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The application of mixed fisheries theory to the cod and redfish stocks of Subarea 2 and Division 3K

by

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INTRODUCTION

In Newfoundland 'fish' means cod unless otherwise stated which gives some indication of the importance of this species to the fisheries of the area. It has provided 80% of the catch of groundfish from Subarea 2 and Division 3K in the last 15 years. If the cod stock is in a depressed state the total groundfish resources of the area must be depressed regardless of the strength or weakness of other species. Therefore it is important to isolate the management need of the cod from those of the other groundfish. In doing this, however, it is necessary to ask whether there are any biological or fisheries interactions to consider with other species. Clearly it is desirable that a mixed fishery model such as that developed by Pope (1975a) be applied, and proposals for management regions be viewed in the light of the model.

THE APPLICATION OF THE SCHAEFER MODEL TO THE GROUNDFISH OF SUBAREA 2 AND DIVISION 3K

Pinhorn (1975) found that the groundfish resources of Subarea 2 and Division 3K exhibited catch per effort trends which correlated significantly with the fishing effort adjusted by Gulland's method (Gulland 1968) to allow for non-equilibrium effects. This was true for three separate units of fishing effort and all three suggested that the overall maximum yield for groundfish was of the order of 400 thousand metric tons. There was however some divergence between the three methods as to the precise cut back in effort which would be required to achieve this maximum sustainable yield. A unit of effort based on 901-1800 ton vessels of France, Portugal and Spain suggested a cut back of 17% from the 1973 level of effort. A unit of effort based on the > 1800 ton vessels of the

USSR and Poland suggested that a cut back of about 13% would be appropriate while a unit of effort based on Spanish other trawler (OT) cod catches suggested a cut back of about 30%. At least part of this divergence is explained by the diversity of the various fleet objectives. The Spanish effort which is based entirely on cod shows the need for the greatest cut back while the USSR and Polish effort, which is amongst the most diverse, shows the least. Another reason for the discrepancy is that only the Spanish effort is adjusted for seasonality and for that fleet, at least, the tendency has been for catches to be increasingly made in the earlier months of the year when cod is most easily caught. The lack of such an adjustment for the other measures of effort might have masked the true increase in fishing effort in recent years. Against this point it should be noted that the levels of fishing mortality estimated by virtual population analysis for the total 2J-3K 3L cod stock have not shown the same increase in recent years as displayed by the Spanish effort. This could be a result of either the Spanish otter trawlers becoming older and becoming less efficient or possibly as a result of optimistically low values of fishing mortality being used to initiate the virtual population analysis. Whichever effort measure is used it is clear from Pinhorn's 1975 work that all three measures suggest that the total groundfish catch per effort for Subarea 2 and Division 3K can be represented by a Schaefer type model. It is also clear that cod is by far the largest component of the groundfish resource and it would therefore seem likely that cod would itself follow a Schaefer type yield curve. Using the Spanish O.T. measure of effort from Pinhorn's (1975) paper and regressing the resulting cod catch per effort on six year running averages of the effort gives a significant linear regression, Figure 1 shows the regression and the resulting yield curve. An alternative method of fitting the Schaefer yield function was suggested by Walter (1975) which consists of regressing the catch per effort in year i+1 against the effort in year i. This method also gives a significant regression and Figure 2 shows the regression and the resulting yield curve. The former regression gives a MSY of 352 000 metric tons at an effort of 217 thousand hours fishing while the latter suggests a MSY of 417 000 metric tons at an effort of 263 thousand hours fishing. Both methods suggest that the stock has been substantially overfished in recent years and that the 1973 level of effort needed cutting back by 32% in the former case or by 18% in the latter case in order to bring the stock back to the MSY level of exploitation.

