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A Bioeconomic Analysis of the Greenland Shrimp Fishery in the Davis Strait

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Abstract *This paper presents a bioeconomic analysis determining the resource rent and optimum effort of the shrimp (*Pandalus borealis*) fishery in the Davis Strait, taking into account the discard behaviour of the fleet.*

It is demonstrated that, from an economic point of view, the shrimp stock in the Davis Strait is substantially overfished. In order to obtain the maximum economic yield, the effort must be reduced by at least 40% compared to the effort level of 1991.

The gain in resource rent by reducing effort is estimated to be at least 20% compared to the resource rent of 1991.

Keywords Bioeconomics, rent, discard, shrimp, Greenland.

Introduction

The shrimp (*Pandalus borealis*) fishery on the offshore fishing grounds in the Davis Strait,[1] shown in Figure 1, started around 1970. During the first few years of fishery the annual yield increased steeply and reached in 1976 a level of about 40,000 tonnes. During the 1980's the reported catches rose even further and in the 1990's catches well above 50,000 tonnes are seen. As shown in Table 1 the fishing fleet participating in the shrimp fishery of the Davis Strait is multinational. The greater part of catches is taken by the vessels from Canada and Greenland, although vessels from Denmark, The Faroe Islands, and France also participate to a minor extent.

Since 1976 the shrimp stock has been assessed by the Scientific Councils of the International Commission for the Northwest Atlantic Fisheries and the Northwest Atlantic Fisheries Organization (ICNAF and NAFO respectively). The recommended total allowable catch (TAC), submitted annually by the Scientific Council of NAFO, is shared between Canada and Greenland in accordance with the geographical distribution of the stock, cf. Table 1.

The offshore fishing fleet of Greenland consists of three types of vessels. A major part of the fishing fleet is constituted by factory trawlers with processing plants on board. As a part of the licence conditions one group of these factory

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[1] *I.e.* the fishing grounds of NAFO sub-area 0 and 1 more than 3 n.m. west of the Greenland archipelago.

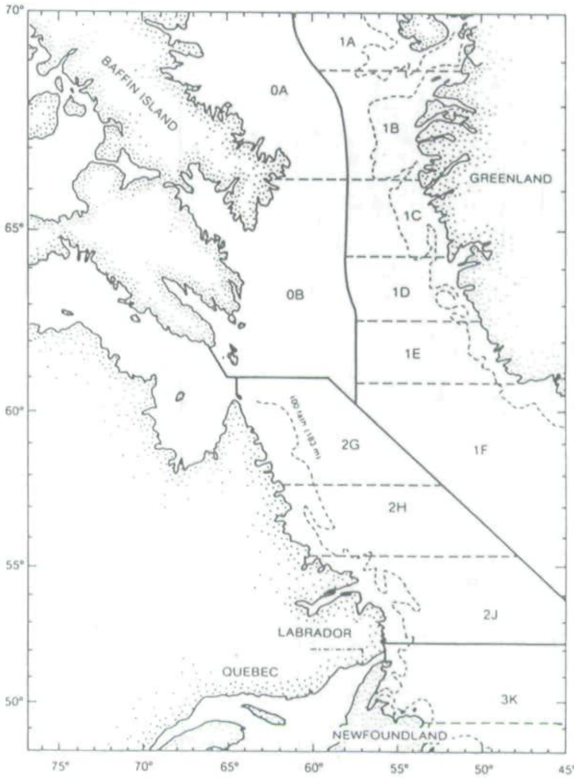

Figure 1. Map showing the NAFO subareas.

trawlers is allowed to process 75% to 90% of the reported catch on board, whereas a second group is allowed to process 30% to 50% of the reported catch only. For both groups the remaining catch of shrimp larger than 2 grammes must be landed to the factories on shore. The third group of vessels participating in the offshore fishery is formed by minor boats with no processing plants on board and no licences to process. These boats are also allowed to fish on the inshore fishing grounds but the entire catch of this part of the fishing fleet must be landed to the factories on shore.

Three main products of shrimp are produced. At sea frozen, unpeeled shrimps which can be either raw or cooked are produced. At the processing industry on shore, the shrimps are cooked and peeled. Besides the type of product the sales prices also depend on the size of the shrimp. The commercial fleet commonly operates with 5 size categories: count[2] 50–70, count 70–90, count 90–120, count 120–150, and count 150+.

From 1984 to 1991 the offshore shrimp fishery of Greenland was regulated by an individual non-transferable quota (INTQ) system. During that period the magnitude of the annual quota of each vessel was decided on by a committee appointed by the Greenland Home Rule.[3] This committee also decided on the total

[2] Count is defined as number of shrimps per kilogramme.
[3] The sub-national government of Greenland.

Table 1
TACs and Offshore Catches of Shrimp (Tonnes) in the Davis Strait (NAFO Sub-area 0 + 1)

	Advised TAC	Effective TAC Greenland	Effective TAC Canada	Catch Greenland	Catch Canada	Catch Others	Total Catch
1976				2,478		40,288	42,766
1977	40,000	36,000		7,081		27,219	34,300
1978	40,000	40,000		5,531		21,338	26,869
1979	29,500	29,500		12,676	245	14,166	27,087
1980	29,500	29,500		28,316	649	7,687	36,652
1981	29,500	30,000	5,000	28,282	1,590	17,428	37,300
1982	29,500	29,800	5,000	32,024	858	3,945	36,827
1983	29,500	29,625	5,000	30,929	2,030	6,308	39,267
1984	29,500	29,925	5,000	32,131	448	3,304	35,883
1985	36,000	36,000	6,120	39,137	233	2,817	42,187
1986	36,000	36,000	6,120	40,668	126	3,790	44,584
1987	36,000	34,000	6,120	37,998	3,252	4,910	46,160
1988	36,000	34,000	6,120	35,947	6,087	1,615	43,649
1989	44,000	32,600	7,520	40,961	7,235	1,735	49,931
1990	50,000	37,455	7,520	45,620	6,177	976	52,773
1991	50,000	37,725	8,500	49,938	6,788	606	57,332
1992	50,000	35,700	8,500				

Source: Anon 1986 and Anon 1992.

number of licences to be issued. In order to improve the rational utilization of the fishing fleet, the Greenland Home Rule implemented an individual transferable quota (ITQ) system in 1991. By this ITQ system the individual quota is tied to the TAC as a fixed proportional share. As a rule, only the total perpetual quota can be sold by the owner to one or several buyers. However, the quota owners were allowed to sell annual quotas or even parts of the annual quotas on condition that the transfer of annual quotas must not assume character of rental of perpetual quotas. In 1991 13 deals in annual quotas or in parts of annual quotas were closed, whereas 4 vessels, out of a total of 46 vessels,[4] sold their entire perpetual quota and left the fishery.

