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Optimal Management of the Iceland-Greenland Transboundary Cod Stock

by

Steen Christensen
Danish Institute of Fisheries Economics Research
University of South Jutland, Niels Bohrsvej 9
DK-6700 Esbjerg, Denmark

and

Hans Lassen
Danish Institute for Marine and Fisheries Research
Charlottenlund Slot, DK 2920 Charlottenlund, Denmark

Abstract

Atlantic Cod (Gadus morhua) in Icelandic waters, in the Davis Strait and east and southeast of Greenland is a transboundary stock which occurs both in the Greenlandic and in the Icelandic Fishing Zone. In some years large numbers of egg, larvae and juvenile cod are carried from the spawning grounds in Icelandic waters to Greenland where they settle and form the basis for a fishery in the following years. The Icelandic component of the cod off Westgreenland home when they reach maturity at the age of about 5 years.

The present paper discuss optimal joint management between Iceland and Greenland of this cod stock. Further, considerations of how Greenland should optimize its fishery without regarding the action of the other are presented.

The analysis applies a standard bioeconomic model of the fisheries and simple game theory in discussing the actions of each party.

Introduction.

The offshore cod (*Gadus morhua*) at West Greenland is a local spawning stock to which in some years a substantial larval inflow from the Icelandic cod stock is added. However, since the mid-sixties spawning success of the local West Greenland cod stock has been low, likely due to low sea temperature at the time of spawning. Taggings in West Greenland indicate that the stock component of Icelandic origin migrate back to the Icelandic spawning grounds at maturity.

During the warm period 1915 - 1965 several good year classes (1917, 1922, 1924, 1926, 1934, 1945, 1956, 1961, 1963) lead to an increase of the cod biomass of Greenland.

The very big catches taken during the 1960'ties, mainly by the German fishing fleet, affected the population structure which consequently became dominated by one or just a few year classes. Therefore, the fishery quickly collapsed when the recruitment failed at the onset of the colder period in the mid and late 1960'ties.

In the late 1970'ties and in the beginning of the 1980'ties the fishery were partly reconditioned, but as it was based almost entirely on the 1973 year class it faded away along with this year class.

Similar the 1984 year class, estimated by ICES at 380 million 3 year old fish, and the 1985 year class, estimated at about 1/5 of the 1984 year class (Anon, 1992), constituted the basis for the increase in the yield of the fishery in 1988 - 90.

The biological management advice presented by the Scientific Council of NAFO (Anon, 1987, 1988, 1989, 1990, 1991) was based on the assumption that these cod were of local West Greenland origin, with only a limited migration to Iceland. The migration was estimated from tagging results which mainly dated from 1950 - 1965. The management measures recommended by the Council aimed at preventing growth overfishing of these two year classes and at reestablishing a spawning stock off West Greenland. However, the total yield of these two year classes has been significantly lower than expected, partly due to a lower average weight at age in the catch than assumed in the assessment and partly due to a very significant emigration out of the Greenland waters. This emigration both started at an earlier age and was much more pronounced than expected.

In the present situation, without a spawning stock off shore West Greenland (Anon, 1993), a potential cod fishery in the future is likely to be based on inflowing larvae of Icelandic origin, and these cod should be expected to home to Iceland when they become mature. Therefore, management of the Icelandic - Greenlandic cod stock may be regarded as management of a transboundary resource shared between two states (Munro, 19xx).

The two countries may have different management objectives. At present a Greenlandic spawning biomass does not seem to be directly influenced by the Icelandic immigrants, the management objective, from a Greenlandic point of view, will, therefore, be to maximize the outcome of the cohort before emigration takes place. From the point of view of Iceland, this strategy may, depending on the perception of the social rate of discount, be considered as growth overfishing.

Based on the assumption that a hypothetical cod stock at Greenland is constituted solely by individuals of Icelandic origin, it is the aim of the present paper to discuss whether cooperation between the joint owners, Greenland and Iceland, may be advantageous, or whether rational management of the individual shares of the resource may be equally good.

The Model.

The bioeconomic model applied in the present study may be described as a two area system as illustrated in Figure 1. The stock of cod of Iceland, represented by area 1, is regarded as a self sustained stock. Larval inflow from area 1 to area 2, representing Greenland, constitute the basis for a fishery in this area until the fish mature and migrate back to area 1.