Apart from the cod, one of the other groundfish resources has also been shown to have a Schaefer type yield curve. This is the redfish. Pinhorn and Parsons (1974) derive several possible yield curves for this species, one of which is based on a six year averaging period, and has an equation governing its equilibrium behaviour of

$$R = 32.47 - 0.0056\ fr \qquad \text{..........}\ 1$$

Where R is the catch per effort of redfish and fr is the fishing effort on redfish averaged over the last 6 years and is measured in standard days fished by vessels of greater than 1800 tons. Thus two of the most important stocks of fish in the region appear to follow Schaefer type yield curves. Since these stocks have accounted for 91% of the total catch in the period it is not perhaps so surprising that the total catch appears to follow a Schaefer type yield curve. Pope (1975a) points out that where total effort develops in a constant ratio on two non-interacting fish stocks and both have parabolic yield functions, then the resulting joint yield function on total effort will also be parabolic. But the maximum yield it predicts need not necessarily be the true MSY of the system nor need the level of effort at which this apparent maximum yield is attained be the level of effort that correctly applied would give the true maximum yields of the system. Horwood (1975) suggests that the equilibrium development trajectory of a fishery need not necessarily pass through the overall MSY of such a system.

AN APPLICATION OF MIXED FISHERY THEORY TO THE COD AND REDFISH STOCKS OF SUBAREA 2 AND DIVISION 3K

Since both the cod and the redfish stocks of subarea 2 and Division 3K have yield curves that can possibly be represented by parabolas the mixed fishery theory advanced by Pope (1975a) should be applicable, provided that there are no strong biological interactions between the species; for example, similar to the type shown by Pope and Harris (1975) for the South African pilchard and anchovy stocks and discussed in detail by Pope (1975b). Attempts to improve the regressions for cod and for redfish using the catch rate of the other species as a second independent variable resulted in no significant coefficients for this variable. It would thus seem that if there are biological interactions between these two species they are of a sufficiently low order to be ignored for practical purposes; consequently the total yield for the redfish and cod was calculated for different levels of fishing effort and assuming no interactions. Figure 3 shows the contours of equal yield in relation to the effort on both species. The individual stock yield curves used to construct this joint stock function were Pinhorn and Parsons (1974) yield curve for the redfish fitted using the six year running averages of effort and the yield curve developed for cod in the previous section and using the six year running average method of fitting. This was chosen in order to choose the more pessimistic and therefore safer formulation and to remain consistent with the overall yield function of Pinhorn (1975). The basis of effort used for the cod was the Spanish OT hours fished. In order to make it compatible with the standard days fished figure for the redfish, it has been divided by twelve. This figure was chosen because of a comparison of the cod catch rates made in this region of the greater than 1800 ton vessel of the USSR with the Spanish OT catch rates, it suggested that this was an appropriate figure. Thus the parallel diagonal lines on Figure 3 show the levels of the total joint effort on the two species in standard days fished by vessels greater than 1800 tons. The contours of equal total yield are concentric ellipses with their major and minor axes parallel to the co-ordinate axis. These indicate that the maximum yield for cod and redfish combined is of the order of 400 thousand metric tons, attained at an overall fishing effort of about 21 500 standard days fishing. It is thus interesting that these two stocks alone exhibit the same MSY yield as that obtained from all groundfish species by Pinhorn (1975) particularly as similar measures of effort and averaging periods were used. This seems to bear out Pope's (1975a) suggestion that the total yield obtained from assessments of total groundfish would tend to give lower bounds to the total maximum sustainable yield of a system. This is more believable when the development trajectory of these two fisheries is examined. This is superimposed on the yield function in Figure 3 and shows that the proportions of fishing effort going on these two fish stocks have fluctuated considerably in the period from 1959 to 1973. It is of course possible that if the other groundfish resources of this region were strongly interactive with cod and redfish then the figure of 400 000 metric tons for cod and redfish alone would be compatible with Pinhorn's (1975) 400 000 metric tons for all groundfish. This is because in that case the other groundfish species might only have increased in abundance after the cod and the redfish were depleted. This hypothesis is superficially tempting in the light of Pinhorn's (1975) Figure 2 which shows the proportion of other species in the catch increasing dramatically after 1969 when the cod and the redfish were both exhibiting low catch rates. Unfortunately, due to the lack of specific effort measures for these species in the area this hypothesis cannot be tested directly. Nevertheless, the presence of older fish in significant quantities in the catch of several of the species of other groundfish, for example roundnose grenadiers (Pinhorn 1974) and Greenland halibut (Bowering and Pitt 1975), suggests that they have not increased vastly in abundance in the recent past, and thus it is probably that they do not strongly interact with the cod or redfish. It is probable that the total groundfish MSY for this region is greater than the 400 000 tons joint maximum yield of the cod and redfish.

