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THE NORWEGIAN INDUSTRIAL TRAWL FISHERY IN THE NORTH SEA

A study on how the total catch in 1975 could have been increased without exceeding the quotas of cod, haddock and whiting

By

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ABSTRACT

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Linear programming is used to demonstrate a way to maximise the total catch in a mixed fishery. Constraints are set by quotas, as well as requirements that the total catch should not be too unevenly distributed between areas and throughout the season. A practical application of this technique in fisheries management depends on a satisfactory prediction of the ratio of the quota-regulated species in the total catch before the season starts.

INTRODUCTION

The Norwegian industrial trawl fishery for Norway pout in the North Sea in 1975 was stopped in November of that year because the quota of whiting had been exceeded by more than 1 000 tonnes. The total catch was 297 000 tonnes, excluding sandeel. The final total landings of bycatch of the quota-regulated species were 1 106 tonnes of cod, 6 942 tonnes of haddock and 15 399 tonnes of whiting.

In 1975 the industrial fishery was unregulated with regard to where and at which time fishing could take place. If there had been quotas, however, for the different fishing grounds in different parts of the season, the total catch could have been substantially larger than 297 000 tonnes, without exceeding the quotas on the regulated species.

The linear programming technique was used in this study. This is a well-known mathematical method in economy which is often used to find an optimal distribution of limited resources. HANSEN (1971) used the method to study the factors determining the economic yield of the Norwegian winter capelin fishery. BROWN, BRENNAN, HEYERDAHL and HENNEMUTH (1973) used linear programming to predict the national catches in ICNAF Subarea 5 and Statistical Area 6. These authors used bycatch ratios of previous years in directed fisheries and national species quotas. Gunderman, Lassen and Nielsen (1974) used linear programming to estimate the maximum catch in the North Sea of cod, haddock, whiting, plaice and sole for 31 different fisheries belonging to 11 nations. Besides quotas on each species, they defined rules on how changes in the fisheries should take place.

Rational fisheries management should not only be determined by the possibilities of taking the largest catch within the constraints set by the quotas on the regulated species. Management should also take into account the structure of the fishing fleet, the possibilities of enforcing the regulations, and the state of the species which are not regulated by quotas. These are factors which are disregarded in the present paper. However, the method applied in this study might be a valuable tool for future optimization of industrial fisheries.

MATERIALS AND METHODS

One defines:

$A_{i,j,k}$ = the weight ratio of the species k in the catch in the j^{th} quarter in area i.

$XC_{i,j}$ = the catch in area i, j^{th} quarter.

Of the relevant species, cod, haddock and whiting were quota-regulated in 1975. The weight ratio of these species in the trawl catches for Norway pout are given in Table 1.

The division of the fishing grounds into the three areas is shown in Fig. 1.

The quantity to be maximised is the total catch XC_{TOT}. Thus the objective function is:

$$XC_{TOT} = \sum_{i=1}^{3} \sum_{j=1}^{4} XC_{i,j} \tag{1}$$

The quotas Q_k, have to be respected. This sets the following three constraints, one for each species:

$$\sum_{i=1}^{3} \sum_{j=1}^{4} A_{i,j,k} \cdot XC_{i,j} \leqslant Q_k \; ; \; k=1,2,3 \tag{2}$$

The Norwegian quotas for cod, haddock and whiting in 1975 were 3 000, 10 000 and 14 300 tonnes respectively. Subtracting the quantities used for consumption, one arrives at 1 625 tonnes ($=Q_1$) for cod, 9 678 tonnes ($=Q_2$) for haddock, and 14 238 tonnes ($=Q_3$) for whiting.

Table 1. The weight percentages of cod, haddock and whiting in the Norwegian industrial trawl fishery in the North Sea in 1975. The percentages and the total catches of the industrial trawlers are given for the relevant areas on a quarterly basis.

Area	Quarter j	Cod k=1	Haddock k=2	Whiting k=3	Total catch (tonnes)
The Patch Bank-	1	2.3	3.6	12.6	17 201
Egersund Bank	2	0.4	2.0	1.4	45 155
area	3	0.0	0.1	0.2	25 802
i = 1	4	0.04	0.7	1.2	28 795
Sum					116 953 $(=C_{1.})$
The Fladen Ground-	1	0.3	9.0	11.7	11 849
Bressay Ground	2	0.3	2.7	20.6	23 746
area	3	0.0	1.3	2.4	65 017
i=2	4	0.1	3.9	10.8	36 574
Sum					137 186 $(=C_{2.})$
The Tampen-	1	1.3	4.3	1.6	5 354
Viking Bank	2	0.9	2.6	2.7	22 906
area	3	0.3	2.2	3.9	5 335
i=3	4	0.9	2.6	0.8	9 307
Sum					42 902 $(=C_{3.})$