The objective function to be maximized is the present value of the resource rent. This function can be expressed as

$$Max\ \pi = \sum_t TR_t(p_{Gr,a}, Y_{Gr,a}, \delta_{Gr}, p_{Is,a}, Y_{Is,a}, \delta_{Is}) -$$

$$TC_t(D_{Gr}, \delta_{Gr}) \qquad (1)$$

where

- TR_t is total revenue of the fishery at time t,
- TC_t is total cost of the fishery at time t,
- $Y_{Gr,a}$ is total Greenlandic catch of cod at age a (weight),
- $Y_{Is,a}$ is total Icelandic catch of cod at age a (weight),
- $p_{Gr,a}$ is sales price in Greenland per kilogramme live weight at age a for cod,
- $p_{Is,a}$ is sales price in Iceland per kilogramme live weight at age a for cod,
- δ_{Gr} is social rate of discount in Greenland,
- δ_{Is} is social rate of discount in Iceland,
- D_{Gr} is effort applied in Greenland waters.

The yield Y of the objective function (1) is calculated by a modified Thompson and Bell yield per recruit model (Thompson and Bell, 1934). The dynamic pool model applied can be expressed as

$$Y = \sum_b \sum_a N_{b,a} \cdot (1-\exp(-Z_{b,a})) \cdot F_{b,a} / Z_{b,a} \cdot w_{b,a} \qquad (2)$$

where

- $N_{b,a}$ is number in area b at age a
- $w_{b,a}$ is weight in area b at age a
- $Z_{b,a}$ is total mortality rate in area b at age a.
- b is area (here Greenland and Iceland)

The present value of the revenue of each fishery is calculated by

$$PV_b = \sum_a Y_{b,a} \cdot p_{b,a} / (1 + \delta_b)^a. \qquad (3)$$

The total mortality rate in the Greenlandic stock at age, $Z_{Gr,a}$, is calculated as

$$Z_{Gr,a} = F_{Gr,a} + M_{Gr,a} + E_{Gr,a} \quad (4)$$

where

$F_{Gr,a}$ is fishing mortality rate in Greenland at age a
$M_{Gr,a}$ is natural mortality rate in Greenland at age a
$E_{Gr,a}$ is emigration rate in Greenland at age a.

The emigration rate in Greenland at age a is calculated by

$$E_{Gr,a} = - \ln(1 - s_{Is,a}) \quad (5)$$

where

$s_{Is,a}$ is the Icelandic maturity ogive at age a.

The Icelandic stock has an emigration rate of zero, i.e.

$$Z_{Is,a} = F_{Is,a} + M_{Is,a} \quad (6)$$

The number of cod in Greenland at age a, $N_{Gr,a}$, is calculated as

$$N_{Gr,a} = N_{Gr,\ a-1} \cdot \exp(-Z_{Gr,a-1}) \quad (7)$$

whereas the number of cod in Iceland at age a, $N_{Is,a}$, is calculated as

$$d\ N_{Is,a} / dt = N_{Is,a} \cdot \exp(-Z_{Is,a}) + N_{Gr,a} \cdot E_{Gr,a} \quad (8)$$

to incorporate the Greenlandic immigrants. (8) has the solution

$$N_{Is,a} = N_{Is,\ a-1} \cdot \exp(-Z_{Is,a-1}) + (E_{Gr,a-1} \cdot N_{Gr,a-1}) / (Z_{Is,a-1} - Z_{Gr,a-1}) \cdot (\exp(-Z_{Gr,a-1}) - \exp(-Z_{Is,a-1})) \quad (9)$$

In both areas, the fishing mortality rate at age, F_a, is assumed to be proportional to the effort, D, and influenced by an age dependent gear selection, S_a, i.e.

$$F_a = S_a \cdot D \quad (10)$$

It is the intention of the present paper, only to discuss the trade value of a single cohort of cod migrating back to Iceland. Therefore, it is assumed that the fishery of Iceland is optimized on long term basis and that no additional effort is applied in Iceland to catch the immigrants. Consequently in all calculations the effort applied by Iceland is regarded as a constant and the marginal cost to catch the immigrants is zero.

In Greenland the effort and the costs are allowed to vary in order to optimize the yield. The cost of the effort applied to catch age group a in Greenland, $C_{Gr,a}$, is calculated by

$$C_{Gr,a} = c_{Gr,d} \cdot D_{Gr,a} \; / \; (1+ \delta_{Gr})^{a} \qquad (11)$$

where

c_d is the cost per unit fishing mortality.

Data and Material.

The input values of S, M, w, and the maturity ogives, presented in Table 1, are adopted from the Report of the Scientific Council of NAFO (Anon, 1991) and from the report of the North-Western Working Group of ICES (Anon, 1993) for Greenland and Iceland respectively.

As demonstrated in the Table (1) there is considerable difference between the weight at age of cod caught in Greenland and in Iceland. At least two factors may account for this difference. First the environmental stress of Greenland may be more pronounced than in Iceland. This could lead to a reduced growth rate. Secondly, and maybe more important, the observed discrepancy may result from the migrating behaviour of the mature component of the stock at Greenland. Assuming that maturity is a function of size rather than of age, emigration would reduce the average weight at age.