POSSIBILITIES FOR THE MANAGEMENT OF THE COD, REDFISH AND OTHER GROUNDFISH STOCK COMPLEX IN SUBAREA 2 AND DIVISION 3K

Management of fish stocks in Subarea 2 and Division 3K has until now been based on individual stock catch quotas designed to maximise the yield of each stock in isolation. In the light of the disturbing trends in catch rate shown by Pinhorn (1975) and indicated by groundfish survey results (Anon. 1975) it is certainly sensible to ask if other methods of management might be more appropriate. In particular it is interesting to ask if either a total effort quota or a total catch quota would serve a useful purpose. Superficially the use of an overall effort quota as the only management control in this region seems likely to be disastrous in the light of the volatility of the development trajectory shown in Figure 3, and clearly such a constraint would seem unlikely to prevent heavy overfishing of redfish. For example the overall level of effort in 1973 was not much different from that in 1959, and also the situation in 1973 for cod was rather similar to that in 1959 (see for example Figure 1). However the redfish stock in 1959 was being exploited at the total destruction level of effort while in 1973 the level of effort on it was rather below the MSY level. This is a feature of the much greater level of effort needed to attain MSY for cod (18000 standard day) compared to that needed to attain MSY for redfish (C 3000 standard days). The case with other species might well be rather similar with a tendency for them to be heavily overfished if they became attractive to fishing effort; For example as a result of a large year class or a further decline in the catch rate of cod. In order to examine this management method more objectively a simulation was made of the cod and redfish fisheries assuming they followed the non-equilibrium form of the Schaefer curve

$$\frac{1}{P}\frac{dP}{dt} = b - aP - qf \qquad \text{................ 2}$$

where P is the stock biomass, f is the fishing effort and q the catchability coefficient. The parameters b and a and q were chosen to be consistent with the fitted yield curves but in order to provide the third parameter it was necessary to assume the MSY level of fishing mortality. Consequently a value of MSY F = 0.2 was adopted for the redfish and a MSY F = 0.3 was adopted for the cod. In order to be able to simulate the joint fishery for both species it was assumed that the proportion of the total effort going on cod was given by

$$(v\, Cq)^n / \left((v\, Cq)^n + (w\, R\hat{q})^n \right) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\, 3$$

where n is some power, v and w are preference weightings for the cod and redfish respectively, C is the biomass of cod, R the biomass of redfish and q and $\hat{q}$ are the respective catchabilities of the two species. This is analogous to the economic weightings used in the model by Clayden (1972) discussed by Garrod and Pope (1972). In order to acquire values of n, v and w a regression of $\ln\left(\frac{fc}{fr}\right)$ on $\ln\left(\frac{c}{r}\right)$ was performed for the years 1959 and 1973 where fc, fr were the effort applied to cod and redfish respectively each year and c and r were the recorded catches per effort of the two species. No significant regression emerged from this analysis and consequently, in order to be able to make a simulation, values of n=2, v=2 and w=1 were adopted. A simulation on these values was performed but, not surprisingly, it did not reproduce the historical series and the developmental trajectory it produced was far less volatile than the true series. In particular, the ratio of effort going on redfish to that going on cod was very much more regular than the ratio observed in the historic series. Table 1 shows the historic series and the simulated series for the period 1959-73. This simulation was extended to show the possible behaviour of the mixed fishery under an overall effort quota (21000 standard days) designed to achieve the MSY for the system. Table 2 shows the results from this simulation. It is apparent that the simulation rapidly settled down to a level of effort for the cod of about 17000 days and a level of effort for the redfish of about 4000. Figure 3 indicates that this would in the equilibrium case achieve a joint yield in excess of 375 thousand metric tons. In fact the simulation finally settles down to a yield of 389 thousand metric tons, a very substantial portion of the joint MSY of 400 thousand metric tons. Thus, if the effort were distributed between stocks according to equation 3 and the two stocks were precisely governed by the Schaefer equation and no other species affected the balance, then the total effort quota could be expected to quite successfully manage these two stocks. This is in line with Horwood's (1975) finding that such a system would tend to converge to some equilibrium level for the two stocks. In fact, of course, the model of fisheries preferences for species (equation 3) is at best a very poor fit to the facts and

Schaefer curves very rarely fit a stock closely. Thus the equilibrium behaviour simulated would in practice tend to be disrupted by random events such as unusually large or small year classes or changes in catchability. Clearly a total effort quota might well be a good deal less efficient than the simulation in Table 2 would suggest.

