A Critical Review of the Fisheries Policy: Total Allowable Catches and Rations for Cod in the North Sea[1]

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Abstract

A purpose of this paper is to give a critical review of the total allowable catch (TAC) policy within the European Union (the EU) for cod in the North Sea. The actual TACs are compared with the biological recommendations about the TAC and the bio-economic optimal TAC. It is shown that the actual TAC follows biological recommendations but that bio-economic principles are poorly reflected in the TAC. The Danish regulatory policy for cod in the North Sea (rations) is analysed by means of a bio-economic model. It is shown that the information requirements needed for conducting a bio-economic optimal allocation of rations are considerable. Furthermore, the actual allocation scheme for rations distribute too high a share of the EU determined Danish quota to small vessels. Taxes and individual transferable quotas (ITQs) combined with bio-economic optimal TACs is presented as an alternative to the existing policy.

Keywords: Cod in the North Sea, Total Allowable Catches, Rations, Taxes and Individual Transferable Quotas

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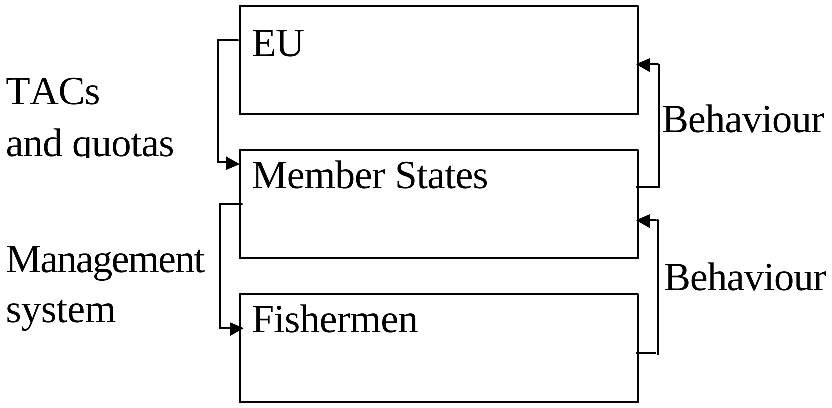
1. Introduction

Within the European Union (the EU) an aspect of the Common Fisheries Policy (CFP) is that a level of total allowable catches (TACs) are defined for main species and are allocated to Member States as quotas. It is then up to the Member States to decide which fishermen that are going to harvest the quota. This is done by the choice of a management system. This management structure is shown in Figure 1.

Figure 1: Management system overview



The purpose of this paper is to give a critical review of this policy structure for cod in the North Sea. Bio-economic optimal TACs will be compared with actual TACs and biological recommendations about the TAC, and it will be argued that the actual TACs ought to reflect bio-economic criteria's to a higher degree. For this reason an bio-economic critique is given of the Member State level in Figure 1 with help from a theoretical model. Demark is used in the critique and Denmark uses rations as the management system for cod in the North Sea.

Note that the overall TAC in the North Sea is decided in bilateral negotiations with Norway. Therefore, the management system outlined in Figure 1 is a simplified representation of the actual management system. However, the EU Member States catch the main part of cod in the North Sea and for this reason the effect that Norway has on the EU TAC is excluded (the EU TAC is taken to be EU determined).

The EU TAC and quota policy is part of the conservation policy. However, there are four additional elements of the CFP. The first element is the control policy, and the purpose of this policy is to secure enforcement of, and compliance with, the TAC. An important principle in the control policy is that the responsibility for control is placed at the Member State level. The EU role is to secure that the enforcement activity does not considerably differ between countries. This is done through the use of EU inspectors. An evaluation of the control policy is to be found in Jensen (2000). The second element of the CFP is the market policy. This policy establishes marketing standards, stabilizes market prices, supports producer's income, and consider consumers interests. An important aspect of the market policy is to guide prices based on the average prices at first-hand sale. Holden (1996) contains an evaluation of the market policy. A third element of the CFP is an external policy. This policy gives the Commission competence to negotiate with non-EU countries in order to secure access to non-EU waters. An evaluation of the external policy is also to be found in Holden (1996). The last aspect of the CFP is the structural policy. The main purpose of this policy is to facilitate structural changes in the fishery sector by granting financial aid. An important aspect of the structural policy is the multi-annual guidance program, according to which objectives for fleet development are decided. Frost *et al* (1995) contains an evaluation of the structural policy. Even though it would be relevant to evaluate the overall CFP, attention is restricted to TAC and quotas in this paper.

A brief description of the history of the EU TAC and quota policy is also useful. The first TAC and quotas were set 25 January 1983. The TACs are allocated to Member States as quotas and the concept of relative stability plays an important role when the TAC is distributed. According to the principle of relative stability the Member States receive a fixed share of the TAC each year. The allocation scheme of the TACs is based on three factors. Firstly, the historical catches in the period 1973-1978. Secondly, special provision is given for areas heavily dependent upon fishing (the Hague Preferences). Thirdly, compensation is given for losses caused by the extension of fishing limits to 200 miles by third countries. The allocation scheme for TACs has not changed since 1983. In 1992 a new regulation came into existence. The new regulation introduced two additional elements. Firstly, the Member States must introduce license systems. Secondly, the Council of Ministers may establish multi-annual or multi-species TACs. However, these instruments have not been implemented in practice.

In section 2, the actual TAC, the recommended TAC and the economic optimal TAC are compared, while section 3 contains an economic critique of ration fisheries. Section 4 discusses alternatives to the existing policy and section 5 concludes the paper.

2. A comparison of various TACs

The purpose of this section is to compare actual TACs with bio-economic optimal TACs and biological recommendations about the TACs (section 2.3.). However, before this is done a brief description of the policy is useful (section 2.1.) and it is necessary to introduce the various TACs (section 2.2.).

2.1 Brief description of the EU TAC and quota policy

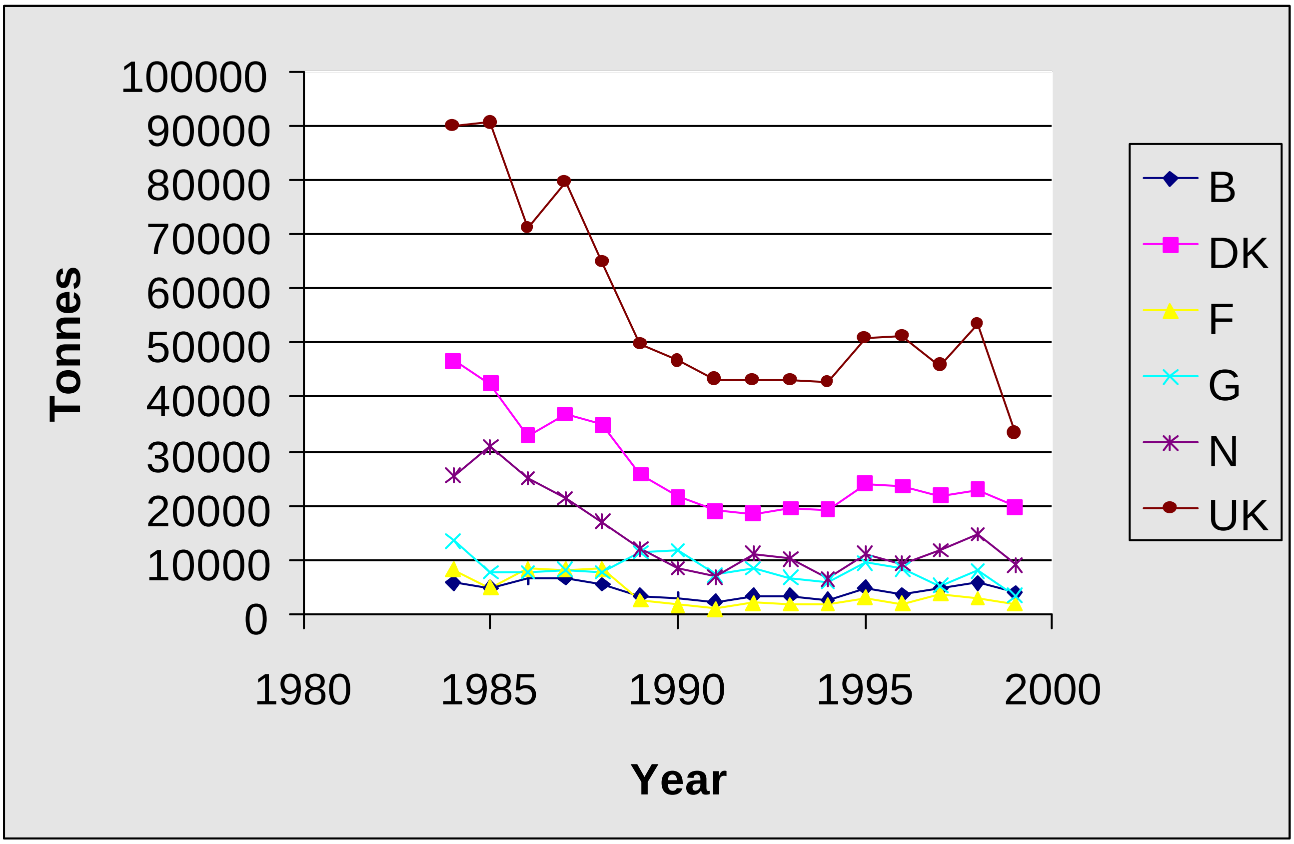
The EU TAC and quota policy is part of EU´s conservation policy. The conservation policy consists of rules for protected areas (Regulation no. 3782/92), regulation of fishing effort (Regulation no. 685/95) and technical protection limits (Regulation no. 850/98) in addition to the TAC and quota policy. The conservation policy is the most important part of the CFP. In the conservation policy fundamental rules for the allocation of resources between Member States are decided (Regulation no. 33760/92). The Member States have placed their competence to regulate to the Council of Ministers. In article 4 in Regulation no. 33760/92 it is stated that the Council of Ministers shall conduct EU initiatives that determine the conditions for accessing the resources. Article 100 in Regulation no. 33760/92 state that the Member States have competence to conduct initiatives with regard to conservation within their own regions if the initiative is stricter than the EU initiatives. The national initiatives only apply to the fishermen in the Member States. A national conservation policy must therefore be in line with the EU conservation policy.