If the constraints set by (2) were the only constraints, it appears from Table 1 that the highest catch could be achieved by closing all the areas in the North Sea except for the Patch Bank – Egersund Bank area ($i = 1$) in the third quarter when the weight percentages of cod, haddock and whiting were all at a minimum. The maximum catch would be limited by the quota on whiting, that is, 14 238 tonnes $\cdot$ $(100/0.2)$ = 7 119 000 tonnes. However, a total catch of 7.1 mill. tonnes within three months in a relatively small area like the Patch Bank – Egersund Bank area is obviously unrealistic.

Thus, in order to achieve a more realistic distribution of the catches between the areas, the following type of constraints are introduced:

The total yearly catch from the area i $(= \sum_{j=1}^{4} XC_{i,j})$ should not be less than a_i % or greater than b_i % of the actual catch in this area in 1975 $(=C_{i.})$. This rule results in six constraints:

$$\frac{a_i}{100} \cdot C_{i.} \leq \sum_{j=1}^{4} XC_{i,j} \;;\; i = 1,2,3 \tag{3}$$

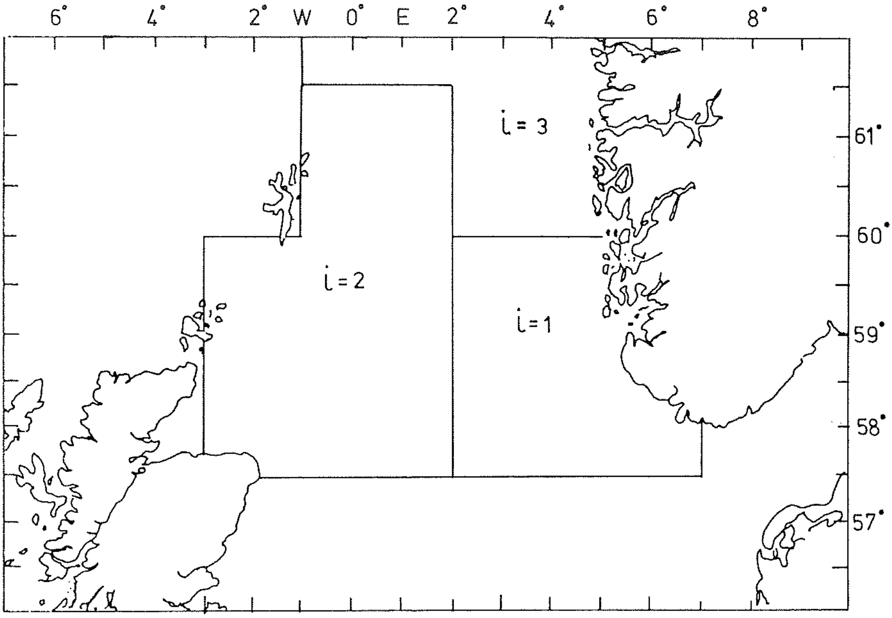

Fig. 1. Fishing grounds of the Norwegian industrial trawlers.
i = 1 The Patch Bank – Egersund Bank area;
i = 2 The Fladen Ground – Bressay Ground area;
i = 3 The Tampen – Viking Bank area.

$$\frac{b_i}{100} \cdot C_{i.} \geqslant \sum_{j=1}^{4} XC_{i,j} \;;\; i = 1,2,3 \tag{4}$$

$C_{i.}$ values are given in Table 1. In this study a_i is set at 50% and b_i at 150% for all areas. This implies that the total catch will be within ± 50% of the actual total catch in 1975, i.e.

$$148\,500 \text{ tonnes} \leq XC_{TOT} \leq 445\,500 \text{ tonnes.}$$

The sum of the three constraints expressed by (3) can be considered as the minimum catch acceptable for the industry. The sum of the three constraints set by (4) can be considered as the limit set by the amount of effort which can be carried out in this fishery by the existing fleet, and by the available resources.

In order to achieve a more realistic distribution of the catches throughout the season, the requirement that maximum $f_{i,j}$% of the total yearly catch within the area i can be taken within the quarter j, is introduced.

This requirement gives the following 12 constraints which should be fulfilled:

$$XC_{i,j} \leq \frac{f_{i,j}}{100} \cdot \sum_{j'=1}^{4} XC_{i,j'} \;\; ; \; j = 1,2,3,4 \;\; ; \; i = 1,2,3 \qquad (5)$$

Two different constant values of $f_{i,j}$ are used in this study, $f_{ij} = 50\%$ and $f_{i,j} = 33{,}3\%$ for all i and j values.