In the present study, the weight at age array of the cod caught in Greenland is adopted from the 1990 report of the Scientific Council of NAFO (Anon, 1990). The immigrants caught in Iceland are assumed to follow the growth pattern of the Icelandic cod stock, adopted from the North-Western Working Group of ICES, but a lack of one year is assumed.

As also demonstrated in Table 1, there is considerable difference between the maturity ogives of the two areas. Following the same lines of arguments as outlined above with regard to the weight at age, this discrepancy may be due to differences in the environment or a result of the homing behaviour of the mature part of the stock.

In the present study, it is assumed that cod emigrate from Greenland at the onset of maturity and the estimated migration ratios, calculated by equation (5), are based on the maturity ogives of the Icelandic stock. However, some mature cod are found in the Greenland waters, but they have been ignored in the present study.

Based on the principle of opportunity costs, Christensen and Vestergaard (1993) estimated the total cost of one fishing day of a shrimp trawler to be between DKK 42.500 and DKK 80,000, depending on the underlying assumption about the level of opportunity cost for labour and the level of the rates of real interest of capital. In the present study, DKK 60,000 is applied as the total cost of one fishing day of a trawler catching cod. Based on information about the cod fishery in 1990, the total number of fishing days is estimated at 1,000 (REF). The total cost of one year is accordingly estimated at DKK 60 million. In 1990 a fishing mortality rate of 0.5 was estimated to apply to the 1984 year class. The cost of one fishing mortality unit, c_d, applied by the Greenlandic fishery, is in this way estimated at DKK 120 million.

Size dependent prices are used in the present study to estimate the value of the catches. A price of DKK 4.5 per kilogramme live weight is assumed for cod of age 3, 4 and 5, whereas a price of DKK 6.00 per kilogramme live weight is assumed for older cod. These prices are very rough estimates based on Greenlandic marked prices. If Iceland is able to generate a bigger value added than Greenland this may be reflected in the prices and may influence on the inclination to cooperate.

Results.

The Local Optimum of Greenland

The net present value of a cohort, at a similar size as the 1984 year class, is indicated in Table 2. In the non cooperative situation, Greenland optimizes its fishery without regarding the effect on the catch potential of Iceland. In that case, the optimal solution for Greenland is to apply a fishing mortality rate at 0.936 and 0.58, equivalent to 1800 and 1,162 fishing days, at age 4 and 5 respectively. At all other age groups the fishing mortality should be zero. The net present value to Greenland is estimated at DKK 554 million and the value of the Icelandic catches of the immigrants is estimated at DKK 508 million.

Figure 2 shows the distribution of the resource rent between Greenland and Iceland in the non cooperative situation as a function of year class size. The Figure indicates that the outcome of Greenland increases with the size of the year class. At small year classes also the profit of Iceland increases with year class size, but from a year class size about 40% of the 1984 year class, the Icelandic share of the resource rent remains almost constant about DKK 500 million.

Joint Optimal Fishery.

The optimal fishery strategy from a joint Greenlandic-Icelandic point of view is to establish cooperation. In the cooperative situation Greenland must leave all the fishing to Iceland to obtain optimality. In that case the total net present value is DKK 2.712 billion, c.f. Table 2.

Sensitivity analysis indicate that this result is very robust with regard to the level of the socio-economic rate of discount and the size of the cohort. Even with a cohort size ten times as large as the 1984 year class and a discount rate at 0,5 the optimal solution implies that all fishing should be undertaken in Iceland.

Figure 3 shows the resource rent at the cooperative solution as a function of the year class strength. The Figure demonstrates that the total resource rent as well as the surplus resource rent increases with year class strength.

Maximum Sustainable Yield.
A management advice based on biological parameters only, i.e. applying $p_{Gr} = p_{Is} = 1$, $c_{d,Gr} = 0$ in the simulations, is dependent on whether the parties cooperate or not. Figure 4 shows, that without cooperation Greenland will obtain the highest yield by applying a very high effort which, in turn, imposes a decrease in the Icelandic yields.

The maximum yield is obtained by cooperation between the parties. If Greenland ceases fishing entirely, the catches of Iceland will increase to about 600,000 tonnes which is about twice the total yield obtained in the non-cooperative situation.

