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BIOLOGICAL AND ECONOMIC IMPLICATIONS OF A MULTI-GEAR FISHERY FOR GREENLAND HALIBUT (*REINHARDTIUS HIPPOGLOSSOIDES*).

by

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ABSTRACT

This paper focuses on the level and distribution of fishing mortality in a multigear fishery, and its effect on biological and economic parameters. The Greenland halibut stock in ICES Sub-areas I and II is at a historically low level. Due to a lack of recruitment observed for this stock, and in order to have an increase in the spawning stock, a cessation of fishing has been advised. Since 1992 trawlers, and gillnet vessels and longliners larger than 90 feet have not been allowed to fish Greenland halibut as target species, but only as bycatch when fishing for other species. Gillnet vessels and longliners smaller than 90 feet have been allowed to participate in a directed fishery for Greenland halibut within a limited quota, a limited area and a limited period each year.

This paper focuses on the economic yield one can expect from the Greenland halibut stock in ICES Sub-areas I and II when gear specific selective properties are taken into consideration. The biological data were collected during a 1992 - 1994 research programme using trawlers, longliners and gillnet vessels in a limited commercial fishery in the same geographical area, i.e., the historical most important fishing area. Quantitative effects of the three gears'different selectivity have been judged out from yield and spawning biomass per recruit (age 3). The profitability analysis of the different gears is based on prices and value of the catch and cost analysis of the fishery the last year of no catch-regulation (1991). Finally, the biological and economic analysis have been combined and evaluated together. The results may be used as guidelines for the management of the stock.

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1. INTRODUCTION

Following the introduction of trawlers in the fishery in the late 1960s, total international landings of Greenland halibut in ICES Sub-areas I and II increased to a level of about 80 000 t in the early 1970s. Total landings were then again reduced to a level around 20 000 t in the 1980s (Anon, 1995b). In 1990-1991 catches taken by Norwegian fishermen increased again, caused by a strict regulation of the northeast Arctic cod fishery, and a subsequent redirection of fishing effort from cod to Greenland halibut.

Already in 1989 the ICES' Advisory Committee on Fishery Management stated that actions should be taken to rebuild the spawning stock of the northeast Arctic Greenland halibut (*Reinhardtius hippoglossoides*) (Anon. 1990). The following observations of the stock and fishery then led to actions taken in 1992. First, the 0-group index dropped to a low level in 1988, and continued to decrease every year up to 1992 (Anon. 1995a). Second, these weak yearclasses measured at the 0-group stage were confirmed to be weak when later measured as 1, 2 and 3 years olds (Hylen and Nedreaas 1995, Smirnov *et al.* 1994, Smirnov 1995). Third, although changes in commercial trawl CPUE is influenced by the effort itself to some but unknown extent and therefore not directly proportional to similar changes in the stock, a 170% increase in effort coupled with a 30% reduction in CPUE from 1987 to 1991 were alarming (Anon. 1995b).

According to the most recent assessment, the spawning stock was stable at around 60 000 tonnes in the period 1976-1987, but was subsequently reduced to a level around 40 000 tonnes in 1992-1993 (Anon. 1995b). This is the lowest level experienced in the time series. The estimate of the spawning stock may change from assessment to assessment dependent on what input tuning data are used, but the lack of recruitment observed in the recent years indicate that the spawning stock biomass is below the level needed to ensure a more normal recruitment under current conditions. Relying very much on the observations from youngfish surveys, the most recent assessment clearly shows that the stock is not within safe biological limits and that the spawning stock will be further reduced in the years to come. Research is, however, currently being conducted to see how strong the anticipated weak yearclasses will turn up in the fishery.

Northeast Arctic Greenland halibut in ICES Subareas I and II is a highly valued and therefore commercially important species. It is mainly caught by trawlers, longliners and gillnet vessels (Table 1). The minimum legal mesh size in trawl in the Norwegian Economic Zone (NEZ) is 135 mm (stretched mesh), and although at present there exist no rules about the mesh size in gillnets, 220 mm nets are used nearly without exceptions.

Due to a stock of northeast Arctic Greenland halibut at a historically low level and a high fishing pressure, strict regulation of the fishery was introduced in 1992[1]. This regulation (only slightly altered since) is as follows:

Small coastal longline and gillnet vessels are allowed to participate in a directed fishery, whereas trawlers and large longline and gillnet vessels are only allowed to catch Greenland halibut as bycatch. Specifically, longliners and gillnet vessels larger than 90 feet and trawlers are allowed to have 5% bycatch of Greenland halibut when fishing for other species. Longliners and gillnet vessels smaller than

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[1] Juveniles of Greenland halibut are also caught as bycatch in shrimp fishery. The use of a sorting grid has from 1. January 1993 been made mandatory in the shrimp fishery. In addition the fishing grounds are being closed if the bycatch in the shrimp-catches includes more than 300 Greenland halibut pr ton shrimp.

90 feet are allowed to participate in a directed fishery for Greenland halibut within a limited quota, a limited area and a limited period each year.

In this paper we discuss how biological and economic indicators vary in response to which gear used when fishing Greenland halibut. Specifically, we will evaluate how yield and spawning stock per recruit differ between the three gears, and how prices, costs and profitability vary between the gears.

2. MATERIAL AND METHODS

Biological effects of fishing Greenland halibut with different gears

More general biological effects of fishing Greenland halibut with different gears are analysed by yield per recruit (Y/R) and spawning stock per recruit (SSB/R) for each of the three gears separately, and combinations of the gears in a multi-fleet Y/R. For the analyses the input fishing patterns for trawl (135 mm stretched mesh in codend), longline, and gillnet (220 mm stretched mesh) have been estimated by Separable-VPA (Sep-VPA) from a limited commercial fishery within a research programme in the same area and at the same time over a three-year period (1992-1994) with little but constant effort.

Fishing pattern

Table 2 shows a) the international 1991 catches for trawl (a mixture of both 100 mm and 135 mm mesh sizes), longline and gillnet (unknown mixture of different mesh sizes) and b) the resulting fishing patterns scaled to the reference ages 7-12. Other input data for yield per recruit analyses have been taken from Anon. 1995b.

