	-	-	1	+	-	+	-	+	-	-	1	6	+	68	-	1	-	59	1	142
ICNAF 3 Ps	-	1	28	-	-	-	-	2	2	-	-	-	+	-	-	+	+	-	27	-	1	-	4	+	65
ICNAF 4T-Vn	-	48	4	-	-	-	-	2	+	+	-	-	-	-	+	+	1	-	5	-	+	+	+	+	60
Other ICES Stocks	17	-	-	96	12	-	+	32	-	38	+	2	-	25	7	64	-	-	+	27	121	-	52	-	493
Other ICNAF Stocks	-	64	32	-	2	-	-	29	+	+	+	-	+	-	-	2	18	+	64	-	3	21	13	+	248
Total	20	116	179	96	84	25	+	158	2	228	254	2	+	25	333	127	190	1	280	27	423	21	618	60	3269

Table 4 **Summary of fleet statistics**

Year	Total Catch ('000 tons)	Vessel Category: <150[2)]	151-500	501-900	901+	Best estimate total fleet all countries — Non-Mobile: <150[2)]	151-500	Mobile: 501+[3)]
1960	1 840	42	342	456	124	42	342	934
1961	1 886	43	357	447	143	43	357	1 057
1962	1 941	45	344	436	144	45	344	1 090
1963	1 915	45	358	413	160	45	358	1 084
1964	1 835	45	381	398	165	45	381	1 012
1965	1 861	45	401	397	177	45	401	1 049
1966	1 882	44	419	419	172	44	419	1 048
1967	2 036	43	433	412	210	43	433	1 233
1968	2 235	42	426	400	226	42	426	1 440
1969	2 151	40	437	375	224	40	437	1 336
1970	2 090	40	456	356	215	40	456	1 089

Columns 2–6: Data from countries returning statistics[1)]

1) No data were available for the total North Atlantic for Denmark (Faroes), U.S.S.R., U.S.A.

2) Approximate thousands of vessels. Includes 25 000 Norwegian vessels as estimated by census 1960. Excludes U.S.A. vessels.

3) From the performance of vessels and catches returned for 1970 the annual catch of one unit >901 GRT = 2.5 units (501-900 GRT). Using this factor for the sampled vessels, the two vessel categories have been amalgamated to a single class >501 GRT and then raised to estimate the total fleet of all countries in this category on the indicated assumption that 95% of the unsampled catch was taken by vessels in this category, or having equivalent mobility in choice of area of fishing.

Table 5a Notional fishing effort per stock (English fishing hours ('000) raised by simple 3% increase in efficiency per year relative to 1960)

N.B. The conversion from Spanish fishing effort to English is very imprecise owing to lack of overlap in the fishing activity of the two fleets. As a result the level of fishing effort subtotalled for ICNAF may only be accurate ± 20%, but the trend is valid. If effort is underestimated, as seems most probable, catch per unit effort for most ICNAF stocks would be lower.

Year	ICES I+IIa 1)	ICES IIb 1)	ICES Va non-sp. 1)	ICES Va Spawning 2)	ICNAF E+F + ICES XIV 3)	ICNAF 1A-D 4)	ICNAF 2G-3L 5)	ICNAF 3NO 6)	ICNAF 3 Ps 6)	ICNAF 4T-4VN 6)	Subtotal NEAFC 7) + ICNAF 1E+F	Subtotal ICNAF	Total
1960	933	420	578		91	159	280	76	69	54	2 022	636	2 658
1961	1 068	337	602		103	229	339	70	89	55	2 110	782	2 892
1962	1 193	298	629		103	322	296	46	52	47	2 223	766	2 986
1963	1 212	334	643		120	253	287	45	49	44	2 309	678	2 987
1964	796	206	613		108	203	403	50	37	43	1 723	736	2 459
1965	765	322	621		61	219	429	66	37	48	1 769	799	2 568
1966	785	323	552		63	195	398	80	48	50	1 723	781	2 494
1967	846	362	494		76	254	421	167	57	45	1 778	944	2 722
1968	1 607	321	423		84	238	570	123	52	37	2 435	1 020	3 455
1969	1 337	446	353		60	133	587	105	46	36	2 196	857	3 053
1970	1 169	397	420		49	64	517	105	68	47	2 035	801	2 836

Table 5b Catch per Notional Unit Fishing Effort

Year	ICES I+IIa	ICES IIb	ICES Va non-sp.	ICES Va Spawning	ICNAF E+F + ICES XIV	ICNAF 1A-D	ICNAF 2G-3L	ICNAF 3NO	ICNAF 3 Ps	ICNAF 4T-4VN	Subtotal NEAFC + ICNAF 1E+F	Subtotal ICNAF	Total
1960	0.50	0.37	0.41		0.95	1.14	1.72	1.05	1.06	1.35			
1961	0.59	0.44	0.32		0.89	1.19	1.51	1.01	0.94	1.29			
1962	0.65	0.46	0.33		1.05	1.12	1.73	0.74	0.94	1.62			
1963	0.55	0.35	0.35		1.08	1.27	1.78	1.51	0.96	1.77			
1964	0.41	0.53	0.31		1.07	1.32	1.56	1.24	1.41	1.67			
1965	0.45	0.31	0.37		1.34	1.35	1.44	1.45	1.35	1.56			
1966	0.44	0.42	0.34		1.43	1.49	1.57	1.33	1.33	1.28			
1967	0.52	0.36	0.39		1.46	1.35	1.61	1.33	1.07	1.09			
1968	0.37	0.51	0.53		1.56	1.17	1.59	1.30	1.42	1.46			
1969	0.69	0.57	0.59		1.50	1.06	1.42	1.05	1.28	1.58			
1970	0.54	0.60	0.59		1.47	1.05	1.09	0.99	1.04	1.57			

Source	Conversion to English Unit
1) English hours fishing (OT 501-900 GRT)	1.00
2) No data available (Fishery by Iceland only)	
3) English hours fishing (ICNAF S.A. 1 Div. E&F only. OT all classes)	1.00
4) German days fished (OT 501-900 GRT May-August only)	11.51
5) Portuguese hours fishing (OT all classes)	1.00
6) Spanish hours fishing (OT all classes)	1.00
7) Excludes fishing effort in the Iceland spawning fishery for which there are no data.	