The purpose of the EU conservation policy is to secure a rational use of the resources and to consider the interests of the fishing industry. The latter implies that the conservation policy must take into account, for example, economic conditions in fishery dependent regions. Before 31 January 2002 the Council of Ministers must agree on a new conservation policy.

The main instrument in the conservation policy is quota setting. The TACs are fixed on a yearly basis, and the quotas are allocated to the Member States according to the principle of relative stability, which secure the Member States a constant share of the TAC. As mentioned in the introduction, the allocation scheme was decided in 1983, and has not been changed since.

But which Member States participate in the fisheries in the North Sea? In order to highlight this some data from Anon (1999) on catches is presented.

Figure 2: The Member States catches of cod in the North Sea, 1984-1999



Source: Anon (1999)

Figure 2 shows that most part of the cod in the North Sea are caught by vessels registered in the United Kingdom. Indeed, the United Kingdom vessels catch the same amount as the rest of the EU Member States. Danish fishermen make the next largest catch of cod in the North Sea.

2.2 Various TACs

In this section the principles for the biological recommendations about the TAC are rewieved (section 2.2.1). Furthermore, a model for fixing the economic optimal TAC is outlined (section 2.2.2) and the objectives behind fixing the actual TAC are discussed (section 2.2.3).

2.2.1 The recommended TAC

For cod in the North Sea, ICES Advisory Committee on Fisheries Management (ACFM) recommends a TAC each year based on commercial catch data and vessel surveys. The TAC calculated by ACFM is a biological recommendation based on a precautionary approach, and reference points stated in terms of fishing mortality rates and spawning stock biomass are key concepts. Two kinds of reference points are calculated:

- Safe biological limits
- Precautionary reference points

The concept of safe biological limits was first introduced in ACFM advice in 1981 and was further developed in 1986. If a fish stock shall be within safe biological limits two conditions must be fulfilled. Firstly, there must be a high probability that the spawning stock biomass is above the threshold where recruitment is impaired. Secondly, there must be a high probability that the fishing mortality rate is below the mortality rate that will drive the spawning stock biomass to the biomass threshold that must be avoided. The biological threshold can be called B_{LIM} and the fishing mortality F_{LIM}. Formally, F_{LIM} is the fishing mortality that must be avoided with a high probability because of unknown population dynamics, while B_{LIM} is the spawning stock biomass below which the dynamics of the stock is unknown. In order to have a high probability of avoiding B_{LIM} and F_{LIM}, management actions must be taken before the reference points are reached. The precision with which the reference points are known and the risk, which is tolerable are important factors in determining the distance away from the reference points. Therefore, precautionary reference points B_{PA} and F_{PA}, are introduced. Formally, B_{PA} is the spawning stock biomass below which management action should be taken according to the precautionary approach, and F_{PA} is the precautionary reference point for fishing mortality. The precautionary reference points secure a high probability for avoiding F_{LIM} and B_{LIM}. In the yearly recommendations about the TAC, F_{PA} and B_{PA} act like constraints. Exceeding F_{PA} indicates that over fishing takes place and the TAC is not consistent with the precautionary approach. If ACFM´s biological models show that the spawning stock is below B_{PA} a rebuilding plan is also suggested.

2.2.2 Bio-economic optimal TACs

In order to compare the actual TACs with the bio-economic optimal TACs, a model from Arnason *et al* (2000) is used. A feedback rule, which is defined as an expression for what the optimal quota in the next period must be as a function of present variables, is used. The wish to find more realistical quotas has led many authors to recommend the use of feedback rules, see for example Clark and Munro (1978) and Conrad and Clark (1987).

The theoretical model that is used is from Sandal and Steinshamn (1997a), (1997b), (1997c) and (1997d). What is new in this model is that in many cases, where it was considered impossible to calculate an optimal quota, it is possible in this model. In the model the optimal quota depends on the society’s time horizon. However, Arnason *et al* (2000) assume an indefinite time horizon. Moreover, a case without discounting is analysed, since discounting only means small corrections in the optimal path, see for example Mendelsohn (1982) and Sandal and Steinshamn (1997a) and (1997c).

Firstly, the theoretical model is introduced. The maximisation problem is:

$$\mathrm{Max}\left(\int_0^\infty \pi(y,x,t)\right)dt \tag{1}$$

s.t.

$$\frac{dx}{dt} = G(x) - y \tag{2}$$

Where

y is catch
x is the fish stock
t is time
G(x) is the natural growth
$\pi(.)$ is profit or resource rent

A general formulation of the profit is:

$$\pi(y, x) = p(y)y - c(y, x) \tag{3}$$

Where:

p(y) is the inverse demand function
c(x, y) is the cost function

It is assumed that the profit function is quadratic in y. However, the profit function can be any arbitrary function of x. These assumptions means that the demand function must be approximated by a linear demand curve or that prices are constant. Moreover, the assumption means that the cost function is maximally quadratic in y. Compared to the traditional models this is a less restrictive assumption, since non-constant prices and increasing marginal costs are allowed. A model with constant prices and marginal costs will recommend bang-bang control as an adjustment process towards equilibrium. The practical importance of this for fishery policy is limited. The model used here recommends a little fishing even if the actual stock is very much lower than the optimal stock. The magnitude of this depends on the society's preferences with respect to time. If society has an indefinite time horizon, as assumed here, the fishermen will receive the largest possible profit, but an asymptotical adjustment towards equilibrium is received.

Since both p (y) and c(y,x) are quadratic in y, (3) can be written as:

$$\pi(y, x) = g(x)y - K(x)y^2 \tag{4}$$

Where

g(x) are linear terms
K(x) are quadratic terms

The optimal equilibrium is characterised by steady-state equilibrium and maximisation of the profit function. This equilibrium is called (x*, y*), where y* = G(x*).

Now the sustainable yield is defined as:

$$S(x) = \pi(G(x), x) \qquad (5)$$

S(x) is the profit coupled to every possible stock, given biological equilibrium, and x* is the stock size that maximises S(x).

To find the optimal TAC, y(x), it is necessary to consider how x* is reached. It can be shown that the optimal adjustment path, if the society has an indefinite time horizon, is given by[2]:

$$y(x) = G(x) + / - ((S(x^*) - S(x)) / K(x))^{0,5} \qquad (6)$$

Arnason *et al* (2000) use this model to calculate bio-economic optimal TACs for cod in the North Sea. In order to calculate the bio-economic optimal TACs it is necessary to have parameter estimates for the growth and profit functions. Various variants of the logistic growth function are estimated, and the function that gives the best fit is:

$$G(x) = rx(1 - \frac{1}{C}x^2) \qquad (7)$$

With:

r = 0.53
C = 1218680

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[2] For a proof of (6) see Sandal and Steinshamn (1997d).