Table 3a shows the number at age of Greenland halibut caught by the three gears during the limited commercial fishery in 1992-1994. Assuming a constant fishing pattern during these three years, the catch number at age data for each gear were used as input to three Sep-VPAs to give gear specific fishing patterns. The reference ages in the Sep-VPA were set at the age where the biggest catches occurred (i.e., approximately age at full recruitment). This was age 7 for trawl and age 10 for longline and gillnet. Based on the observed catch in numbers at age the terminal S (fishing mortality on the oldest age group relative to the reference age) was set equal to 0.5 for all gears, i.e., a dome-shaped pattern. The fishing patterns produced by Sep-VPA turned out to be slightly different dependent on the input terminal fishing mortality (F) on the reference age. An approximate level of the fishing mortalities in recent years at age 7 for trawl and age 10 for longline and gillnet was used as input for the terminal F, i.e., 0.40 for trawl and 0.08 for longline and gillnet. Table 3a shows a deficiency of 9 year old fish, for which wrong age reading may be the explanation. The fishing pattern on the 9 year olds was set as the average of age group 8 and 10. The resulting gear specific fishing patterns and other biological input parameters are shown in Table 3b and adopted for further yield per recruit analyses.

Yield- and spawning stock per recruit analyses, traditional and multi-fleet.

The ICES Fisheries Assessment Package (IFAP) was used for running the analyses. Input data are given in Tables 2 and 3. A criterion set before making the multi-fleet analyses was that all three gears should be included, and that the fishing mortality on the reference ages 7-12 for each gear should never be less than 0.05. The multi-fleet Y/R programme has been developed at the ICES Secretariat and incorporated in the IFAP-package (see Appendix 1).

Economic effects of fishing Greenland halibut with different gears

To get a realistic picture of the costs and income for the different vessel groups when the fishermen could optimise the management of their vessels, i.e. under a regime of no regulation, data prior to 1992 (the year when the fishery was regulated) should be used. In our analysis, data from 1991 have been used. During that year, 341 vessels caught Greenland halibut[2]. Unfortunately, for our purpose, no vessel group fished **only** Greenland halibut, but harvested several stocks among which cod, haddock and saithe. Cost and income data for each vessel will therefore reflect the economic conditions for vessels fishing various species. However, to get the best possible data for the fleet harvesting Greenland halibut we will use data from vessels where such catch constitutes substantial amounts. Specifically, data from the following vessels were drawn:

Trawl. To represent the gear trawl we use data from licensed trawlers of a length above 34 metres catching more than 500 tonnes of Greenland halibut.

Longline. To represent the gear longline, we use data from vessels of a length above 34 metres catching at least 100 tonnes of Greenland halibut.

Gillnets : To represent gillnets, we use data from vessels of a length above 32 metres catching at least 100 tonnes of Greenland halibut.

We found 12 trawlers, 7 longliners and 4 gillnet vessels satisfying the above-mentioned criteria.

Prices and value when catching Greenland halibut

In Norway all fish landed has to be sold through the fishermen's sales organisation. The catch, its value and various other data are registered by the buyers on sales notes, and later transferred to the Norwegian Directorate of Fisheries for the yearly production of fishery statistics. We used this sales note system to find the average price pr. kilogram and average value of catch per vessel for the above mentioned gear groups.(See table 4)

The price obtained by the trawlers was somewhat lower than the price obtained by the vessels using longline and gillnet. The same divergence was found in 1990. The lower price may be explained by the size of the fish (selectivity properties of the gear) and where the catch was delivered. With reference to the different gear selectivity observed in the research programme, the mean length of Greenland halibut caught by 135 mm trawl (ca. 51 cm) is generally smaller than the fish caught by longliners (ca. 60 cm) which again is smaller than the fish caught by 220 mm (stretched mesh) gillnets (ca. 65 cm) (Nedreaas *et al.* 1993). Trawlers deliver a large amount of their catch in the northern part of Norway, whereas vessels fishing with longline or gillnets lands the catch mainly in the southern part of Norway. The processing industry in the southern part of Norway are closer to the markets in Europe and this advantage may partly explain the price difference. Another reason may be that in southern Norway where the longliners and the gillnet vessels land their fish, fishermen's catches are sold through

[2] Source: Norwegian fishery statistics, 1991

auctions. In northern Norway, the price fishermen gets for their catch is negotiated on a long term basis.

Keeping in mind that the longliners and the gillnet vessels achieved a higher price for their products in 1991, we turn to the cost of fishing Greenland halibut.

Costs when catching Greenland halibut

Fishermen's expenses covers a broad range of items from financing the vessel, paying salary to the crew, buying fuel and numerous other goods and services that are necessary to keep the boat operating. As mentioned above, no vessel group has Greenland halibut as its only target species. In fact, in a 20 year perspective which is the normal life time for a fishing vessel, it is more correct to say that investments in the vessels fishing Greenland halibut has been based on other fisheries; mainly cod, haddock, saithe, ling and tusk. It is therefore reasonable to state that the investment costs would have incurred irrespective of whether or not the vessels should be fishing for Greenland halibut. We will therefore treat the fixed costs as given or "sunk". Consequently, in our analysis we will focus upon variable costs only.

For a species like Greenland halibut, one would expect costs to vary with the size of the biomass. A larger biomass often implies higher density of fish and for a certain amount of effort the catch should increase. To calculate a stock-dependent cost-function we would need time-series of biomass, catch and effort-levels for the three gears involved in the fishery. Acquiring data to estimate a cost-function as such is beyond the scope of our work, and consequently we rely on rougher methods.

The variable costs per kg can be found by dividing the average variable costs during 1991 (for the vessels in the respective groups) with their total catch of all species the same year. This gives an estimate of variable costs pr kg fish caught, and we use this estimate as an approximation to the cost of fishing Greenland halibut. Table 5 shows the variable costs for the vessel mentioned above[3].

Taking the total catch of the vessels into consideration, trawl is the most efficient gear, in terms of variable costs/kg. The variable cost of catching a kg fish with either longline or gillnets are approximately 20% higher than catching a kg fish with trawl.

As indicated above, our method for finding variable costs per kg is subject to criticism. On the other hand, the purpose of this paper is not to quantify the absolute profitability of fishing Greenland halibut, but to shed light on the *difference* in profitability between the three gears. Appendix 3 gives an alternative method for estimating variable costs. However, a priori the variable costs we find seems to make sense: Trawl is the most cost-efficient gear, and the difference found seems also to be realistic when fishing for Greenland halibut. The fishery for Greenland halibut was known to be profitable in 1991, and the prices and costs found underlines such knowledge.

[3] Appendix 2 gives an explanation of data used.

