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Multi-objective management in fisheries: The case of the Danish industrial fishery in the North Sea

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Preface

Managing fisheries in a multi-objective framework has received increasing attention in the last decade. This is primarily due to a wish from managers to legitimate the regulatory system imposed, and obtain increased compliance. All relevant stakeholders in the specific fishery are involved and the management is centred upon their preferences.

This report presents a study of the possible consequences of managing the Danish industrial fishery in the North Sea in a multi-objective framework. An array of stakeholders has been interviewed and their preferences between seven objectives have been elicited. This work was carried out by Institute for Fisheries Management & Coastal Community Development (IFM, Denmark). In the present report, a multi-objective goal-programming model is set up. The model is used to determine short run and long run consequences on the fishery, if it was managed using the weights of each stakeholder. This is followed-up by a discussion of the implications for management in relation to the specific fishery, but also about the applicability and effectiveness of the approach in general.

The present study has been carried out with the financial support of the Commission of the European Communities Fifth Framework programme, ”Multiple Objectives in the Management of EU Fisheries” – QLK5-1999-01273. However, the views expressed in the paper do not necessarily reflect the views of the EU Commission and do not anticipate the Commission’s future policy in this area.

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1. Introduction

The Danish industrial fishery in the North Sea is a fishery which gives rise to a significant economic surplus (see Andersen and Løkkegaard, 2002). Another characteristic is the presence of many stakeholders, which often have contradicting opinions about the objectives of the fishery. Amongst the stakeholders are fishermen, regulators, environmentalists and labour unions. This makes the fishery interesting to analyse in a multi-objective framework.

In a previous analysis, eleven stakeholders were interviewed, and their ranking between several objectives was determined. This was done by using the Analytic Hierarchy Process method. This method elicits the ranking between the included objectives, and represents it by a set of weights.

In order to analyse the optimally managed fishery from the perspective of each stakeholder, a bioeconomic model has been developed. A static model is chosen, because the biological links in the analysed fishery is almost impossible to derive. This is due to the fact that the industrial species are short-lived species. Long run dynamic effects are thus excluded. Given the assumption that the availability of industrial species, i.e. level of catches, are unchanged in the years to come, it has however been possible to model some likely long run trends in the development of the industrial fleet.

The model is set up in a multi-objective goal-programming framework and programmed in the optimisation software GAMS (General Algebraic Modeling System). By using this set-up, it is possible to evaluate the effects on the fishery, if the weights from each stakeholder are used to weigh the objectives together.

In goal programming, target values are determined for all the objectives and the model aims to minimise the total deviation from these. The weights are applied to construct the weighted sum of deviational variables that is minimised. Clearly, the weights are fundamental to the outcome, i.e. the optimal management. This is consistent with the perception that optimal management differs for different stakeholders, e.g. between fishermen's organisations and environmental organisations.

The model is based on data from 1999 covering trawlers above 18 metres in length, having at least one percent of their total catch value comprised of North Sea industrial species. Due to seasonality in the fishery, the Danish industrial fishery in the North Sea is a multi-species fishery. The main target species are sandeel, sprat, blue whiting

and Norway pout, but important bycatches of different valuable consumption species may occur.

The three primary data sources are the Danish Directorate of Fisheries, the Danish Institute of Fisheries Research and the account statistics for fisheries, prepared by the Statistics Division at the Danish Research Institute of Food Economics.

A formal representation of the optimisation model/methodology is the topic of Chapter 2. Then the construction and contents of the dataset are considered in Chapter 3. Hereafter the model implementation is described in Chapter 4 in terms of model dimensions and calculation of costs and catches per day. In addition, the strict mathematical formulation of the model, outlining the equations, is put forward. Chapter 5 contains a presentation of the stakeholders, how they are grouped, and the corresponding weights. Moreover a basis scenario is introduced. A series of model runs, one for every stakeholder and stakeholder group, generate the results. These are considered in Chapters 6 and 7 for the short run and long run scenarios, respectively. The effectiveness and applicability of this form analysis is the topic of Chapter 8, which concerns the implications for management. Finally, general conclusions are drawn in Chapter 9.