Where:

r is the intrinsic growth rate
C is the carrying capacity

Since the model also allows for non-constant prices, a linear demand function is also estimated. However, the slope of this demand function is insignificant, and so the analysis continues with a constant price of 10.4. Lastly, the following cost function is calibrated:

$$c(y,x) = a + \frac{by^2}{x} \tag{8}$$

With:

a = 481315. 05
b = 15.442

With these parameter estimates it is possible to calculate the optimal catch.

2.2.3 Actual TACs

In article 4 of Regulation no. 3760/92 it is stated that:

> *"Measures shall be drawn up in the light of available biological, socio-economic and technical analyses"*

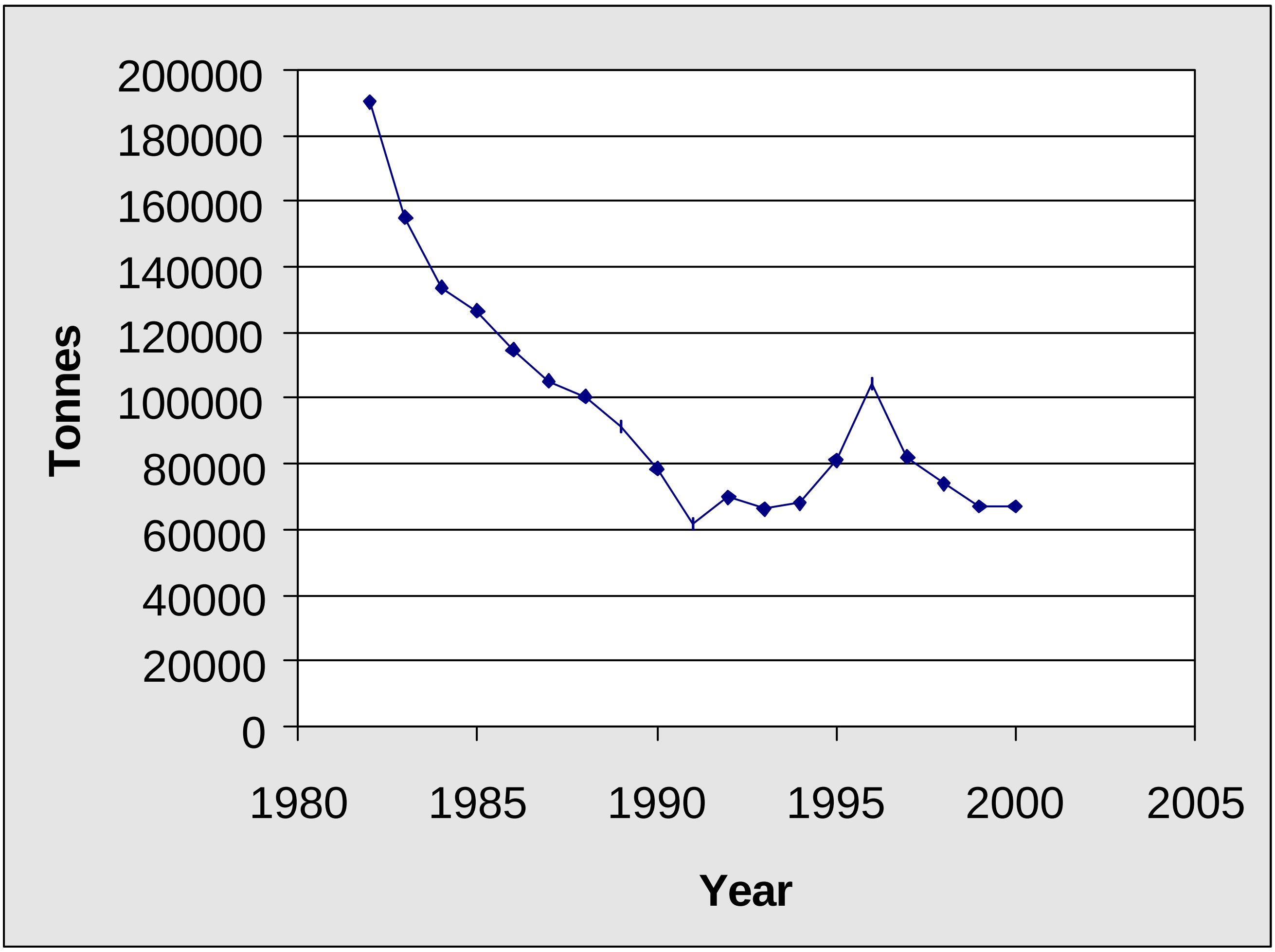
This implies that scientific advice shall be incorporated, when decisions about the TAC are made. However, a problem with presenting scientific advice is the lack of specific management objectives. As seen above, both biological, socio-economic and other technical (including bio-economic) considerations must be incorporated when the TAC is selected. However, both biologists and economists will agree that a well-defined management objective is necessary when advice is presented. Another problem is the way scientific advice is presented. Both politicians and administrators demand concise summaries on which to base their actions and indeed the advice presented by ACFM is easy to read. However, a problem with only reading concise summaries is that the administrators do not fully understand the assumptions on which the advice is based.

The fishing industry often complains that it is subject to arbitrary decisions, which are based only upon scientific advice. However, according to Regulation no. 33760/92 each Member State can also use other arguments for fixing the TAC. Indeed, it was shown above that the objective is so vague that any argument can be used. Therefore, the fishing industry is in the position to argue for their wishes with respect to the TAC. It is therefore useful to make a comparison of the recommended TAC, the bio-economic optimal TAC, and the actual TAC to see what factors influence the actual TAC.

2.3 A comparison for cod in the North Sea

Before the comparison is presented it is useful to present ACFM estimates for the spawning stock.[3] This is done in Figure 3.

Figure 3: The spawning stock for cod in the North Sea



Source: Anon (1999)

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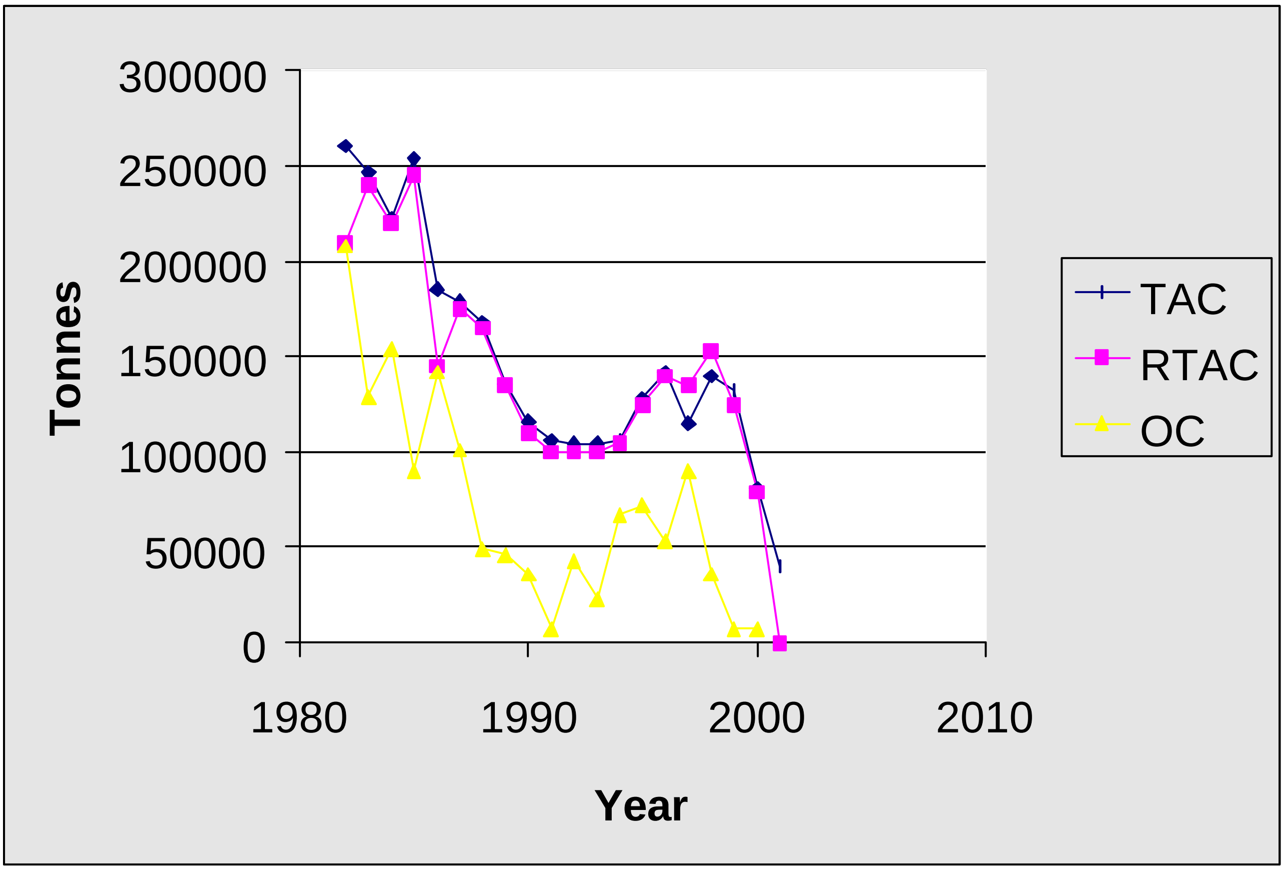
[3] This and the following data series are placed in appendix 1.