From a biological point of view the problem of aging the shrimp constitutes one of the major tasks of the stock assessment. Although much effort has been put into this work, aging difficulties has so far been a hindrance for application of analytical assessment models such as virtual population analysis (VPA) (Horsted, 1990). As a consequence, the annual TACs have been based on log-book information of commercial fishery catches.

In 1992, NAFO took into account, an index of catch per unit effort (CPUE) of

[4] At the beginning of 1991 37 companies were engaged in the fishery. Of these 35 companies owned one vessel each, whereas 2 companies owned 4 and 7 vessels respectively. At the end of 1991 30 companies owned one vessel each whereas 3 companies owned 2, 3, and 7 vessels respectively.

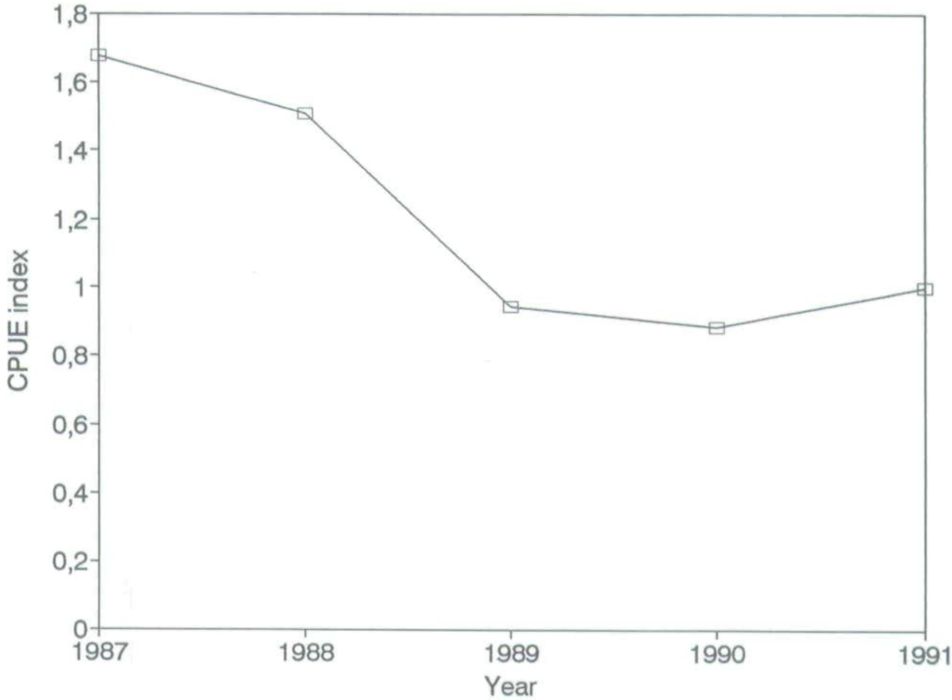

Figure 2. Yearly CPUE indices calculated for shrimp >8.5 grams. Source: Carlsson and Lassen (1991).

large shrimp (>8.5 gram). This index was based on 5 years of commercial catches from 22 Greenland factory trawlers and was standardized with regard to area, month, year, and vessel (Carlsson and Lassen, 1991). The data, Figure 2, indicated a declining CPUE in the commercial fishery. Only large shrimp are included in this index, and since the discard is considered insignificant, the observed trend is thought not to be influenced by any changes in discard practice during the period in question. The declining tendency is, therefore, assumed to describe an actual reduction in the share of large shrimp in the stock. Furthermore, in 1992 length frequency data from survey samples were also included in the assessment (Anon, 1992). From this date it became evident, that the 1985 year class constitutes almost the entire catchable stock of shrimp in the Davis Strait, and that apart from the 1989 year class, younger year classes are insignificant to the stock. On that basis NAFO recommended a precautionary 20% reduction in the shrimp quota in 1993 to secure future recruitment (Anon, 1992).

Shrimp is by far the most important species in the Greenland fisheries and forms the present basis of the economy of the country. The export earnings in 1991 totalled more than US$ 310 million and in 1992 US$ 280 million which is more than 90% of the total export earnings of Greenland.

Based on present knowledge of the biological characteristics of the shrimp stock in the Davis Strait, and on economic information of cost and earnings of the commercial fleet, the present paper offers a bioeconomic analysis relating yield and effort. The paper presents an estimate of the resource rent and of the optimum effort of the shrimp fishery of Greenland.

The Model

The objective function applied in the present study to maximize the resource rent of the fishery can be expressed by the following equation:

$$\text{Max } \pi = TR(p_{lk}, H_{lk}) - TC(G_{lk}, H_{lk}, E) \quad (1)$$

where
- E is total effort,
- TR is total revenue of the fishery,
- TC is total cost of the fishery,
- p_{lk} is sales price per kilogramme live-weight of count 1 and product k,
- H_{lk} is reported catch of count l used to produce product k,
- G_{lk} is gross revenue of reported catch of count l used to produce product k.

In the model the harvest function is specified as

$$H_{lk}(E) = (Y_l(E) - D_l(Y_l)) \cdot \alpha_{lk} \quad (2)$$

where
- Y_l is the total catch of count l,
- D_l is the discard of count l,
- α_{lk} is the proportion of the reported catch of count l used to produce product k.

There are two reasons why application of a static bioeconomic model is preferred to that of a dynamic model. Firstly; maximizing the flow of the resource rent is consistent with maximizing the present value of the stream of resource rents by a dynamic model applying an interest rate at zero. As the socio-economic discount rate in Greenland is low (Anon, 1990) the steady state solution of the dynamic model is similar to the static solution (Clark, 1985). Secondly; as the dynamic model assumes perfect information and certainty about the future states of the system, such an approach, at least from a practical point of view, is unsuitable (Lindner, Campbell, and Bevin, 1992), and will give no additional insight into the value of the fishery.

The only year with full information about the economic parameters (cost and earnings), 1991, has been selected as the reference year of the study. Therefore, the estimates of the maximum sustainable yield (MSY), the maximum sustainable revenue (MSR), and the maximum economic yield (MEY) derived from the present bioeconomic model may not be perfect estimates of these values in other years. To improve the applicability of the present study, different scenarios are thus presented, applying different assumptions on the natural mortality rate and different levels of opportunity costs.

