International Council for the Exploration of the sea

C.M.1996/P:4
Theme Session on Management faced with Multiple Objectives

Bioeconomic and biological effects of size selective harvesting of North-East Arctic cod

by
Stefán Andreasson and Ola Flaaten
The Norwegian College of Fishery Science, University of Tromsø
9037 Tromsø, Norway

Gear technologists have in recent years developed rigid sorting grids, Sort-X, in bottom trawls, to improve the size selectivity of this type of gear. Experiments with the Sort-X system in the aft sections of trawls were carried out aboard Norwegian and Russian trawlers along the coast of Northern Norway and in the Barents Sea.

This paper uses data from these experiments to analyse the bioeconomic effects of the Sort-X trawl selectivity system, using i.a. resource rent, employment and catch as performance indicators. The results are compared to those of other types of gear and vessels in use. A bioeconomic model, based on a cohort model of the Baranov-Beverton-Holt type, has been designed for this purpose. Since fishing gear with perfect selectivity is not available, simulation experiments were used to derive the bioeconomic results. Norwegian costs and earnings data were used.

The analysis shows that from a resource rent and catch point of view the Sort-X system with 55 mm bar distance performs better than traditional trawl, and that the 1995 improvements of Sort-X yield a system which performs better than the 1990-1992 Sort-X. However, the selectivity pattern of large mesh size gillnet used on coastal vessels seems to be superior to the other fisheries. The bioeconomic and biological efficiency of Sort-X with bar distances of 80 and 100 mm is found to be greater than with 55 mm.

Key words: Barents Sea, Bioeconomics, Cod fisheries, Multiple objectives, Selective harvesting

1. Introduction

The problem of fisheries' bycatch and discards has been acknowledged for a long time in the literature on fisheries management. Alversson et al. (1994) gives an excellent review of such problems on a global scale. They estimate that on average 27.0 million tonnes of fish are discarded each year in commercial fisheries. After tropical shrimp trawl, bottom trawl is among the gear types that generates the highest proportion of discards.

Bycatch of non-targeted species and size groups is well known in bottom trawl fisheries in Norwegian waters. Discard is forbidden but difficult to police. Research has been conducted to develop nets and gear technology to reduce bycatch levels in trawl, as well as in traditional coastal fisheries using gillnet, longline, handline and Danish seine. The development of rigid sorting grids (Sort-X) in bottom trawls has been successful with respect to size selectivity of cod (Gadus morhua), and haddock (Melanogrammus aeglefinus). (See the appendix; Larsen et al., 1992; and Larsen and Isaksen, 1993 for further description of the Sort-X system, and the working principle of it).

The aim of this paper is to study the bioeconomic effects on harvest rates, resource rent, vessel profitability, employment etc. of using the Sort-X selectivity in bottom trawl fishing for North East Arctic cod. For comparison, the bioeconomic results of conventional trawl selectivity and coastal fishing will also be derived. Three different types of fisheries, foreign trawl, Norwegian trawl and Norwegian coastal fisheries are calculated in the analysis.

The biological part of the model is a traditional Baranov-Beverton-Holt model with constant natural mortality and exogenous recruitment. In the 11 scenarios presented in this paper, the annual recruitment to the fishable stock is inversely repeated from the 30 year period 1963-92. The economic part of the model includes size-dependent price of fish, total costs of fishing effort, stock output elasticities different from one, and a 5% p.a. social rate of discount.

2. Bioeconomic modelling

For the fisheries managers, fishing mortality (or rather fishing effort or harvest quotas) is the main means which can be used to control the fishery. The relative distribution of fishing mortality between age classes depends on the choice of gear type. Each gear type has a specific selection pattern, described by the age and fishery (gear/vessel type) dependent selectivity parameter. By varying fishing effort and the selection pattern, the fisheries manager can, at least in theory, control the overall fishing mortality and partly control the age-dependent fishing mortality.

An owerview of the symbols and the definitions and units of variables and parameters used in the model is shown in the appendix, table A.1.

2.1. Biological part

The NE-Arctic cod stock consists of several year classes; it is common to use the Baranov-Beverton-Holt model for analyses of stock dynamics with and without harvesting. The number of a year old fish at the beginning of year y, $N_{a,y}$, will decrease during the year due to natural mortality and fishing. At the beginning of next year the number of fish is given by

$$(1)\quad N_{a+1,\,y+1} = N_{a,y} \bullet e^{(-(s_{a,k}F_k + s_{a,l}F_l + s_{a,m}F_m + M))} \quad ;\ t_c \le a \le t_s\ ,$$

when there are three fisheries, k, l, and m. s is the selectivity parameter and F is the fishing mortality.

The biomass of age class a at the beginning of the year y is the product of number of fish and average weight of fish in stock:

$$(2)\quad B_{a,y} = N_{a,y} w_{a,b}\ ,$$

and the biomass of the fishable part of the stock is

$$(3)\quad X_y = \sum_{i=t_c}^{t_x} B_{a,y} \ .$$

The catch in number of age class a in year y for fishery j is

$$(4)\quad Y_{a,y,j} = N_{a,y}(1 - e^{(-(s_{a,k}F_k + s_{a,l}F_l + s_{a,m}F_m + M))})\frac{s_{a,j}F_j}{s_{a,k}F_k + s_{a,l}F_l + s_{a,m}F_m + M},$$

where M is the age independent natural mortality .

The catch in biomass is

$$(5)\quad h_{a,y,j} = Y_{a,y,j}w_{a,j} \ .$$

For a given fishery j the total annual catch, in biomass, of all age classes is

$$(6)\quad H_{y,j} = \sum_{i=t_c}^{t_x} h_{a,y,j}$$

The total annual catch for all fisheries is

$$(7)\quad H_{y,total} = \sum_{j=k,l,m} H_{y,j}$$

A fishing rule that will be used is that a given share, τ, of the fishable stock at the beginning of the year may be harvested during that year. With this annual quota, the total allowable catch (TAC) is

$$(8)\quad Q_{y,total} = \tau X_y$$

The total allowable catch is shared in fixed proportions among the fishing fleets harvesting the cod stock. However, these relative shares, ϕ_j, may be varied to study the biological and economic effects of reallocated quotas. The total quota for fishery (fishing fleet) j is

$$(9)\quad Q_{y,j} = \phi_j Q_{y,total}$$

where the sum of all ϕ_j equals unity.

It is assumed that the quotas are binding, i.e. the following condition is fulfilled:

$$(10)\quad Q_{y,j} - H_{y,j} = 0$$

Fishing mortality will be varied for each fishery until (10) is fulfilled.

2.2. Economic part

For fishery j the annual gross revenue from the harvesting of one age class is the price of fish times harvest:

$$(11)\quad tr_{a,y,j} = p_{a,j} h_{a,j} \ ,$$

and fishery j´s total gross revenue is

$$(12)\quad TR_{y,j} = \sum_{i=t_c}^{t_v} tr_{a,y,j} \ .$$

The total annual gross revenue for all fisheries is

$$(13)\quad TR_{y,total} = \sum_{j=k,l,m} TR_{y,j} \ .$$

The catch per unit of effort (CUPE) is assumed independent of the total effort used, i.e. the effort output elasticity, α, equals unity in the catch function $h = qE^{\alpha} X^{\beta}$.