Figure 3 reveals that the spawning stock decreased in the period 1982-1994. In the period 1995-1996 the stock started to recover, but in the period 1996 and onwards the spawning stock decreased again. In Anon (1999) it is estimated that B_{LIM} = 70,000 tonnes, while B_{PA} = 150,000 tonnes. Therefore, the stock is at present below the safe biological limit and has been below the precautionary reference point that secures a high probability for B_{LIM} since 1983. Furthermore, Anon (1999) estimates that the number of recruiters in year 2000 will be small. For this reason ACFM recommends that catches for cod in the North Sea for year 2001 shall be at the lowest possible level and that a rebuilding plan is necessary in order to secure B_{PA}. The rebuilding plan should include provisions to deter directed fishing, reduce by-catches of cod, and deter discarding and illegal landings.

Now the recommended TACs, the bio-economic optimal TACs, and the actual TACs can be compared. This is done in Figure 4.

Figure 4: The recommended TAC (RTAC), the bio-economic optimal TAC (OC) and the actual TAC (TAC)



Source: Anon (1999) and own calculations.

Figure 4 reveals that the actual TAC follows the recommended TAC reasonably closely. This indicates that biological principles such as safe biological limits and precautionary reference points play a major role when the TACs are determined. The first divergence occurs when the TACs was first legally established in 1982. The second divergence occurs in 1986, while the third divergence occurs in 2001. All these divergences arise because the fishing industry interests influence the political decisions on the TAC, and fishermen perceive higher catches to be in their interest. Above it was mentioned that the objective of the TAC policy could be interpreted in a way that bio-economic principles should be reflected in the TAC. As shown in Figure 4 this appears not to be the case. The bio-economic optimal TAC is much lower than the actual TAC. However, it could be argued that if the two curves follow each other, optimal TACs would be reflected in actual TACs. Such a conclusion is, however, not right. By the way optimal TACs is calculated, it is partly determined by actual stock size. But the actual TAC also reflects actual stock size. Therefore, the fact that there is a large discrepancy between bio-economic optimal TACs and actual TACs indicates that bio-economic principles are not reflected in the actual TAC.

This conclusion may also be seen from the correlation coefficients, r, presented in Table 1. Apart from actual TACs, recommended TACs, and bio-economic optimal TACs, correlation coefficients have also been calculated for actual catches (CA) and the spawning stock (SS). Furthermore, t-statistics are calculated and the statistics are presented in parenthesis. It can be discussed whether the correlation coefficients should be calculated in total values or differences in values. Here it is chosen to do the calculations in total values, because it must be assumed that the fishermen react to totals. The disadvantage of calculating in totals is that the correlation coefficients are higher, because of a trend in the data set. Therefore, the interpretation must focus on small differences in the coefficients.

Table 1: Correlation coefficients

	TAC	**CA**	**SS**	**RTAC**	**OC**
TAC	--------------	0.85 (6.47)	0.93 (10.23)	0.96 (13.61)	0.79 (5.22)
CA	0.85 (6.47)	--------------	0.86 (6.81)	0.75 (4.58)	0.86 (6.63)
SS	0.93 (10.23)	0.86 (6.81)	--------------	0.85 (6.50)	0.88 (7.72)
RTAC	0.96 (13.61)	0.75 (4.58)	0.85 (6.50)	--------------	0.70 (3.94)
OC	0.79 (5.22)	0.86 (6.63)	0.88 (7.72)	0.70 (3.94)	

All the correlation coefficients are high and significant. The correlation coefficients for actual catches against the other variables indicate what variables the fishermen respond to. Naturally, r is highest for actual TACs. Therefore, actual TACs govern the fishermen's behaviour. However, the correlation coefficients for bio-economic optimal TAC are higher than the coefficients for recommended TAC. This can be seen as reflecting the fact that profits are included in the calculations of the bio-economic optimal TACs and that profit partly governs the behaviour of the fishermen.

But what principles govern the actual TAC? It is seen that the actual TAC is highly correlated with the recommended TAC and the spawning stock. Since the spawning stock partly governs biological recommendations, this reflects the fact that biological recommendations play a major role when the actual TAC is fixed. By contrast, bio-economic principles are not reflected in the TAC. This may be criticised. Fishing cod in the North Sea is also an economic activity and actual fisheries management should also reflect the profits that can be achieved. Therefore, a bio-economic critique of the Danish fisheries management policy for cod in the North Sea is now given.

3. A bio-economic critique of the Danish ration policy

The purpose of this section is to give a bio-economic critique of the Danish ration policy for cod in the North Sea by means of a theoretical analysis (section 3.3.). Before this is done a theoretical model must be outlined (section

3.2.) and the Danish ration fishery for cod in the North Sea must be introduced (section 3.1.).

3.1 Brief description of the Danish fishery regulation for cod in the North Sea

As mentioned in the introduction it is the responsibility of the Member States to decide on how the quota is allocated to fishermen. The 1999 regulation is based on Regulation no. 802 of 11 November 1998, and this regulation is the basis for the description of the Danish regulation. Cod in the North Sea is managed as a ration fishery. First the quotas are distributed on time periods, and then a given amount of catch is determined as a function of vessel size measured in length, taking into account seasonal variations in the stock (see Tables 2 and 3).

Table 2: Allocation of cod quota on time periods, 1999

Time period	North Sea % of total annual
1 Jan-30 Apr	33
1 May-31 Aug	33
1 Sep-31 Dec	33

Table 3: Allocation of cod rations on vessel size, May-June ration period, 1999

Vessel size in Loa, metres	North Sea Tonnes
0-9	8.5
9-12	15.5
12-16	26
20-24	31.5
24-	35

A ration period is two months. The ration can be exceeded by 20%. The quantity by which the ration is exceeded is subtracted from the vessel ration in the next period.

If the normal fisheries economic terms are used, the ration fishery could be thought of as a variant of an individual non-transferable quota system. However, the ration fishery does not imply a property right to the fishermen, since part of the ration can be lost.

In order to describe the Danish fishery for cod in the North Sea, some data from Anon (1997) are presented.

Table 4: Distribution of Danish fishing activity in the North Sea, 1997, % of days at sea

Cod	Cod, plaice and sole	Flatfish	Norwegian lobster, cod and flatfish	Herring, mackerel and flatfish	Industrial fishery
6	19	17	9	5	44

Source: Calculations based on Anon (1997)

Table 4 reveals that 6% of the Danish fishing day activity in the North Sea is allocated to fishing cod alone. However, in total 34 % of the Danish fishing day activity is in some way related to cod.

With respect to the Danish fishery in general, Table 5 reveals which vessels mostly catch cod.

Table 5: Danish catch of cod per vessel, 1997, Tonnes per Vessel

Trawlers under 50 GT	Trawlers between 50 and 199 GT	Trawlers over 200 GT	Danish Seiners	Netters under 20 GT	Netters over 20 GT
67.5	82.7	14.8	50.9	34.9	105.9

Source: Anon (1997)

From Table 5 it is seen that Netters under 20 GT and Trawlers between 50 and 199 GT catch most cod per vessel. An average number of cod per vessel is caught by Trawlers under 50 GT and Danish Seiners. Trawlers over 200 GT do not catch much cod per vessel.

Table 6 reveals the current operating profit in relation to the costs by fishing cod in Denmark.

Table 6: Current operating profit in relation to the costs by fishing cod in Denmark, 1997,%

Cod	Cod, plaice and sole	Flatfish	Norwegian lobster, cod and flatfish	Herring, mackerel and industrial fishery	Industrial fishery
27.7	27.6	39.2	23.2	33.2	24.2

Source: Anon (1997)

It is seen that fishing the flatfish is the most profitable part of the Danish fishery. Of the cod fisheries, the mixed fisheries and fishing cod alone yields approximately the same profit.

