

Modelling Economic Response to Combined Harvest and Effort Control in Fishery

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A number of European fishing fleets have been regulated through a combination of quota and effort (sea days) controls since 2004. These two regulation schemes are however interrelated, i.e. a given quota limit will necessarily determine the effort used, and vice versa. A bioeconomic feedback model is presented that takes into account this causality between effort and harvest control, and switches back and forth between these two regulation schemes depending on which is the binding rule. The model is based on biological stock projection, and quotas are set using the Pope approximation, while an economic production function is used to estimate harvest when effort is binding. The economic response of the fleet is modelled through a dynamic investment/disinvestment module that evaluates the change in fleet capacity given the economic outcome of the fishery. A simple example is presented for Danish seiners catching cod in the North Sea.

The model has been constructed as part of the 6th framework project ‘Operational Evaluation Tools for Fisheries Management Options (EFIMAS)’.

Keywords: Combined Quota and Effort Control, Bio-Economic Modelling, FLR (Fisheries Laboratory in R)

1 **Introduction**

2 With the introduction of the 2002 reform (EC 2002) of the Common Fishery Policy (CFP) for EU
3 waters, effort control was introduced alongside quota control and limited entry to the fishery in
4 form of capacity restrictions (fishing licenses). The reasons to include effort control parallel to
5 quotas are (i) with the large overcapacity of the European fishing fleet, quotas do not seem adequate
6 to limit the actual amount of fish being caught, and (ii) the multi-species nature of most fisheries
7 often results in over-exploitation and subsequent discarding of some species, which may to some
8 degree be avoided by effort control.

9

10 Implicitly in the introduction of effort-regulation is the assumption that harvest and effort are
11 interrelated, i.e. a given observed harvest will necessarily determine the effort used, and
12 correspondingly a given effort will determine the harvest. Thus given combined quota and effort
13 regulation, one of the two will always be the limiting factor that determines the actual harvest taken.

14

15 It is therefore important to acknowledge this issue of causality between regulation methods when
16 modelling the effects of a given management scheme. This paper presents a bio-economic
17 simulation model developed with the aim to assess the economic as well as biological effects of
18 recovery plans including effort control, taking into account the causal relationship between the
19 quota-restrictions and the additional sea days limitations. The model is thus able to switch between
20 harvest and effort control of the fishery. This switching mechanism is an improvement of existing
21 bio-economic models that usually considers either harvest or effort-control. As such the model
22 presented in this paper opens up for more realistic and complete assessments of the new CFP.

23

24 The model is has been implemented in FLR (Fisheries Laboratory in R, Kell et al. 2007), which is a
25 ‘collection of tools in R that facilitates the construction of bio-economic simulation models of
26 fisheries and ecological systems’ (FLR 2007). FLR has been developed under the 6’Th framework
27 programme EFIMAS (Operational Evaluation Tools for Fisheries Management Options, EFIMAS
28 2007). R is a freeware/shareware system for statistical computation and graphics. The model
29 presented in this paper is based on the so-called AHF model developed in connection with EFIMAS
30 and presented in Hoff and Frost 2006.

31

1 The model uses the example of Danish seiners catching cod in the North Sea as a specific case
2 study, employing the recovery scheme for the North Sea cod set by the European Commission in
3 2004 (EC, 2004). As is well-known, the cod-stock in the North Sea has been steadily decreasing
4 since the early 1970's, and is at present at the lowest level observed over the last century (ICES,
5 2005). The cod spawning stock biomass (*SSB*) should be at least $SSB_{lim} = 70.000$ tonnes to be able
6 to reproduce itself, and seeing that the biomass in 2005 was ~50.000 tonnes it is clear that the stock
7 may suffer from reduced reproductive capacity. In 2004 the European Commission thus introduced
8 a specific recovery plan for the North Sea Cod (EC, 2004), formulating harvest and effort control
9 rules with the aim to increase the stock above the precautionary level of $SSB_{Pa} = 150.000$ tonnes.
10 The harvest rule states that the catch in a given year must be set at a level that allows the *SSB* of cod
11 to increase with at least 30% relative to the previous year, until the precautionary level is reached.
12 Moreover the fishing mortality rate must not exceed 0.65. These aims are enforced through
13 combined TAC and effort regulation, the latter stating that seine vessels must not have more than 22
14 active fishing days in the North Sea a month.