2. Description of the model

This chapter presents the general aspects of the model formulation. The model is set up in a multi-objective goal programming (GP) framework. A general treatment of the GP and other multi-objective methodologies is beyond the scope here. Instead, readers are encouraged to read Steuer (1986) and Romero (1991). A review of the applications to fisheries can be found in Mardle and Pascoe (1999).

When solving the GP problem in relation to the Danish fisheries, two variables can be considered as endogenous. These are the number of days at sea and number of vessels, where the former includes all the time between leaving and returning to the homeport[1].

When choosing the endogenous variables, it is necessary to consider which time horizon is analysed. A distinction can be made between the short run and long run. In the short run, the number of vessels and their characteristics are not considered changeable. The number of days at sea is therefore the only changeable variable. In the long run, both variables can be changed and are thus assumed endogenous.

The model formulation consists of three main components:

A. Achievement function
B. Goal constraints (short and long run)
C. General modelling constraints (short and long run)

In correspondence with the three main above-mentioned components, the structure of the GP programme is expressed as follows:

(A) $$Minimise \sum_i w_i \times \left(\frac{n_i + p_i}{\max dev_i} \right)$$ for i=1,..,k

s.t.:

(B) $$f_i(\boldsymbol{x}, \boldsymbol{y}) + n_i - p_i = f_i^*$$ for i=1,..,k

(C) $$\boldsymbol{x} \in X, \boldsymbol{y} \in Y \quad ; \quad n_i, p_i \geq 0$$ for i=1,..,k

[1] The number of days at sea is used instead of fishing time, i.e. the time where the gear is deployed, the reason being that the former includes the total time where the vessels are performing an economic activity.

where:

- $\boldsymbol{x}$ and $\boldsymbol{y}$ are vectors of the endogenous variables, i.e. number of vessels and days at sea (per vessel) respectively ($\boldsymbol{x} \in X$ and $\boldsymbol{y} \in Y$ represents a set of constraints – general modelling constraints that enclose the set of feasible solutions)
- $f_i(\boldsymbol{x},\boldsymbol{y})$ is objective function i
- f_i^* is the target value of $f_i(\boldsymbol{x},\boldsymbol{y})$
- $\max dev_i = \max\{f_i^* - f_{i*}, f_{i*} - f_i^*\}$ is the maximum deviation from target i, where f_{i*} is the anti-ideal value for objective function i
- n_i and p_i are negative and positive deviational variables from f_i^* (under- and overachievement)
- w_i is the weight associated with objective i
- k is the number of objectives

Determination of target and anti-ideal values is commented in the next section.

When the GP problem is solved, the achievement function (A) is minimised subject to goal constraints (B) and the general modelling constraints (C). This way a solution is sought that best satisfies all the goals simultaneously (that is, so that the individual objectives are all as close to their target value as they can possibly be at the same time). Not all objectives can meet their target simultaneously[2] and a "best alternative" is required. In the goal constraints, non-negative deviational variables measure the distance to the target. This means that the achievement function expresses the aggregated distance from all the goals. In other words, minimising the achievement function corresponds to finding the solution that minimises the overall (weighted 1-norm) distance to the targets. The weights represent the preference structure of the decision maker.

Determination of weights is a crucial task in multi-objective programming. Previous research, conducted by IFM (Nielsen and Mathiesen, 2002), has brought forward the different stakeholders' preferences. Using the Analytic Hierarchy Process (AHP) method (Saaty, 1980), the individual stakeholders' ranking between the objectives has been elicited. A weighting vector represents the individual stakeholder's ranking of objectives. By applying such weights, the stakeholders' preferences are directly incorporated into the GP programme.

[2] Ignoring the trivial case with no trade-off between objectives.

Since the objectives are measured in different units (currency, weight, activity) and have different numerical values, the deviations are scaled. Scaling is applied to avoid a solution of the model that is biased, giving some goals artificially higher weights. The choice of scaling factor varies in GP formulations, cf. Romero (1991). Often target values or maximum range of the objective are applied[3]. The maximum range is being used for this model. Note that it relates deviations to the interval [0,1][4].