3. RESULTS

Yield per recruit (Y/R) and Spawning Stock Biomass per recruit (SSB/R)

1991-situation

Figure 1 shows the Y/R and SSB/R curves with the actual 1991 fishing pattern and weight-at-age as input. With a high total $F_{7\text{-}12}$=1.0 in 1991, the Y/R were 68 grams (or a yearly long term yield of about 1 800 tonnes assuming a recruitment of 27 mill. specimens at age 3) less than at $F_{max}\approx0.30$. The SSB/R was 1 540 grams less (on long term, corresponding to 42 000 tonnes less SSB assuming a recruitment of 27 mill. specimens at age 3). In Table 6 the results in Y/R, SSB/R, and catch are given for different gear combinations (different combinations of the 1991 gear specific fishing patterns) and F-levels. The catch is calculated from the stock in numbers at the beginning of 1991 (Anon. 1995b). We see from the table that the more of the total F is taken by gillnet, the higher Y/R and SSB/R will be obtained. However, the F_{max} level for gillnet was impossible to define in 1991, and this is the reason why Y/R is higher at F=1.0 when only using gillnets.

The observed big reduction in total catch when using Option A in table 6, instead of the actual fishing pattern, is caused by older and fewer fish in the exploited age groups and the fact that trawl also caught a lot of fish younger than the 7 - 12 reference ages.

General situation

The gear specific fishing patterns constructed from the 1992-1994 research programme are much more comprehensive, exact and correct than the 1991 patterns for the three gears the way they are used in the Greenland halibut fishery at present. Figure 2 shows the Y/R and SSB/R curves for trawl (135 mm stretched mesh in codend), longline, and gillnet (220 mm stretched mesh) with fishing patterns and weight-at-age from the 1992-1994 fishery as input. Using only one gear, longline will give the highest Y/R for fishing mortalities less than 0.25. Above F=0.25, gillnet will produce the highest Y/R. Highest SSB/R will at all F-levels be achieved by using gillnets. Gillnet and longline alone would give 15-20% higher Y/R (up to 150 grams corresponding to a yearly quota of 4 500 tonnes assuming average recruitment) than if only trawl was to be used. The gear effect is more pronounced when looking at SSB/R. Then using trawl alone would result in 30-40 000 less SSB on the long term assuming constant average recruitment.

For combinations of gears, maximum Y/R and SSB/R will be achieved by allocating as much as possible to gillnet and longline, and the multi gear analyses are therefore influenced by this. In Table 7 the results in Y/R, SSB/R and the long term annual catch are given for the overall F_{max} level equal to 0.45 and the $F_{0.1}$ level of 0.20. For further economic analysis, options are given both for the best gear combination and the gear combination giving lowest Y/R.

Profitability of different gears.

Our estimates of prices and costs per vessel group show the economic conditions for the different vessel groups fishing Greenland halibut in 1991. As mentioned above, the fishery was regulated in 1992, so 1991 was the last year fishermen could operate their vessels free. According to these estimates, we find longliners and gillnet vessels to be more profitable than trawl. Although trawl is the most cost-efficient gear, the two other vessel groups achieve a higher average price pr kg, and the profitability for the latter two will thus be highest. In Table 8, the profitability per kg for the different gears is shown.

1991-situation

As shown above, the fishing pattern in 1991 was not optimal according to biological criteria, and a redirection of effort from trawl to gillnet vessels would have increased both Y/R and SSB/R. Although such a change in the fishing pattern would have increased the long term yield, Table 9a and 9c-e shows that in the short term, the total catch would fall. If the total fishing mortality was directed with 0.90 to gillnet and 0.05 to trawl and long line, total catch would fall from approximately 31 000 tonnes to approximately 17 000 tonnes (a reduction of approximately 45%). The profitability, on the other hand, would only fall by 36%, as more of the catch would have been taken by the more profitable gillnet vessels.

A less drastic redirection of effort would be a fishing pattern where trawl and long-liners each were given a fishing mortality of 0.35 and gillnet 0.30. In relation to the actual fishing pattern, short term loss in catch would be approximately 19%, whereas profitability would only be reduced by 14%. However, Y/R and especially SSB/R would not be as high as the above mentioned more radical redirection of effort would give.

Table 9b and 9f-h shows analogous results at the 1991-F_{max} level of 0.30.

General situation

In 1991, the stock was outside safe biological limits and analysis of beneficial exploitation pattern may be of limited relevance when discussing the management of the stock of Greenland halibut in a more general perspective. In a more general situation, biological indicators show that for total fishing mortalities less than F=0.25, a redirection of effort towards long line would be beneficial, whereas for fishing mortalities higher than this level a redirection of effort towards gillnet would be better.

In such a situation, we have calculated which catch the stock would have given in the long term according to different fishing mortalities and different fishing patterns. Starting out with a low level of fishing mortality, the $F_{0.1}$ level, table 9k,l shows that catch and profitability would be higher if long-liners rather than trawlers took most of the fish. The difference in catch and profitability by allocating most of the fishing mortality to trawlers rather than to long liners is small. Accordingly, at a fishing mortality of $F_{0.1}$, the two different fishing patterns will produce quite similar results, both biological and economic. At such a low level of fishing mortality, this result indicates a degree of freedom for managers as how to divide the catch between gears.

Applying a higher fishing mortality, for example the F_{max} , the more of the catch taken by gillnet, the higher the total catch and the higher the profitability would be (see Table 9i,j). Allocating a fishing mortality of 0.35 to gillnet and 0.05 to trawl and long-line each will give a 13% higher total catch and profitability nearly 30% higher than allocating 35% to trawl and 0.05 to gillnet and long line each.

4. DISCUSSION

The results have shown that fishing at the $F_{0.1}$ level of 0.20 in the long term will yield nearly the same total catch as fishing at the F_{max} level of 0.45. This is due to a rather flat Y/R curve above $F_{0.1}$. When fishing at the $F_{0.1}$ level, the catch rates will be higher since the effort needed to catch the same amount will be less. There are other obvious advantages of fishing at the lower mortality level. More of the fish will reach maturity and increase the SSB. This will also increase the size of the fish in the catches irrespective of gear type. Although it is difficult at present to define the optimum size of the SSB, it is without doubt a good biological investment to secure a high spawning stock. This will also stabilise future quotas since it will act as a buffer in poor recruitment years. The F_{max} level may often also be difficult to define (in the present study for gillnets in 1991), and it is therefore recommended to be on the left side of this, e.g. at the $F_{0.1}$ -level, especially since the long tem catches will nearly be the same. A small difference in Y/R at the $F_{0.1}$ and F_{max} level tells us that the recruitment will be the essential factor for the size of Y/R, and the recruitment is dependent on the SSB.

Long term guidelines like Y/R, SSB/R and long term profitability suggests a much lower fishing mortality than the one applied in 1991. For fishing mortalities less than F=0.25, our results indicate that longline is the most preferable gear according to criteria's as Y/R, SSB/R and long term profitability. For fishing mortalities above F = 0.25, the guidelines indicate that a fishing pattern giving most to gillnets would be preferable.