15

16 A large part (in 2003, 37 vessels of in all 62 vessels) of the Danish seine fleet fish in the North Sea
17 at a full- or part-time basis. The Danish seiners generally target cod and plaice and the landings
18 value of cod for this fleet segment on the average constitute ~25% of the total landings value for
19 this segment in the period 2002-2004. The Danish seiners fishing in the North Sea take ~10% of the
20 total Danish cod landings from the North Sea, while the Danish share of cod in the North Sea
21 constitutes ~20% of the North Sea TAC for the European Union. Thus the Danish seiners take
22 $10\% \cdot 20\% = 2\%$ of the EU TAC of cod in the North Sea. As such the Danish seine fleet will not
23 have any significant influence on the state of the cod stock in the North Sea. But contrary to this the
24 reduction of cod quotas in connection with the recovery program mentioned above may have a
25 significant influence on the economy of the Danish seiners fishing in the North Sea.

26

27 **The model**

28 The model comprises a biological and an economic operation module, the former simulating the
29 stock assessment and establishment of quotas each year, while the latter simulates the economic
30 dynamics of the fleet, i.e. fleet catches and earnings, fleet effort, and investment/disinvestment in
31 capital.

32

1 As mentioned in the introduction, the model is generally an improvement of existing bio-economic
 2 models (see for example Skjold et al. 1996, Danielsson et al. 1997, Garza-Gil et al. 2003 and
 3 2006, and Da-Rocha and Gutiérrez 2004 and 2006) in that sense that it is able to take into account
 4 parallel quota and effort regulation, as introduced by the new CFP. In this respect the model is an
 5 important contribution to the on-going work of assessing existing and proposed management
 6 schemes. As such it should be kept in mind, that although the model presented below has a specific
 7 focus on evaluating the effect on one fleet of the cod-recovery program in the North Sea, the model
 8 can easily be applied to other scenarios.

9
 10 The model is initiated in each year y ($y > 1$) of the simulation period by evaluating the number of
 11 vessels NV_{Fl}^y (capacity) in the fleet¹ Fl at the start of year y , based on previous years total profit (for
 12 all species being caught by the fleet):

$$\begin{aligned}
 & NV_{Fl}^y = \begin{cases} NV_{Fl}^{MAX} & ; \Delta NV_{Fl}^y > (NV_{Fl}^{MAX} - NV_{Fl}^{y-1}) \\ NV_{Fl}^{y-1} + \Delta NV_{Fl}^y & ; (NV_{Fl}^{MIN} - NV_{Fl}^{y-1}) \leq \Delta NV_{Fl}^y \leq (NV_{Fl}^{MAX} - NV_{Fl}^{y-1}) \\ NV_{Fl}^{MIN} & ; \Delta NV_{Fl}^y < (NV_{Fl}^{MIN} - NV_{Fl}^{y-1}) \end{cases} \\
 & \Delta NV_{Fl}^y = \begin{cases} \frac{I_{Fl}^+ \cdot \overline{NP}_{Fl}^y}{V_{Fl}^{In}} ; \overline{NP}_{Fl}^y \geq 0 \\ \frac{I_{Fl}^- \cdot \overline{NP}_{Fl}^y}{V_{Fl}^{OUT}} ; \overline{NP}_{Fl}^y < 0 \end{cases} \quad (1)
 \end{aligned}$$

$$\overline{NP}_{Fl}^y = \frac{(1 - (1+r)^{-LT})}{r} \cdot \left(\frac{1}{LGT_{Fl} + 1} \sum_{i=0}^{LGT_{Fl}} \Pi_{Fl}^{(y-1)-LAG_{Fl}-i} \right)$$

15
 16 In principle, the entry exit function is based on future expectation but because of lack of
 17 information past evidence in terms of profit is used. It is assumed that the change in capacity is
 18 determined by the opportunity cost of capital including an option for asymmetry in entry and exit.
 19 The price of a vessel V_{Fl} transforms pecuniary capital into physical capital, and the reciprocal of V_{Fl}
 20 includes the fisherman's perception of opportunity costs, see also Bjørndal and Conrad (1987).

