The economics of size selective harvesting - the case of barents sea cod fisheries.

Stefan Andreasson and ***Ola Flaaten***
The Norwegian College of Fishery Science University of Tromso
9037 Tromso, Norway.
Tel.: +4777644000
Fax.: +47 77646020
e-mail: olaf@nfh.nit.no

Table of Contents.

Abstract

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 experiences to analyses the bioeconomic performance of the Sort-X trawl selectivity system, and to compare the results 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 tins 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 the Sort-X system 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.

1. Introduction

The problem of fisheries' by-catch 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 an 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.

By-catch 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 by-catch levels in trawl, as well as in traditional coastal fisheries using gillnet, long-line, hand-line 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 astern, and the working principle of it).

The aim of this paper is to study the bioeconomic effects on resource rent, harvest rates, vessel profitability etc. of using the Sort-X selectivity in bottom trawl fishing for North East Atlantic 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 pan of the model is a traditional Baranov-Beverton-Holt model with exogenous recruitment. In one set of scenarios, the annual recruitment to the fishable stock is inversely repeated from the last 30 years, whereas constant recruitment is used in an alternative set of scenarios. The economic part of the model includes size-dependent price of fish, total costs of fishing effort, stock output elasticity 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.

2.1. List of inputs and definitions.

The symbols and the definitions of variables and parameters used in the model are shown in table 1.

Table 1: Notations, definitions and units

Symbol	definition	Unit
$F_{y,j}$	Fishing mortality, year y, fishery j	---
M	Natural mortality	---
N_{ay}	Number of fish, age class a, year y.	Numbers
$B_{a,y}$	Biomass of fish, age class a, year y	Tonnes
.X_y	Fishable part of stock, year y.	Tonnes
R_y	Number of recruits to the fishable stock, year y	Numbers
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	---
$Y_{a,y,j}$	Catch in number, age class a, year y, fishery j	Numbers
$h_{a,y,j}$	Catch in biomass, age class a, year y, fishery j	Tonnes
$H_{y,j}$	Catch if all age class, year y. fishery j	Tonnes
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	Tonnes
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 kg
r	Social rate of discount	
$TR_{y,j}$	Total gross revenue, year V, 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

2.2. The model.

Biological part.

The NE-Arctic cod stock consists of several year classes; it is common to use the Baranov-Bverton-Holt model for analyses of stock dynamics with and with 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. Al the beginning of next year the number of fish is given by

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

when there are three fisheries, k, l, and m

The biomass of age class a at the beginning of the year y is

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

and the biomass of the fishable part of the stock is

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

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

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

and the catch in biomass is

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

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

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

the total annual catch for all fisheries is

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

A fishing rule that will be used is that a given share, T, 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) $$Q_{y,total} = \tau X_y$$

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

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

where the sum of all ϕ equals unity.

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

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

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

Economic part

For fishery j the annual gross revenue from the harvesting of one age class is

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

and fishery js total gross revenue is

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

the total annual gross revenue for all fishery is

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

The catch per unit of effort (CUPE) is assumed independent of the total effort used, i.e. the effort output elasticity, α, equal 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 /3 from FIaaten (1987) and Skjold (1995), and we estimate q based on fishery statistics from The Directorate of Fisheries in 1986-1993 (Fiskeridirektoratet. pers.comn.).

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

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

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

(16) $$TC_{y,j} = E_{y,j}\, C_j.$$

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

For fishery j the annual net revenue from fishing is

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

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

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

for the reference year y_0, when $t = y - y_0$.

The present value of one year's resource rent from all fisheries is

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

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

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

and the total period catch for all fisheries is

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

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 vessel in fishery j necessary to supply fishing effort $E_{y,j}$ is

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

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

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

Using $n_{y,j}$ and nj 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) $F_a = S_a F$

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

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

3. The biological, economic and technical data.

3.1. Biological data.

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 shown in table 2. The variable recruitment from year 30 is shown in the appendix, table A.1, whereas table A.2 shows the biomass of each age class for the reference year, 1993.

Table 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)
ts	Year	15	(ICES, 1995)

The age-specific weight of cod, in the stock and in the catches, differs due to gear selectivity and heterogeneous distribution of fish and fishing vessels. Table 3 shows average age-specific weights of cod in the fishable stock, and in the catches of the three fisheries to be studied.