3.2 A management model

The purpose of this section is to introduce a management model that can be used to evaluate the Danish ration policy. The simplest model that will yield consistent predictions is selected from Clark (1990). However, note that the results of the analysis generalise to more advanced models, see for example Clark (1980). A model with one species is adopted.[4] Furthermore, it is assumed that one variable can represent the development in the biomass,[5] and uncertainty is disregarded.[6] Also, fixed costs are assumed away[7] and the price is assumed to be exogenously given.[8] Lastly, the growth function is assumed to be well behaved[9] and the work is done within continuous time.[10]

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[4] See for example Garrod (1973), Mercer (1982), Pauly and Murphy (1982) and May (1984) for a discussion of economic multi-species models. Early biological multi-species models include Andersen and Ursin (1975) and Andersen *et al* (1973).

[5] See for example Beverton and Holt (1957), Turvey (1964), Clark *et al* (1973), Hanneson (1975), Waugh and Calvo (1974), Beddington and Taylor (1973), Botsfod (1981) and Getz (1988) for a discussion of vintage models.

[6] Andersen and Sutinen (1984) give an overview of stochastic bio-economics.

[7] A bioeconomic model with investments is to be found in Clark *et al* (1979).

[8] See Anderson (1973) and Copes (1972) for a discussion of traditional demand curves in fishery economics.

[9] See for example Hirch and Small (1974) for a discussion of Allee-effects.

[10] Discrete time models are to be found in Mann (1970), Ploude (1971), Spence and Starrett (1975) and Levhari *et al* (1981).

In section 3.2.1 fishermen behaviour is discussed, while the bionomic[11] equilibrium is outlined in section 3.2.2. A discussion of bio-economic optimal exploitation is presented in section 3.2.3.

3.2.1 Fishermen behaviour

Assume that n vessels exist and call E_i effort for vessel i. The following short-run production function is introduced:

$$y_i = q(x)E_i \tag{9}$$

Where:

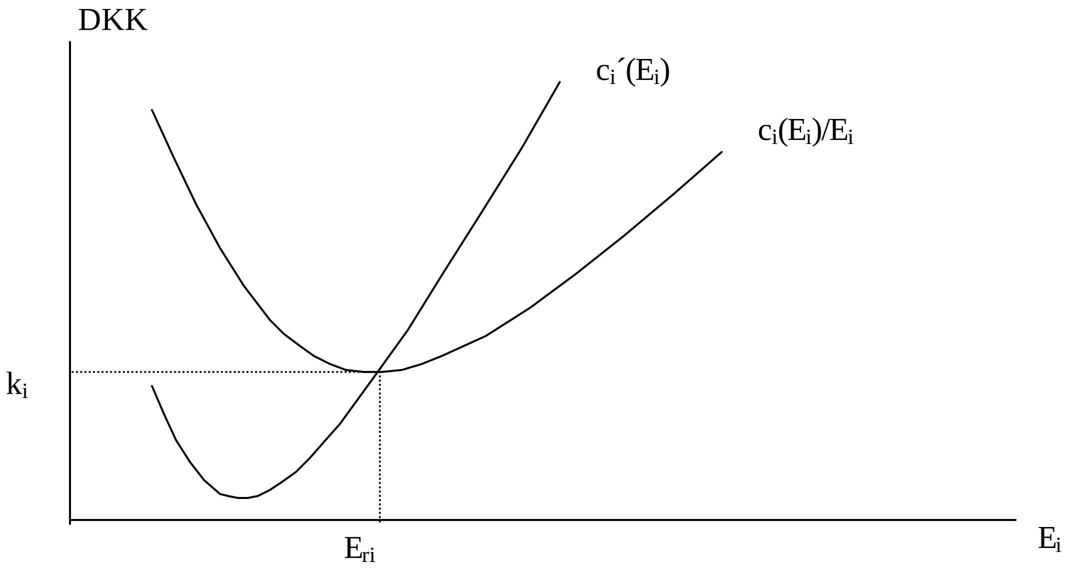
x is the stock size

y_i is the catch of vessel i

q(x)/x is the catchability and q(x)/x = a constant corresponding to a Schaefer-model. Here it is assumed that $q'(x) > 0$ (the catchability increases with the stock size)

The cost function for effort for vessel i is $c_i(E_i)$. The assumptions regarding the cost function are introduced in Figure 5.

Figure 5: The marginal and average cost functions for fisherman i



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[11] The bionomic equilibrium is characterized by biological equilibrium and an effort level, where total revenue equals total cost for the marginal vessel because of open access without regulation.

At the point E_{ri} average costs equal marginal costs, and k_i is the value of the cost function at this point.

Now the individual profit functions can be introduced. The profit function for fishermen i is:

$$\pi_i(x, E_i) = pq(x)E_i - c_i(E_i) \tag{10}$$

where p is a constant price. The individual fisherman selects E_i in order to maximise the profit. This corresponds to perfect competition (every individual fisherman ignores the effect on the fish stock).

The first-order condition says that:

$$\begin{cases} \frac{\delta c_i}{\delta E_i} = pq(x) \text{ for } pq(x) \geq k_i \\ E_i = 0 \text{ for } pq(x) < k_i \end{cases} \tag{11}$$

(11) indicates that the marginal revenue is set equal to marginal costs. Note that the effort will be larger than or equal to E_{ri} if the individual fisherman selects a positive effort.

From the first-order condition, effort as a function of stock size can be obtained:

$$E_i = E_i(x) \tag{12}$$

With the assumptions that $q'(x) > 0$ and $E_i > E_{ri}$, it will be the case that $E_i'(x) > 0$. In other words, effort is increasing with stock size.

The fishermen leaves the industry if $pq(x) < k_i$. This can be used to obtain a reservation stock because $E_i = 0$, if:

$$x < x_i = q^{-1}\left(\frac{k_i}{p}\right) \tag{13}$$

where x_i is an individual reservation stock. Now it is useful to list fishermen with increasing k_i:

$$k_1 \leq k_2 \leq ....\leq k_n \quad (14)$$

Fishermen with a low k_i can be considered as being more efficient, and they can fish profitably at a lower x. This leads to the conclusion that fishermen also can be listed after their reservation stocks:

$$x_1 \leq x_2 \leq ....\leq x_n \quad (15)$$

Now a characterisation of the bionomic equilibrium is required.

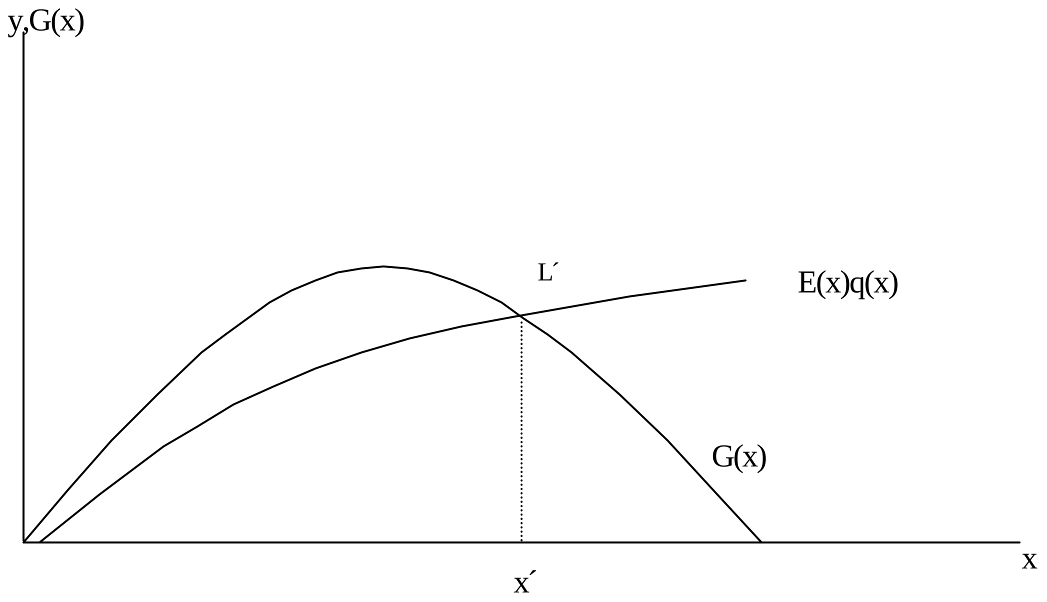
3.2.2 Bionomic equilibrium

The total effort is given as $E = \sum E_i$,[12] and the total catch, y, is:

$$y = q(x)E \quad (16)$$

The bionomic equilibrium is illustrated in Figure 6.