In the following two sections, the different objectives and constraints included in the model will be presented and partly discussed. The mathematical formulation of the objectives and constraints is placed in Chapter 4.

2.1. Objectives and achievement function

Seven objectives are included in the modelling of the Danish industrial fishery in the North Sea. Initially, there were eight objectives, but one has been omitted. The excluded objective was "Stop the industrial fishery in the North Sea". A treatment of this objective, together with reasons and implications of the exclusion, will be discussed later on.

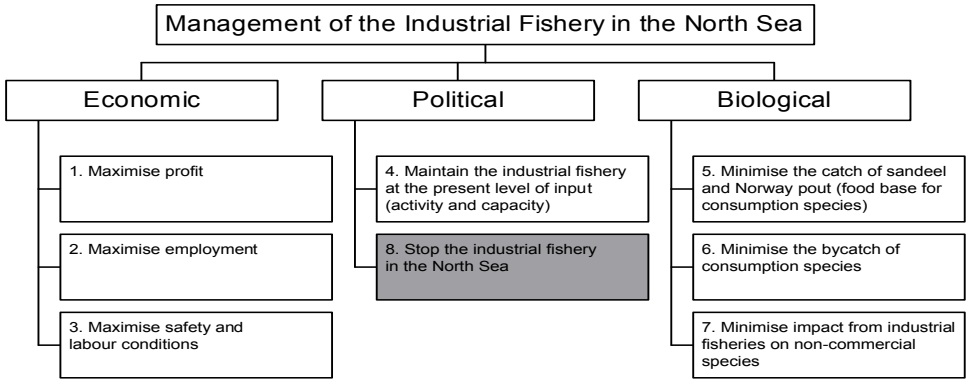
The objectives can be categorised into three groups: 1) economic, 2) political and 3) biological objectives. The seven (eight) objectives are shown in Figure 2.1.

Meaningful mathematical formulations of the objectives are fundamental to the model. The seven objective functions ($f_i(x,y),\ i=1,..,7$) are incorporated in the goal constraints (B). The background and modelling of each objective will therefore be discussed below.

[3] The first method is not applicable to this model, since some of the target values are zero.

[4] A third scaling method, where deviations are related to the 1999 values of the objective functions, has also been applied to the model. Comparing the resulting outcome of the two methods gave an impression of the sensitivity with respect to scaling. Actually, the results were similar with exception of smaller deviations, so choosing between these two methods would not be decisive for the outcome.

Figure 2.1. Hierarchy of objectives



Source: Nielsen and Mathiesen, 2002.

1. **Maximise profit**
   This objective is the classical economic assumption with respect to the objective of producers, i.e. fishermen. It is related to the wish of having the highest return on the invested capital.

   In the short run, profit is measured as total yearly contribution margin i.e. catch value less variable costs. In the short run scenarios it is assumed that fixed costs do not influence the behaviour of the vessels.

   In the long run, profit is measured as total yearly profit i.e. catch value less both variable and fixed costs. Here the fixed costs are relevant to include, because vessels can alter the size of fixed factors.

2. **Maximise employment**
   Maximising the number of fulltime employees can be important for many different reasons. Amongst these are regional and employment aspects.

   This objective is modelled by maximising the total yearly payment of labour. The physical number of employees is not used due to data limitations. However, by dividing the yearly total by the average salary of an industrial worker, which is considered the opportunity employment for fishermen, an approximation can be found.

3. **Maximise safety**
   Securing safe and reasonable working conditions onboard the vessels can be relevant in order to attract and keep employees in the fishing sector.

   Safety is, however, a less tangible objective to put into numerical terms. Aspects like number of employees, and/or size and condition of the vessel both seem relevant. However, it has been chosen to maximise the total maintenance cost, which includes cost for maintenance of vessel, machines, electronic equipment and other assets. The motive for choosing maintenance cost stems from the consideration that the higher these costs are, the more is being done to keep the vessel in an updated working order.