If data is available, the parameters q and β may be estimated simultaneously. For this report we shall use estimates of β from Flaaten (1987) and Skjold (1995), and we estimate q based on fishery statistics from The Directorate of Fisheries in 1986-1993 (Fiskeridirektoratet, 1996).

$$(14)\quad \hat{q}_j = \frac{H_{h,j}}{X_h^{\beta_j} E_{h,j}} .$$

where the subscript h denotes historical values for H, X and E.

In the model simulations the fishing effort, E, necessary to catch a given quota $(H = Q)$ is found from

$$(15)\quad E_{y,j} = \frac{H_{y,j}}{X_y^{\beta_j} \hat{q}_j} \ .$$

For fishery j, the total annual harvesting cost is the product of fishing effort and the average cost per unit of effort:

$$(16)\quad TC_{y,j} = E_{y,j} c_j ,$$

The average cost of effort includes operating costs as well as opportunity costs of capital and labour. The total annual harvesting cost for all fisheries is

$$(17)\quad TC_{y,total} = \sum_{j=k,l,m} TC_{y,j} \ .$$

For fishery j the annual net revenue from fishing is

$$(18)\quad NR_{y,j} = TR_{y,j} - TC_{y,j} \ ,$$

and the total net revenue for all NE-Arctic cod fisheries is

(19) $NR_{y,total} = \sum_{j=k,l,m} NR_{y,j}$.

Thus, $NR_{y,total}$ is the resource rent from the cod stock in year y. The present value of this resource rent is

(20) $\pi_{y,j} = \frac{NR_{y,j}}{(1+r)^t}$,

for the reference year y_0, when $t = y - y_0$, and r is the social rate of discount.

The present value of one years resource rent from all fisheries is

(21) $\pi_{y,total} = \sum_{j=k,l,m} \pi_{y,j}$.

Using a 30 year simulation period, fishery j's total catch for the whole period is

(22) $H_{total,j} = \sum_{y=1}^{30} H_{y,j}$,

and the total period catch for all fisheries is

(23) $H_{total,total} = \sum_{y=1}^{30} H_{y,total}$.

The definitions of $TR_{total,j}$, $TR_{total,total}$, $TC_{total,j}$, $TC_{total,total}$, $NR_{total,j}$, $NR_{total,total}$, $\pi_{total,j}$ and $\pi_{total,total}$ are equivalent to those of H in (22) and (23).

Equations (11)-(23) are related to economic and harvest variables for each fishery or for their total. It is also of interest to study the average catches and economic performances per vessel. For a given year, y, the number of vessels in fishery j necessary to supply fishing effort $E_{y,j}$ is

(24) $n_{y,j} = \frac{E_{y,j}}{f_j}$,

where f is the number of fishing days per vessel year.

The average number of vessels over the 30 year simulation period is

(25) $\bar{n} = \frac{1}{30} \sum_{n=1}^{30} n_{t,j}$.

Using $n_{y,j}$ and $\bar{n}_j$, the average catches and economic performances per vessel may be computed. The model results can then be compared to historic data to see whether they are of reasonable size or not. It is important in particular to check that the simulated harvest per vessel does not exceed the real capacity.

Note that fishing mortality is not proportionate to fishing effort in this model. From equation (1) it is seen that the real age-dependent fishing mortality, F_a, is proportionate to the hypothetical fishing mortality, F, with the selectivity parameter as the constant:

$$(26)\quad F_a = s_a F .$$

Since $H = \sum_a F s_a B_a$ (see equation (1) and (6)), and by using equation (15), the following relationship between F and E holds

$$(27)\quad F = \frac{qE^{\alpha} X^{\beta}}{\sum_a s_a B_a} .$$

Assuming $\alpha = 1$ we have

$$(28)\quad E = \frac{qFX^{\beta}}{\sum_a s_a B_a} .$$

2.3. Employment part

A regional input-output model (Bardarson, 1994; Bardarson and Heen,1995) is used to estimate direct and indirect employment impacts of cod fisheries in four North and North-West Norwegian counties.

The employment multipliers, $L_{j,z,u}$, are multiplied with the final sales values of the cod processing industries. The final sales value is the product of catch, $H_{j,z,u}$, ex-vessel price of fish, $p_{a,j}$, and value added ratio, v_u, due to processing. The total employment impact of the cod fisheries in the four counties, is given by:

$$(29)\quad Z = \sum_{j=1}^{2} \sum_{z=1}^{4} \sum_{u=1}^{3} L_{j,z,u} \bullet H_{j,z,u} \bullet p_{a,j} \bullet v_u .$$

3. The biological, economic and technical data

3.1. Biological data

The value of natural mortality M, age of recruitment to fishable stock t_c, maximum age of fish t_s, and average recruitment R_y for the 30 year period (1963-1992) are taken from an ICES report and are shown in the appendix, table A.2. The variable annual recruitment from year 1 to year 30 is shown in the appendix, figure A.2. The biomass of each age class for the reference year, 1993, is calculated based on numbers at age from ICES, 1995 and the average weight at age in stock shown in the appendix, table A.3. This table shows also the average age-specific weights of cod in the catches of the three fisheries to be studied. The age-specific weight of cod in the catch and in the stock differ due to different gear selectivity and heterogeneous distribution of fish and fishing vessels.

3.2. Economic data

1993 is used as the reference year, and prices and costs have been adjusted accordingly by means of the Norwegian consumer price index. Norwegian data on fish prices and cost of effort has been used also for the foreign trawl fisheries.

Age specific ex-vessel prices of fish, in NOK per kg round weight, are calculated based on average landing prices from North-West and North Norway for 1991-1993 (Råfisklaget, 1995). The results are shown in the appendix, table A.4.

Harvesting cost per vessel day are shown in the appendix, table A.5. The harvesting cost include the opportunity cost of capital and labour.

The actual number of days that each vessel fishes annually depends on i.a. variable and fixed costs and on seasonal variation of catch per unit of effort (CUPE) and the price of fish. In this paper each of the trawlers and the coastal vessels fish 300 and 200 days per year, respectively. These figures are close to the actual ones reported in Norwegian cost and earnings studies (see Fiskeridirektoratet, 1989-1993), and were used to derive the cost per vessel day data in the appendix, table A.5.

In the computation of the present value of resource rent, the social rate of discount equals 5 percent p.a.

Direct and indirect employment from Norwegian cod fisheries in four counties in North and North-West Norway (Finnmark, Troms, Nordland, Møre & Romsdal) are calculated. It is assumed that all Norwegian cod catch are landed in these counties.* The distribution of the chatches between the four counties and to different group of vessels (coastal and trawl) are estimated based on data from Fiskeridirektoratet (1996). The estimates are shown in the appendix, table A.6. Values of the employment multipliers, the distribution of the chatches to different processing usage (fresh, frozen, and dried/salted) and the value added ratio due to processing are taken from Bardarson and Heen (1995).

3.3. Technical data

The selectivity curve is usually shown in selectivity of length of fish. In this paper the length is converted to age of fish, based on the average age/length distribution for the period 1989-1995 (Korsbrekke, pers.comn).