Figure 6: The bionomic equilibrium



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[12] The conditions for such an aggregation to be possible is in fact quite restrictive; see Squires (1987).

In Figure 6, G(x) is the natural growth rate. Since the interest is in finding a bionomic equilibrium a curve that reflects optimal catches must be drawn and this curve is E(x)q(x). In L´ the marginal fishermen, j, have a reservation stock of x´. Because total revenue equals total costs for the marginal vessel, L´ in Figure 6 can be expressed as:

$$\pi(x',E_j) = pq(x')E_j - c_j(E_j) = 0 \tag{17}$$

or:

$$pq(x') = \frac{c_j(E_j)}{E_j} \tag{18}$$

Therefore, the marginal revenue equals average costs for the marginal vessel in the bionomic equilibrium, and the marginal vessel operates at a zero-profit point, where $E_j = E_{rj}$. The infra-marginal vessel operates with profit and equals marginal revenue and marginal costs. In a simple fishery economic model it is assumed that vessels are homogeneous, and the resource rent is dissipated because of open access without regulation. Here the resource rent is not dissipated for infra-marginal vessels because vessels are heterogeneous.

To conclude, the bionomic equilibrium is characterised by:

$$G(x') = q(x')E(x') \tag{19}$$

$$\frac{\delta c_i(E_i)}{\delta E_i} = pq(x') \text{ for } 1 \le i \le j \tag{20}$$

$$\frac{c_j(E_j)}{E_j} = pq(x') = k_j \tag{21}$$

3.2.3 Bio-economic optimal exploitation

Here a central authority (society), that can control the effort of all vessels, is imagined. Society maximises the present value of future resource rents in indefinite time. If t is the time, the maximisation problem is:

$$\text{Max}\int_{o}^{\infty} e^{-rt}\left(\sum_{i=1}^{n}\pi_i(x,E_i)\right)dt \tag{22}$$

s.t

$$\frac{dx}{dt} = G(x) - q(x)\left(\sum_{i=1}^{n}E_i\right) \tag{23}$$

where r is the discount rate.

Optimal control theory is used to solve this problem and expressing the Hamiltonian, $\underline{H}$, in terms of current shadow price, μ, yields:

$$\underline{H} = \sum_{i=1}^{n}\pi_i(x,E_i) + \mu\left(G(x) - q(x)\left(\sum_{i=1}^{n}E_i\right)\right) \tag{24}$$

The maximum principle implies that:

$$\frac{\delta c_i(E_i)}{\delta E_i} = (p-\mu)q(x) \tag{25}$$

$\mu q(x)$ is the user cost of the fish stock, and in optimum the value of the marginal revenue equals the marginal social cost including the user cost.

From the adjoint equation it is obtained that:

$$\frac{d\mu}{dt} = (r - G'(x))\mu - (p-\mu)q'(x)\left(\sum_{i=1}^{n}E_i\right) = 0 \tag{26}$$

The equilibrium solution is characterised by the following conditions:

$$G(x) = q(x)\left(\sum_{i=1}^{n}E_i\right) \tag{27}$$

$$(r - G'(x))\mu = (p - \mu)q'(x)(\sum_{i=1}^{n} E_i) \tag{28}$$

$$\frac{\delta c_i(E_i)}{\delta E_i} = (p - \mu)q(x) \tag{29}$$

$$\frac{c_j(E_j)}{E_j} = \frac{\delta c_j(E_j)}{\delta E_j} = k_j \tag{30}$$

(27) – (30) can be solved. This yields:

$$G'(x) + \frac{k_j q'(x)G(x)}{(q(x)^2(p - \frac{k_j}{q(x)}))} = r \tag{31}$$

(31) is a modified version of the normal golden rule for exploitation of renewable resources and can be given a capital theoretical interpretation.[13] $G'(x)$ is the marginal productivity of the fish stock, and $k_j q'(x)G(x)/q(x)^2(p - k_j/q(x))$ is the marginal stock effect. In optimum the sum of these two terms must equal the interest rent.

The optimum can be illustrated as in Figure 7.

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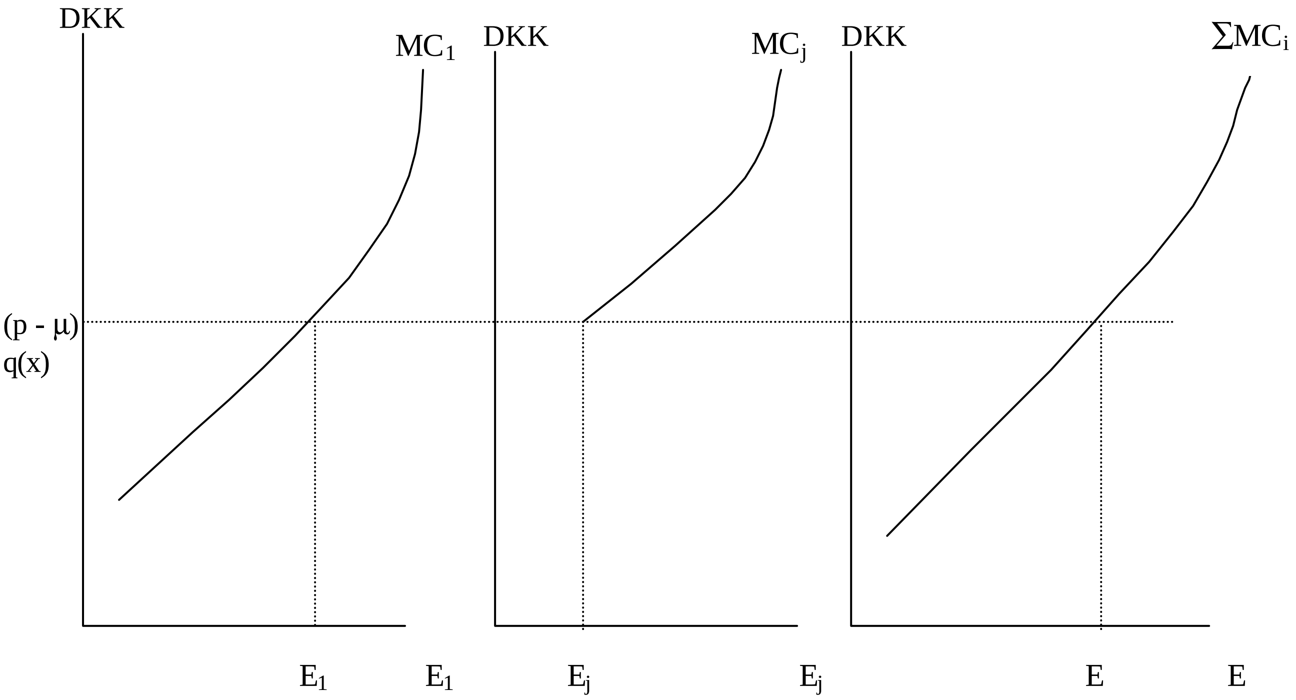
[13] See Clark (1990) for an extensive treatment of a fishery with a capital theoretical approach and an interpretation of (31).

Figure 7: The optimum



Following (29), the bio-economic optimal equilibrium is where all fishermen operate at the same marginal costs equal to (p - μ)q(x). Under open access without regulation all vessels operate at the same marginal costs equal to pq(x).

The bio-economic optimal equilibrium (x^*, E^*, j^*; E_i^*) may be compared with the bionomic equilibrium. It will be the case that:

$$x' < x^* \tag{32}$$

$$E > E^* \tag{33}$$

$$j > j^* \tag{34}$$

$$E_i > E_i^* \tag{35}$$

That individual effort is larger in the bionomic equilibrium can be explained by the fact that effort in this equilibrium does not incorporate the user cost of the fish stock. (34) is holding because entry in the bionomic equilibrium continues until the average cost is equal to the marginal revenue. Because there are more vessels and individual effort is larger in the bionomic equilibrium, total effort will also be larger and stock size smaller.

This model can be used to predict the effect of various management systems. In section 3.1. the Danish regulation of cod in the North Sea was described as a ration fishery. What effect will the model predict for such a management regime?

3.3 A bio-economic critique of ration management

Firstly, note that the possibility of exceeding the quota by 20% will increase the fishermen's possibility to make adjustments. Therefore, the effect of the 20% rule is to increase the efficiency in the fishing fleet. However, for the purpose of analysing the ration fishery, it is useful to disregard the possibility of exceeding the ration.