Estimating the Biological Parameters

The equilibrium catch, Y in the harvest function (2), is calculated using a modified Thompson and Bell yield per recruit model (Thompson and Bell, 1934). The dynamic pool model applied can be expressed as

$$Y = \sum_i R_i \cdot (1 - \exp(-(F_i \cdot S_i + M))) \cdot F_i \cdot S_i/(F_i \cdot S_i + M) \cdot w_i \quad (3)$$

where
R_i is recruitment at age i,
F_i is fishing mortality rate at age i,
w_i is weight at age i,
S_i is gear selection factor at age i,
M is natural mortality rate.

The recruitment at age i, R_i, of the catch equation (3) is calculated by:

$$R_i = R_{i-1} \cdot \exp(-(F_{i-1} \cdot S_{i-1} + M)) \quad (4)$$

and the weight at age i, w_i, is estimated by

$$w_i = 0{,}000711 \cdot l_i^{2{,}93} \quad (5)$$

(Carlsson, 1993) where l_i is length at age i.

Assuming growth according to the von Bertalanffy growth equation (Bertalanffy, 1938), the length at age i, l_i, is estimated by

$$l_i = L_\infty(1 - \exp(-k(i - t_0)) \quad (6)$$

where
L_∞ is the infinite length,
k is the growth rate,
t_0 is the age at which growth according to the growth equation is initiated.

By linear regression of the annual increment against the lengths at ages suggested in 1989 by the Working Group On Shrimp Aging (Savard, Parson and Carlsson, 1989), the parameter L_∞ of the growth equation (6) is estimated at 35.65 mm and k at 0.154. Subsequently t_0 is estimated at 0.7 as described by Gulland (1983).

In order to estimate the total mortality rate, Z, of the catchable stock, and subsequently the fishing mortality rate, F, the Jones and van Zalinge (Jones and van Zalinge, 1981) equation

$$\ln(C(L,L_\infty)) = a + Z/k \ln(L_\infty - L) \quad (7)$$

where
$C(L,L_\infty)$ is the cumulated catch of shrimp larger or equal to length L,
Z is the total mortality,
k and L_∞ are von Bertalanffy growth parameters estimated by the growth equation (6),

was applied to a length distribution of the catchable stock in 1991, estimated by observers from the Greenland Fisheries Research Institute (Carlsson and Kanneworff, 1992). Using linear regression, Z/k, the slope of the cumulated catch curve,

Figure 3, is estimated at 7.79. Accordingly Z of the fully recruited size groups in 1991 is estimated at 1.2.

In order to calculate the fishing mortality rate, F, of 1991 from the total mortality, Z, assumptions must be made with regard to the level of the natural mortality, M. No information is available in the literature on the level of the natural mortality of shrimps in the Davis Strait. However, the Scientific Council of NAFO (Anon, 1977) suggests 0.2–0.3 as an estimate of the Icelandic shrimp stock, whereas the natural mortality rate of shrimps of Skagerrak and Fladen Ground in the North Sea is believed to be higher than 0.5. Assuming that predation on shrimp in the Davis Strait is reduced due to the current very poor condition of the stock of cod, and assuming that the diversity of potential predators is low compared to Fladen Ground and Skagerrak, 0.3 is adopted in the present study as an estimate of M in 1991. Accordingly, F of the fully recruited size groups in 1991 is estimated at 0.9.

Applying the length-weight equation (5), the length groups of the observer programme are transformed into weight groups which are subsequently divided into the 5 commercial size categories. This distribution, shown in Table 2, is used as an estimate of the distribution of the commercial catches of 1991, assuming there had been no discard.

In order to calculate the equilibrium yield of each count group, the Y_1's in the harvest equation (2), the equilibrium catch, Y in the catch equation (3), is distributed on the different size categories, by algorithms adopted from the bioeconomic multi-species model Beam 4 (see Sparre and Willmann, 1992). In these calcula-

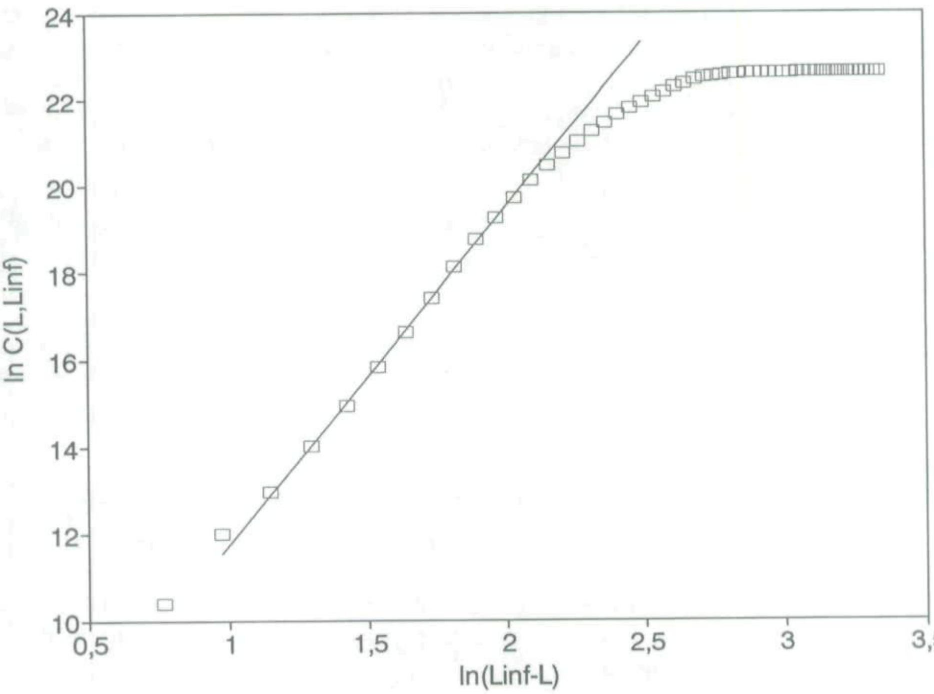

Figure 3. Cumulated catch curve applying the Jones and Van Zalinge (1981) equation to length composition data of 1991. C(L,Linf) is the cumulated catch of length L and above.

Table 2
Estimated Biological Input Parameters. Numbers in Brackets Refer to Equations in Text.