In the present study the sexes have been combined. More detailed Y/R studies should however investigate the impact different growth and maturity of the sexes may have on the results. A departure from 1:1 in the sex ratio of catches cannot necessarily be equated with a corresponding difference in fishing mortality on the two sexes. Their natural mortality rates may also differ, and the reproductive capacity and behaviour of the two sexes is poorly known. It seems impossible to conduct a sex differentiated fishery of Greenland halibut on area and season, but the sex composition of trawl, long line and gillnet catches are clearly different (Nedreaas et al, 1993). If wanted, it should therefore be possible to equalise the sex ratio by adjusting the gear selective properties and allocations of quotas. For example, gillnets with lower mesh size will catch the sexes in a more equal ratio.

The results obtained are useful guidelines for a stock in equilibrium. As the stock of Greenland halibut p.t. is outside safe biological limits, application of lower fishing mortalities to increase Y/R, SSB/R and long term profitability in order to reach such an equilibrium will result in a reduction in short term catches. Such a loss in short term catches and profitability can be seen as an investment in order to increase future yields from the stock. A cost-benefit analysis of such an investment where future benefits are discounted would be interesting to conduct, but is beyond the scope of this paper.

To reach the preferred state of equilibrium, there are many paths. The above mentioned guidelines shows the main direction of the way to go, but more short term information will also be needed in order to ensure a sound management of the fishery. Knowledge of short term variations in recruitment, natural mortality, growth, costs and prices will be important when deciding upon the yearly exploitation level and pattern.

5. CONCLUSIONS

When the spawning stock of Greenland halibut is not within safe biological limits it should be rebuilt. Such a situation calls for a precautionary approach when managing the stock, i.e. a fishing mortality close to $F_{0.1}$. Under a fishing mortality at that level, our results indicate that managers have a degree of freedom of how to allocate a given quota to different gears.

When the spawning stock is within safe biological limits, a higher fishing mortality may be allowed, for example F_{max}. Under a fishing pressure at that level, our results indicate that both Y/R, SSB/R and profitability would increase by favouring gillnet vessels.

Even though the stock is within safe biological limits, our results show that the long term catches at a fishing mortality of $F_{0.1}$ are close to the long term catches at F_{max}. In addition, a fishing mortality at F_{01} will ensure that the SSB will be kept at a higher level and increase the likelihood for stable and higher recruitment.

Both Y/R and SSB/R are long term indicators. In the short term, there may be other more important indicators when managing the fishery, for example variations in recruitment, weight or price. The results should therefore be handled with care.

Allocating different shares of a quota to different vessel groups will, because of gear specific selectivity patterns, have consequences for the choice of total fishing mortality. In addition, the economic performance of the gears will constitute an important argument as to how such a quota should be divided. When assessing a fish stock and giving advice on the exploitation of the stock, both biological and economic aspects should be taken into consideration.

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TABLES AND FIGURES

Table 1. Norwegian landings of Greenland halibut by gear in 1980-1991 (in metric tonnes).

Year	Gillnet	Longline	Trawl	Others	Total catches
1980	1 189	336	1 537	94	3 156
1981	730	459	2 948	63	4 200
1982	748	679	1 763	17	3 207
1983	1 648	1 388	1 807	16	4 859
1984	1 200	1 453	1 649	38	4 340
1985	1 668	750	2 933	85	5 436
1986	1 677	497	5 674	44	7 892
1987	2 239	588	4 331	103	7 261
1988	2 815	838	5 381	42	9 076
1989	1 342	197	8 890	192	10 621
1990	1 372	1 491	13 393	987	17 243
1991	1 904	4 552	21 069	63	27 588

Source: The Norwegian Directorate of Fisheries.

Table 2. a) International catch in numbers (thousands) at age of Greenland halibut in 1991 by gear (ICES Working Group figures). b) Input parameters for Yield per recruit analyses based on the 1991 biological and fishery data (Anon. 1995b).

a

Age	Total numbers (in thousands)	Trawl	Shrimp trawl	Longline	Gillnet
3	374	213	161		
4	2004	1680	324		
5	3185	2775	410		
6	3739	3503	227	9	
7	4535	4222	123	184	6
8	2264	1838	48	343	35
9	991	583	18	325	65
10	1235	841	16	271	107
11	744	536	8	122	78
12	647	388	4	144	111
13	170	70	1	40	59
14	256	140	1	63	52
15+	497	309	3	129	56
Sum	20641	17098	1344	1630	569
Tonnes	32133	24516	1106	4561	1950

b

							Fishing pattern			
Age	Natural mortality	Maturity ogive	Prop. of bef.spaw.	Prof.of bef.spaw.	Weight in stock	Weight in catch	Total	Trawl	Longline	Gillnet
3	0.1500	0.0000	0.0000	0.0000	0.290	0.290	0.03	0.04	0.00	0.00
4	0.1500	0.0500	0.0000	0.0000	0.600	0.600	0.09	0.13	0.00	0.00
5	0.1500	0.2000	0.0000	0.0000	0.770	0.770	0.14	0.19	0.00	0.00
6	0.1500	0.5900	0.0000	0.0000	1.050	1.050	0.30	0.42	0.00	0.00
7	0.1500	0.7000	0.0000	0.0000	1.380	1.380	0.60	0.82	0.13	0.01
8	0.1500	0.7200	0.0000	0.0000	1.750	1.750	0.64	0.75	0.51	0.10
9	0.1500	0.7600	0.0000	0.0000	2.200	2.200	0.42	0.36	0.73	0.29
10	0.1500	0.8500	0.0000	0.0000	2.600	2.600	1.22	1.19	1.41	1.08
11	0.1500	0.9400	0.0000	0.0000	2.790	2.790	1.34	1.38	1.16	1.44
12	0.1500	1.0000	0.0000	0.0000	3.280	3.280	1.77	1.51	2.06	3.09
13	0.1500	1.0000	0.0000	0.0000	3.890	3.890	0.92	0.54	1.12	3.23
14	0.1500	1.0000	0.0000	0.0000	4.380	4.380	1.29	1.00	1.65	2.64
15+	0.1500	1.0000	0.0000	0.0000	5.290	5.290	1.10	0.97	1.48	1.25
Unit	-	-	-	-	Kilograms	Kilograms				

Table 3. a) Catch in numbers (hundreds) at age of Greenland halibut by gear from the limited commercial fishery during the research program in 1992-1994. b) Input parameters for Yield per recruit analyses based on the 1992-1994 biological and fishery data.