The selectivity curves for some of the different types of trawls in use and under development for commercial fishing, are shown in figure 1. This figure also shows the selectivity curve for

* In the period 1980-1993, 93% of the Norwegian cod catch was landed in Finmark, Troms, Nordland and Møre & Romsdal.

large mesh size gillnets, being used parts of the year by parts of the coastal fleet. The average selectivity of the coastal fleet is different, as shown in the appendix, table A.7.

Figure 1 shows six different selectivity curves for trawl and one for gillnet with big mesh size. The **NO**-curve is based on data from selectivity experiments with the regular Norwegian trawl in 1989, and the **RU**-curve is based on data from selectivity experiments with regular Russian trawl in the same year (135 mm mesh size in the codend of the trawl)(Isaksen et al., 1989). The **½NO+½RU**-curve is the arithmetic average of the NO and the RU curves. The argument for using the ½NO+½RU-curve is that approximately 40% of the Russian trawlers and all of the other foreign trawlers used the «Norwegian» type of trawl in 1989 (Larsen, pers.comn). The **SX90-92**-curve is based on data from several selectivity experiments with Sort-X in 1990-1992, and the **SX95**-curve is based on data from Sort-X experiments in 1995 (Larsen, pers.comn). In both cases the Sort-X selectivity curves are from experiments with 55 mm bar distance and blinded codend.

The **SX95*NO**-curve is based on multiplication of the values for the SX95-curve and the NO-curve. The argument for using the SX95*NO-curve is that this curve theoretically combines grid selectivity and mesh selectivity as two independent selectivity processes when Sort-X is used in regular trawl (Korsbrekke pers.comn.). The **SX80/55**-curve has 80 mm bar distance in the forward grid and 55 mm in the lower grid, whereas **SX80-** and **SX100**-curve have equal bar distances in both grids, 80 and 100 mm, respectively. In these experiments the mesh size in the codend was 135 mm. The **Gillnet**-curve is a selectivity curve for gillnet with big mesh size (Larsen, 1991).

Table A.7 in the appendix shows the selectivity values for trawl, the average selectivity values for coastal fisheries, and the selectivity values for gillnet with big mesh size.

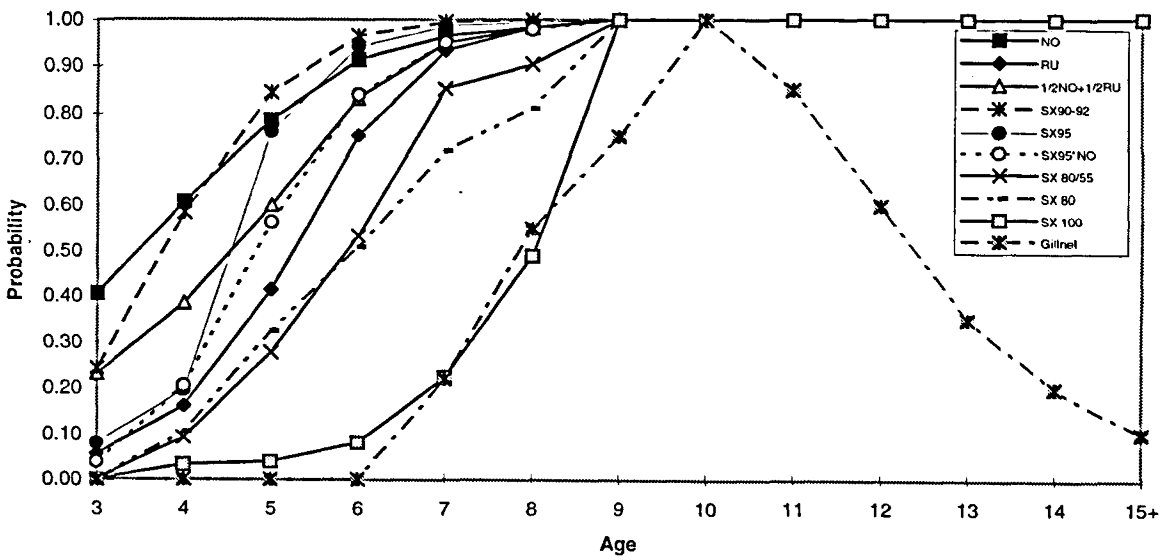


Figure 1. The selectivity curves show the probability that a fish of a specific age is trapped when encountered by the gear.

Sources: NO (Norwegian trawl) and RU (Russian trawl) -Isaksen et al. (1989). ½NO+½RU (Combination of NO and RU). SX90-92 (Sort-X experiments 1990-92), SX95 (Sort-X experiments 1995) and SX80/55, SX80 and SX100 (Sort-X experiments 1995-96) -Larsen (pers.comn.). SX95*N0 (Theoretical combination of SX95 and NO). Gillnet -Larsen (1991).

To estimate the fishing effort necessary to catch the quota, we use the Cobb-Douglas production function. The parameters of the harvest functions (catchability coefficient q, stock output elasticity β, and effort output elasticity α) are given in the appendix, table A.8.

The data used for the calculation of q are from Flaaten (1987), Fiskeridirektoratet (1995), ICES (1995) and Skjold (1995), and the calculations are shown in Andreasson (1996).

3.4 Relative harvest share

The three fisheries' relative catches of cod varied somewhat from year to year. The TAC for North East Arctic cod is currently shared equally between Norway and Russia, after the deduction of approximately 10% for other countries (Paulsen and Steinshamn, 1994). The latter are mainly EU-countries. Russia and other countries hardly use other gear than trawl to catch their shares, whereas Norway has a significant fleet of coastal vessels using gillnet, handline, longline and Danish seine. Table 1 shows relative shares of TAC for foreign trawlers, Norwegian trawlers, and Norwegian coastal vessels used in this paper.

Table 1. Each fishery's share of TAC, in percent.

Foreign trawl fisheries	Norwegian trawl fisheries	Norwegian coastal fisheries
55,00 1)	15,75	29,25

1) Of which 45.00 is Russian.
Sources: Assumed values, based on data from ICES (1995) and Paulsen and Steinshamn (1994).

The selectivity curves vary among gear types used by coastal vessels. Therefore, to calculate the average selectivity curve for the coastal vessels, it is necessary to know the distribution of these vessels' catch between gear types. This distribution is shown in the appendix, table A.9.

4. Results

The bioeconomic results for i.a. resource rent, harvest rate, employment and vessel profitability are derived for 11 combinations of selective harvesting of North East Arctic cod. For the selectivity pattern in the reference scenario, scenario 1, the average annual resource rent and catch over the 30 year period for the three fisheries has been calculated. For the Norwegian fisheries the average annual employment is also calculated. Table 2 gives a survey of selectivity curves used in the various scenarios.