Similar simulations were made of the effects of overall catch quotas. The levels of quota considered were 250, 260, 270, 280, 290, 300, 310, 320 and 330 thousand metric tons. The method of making these simulations was to divide each year into ten equal periods and simulate in each period the proportion of fishing effort being applied to each stock, according to equation 3. Fishing was stopped at the end of the time period in which the catch quota was exceeded. This method of simulating a catch quota invariably led to the quota being exceeded, in some cases by amounts in excess of 10%. (Thus accidentally adding verisimilitude to the simulation). A total effort constraint of 30 000 days was put into the simulation to avoid quotas being taken by improbably high levels of fishing effort. All of the quotas over 310 thousand tons eventually came up against this constraint, implying that they would lead to overfishing of the two stocks if applied at present. It would however be possible to bring total catch quotas up to some higher level at a later time if the stocks were first allowed to rebuild at the lower quota levels. The simulations showed the same well behaved distribution of fishing effort observed for the effort quota simulation. Since this was achieved under the same model assumptions this simulated behaviour is open to the same criticisms as were levelled of effort quotas. A third possibility for management would be a stock constraint as suggested by Garrod (1975). This would imply reducing fishing until the cod catch rate increased to 1.62 tons per Spanish OT hour and until the catch rate of redfish increased to 16.24 tons per standard day fished. This would imply resting the cod for about 2 years or fishing at an effort level below MSY for a longer period. The catch rate of redfish is currently at about this level.

DISCUSSION

The Schaefer curves fitted to the cod for Subarea 2 and statistical area 3K suggests that this fish stock has been very seriously overfished in recent years. The overall yield function for redfish and cod suggests that Pinhorn's (1975) estimate of 400 000 tons for the total groundfish resources of this region may be somewhat pessimistic but still implies that the 1973 level of fishing effort needs reducing by about 28% on these two stocks. The lack of observable biological interaction between these two stocks and indeed the other groundfish stocks suggests that there is no biological reason why individual stock catch quotas should not be successful provided they are set at the right level.

A study of the development trajectory in Figure 3 suggests that the directed fisheries for these two species are sufficiently pure (ie have low by-catch rates) to include the joint MSY levels of effort in a region that is attainable. Thus the possible arguments relating to the overall attainable MSY of a system's being lower than the joint MSY, advanced in Pope (1975a), are not valid in this case. While the overall MSY is attainable in the longterm equilibrium sense, simulations of a total catch quota suggest that such a quota or the sum of the two species quotas should be well below the MSY level of 400 thousand tons due to the depleted state of the cod stock.

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TABLE 1

Simulation of the historic series for the cod and redfish stocks

	Historical levels of Cod and Redfish Effort		Redfish as % of Cod	Simulated levels of Cod and Redfish Effort		Redfish as % of Cod
	Cod	Redfish		Cod	Redfish	
1959	21667	5800	27	22139	5861	26
1960	18333	5700	31	19530	4470	23
1961	12500	4200	34	14077	2922	21
1962	10830	1100	10	10907	2092	19
1963	12500	1200	10	11820	2179	18
1964	15000	4200	28	16011	2989	19
1965	20000	2400	12	19276	3723	19
1966	22500	2800	12	20885	4115	20
1967	19170	2000	10	18414	3586	19
1968	25830	1400	5	22613	4387	19
1969	28330	1700	6	25067	4933	20
1970	31670	1400	4	26709	5291	20
1971	30830	1700	6	26734	5266	20
1972	37500	1600	4	32524	6476	20
1973	26667	2400	9	24285	4715	19