Table 6 Percentage distribution of catches in 1970 by vessel categories with different degrees of mobility

	Non-Mobile <500	Part-Mobile 501-900	Mobile 901+
Stocks in Model			
Barents Sea/Bear Island	36	42	22
Norway Coast	77	14	9
Iceland	71	25	4
Greenland East, 1E+F	15	17	68
Greenland 1A-D	25	34	41
Labrador 2G-3L	18	18	64
Grand Bank 3NO	7	61	32
3Ps	39	53	8
4Ts - 4Vn	64	24	12
Other Stocks			
3Pn - 4Rs	38	9	53
4Vs - 4X	34	46	20
5	73	24	3
Catch ('000 tons)	1 048[1)]	721	757
% of Total Catch	41	29	30

1) Includes 86 000 tons landed by this category of U.S.S.R. vessels fishing Barents Sea/Bear Island which may be considered as mobile effort if used with support craft.

Table 7 Distribution of fishing effort in 1970 between vessel categories

	'000 hours corrected (See Table 5a)			Total	'000 hours uncorrected
	<500	501-900	900+		501 GRT+
Barents Sea/ Bear Island	421	491	257	1 169	524
Norway Coast	305	56	36	397	64
Iceland Non-spawning	0	420[2)]	-	420	294
Iceland Spawning	(620)[1)]	0	0		
Greenland East, 1E&F	8	8	33	49	29
Greenland 1A-D	16	22	26	64	34
Labrador 2G-3L	93	93	331	517	297
Grand Bank 3NO	7	64	34	105	69
St Pierre 3Ps	27	36	5	68	29
4T - 4Vn	30	11	6	47	12

NB Estimated total hours fished by vessels 501 + GRT...... = 1 352 000

Equivalent number of fishing days (F.R.W. Germany Day fished = 11.51 English hours) .... = 117 000

Total number of vessels in this class (estimated Table 4) .... = 600 - 700

Implied days fishing per vessel year .... = 195 - 167

1) Adapted to simulate appropriate fishing mortality; it does not measure fishing effort.

2) Includes some catch by vessels of other categories which are not separated in the statistics for this sector of the fishery at Iceland.

Table 8 Recruitment by year classes, 3 year olds (in millions)

Year	ICES I + IIb	ICES IIa	ICES Va: Iceland Non-Sp.	ICES Va: Iceland Sp.	ICES XIV, ICNAF 1E-F	ICNAF 1A-D	ICNAF 2G - 3L	ICNAF 3NO	ICNAF 3 Ps	ICNAF 4T - 4Vn
1957	1 028		124		85	371	999	(100)	(50)	135
1958	1 233		198		62	93	551	(100)	(50)	49
1959	1 034		125		18	65	583	(100)	47	62
1960	693		142		61	289	487	(100)	36	45
1961	513		291		177	338	967	(100)	71	65
1962	1 117		229		79	133	1 867	50	87	52
1963	2 111		214		132	133	2 675	60	105	63
1964	1 458		318		26	41	1 443*	444	108	119
1965	122		164		8	61	461*	114	64	131
1966	48		218		25*	42	1 914*	195	200*	(80)
1967	39		200*		25*	30*	2 259*	87	80*	(80)
1968	16		(200)		72*	90*	2 000*	228	180*	(80)
1969	400*		(150)		25*	30*	(1 000)	(100)	(180)	(80)
1970	1 700*		(200)		25*	30*	(1 000)	(100)	(180)	(80)

* Preliminary estimates based upon pre-recruit surveys or commercial data of newly recruited year classes.

Values in brackets are interpolated for computation in the model (Section III).

Table 9 Summary of F per total stock as mean of ages 7-12 estimated by virtual population analysis

Year	Arcto-Norwegian ICES I, IIa + IIb	Iceland non-sp.+ spawning ICES Va	Greenland East, ICES XIV ICNAF 1E-F	Grenland ICNAF 1A-D	ICNAF 2G-3L	ICNAF 3NO 1)	ICNAF 3Ps	ICNAF 4T-4Vn
1960	.50		.25	.19	-	.26	.43	.47
1961	.65		.33	.35	.40	.25	.54	.37
1962	.63		.42	.49	.41	.16	.40	.35
1963	.86	.60	.43	.59	.32	.16	.30	.45
1964	.72	.77	.52	.85	.48	.18	.50	.46
1965	.50	.74	.50	.51	.61	.23	.42	.60
1966	.50	.57	.43	.49	.44	.28	.80	.39
1967	.63	.74	.53	.70	(.61)	.58	.51	.28
1968	.49 2)	1.24	.29	1.06	(.75)	.43	.46	.25
1969	.82 2)	.90	(.25)	(.76)	(.70)	.37	(.55)	(.25)
1970	(.60) 2)	.94	(.30)	(.49) 3)	(.40)	.37	(.55)	(.30)

N.B. Estimates for recent years given in brackets are less reliable.

1) Based upon a value of q for 1960-1964 applied to estimated effective fishing effort.

2) These values differ slightly from estimates presented in the North-East Arctic Fisheries Working Group Report 1972 for technical reasons.

3) This value differs from that given for Subarea 1 as a whole in ICNAF Mid-term Assessments Committee Report 1972, because the fishery has here been split to take account of the interrelationship between the Iceland and Greenland stocks.

Table 10 Present status of stocks relating the present (1966-70) fishing mortality to the fishing mortality at the maximum sustainable yield per recruit, and at F_{opt} (see text page 5 for definition)

Stock	Arcto-Norwegian[2] I+IIa+IIb (a)	Arcto-Norwegian[2] I+IIa+IIb (b)	Fish of Iceland & Greenland immigrants	East Greenland E + F	West Greenland 1A-D	Labrador-Newfoundland 2G - 3L	Grand Bank 3 NO	3 Ps	4T and 4Vn
Source	Anon 1972 Growth (a)	Anon 1972 Curve (b)	This meeting[3]	This meeting	Horsted & Garrod (1969) This meeting	Pinhorn	Pinhorn & Wells (1970)	Pinhorn (1972)	Halliday (1972)
Fishing mortality for given objective[1]									
Recent F(1966-1970)	.6		.9	.4	.7	.6	.4	.6	.3
F_{opt}	.37	.38	.42	.45	.35	.23	.10	.20	.4-.45
F_{max}	1.20	.55	1.40	.65	.56	.40	.20	.30	
F_{95}	.42	.36	.65	.46	.36	.25	.12	.19	
F_{90}	.35	.32	.48	.39	.30	.20	.10	.16	
Surplus F, over F_{opt} as % in 1966-70 of recent F 1966-70	38		53	NIL	50	62	75	67	NIL

Notes: 1) F_{max}, F_{95}, F_{90} were calculated as the fishing mortalities giving the maximum, 95% or 90%, of the maximum <u>yield per recruit.</u> The fishing mortality giving the maximum <u>total</u> sustained yield could not be calculated, but is possibly not far from F_{opt}.