Table 2. The combination of selectivity curves used in the scenarios. 1)

Scenario	Foreign trawl fisheries	Norwegian trawl fisheries	Norwegian coastal fisheries
1	½ NO + ½ RU	NO	Mixed coastal fisheries
2	½ NO + ½ RU	SX 90-92	Mixed coastal fisheries
3	½ NO + ½ RU	SX 95	Mixed coastal fisheries
4	½ NO + ½ RU	SX 95*NO	Mixed coastal fisheries
5	SX 95	SX 95	Mixed coastal fisheries

6	SX 95*NO	SX 95*NO	Mixed coastal fisheries
7	SX 95*NO	SX 95*NO	Large mesh size gillnet
8	SX 80	SX 80	Mixed coastal fisheries
9	SX 80/55	SX 80/55	Mixed coastal fisheries
10	SX 100	SX 100	Mixed coastal fisheries
11	SX 100	SX 100	Large mesh size gillnet

1) For acronyms, see figure 1.

The highest average annual resource rent, approximately 1,750 million NOK, is found for an annual catch equal to 20 percent of the stock level at the beginning of the year. The average annual catch and Norwegian employment have the maximum values 694 thousand tonnes and 11,628 man-year for catch stock level ratios of 25 and 23 percent, respectively. Figure 2 clearly shows that the resource rent has a pronounced maximum compared to that of catch and employment.

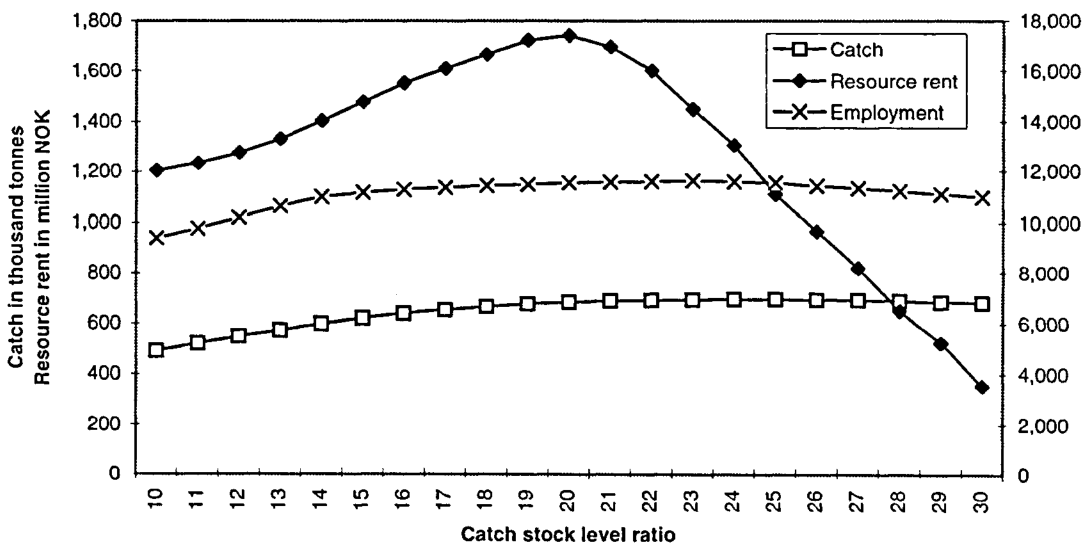
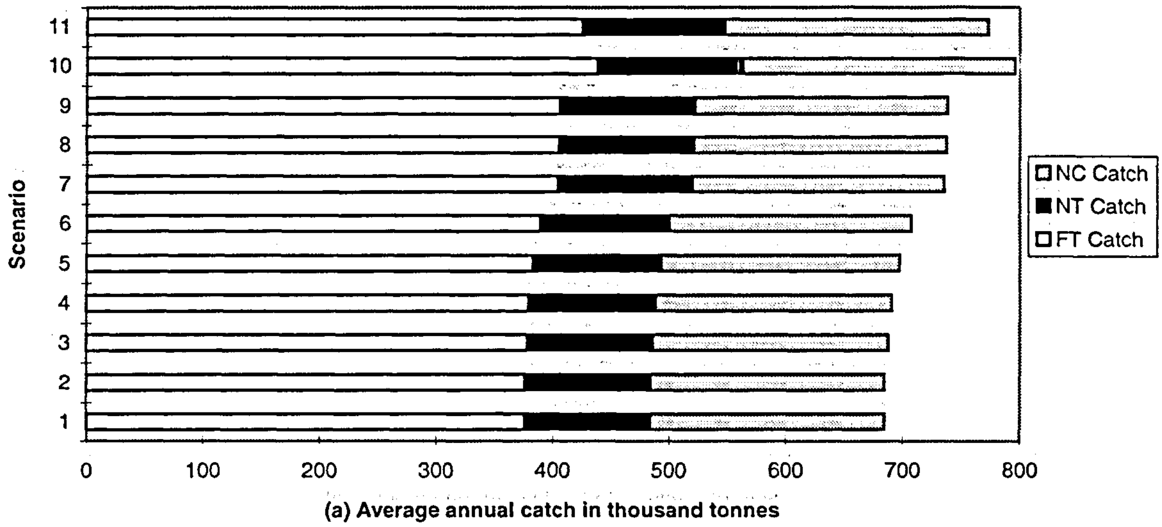


Figure 2. The average annual resource rent in million NOK catch in thousand tonnes for all fisheries and Norwegian employment in man-year, for the 30 year period, as a function of the harvest stock level ratio.

The reference scenario is based on the assumption that Norwegian trawl and coastal fisheries use their traditional gears and nets with the selectivity parameters shown in the appendix, table A.7, and that the foreign trawlers use the average selectivity of traditional Norwegian and Russian trawl. The justification for the latter is that Russian and other foreign trawlers are, to an increasing extent, using gear with technical characteristics similar to Norwegian trawls (Larsen, pers.comn.).

Figure 3 shows results for harvesting with 11 different selectivity pattern. Using catch and resource rent as performance criteria, the results of scenarios 1-11 for the three fisheries are shown. The result for the Norwegian fisheries, included present value of rent and employment, are shown in table 3. In the appendix, tables A.10-A.12 catch, resource rent, present value of resource rent, average ex-vessel price of fish, and rent as percent of price, are shown for the three fisheries.



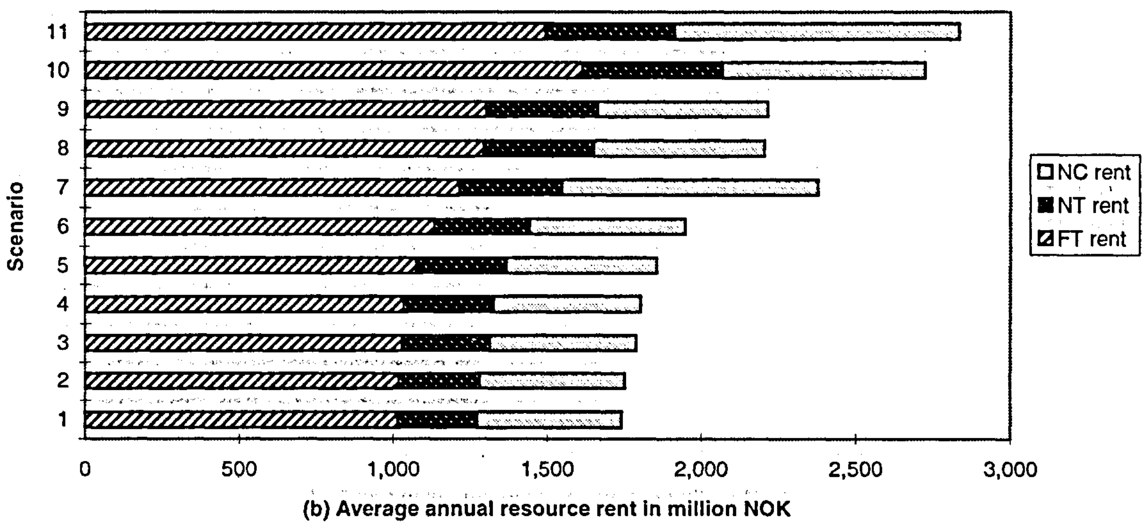


Figure 3. The average annual catch in thousand tonnes (panel a) and resource rent in million NOK (panel b) for the 11 scenarios with different selectivity pattern. NC (Norwegian coastal fisheries), (NT) Norwegian trawl fisheries, (FT) Foreign trawl fisheries.