Table 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	8.08	10.12	8.08	8.08
11	9.31	12.35	10.20	10.20
12	10.69	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.S3	15.00	15.00

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

3.2. Economic data.

1993 is used us 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 fisheries.
Age-specific prices of fish, in NOK per kg fish round weight, are calculated based on average landing prices from Northwest and North Norway for 1991-1.993 (Rafisklaget, 1995); the results are shown in table 4.

Table 4: Price per kg fish in NOK.

Age	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

Source: Calculated based on data from Rafisklaget (1995)

The alculation assumes that head cut fish less than 45 cm are 3-4 year old, head cut fish between 45 and 60 cm are 5-6 year old, and head cut fish above than 60 cm are seven years and older. The multiplication factor 1.5 is used to convert gutted fish to round weight fish (Kontrollverket, 1995). Table A.3 in the appendix shows the data used for the calculation of the fish prices in table 4.

Harvesting cost per vessel day are shown in table 5. The harvesting cost includes the opportunity cost of capital and labour.

Table 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 Fiskeriderektorated (1989-1993), kommunaldepartementet(1995), skattedirektoratet(1995).

Statistik sentralbyra (1995). For detail see Andreasson (1996).

The actual number of days, which each vessel fishes annually, depends on, i.e. 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 Fiskeriderektorated, 1989-1993), and were used to derive the cost per vessel day data in table 5.

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

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 properties of trawls in use and under development for commercial fishing are shown in figure 1. This figure also shows the selectivity curve for large mesh size gillnets being used by parts of the coastal fleet. The average selectivity of the coastal fleet is different, as shown in the appendix, table A.4.

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 (Isaksen et.al., 1989). The l/2NO+l/2RU -curce is the arithmetic average of the NO and the RU curves. The argument for using the 1/2NO+1/2RU-curve is that approximately 40% of the Russian trawlers and all of the other foreign trawlers used rli.-«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). All Sort-X selectivity curves are from experiments with 55-mm bar distance. The SX95*NO-curve is based on multiplication of the values in the SX95-curve and the NO-curve. The argument for using the SX95:iiNO-cu^ve 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 Gillnet-curve is a selectivity curve for gillnets with big mesh size (Larsen. 19.91).

Table A.4 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.