TABLE 2

Simulation of an overall effort quota from 1974 onwards

Total effort is 210,000 standard days

Year	Total Effort		Total Yield
	Cod	Redfish	
1974	14949	6051	227582
1975	15915	5085	260324
1976	16406	4594	290976
1977	16654	4346	316071
1978	16772	4228	335382
1979	16819	4181	349758
1980	16827	4173	360282
1981	16816	4184	367939
1982	16798	4202	373510
1983	16778	4222	377560
1984	16758	4242	380567
1985	16741	4259	382772
1986	16727	4273	384408
1987	16716	4284	385627
1988	16706	4294	386539
1989	16699	4301	387223
1990	16693	4307	387737
1991	16689	4311	388124
1992	16686	4314	388417
1993	16683	4317	388637
1994	16681	4319	388804
1995	16680	4320	388930
1996	16678	4322	389025
1997	16678	4322	389098
1998	16677	4323	389152
1999	16676	4324	3891[illegible]
2000	16676	4324	3892[illegible]5
2001	16676	4324	389248
2002	16675	4325	389267
2003	16675	4325	369280

F 11

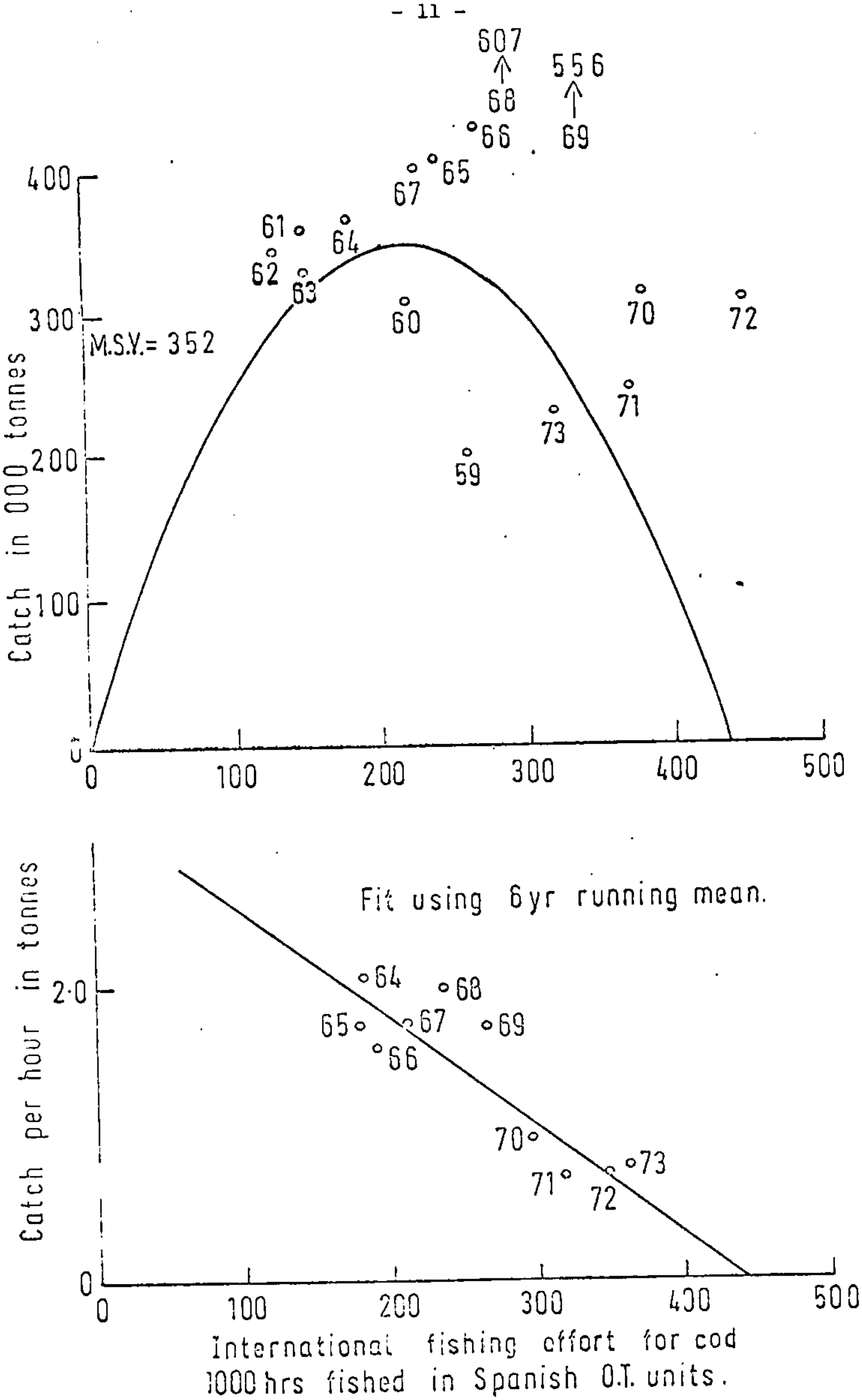

Fig. 1. Regression of cod catch per unit effort against a 6-year MSY average of effort and the resulting Schaefer type yield curve.