Scenario 1 has the lowest average catch, resource rent, and employment. Scenario 10 has the highest performance according to the catch criteria, whereas scenario 11 has highest average annual resource rent. Table 3 shows that for the Norwegian fisheries there is less variance in total costs than in total revenue between scenarios. Scenario 1 has the lowest catch and the lowest resource rent, whereas scenario 10 has the highest catch and scenario 11 has the highest resource rent.

Table 3. Scenario results for the Norwegian fisheries. Average annual catch, gross revenue, total cost, resource rent, present value of the resource rent and employment.

	Catch ('000 tonnes)	Gross revenue (million NOK)	Total cost (million NOK)	Resource rent (million NOK)	Present value of resource rent (million NOK)	Employment (man-year)
1	308	2,287	1,559	728	310	11,549
2	308	2,295	1,560	734	313	11,584
3	309	2,323	1,563	760	325	11,727
4	311	2,333	1,564	769	329	11,778
5	314	2,349	1,570	780	334	11,861
6	318	2,392	1,578	814	349	12,077
7	331	2,737	1,573	1,164	505	13,817
8	332	2,512	1,601	911	391	12,683
9	332	2,514	1,601	913	393	11,937
10	358	2,758	1,647	1,111	478	13,925
11	348	2,925	1,582	1,343	572	14,769

The relative resource rent, i.e. the resource rent per kg harvest as a percentage of the fish price, varies between 31.5% for scenario 1 and 47.2% for scenario 11 for the Norwegian coastal fisheries. The Norwegian coastal fisheries have the lowest (scenario 1) and the highest (scenario 11) relative resource rent of the three fisheries. However, except for scenario 7 and 11, the relative resource rent of the Norwegian coastal fisheries varies very little between the scenarios (for details, see the appendix, A.10-A.12. The difference in the relative resource rent of scenarios 11 and 1 is approximately 9 and 11 percentage points for the foreign and the Norwegian trawl fisheries, respectively.

Note that for the one scenario shown in figure 2 the resource rent varies mainly due to costs, whereas in figure 3 panel b, the differences in resource rent between scenarios are mainly due to differences in average fish price and catch

5. Discussion and conclusion.

This applied analysis of size-selective harvesting of North East Arctic cod shows that there is a great potential for generating economic rent by limiting fishing effort and harvest, and by choosing the right selectivity pattern. The catch law of keeping the annual TAC equal to 20 percent of the stock level at the beginning of each year, was derived by maximising the average annual resource rent in scenario 1. This catch law is used in all scenarios. This, of course, does not imply that the average annual resource rent has been maximised for the selectivity pattern given in each scenario. However, it provides a simple way of comparing the effects on resource rent, catch and employment from variations in the selectivity pattern.

The analysis shows that the Sort-X system with 55mm bar distance performs better than traditional trawl, with respect to rent, catch and employment, and that the system arising from the 1995 improvements of Sort-X performs better than the 1990-1992 Sort-X. However, the selectivity pattern of large mesh size gillnet seems to be superior to both conventional trawl and 55mm Sort-X, as scenarios 1-7 show. Scenarios 8-11 are based on trawl selectivity derived from 1995 and 1996 Sort-X experiments with 80-100 mm bar distances and regular mesh size of 135mm in the codend of the trawl. These scenarios show that increased bar distance in Sort-X can increase both catch and resource rent.

Note that scenario 11 where the coastal fleet only use large mesh size gillnet, has higher average resource rent than scenario 10. However, both Norwegian and foreign trawl have lower resource rent in scenario 11 than in scenario 10, (see the appendix, tables A.10-A.12). From a resource rent perspective of the North-East Arctic cod fisheries, coastal fishing with large mesh size gillnet has its advantages, as scenarios 7 and 11 demonstrate.

A main finding for scenario 1, presented in figure 1 is that the resource rent is more sensitive to changes in the harvest stock level ratio than are the harvest and employment. To test whether this applies to scenarios 2-11, the average annual catch, employment and resource rent were calculated also for harvest stock level ratio of 25 percent, and compared to those of the 20 percent case. The resource rent drops heavily, by between 20 and 30 percent, whereas the effects on harvest and employment are relatively small.

The eleven scenarios presented in this paper were based on exogenous variable recruitment. However, computation of eleven scenarios based on constant recruitment, equal to the average recruitment 1963-1992, shown in the appendix, figure A.2, had very little effect on the relative performance of the eleven scenarios. Thus, the results presented in this paper by and large hold also for the case of constant recruitment.

A long run effect of decreased fishing mortality is increased catch per vessel due to increased stock level. The average annual catch per vessel in the three fleet categories (see the appendix, tables A.10-A.12) seem to be within the actual capacity of such vessels. However, it could still be that the actual capacity is exceeded in one or more of the 30 year of simulation, since none capacity limits are built into the model.

Bioeconomic aspects of bymortality of fish escaping through the grid or the cod end of the trawl have not been included in this study. The main reason for this is that gear-technological and biological studies indicate that such bymortality problems are very small for cod (Soldal et al., 1993). Future research should, however, also include the economic aspects of bymortality. This also applies to any bymortality of fish encountered by the gear types of the coastal fleet.

The stock level at the end of the 30 year simulation period is more than 5 million tonnes for all eleven scenarios. This is about the double of the 1995 level and about the same as in 1946-48. The question of whether food scarcity, cannibalism or other density dependent effects might reduce the value of the optimal fishing is left to future research. This will probably require a multispecies approach.

Recent research on the relationship between catch per unit of effort of Norwegian trawlers and the stock level and age distribution (Skjold, Eide and Flaaten, 1996) shows less density dependence than used in this paper. Including this in future analysis will probably reduce the economic gain from increasing the stock level to the extent derived in this paper.

The employment effects derived include fishing, processing, and distribution of fish products as well as activities is related input and consumer industries. However, it does not include employment effects from spending of the resource rent.

The analysis of this paper is based on the assumption that there is clearly defined ownership of the cod stock. Since the cod actually migrates into international waters, in the North East Barents Sea, loophole fishing from an international trawler fleet reduces the incentives of Norway and Russia to invest in the resource. Non-cooperative and cooperative game theory should be used in the future research to investigate such problems.

Acknowledgements.