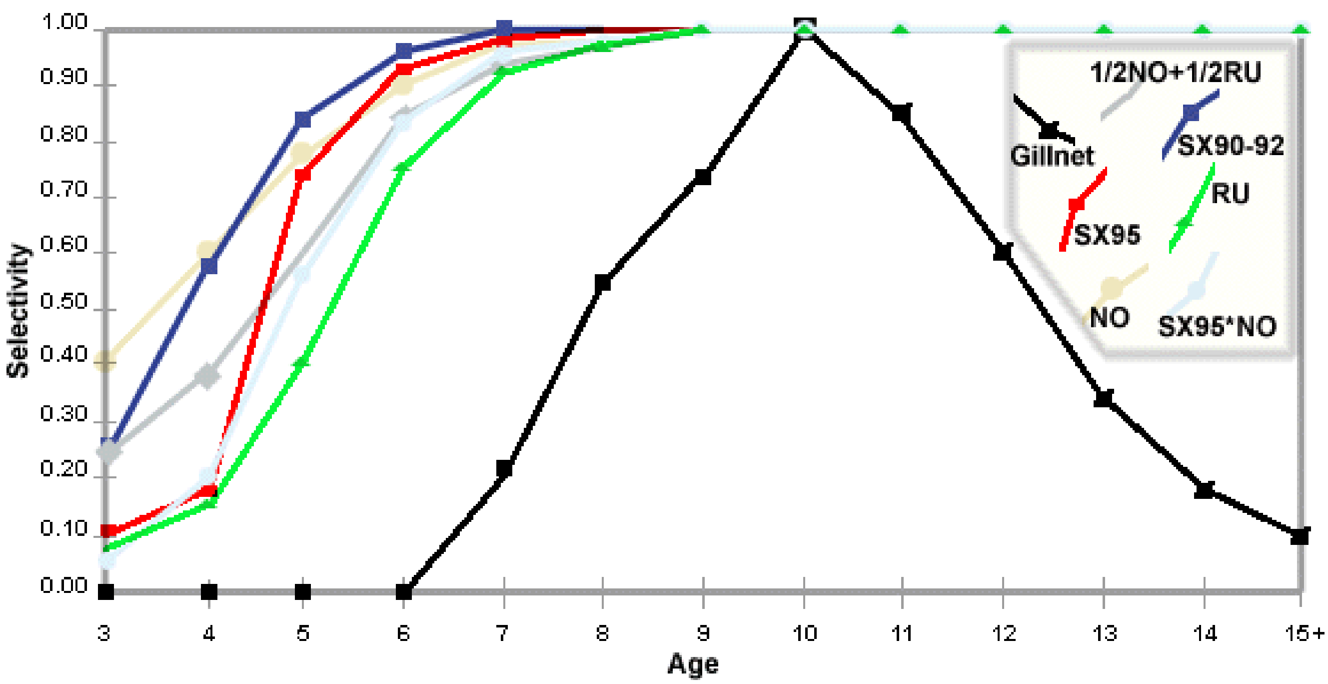

Figure 1: The selectivity curve show the probability that a fish of a specific age is trapped when encountered by the gear.

Sources: NO (Norwegian trawl) and RU (Russian trawl)- Isaksen et.al. (1989). 1/2NO+1/2RU (Combination of NO and. RU), SX90.92 (Sort-X experiment l990-92) Larsen (pers-comm.). SX90NO (Theoretical combination of SX95 and NO). Gillnet-Larsen (1991).

To estimate the fishing effort we use the Cobb-Douglas production function. The parameters of the harvest functions (catchability coefficient q, stock output elasticity p, and effort output elasticity α) Lire given in table 6.

Table 6: Parameters of the harvest function.

	Foreign trawl fisheries	Norwegian trawl fisheries	Norwegian coastal fisheries	Norwegian gillnet fisheries
q 1)	1.43E-04	1.431.E-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 Fiskeriderektoratet (1995), and ICES(1995).
2) Flaaten (1987), and Skjod (1995).
3) Assumed values, due to differing result found in Flaaten (1987) and Skjold (1995).

The data used for the calculation of q are shown in the appendix, table A.5.

3.4 Relative harvest share.

The three fisheries relative catches of cod varied somewhat from year to yea). The TAC for North East Atlantic 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 share, whereas Norway has a significant fleet of coastal vessels using gillnet, hand-line, long-line and Danish seine. Table 7 shows relative shares of TAC for foreign trawl fisheries.

Table 7.: 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.

Source: Assumed values, based on data from ICES (1995) 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.6.

4. Results.

The bioeconomic results for i.a. resource rent, harvest rate and vessel profitability are derived for 7 combinations of selective harvesting of North East Arctic cod. For the selectivity pattern in the reference scenario, the total resource rent over the 30-year period for the three fisheries has been calculated. Figure 2 shows this resource rent for varying 2 relative catches. Figure 2 shows this resource rent-approximately 52.264 million NOK, is found for an annual catch equal to 20 percent of the stock level at the beginning of the year.