a

	Trawl (in hundreds)			Longline (in hundreds)			Gillnet (in hundreds)		
Age	**1992**	**1993**	**1994**	**1992**	**1993**	**1994**	**1992**	**1993**	**1994**
4	237	260	201						
5	981	1557	1552	6	12	6			
6	1179	1145	1494	8	19	10			
7	1327	1686	1685	35	73	40	1	5	3
8	681	773	705	25	56	34	4	14	11
9	86	44	62	1	2	12	0	3	4
10	350	458	370	49	96	47	66	129	158
11	146	190	152	25	44	27	80	195	89
12	87	63	40	7	11	13	14	25	30
13	24	21	12	2	2	4	3	4	6
14	12	12	8	1	2	1	1	1	2

b

	Trawl		Longline		Gillnet	
Age	Exploit. pattern	Weight in catch	Exploit. pattern	Weight in catch	Exploit. pattern	Weight in catch
3	0.0090	0.260	0.0000	0.260	0.0000	0.260
4	0.0230	0.520	0.0000	0.520	0.0000	0.520
5	0.1880	0.730	0.0040	0.780	0.0030	0.780
6	0.2940	0.960	0.0090	0.960	0.0000	0.960
7	0.7530	1.300	0.0700	1.310	0.0010	1.340
8	0.7640	1.800	0.1000	1.810	0.0030	1.820
9	0.9410	2.170	0.9230	2.120	0.5100	2.120
10	1.1340	2.550	1.8450	2.610	1.0200	2.620
11	1.3140	3.300	1.8130	3.350	2.9990	3.340
12	1.0930	4.130	1.2490	4.140	1.4680	4.170
13	0.5090	4.880	0.7320	4.980	0.7190	4.970
14	0.3760	6.240	0.9230	6.290	0.5100	6.020
15+	0.3760	6.500	0.9230	6.500	0.5100	6.500
Unit	-	Kilograms	-	Kilograms	-	Kilograms

Age	Recruit-ment	Natural mortality	Maturity ogive	Prop.of F bef.spaw.	Prop.of M bef.spaw.	Weight in stock
3	1.000	0.1500	0.0000	0.0000	0.0000	0.260
4	.	0.1500	0.0333	0.0000	0.0000	0.520
5	.	0.1500	0.2467	0.0000	0.0000	0.730
6	.	0.1500	0.5500	0.0000	0.0000	0.960
7	.	0.1500	0.6767	0.0000	0.0000	1.300
8	.	0.1500	0.7167	0.0000	0.0000	1.800
9	.	0.1500	0.7633	0.0000	0.0000	2.170
10	.	0.1500	0.8900	0.0000	0.0000	2.550
11	.	0.1500	0.9367	0.0000	0.0000	3.300
12	.	0.1500	0.9867	0.0000	0.0000	4.130
13	.	0.1500	1.0000	0.0000	0.0000	4.880
14	.	0.1500	1.0000	0.0000	0.0000	6.240
15+	.	0.1500	1.0000	0.0000	0.0000	6.500
Unit	Numbers	-	-	-	-	Kilograms

Notes: Run name : MULTI01
Date and time: 05MAY95:09:16

Table 4. Catch, prices and value of Greenland halibut:

Type of vessel	Number of vessels	Average catch in 1991 (tonnes)	Average value of catch (NOK)	Average price (NOK/kg)	Value of Greenland halibut as percent of total value of catch per vessel
Trawlers	12	865	9.0 mill.	10.5	53%
Longliners	7	263	3.3 mill.	12.7	30%
Gillnet vessel	4	258	3.3 mill.	12.7	40%

Table 5. Cost analysis[4]:

Type of vessel:	Number of vessels	Average catch of all species (tonnes)	Average catch of Greenland halibut (tonnes)	Variable costs/vessel (1000 NOK)	Variable costs (NOK/kg)
Trawl	11	2 085	865	12 600	6.0
Longliners	2	1 126	263	8 167	7.3
Gillnet vessel	2	844	258	6 095	7.2

4 Not all vessel report data on costs and earnings to the Directorate of Fisheries. Only 11 of the 12 trawlers, 2 of 7 long-liners and 2 of 4 gillnet vessels in our group have reported to the database.

Table 6. Y/R and SSB/R and the resulting catch for different combinations of the 1991 gear specific fishing patterns. Actual-1.0 and Actual-0.3 refers to the actual gear combination in 1991 at the actual fishing mortality of 1.0 and at Fmax=0.3. Options A-F show comparative results using alternative gear combinations.

Fishing-pattern	F 7-12 Trawl	Longline	Gillnet	Total	Y/R grams	SSB/R grams	Catch (in tonnes) Trawl	Longline	Gillnet	Total
Actual-1.0	0.70	0.20	0.10	1.00	670	1150	24516	4561	1950	31027
Actual-0.3	0.21	0.06	0.03	0.30	738	3024	9126	1777	789	11692
Option A	0.05	0.05	0.90	1.00	788	2543	1913	1072	13930	16915
Option B	0.35	0.35	0.30	1.00	712	1577	12647	7448	5095	25190
Option C	0.00	0.00	1.00	1.00	828	3010	0	0	15355	15355
Option D	0.05	0.05	0.20	0.30	770	3272	2203	1451	4946	8600
Option E	0.10	0.10	0.10	0.30	753	3245	4383	2922	2543	9848
Option F	0.00	0.00	0.30	0.30	806	4118	0	0	7255	7255

Table 7. Y/R and SSB/R and the resulting long-term catch for different gear combinations at the maximum multi-fleet Y/R level at $F_{7\text{-}12}$=0.45 and at $F_{0.1} \approx 0.20$.