Discussion

In the scenario discussed above, assuming that the year class strength is equivalent to the 1984 year class, cooperation increases the total net present value of the cohort by DKK 1.652 billion compared to the non-cooperative situation. Greenland would at least require a compensation of DKK 554 million for giving up their fishing rights. The excess amount of DKK 1,098 billion may be regarded as the profit obtained by cooperation. This amount is to be distributed between the parties, due to their relative bargaining power, to obtain Pareto-efficiency.
In the present study, it is assumed that the Icelandic fishery is optimized on long term basis and that the immigrants are caught without applying any additional effort. As the value of the Icelandic catches of the immigrants in this way is obtained without optimizing the Icelandic effort, the cooperative solution is likely to be slightly more advantageous than suggested here. Wether Iceland should adapt the effort to increase the catches of the immigrants depends on the frequency of the good year classes and on the flexibility of the Icelandic fishing fleet.

The immigrants from Greenland to Iceland would also contribute to the spawning and should enhance recruitment. Also in that case, the coorperative solution would be more beneficial in the long term, depending on the stock recruitment relationship.

The discussion has so far concentrated on the situation where a strong year class is recognized in Greenland. If the parties wants to establish a long term agreement they must negosiate without knowledge about future yearclass strengths. This situation is considered as a game between two opponents: Iceland who pays Greenland a fixed amount annually and Greenland, who then denounce fishing for cod.

As the net revenue from the fishery is dependent on the year class strengths in the coming years, a frequency distribution of the year class strengths of the yearclasses 1964 - 1986 relative to the 1984 year class was constructed. The information about year class strength, Table 3, was kindly provided by Mr. Hovgaard (1993). The frequency distribution, shown in Table 4 is considered to represent the distribution of yearclass strength to be observed in the period for which the agreement is valid.

Assuming equilibrium conditions, i.e. that recruitment is equal to the average recruitment of the period 1967 - 1989, the annual resource rent is estimated to DKK 160 million, which can be obtained if there is cooperation between the parties, i.e. the fishing effort in Greenland waters is zero. As indicated in Table 4, Iceland must compensate Greenland with an annual amount of at least DKK 37 million, which is the average net revenue in the non-cooperation situation.

To estimate the probability that an agreement between the two parties will pay off in a non equlibrium situation, a probability distribution was constructed as follows: for each year of the agreement, a yearclass strength was sampled from the empirical distribution of yearclasses 1964-1986 (age 3). Two revenues were calculated. The revenue to Iceland under joint optimal fishing less the contribution Iceland would get even if Greenland decided to follow its local optimal strategy. Second, the revenue Greenland would get if she adopted the local optimal strategy. These revenues were each summed over the entire period of the agreement. The simulation was repeated 1000 times and the resulting cumulative curves of the total revenue to Iceland and to Greenland are shown in <u>Figure 5</u> (a 20 year agreement) and in <u>Figure 6</u> (a 5 year agreement).

The price for such a long-term agreement is to be discussed based on these curves. E.g. if Iceland pays Greenland 2,000 mill. DKK over 20 years (100 mill DKK per year) then Greenland would in more than 90 % of the cases simulated have done better from the agreement than by fishing optimally in its own waters. Iceland would under such a 100 mill DKK annually agreement have lost money in a little more than 30 % of the cases.

If the agreement is only 5 years the risks increased. Consider a 500 mill DKK agreement (again 100 mill DKK annually), as can be seen from Figure 6, Greenland would now in a little less than 80 % of the cases have done worse, while Iceland in a little less than 60 % of the cases would have lost money from such a transaction.

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Table 1. Natural mortality ratios, M, Emigration ratios, E, selection parameters, S, weights, w, and maturity ogives, s.

Age	Greenland[1]					Iceland[2]			
	S	M	w	E[3]	s	S	M	w	s
3	0.039	0.2	0.86	0.020	0.01	0.066	0.2	1.26	0.020
4	0.520	0.2	0.91	0.070	0.03	0.328	0.2	1.78	0.068
5	1	0.2	1.02	0.286	0.06	0.599	0.2	2.58	0.249
6	1	0.2	1.36	0.719	0.08	0.856	0.2	3.63	0.513
7	1	0.2	2.04	1.465	0.65	1.089	0.2	4.90	0.769
8	1	0.2	2.12	2.313	0.90	1.152	0.2	6.30	0.901
9	1	0.2	2.20	3.037	0.98	1.152	0.2	7.69	0.952
10	1	0.2	2.89	3.689	1	1.152	0.2	9.35	0.975
11	1	0.2	3.79	5.116	1	1.152	0.2	10.92	0.994
12	1	0.2	5.36	3.912	1	1.152	0.2	12.77	0.983
13	1	0.2	5.36	4.962	1	1.152	0.2	14.52	0.993

[1]Source: Anon, 1991.
[2]Source: Anon, 1993.
[3]Based on Icelandic maturity ogives

Table 2. Net present value, million DDK.