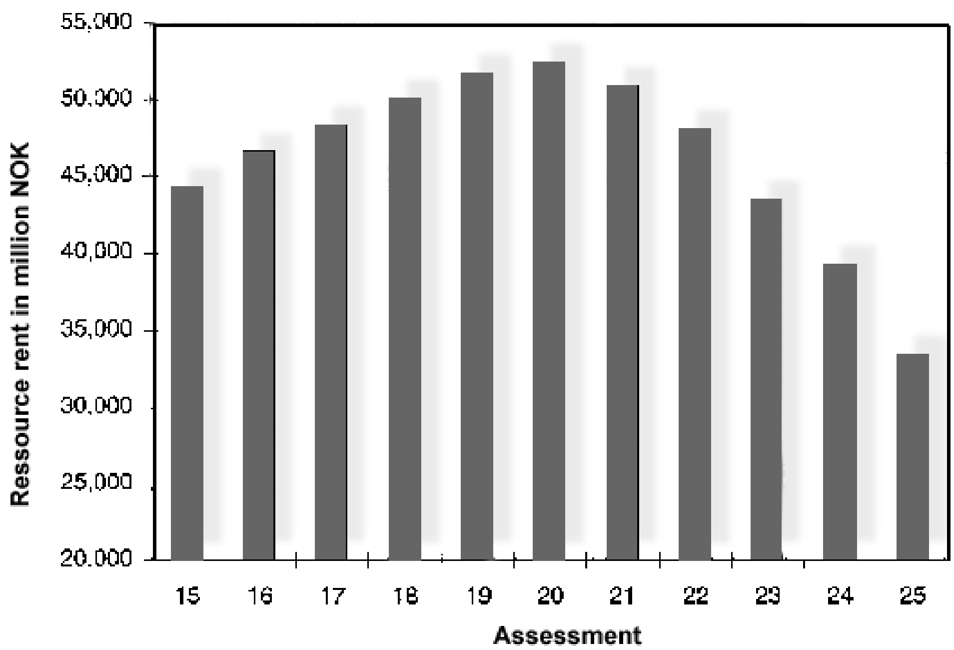

Figure 2: the total resource in million NOK as a function of the harvest stock level ratio.

Table 8. The combination of selectivity curves used in the scenario. 1

Simulation	Foreign trawl fisheries	Norwegian trawl fisheries	Norwegian coastal fisheries
1 and 8	½ NO + ½ RU	NO	Mixed coastal fisheries
2 and 9	34 NO + 34 RU	SX9O-92	Mixed coastal fisheries
3 and 10	34 NO + 34 RU	SX95	Mixed coastal fisheries
4 and 11	34 NO + 34 RU	SX95*NO	Mixed coastal fisheries
5 and 12	SX95	SX95	Mixed coastal fisheries
6 and 13	SX95*NO	SX95*NO	Mixed coastal fisheries
7 and 14	SX95*NO	SX95*NO	Large mesh size gillnet

1) For acronyms, see figure 1

Simulation 1 is the reference scenario. This 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.4, and that the foreign trawlers use the average selectivity of traditional Norwegian and Russian trawl. The justification for the latter is that Russian and oilier foreign trawlers are, to an increasing extent, using gear with technical characteristics, similar to Norwegian trawls (Larsen, pers.comn.).

Using catch, resource rent and present value of rent as performance criteria, the results of the variable recruitment scenarios 1-7 are shown in tables 9-14, The results of scenarios 8-14, with constant recruitment, are shown in the appendix, tables A.7-A.12.

Table 9. : Total results for all Fisheries for the 30-year period

	Catch (*000 tonnes)	Gross revenue (million NOK)	Total cost (million NOK)	Resource rent (million NOK)	Present value of resource rent (million NOK)	Average price (NOK per kg.)	Rent as per cent of price
1	20.486	155.745	103.481	52.264	22.212	7.60	33.56
2	20.525	156.103	103.534	52.570	22.347	7.61	33.68
3	20.631	157.344	103.678	53.667	22.847	7.63	34.11
4	2l.674	157.S22	103.738	54.083	23.033	7.63	34.27
5	20.899	159.679	104.033	55.646	23.720	7.64	34.85
6	21.225	162.891	104.484	58.407	24.953	7.67	35.86
7	22.033	176.167	104.879	71.289	30.651	8.00	10.47

Table 9 shows the total results for all three Fisheries. Scenario 1 has the lowest catch, resource rent and present value of rent, and Scenario 7 has the highest performance according to these criteria. Table 9 also shows that there is less variance in total costs than in total revenue between scenario. Scenario 1 has the lowest catch and the lowest price, whereas scenario 7 has the highest catch and the highest price.

Table 10 shows that, for the total fisheries, the ranking of the 7 scenarios is the same for any of the three performance criteria.

Table 10 : Differences in results from simulation 1 in percent, for all fisheries.

	Catch	Gross revenue	Total cost	Resource rent	Present value of resource rent
2	0.19	0.23	0.05	0,58	0.60
3	0.71	1 03	0.19	2,68	2.86
4	0,92	] .33	0.25	3.48	3.69
5	2.02	2.53	0.53	6.47	6,79
6	3.61	4.59	0,97	11.75	12.34
7	7.55	3.11	1.35	36.40	37.99

Tables 11-14 show that, for all three fisheries, scenario 7 performs best according to any of the criteria. The ranking of the 7 scenarios is also the same for the three fisheries, independent of which performance criteria are being used.