Size distribution of commercial catches in 1991 assuming no discards.[1]	Count[5]	50–70	70–90	90–120	120–150	150+
	Percent	2.2	16.5	31.9	25.2	24.2
Total mortality Z. (6) and (7)[1]	$Z = F + M = 1.2$					
von Bertalanffy growth parameters (6)[2]	$L_\infty = 35.65$ mm, $t_0 = -0.7$, $k = 0.154$					
Gear selectivity (8)[3]	$L_{50} = 19.88$ $L_{75} = 22.38$					
Discard ratios (11)[1,4]	Count	120–150	150+			
	Percent	8.1	69.1			

[1] Source: Based on data from Carlsson and Kanneworff (1992).
[2] Source: Based on data from Savard, Parson and Carlsson (1989).
[3] These estimates are not in accordance with the findings of Thorsteinsson (1989), and Christensen and Lassen (1990), who estimate the selection factor for a standard commercial trawl with 43 mm mesh size to about 0.35 equivalent to a L_{50} at 15 mm. The discrepancy may partly be due to differences in sampling procedures between stratified random trawl surveys and commercial fishing seeking out the fishing grounds with the optimal size composition. Furthermore, as the estimate L_{50}, of the logistic selection curve obtained from tuning the size composition of the estimated equilibrium catch predicted, depends on the underlying von Bertalanffy growth parameters, the two estimates may not be comparable. Therefore L_{50} and l_{75}, estimated by the present model should be regarded as statistical fitting parameters, rather than actual estimates of the specific selection parameters.
[4] Source: Log-books.
[5] Count = numbers per kilo.

tions the initial recruitment $R_0 = 1$ and the effort is assumed equivalent to the 1991 level. This calculated size distribution is fitted, iteratively, to the estimated size distribution of the commercial fishery during 1991 (Table 2), by multiplying the fishing mortality rate in the catch equation (3) by an age dependent gear selectivity parameter. The selectivity parameter, S, is defined by an equation approximating the logistic selection curve, i.e.

$$S_i = 1/(1 + \exp(T1 - T2 \cdot i)) \tag{8}$$

where

$$T1 = t_{50} \cdot \ln(3)/(t_{75} - t_{50})$$
$$T2 = \ln(3)/(t_{75} - t_{50})$$

and

$$t_{50} = t_0 - (1/k)\ln(1 - L_{50}/L_\infty)$$
$$t_{75} = t_0 - (1/k)\ln(1 - L_{75}/L_\infty)$$

where i is age and t_0, k and L_∞ are the von Bertalanffy growth parameters (Hoydal, Rørvik and Sparre, 1982).

Subsequently, the catch volume estimated by the model (3) applying $R_0 = 1$, is adjusted to the total catch of 1991 by multiplying Y of the catch equation by an appropriate level of recruitment:

$$R_0 = Y_{1991}/Y_{R0=1} \tag{9}$$

where Y_{1991} is an estimate of the total catch, including discard, in 1991.

According to the observer programme, two kinds of discard take place (Lehmann and Degel, 1991). Shrimp is discarded partly due to low quality (quality discard) and partly due to inferior size (size discard), in order to "high-grade" the catch. The amount of quality discard is low compared to the size discard and is disregarded in the present analysis. The observer programme (Carlsson and Kanneworff, 1992) found that the size discard in the Greenland fleets consists of shrimps less than 8.5 g, i.e. less than count 120.[5] This is consistent with estimates obtained applying the multi-species model of Clark (1985) modified into a single species model with size dependent prices (see Vestergaard, 1992). Therefore, if high-grading has taken place during 1991 fishery, the ratio of large shrimps (> count 120) becomes over represented in the reported catch, compared to the expectations according to the size distribution of the catchable stock in 1991. For every vessel the volume of the actual catch, y, before discarding takes place, can be calculated as

$$y = h(>120)/y(>120) \cdot h \tag{10}$$

where $h(>120)$ is the ratio of large shrimp of the reported catch, $y(>120)$ is the ratio of large shrimp expected assuming no discard, and h is the reported catch. Thus it is found that only the vessels with permission to process 75%–90% of the reported catch, discard shrimps for the purpose of high-grading.

The total discard of the Greenland fleet in 1991 is estimated at 9,017 tonnes, taking the difference between the sum of actual catches of high-grading vessels, the reported catches of non-high-grading vessels, and the total reported catch in 1991. Assuming that fleets from the other countries follow the same discard pattern, the discard in 1991 from these fleets is estimated at 4,180 tonnes. Adding these discard figures to the total reported catch, the total catch in 1991, Y_{1991}, is estimated at 70,301 tonnes, of which 13,197 tonnes are discarded.

In order to calculate the volume of discard of each count group, the actual catch of 1991, Y_{1991}, distributed into the commercial size groups by the count group ratios of the observer programme (Table 2), is subtracted from the volume of the corresponding size groups of the total reported catch, (Table 3), i.e.:

$$D_{l,1991} = Y_{l,1991} - H_{l,1991} \tag{11}$$

where $Y_{l,1991}$ and $H_{l,1991}$ is total and reported catch of count l in 1991.

The total volume of the size discard of 1991, 13,197 tonnes, is according to equation (11), equivalent to a discard rate of 8.1% of the catch of count 120–150 and of 69.1% of the catch of count 150+ (Table 2).

Standardization of Effort

Since the aim of the present study is to provide recommendations on the optimum effort of the shrimp fishery, a link between the biological model of the preceding

[5] The discard practice during the observer programme, is believed to have been uninfluenced by the presence of the observers during the fishing, as they did not represent the authorities in any way, but had a strict scientific assignment.

Table 3.
Total Catch and Discard in 1991. Tonnes.

Count (1)	Reported catch[1] H_1, 1991	Discard D_1, 1991	Total catch Y_1, 1991
50–70	1,546	0	1,546
70–90	11,608	0	11,608
90–120	22,409	0	22,409
120–150	16,283	1,433	17,715
150+	5,258	11,764	17,023
Total	57,104	13,197	70,301

[1] Source: Log-books and estimates.

paragraphs and the economic model of the following paragraphs is established through standardization of the effort applied in 1991, assuming that the fishing mortality rate is proportional to effort. As detailed information on the costs and earnings are accessible for the reference trawler of the CPUE index (Figure 2) only, the total effort of 1991 is standardized in number of fishing days of this particular vessel as described by Hannesson (1978) and Gulland (1983).