4. **Maintain the industrial fishery at present level of input in the North Sea**
   Sustaining the current level of activity is based on various political issues. The primary reason is related to the Multi-Annual Guidance Programme.

   From a modelling perspective, this objective is decomposed into two measures in form of activity and capacity. Activity is measured as the sum of days at sea times kW per day, while capacity is measured as the sum of vessels times tonnage per vessel. The activity measures are thus directly related to the measures used in effort and capacity regulation in the European Union.

   The aim in this objective is to keep total activity and capacity at the 1999 level.

5. **Minimise catch of sandeel and Norway pout (food base for consumption species) in the North Sea**
   Many of the consumption species found in the North Sea are predators of sandeel and Norway pout. Thus, in order to increase the availability of food for the consumption species a reduction in the catch of these species could be relevant[5].

   The objective is modelled by minimising the total catch volume of sandeel and Norway pout caught in the North Sea.

[5] Even though this is primarily the concern of UK stakeholders (Nielsen and Mathiesen, 2002), it may also influence the Danish fishery of other species. A possible effect from reducing the catch of sandeel and Norway pout, so that other fisheries become more attractive, is not incorporated in the model.

6. **Minimise bycatch of consumption species in the North Sea**
   In some situations, the industrial fishery has a bycatch of consumption species. This is an undesired outcome, because it influences the catch possibilities in the consumption fishery.

   In some sense, this objective corresponds to minimising non-clean industrial fisheries, i.e. catch of consumption species when they are not targeted. Alternatively, one could choose to minimise catch of consumption species all together. However, this would remove the clean consumption fishery, which is not implied by the objective.

7. **Minimise impact on birds etc. in a specific area**
   An area around the Scottish coast is a bird reserve for kittiwake. The availability of food for these birds is considered important, because it is their breeding grounds. The seventh objective therefore seeks to minimise the total catch volume of all species in that specific area of the North Sea.

The model covers other fishing areas than the North Sea in order to include all the revenues and costs related to fishing activities of the included vessels. This will be discussed in detail later, but is mentioned here because of the importance in relation to the objectives. The objectives are only related to activities performed in the North Sea with one exception. In the long run scenario, the profit objective is set to maximise the profit in all areas. The reason being that a division of the fixed costs between areas was not considered possible.

In order to determine the target (ideal) values, ahead of running the GP model, optimisations are performed where one objective is maximised (minimised) at a time, disregarding the others and subject to the constraints in (C). In this way, each target becomes an upper (lower) bound for a feasible objective value. Obviously, objective 4 is different with the 1999 level being the target.

For example the following program is solved to determine f_1^*:

$$\begin{aligned} &Maximise\ f_1(\boldsymbol{x}, \boldsymbol{y}) \\ &s.t.: \\ &\boldsymbol{x} \in X, \boldsymbol{y} \in Y, \end{aligned}$$

where the restrictions on $\boldsymbol{x}$ and $\boldsymbol{y}$ are the same as in (C).

For the seven optimisations with only one objective, the resulting output of the endogenous variables, i.e. number of vessels and days at sea, is used to calculate the other objective function values. Let f_i^* be the ideal value found by optimising objective i disregarding the others. Let f_{ij} ($j \neq i$) be the value for objective j calculated from the output. This gives rise to the following square (trade-off) matrix:

$$\begin{pmatrix} f_1^* & \cdots & f_{1j} & \cdots & f_{17} \\ \vdots & \ddots & & & \vdots \\ f_{i1} & & f_{i=j}^* & & f_{i7} \\ \vdots & & & \ddots & \vdots \\ f_{71} & \cdots & f_{7j} & \cdots & f_7^* \end{pmatrix}$$

For each column (objective) j (j=1,..,7), the anti-ideal value is determined by finding the f_{ij} ($i \neq j$) that gives rise to the greatest difference between the ideal value f_j^* and f_{ij}.

It is emphasised that determination of target and anti-ideal values is carried out prior to running the GP programme. They work as parameters in the GP programme (A)-(C).