We would like to thank B. Bogstad, B. Dreyer and K. Korsbrekke for their generous help with data, K. Heen for his help with the input-output analysis, and in particular R. Larsen for providing selectivity data from the Sort-X experiments. This research has been partly founded by the Norwegian Research Council's Program for Marine Resource Management (grant no. 108164/110), whose assistance is gratefully acknowledged.

6. References

Alverson, D.L., Freeberg, M.H., Murawski, S.A, and Pope, J.G, 1994: A global assessment of fisheries bycatch and discards. FAO Fisheries Technical paper No. 339.

Andreasson, S., 1996: Datagrunnalg for økonomiske vurderinger av Sort-X. Internt Sort-X notat no. 8, 5 februar 1996. Norges Fiskerihøgskole, Universitetet i Tromsø.

Bardarson, H., 1994 Torskefiskerienes regionøkonomiske virkninger i Nord-Norge. Fiskerikandidatoppgave, Norges Fiskerihøgskole.

Bardarson, H. and Heen, K., 1996: Regionaløkonomiske virkninger av flerbestandsforvaltning. Rapport. Norges Fiskerihøgskole.

Bogstad, pers.comn.: Weight at age in Norwegian fisheries. Data files from Institute of Marine Research in October 1995. (Bjarte Bogstad, Havforskningsinstituttet).

Fiskeridirektoratet, 1989-1993: Lønnsomhetsundersøkelser for fiskefartøyer 13 m l.l. og over i årene 1989 til 1993. (Annual profitability studies for Norwegian fishing vessels 13m and above, in Norwegian with English summary) Budsjettnemda for fiskerinæringen (Separate number for each year).

Fiskeridirektoratet, 1995: Information from the Directorate of Fisheries over catch in biomass and fishing effort in number of vessel days. Information for trawlers in 1986-92 and for coastal vessels in 1993.

Fiskeridirektoratet, 1996: Norwegian fishery statistics 1980-1994. Different datafiles from the Directorate of Fisheries.

Flaaten, O., 1987: Sesongvarierende bestandstilgjengelighet og produktfunksjoner i Lofotfiske. Forut-rapport nr. EP 7005/1-87.

Havforskningsinstituttet, 1995: Ressursoversikt 1995. Fisken og Havet, Særnummer 1.-1995 Havforskningsinstituttet.

ICES, 1995: Report of the Arctic Fisheries Working Group, ICES Headquarters, 23 August-1 September 1994.C.M 1995/Assess:3.

Isaksen B., Lisovsky S., and Sakhno V.A., 1989: A Comparison of the Selectivity in Codends used by the Soviet and Norwegian Trawler Fleet in the Barents Sea. FTFI-notat.

Kommunaldepartementet, 1995: Information over holiday pay rate (in percentage of wage per hour). Kommunaldepartementet 18. oktober 1995.

Kontrollverket, 1995: Table over multiplication factor from gutted weight to round weight. Fiskeridirektoratets Kontrollverk 1995.

Korsbrekke, K., pers.comn .: Information about age/length distribution and estimation of swept area in 1989-1995. Data files from Institute of Marine Research in July 1995. Information about calculation of selectivity curves in November 1995. (Knut Korsbrekke, Havforskningsinstituttet).

Larsen, N. J., 1991: Kystfiske eller trålfiske -En bioøkonomisk simuleringsmodell for norsk-arktisk torsk. Fiskerikandidatoppgave; Norges Fiskerihøgskole.

Larsen, R. B., pers.comn.: Date from Sort-X experiments in 1990-1995. Various information about gear technology and gear selectivity. (Roger B. Larsen, Norges Fiskerihøgskole).

Larsen, R.B., Lisovsky, S., Isaksen, B., Sakhno, V.A., and Marteinsson, J.E., 1992: Experiment with Sorting Grid (Sort-X) made by Russian and Norwegian Trawlers in July 1992. Report to the 21th Session of the mixed Norwegian-Russian Fishery Commission.

Larsen, R. B., and Isaksen, B., 1993: Size selectivity of rigid sorting grids in bottom trawls for Atlantic cod (Gadus morhua) and haddock (Melanogrammus aeglefinus). ICES mar. Sci. Symp., 178-182.

Paulsen, O.A, and Steinshamn, S.I., 1994: Langsiktig fordeling av fiskeressurser mellom flåtegrupper. Norut Samfunnsforskning rapport 16/94.

Råfisklaget,1995: Information about quantity and value of fish landings in North-West and North Norway in 1991-1993, divided after gear type. Information from Råfisklaget 19. September 1995.

Selfi, 1995: Sort-X - Standard type for vessels over 30 m. User manual. Selfi A/S 1995.

Selfi, 1996: Sort-X - News. March 1996. Selfi A/S 1996.

Skattedirektoratet, 1995: Table over payroll tax rate. Skattedirektoratet 1995.

Skjold, F., 1995: Estimering av elastisiteter i produktfunksjoner. Oppsummering. 3 July 1995.

Skjold, F., Eide, A., Flaaten, O., 1996: Production Functions of the Norwegian bottom trawl fisheries of cod in the Barents Sea. ICES C.M 1996/P3.

Soldal, A.V., Engås, A., and Isaksen, B., 1993: Survival of gadoids that escape from a demersal trawl. ICES mar. Sci. Symp. 196: 122-127.

Statistisk Sentralbyrå, 1995: Statistisk Årbok 1994. Statistics Norway, Oslo.

Appendix

Sort-X. Construction and Working principles (Sources: Selfi, 1996).

The Sorting system (Sort-X) consists of two separate sorting grids with fixed bar distance (usually 55 mm) connected to a third section with a PVC canvas covered frame. The frame has a function of guiding away in order to sort small fish out from the trawl and keeping the Sort-X system balanced during the operation. The grids replace the upper panel in the extra net section which is placed between the belly/bating and the extension of the trawl (i.e. a lengthened part in front of the codend). The grids cover an area of 3.2 m^2 and the first sorting grid and the PVC-canvas covered frame are placed at a certain angle of attack to the water flow, while the sorting grid in the middle is placed parallel to the trawl. The modules are made of stainless and acid proof steel, and the three sections are joined together in a way that makes the system flexible. As soon as the gear is in operation, the system will be opened and kept in steady and correct position by use of chains between the first sorting grid and the guiding frame.

The small fish will pass between the bars of the sorting grids, while the bigger fish will pass underneath the system and continue to the codend. Therefore, the bar distance decides what sizes of fish escape. Due to a rigid construction like this installed into the trawl, the fish will be sorted out at an earlier stage in the catch process compared to normal codends.

The working principle of the Sort-X system, and it's location in bottom trawl are shown in figure A.1.