According to the log-books, the 22 factory trawlers on which the CPUE index is based had a total catch of 20,157 tonnes of large shrimp in 1991. As the CPUE index is standardized to 1 in 1991, the effort applied by this part of the fleet is equivalent to 20,157 standard effort units (SEU). Adding the volume of the small shrimp produced on board, the landings of small shrimp to the factories on shore, and the estimated discards of 1991, the catch totalled 41,650 tonnes in 1991. That catch volume was, thereby, obtained using 20,157 SEU. Accordingly, the CPUE of the reference trawler, with regard to the entire catchable stock, was 2.0663.

Since log-books from that part of the fishing fleet not licensed to produce shrimp on board do not include any reliable information on effort, and as no access to log-books of vessels from foreign countries was available, the effort of this section of the fleet is estimated in terms of SEU. This is achieved by dividing the total catches of these vessels by the CPUE of the reference trawler (Sathiendrakumar and Tisdell, 1987). In this way the total effort of 1991 is estimated at 34,023 SEU.

According to log-book data, the reference trawler in 1991 caught 376 tonnes of large shrimp in 135 fishing days. The total number of standard fishing days of the entire fleet participating in the fishery in 1991 may accordingly be estimated at: $34{,}023 \cdot 1/376 \cdot 135 = 12{,}215$ standard fishing days. The figures used in standardization of the effort are summarized in Table 4.

Estimation of the Economic Parameters

The total costs function, (TC) of the objective function (1), can, based on information of the costs of the reference trawler from the accounts and information about unit prices, be formulated as:

$$TC = \sum_{l,k} (c(G_k) \cdot G_{lk} + c(H_k) \cdot H_{lk}) + c(E) \cdot E \qquad (12)$$

Table 4
Figures Used to Standardize Effort

	Reported catches[1] (tonnes)	Standard effort units
Canada and other countries	7,166	5,491
Greenland	49,938	
Factory trawlers (75%–90%)	32,633	20,157
production of large shrimps	20,157	
production of small shrimps	6,149	
landings	6,327	
Factory trawlers (30%–30%)	10,459	5,062
Trawlers (0%)	6,846	3,313
Total	57,104	34,023

[1] Source: Anon 1992 and log-books.

where

$c(G_k)$ is the costs as a proportion of the value of the reported catch (%),

$c(H_k)$ is the cost per kilogramme depending on the volume of the reported catch ($),

c(E) is the cost per unit effort depending on effort ($).

The first two elements of the cost equation (12) are related to the production process of the shrimp catch. The costs, depending on the volume of the catch include: insurance, transport, salt, handling and packaging materials. These costs are proportional to the amount produced, and Table 5A shows the costs per kilogramme. The costs depending on the value of the catch are sales provision and resource tax. Resource tax is excluded, however, as it is a transfer payment. Sales provision is a fixed share of the gross revenue (see Table 5A).

The final element of the cost equation (12) is costs depending on effort. As the biological model applied in this paper is an equilibrium model, giving information about the yield of the fishery on long term basis, all the costs are variable and therefore, the short run fixed costs are also treated as costs depending on effort.

Table 5
Costs of the Reference Trawler. 1991.

A. Costs depending on volume and value of the reported catch.

	Raw-frozen	Sea-cooked	Cooked and peeled
Costs per kg (US$)	0.78	0.58	0.06
Sales provision	4%	4%	0%

B. Fixed costs and costs depending on effort. US$.

Effort costs	540,324
Fixed coses	175,304
Operating costs	715,628

Source: Accounts of reference trawler and information about unit prices.

The costs depending on effort include fuel, repair, and maintenance of equipment and vessel. The crew's wages are also considered as effort costs. The short run fixed costs comprise administration, insurance of the vessel, interest, and depreciation.

The prices used to calculate the costs are based on the principle of opportunity cost, i.e. the value that the factors could have produced in the best alternative use, which is appropriate in determining the long-term economic efficiency.

In the long run, changes in the total effort are linked to changes in the participating number of vessels and, therefore, the effort costs should reflect the opportunity cost of vessels.[6] The effort is defined as total fishing days expressed in reference trawler units which consequently is proportional to number of vessels of reference trawlers, as the fishery is full time. If the fleet was composed only of reference trawlers, i.e. the effort is homogeneous from an economic point of view, the opportunity costs of effort units would be constant[7] (Cook and Copes, 1987) and the effort costs linear in effort. If effort is non homogeneous or homogeneous units of effort will only enter the fishery at higher prices, then the effort cost will be increasing in effort. If effort is non homogeneous, then some intra marginal rents are earned by the more efficient units of effort (Cook and Copes, 1987). It is impossible to test whether or not vessels can be assumed to be economically homogeneous, because of data limitations. However, using an increasing marginal cost function will not significantly change the result (Andersen, 1982). It should be noted that non-linear marginal and average costs curves are obtained, if the costs are expressed as a function of the catch because of non-linearity in the catch function (3).

Table 5B shows the effort costs exclusive of wages and capital expenses. The opportunity costs of fuel, gear, administration *etc.* are the observed prices, whereas the opportunity costs for wages and capital costs are estimated.

The value of the reference trawler is calculated at US$ 8.35 million. In Norwegian investigations the lifespan of similar vessels is estimated at 23.8 years (Anon, 1990). The capital cost is estimated as a simple annuity. Two different real interest rates are used. One is calculated as the average nominal interest rate on long term bonds, 10.1%, corrected by the inflation rate in Greenland, 1.83%, leading to a real interest rate at 8.12%. As profits of investments in general are lower than private enterprises normally requires (Westerlund, 1988), investments in real assets in Greenland are mainly made by the Greenland Home Rule. Furthermore, many projects in the budget for the investments of the Greenland Home Rule have not been evaluated economically (Anon, 1991), indicating that the real constraint on investments in Greenland is a lack of good projects rather than lack of capital. Therefore, a lower estimate at 3% of the real interest rate has also been applied.

The vessel owner calculates the wages of the crew as a percentage of the gross earnings deducted by costs shared by the vessel and the crew, *i.e.* freight, insurance, sales provision, and resource tax. This figure does not reflect the opportunity costs, due to non-existent or limited alternative employment possibilities. The wages in the fishing industry are used, therefore, as opportunity costs for

[6] It is reasonable to assume that the production of effort is efficient, as there are not restrictions on the use of inputs.

[7] The factor prices are assumed exogeneous given.

Table 6
Costs (US$) of the Reference Trawler in 1991 for Three Alternative Levels of Opportunity Costs for Labour, and for Two Alternative Rates of Real Interest of Capital.