	Greenland	Iceland	Total
Non-cooperation	553.571	507.740	1,061.311
Cooperation	0	2,712.904	2,712.904

Table 3. Year class strength in Greenland waters 1967 - 1989, relative to year class 1984. Source: Hovgård, pers.com.

Year	1960	1970	1980
0		0.07	0.22
1		0.16	0.01
2		0.03	0.12
3		0.02	0.02
4		0.03	0.02
5		0.04	0.01
6		0.40	0.01
7	0.15	0.08	1.00
8	0.16	0.08	0.13
9	0.13	0.06	0.00

Table 4.

Relative year class strength	Year class frequency	Non-cooperation		Cooperation total net revenue
		Greenland net revenue	Iceland net revenue	
0	9	0	0	
0.1	5	0	313.9	313.9
0.2	6	12.2	421.0	546.6
0.3	1	53.6	440.0	819.8
0.4	1	107.4	474.4	1093.1
0.5	0	171.3	473.9	1366.4
0.6	0	239.1	501.9	1639.7
0.7	0	311.6	501.9	1912.9
0.8	0	388.7	505.4	2186.2
0.9	0	469.4	506.6	2459.5
1.0	1	554.0	507.7	2717.9
1.1	0	640.5	508.9	3006.0
1.2	0	728.8	514.6	3279.3

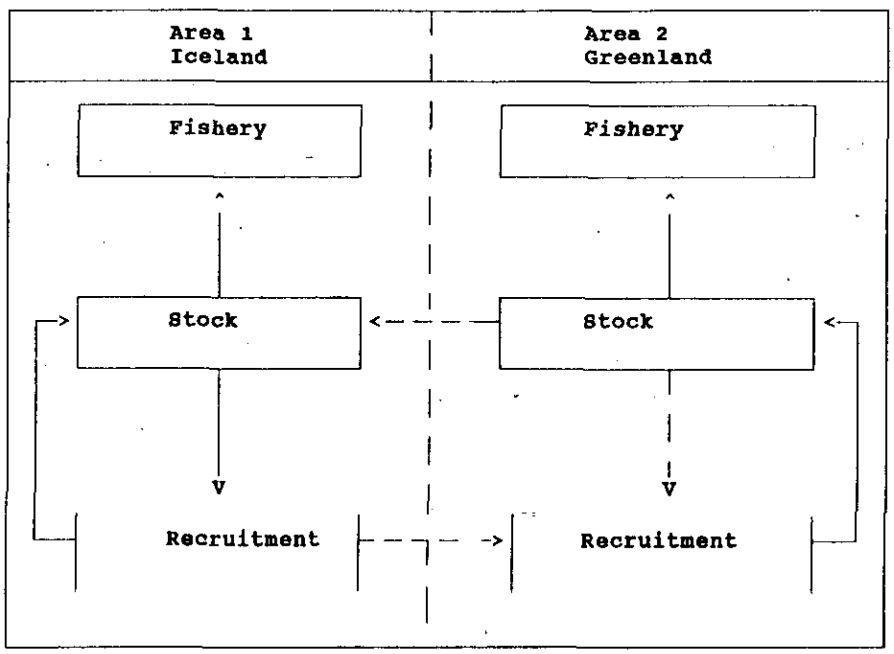

Figure 1. Stock dynamics applied to the bioeconomic fishery model of the Iceland - Greenland transboundary cod stock.