Table 11. : Foreign trawl fisheries

	Total results for the 30 year period			Average result per vessel per year			
	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 percent of price
1	11,267	30,413	12,895	3,501	9,449	7.73	34.91
2	11,2^9	30,540	12,951	3,506	9.485	7.73	35,00
3	1 !,347	30.87]	13.099	3.520	9.577	7,73	35.22
4	11,371	31,012	13.160	3,526	9,617	7,72	35.31
5	11,494 11,494	32,255	13.715	3,556	9.980	7.76	36.16
6	11,674	33,985	14,492	3.599	10,479	7,81	37.29
7	12,119	36.378	15.503	3.702	11.112	7,76	38.68

Table 12. : Norwegian trawl fisheries

	Total results for the 30 year period			Average result per vessel per year			
	Catch *000 tonnes	Resource rent (million NOK)	Present value of resource rent million NOK1	Catch (tonnes)	Resource rent(*000 NOK) NOK)	Average price (NOK per Kg)	Rent as per cent of price
1	3.227	7..04	3.270	3,501	8,468	7 .45	32.46
i	3.233	7.934	3.329	3.506	8.605	7.48	32.81
i	3,249	8,573	3,625	3.520	9.288	7.64	34.52
4	3,256	8.785	3.723	3-526	9.513	7.69	35,06
5	3.292	14.566	3,735	3.556	9.534	7.64	35.11
6	3.343	9.332	3,964	3.599	10,04	7,69	36.32
7	3,470	10.039	4.264	3.702	10,708	7.65	37.80

Table 13. : Norwegian coastal fisheries

	Total results for the 30 year period			Average result per vessel per year			
	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 of price cent or pi'iL-c.'
1	5,992	14.048	6,047	306	71S	7.44	31.51
2	6.004	14.096	6,067	307	720	7.44	31.56
3	6,034	14,223	6,123	308	725	7.43	31,71
4	6,047	I4.286	6.150	308	728	7,43	31.79
5	6.113	14,566	6,270	310	739	7.42	32.I2
6	6.208	15,090	6,498	313	760	7.42	32 76
7	6,445	24,871	10.884	329	1,270	8.62	44,77

Table 14. : Norwegian trawl fisheries. Differences in results from simulation 1 in percent

	Catch	Resource rent	Present value of resource rent
2	0.19	1.67	1.79
3	0.71	9.85	10,83
4	0.92	12.57	13,85
5	2.02	13 .08	14.21
6	3,61	19.58	21.21
7	7.55	28.63	30,41

Table 13 shows that 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 45.0% for scenario 7 for the Norwegian coastal fisheries. The Norwegian coastal fisheries have the lowest (scenario 1) and the highest (scenario 7) relative resource rent of the three fisheries. However, excluding scenario 7, the relative resource rent of the Norwegian coastal fisheries varies very little between scenarios 1-6.

Tables 11 and 12 show that the difference in the relative resource rent of scenarios 7 and 1 is 4 and 5 percentage points for all the foreign and the Norwegian trawl fisheries, respectively.

The results of the constant recruitment scenarios 8-14 are shown in the appendix, tables A.7-A.12. The relative performance of the fisheries and the scenarios are mainly the same as for the variable recruitment case above.

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 [c. 1" percent of the stock level al 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 and catches from variations in the selectivity pattern.

The analysis shows that the Sort-X system performs better than traditional trawl, and that the system arising from the 1995 improvements of Sort-X performs better than the 1990-!*"1:' Sort-X. However, the selectivity pattern of large mesh size gillnet seems to be superior for all others, as scenarios 7 and 14 show.

Bioeconomic aspects of by-mortality 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 by-mortality problems are relatively small for cod (Soldal et al., 1993). Future research should, however, also include the economic aspects of by-mortality, this also applies to any by-mortality of fish encountered by the gear types of coastal fleet.

Recent Sort-X experiments with bar distances between 55 and 100 mm, and regular mesh size (135 mm) in the cod end of the trawl, show significant increase in the average size of fish in the catch (R. Larsen, pers. comn.). The bioeconomic results of applying this modified Sort-X will be presented in another paper.

Acknowledgements.

We would like to thank B. Bogstad, B. Dreyer and K. Korsbrekke for their generous help with data, 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 (gram no. 108! 64/110), 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 Okonomiske vurderinger av Sort-X. internt Sort-X notat no. 8, 5 februar 1996. Norges Fiskerihogskole. Universitetet Tromso.