	F 7-12 Trawl	Longline	Gillnet	Total	Y/R grams	SSB/R grams	Catch (in tonnes)[2] Trawl	Longline	Gillnet	Total
Fmax level										
Option A	0,05	0,05	0,35	0,45	859	3425	2251	3506	17293	23050
Option B	0,35	0,05	0,05	0,45	756	2356	14680	3320	2401	20401
F0,1 level										
Option A	0,05	0,1	0,05	0,2	794	5224	4062	12671	4648	21381
Option B	0,1	0,05	0,05	0,2	759	5118	8703	6818	5000	20520

[2] Recruitment at age 3 set equal to the average recruitment in 1972-1990 (Anon. 1995b)

Table 8. Profitability:

Type of vessel	Prices (NOK/kg)	Variable costs (NOK/kg)	Profitability (NOK/kg)
Trawlers	10.4	6.0	4.4
Longliners	12.7	7.3	5.4
Gillnet vessels	12.7	7.2	5.5

Table 9. Profitability of different gears:

Table 9a. Actual F-pattern 1991, F =1,0, Y/R=670g, SSB/R=1150g:

Type of vessel	F_{7-12}	Catch	Prices	Variable costs	Profitability	Profitability/kg
Trawlers	0.70	24 516	10.4	6	107 870.40	
Longliners	0.20	4 561	12.7	7.3	24 629.40	
Gillnet vessels	0.10	1 950	12.7	7.2	10 725.00	
Total	1.00	31 027			143 224.80	4.62

Table 9b. Actual F-pattern 1991, F =0,3, Y/R=738g, SSB/R=3024g:

Type of vessel	F_{7-12}	Catch	Prices	Variable costs	Profitability	Profitability/kg
Trawlers	0.21	9 126	10.4	6	40 154.40	
Longliners	0.06	1 777	12.7	7.3	9 595.80	
Gillnet vessels	0.03	789	12.7	7.2	4 339.50	
Total	0.30	11 692			54 089.70	4.63

Table 9c. F-pattern; **option A** , F =1,0, Y/R=788g, SSB/R=2543g:

Type of vessel	F_{7-12}	Catch	Prices	Variable costs	Profitability	Profitability/kg
Trawlers	0.05	1 913	10.4	6	8 417.20	
Longliners	0.05	1 072	12.7	7.3	5 788.80	
Gillnet vessels	0.90	13 930	12.7	7.2	76 615.00	
Total	1.00	16 915			90 821.00	5.37

Table 9d. F-pattern; **option B** , F =1,0, Y/R=712g, SSB/R=1577g:

Type of vessel	$F_{7\text{-}12}$	Catch	Prices	Variable costs	Profitability	
Trawlers	0.35	12 647	10.4	6	55 646.80	
Longliners	0.35	7 448	12.7	7.3	40 219.20	
Gillnet vessels	0.30	5 095	12.7	7.2	28 022.50	Profitability/kg
Total	1.00	25 190			123 888.50	4.92

Table 9e. F-pattern; **option C** , F =1,0, Y/R=828g, SSB/R=3010g:

Type of vessel	$F_{7\text{-}12}$	Catch	Prices	Variable costs	Profitability	
Trawlers	0.00	-	10.4	6	-	
Longliners	0.00	-	12.7	7.3	-	
Gillnet vessels	1.00	15 355	12.7	7.2	84 452.50	Profitability/kg
Total	1.00	15 355			84 452.50	5.5

Table 9f. F-pattern; **option D** , F =0,3, Y/R=770g, SSB/R=3272g:

Type of vessel	$F_{7\text{-}12}$	Catch	Prices	Variable costs	Profitability	
Trawlers	0.05	2 203	10.4	6	9 693.20	
Longliners	0.05	1 451	12.7	7.3	7 835.40	
Gillnet vessels	0.20	4 946	12.7	7.2	27 203.00	Profitability/kg
Total	0.30	8 600			44 731.60	5.20

Table 9g. F-pattern; **option E** , F =0,3, Y/R=753g, SSB/R=3245g:

Type of vessel	$F_{7\text{-}12}$	Catch	Prices	Variable costs	Profitability	
Trawlers	0.10	4 383	10.4	6	19 285.20	
Longliners	0.10	2 922	12.7	7.3	15 778.80	
Gillnet vessels	0.10	2 543	12.7	7.2	13 986.50	Profitability/kg
Total	0.30	9 848			49 050.50	4.98

Table 9h. F-pattern; **option F** , F =0,3, Y/R=806g, SSB/R=4118g:

Type of vessel	$F_{7\text{-}12}$	Catch	Prices	Variable costs	Profitability	
Trawlers	0.00	-	10.4	6	-	
Longliners	0.00	-	12.7	7.3	-	
Gillnet vessels	0.30	7 255	12.7	7.2	39 902.50	Profitability/kg
Total	0.30	7 255			39 902.50	5.5

GENERAL

Table 9i. $F_{max=0,45}$, **option A** , Y/R=859g, SSB/R=3425g:

Type of vessel	$F_{7\text{-}12}$	Catch	Prices	Variable costs	Profitability	
Trawlers	0.05	2 251	10.4	6	9 903.96	
Longliners	0.05	3 506	12.7	7.3	18 934.56	
Gillnet vessels	0.35	17 293	12.7	7.2	95 109.30	Profitability/kg
Total	0.45	23 050			123 947.82	5.38

Table 9j. $F_{max=0,45}$, **option B** , Y/R=756g, SSB/R=2356g:

Type of vessel	$F_{7\text{-}12}$	Catch	Prices	Variable costs	Profitability	
Trawlers	0.35	14 680	10.4	6	64 593.32	
Longliners	0.05	3 320	12.7	7.3	17 925.84	
Gillnet vessels	0.05	2 401	12.7	7.2	13 206.05	Profitability/kg
Total	0.45	20 401			95 725.21	4.69

Table 9k. **$F_{0,1}$ level, option B** , Y/R=794g, SSB/R=5224g:

Type of vessel	F 7-12	Catch	Prices	Variable costs	Profitability	
Trawlers	0.05	4 062	10.4	6	17 874.56	
Longliners	0.10	12 671	12.7	7.3	68 421.24	
Gillnet vessels	0.05	4 648	12.7	7.2	25 564.00	Profitability/kg
Total	0.20	21 381			111 859.80	5.23

Table 9l. **$F_{0,1}$ level, option C** , Y/R=759g, SSB/R=5118g:

Type of vessel	$F_{7\text{-}12}$	Catch	Prices	Variable costs	Profitability	Profitability/kg
Trawlers	0.10	8 703	10.4	6	38 292.32	
Longliners	0.05	6 818	12.7	7.3	36 814.50	
Gillnet vessels	0.05	5 000	12.7	7.2	27 497.80	
Total	0.20	20 520			102 604.62	5.00