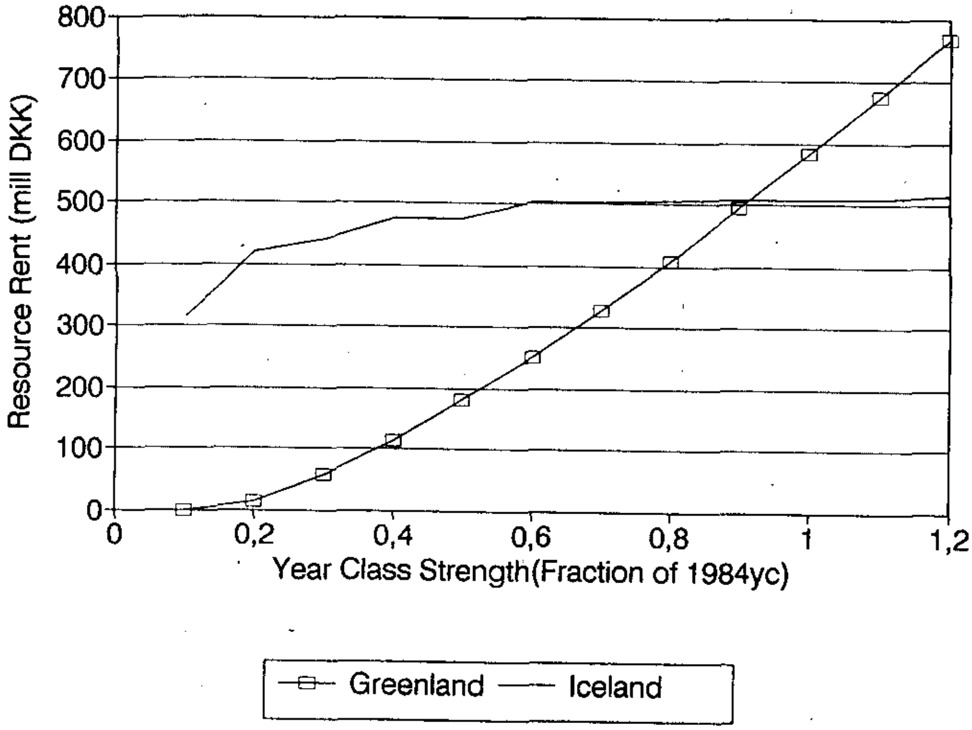

Figure 2. Distribution of the resource rent as a function of year class strength in the non cooperative situation.

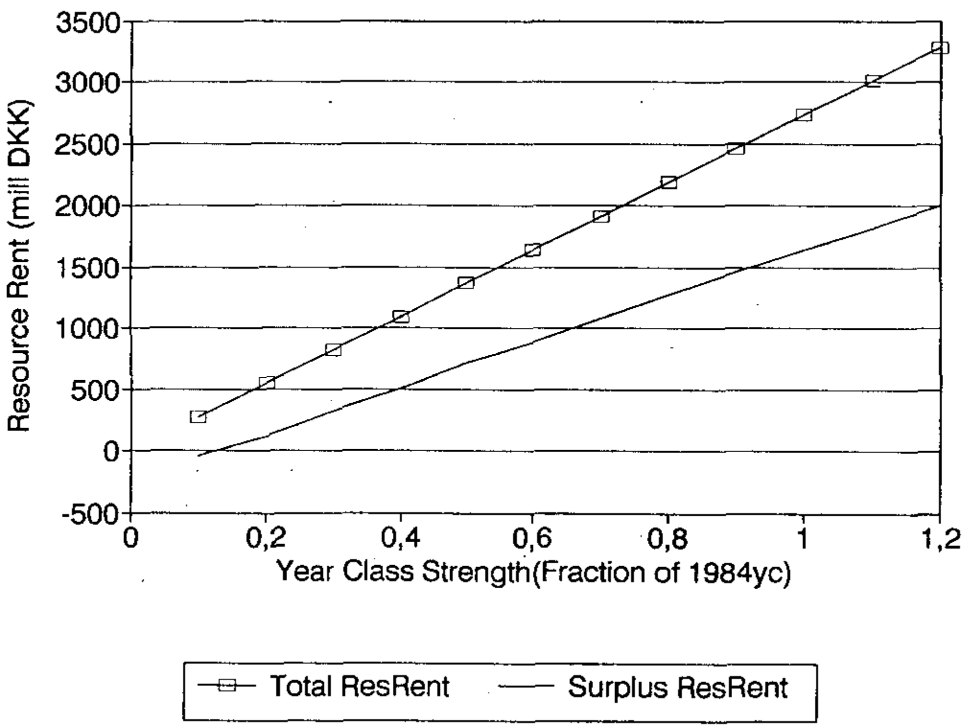

Figure 3. The total resource rent of Greenland and Iceland (Total ResRent) in the cooperative situation and the surplus resource rent obtained by cooperation (Surplus ResRent).