¹ In the present case the 'fleet' specifies that part of the Danish seine fleet that operates specifically in the North Sea.

1 NV_{Fl}^{MAX} and NV_{Fl}^{MIN} are the maximum and minimum number of vessels allowed in the fleet. \overline{NP}_{Fl}^y
 2 is the average discounted (total) profit over LGT years for fleet Fl , used for evaluating capacity
 3 change. V_{Fl}^{In} and V_{Fl}^{OUT} are the prices per unit capacity of investment/disinvestment. I_{Fl}^+ and I_{Fl}^- are
 4 reflecting partial adjustment, i.e. the shares of positive respectively negative profits used for
 5 investment/disinvestment in capacity, indicating that not necessarily all positive profit is invested in
 6 new capacity, nor that all negative profit is necessarily regained by selling capacity. LAG_{Fl} is the lag
 7 in investment decision, i.e. the number of years it takes from deciding to invest/disinvest until the
 8 change is actually put into force. Π_{Fl}^y is the net total profit taken by fleet segment Fl in year y . It is
 9 at present assumed that there is no decommissioning.

10
 11 The next step is to determine the stock of the target species (in the present case cod) at the
 12 beginning of year y and set the catch/quota of the species for this year. In the present context the
 13 stock at the beginning of each year is set by the Pope approximation to cohort analysis (Sparre,
 14 1998):

$$15 \quad N_a^y = N_{a-1}^{y-1} \cdot \exp(-m_{a-1}) - C_{a-1}^{y-1} \cdot \exp(-m_{a-2}/2) \quad ; \quad y > 1 \quad (2)$$

16
 17 N_a^y is the number of cod in the stock at age a in year y . C_{a-1}^{y-1} is the number of cod caught in year $y-1$
 18 at age $a-1$. m_{a-1} is the natural mortality of the stock at age $a-1$. The number of recruits N_1^y is set
 19 by the Ricker stock-recruitment relationship, based on historical stock and recruitment numbers
 20 dating back to 1963 (ICES, 2006). It has been chosen to use the Pope approximation rather than the
 21 more correct cohort equation $N^y = N^{y-1} \cdot \exp(-(M + F))$, as the Pope formula has also been used to
 22 set the quotas in year y . By using this approach, instead of the cohort formula, the quotas are set
 23 directly without the need to estimate the fishing mortality rate.

24
 25 While the cod SSB is below the precautionary level $SSB_{pa} = 150.000$ tonnes the cod quota in year y
 26 is set according to the harvest rules stated above, i.e. that the spawning stock biomass of cod must
 27 increase by at least 30% each year until the precautionary level is reached. I.e. $SSB^y = 1.3 \cdot SSB^{y-1}$
 28 with $SSB^y = \sum_a N_a^y \cdot w_a \cdot mat_a$, where w_a and mat_a is the weight and fraction of mature individuals
 29 at age a of the stock. Thus the management rule states that
 30

1 $\sum_a N_a^y \cdot w_a \cdot mat_a \geq 1.3 \cdot \sum_a N_a^{y-1} \cdot w_a \cdot mat_a$. Seeing that $mat_1 \sim 0$ for cod this rule is approximately
 2 fulfilled if $N_a^y \geq 1.3 \cdot N_a^{y-1}$ for $a > 1$. Using the Pope formula (equation 2) and rearranging a bit, the
 3 quota in year y must fulfil:

$$4 \quad q_a^y \leq N_a^y \cdot \exp(-m_a/2) - 1.3 \cdot N_{a+1}^y \cdot \exp(m_a/2) \quad ; \quad a \geq 1 \quad (3)$$

6
 7 In the present model q_a^y has been set equal to the above expression when this is greater than zero,
 8 while $q_a^y = 0$ otherwise. The latter case then indicates a ban of fishing cod at certain ages, usually
 9 the young fish.