2) Calculated for two alternative growth curves.

3) Calculated with F increasing with age between 3 and 9 years old, referring to fish of Icelandic origin and immigrants from Greenland. Tabulated values refer to 9 years and older.

Table 11 Stock composition at the beginning of 1960 (in millions)

Age Groups	ICES Subarea I Div. IIb 1)	ICES Div. IIa 5)	ICES Subarea Va non-spawning 2)	ICES Subarea Va spawning 5)	Greenland, ICES Subarea XIV + E+F 2)	ICNAF Greenland A-D 2)	ICNAF 2G-3L 3)	ICNAF 3 NO 3)	ICNAF 3 Ps 3)	ICNAF 4T-4Vn 4)
3	1 059		124		85	371	999	150	(50)	135
4	664		228		88	115	662	75	47	143
5	297		102		14	38	413	30	73	71
6	243		43		10	26	283	33	23	48
7	85		57		38	90	243	18	13	20
8	29		26		6	15	188	7	9	6
9	30		21		4	11	128	6	4	3
10	30		43		10	24	100	3	2	4
1	10		2		2	6	72	2	1	1
2	5		1		2	14	45	2	1	1
3	1				5		47	2	1	1
14+					1		54	5		

1) Working papers of North-East Arctic Fisheries Working Group
2) Present Report
3) ICNAF Assessment Committee Report, Mid-term 1972
4) Pinhorn 1970
5) The stock in these fisheries is generated by survivors from the stocks in the Barents Sea/Bear Island and Iceland non-spawning fisheries.

Table 12 Estimates of population biomass ('000 tons)

Years	ICES I+IIb	ICES IIa	ICES Va non-sp.	ICES Va spawning	ICES XIV ICNAF 1E-F	ICNAF 1A-D	ICNAF 2G-3L	ICNAF 3 NO	ICNAF 3 Ps	ICNAF 4T-4Vn
1960	2 756		3 072		540	1 272	3 473		272	355
1961	2 905		3 272		570	1 327	2 951		268	390
1962	2 878		2 586		538	1 217	2 793		188	401
1963	2 556		2 654		498	1 085	2 588		180	380
1964	2 090		2 680		520	1 059	2 475		193	324
1965	2 329		2 722		480	1 069	2 510	not available	192	268
1966	3 227		2 951		616	1 023	2 853		210	218
1967	4 098		3 036		640	875	2 455		208	213
1968	3 645		3 054		417	601	2 625		222	235
1969	2 853		2 928		509	387	2 625		218	262
1970	2 091		2 876		384	282	2 693		286	282

Table 13 Comparison of fishing mortality (average 7-12 year olds) and notional fishing effort to calculate catchability (q) expressed as fishing mortality per million hours fishing

	Barents Sea 1) Bear Island			Norway Coast 1)			Iceland 2) non-sp.			Iceland 3 spawning			Greenland East, E + F		
	F	f	q	F	f	q	F	f	q	F	f 3)	q 3)	F	f	q
1960	.24	933	.253	.26	420	.612 x		578		.62	620	1.000	.22	91	2.418
1961	.33	1 068	.314	.32	337	.964 x		602		.62	620	1.000	.31	103	3.010
1962	.29	1 193	.245	.34	298	1.151 x		629		.62	620	1.000	.35	103	3.398
1963	.35	1 212	.291	.51	334	1.533 x	.20	643	.311	.62	620	1.000	.34	120	2.833
1964	.29	796	.364	.43	206	2.073 x	.17	613	.277	.62	620	1.000	.50	108	4.630
1965	.21	765	.275	.29	322	.901	.21	621	.338	.53	530	1.000	.50	61	8.197
1966	.20	785	.261	.30	323	.916	.20	552	.362	.37	370	1.000	.43	63	6.825
1967	.32	846	.382	.31	362	.851	.18	494	.364	.56	560	1.000	.60	76	7.895
1968	.22	1 607	.137	.27	321	.844	.27	423	.638	.97	970	1.000	.29	84	3.452
1969	.51	1 337	.385	.31	446	.695	.23	353	.651	.67	670	1.000	.25	60	4.167
1970	(.27)	1 169	(.230)	(.33)	397	(.834)	(.32)	420		(.62)	620	1.000	(.30)	49	(6.122)
Mean q			.285			.851			.420						4.813

	Greenland A-D			2G - 3L			3NO			3Ps			4T - Vn		
	F	f	q	F	f	q	F 3)	f	q 3)	F	f	q	F	f	q 3)
1960	.19	159	1.195	-	280	-	.26	74	3.500	.43	69	6.232	.47	54	8.704
1961	.35	229	1.528	.40	339	1.180	.25	70	3.500	.54	89	6.067	.37	55	6.727
1962	.49	322	1.522	.41	296	1.385	.16	46	3.500	.40	52	7.692	.35	47	7.447
1963	.59	253	2.332	.32	287	1.115	.16	45	3.500	.30	49	6.122	.45	44	10.227
1964	.85	203	4.187	.48	403	1.191	.18	50	3.500	.50	37	13.514	.46	43	10.698
1965	.51	219	2.329	.61	429	1.422	.23	66	3.500	.42	37	11.351	.60	48	12.500
1966	.49	195	2.513	.44	398	1.106	.28	80	3.500	.80	48	16.667	.39	50	7.800
1967	.70	254	2.756	(.61)	421	(1.449)	.58	167	3.500	.51	57	8.947	.28	45	6.222
1968	1.06	238	4.454	(.75)	570	(1.316)	.43	123	3.500	.46	52	8.946	.25	37	6.757
1969	(.76)	133	(5.714)	(.70)	587	(1.193)	.37	105	3.500	(.55)	46	(11.957)	(.25)	36	6.944
1970	(.49)	64	(7.656)	(.40)	517	(.774)	.37	105	3.500	(.55)	68	(8.088)	(.30)	47	(6.383)
Mean q			3.290			1.262		3.500				9.589			8.219

x) Values excluded from calculation of mean q.

Footnotes 1) and 2) : Estimates of fishing mortality have been calculated for the total stock fished in both areas and divided between the sub-stock units by the proportion of the catch taken in each fishery. The total fishing mortality on each total stock is given by direct addition (see Table 9).