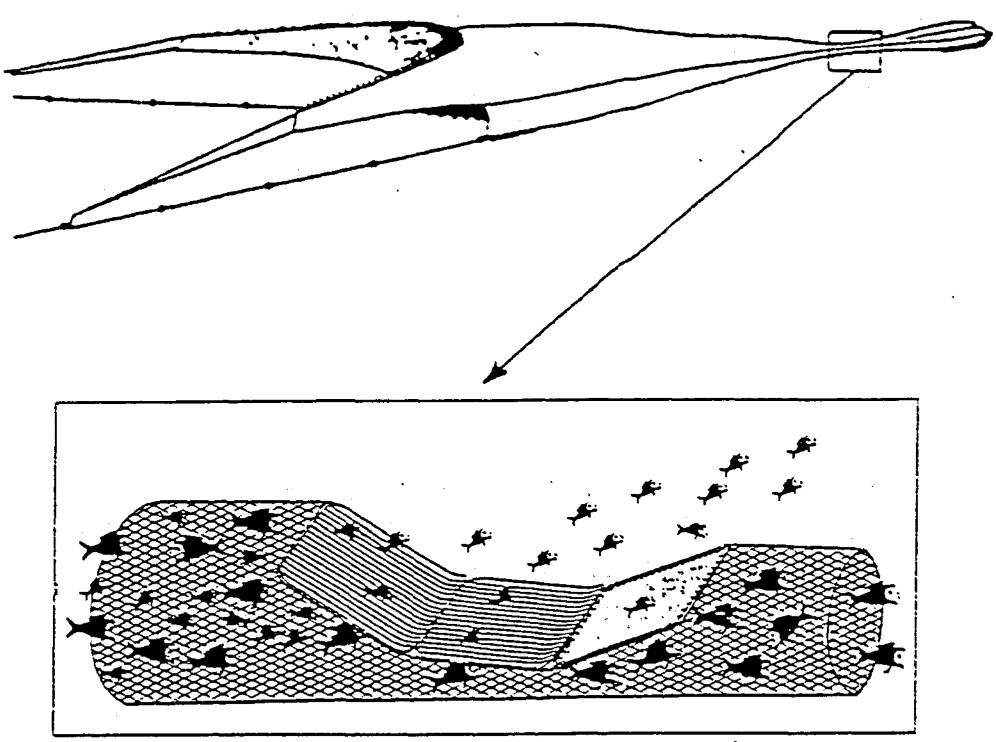


Figure A.1. An indication of the location of Sort-X in a bottom trawl, and the working principle of it. (Sources: Selfi, 1995)

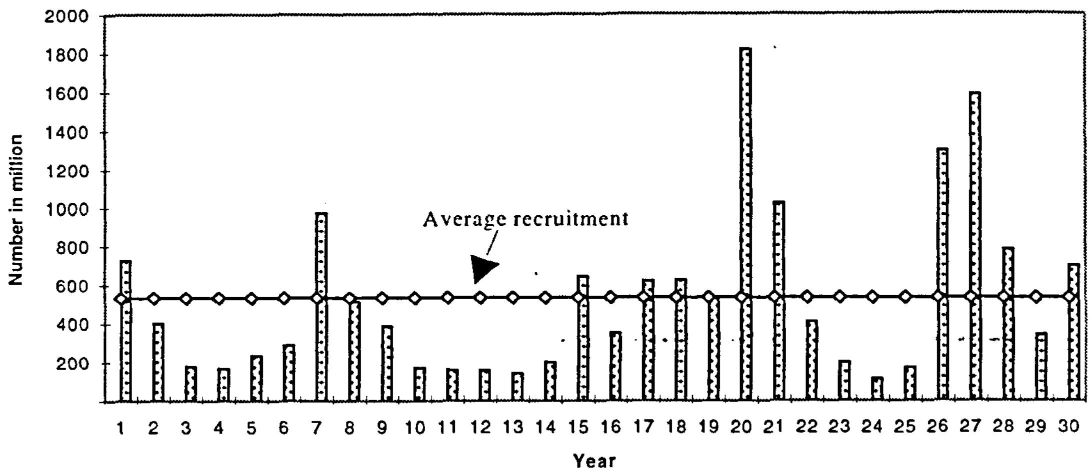


Figure A.2. Recruitment to the fishable stock in number.
Sources: Based on recruitment in 1963-1992, backwards (ICES, 1995). Recruitment in year 1 is the same recruitment as in 1992, and recruitment in year 30 is the same recruitment as in 1963.

Table A.1. Symbols, definitions and units.

Symbol	Definition	Unit
$F_{y,j}$	Fishing mortality, year y, fishery j	---
M	Natural mortality	---
$N_{a,y}$	Number of fish, age class a, year y.	Number
$B_{a,y}$	Biomass of fish, age class a, year y.	Tonne
X_y	Fishable part of stock, year y.	Tonne
R_y	Number of recruits to the fishable stock, year y	Number
t_c	Age of recruitment	Year
t_s	Maximum age of harvesting	Year
$w_{a,b}$	Average weight of fish in stock, age class a	Kg
$w_{a,j}$	Average weight of fish in landings, age class a, fishery j	Kg
$s_{a,j}$	Selectivity parameter, age class a, fishery j	---
$E_{y,j}$	Fishing effort, year y, fishery j	Day
$Y_{a,y,j}$	Catch in number, age class a, year y, fishery j	Number
$h_{a,y,j}$	Catch in biomass, age class a, year y, fishery j	Tonne
$H_{y,j}$	Catch of all age class, year y, fishery j	Tonne
$H_{j,z,u}$	Fishery j's catch, landed in county z, prosessing usage u	Tonne
τ	Share of fishable biomass 1. January, to be harvested that year	---
ϕ_j	Fishery j's relative share of total annual catch	---
$Q_{y,j}$	The total quota, year y, fishery j	Tonne
q_j	Catchability coefficient, fishery j	---
β_j	Stock output elasticity, fishery j	---
α_j	Effort output elasticity, fishery j	---

$p_{a,j}$	Price of fish, calculated for wet weight, age class a, fishery j	NOK per kg
c_j	Cost per unit of effort, fishery j	NOK per vessel day
r	Social rate of discount	---
$TR_{y,j}$	Total gross revenue, year y, fishery j	NOK
$TC_{y,j}$	Total harvesting cost, year y, fishery j	NOK
$NR_{y,j}$	Net revenue (resource rent), year y, fishery j	NOK
$\pi_{y,j}$	Present value of resource rent, year y, fishery j	NOK
f_j	Days of fishing per vessel year, fishery j	Day
$L_{j,z,u}$	Employment multiplier fishery j, landed in county z, prosessing usage u	---
v_u	Value added ratio, prosessing usage u	---
Z	Man year	Number

Table A.2. The values, units and sources of some biological parameters.

Variable	Unit	Value	Source
M	---	0.2	(ICES, 1995)
R_y (average year)	Numbers in thousands	527,751	(ICES, 1995)
t_c	Year	3	(ICES, 1995)
t_s	Year	15	(ICES, 1995)

Table A.3. Average age-specific weight in stock and harvest of NE-Arctic cod, in kg.

Age	Stock.	Foreign trawl fisheries	Norwegian trawl fisheries	Norwegian coastal fisheries
3	0.36	0.60	0.84	1.18
4	0.84	1.08	1.64	1.63
5	1.45	1.71	2.34	2.17
6	2.35	2.47	2.92	2.94
7	3.47	3.63	4.26	3.96
8	4.86	5.36	5.35	5.20
9	6.41	7.44	6.65	6.65
10	8.06	10.12	8.08	8.08
11	9.31	12.35	10.20	10.20
12	10.66	15.59	11.49	11.49
13	12.50	17.52	12.50	12.50
14	13.90	20.04	13.90	13.90
15+	15.00	20.83	15.00	15.00

Sources: Source for average weight at age in stock and in foreign trawl fisheries is ICES (1995). Source for average weight at age in Norwegian fisheries is data file from Marine Resource Institute (Bogstad pers.comn.).