The objective function given by equation (1) and the constraints defined by (2), (3), (4) and (5) define a problem in linear programming. This mathematical technique is described in most text-books on optimization, for example WALSH (1971). The present study utilized a computer programme from KUESTER and MIZE (1973) which is based on the simplex algorithm.

The outcome of the present optimization problem is catch quotas (irrespective of species) for each area and quarter of the year which give the largest possible total catch within the defined constraints.

RESULTS

Example 1. $f_{i,j} = 50\%$

This value of f in the constraints set by relation (5) implies that an area can not be closed for more than two quarters of the year. Table 2 gives the optimal distribution of the quotas maximising the total catch in the Norwegian trawl fishery for Norway pout.

Table 2 shows that with the constraints (2), (3), (4) and $f_{i,j} = 50\%$ in (5), the total catch could be increased by 43%. This would require that no

Table 2. Example 1. The distribution of quotas in areas and quarters giving maximum total catch (tonnes). The number in brackets give the differences compared with the actual catches in 1975.

Quarter	Area: The Patch Bank-Egersund Bank area i=1	Area: The Fladen Ground-Bressay Ground area i=2	Area: The Tampen-Viking Bank area i=3	Total
1	0 (−100%)	0 (−100%)	32 250 (+502%)	32 250 (− 6%)
2	0 (−100%)	0 (−100%)	0 (−100%)	0 (−100%)
3	87 750 (+240%)	92 693 (+ 43%)	0 (−100%)	180 443 (+ 88%)
4	87 750 (+205%)	92 693 (+153%)	32 250 (+247%)	212 693 (+185%)
Total	175 500 (+ 50%)	185 386 (+ 35%)	64 500 (+ 50%)	425 386 (+ 43%)

industrial trawling was allowed in the Patch Bank – Egersund Bank area and in the Fladen Ground – Bressay Ground area in the first half of the year. The Tampen – Viking Bank area would have to be closed in the second and third quarters.

The by-catch of the quota-regulated species would have been 837 tonnes of cod, 7 748 tonnes of haddock, and 14 238 tonnes of whiting (= the quota). The quota of whiting is the limiting factor.

Example 2. $f_{i,j} = 33.33\%$

This value of $f_{i,j}$ implies that an area can be closed for no more than one quarter. Table 3 gives the optimal quota allocation.

Table 3. Example 2. The distribution of quotas in areas and quarters giving maximum total catch (tonnes). The numbers in brackets give the differences compared with the actual catches in 1975.

Quarter	Area			Total
	The Patch Bank-Egersund Bank area i=1	The Fladen Ground-Bressay Ground area i=2	The Tampen-Viking Bank area i=3	
1	0 (−100%)	44 675 (+277%)	5 006 (− 6%)	49 681 (+ 44%)
2	58 500 (+ 30%)	0 (−100%)	21 500 (− 6%)	80 000 (− 13%)
3	58 500 (+127%)	44 675 (− 31%)	16 494 (+209%)	119 669 (+ 24%)
4	58 500 (+103%)	44 675 (+ 22%)	21 500 (+131%)	124 675 (+ 67%)
Total	175 500 (+ 50%)	134 025 (− 2%)	64 500 (+ 50%)	374 025 (+ 26%)

The change of $f_{i,j}$ from 50% to 33.33% would result in a decrease of the maximum possible catch by 51 361 tonnes to 374 025 tonnes. The by-catch would be 938 tonnes of cod, 9 678 tonnes of haddock (= the quota) and 14 238 tonnes of whiting (= the quota).

Tables 2 and 3 give the maximum catch which could be taken in areas 1 and 3, that is 150% (= b_i in relation (4)) of the actual catch in 1975. Only in area 2 is it possible to increase the catches without violating relation (4).

TRANSFERABLE QUOTAS

According to an agreement in the North-East Atlantic Fisheries Commission (NEAFC), any Contracting State was allowed to transfer up to 3 000 tonnes between the quotas of cod, haddock and whiting in 1976.

Example 3

Example 1 was re-calculated with a reduction of 600 tonnes in the cod quota, a reduction of 1 000 tonnes in the haddock quota, and an increase of 1 600 tonnes in the whiting quota. The quotas then became 1 025 tonnes of cod, 8 678 tonnes of haddock and 15 838 tonnes of whiting. The results are given in Table 4.

Table 4. Example 3. The distribution of quotas in areas and quarters giving maximum total catch (tonnes). The numbers in brackets give the differences compared with the actual catches in 1975.