Footnote 3): These figures have been derived for computational purposes.

Table 14a Seasonal pattern of fishing as the deviation of the average CPUE for each separate month over a number of years, from the annual mean CPUE for all months

Months	ICES I + IIb	ICES IIa	Iceland non-sp. ICES Va	Iceland spawning ICES Va	Greenland East, ICES XIV, E+F	Greenland A-D	2G - 3L	3 NO	3 Ps	4T-4Vn
Jan.	95	159	67	78	70	127	168	6	6	70
Feb.	78	164	-	194	80	123	167	6	6	53
Mar.	92	173	107	200	100	135	129	112	112	60
Apr.	108	195	113	222	135	100	122	200	200	79
May	131	104	133	222	150	112	100	135	135	93
June	152	-	133	111	133	96	89	147	147	157
Jul.	125	-	131	56	75	80	134	177	177	199
Aug.	115	72	93	28	40	51	55	59	59	180
Sept	102	55	93	28	42	33	63	94	94	118
Oct.	62	36	80	28	43	37	63	106	106	72
Nov.	77	41	67	28	48	80	55	129	129	67
Dec.	115	68	77	28	57	102	55	112	112	60

Table 14b. Seasonal variation in catchability coefficient

Monthly Catchability Coefficient \ mean q	.285	.851	.420	1.000	4.813	3.290	1.262	3.500	9.589	8.219
Jan.	.266	1.353	.281	.780	3.369	4.178	2.120	.210	.575	5.753
Feb.	.218	1.395	-	1.940	3.850	4.046	2.107	.210	.575	4.356
Mar.	.257	1.472	.449	2.000	4.813	4.441	1.627	3.920	10.739	4.931
Apr.	.302	1.659	.474	2.220	6.497	3.290	1.539	7.000	19.178	6.493
May	.366	.885	.559	2.220	7.219	3.684	1.262	4.725	12.945	7.644
June	.425	-	.559	1.110	6.401	3.158	1.123	5.145	14.095	12.493
July	.350	-	.550	.560	3.609	2.632	1.691	6.195	16.972	16.356
Aug.	.322	.612	.390	.280	1.925	1.677	.694	2.065	5.657	14.794
Sept	.285	.468	.390	.280	2.021	1.085	.795	3.290	9.013	9.698
Oct.	.173	.306	.336	.280	2.069	1.217	.795	3.710	10.164	5.918
Nov.	.215	.348	.281	.280	2.310	2.632	.694	4.515	12.369	5.507
Dec.	.322	.578	.323	.280	2.743	3.355	.694	3.920	10.739	4.931

Sources: See Table 11 for ICES Stocks
ICNAF Statistical Bulletin, CPUE of selected countries for ICNAF Stocks

Table 15 Pattern of recruitment to the fishery, the fishing mortality in each age group as a percentage of the average fishing mortality of age groups 7-12

Age group	ICES I+IIb	ICES IIa	ICES Va non-sp.	ICES Va spawning	ICES SA XIV ICNAF SA 1, E+F	ICNAF SA 1, A-D	ICNAF 2G-3L	ICNAF 3NO	ICNAF 3Ps	ICNAF 4T-4Vn
3	.10	0	.05	.01	.01	.09	.02	.20	.04	.02
4	.59	0	.23	.03	.08	.27	.14	.60	.38	.21
5	1.17	.03	.82	.04	.41	.64	.34	1.00	.11	.51
6	1.45	.06	1.00	.11	.67	1.00	.61		.85	.77
7	1.45	.14		.29	1.00		1.00		1.00	1.00
8	1.34	.51		.55						
9	1.07	1.17		.85						
10	.86	1.43		1.00						
11	.86	1.46								
12	.48	1.23								
13	.48	1.23								
14	.48	1.23	↓	↓	↓	↓	↓	↓	↓	↓

Table 16 Growth rate, i.e. round fresh weight at each age in kilogrammes

3	.43		1.48			.62	.18	.47	.28	.22
4	.84		2.41			1.18	.44	.79	.69	.54
5	1.36		3.45			2.10	.82	1.37	1.08	1.00
6	2.00		4.32			3.08	1.24	2.47	1.68	1.67
7	2.92		5.16			3.81	1.71	3.55	2.40	2.05
8	3.87		5.72			4.54	2.17	4.93	3.21	2.84
9	5.25		6.29			5.55	2.62	6.05	4.10	3.37
10	6.50		6.73			6.00	3.07	7.50	5.08	3.96
11	8.23		7.19			6.50	3.47	9.23	6.03	4.45
12	9.43		7.58			6.50	3.83	11.06	7.00	4.80
13	10.60		8.00			6.50	4.15	12.40	8.05	5.17
14	11.80		8.47			6.50	4.43	13.80	9.16	5.75

Table 17 Summary of COD catches simulated for different management strategies

Strategy	Run	Level of Fishing Effort	Objective
1	3	1970	Control series fishing effort stabilised at present level
2	6	Effort from year 3 x 0.5	Abrupt reduction of effort to the level for F_{opt} overall
3	8	Effort from year 3 x 1.5	Abrupt increase of effort to a level 50% above 1970
4	7	Effort from year 4-8 x 0.90	Phased reduction of effort, -10% per years 4-8
5	4	Effort increasing +5% all years	Gradual increase in fishing effort at 5% per year

Average catch per year ('000 tons) over a 10 year period

Strategy	Run	I+IIb	IIa	Iceland Non-sp.	Iceland Sp.	E.Greenland E+F	1A-D	2G-3L	3 NO	3 Ps	4T-4Vn	$\sum$
1	3	361	111	254	117	91	140	680	123	77	65	2 021
2	6	265	115	199	108	77	116	613	116	79	62	1 749
3	8	407	102	287	115	96	149	695	122	76	65	2 114
4	7	288	108	222	105	81	119	629	114	75	62	1 806
5	4	400	106	278	118	96	149	697	124	77	66	2 110

Average catch per unit effort over a 10 year period

Strategy	Run	I+IIb	IIa	Iceland Non-sp.	Iceland Sp.	E.Greenland E+F	1A-D	2G-3L	3 NO	3 Ps	4T-4Vn	$\sum$
1	3	.39	.26	.38	(.27)	.61	.69	1.38	.87	.67	.69	
2	6	.55	.41	.44	.41	.83	.98	1.99	1.29	1.04	1.01	
3	8	.32	.20	.32	.21	.50	.54	1.10	.53	.55	.69	
4	7	.44	.33	.42	.32	.70	.84	1.57	1.01	.78	.82	
5	4	.34	.22	.34	.23	.54	.59	1.19	.75	.58	.59	