10

11 When the cod SSB is higher than SSB_{Pa} it is assumed that the aim is to keep $SSB^y \square SSB_{Pa}$. Using
 12 the above argumentation, the quota is then set equal to:

13

$$14 \quad q_a^y = N_a^y \cdot \exp(-m_a/2) - N_{a+1}^y \cdot \exp(m_a/2) \quad ; \quad a \geq 1 \quad (4)$$

15

16 The total quota of cod in the North Sea in year y is then given by:

17

$$18 \quad Q^y = \sum_a q_a^y \cdot w_a \quad (5)$$

19

20 If all fleets sharing this quota are able to take their full TAC's this will be equal to the catch of
 21 North Sea cod in year y, but given the additional effort restriction, the fleets may not be able to take
 22 their full TAC's, as will be shown below, thus decreasing the actual total cod catch in year y.

23

24 The TAC for the Danish seine fleet operating in the North Sea is next given by:

25

$$26 \quad TAC_{Fl}^y = FSS_{Fl} \cdot CS \cdot Q^y \equiv \sum_a tac_{Fl,a}^y = \sum_a FSS_{Fl} \cdot CS \cdot q_a^y \cdot w_a \quad (6)$$

1 CS is the country share² of the total cod quota, and FSS_{Fl} is the fleet segment share of the country
 2 TAC. Both are assumed constant in the present context. $tac_{Fl,a}^y$ is defined as the TAC of cod at age
 3 a for the fleet. It is of course unrealistic to enforce age-disaggregated TAC's for real, but this
 4 illustrates the above point, that it may be forbidden to harvest cod at certain ages. TAC_{Fl}^y will be the
 5 amount of cod harvested by the fleet in year y , given that the effort (number of sea days per vessel)
 6 $Etac_{Fl}^y$ necessary to take this TAC will not exceed the effort limit $Emax_{Fl}^y$ set by the recovery
 7 scheme. $Etac_{Fl}^y$ is estimated by:

$$9 \quad Etac_{Fl}^y = \frac{TAC_{Fl}^y}{NV_{Fl}^y \cdot QPUE_{Fl}^y} \quad (7)$$

10
 11 $QPUE_{Fl}^y$ is the (quota) catch of cod per unit effort (i.e. per fishing day), and is given by:

$$12 \quad QPUE_{Fl}^y = cpue_{Fl}^1 \cdot \left(\frac{SB^y}{SB^1} \right)^{\beta_{Fl}} \cdot \left(\frac{TAC_{Fl}^y}{TAC_{Fl}^1} \right)^{-\gamma_{Fl}} \quad ; \quad \beta_{Fl}, \gamma_{Fl} \geq 0 \quad (8)$$

$$13 \quad cpue_{Fl}^1 = \frac{H_{Fl}^1}{NV_{Fl}^1 \cdot E_{Fl}^1}$$

14
 15 E_{Fl}^1 is the actual effort (number of days at sea) used on the average per vessel in fleet segment Fl in
 16 the initialisation year where this, and the number of vessels NV_{Fl}^1 , are known from observations.
 17 $cpue_{Fl}^1$ and H_{Fl}^1 are the observed catch per unit effort and total harvest of cod (measured in weight)
 18 for the Danish seine fleet in the start year. SB^y is the stock biomass in year y given by $\sum_a N_a^y \cdot w_a$.
 19 Notice the difference between the quota catch per unit effort $QPUE_{Fl}^y$, which can be estimated at
 20 the beginning of the year based on the quotas, and the actual observed catch per unit effort
 21 $CPUE_{Fl}^y$, which can only be evaluated at the end of the year when the actual fleet catches are
 22 known. $CPUE_{Fl,s}^y$ is evaluated as $QPUE_{Fl,s}^y$, i.e. as:

23

² Also called the relative stability.

$$1 \quad CPUE_{Fl}^y = cpue_{Fl}^1 \cdot \left(\frac{SB^y}{SB^1} \right)^{\beta_{Fl}} \left(\frac{H_{Fl}^y}{H_{Fl}^1} \right)^{-\gamma_{Fl}} \quad ; \quad \beta_{Fl}, \gamma_{Fl} \geq 0 \quad (9)$$

2

3 The only difference being that it is now the actual observed cod harvest H_{Fl}^y and not the TAC's that
 4 are used in the last fraction (the two will be equal if it is possible for the fleet to catch the total
 5 TAC). Notice that it is assumed that the catch per unit effort increases with the stock, but decreases
 6 with the catch weight. The latter is based on the assumption that the production relationship
 7 between catch and effort displays non-increasing returns to scale.