Bogsad, per. Comm.: Weignt al age in Norwegian fisheries. Data files from Institute of Marine Research in October 1995. (Bjarte Bogstad, Havforskningsinstituttet).

Fiskeridirektoratet, 19S9-1993: Lonnsomhetsundersokclser for fiskefart0yer 13 m 1.1. og over i arene 1989 til 1993. (Annual profitability studies for Norwegian fishing vessels 13m and above, in Norwegian with English summary) Budsjetlnemda for fiskerinceringen (Separate number for each year).

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

Flaaten, 0., 1987: Sesongvarierende bestandstilgjengelighet og produktfunksjoner i Lofotfiske. Forut-rapport nr. EP 7005/1-87.

Havforskningsinstituttet, 1995: Ressursovcrsikt 1995. Fisken og Havet, Sasrnuimmer 1-1995 Havforskningsinstituttet.

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

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

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

Kontrollverkelt 1995: Table over multiplication factor from gutted weigh! to round weight. Fiskeridirektoratet 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. havforskninasinstituttet).

Larsen, N. J.. 1991: Kystfiske c!lcr tralfiske -En biookonomisk simuleringsmodell for norsk-arklisk torsk. Fiskerikandidatoppgave Norges Fiskerihomgskole.

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

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 21st Session of the mixed Norwegian-Russian Fishery commission .

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

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

Rafisklaget.1995: Information about quantity and value offish bindings in North-west and North-Norway in 1991-1993, divided after gear type. Information from Rafisklaget, 19 September 1995.

Selfi. 1995; Sort-X - Standard type for vessel over 30 m User manual. Selfi A/S 1995.Q'i Selfi. 1996: Sort-X - News. March 1996. Selfi A/S 1996.

Skatterdirektoratet,1995: Table overpayroll tax rate. Skatterdirektoratet 1995.

Skjold, F., 1995: Estimering av elastisiteter i produkfunksjonner. Oppsummering.3 july 1995.

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

Statistik Sentralbyra, 1995: Statistik Arbok 1994. Statistik Sentralbyra, 1995.

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 i.e. 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 cod-end). The grids cover an area of 3.2 m² 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 the 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 cod-end. Therefore, the bar distance that decides what sizes of fish that 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 cod-ends.

The working principle of the Son-X system, and its location in bottom trawl are shown in figure A.1

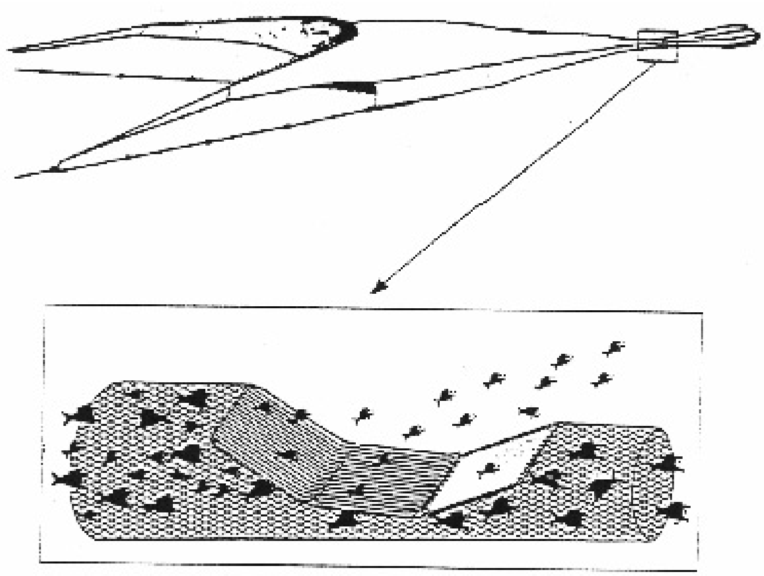

Figure A.1 An indication of the location of Sort-X in a bottom trawl, and the working principle of it. (Sources: Selfi. 1995)

Data.

Table A.1 : Recruitment to the fishable stock in number.