	3%	8.12%
Capital cost	186,013	301,400
Operation cost	715,628	715,628
Labour cost		
Normal share	670,350	670,350
Unemployment	0	0
Fishing industry	291,961	291,961
Total cost:		
Normal share	1,571,991	1,687,378
Unemployment	901,641	1,017,028
Fishing industry	1,193,602	1,308,989
Total cost per fishing day:		
Normal share	11,644	12,499
Unemployment	6,679	7,533
Fishing industry	8,841	9,696

employment in one cost function, whilst in another cost function the opportunity cost of labour is fixed at zero.

Combining these assumptions concerning opportunity costs, six different estimates for both the effort costs, and the effort costs per unit effort, are obtained as illustrated in Table 6. The total revenue function, (TR) of equation (1), is formulated as:

$$TR = \sum_{l,k} p_{lk} \cdot H_{lk} \tag{13}$$

The sales prices p_{lk}, which depend on the size of the shrimp and the product, are shown in Table 7. In order to use equal prices showing the social earnings obtained by the harvesting sector, the size dependent sales prices for the production of cooked and peeled shrimps on shore are calculated to include the profit in the fish processing industry.

The parameters α_{lk} in the harvest equation (2), from which the reported catch (H_{lk}) is calculated, show the proportion of the reported catch of count l used to produce product k. The estimates of α_{lk}, which are based on the observed count and product distribution of the reported catch in 1991, are shown in Table 8.

In the model the average net sales prices,[8] nsp_l, estimated as

[8] Compared to traditional production models assuming constant prices the present model includes size dependent prices based on the observed product mix in 1991. It is assumed, however, that the changes in the supply of shrimp from Greenland do not affect the market prices. This assumption may be inappropriate given that Greenland supplies 30% of the world market with cold water shrimps. No information on price elasticity of shrimps is available from the literature.

Table 7
Sales Prices and Average Net Sales Prices. US$ per Kilogramme.

Count	Sales prices[1]			Average net sales price
	Raw-frozen	Sea-cooked	Cooked and peeled	
50–70	16.89	8.13	1.88	13.73
70–90	7.11	5.63	1.88	5.36
90–120	4.85	4.03	1.71	3.28
120–150	2.92	2.50	1.36	1.55
150+			0.91	0.85

[1] Average prices for 1991 submitted by the Greenland Home Rule.

$$nsp_l = \sum_k ((1 - c(G_k)) \cdot p_{lk} - c(H_k)) \cdot \alpha_{lk} \quad (14)$$

are used to calculate the revenue, see Table 7.

The applied objective function is derived by substituting equations (2), (12) and (13) into equation (1):

$$\text{Max } \pi = \sum_l \left(\sum_k ((1 - c(G_k)) \cdot p_{lk} - c(H_k)) \cdot \alpha_{lk} \right) \cdot (Y_l - D_l) - c(E) \cdot E \quad (15)$$

The first part of this equation shows the total net revenue and the second part is the effort costs.

Results

The estimated yield curves are shown in Figure 4 along with the revenue curve and two cost curves based on two different levels of opportunity costs. The Figure shows that in 1991 Greenland and foreign vessels applied an effort of 12,215 standard fishing days. The total catch in 1991 is estimated by the model at 70,270 tonnes of which 13,823 tonnes were discarded and 56,447 tonnes produced on board or landed to the factories on shore.

Figure 4 also indicates that the resource rent in 1991 is between US$ 33.8 and

Table 8
α_{lk}, the Proportion of Reported Catch of Count l Used for Producing Product k

Count	Raw-frozen	Sea-cooked	Cooked and peeled
50–70	0.857	0.045	0.097
70–90	0.720	0.182	0.097
90–120	0.406	0.496	0.097
120–150	0.114	0.295	0.591
150+	0.000	0.000	1.000

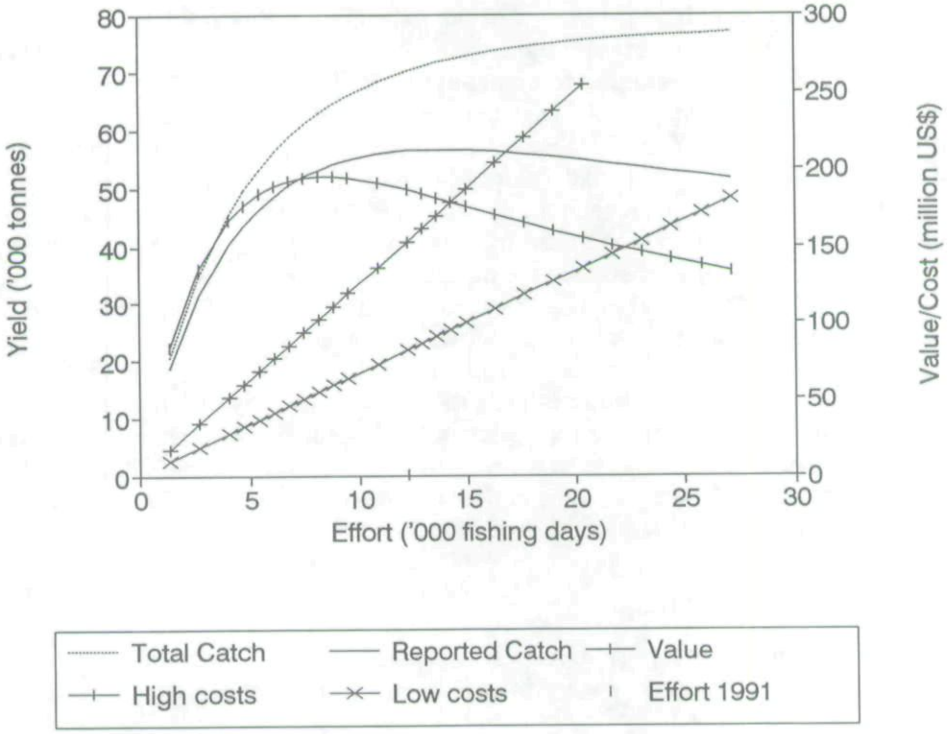

Figure 4. Estimated yield and costs curves applying 0.3 as the level of natural mortality rate.

104.8 million, depending on the choice of costs, whereas the maximum economic yield, MEY, is estimated to be between US$ 117.3 and 148.2 million.