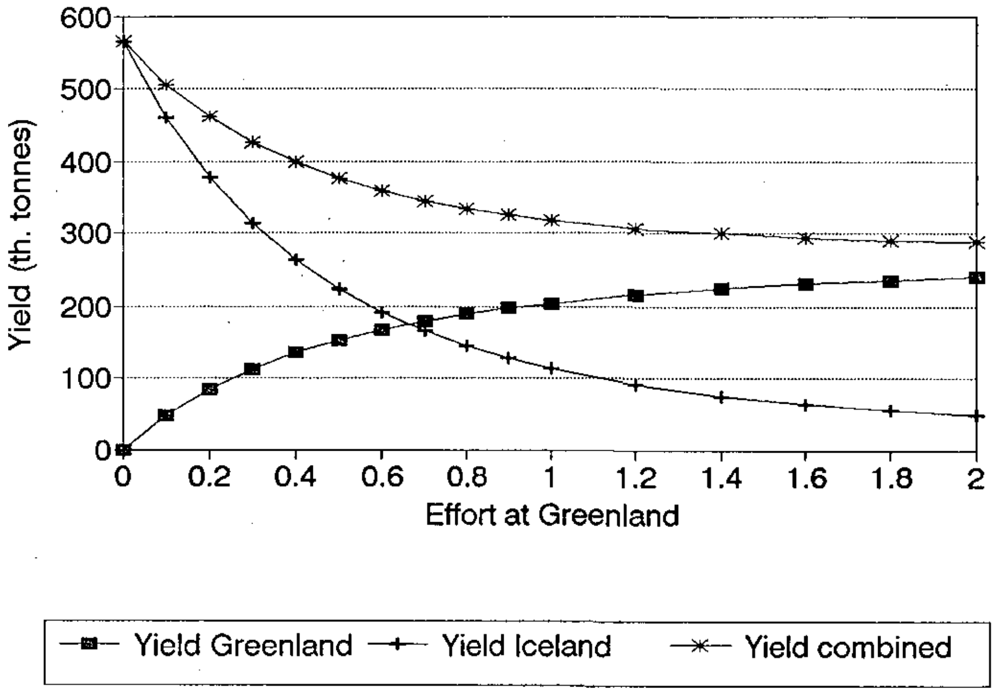

Figure 4. Yield as a function of effort applied by Greenland.

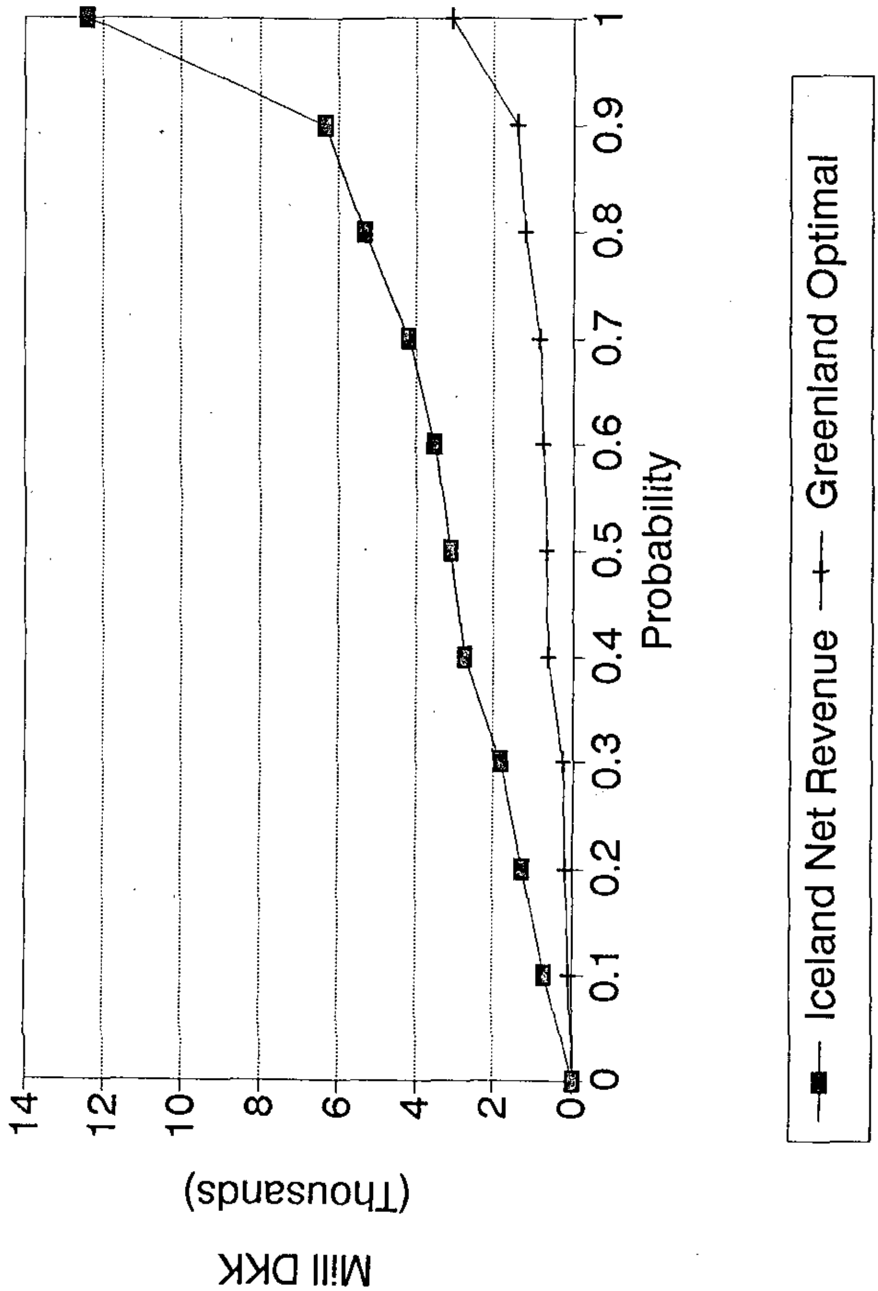

Figure 5. A 20 years game in a non equilibrium situation. Greenland Optimal: the revenue Greenland would obtain if she adopted the local optimal strategy. Iceland Net Revenue: The Iceland revenue under joint optimal fishing less the contribution to Iceland in case Greenland adopts the local optimal strategy.