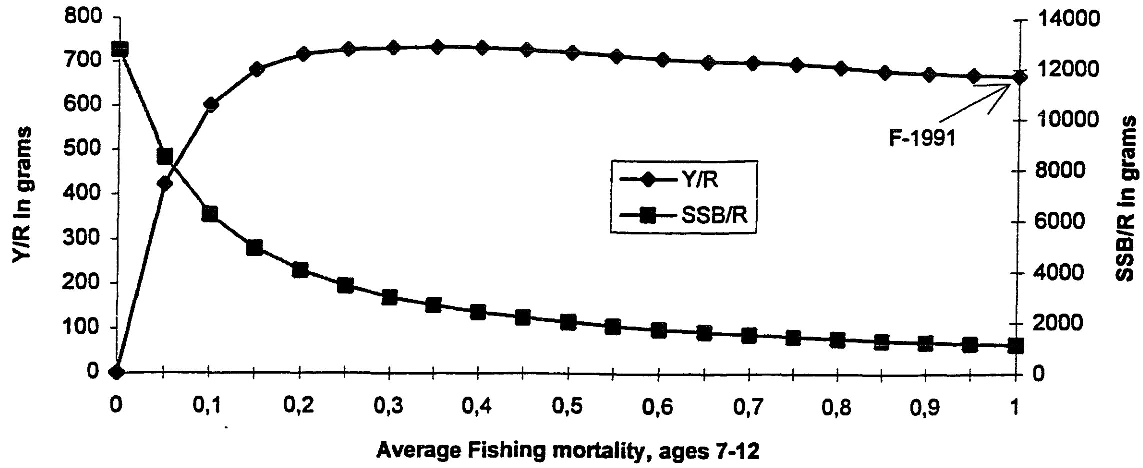

Figure 1. Yield per recruit and Spawning Stock Biomass per recruit curves for Greenland halibut in ICES Sub-areas I and II based on the actual 1991 fishing pattern (trawl, longline and gillnet combined). The total fishing mortality $F_{7\text{-}12}$=1.0 is pointed out.

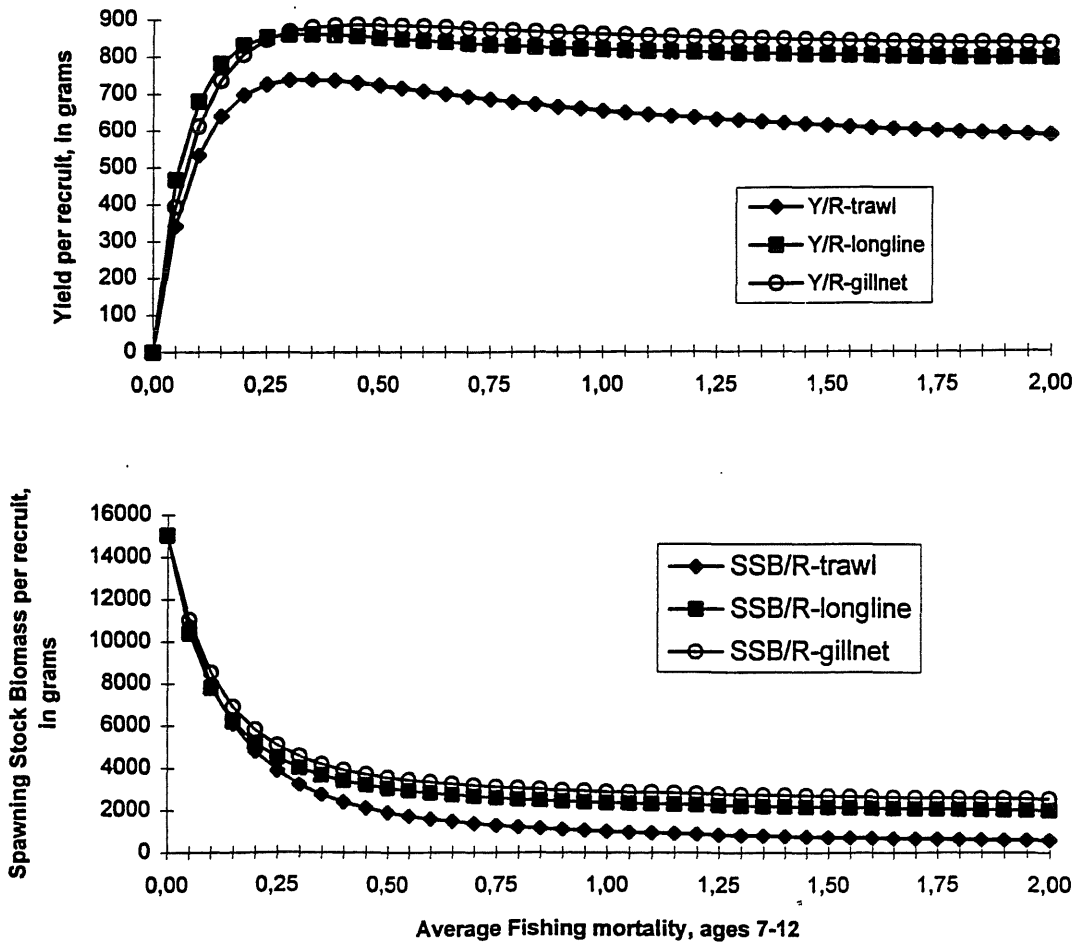

Figure 2. Yield per recruit and Spawning Stock Biomass per recruit curves for 135 mm trawl, longline and 220 mm (stretched mesh) gillnet in the fishery for Greenland halibut in ICES Sub-area II.

APPENDICES

Appendix 1:

Multi fleet Y/R program. Basic computations. The program has been developed at the ICES Headquarter in Copenhagen, and has been implemented in the ICES Fisheries Assessment Package (IFAP) (Leif Pedersen, pers.comm.).

$$(5)\quad Y(f,a) = w(f,a) * N(a) * \frac{F(f,a)}{Z(a)} * (1 - e^{-Z(a)})$$

where:

```
Y  yield
w  weight in catch
N  stock size in numbers
F  fishing mortality
Z  total mortality

f  fleet
a  age
```

However, before the above formula can be used, the following computations must be made:

1. The F(f,a) must be computed from the externally given exploitation pattern S(f,a) and F-factors fac(f):

$$(1)\quad F(f,a) = S(f,a) * fac(f)$$

The user sets the number of F-factors fac(f), and each value corresponds to one point of the Y/R curve. Normally, fac(f) run through a range of values but, as you may recall, it may also be constant for a particular fleet.

2. The total fishing mortality by age is a simple sum of the fleets:

$$(2)\quad F(a) = \underset{f}{SUM}\ F(f,a)$$

3. The total mortality is then

$$(3)\quad Z(a) = F(a) + M(a)$$

where M(a) is externally given.

4. Finally the stock size is computed by the usual equation

$$(4)\quad N(a+1) = N(a) * e^{-Z(a)}$$

where N(1) is externally given (for a plus group there is a special computation).

Given (1) - (4), (5) can be applied, and this is done, as said above, for each set of F-factors fac(f).