The difference between the total catch curve, also shown in Figure 4, and the curve showing the reported catch, represents the discard. By multiplying the discard volume at count groups (Table 3) by the corresponding sales prices (Table 7) the total value of the size discard in 1991 is estimated at US$ 12.219 million.

As the natural mortality rate is associated with some uncertainty, Table 9 shows the estimates of MSY, MSR, and MEY derived from the bioeconomic

Table 9

Maximum Sustainable Yield (MSY) (Tonnes), Maximum Sustainable Revenue (MSR), and Maximum Economic Yield at High Costs (MEY1), and at Low Costs (MEY2) (Million US$), along with the Corresponding Effort (E) (Standard Fishing Days) at Different Values of the Natural Mortality Rate (M), Assuming No Change in the Discard Behaviour.

M	E_{MSY}	MSY	E_{MSR}	MSR	E_{MEY1}	MEY1	E_{MEY2}	MEY2
0.2	9,161	57,533	6,108	217.2	4,275	153.1	4,886	180.0
0.25	11,250	56,544	7,715	203.8	4,500	133.8	5,143	162.3
0.3	13,572	56,621	8,143	195.0	4,750	117.3	6,108	148.2
0.35	17,245	57,740	10,059	189.7	5,030	103.2	6,467	136.7
0.4	22,140	60,576	12,215	189.3	5,344	92.2	6,871	128.4

model, applying five different values of the natural mortality rates (M), and two different assumptions concerning the cost level. The Table illustrates, that if M is high, a greater effort is required to obtain MSY, MSR, and MEY than required at lower values of M. The Table also demonstrates that more fishing days are required to obtain MSY than MSR, and likewise, more fishing days are required to obtain MSR than MEY for all values of M.

Table 10 shows the effort reduction required in 1991 to obtain MEY along with the estimated value of the long term increase in resource rent by that reduction, assuming that there is no change in the discard behaviour. It is demonstrated that, compared to the effort level of 12,215 standard fishing days in 1991, a reduction is required to obtain MEY for all values of M. The magnitude of the optimal effort reduction depends on M. Low values of M require larger reductions than high values of M, but in any case the effort should be reduced by at least 37.5%.

The benefit of the effort reduction depends on the level of M and on the costs and prices. The biggest increase in the resource rent, 366% (=US$ 120.2 million), is obtained at low M whereas the smallest increase, 19% (=US$ 20.5 million) is expected by an effort reduction at high M.

Discussion and Conclusion

The calculations of the present paper are based on the assumptions that the shrimp stock and the catches were in equilibrium in 1991, the year of reference. This was probably not the case, however, as survey data indicate that the 1985 year class constituted the major part of the catches in 1991 and, apart from the year class of 1989, no younger year classes were present in significant numbers. Accordingly, the assumption of constant recruitment may not be fulfilled and the expected long term economic benefit from reducing the effort, may be significantly lower than suggested by the present paper. In case of a decline in the total

Table 10

Effort Reduction (%) Required to Reach Maximum Sustainable Economic Yield (MEY), the Estimated Corresponding Long-Term Increase in Economic Rent, in Yield at High and Low Levels of Costs, and at Different Values of the Natural Mortality Rate (M).

	Optimal reduction in effort and costs (%)		Long term increase in resource rent (%)		Long term change in revenue (%)		Long term reduction in reported catch (%)	
M	High costs	Low costs	High costs	Low costs	High costs	Low costs	High costs	Lows costs
0.2	65.0	60.0	366.0	73.1	+11.0	+15.0	14	9
0.25	63.2	57.9	307.0	55.7	+2.0	+6.1	19	14
0.3	61.1	50.0	247.8	41.4	−5.2	+1.4	23	14
0.35	58.8	47.1	201.4	27.7	−11.1	−3.8	26	17
0.4	56.3	37.5	152.1	19.2	−16.4	−5.3	28	14

stock size, however, an effort reduction may still be advantageous, in order to maintain a stock size sufficient to secure the future recruitment. Nevertheless, as no information about the stock/recruitment relationship is accessible from the scientific literature, it has not been the purpose of the present study, to deal with the problems of recruitment overfishing.

In the event of highly variable year class strength, the assumption of a constant mortality rate of all cohorts, may prove to be wrong. Most probably the large cohorts, or those following large cohorts, may be exposed to a greater natural mortality rate than average ones, owing to density dependent competition. Furthermore, in that event, the theoretical optimum effort level may differ from those suggested by the present paper, since a greater effort must be applied to a cohort exposed to an above average natural mortality rate, in order to optimize the fishery.

The effort applied in 1991 is similar to the effort level of the maximum sustainable yield (MSY), estimated at 13,572 standard fishing days, whereas a 33% reduction of effort is required to reach the maximum sustainable revenue (MSR). To obtain the maximum economic yield (MEY), which is estimated to be between US$ 117.3 and 148.2 million, the effort must be reduced even further i.e. by 50% or 60% depending on the choice of costs. In other words, depending on the choice of costs, the equilibrium resource rent may be 1.4 to 3.5 times higher than obtained in 1991. Consequently it may be argued, that recommendations aiming at a maximization of the catch volume, might lead to application of an effort level which, from an economic point of view, may cause substantial overfishing.

Furthermore, as demonstrated in Table 9, the effort to obtain MSY (E_{MSY}) is more sensitive to changes in the basic assumptions with regard to the level of the natural mortality rate, than is the case considering the effort required to obtain MEY (E_{MEY}). Advice about the optimum effort of the shrimp fishery of the Davis Strait in economic terms (MEY) is, therefore, less sensitive to uncertainties of the actual level of the natural mortality rate than advice in terms of maximizing the long term catch volume (MSY).

The expected long term increase in resource rent is based on the combined effect of reduced costs, changes in the total volume of the catches, and changes in the size distribution of the stock towards larger and more valuable individuals. Table 10 shows that the gain in resource rent is primarily ascribed to the reduction in costs, and changes in the revenue are positive only where low values of the natural mortality rates are concerned. The Table shows that assuming $M = 0.3$, and that costs are high, the volume of the equilibrium reported catch will decrease by about 20% in the long term, if the optimum effort is applied. At high costs the revenue will also decrease as the value of the catch reduction exceeds the gain from the induced changes in the stock composition. At low costs, the change in revenue is small, though positive.

In the present study, the resource rent is maximized assuming that the discard pattern of 1991 remains unchanged. Hence, the absolute amount of discard changes when effort and stock vary, whereas the relative amount of discard remains constant. The discard behaviour may sell be influenced by changes in year class strength, however, as the purpose of the size discard is to "high-grade" the catch.