8

9 The number of sea-days (equation 7) necessary per vessel in the fleet to catch the TAC may
 10 however exceed the effort limit set by the recovery plan $E_{max_{Fl}}^y$, and it will thus not be possible for
 11 the fleet to harvest it's total TAC. If $E_{tac_{Fl}}^y > E_{max_{Fl}}^y$ the actual harvest of cod for the fleet segment
 12 are estimated by scaling down the TAC:

13

$$14 \quad h_{Fl,a}^y = tac_{Fl,a}^y \cdot \left(\frac{E_{max_{Fl}}^y}{E_{tac_{Fl}}^y} \right)^{\frac{1}{1+\gamma_{Fl}}} \quad (10)$$

15

16 $h_{Fl}^{y,a}$ is then the actual cod harvest at age a taken by the fleet in year y . The scaling used in equation
 17 (10) is derived using the CPUE relationship given in equation (9) and demanding (i) that the
 18 number of vessels stays constant and (ii) that the observed effort used by the fleet in year y will be
 19 equal to $E_{max_{Fl}}^y$, given by:

20

$$21 \quad E_{max_{Fl}}^y \equiv E_{obs_{Fl}}^y = \frac{\sum_a h_{Fl,a}^y}{NV_{Fl}^y \cdot CPUE_{Fl}^y} \quad (11)$$

22

23 With $CPUE_{Fl}^y$ given by equation (9). The above steps are summarised in table 1 that shows the
 24 actual observed effort E_{Fl}^y used and harvest $H_{Fl}^{y,a}$ taken by fleet Fl at the end of year y .

25

26 <<Table 1 Here>>

1 Finally if the fleet is not able to catch it's total TAC the cod quota will not be fully exploited, and
 2 the actual catches of cod in year y will then be³:

$$3 \quad C_a^y = q_a^y - tac_{Fl,a}^y + h_{Fl,a}^y \quad (12)$$

4
 5
 6 The total landings value (including all species caught) R_{Fl}^y of the fleet segment in year y are given
 7 by:

$$8 \quad R_{Fl}^y = \frac{1}{CVF_{Fl} \cdot CCF_{Fl}} \sum_a p_a^y \cdot H_{Fl,a}^y \cdot w^a \quad ; \quad p_a^y = p_a^1 \cdot \left(\frac{Q^y}{Q^1} \right)^{\alpha_s}, \quad \alpha_s \leq 0 \quad (13)$$

9
 10
 11 CCF_{Fl} is the fraction that the cod harvested in the North Sea constitutes of the total cod catch⁴ for
 12 the Danish seiners operating in the North Sea (measured in weight). CVF_{Fl} is the fraction the total
 13 catch value of cod (for all fishing grounds) constitutes of the total catch value for the Danish seiners
 14 operating in the North Sea. Scaling the earnings from the cod catch in the North Sea by these two
 15 factors ensures that R_{Fl}^y estimates the total revenue of the fleet, for all species caught in all operating
 16 areas.

17
 18 The variable VC_{Fl}^y and fixed FC_{Fl}^y costs are given by:

$$19 \quad VC_{Fl}^y = VC_{Fl}^1 \cdot \left(\frac{E_{Fl}^y \cdot NV_{Fl}^y}{E_{Fl}^1 \cdot NV_{Fl}^1} \right) \quad (14)$$

$$20 \quad FC_{Fl}^y = FC_{Fl}^1 \cdot \left(\frac{NV_{Fl}^y}{NV_{Fl}^1} \right) \quad (15)$$

21
 22
 23
 24 I.e. the variable costs are scaled by the effort relative to the variable costs in year 1, and the fixed
 25 costs are scaled by the capacity. Finally the total profit taken by the fleet in year y is given by:

³ Assuming that the part of the quota taken by other vessel groups will be fully exploited.