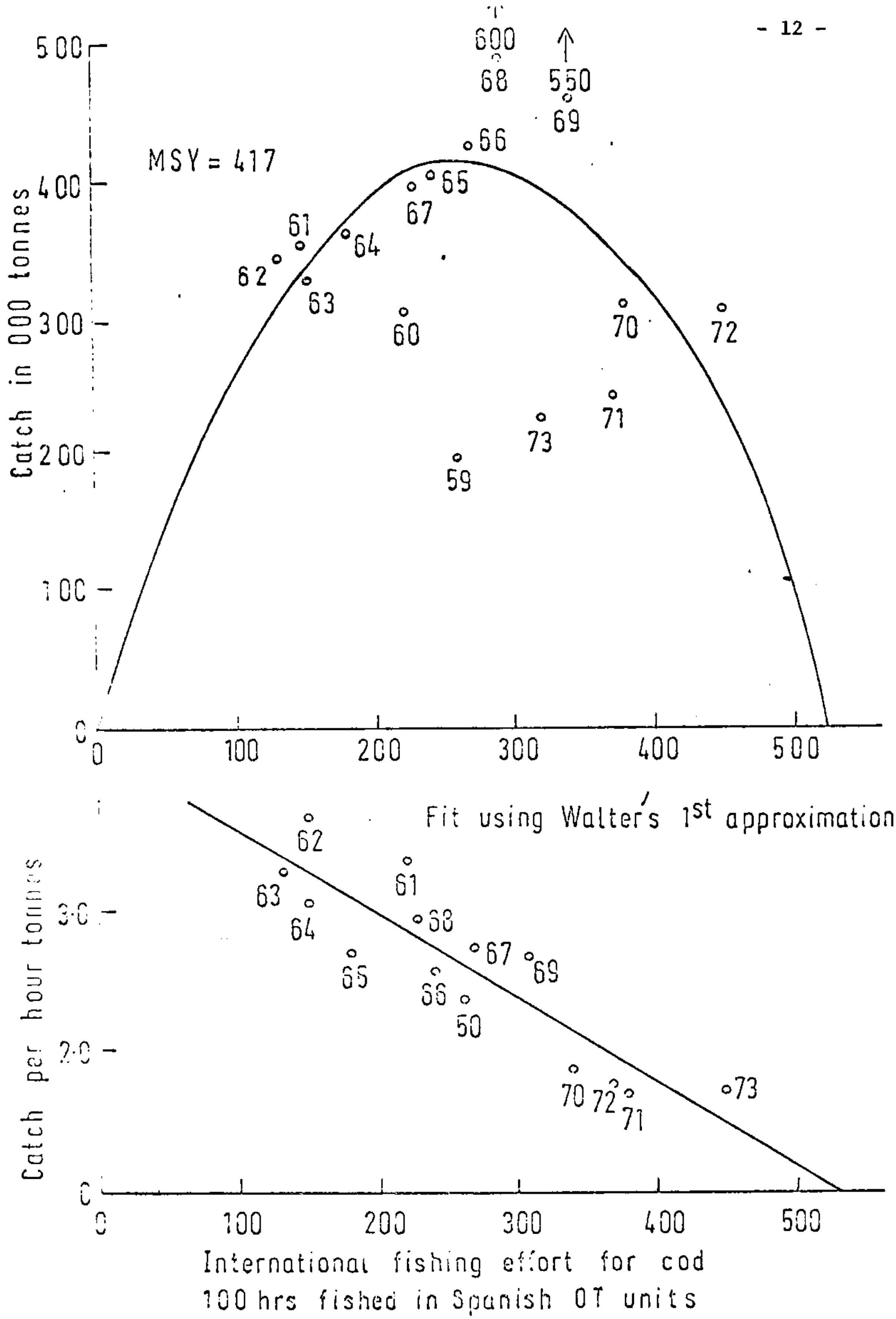

Fig. 2. Regression of cod catch per unit effort against fishing effort in the previous year (Waller's method, 1st approximation) and the resulting Schaefer type yield curve.