Year	Number in million
I	726.386
2	398.247
3	176.968
4	166.273
5	234.239
6	289.159
7	971.556
8	509.134
9	383.823
10	168.631
11	157448
12	157.843
13	140.443
14	198.853
15	639,421
16	347.710
17	614.151
18	621 .899
19	524.555
20	1,818797
21	1.015.579
22	404.979
23	197.050
24	111.968
25	169.748
26	1.292.664
27	1.582.377
28	778.090
29	338.995
30	694.531
Average recruitment	527.75 1

Source: Based on recruitment in 1963-1992. Backwards (ICES, 1995). Recruitment in year 1 is the same recruitment in year 30, is the same Recruitment as in 1963.

Table A.2. : Biomass and age structure of the stock of the reference year, 1993, in '000 tonnes.

Age	Biomass 1)
3	290.752
4	482.055
5	332.450
6	157.280
7	136.773
8	186.852
9	172.666
10	379.642
11	63.196
12	10.500
13	1.075
14	1.542
15+	0.810
Total	2.215.597

Source 1) calculated based (in stock number at age (ICES. 1995). and average age specific weight in stock (table 3).

Table A.3. : The data used for the calculation of the 1993 age-specific fish price.

	1991			1992		1993		Average 1991-93		1993
Type of fisheries	Fish size (cm)	Quantity (Tonnes)	Value('000 NOK 1993 prices)	Quantity (Tonnes)	Value ('000 NOK 1993 prices)	Quantity (Tonnes)	Value ('000 NOK 1993 prices)	Quantity (Tonnes)	Value '000 NOK 1993 prices)	Price (NOK per kg)
Trawl	Over 60	28,924	281,567	44,609	370,787	44,200	319,080	39,245	323,811	8.25
Trawl	*45-60*	27,432	233,788	51,531	384,563	78,825	445,268	52,596	354,540	6.74
Trawl	Under 60	1,724	13,269	12,043	75,286	21,409	115,027	11,725	67,861	5.79
Coastal	Over 60	45,695	444,152	53,537	483,864	59,879	444,247	53,037	457,421	8.62
Coastal	45-60	6,353	43,303	5,628	36,371	7,496	42,176	6,493	40,617	6.26
Coastal	Under 60	272	1,494	284	1,531	343	1,821	300	1,616	5.39

Sources: Rafisklaget (1995).

Table A.4. : Selectivity values.

Age	NO 1)	RU 1)	SX90-92 2)	SX95 2)	1/2NO+1/2RU	SX95*NO	Gillnet Big mesh size 3)	Coastal Fisheries 4)
3	0,4066	0,0567	0,2442	0,0805	0,2317	0,0386	0,0000	0,0525
4	0,6073	0,1615	0,5839	0,1960	0,3844	0,2050	0,0000	0,3090
S	0,7858	0,4143	0,8433	0,7606	0,6001	0,5639	0,0000	0,5310
6	0,9128	0,7512	0,9651	0,9417	0,8320	0,8381	0,0000	0,4778
7	0,9646	0,9321	0,9950	0,9863	0,9484	0,9498	0,2200	0,4192
8	0,9834	0,9824	0,9992	0,9927	0,9829	0,9790	0,5500	0,5268
9	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	0,6258
11	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	0,6000	0,3975
13	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	0,2000	0,2270
15+	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	0,1000	0,1885

Sources:

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

Table A.5.: Calculation of the catchability coefficient *q*

Calculation of *q* for trawl.					
Year	Catch (tonnes) (1)	Vessel day (1)	Fishable stock (tonnes) (2)	β(3)	*q*
1986	101,856	14,272	1,239,359	0.75	1.92E-04
1987	169,990	20,085	1,122,788	0.75	2.45E-04
1988	120,568	21.750	834,791	0.75	2.01E-04
1989	61,863	13,888	1,018,213	0.75	1.39E-04
1990	26,883	9,478	1,168,337	0.75	7.98E-05
1991	31,671	11,553	1,689,446	0.75	5.85E-05
1992	57,528	11,545	2,165,498	0.75	8.83E-05
Average year	**81,480**	**14,653**	**1,319,776**	**0.75**	**1.43E-04**
Calculation of q for mixed Norwegian coastal fisheries.					
Year	Catch (tonnes) (1)	Vessel day (1)	Fishable stock (tonnes) (2)	β(3)	*q*
1993	**77,960**	**60,657**	**2,319,776**	**0,75**	**1.43E -04**
Calculation of *q* for Norwegian gillnet fisheries					
Year	Catch (tonnes) (1)	Vessel day (1)	Fishable stock (tonnes) (2)	β(3)	*q*
1993	**40,590**	**32,520**	**2,619,552**	**0.73**	**2.58 E -05**

Sources: 1) Fiskerdirektoretet *(1995).*
2) ICES *(1995).*
3) Skjold *(1995).*
4) Flaaten (1987).