⁴ I.e. the total cod catch in the North Sea and other fishing grounds (e.g. Skagerrak).

1

$$2 \quad \Pi_{Fl}^y = R_{Fl}^y - VC_{Fl}^y - FC_{Fl}^y \quad (16)$$

3

4 This brings the model back to the start, as this profit is used in the subsequent years to assess the
5 change of fleet capacity (equation 1), which, as it is seen by the above model, is strongly dependent
6 on the fleet harvest, and thus on the current management scheme.

7

8 **Data**

9 The start year in the simulation is set to 2003, i.e. the year before the cod recovery plan was set into
10 force. The simulation is run for 10 year, which has proven more than adequate for the stock to
11 recover in the given model setup.

12

13 The cod stock is initialised in 2003 using cohort and catch data presented by the ICES Working
14 Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (ICES, 2006). It is
15 assumed that the natural mortality and the maturity rate of the stock are constant throughout the
16 simulation period, and equal to the values also given in ICES (2006). Table 2 gives the stock and
17 catch data used to initialise the stock.

18

19

20 The Danish seine fleet operating in the North Sea is initialised using data from the Annual
21 Economic Report on the Economic Performance of Selected European Fishing Fleets (AER, 2004),
22 and from the Danish Fishery Statistics. A summary of the data used to initialise the fleet in 2003 is
23 given in table 3.

24

25 <<Table 2 Here>>

26

27 <<Table 3 Here>>

28

29 The maximum number of sea days in a year for a Danish Seine vessel is set to $12 \cdot 22 = 264$ days
30 according to the CFP effort regulation. The maximum number of vessels allowed in the fleet is set
31 (a bit arbitrary) to twice times the number of vessels in 2003, i.e. to 74 vessels, thus allowing the

1 fleet to expand if there is positive profits. The minimum number of vessels is set to 1, thus allowing
2 the fleet to recover after a period of severe negative profits⁵.

3
4 Finally the Danish share (relative stability) of the North Sea cod quota is equal to $CS_{DK}^{Cod} = 20.45\%$,
5 and the exponents used in the *CPUE* evaluations have been set to $\beta_{Fl} = 0.8$ and $\gamma_{Fl} = 1$.

6 7 **Simulation results**

8 The model has been run from the initialisation year 2003 until 2012 which has proven a more than
9 sufficient time-period for the stock to recover. When running the simulation with the above
10 parameters the stock and recruitment follows the paths shown in figure 1. It is seen that SSB
11 increases above the precautionary limit of 150.000 tonnes and stabilises around 210.000 tonnes. The
12 recovery of the cod stock to above the precautionary limit takes around 6 years.

13
14 <<Figure 1 Here>>

15
16 Figure 2 shows the development in the fleet effort (number of sea days per vessel) and capacity
17 (number of vessels). Figure 3 shows economic indicators for the fleet, and figure 4 shows the fleet
18 TAC's and catches during the simulation period.

19
20 <<Figure 2 Here>>

21
22 <<Figure 3 Here>>

23
24 <<Figure 4 Here>>

25
26 Figure 2 firstly shows that the fleet capacity decreases steeply throughout most of the recovery
27 period (2004 to ~2008), but then starts to rise as the stock has recovered. The reason for the initial
28 fall in capacity is the negative profit (figure 3) for the fleet at the beginning of the simulation period
29 that, given the lag in investment (cf. equation 1), is followed by a period of disinvestment. This
30 unfavourable economic situation for the fleet at the beginning of the period is caused by a

⁵ If the minimum number of vessels is set to zero, no earnings will be created at all for the fleet in the model, and the fleet will thus never be allowed to recover/reinvest when the stock has recovered.

1 combination of low TAC's and severe overcapacity, and the disinvestment is the natural reaction to
2 this. It must however be kept in mind that it is probably unrealistic that the fleet disinvests down to
3 only ~5 vessels, as many vessels will probably choose to stay in the fishery despite the negative
4 earnings.