Quarter	Area						Total	
	The Patch Bank-Egersund Bank area i=1		The Fladen Ground-Bressay Ground area i=2		The Tampen-Viking Bank area i=3			
1	0	(−100%)	0	(−100%)	7 477	(+ 40%)	7 477	(− 78%)
2	0	(−100%)	0	(−100%)	24 773	(+ 8%)	24 773	(− 73%)
3	87 750	(+240%)	102 750	(+ 58%)	0	(−100%)	190 500	(+ 98%)
4	87 750	(+205%)	102 750	(+181%)	32 250	(+247%)	222 750	(+198%)
Total	175 500	(+ 50%)	205 500	(+ 50%)	64 500	(+ 50%)	445 500	(+ 50%)

The amounts of cod, haddock and whiting caught with the catch distribution given in Table 4 would be 748, 7 850 and 15 838 tonnes (= the quota) respectively.

The transfer of 1 600 tonnes from the cod and haddock quotas to the whiting quota would increase the maximum catch from 425 386 tonnes (Table 2) to 445 500 tonnes (Table 4). An additional increase in the total catch is not possible since relation (4) sets a maximum of 445 500 tonnes for b_i at 150%.

Example 4

Example 2 was re-calculated with a reduction of 600 tonnes on the cod quota, an increase of the haddock quota by 250 tonnes and the whiting quota by 350 tonnes. The quotas thus became 1 025 tonnes of cod, 9 928 tonnes of haddock and 14 588 tonnes of whiting. The results are given in Table 5.

The amounts of cod, haddock and whiting caught in this example would be 959, 9 928 (= the quota) and 14 588 tonnes (= the quota) respectively.

Example 2 gave the conditions which allowed the least increase (+ 26%) in the total catch. The transfer of quotas in example 4 would only increase

Table 5. Example 4. The distribution of quotas in areas and quarters giving maximum total catch (tonnes). The numbers in brackets give the differences compared with the actual catches in 1975.

Quarter	Area: The Patch Bank-Egersund Bank area $i=1$	Area: The Fladen Ground-Bressay Ground area $i=2$	Area: The Tampen-Viking Bank area $i=3$	Total
1	0 (−100%)	46 217 (+290%)	6 483 (+ 21%)	52 700 (+ 53%)
2	58 500 (+ 30%)	0 (−100%)	21 500 (− 6%)	80 000 (− 13%)
3	58 500 (+127%)	46 217 (− 29%)	15 017 (+181%)	119 734 (+ 25%)
4	58 500 (+103%)	46 217 (+ 26%)	21 500 (+131%)	126 217 (+ 69%)
Total	175 500 (+ 50%)	138 651 (+ 1%)	64 500 (+ 50%)	378 651 (+ 27%)

the maximum catch by 4 626 tonnes when the other conditions were as in example 2. Only a small additional increase of the maximum catch is possible since no more than 66 tonnes of the cod quota would remain unfished in example 4.

DISCUSSION

The constraints set by the relation (5) imply that the catches would be distributed throughout the season. One could have required explicitly that the catch within the j^{th} quarter of the year should at least be of a certain minimum size $C_{min,j}$, i.e.:

$$\sum_{i=1}^{3} XC_{i,j} \geq C_{min,\ j} \tag{6}$$

If, instead, the requirement is that at least $d\%$ of the total catch should be taken within the j^{th} quarter of the year, the mathematical relation would be:

$$\sum_{i=1}^{3} XC_{i,j} \geq \frac{d}{100} \cdot XC_{TOT} \tag{7}$$

The objective function (1) is the total catch in tonnes. Instead of maximising the weight of the catch, the value of the catch could have been maximised. The objective function would then be:

$$\sum_{i=1}^{3} \sum_{j=1}^{4} V_{i,j} \cdot XC_{i,j} \tag{8}$$

where $V_{i,j}$ is the value per unit weight of the catch from area i, in the j^{th} quarter. These two objective functions, (1) and (8), would probably result in two different optimal quota allocations unless $V_{i,j}$ is the same for all i and j values.

An assumption in this study is that the relative catch compositions (Table 1) are constant within the time intervals and the areas (Fig. 1) used. This is a crude approximation. It is not a problem from the mathematical point of view to use more and smaller time and area units than those used in the present study, but it becomes more difficult to get reliable data for the catch composition when refinements of the time and area units are introduced.

It is also assumed in this study that the relative catch compositions are independent of the size of the catches in the different areas through the year. The goodness of this assumption weakens as the hypothetical catches (Table 2–5) depart from the real 1975 catches.

If this method is to have any practical application in fisheries management, a main problem is to satisfactorily predict, before the season starts, the ratio of the quota-regulated species in the catch at the different grounds in each part of the season. This problem, however, is outside the scope of the present paper.

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