Table A.6.: The distribution of the coastal fleet' s quota between gear types.

Gillnet. Big mesh size	Gillnet. Small mesh size	Hook. Long-line and hand-line	Danish Seine
38.50%	16.50%	30.00%	15.00%

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

Results.

Table A.7. : Total results for all fisheries for the 30 year period

	Catch ('000 tonnes)	**Gross revenue (million NOK)**	**Total cost (million NOK)**	**Resource rent (million NOK)**	**Present value of resource rent (million NOK)**	**Average price (NOK per Kg)**	**Rent as per Cent of price**
8	22,183	169,307	107,513	61,794	30,092	7.63	36.50
9	22,231	169,740	107,577	62,163	30,261	7.64	36.62
10	22,353	171,158	107,740	63,419	30,846	7.66	37.05
11	22,397	171,667	107,797	63,871	31,052	7.66	37.21
12	22,654	173,726	108,142	65,585	31,867	7.67	37.75
3	23,012	177,288	108,607	68,681	33,289	7.70	38.74
14	23,920	191,941	108,451	83,490	40,247	8.02	43.50

Table A.8. : Differences in results from simulation 8 in percent, for all fisheries.

	Catch	Gross revenue	Total cost	**Resource rent**	Present value of resource rent
9	0.22	0.26	0.06	0.60	0.56
10	0.77	1.09	0.21	2.63	2.50
11	0.97	1.39	0.26	3.36	3.19
12	2.12	2.61	0.58	6.13	5.90
13	3.74	4.71	1.02	11.14	10.62
14	7.83	13.37	0.87	35.11	33.74

Table A.9. Foreign trawl fisheries

Total results for the 30 year period				**Average result per vessel per year**			
	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 office
8	12,200	36,122	17,605	3,665	10,852	7.77	38.12
9	12,227	36,284	17,677	3,671	10,895	7.77	38.21
10	12,294	36,675	17,848	3,687	10,999	7.76	38.43
11	12,318	36,819	17,909	3,693	11,038	7.76	38.52
12	12,460	38,175	18,565	3,726	11,415	7.79	39.32
13	12,657	40,110	19,462	3,772	11,953	7.84	40.42
14	13,156	43,055	20,669	3,888	12,725	7.80	41.94

Table A.10. : Norwegian trawl fisheries

	Total results for the 30 year period			Average result per vessel per year			
	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
8	3,494	9.313	4,528	3.665	9.770	7.47	35.67
9	3,501	4,459	4,599	3,671	9,918	7.50	36.02
10	3,521	10,178	4.952	3.687	10.660	7.67	37.70
11	3.528	10,422	5.071	3.693	10.41 1	7.73	38.24
12	3,568	10,463	5.084	3,726	10.925	7.66	38.27
13	3,625	11,039	5.351	3.772	11.488	7.72	39.47
14	3.767	1 1,893	5.705	3.8S8	1 2.275	7.69	41.06

Table A.11. : Norwegian coastal fisheries

	Total results for the 30 year period			Average result per vessel per year			
	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
8	6,488	16.360	7,958	316	796	7.46	33.7 S
9	6.503	16.420	7,984	316	799	7,46	33.84
10	6,538	1&.566	8,045	317	804	7.45	33.99
11	6.551	16.629	8,072	318	806	7,45	34.06
12	6.626	16.947	8.2 I8	320	818	7,44	34.38
1313	6,73 1	17.531	8.476	323	841	7.44	35.00
14	6.997	28.541	13.873	345	1.407	8,62	47.32

Table A. 12. : Norwegian trawl fisheries. Differences in results from simulation S. in percent.

	Catch	Resource rent	Present value of resource rent
9	0.22	1.57	1.56
10	0.77	9,29	9.37
11	0.97	1 1.92	11.99
12	2 12	12.35	12.27
13	3.74	18.54	18.18
14	7.83	27,71	26.00