5
6 Figure 2 secondly shows that the effort limit of 264 days per vessel is reached each year throughout
7 the management period (2004-2012), thus meaning that the fleet is not in any year able to take the
8 full TAC of cod. The fleet cod catch and TAC are shown in figure 4, that shows that the part the
9 fleet is able to take of it's TAC decreases during the simulation period. The reason for this
10 discrepancy is to be found in the decreasing capacity of the fleet. It has been shown by additional
11 simulations that if the fleet had not been allowed to disinvest it would have been able to take larger
12 parts of the yearly TAC, but with negative earnings each year due to the overcapacity.

13 14 **Discussion and conclusion**

15 The model and the case study presented above is of course a simplification of the actual dynamics
16 between fishing biology, management plans and economy. During the construction of the model
17 and running of the simulation is has clearly appeared that the model is extremely sensitive to the
18 initialisation parameters⁶ of the model. This said it is still the belief of the authors that the model
19 gives a plausible indication of the possible development of a fish stock under a recovery scheme,
20 and especially of the corresponding response of a given fleet on the changing quota situation during
21 the recovery period. It is especially interesting to follow the response of the fleet to the additional
22 effort limitation on fishing days. This is the limiting factor all through the simulation period for the
23 case study presented, and would still be even though the fleet was not allowed to disinvest. These
24 specific simulations thus indicate that it may be difficult for fleets to take their full TAC's of the
25 protected species if additional effort limitations are set into force. This is of course an advantage
26 from a biological point of view, as it will allow the threatened stocks to recover faster, but is quit a
27 disadvantage for the involved fleets.

28
29 Simplified or not the presented model gives a very detailed account of the possible response of a
30 fishery to combined effort and quota regulations. As such the value of this new model is especially
31 found in the fact that it provides stakeholders with additional socio-economic information about the

⁶ Or conditioning

1 possible effects of new management regimes including effort regulation. It should be clear that the
2 model can be extended to more fleets and more species, and that the model as such is a valuable
3 addition to the ongoing research in evaluation of management schemes.

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Table and Figure Captions

Table 1. Actual catch taken and effort used by fleet Fl by the end of year y.

Table 2. Initialisation data (year=2003) for the cod stock in the North Sea. Source: ICES (2006).

Table 3. Initialisation data (year=2003) for the fleet of Danish seiners operating in the North Sea.

Figure 1. Development of Spawning Stock Biomass (SSB), Stock Biomass (SB) and recruitment (R) during the simulation period.

Figure 2. Effort (number of sea days per vessel) and capacity (number of vessels) during the simulation period for the fleet of Danish seiners operating in the North Sea

Figure 3. Variable and fixed costs (VarC, FixC), total revenues (Rev) and total profits (Prof) during the simulation period for the fleet of Danish seiners operating in the North Sea.

Figure 4. Yearly cod TAC's and catches during the simulation period for the fleet of Danish seiners operating in the North Sea

Table 1. Actual catch taken and effort used by fleet F_l by the end of year y .

Actual effort and catch by the end of the year	$Etac_{F_l}^y \leq Emax_{F_l}^y$	$Etac_{F_l}^y > Emax_{F_l}^y$
$E_{F_l}^y$	$Etac_{F_l}^y$ (equation 7)	$E max_{F_l}^y$ (equation 11)
$H_{F_l}^{y,a}$	$tac_{F_l,a}^y$ (equation 6)	$h_{F_l,a}^y$ (equation 10)

Table 2. Initialisation data (year=2003) for the cod stock in the North Sea. Source: ICES (2006).

Age	Stock numbers at age (Thousands)	Catch numbers at age (Thousands)	Natural mortality	Maturity	Catch weight at age (kg)
1	89142	8911	0.8	0.01	0.275
2	69782	19591	0.35	0.05	0.752
3	17433	4621	0.25	0.23	1.533
4	9899	2729	0.2	0.62	3.191
5	1538	460	0.2	0.86	5.113
6	241	68	0.2	1	7.27
7+	261	50	0.2	1	11.076

Table 3. Initialisation data (year=2003) for the fleet of Danish seiners operating in the North Sea.