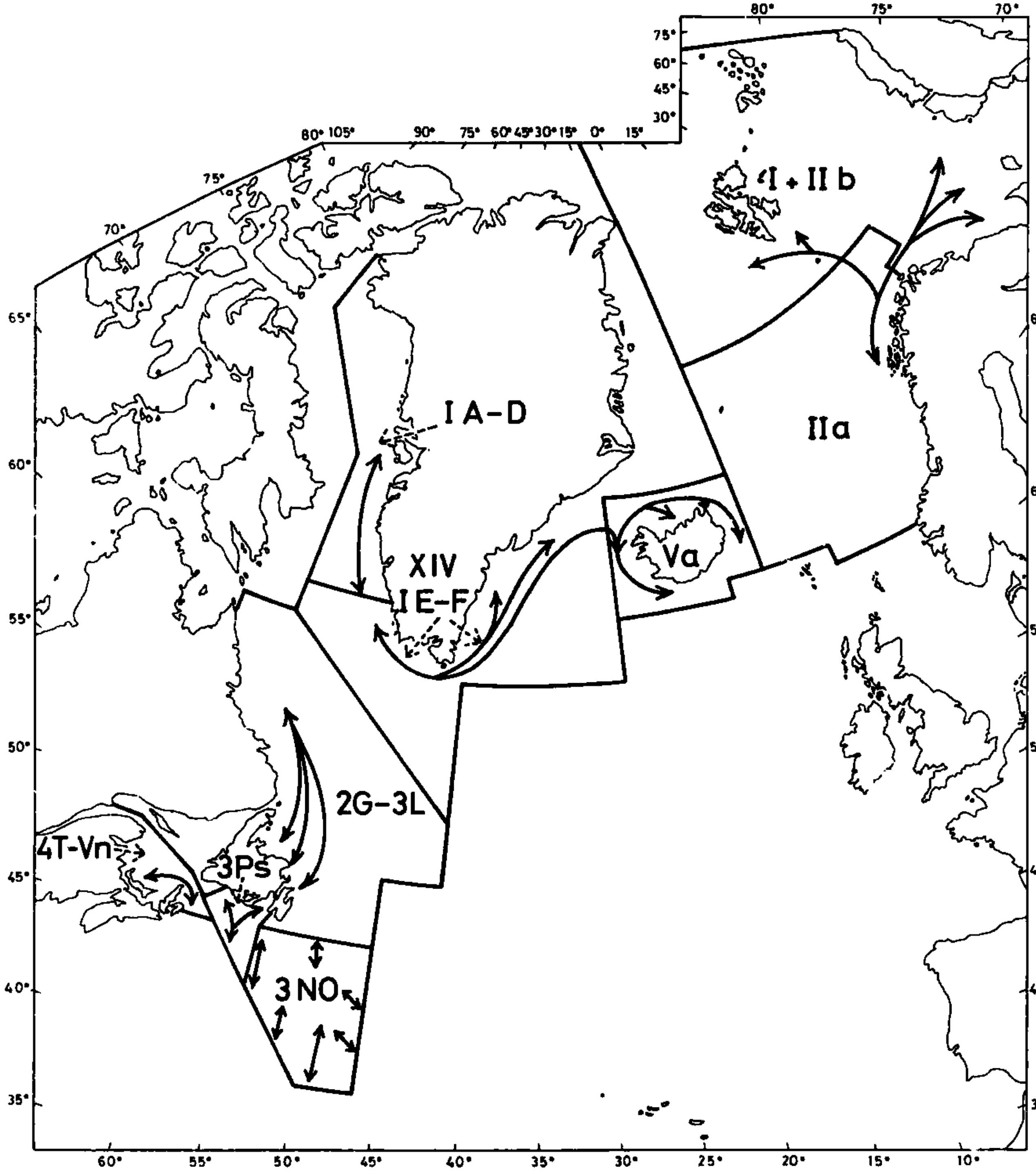


Figure 1. Main North Atlantic Cod Stocks and their Migrations.