In order to predict the effects of a ration fishery, two ration periods, 1 and 2, are for simplicity considered. Let y_{1i} and y_{2i} denote catches for fisherman i in period 1 and 2, and denote E_{1i} and E_{2i} the effort for fisherman i in the two periods. Denote the ration in period 1 Q_1 and the ration in period 2 Q_{2i} and assume that $Q_{1i} < Q_{2i}$. Furthermore, assume that the catchability is identical in both periods.[14] Since $y_{ti} = q(x)E_{ti}$, the ration restriction corresponds to $q(x)E_{ti} \leq Q_{ti}$, where t denote time periods and t = 1,2. Furthermore, assume that the number of fishermen is large so that each fisherman ignores the effect of the resource restriction (perfect competition). With this notation fisherman i maximises:

$$\mathrm{Max}(pq(x)E_{1i} - c_{1i}(E_{1i}) + pq(x)E_{2i} - c_{2i}(E_{2i})) \tag{36}$$

s.t.

$$q(x)E_{1i} \leq Q_{1i} \tag{37}$$

$$q(x)E_{2i} \leq Q_{2i} \tag{38}$$

Because catchability is identical in the two periods and $Q_{2i} > Q_{1i}$, there are three possibilities. This can be analysed using Kuhn-Tucker conditions. Assume first that (37) and (38) are binding. In this case the first-order conditions are:

$$(p - \lambda_{ti})q(x) = \frac{\delta c_{ti}(E_{t1})}{\delta E_{ti}} \quad \text{for } t = 1,2 \tag{39}$$

where λ_{ti} is a Lagrange-multiplier for period t for fisherman i. Optimality requires that $\mu = \lambda_{1i} = \lambda_{2i} = \lambda_{1j} = \lambda_{2j}$ for all $j \neq i$. In other words, the shadow prices must be identical between vessels and periods and equal to the user cost of the fish stock as derived in section 3.2.3. The reason for this is that if the shadow price is greater in period 2 than in period 1, the profit can be increased by letting the fisherman catch more in period 2 and less in period 1 The information requirements of this system are enormous, and as the ration fishery currently is managed in Denmark, bio-economic optimality will certainly not be reached, since the allocation schemes are based on other objectives such as distribution. This point is explored further below.

Assume next that the ration restriction in periods 1 and 2 is non-binding. In this case the first-order conditions are:

$$pq(x) = \frac{\delta c_{ti}(E_{ti})}{\delta E_{ti}} \quad \text{for } t = 1,2 \tag{40}$$

This corresponds to the open access condition without regulation, and therefore rations have no effect on the effort. There is still too much effort as under open access without regulation. This result is by no means surprising, because none of the restrictions are binding.

Because $Q_{2i} > Q_{1i}$ a possibility is also that (37) is binding, while (38) is non-binding. Now (39) holds for period 1 and (40) for period 2 and optimality requires that $\lambda_{1i} = \lambda_{1j} = \mu$ for $j \neq i$. As in the case where both restrictions is binding the information requirements of this system, is enormous and in addition to this an open access problem without regulation arises for period 2.

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14 The assumptions about identical catchability are selected, since the main point with the analysis of ration fishery can be captured with this assumptions.

For cod in the Baltic Sea a special rule is that if catches is less than 80% of the ration in one period, next periods rations will be reduced to the catches in the previous period. In order to analyse this rule let Q_{i1} denote period 1´s ration and Q_{i2} period 2´s ration and assume that $Q_{i1} > Q_{i2}$. Part of the ration restriction for period 2 can now be formulated as $q(x)E_{i1} \geq q(x)E_{i2}$ if $q(x)E_{i1} \leq 0.8Q_{i1}$. Furthermore, assume that the ration restriction is non-binding in period 1 and that $q(x)E_{i1} \leq 0.8Q_{i1}$. Now the first-order condition for period 1 is $(p + \lambda_{i2})(q(x)) = \delta C_{i1}(E_{i1})/\delta E_{i1}$. This condition shows that the fisherman faces an opportunity cost for fishing less than 80% of the ration in period 1. This cost is value of the loss of fishing opportunity in period 2. Furthermore, the 80% rule creates an interaction between time periods and thereby raises the information requirements.

A further critique concerns the allocation scheme in Tables 2 and 3. A brief glance at the scheme reveals that they are based on objectives such as distribution. In theory the optimal allocation of rations secures that the marginal profit (resource rent) is equal between vessels and periods (see (39)). The information requirements of such an allocation scheme are enormous, so a proxy must be found. A very rough proxy based on available information is that a group of vessels share of the quota is its share of the total rent in the fishing industry. Formally, if there are three groups of vessels (1, 2 and 3), the share of the ration of group 1 is:

$$\frac{(TR_1 - VC_1)}{\sum_{i=1}^{3}(TR_i - VC_i)} \tag{41}$$

where:

TR_1: The total revenue for group 1.

VC_1: The variable costs for group 1.

TR_1- VC_1: Group 1 rent

$\sum(TR_i - VC_i)$: The total rent for all groups

In order to highlight the ineffiency of the existing ration system, such calculations have been done for cod. The results are summarized in Table 7.[15]

Table 7: Calculated allocations of rations on individual vessels, Tonnes per year

Trawlers less than 17 metres	**Trawlers between 17 and 32 metres**	**Trawlers over 32 metres**	**Danish Seiners between 12 and 20 metres**	**Netters under 13 metres**	**Netters over 13 metres**
13	28	18	10	11	109

The calculations are based on an assumption that the vessels within the categories are homogeneous. Compared to Table 3 the figures reveal that the large vessels receive too small a share of the total quota. Therefore the adopted allocation scheme is not bio-economic optimal.

As a result of the analysis in this section it follows that the ration system is expected to perform poorly. It is therefore important to suggest alternative management regimes. To study these alternatives the management model from section 3.2. will be used.

4. Bio-economic alternatives to the fishery policy

What will be an optimal policy? At the EU level bio-economic optimal TACs can be calculated using a feedback rule. These can be distributed to Member States in an optimal fashion.[16] Therefore an alternative to the Danish ration policy must be found. In this section attention is turned to two bio-economic orientated regulatory approaches that will secure an optimum:

- Taxes (section 4.1.)
- ITQs (section 4.2.)

It is important to state that ITQs and taxes must be used in all countries fishing in the North Sea. Therefore, the selected regulatory approach must also be used in other Member States in the EU.

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[15] Appendix 2 gives the details of the calculations.

[16] For example, through a system of individual transferable quotas (ITQs).

4.1 Taxes

Identification of a shadow price in situations with externalities is a well-known principle in welfare economics. Let the analysed period be a year. From (25) the optimality condition is:

$$\frac{\delta c_i(E_i)}{\delta E_i} = (p - \mu)q(x) \tag{42}$$

A tax per unit of fish caught of $\mu = \tau$ will get an otherwise unregulated fishermen to act optimally. This can be seen in the following way. With the tax the individual fisherman's maximisation problem is:

$$\pi_i(x, E_i) = (p - \tau)q(x)E_i - c_i(E_i) \tag{43}$$

The first-order condition is:

$$\frac{\delta c_i(E_i)}{\delta E_i} = (p - \tau)q(x) \tag{44}$$

and with $\tau = \mu$ a first-best optimum is reached. Therefore, a tax per unit of caught fish can result in a first-best optimum.

A problem with taxes is that the fishermen will be opposed to them. As under open access without regulation the fishermen get a resource rent of zero or at least only infra-marginal rents. The resource rent goes to society. However, including a restriction in the maximisation problem may solve this problem. This restriction could be formulated as a minimum resource rent to the fishermen. Another problem arises with regard to the calculation of the optimal tax. The calculation poses big information requirements (for example the cost structure of every vessel must be known). However, with a principal-agent analysis it is possible to include these information problems in the calculation of taxes. Furthermore, a problem that has been mentioned with taxes is that it is necessary with constant adjustment of the tax rate. However, because the analysed period is a year this problem is by no mean higher than with adjustments of ITQs. The last problem that can be mentioned with taxes is that there can be large administrative cost associated with this management approach.

4.2 ITQs

Another economically orientated management regime is ITQs. In the EU a system of ITQs is used in the Netherlands, and in a modified way in the United Kingdom. A basic principle within welfare economics is that transferable permits and taxes are equivalent as means of correcting externalities in terms of efficiency.