Parameter	Value
Number of vessels (NV_{Fl}^1)	37
Fishing days per vessel (E_{Fl}^1)	171
Variable cost for the total fleet (VC_{Fl}^1)	$8415 \cdot 10^3$ €
Fixed cost for the total fleet (FC_{Fl}^1)	$3581 \cdot 10^3$ €
Price per unit capacity of investment (V_{Fl}^{In})	$350 \cdot 10^3$ €
Price per unit capacity of disinvestment (V_{Fl}^{OUT})	$437 \cdot 10^3$ €
Investment Fraction (I_{Fl}^+)	0.125
Dis-investment Fraction (I_{Fl}^-)	0.125
Lag in investment decision (LAG_{Fl})	1 year
Number of year for averaging profit (LGT)	2 years
Discount rate (r)	5%
Expected lifetime (LT)	20 years
Catch value fraction (CVF)	0.29
Catch weight fraction (CCF)	0.61
Fleet Segment Share (FSS)	0.08

Figure 1. Development of Spawning Stock Biomass (SSB), Stock Biomass (SB) and recruitment (R) during the simulation period.

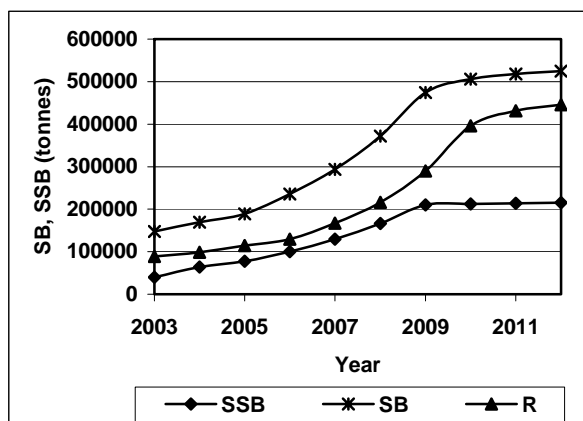


Figure 2. Effort (number of sea days per vessel) and capacity (number of vessels) during the simulation period for the fleet of Danish seiners operating in the North Sea

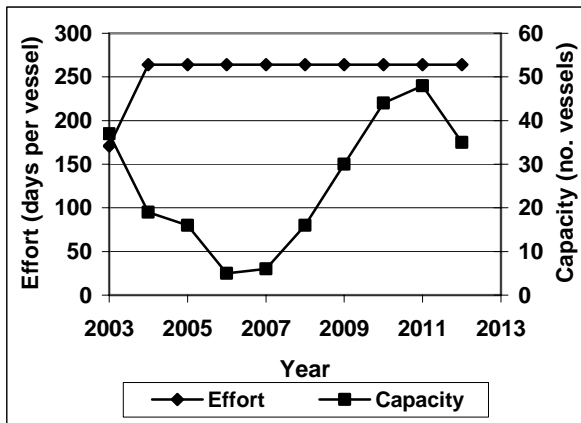


Figure 3. Variable and fixed costs (VarC, FixC), total revenues (Rev) and total profits (Prof) during the simulation period for the fleet of Danish seiners operating in the North Sea.

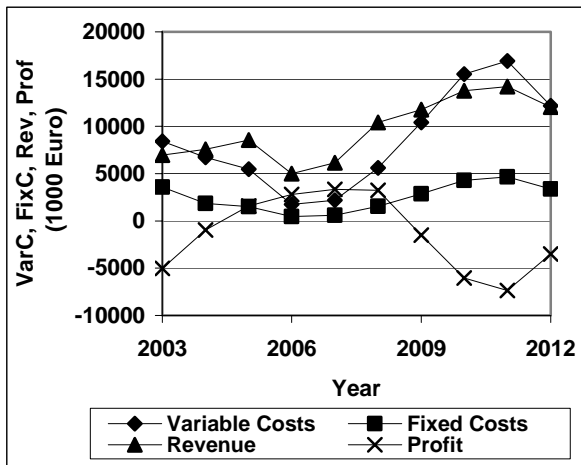


Figure 4. Yearly cod TAC's and catches during the simulation period for the fleet of Danish seiners operating in the North Sea