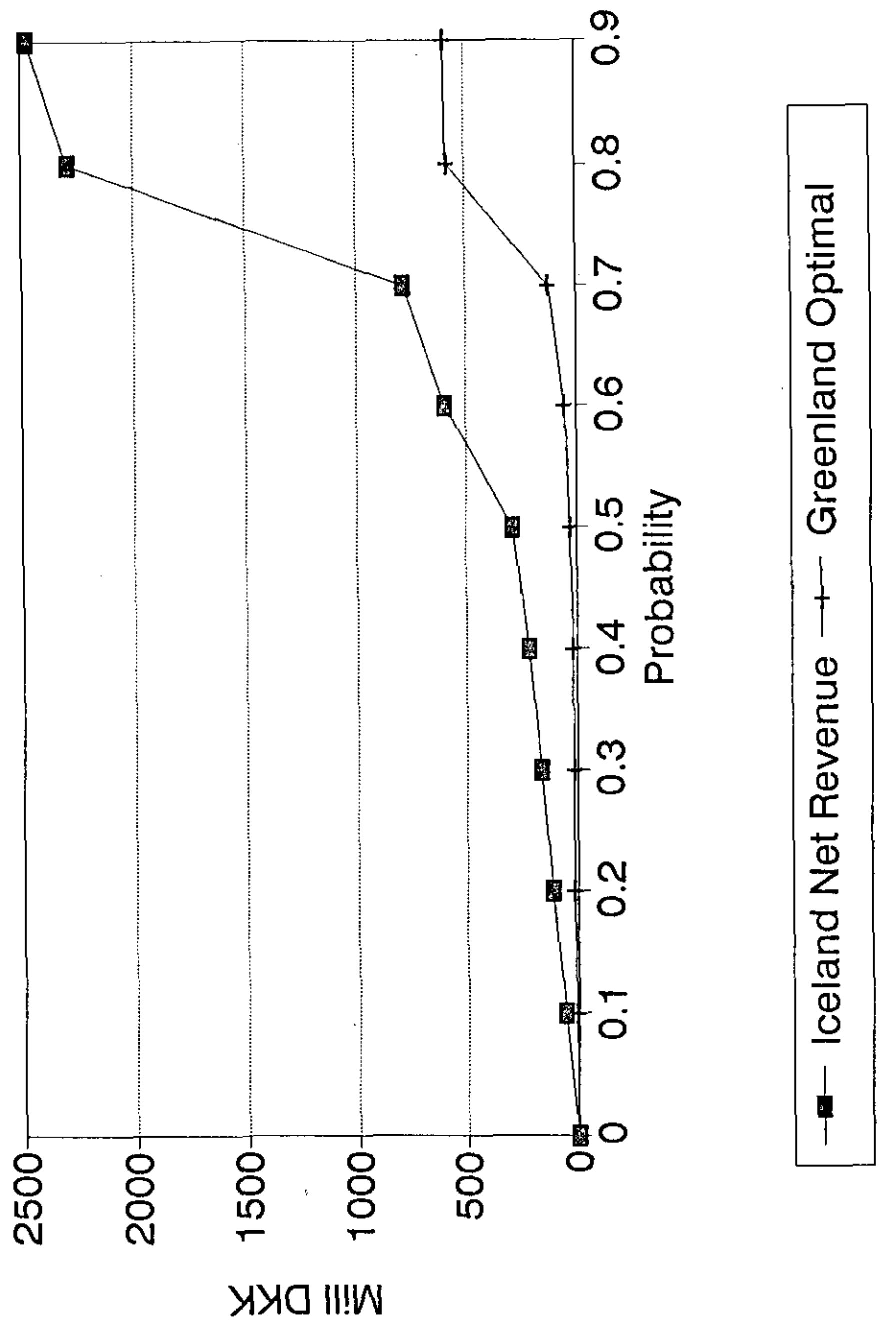

Figure 6. A 5 years game in a non equilibrium situation. Greenland Optimal: the revenue Greenland would obtain if she adopted the local optimal strategy. Iceland Net Revenue: The Iceland revenue under joint optimal fishing less the contribution to Iceland in case Greenland adopts the local optimal strategy.