Now the management model is used to show this result. Assume that the quota allows fishermen i to catch with a rate Q_i. Therefore, every fisherman's maximisation problem is:

$$\text{Max}\, \pi_i(x, E_i) = pq(x)E_i - c_i(E_i) \tag{45}$$

s.t.

$$y_i = q(x)E_i \le Q_i \tag{46}$$

This can be written as:

$$\text{Max}\, \theta_i(x, y_i) = py_i - c_i\left(\frac{y_i}{q(x)}\right) \tag{47}$$

s.t.

$$y_i \le Q_i \tag{48}$$

Every fisherman can buy and sell quota units. Given the fisherman's existing quota is Q, under what conditions will the fisherman choose to buy an extra quota unit? Assume that a competitive market for trade with quotas exists and that the price on this market is m per unit.

The benefit associated with a marginal quota unit is the marginal increase in the resource rent. Therefore:

$$MB = \frac{\delta\theta_i(x, y_i)}{\delta Q_i} \tag{49}$$

The fisherman will buy more quotas when $\delta\theta_i(x, y_i)/\delta Q_i > m$, and sell quotas when $\delta\theta_i(x, y_i)/\delta Q_i < m$. Therefore, the following equation specifies fisherman i´s demand:

$$\frac{\delta\theta_i(x, y_i)}{\delta Q_i} = m \tag{50}$$

From (47) and (48) it is obtained that:

$$\frac{\delta\theta_i(x, y_i)}{\delta Q_i} = p - \frac{1}{q(x)\frac{\delta c_i(Q_i/q(x))}{\delta Q_i}} \tag{51}$$

(51) can be written as:

$$\frac{\delta c_i(Q_i/q(x))}{\delta Q_i} = (p - m)q(x) \tag{52}$$

It is obvious that every fisherman will only be satisfied with a quota if it is fully utilised. Therefore, $y_i = Q_i$ and $E_i = y_i/q(x) = Q/q(x)$. (52) can therefore be written as:

$$\frac{\delta c_i(E_i)}{\delta E_i} = (p - m)q(x) \tag{53}$$

This equation can be understood in an alternative way. When the fisherman chooses to catch $y_i = Q_i$, an opportunity costs arises, since the quota could have been sold.

In order to complete the ITQ model it must be shown how m is fixed. Let $Q = \sum Q_i$, be the total quota allocated to fishermen. The total demand, if the price is m, is $D(x, m) = \sum D_i(x, m)$. The quota price is determined by supply equal to demand:

$$Q(x,m) = Q \tag{54}$$

It follows that society can control m by choosing Q. It is therefore seen that taxes and ITQs are equivalent. By choosing Q such that m = μ, a first-best optimum is reached.

However, there are also problems associated with an ITQ system. Extensive control programs must often follow ITQ systems. Furthermore, transferable permits assume a perfect function of markets; see for example Dasquapta *et al* (1982).

Even though taxes and ITQs are equivalent in terms of efficiency, their distributional implications are different. In the case of taxes the resource rent goes to the society, while the resource rent goes to the original quota owner in the case of ITQs.

5. Conclusion

In this paper the EU TAC policy for cod in the North Sea has been discussed. The actual TACs have been compared with the biological recommendations about the TACs, and the bio-economic optimal TACs. It was shown that the biological recommendations and the actual TACs follow each other closely. Therefore, biological principles govern the actual TAC. However, the comparison of the actual TACs and bio-economic optimal TACs shows that bio-economic principles are poorly reflected in the TAC. However, fishing is an economic activity and the actual TAC should reflect the economic optimal TAC to a greater degree.

A bio-economic critique of the Danish management system for cod in the North Sea is given. Denmark uses rations to manage the cod fishery in the North Sea, and by means of a theoretical analysis it is shown that the information requirements for securing an optimum is very large. Furthermore, the actual allocation scheme of rations distributes too large a part of the quota to small vessels.

Alternatives to the ration regime have also been briefly studied and taxes and ITQ systems are recommended, combined with bio-economic optimal TACs. It is important to note that all Member States fishing cod in the North Sea must adopt the same management regime. It is therefore possible that taxes or ITQs must be used at the EU level in order to secure optimality. For this reason, Jensen and Vestergaard (1999) study a EU tax on effort.

The calculation of the bio-economic optimal TACs is based on a single-species assumption. However, the figures in the text show that the cod fishery in the North Sea is a multi-species fishery. The calculation of bio-economic optimal TACs using a multi-species assumption is a promising area for future research. Another promising research area is to include uncertainty about the stock size in the calculations of the bio-economic optimal TAC. The calculations of the bio-economic optimal TAC in this paper were done using a deterministic model, but the stock estimates by Anon (1999) are not exact.

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Appendix 1: The data

Table A: The data series

Year	TAC (tonnes)	Catches (tonnes)	Spawning Stock (tonnes)	Recommended TAC (tonnes)	Stock (tonnes)	Optimal Catch (tonnes)
1982	260600	303251	190267	210000	840297	208000
1983	246670	259287	155113	240000	649374	129000
1984	222920	228286	133669	220000	718477	154000
1985	252770	214629	126553	245000	503183	90000
1986	185220	204053	114619	145000	683575	142000
1987	179100	216213	105190	175000	571797	101000
1988	168390	184240	100389	165000	426804	49000
1989	135650	139936	91308	135000	417331	46000
1990	115850	125314	78553	110000	329129	36000
1991	105945	102478	61659	100000	297724	7000
1992	104345	114020	69786	100000	410010	43000
1993	104345	121749	66227	100000	349938	23000
1994	106165	110634	67972	105000	478719	67000
1995	127950	138523	80981	125000	490099	72000
1996	141370	126423	104369	140000	438419	53000
1997	115000	124000	82000	135000	503000	90000
1998	140000	146000	74000	153000	321000	36000
1999	132400	96000	66000	125000	290000	7000
2000	81000		67000	79000	299000	7000
2001	40000			0		

Appendix 2: Profit calculations

B: Profit Table calculations, 1998

	Trawlers under 50 GT	**Trawlers between 50-199 GT**	**Trawlers over 200 GT**	**Danish Seiners**	**Netters under 20 GT**	**Netters over 20 GT**
A. Gross output for cod 1000kr/firm	553.5	950	267.4	1241.7	587.8	1949
B. Gross output in total 1000kr/firm	1552.2	4187.8	11077.7	2529.8	880.2	2494.5
C. Share of cod	0.36	0.23	0.02	0.49	0.67	0.78
D. Total costs 1000kr/firm	1138	3602.7	8757.6	1920.5	618.7	1959.4
E. Total costs of hired labour. 1000kr/firm	390.9	1334.4	3132.2	830.2	204.1	868.3
F.Depreciation	185.2	615.3	1551.9	232.7	128.2	324
G. Labour input of crew. Days at sea	179	527.5	917.3	196.6	108.7	540.9
H. Labour input of fisherman. Days at sea	163.9	147.3	147	166.7	150.3	194.1
I. Wage per day	2.18	2.53	3.41	4.22	1.88	1.61
J. Labour cost of fishermen	357.92	372.6	501.96	703.94	282.21	311.59
K. Variable costs	1310	3360	7707.66	2391.74	772.7	1635
L. Variable costs of cod	471.89	772.80	154.15	1172	517.72	1276
M. Vessel profit	81.61	177.20	113.25	69.75	70.10	673

Table B: Continued

	Trawlers under 50GT	**Trawlers between 50-199 GT**	**Trawlers over 200 GT**	**Danish Seiners**	**Netters under 20 GT**	**Netters over 20 GT**
N. Number of vessels	422	114	122	94	396	74
O. Total profit to the group	34400	20200	13816	6567	27759	49831
P. Share of total profit	0.23	0.13	0.09	0.04	0.18	0.33
Q. Groups ration (Tonnes)	5639	3187	2207	981	4414	8092
R. Individual ration (Tonnes)	13	28	18	10	11	109

C is calculated as A/B, while I is E/G. J = I*H, K = J + D - F, L = K* C, M = A – L, O = N*M. P is O divided by the total profit. The Danish quota for cod in the North Sea is 24520 tonnes for 1999. Q = P *24520, and R = Q/N.

Using a register for decommissioned vessels it is possible to transform the categories in GT to categories in metres. The register covers decommissioned vessels in 1987-93. However, a problem is that the vessels decommissioned can be different from the vessels that are not decommissioned. On basis of the register the following equations have been estimated:

Below 12 metres $\text{GT} = -14.433 + 2.652 * \text{length} \quad R^2 = 0.85$

Between 12 and 24 metres $\text{GT} = -78.888 + 7.57 * \text{length} \quad R^2 = 0.90$

Over 24 metres $\text{GT} = -219.198 + 13.27 * \text{length} \quad R^2 = 0.69$

Now the categories from table A can be inserted in the relevant equations. This yields the categories in the text.

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