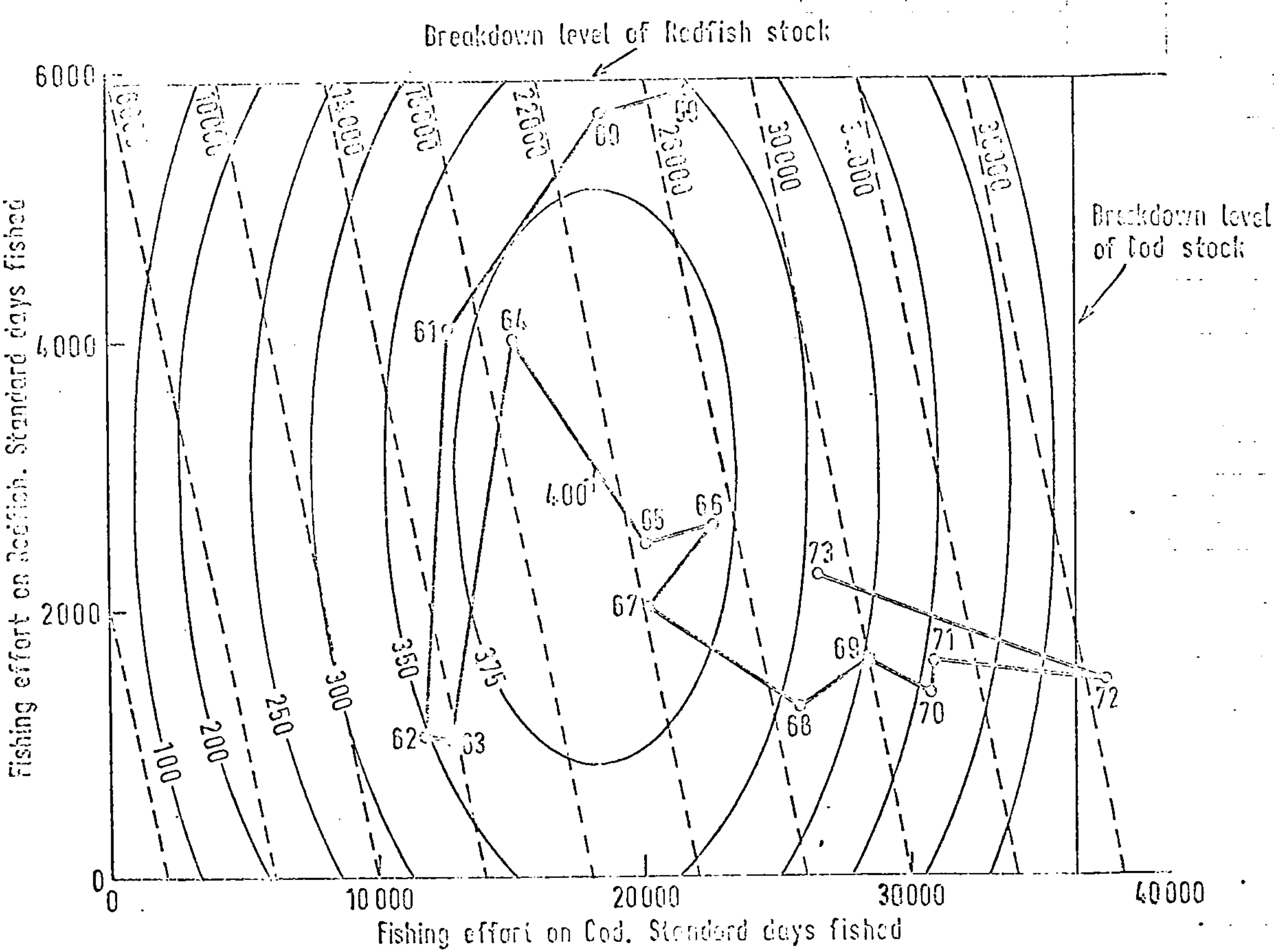

Fig. 3. Contours of total yield, contours of total effort (broken lines) and the development trajectory of the fishery of cod and redfish in Subarea 2 and Division 3K.