Clark (1985) shows that the incentives to high-grading are increased further, if the fixed trip costs increase and/or the "turnaround" time increases.[9] By including binding boat quotas in the model, discard incentives are increased further. However, the earnings from one extra day of fishing to replace small (low valued) shrimps, with large (high valued) shrimps, depends on the price differences between the size categories of the shrimps and the size composition of the catch together with the effort costs. These factors also influence the discard behaviour. For the managers it implies that a tax on high valued shrimps or/and subsidy on low valued shrimps could also change the discard patterns.

Based on opportunity cost considerations, the resource rent in 1991 is estimated to be between US$ 33.8 and 104.8 million. The private costs for the Greenland section of the fleet in 1991 were higher than the applied opportunity costs as the Greenland Home Rule collected US$ 23.5 million as resource tax. Furthermore, there has been an excess payment from the production factors at about US$ 7.8 million, estimated from the vessel accounts assuming the high total cost level. This may partly, alongside recruitment failures, explain the current serious short term economic situation of many vessels. Since 1991 the resource tax has been reduced from 11% to 1% of the gross revenue and the crew's wages have also been reduced in order to improve the economic conditions.

Under ITQ's, the incentive for the fishermen is to use efficient and cost effective fishing practices to maximize the value of their quotas. This incentive also exists under ITNQ, although under ITQ the decisions are decentralized, while under ITNQ—at least in Greenland—the decisions to enter the fishery and the size of the individual quota's were decided upon by the Greenland Home Rule. However it is possible under INTQ to generate rents. If the cost structure of each vessel is known in detail a cost effective quota can be assigned to each vessel, thus INTQ corresponds to ITQ (Clark, 1985). If the fishery is overexploited from an economic point of view, as is the case here, then rationalizing the fleet can be a difficult task under INTQ, since the decision to exclude vessels from the fishery has to be taken by the authorities who, in turn, are subject to political pressure.

Although ITQs were introduced into that situation in 1991, the Greenland Home Rule continued with an unchanged total quota. In 1992 the total quota was slightly decreased. The short run effect (Grafton, 1992) of introducing ITQs[10] can be defined as adjustment of quotas from less efficient fishermen to fishermen who can use them more efficiently which will lead to a better utilization of a given fleet. In the long run the adjustment is connected to the number of participating fishermen/vessels or the size of the fleet by entry and exit of vessels.

As mentioned in section one, the fishermen are not allowed to sell parts of the perpetual quota, so the adjustment in the short run must be related to trade in the annual quotas. The transfer of annual quotas must not attain resemblance of rental of perpetual quotas. Therefore, the short run changes[11] and the potential gains in rent can only be viewed as temporary.[12] But the revenue curve and the reported

[9] The constraints in the model are the hold size and the length of the season.
[10] More precisely in the case of Greenland, transferability.
[11] The short run cost curve will shift downwards, assuming that the buying fishermen are more efficient than the selling fishermen.
[12] However, from May 1993 it is possible to sell parts of the perpetual quota, if the parts exceed 100 tonnes.

catch curve can change to the extent the discard change. In some cases, if the quota price is lower than the marginal costs of discarding, it is advantageous to buy additional quotas in order to increase the landings and to reduce the discard. The revenue curve and the reported catch curve will shift upwards.

The major effects of transfers of perpetual quotas, where the number of vessels decrease, are a decrease in total effort and costs, and an increase in the average quota per vessel. Even in the case where homogeneous effort is assumed, trade in quotas could be expected because of incentives of the fishermen to invest in long term gains from the increase in the fish stocks.

Both in the short run and the long run efficiency gains can be expected because of the transferability of the individual catch quotas. Therefore, our estimate of the gain in resource rent from reducing fishing effort may be considered to be a minimum estimate.

Only four vessels left the fishery in 1991 and in each case the Greenland Home Rule participated, with either loans, subsidies, or both with the purpose to speed up the capacity reduction process. The purchase and sale prices observed in the quota market were non-clearing prices. In principle the Greenland Home Rule bought quotas at a price which made it possible for the selling vessel to leave the fishery, and maintained a selling price so that the buying vessels were able to stay. In 1992, a further six vessels left the fishery, and once again the Greenland Home Rule participated in the process.

Information of the resource rent can be obtained from the quota price (Arnason, 1990). In a perfectly competitive market, the price for a perpetual quota unit is equal to the net present value of the expected future flow of resource rent per quota unit. The expected annual resource rent can in this way be expressed as:

$$\pi^e = \tau \cdot r \tag{16}$$

where

π^e is the expected annual resource rent per quota unit.

τ is the price for a perpetual quota unit.

r is the discount rate.

The observed price for a perpetual quota unit (kilo) after subtracting the payment made by the Home Rule is about US$ 1.56 (Leth, 1993). The rate of discount used is 8.12%. The estimate of annual resource rent per quota unit is US$ 0.127, and if multiplied by the total quota in 1991 (57,332 tonnes) the estimate of the expected annual resource rent is US$ 7.3 million. This reflects the private sectors expectations to the future flow of resource rent. The estimate of the resource rent in 1991 was calculated at US$ 33.4 million assuming that costs are high. However, this figure also covers the resource tax collected by the Home Rule, and subtracting this tax leaves US$ 9.9 million to the private sector. There can be several reasons for the difference between the resource rent calculated based on the bioeconomic model and the resource rent based on the quota price. First, the method using the price of a perpetual quota estimates the expected rent, and not the actual rent. Secondly, the market is probably distorted by the subsidies made by the Home Rule. Thirdly, as the ITQ system is implemented in the same year as the calculations are made for, the market cannot be expected to be in equilibrium.[13]

However, given that the fishermen, in general, are uncertain about the effects of a new management system, along with stock uncertainty because of current declining catch per unit effort of large shrimps, the difference between expected annual resource rent and the calculated resource rent is not large.

The ITQ-system alone does not eliminate the discard of small shrimps (Copes, 1986). To reduce the discard the Greenland Home Rule has increased the number of fishing inspectors primo 1993, and the legal minimum net size has been increased from 40 mm to 55 mm. With an additional reduction of the fleet, permitting increased quotas per boat, these measures are expected to reduce the discard. These changes would lead to alternative catch curves and a different revenue curve in the present model.

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[13] See also Lindner, Campbell and Bevin (1992) for further discussions about the usefulness of the quota prices as a proxy for resource rent.

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