Appendix 2: Calculation of costs per kg for the respective gears

The Norwegian Directorate of Fisheries operates a database containing yearly reports of costs and earnings by fishing vessel, from which annually analysis of costs and earnings in the fishing fleet are produced. From this database we have drawn information from the following vessels in 1991:

Trawl. Licensed trawlers of a length above 34 metres catching more than 500 tonnes of Greenland halibut. This group consist of 11 vessels.

Longline. Vessels of a length above 34 metres catching at least 100 tonnes of Greenland halibut. This group consist of 2 vessels.

Gillnets : Vessels of a length above 32 metres catching at least 100 tonnes of Greenland halibut. This group consist of 2 vessels

These vessels were chosen because the catch of Greenland halibut constituted a significant part of their catch this year. From the database we may find total costs specified on various items, and for the three gear groups we found the following:

Table A1 Specification of costs per average vessel

Specification of costs (NOK). Average per vessel	Trawl 11 vessels	Long line 2 vessels	Gill net 2 vessels
Catch (kg)	2.084.800	1.125.700	843.600
Fuel	2.804.653	703.098	457.401
Bait		620.374	
Packing	471.300	32.648	104.470
Hired labour	238.818	500	53.373
Telephone	494.921	267.905	186.257
Social taxes	64.198	28.975	111.668
Product tax	741.260	475.781	358.179
Various insurances	73.459	47.906	13.850
Various costs	548.800	140.611	365.870
Gear insurance			23.404
Gear maintenance	1.232.732	525.104	566.990
Vessel insurance	534.295	2.133.200	224.464
Vessel maintenance	1.656.978	925.602	622.951
Depreciation	2.667.297	1.569.141	253.803
Interest	2.031.272	1.517.252	1.424.999
Calculatory interest on own capital	581.449	250.189	4.431
Packet insurance	62.156	45.773	32.650
Remuneration to crew	6.002.892	5.871.758	3.891.103
Sum costs	20.206.480	14.655.817	8.695.863
Sum variable costs	12.599.574	8.166.754	6.095.311
Total costs (NOK/kg)	9,69	13,02	10,31
Variable costs (NOK/kg)	6,04	7,25	7,23

Source: Annual analysis of cost and earnings of the fishing vessels, 1991.
Directorate of Fisheries, Bergen, Norway

The categories shaded are considered to be cost items that will vary in proportion to the activity of the vessel. Remuneration to the crew is calculated as a certain percentage of the value of the catch, and is therefore directly proportional to the catch.

We do admit that there are significant aspects which this method do not take into account. Among these are:

*** Time spent on the fishery may not be proportional to catch from the fishery**

By using estimates of variable costs per kg of all fish caught by the vessel as an approximation to the variable costs per kg of fishing Greenland halibut, we assume that the costs of fishing this specie is equal to the vessels average costs when fishing for other species as well. The following information will show that this is not always the case:

A. Statistics drawn from Norwegian trawlers log-books show that catch per unit effort is significantly lower when Greenland halibut is the target species than when fishing other species. On the average Norwegian trawlers caught 0.555 tonnes fish per trawl-hour in 1991, but when Greenland halibut dominated in the catches, they caught 0.364 tonnes per hour. Although remuneration to crew is based on the value of the catch, and not dependent upon time spent in the fishery, some of the variable costs are proportional to hours of trawling. Consequently variable costs per kg should be higher when fishing Greenland halibut than when fishing other species. We do, however, not possess similar data for the two other vessel groups and are therefore obstructed from comparing costs related exclusively to the catch of Greenland halibut.

B. The Institute of Marine Research in Norway has conducted scientific fishery for the specie during the years 1992 - 1994, using different vessels fishing with trawl, longline and gillnets. It was then found that trawlers (factory trawlers not included) used 9.5 days to catch 100 tonnes of Greenland halibut, whereas longline and gillnets used 30.0 and 15.0 days respectively (Nedreaas,1995). According to this, trawl are more and longline less cost-effective than what was stated above.

*** Calculated costs should be based on more than one year**

Of course it would be beneficial to base the costs of fishing Greenland halibut on more than one year. As the fishery was TAC - regulated in 1992, a time serie including years prior to 1991 should be used. This option was investigated but not used for two reasons. First, the catch increased rapidly during the years prior to 1991, and cost figures would therefore not be comparable. Second we lack cost data for part of the relevant vessels prior to 1994.

Appendix 3 An alternative method for finding the variable costs in the fishery for Greenland halibut

An alternative method for finding variable costs pr kg is the following: If fishermen behave rational and only fish on non-regulated species, they will spread their effort in order to maximise their profits. If they are fishing several species, one would expect that the contribution margin (revenue less variable costs) should be equal from each fishery. Knowing the price and catch of each specie, it is easy to find which variable cost which would give equal contribution margin in the different fisheries.

Consider a case where a vessel operates in two fisheries, and our aim is to find the cost per kg for catching one of the species. Let us assume we have the following information:

The total catch of both species	**X**
The catch of species A	**Xa**
The average price of both species	**P**
The price of species A	**Pa**
The price of species B	**Pb**
The average cost per kg of both species	**C**

We would like to know the following:

The cost per kg of species A	**Ca**
The cost per kg of species B	**Cb**

If no regulations exist and the owner of the vessels only goal is to maximize profit, the following equations will be true:

$$(P - C)*X = (Pa - Ca)(X - Xb) + (Pb - Cb)*Xb \tag{1}$$

and

$$Pa - Ca = Pb - Cb \tag{2}$$

The first equation tells that the total value of the catch will be equal to the sum of the value of the two fisheries. The second equation tells that the profit or contribution margin per kg in the two fisheries is identical. By substituting we find the following:

$$Ca = Pa - Pb + Cb \tag{3}$$

and

$$Cb = \{(Pa - Ca)(X - Xb) - (P - C)*X + Pb*Xb\}/Xb \tag{4}$$

By substituting we find both Ca and Cb. Using this method, we calculated the variable costs per kg for the three vessel groups fishing Greenland halibut, and found the following:

Table A2 Variable costs per kg - alternative method

Gear	Variable costs (NOK per kg)
Trawl	8.7
Long line	10.2
Gillnet	10.8

Considering that the price achieved for Greenland halibut will be in the range 10 - 13 NOK per kg, and the vessel owner also shall cover his fixed costs, these estimates of variable costs are unrealistically high. The reason why these estimates are too high may be that the conditions stated above are not satisfied: Although the fishery for Greenland halibut was not regulated in 1991, the other fisheries were absolutely so (cod, haddock, saithe). In addition, knowledge of information about the costs and income from a Greenland halibut fishery will not be perfect.