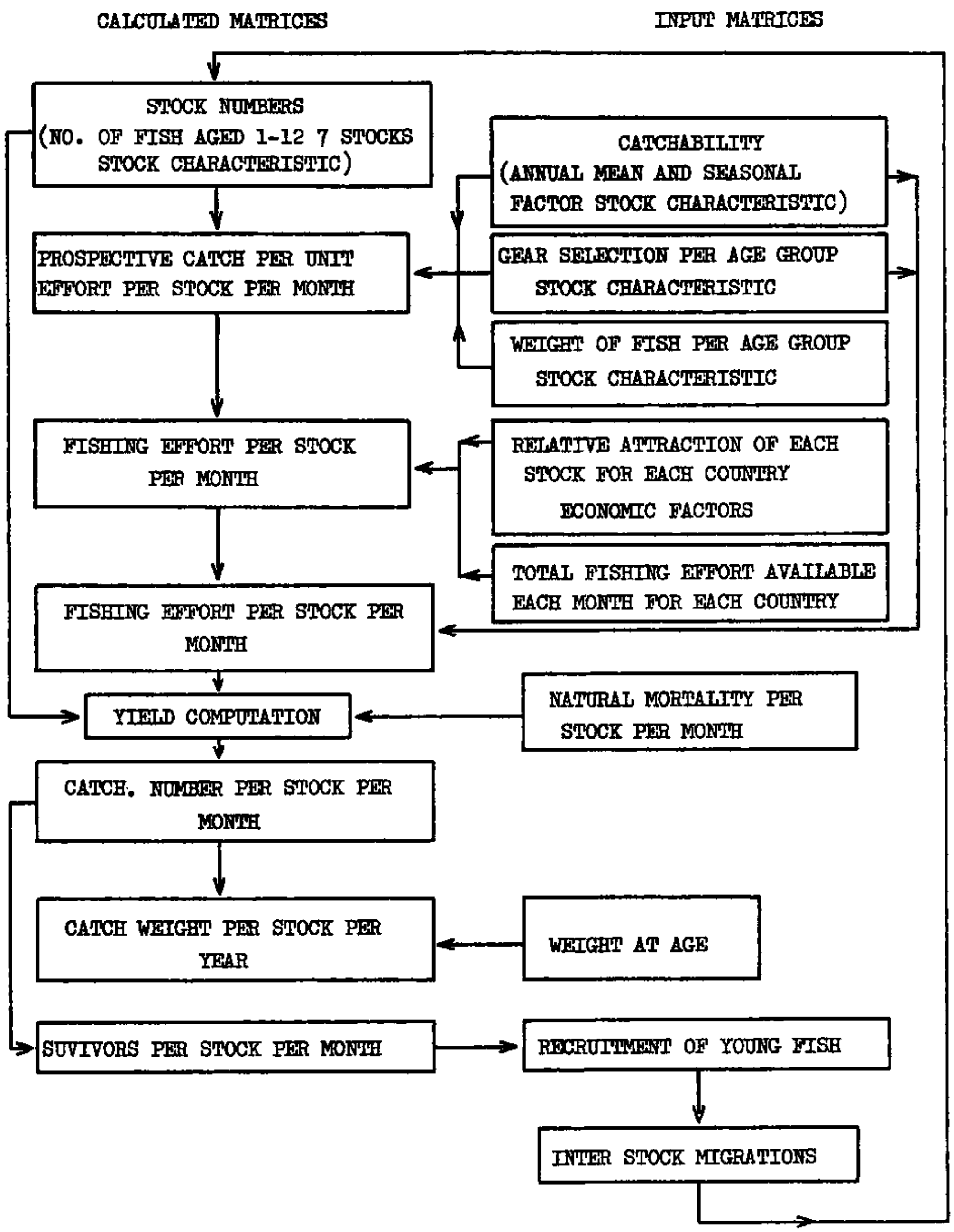
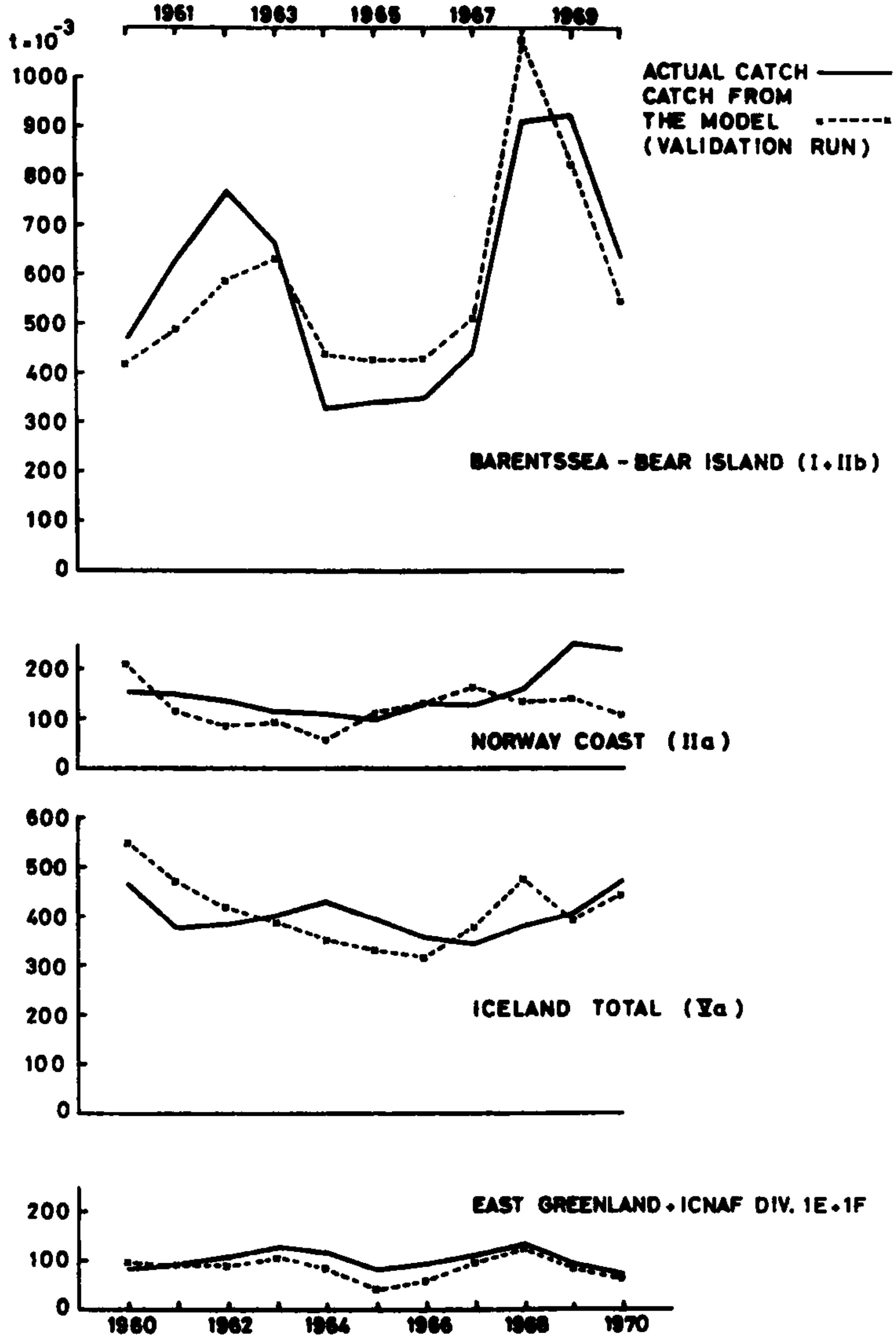