Table A.4. Price per kg fish in NOK.

Age (1)	Foreign trawl fisheries	Norwegian trawl fisheries	Norwegian coastal fisheries
3-4	5.79	5.79	5.39
5-6	6.74	6.74	6.26
7+	8.25	8.25	8.62

(1)The calculation assumes that head cut fish less than 45cm are 3-4 year old, head cut fish between 45 and 60cm are 5-6 year old, and head cut fish above than 60cm are seven years and older. The multiplication factor 1.5 is used to convert gutted fish to round weight fish (Kontrollverket, 1995).
Sources: Calculated based on data from Råfisklaget (1995).

Table A.5. Calculated cost per vessel day, in NOK. 1993.

Trawl fisheries	Norwegian coastal fisheries	Norwegian gillnet fisheries
58,729	7,805	7,832

Sources: Calculated based on data from Fiskeridirektoratet (1989-1993), Kommunaldepartementet (1995), Skattedirektoratet (1995), Statistisk Sentralbyrå (1995). For details see Andreasson (1996).

Table A.6. Cod landings in Norwegian fisheries.

County	Total	Norwegian trawl fisheries	Norwegian coastal fisheries
Finnmark	21%	41%	59%
Troms	23%	33%	67%
Nordland	38%	24%	76%
Møre og Romsdal	18%	49%	51%

Sources: Calculated based on data from Fiskeridirektoratet (1996).

Table A.7. Selectivity values.

Age	NO 1)	RU 1)	SX90-92 2)	SX95 2)	½NO+ ½RU	SX95* NO	SX 80/55 2)	SX 80 2)	SX 100 2)	Gillnet Big mesh size 3)	Coastal fisheries 4)
3	0.4066	0.0567	0.2442	0.0805	0.2317	0.0386	0.0000	0.0000	0.0000	0.0000	0.0525
4	0.6073	0.1615	0.5839	0.1960	0.3844	0.2050	0.0926	0.1054	0.0319	0.0000	0.3090
5	0.7858	0.4143	0.8433	0.7606	0.6001	0.5639	0.2779	0.3254	0.0389	0.0000	0.5310
6	0.9128	0.7512	0.9651	0.9417	0.8320	0.8381	0.5338	0.5097	0.0813	0.0000	0.4778
7	0.9646	0.9321	0.9950	0.9863	0.9484	0.9498	0.8513	0.7178	0.2241	0.2200	0.4192
8	0.9834	0.9824	0.9992	0.9927	0.9829	0.9790	0.9041	0.8109	0.4879	0.5500	0.5268
9	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.7500	0.5873

10	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.6258
11	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.8500	0.5350
12	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.6000	0.3975
13	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.3500	0.2848
14	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.2000	0.2270
15+	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.1000	0.1885

Sources: 1) Calculated from data in Isaksen. et al. (1989).
2) Calculated from data from Larsen (pers.comn.).
3) Larsen (1991).
4) Calculated from data in Larsen (1991).

Table A.8. Parameters of the harvest function.

	Foreign trawl fisheries	Norwegian trawl fisheries	Norwegian coastal fisheries	Norwegian gillnet fisheries
q 1)	1.43E-04	1.43E-04	2.82E-04	2.58E-05
β 2)	0.75	0.75	0.57	0.73
α 3)	1.00	1.00	1.00	1.00

Sources: 1) Calculated based on data from Fiskeridirektoratet (1995), and ICES (1995).
2) Flaaten (1987), and Skjold (1995).
3) Assumed values, due to differing results found in Flaaten (1987) and Skjold (1995).

Table A.9.The distribution of the coastal fleet's quota between gear types.

Gillnet. Big mesh size	Gillnet. Small mesh size	Hook. Longline and handline	Danish Seine
38.50%	16.50%	30.00%	15.00%

Sources: Assumed values, based on data from Havforskningsinstituttet (1995), Paulsen and Steinshamn (1994).

Table A.10. Some results for the foreign trawl fisheries.

	Average annual total result for the 30 year period			**Average annual result per vessel**			
	Catch ('000 tonnes)	Resource rent (million NOK)	Present value of resource rent (million NOK)	Catch (tonnes)	Resource rent ('000 NOK)	Average price (NOK per kg)	Rent as per cent of price
1	376	1,014	430	3,501	9,449	7.73	34.91
2	376	1,018	431	3,506	9,485	7.73	35.00
3	378	1,029	436	3,520	9,577	7.73	35.22
4	379	1,034	439	3,526	9,617	7.72	35.31
5	383	1,075	457	3,556	9,980	7.76	36.16
6	389	1,133	483	3,599	10,479	7.81	37.29
7	404	1,213	517	3,702	11,112	7.76	38.68

8	405	1,292	554	3,715	11,843	7.93	40.20
9	406	1,301	559	3,716	11,920	7.95	40.35
10	438	1,612	695	3,939	14,494	8.15	45.13
11	425	1,491	623	3,878	13,596	8.05	43.56

Table A.11. Some results for the Norwegian trawl fisheries.

	Average annual total result for the 30 year period			**Average annual result per vessel**			
	Catch ('000 tonnes)	Resource rent (million NOK)	Present value of resource rent (million NOK)	Catch (tonnes)	Resource rent ('000 NOK)	Average price (NOK per kg)	Rent as per cent of price
1	108	260	109	3,501	8,468	7.45	32.46
2	108	264	111	3,506	8,605	7.48	32.81
3	108	286	121	3,520	9,288	7.64	34.52
4	109	293	124	3,526	9,513	7.69	35.06
5	110	294	125	3,556	9,534	7.64	35.11
6	111	311	132	3,599	10,048	7.69	36.32
7	116	335	142	3,702	10,708	7.65	37.80
8	116	359	154	3,715	11,485	7.83	39.46
9	116	362	155	3,716	11,594	7.86	39.69
10	125	456	196	3,939	14,332	8.11	44.86
11	122	422	176	3,878	13,432	8.01	43.26

Table A.12. Some results for the Norwegian coastal fisheries.

	Average annual total result for the 30 year period			**Average annual result per vessel**			
	Catch ('000 tonnes)	Resource rent (million NOK)	Present value of resource rent (million NOK)	Catch (tonnes)	Resource rent ('000 NOK)	Average price (NOK per kg)	Rent as per cent of price
1	200	468	202	306	718	7.44	31.51
2	200	470	202	307	720	7.44	31.56
3	201	474	204	308	725	7.43	31.71
4	202	476	205	308	728	7.43	31.79
5	204	486	209	310	739	7.42	32.12
6	207	503	217	313	760	7.42	32.76
7	215	829	363	329	1,270	8.62	44.77
8	216	552	238	320	821	7.43	34.41
9	216	551	238	320	819	7.43	34.47
10	233	655	282	335	942	7.47	37.64
11	226	921	396	344	1,402	8.62	47.23