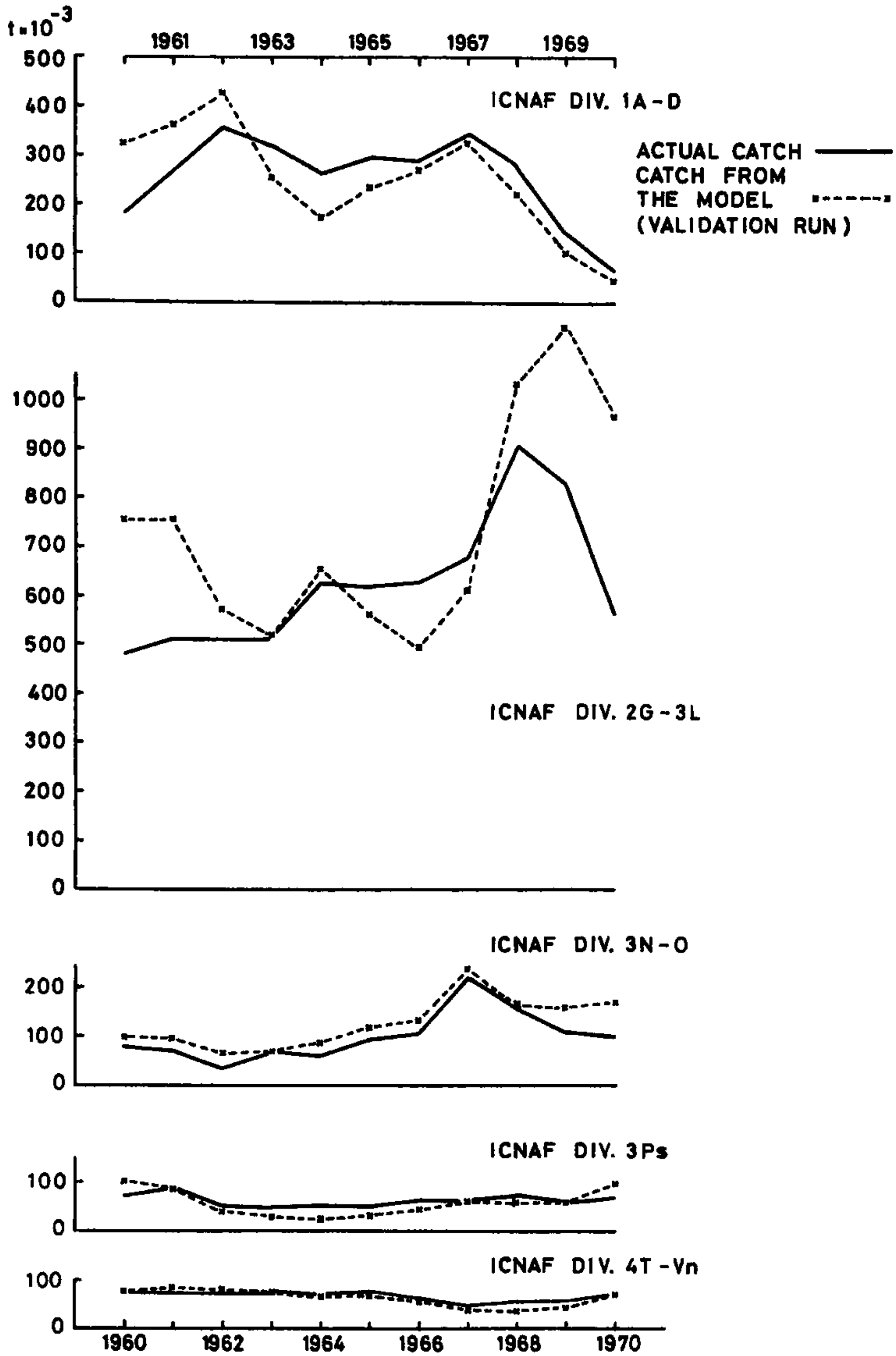
Figure 2. Simplified flow diagram of the simulation model.

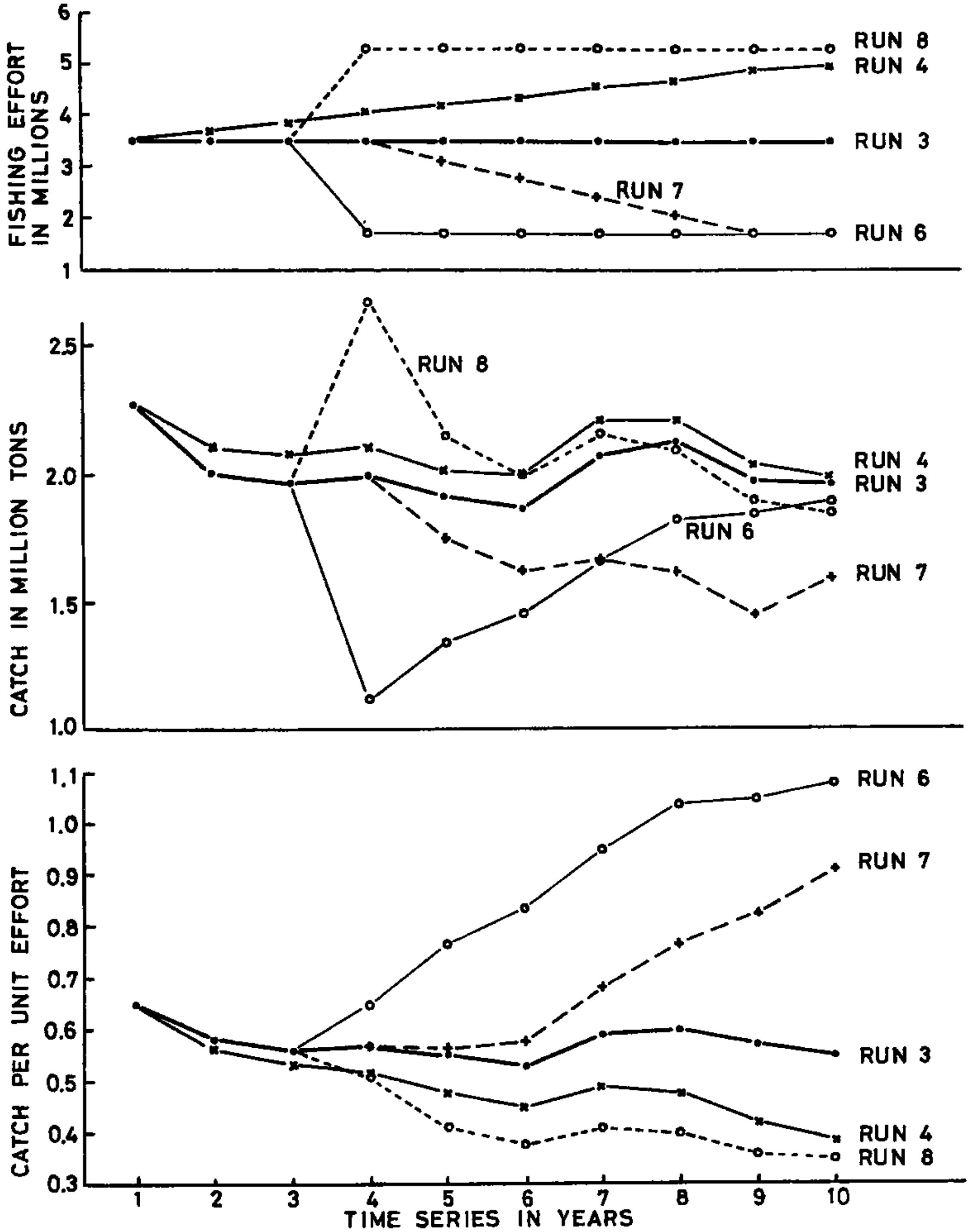


<u>FIGURE 3.</u> Comparison of actual catches in each stock 1960-1970 with catches predicted by a simulation model based upon the calculated parameters of each stock.

continued...

FIGURE 3 (ctd)


t=10^-3
1961
1963
1965
1967
1969
500
400
300
200
100
0
ICNAF DIV. 1A-D
ACTUAL CATCH
CATCH FROM
THE MODEL
(VALIDATION RUN)
1000
900
800
700
600
500
400
300
200
100
0
ICNAF DIV. 2G-3L
ICNAF DIV. 3N-O
200
100
0
ICNAF DIV. 3Ps
100
0
ICNAF DIV. 4T-Vn
100
0
1960
1962
1964
1966
1968
1970



<u>FIGURE 4.</u> Changes in catch and catch per unit effort as a consequence of management to regulate fishing effort on an Atlantic wide basis.

1. (Run 3) To stabilise fishing effort at its 1970 level.
2. (Run 6) To decrease fishing effort in Year 3 to a level that could generate F_{opt} on all stocks, but with no restriction on mobility (i.e. 50% reduction in overall fishing effort).
3. (Run 8) To allow fishing to increase in Year 3 to 50% above its present (1970) level.
4. (Run 7) To decrease fishing effort as (2) by 10% per year from Year 4 to Year 8 and held at that level thereafter.
5. (Run 4) To allow fishing effort to increase by 5% per year over all years.

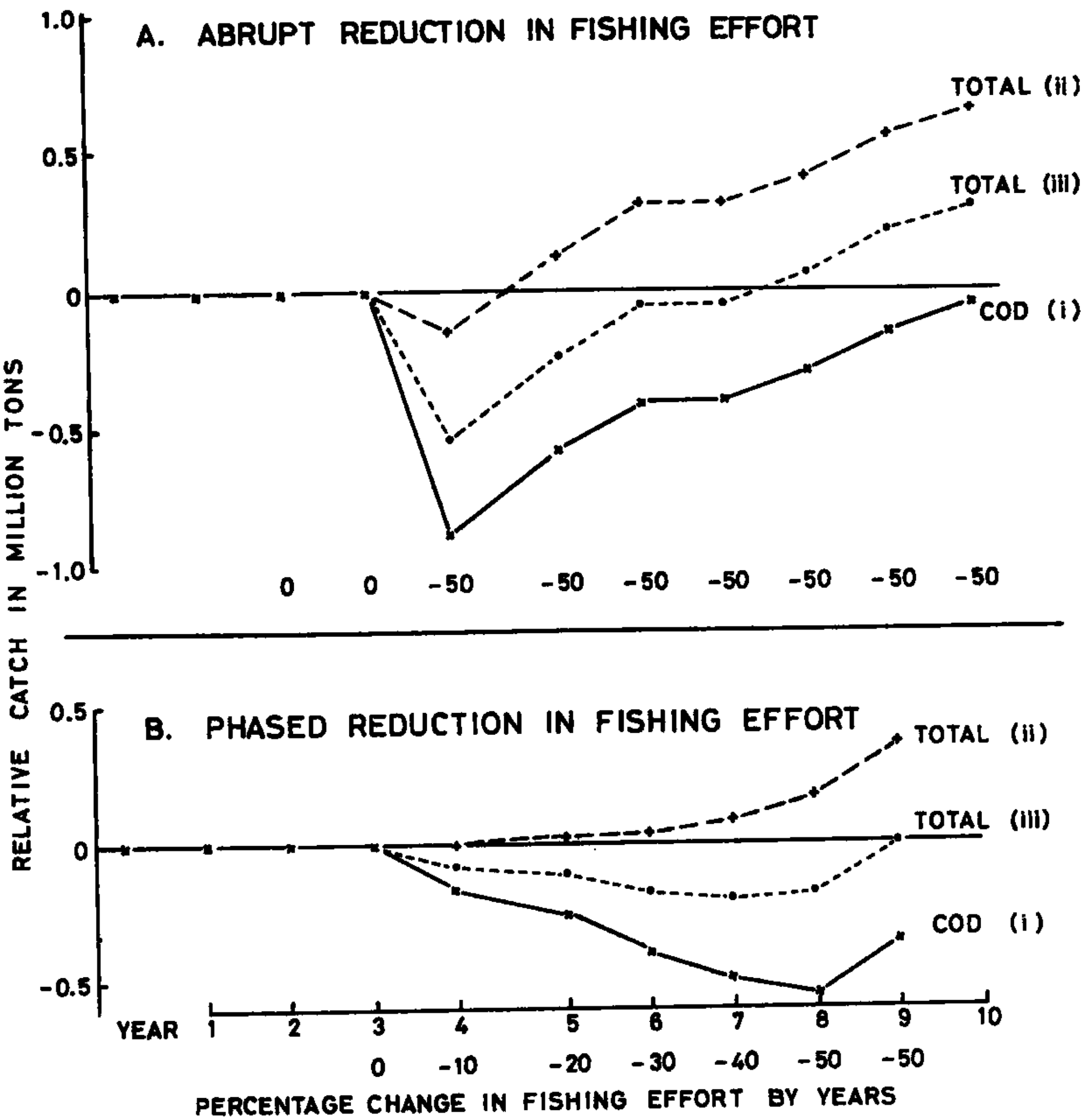


FIGURE 5. Catches under different management strategies compared to the catch under strategy (1), where fishing effort was stabilised at the 1970 level.

A. Strategy 2 (Run 6) reduction of fishing effort to F_{opt} in one year.
  (i) Catch of cod relative to strategy 1 (Run 3).
  (ii) As (i) with the fishing effort displaced from cod redeployed on other non-cod stocks at an assumed catch per unit effort two-thirds the overall catch per unit effort on the cod itself.
  (iii) As (ii) with catch per unit effort of non-cod stocks assumed one-third that of the cod stocks.

B. Strategy 4 (Run 7). Phased reduction of fishing mortality to F_{opt}.
  (i), (ii) and (iii) as for A. above.