2.2. General modelling constraints (short and long run)

General model constraints are designed to ensure a realistic modelling of the fishery. They enclose the set of feasible solutions. Omitting these general modelling constraints would imply a solution that is impossible to realise.

In the short run, six constraints are included:

1. Unchanged number of vessels
2. Non-negative contribution margin per year
3. Minimum number of days at sea per year
4. Maximum number of days at sea per month
5. Catch less than the Total Allowable Catch (TAC)[6]

[6] The model is set up to reflect the consequences on the industrial fishery conducted in 1999, if various stakeholders' preferences are included in a multi-objective framework. It is therefore necessary to assume that the biological parameters do not change in order to maintain the 1999 level. Hence,

6. No fishery takes place without (any) catch

Likewise, six constraints are included in the long run. These are, besides constraints 3, 4, 5 and 6 from above, the following two constraints:

1. Non-negative profit per year
2. Maximum number of vessels

Generally, the constraints are self-explanatory with the exception of constraint 6. This constraint is necessary due to the inclusion of objective 4. Without the constraint, the solution to the GP problem would include the allocation of days at sea to vessels fishing in areas where their catch is very low or zero. Considering that in reality this is not the behaviour of the fishermen, constraint number 6 is included.

constraint 5 ensures that catches are less than or equal to 1999 catches. For the industrial species, the total catch was generally not near the TAC in 1999, thus using the TAC's could imply catches, which were not biologically possible.

3. Data

The analysis only includes trawlers above 18 metres in length with a catch value of industrial species in the North Sea accounting for more than one percent of their total catch[7] value. These trawlers caught the primary part of the industrial catches in the North Sea[8].

Three data sources have been used to produce the parameters and matrices included in the model. These are the Danish Directorate of Fisheries (FD), the Danish Institute of Fisheries Research (DIFRES) and the Danish Research Institute of Food Economics (FOI). From the two former, the number of vessels, catches, number of days at sea and various other physical measures are obtained. From the latter, information about costs are available. Some details concerning the construction of the joined dataset from the three data sources is commented in Appendix A.

Data was extracted from the databases for 1999. This year was chosen because it was the most recent year where cost statistics were available.

In the dataset, a range of different information is available at the individual vessel level. Among the most important are catches based on fishing area, month and species and number of days at sea. Moreover, the dataset contains an array of physical characteristics of the included vessels such as length, tonnage, engine power and homeport.

The subsequent sections serves to give a picture of the fishery in focus and thus the parameters of the model.

3.1. Vessels

The total number of vessels included in the dataset is 147. Table 3.1 shows the number of vessels in the dataset and their distribution among counties. Most of these had their homeport in Ringkøbing County, while the greatest share of large vessels originate from Ribe County, which includes the largest homeport for the industrial fleet, Esbjerg. The last column of Table 3.1 shows that the trawlers fishing in the North Sea constitute a large fragment of all the active trawlers in the Danish fleet, 1999.

[7] When the term catch is used, no consideration is made of discard, since information on this issue is not available. Catch here, and in the following, therefore refers to the amount landed.
[8] Approximately 98% of the industrial catches in the North Sea during the period 1999-2001 were caught by these trawlers.

Table 3.1. Number of vessels with respect to length segment and county[9]

Fleet segment	Nordjylland/ Viborg	Ribe	Ringkøbing	Total	% of active trawlers
Trawlers 18-24m	3	0	19	22	20
Trawlers 24-40m (other)	19	5	9	33	42
Trawlers 24-40m (industrial)	6	26	27	59	94
Trawlers above 40m (other)	4	11	2	17	100
Trawlers above 40m (industrial)	1	10	5	16	100
Total	33	52	62	147	52

Notes: Trawlers are classified as "other", if their catch of industrial species comprise less than 80% of their total catch value.

3.2. Days at sea

Days at sea together with number of vessels describe the activity in the fishery. Relating number of days at sea to fishing areas highlights that the primary part (57%) of the days at sea is spent in the Central North Sea, which is consistent with the way vessels are selected. The Northern North Sea accounts for 16% and the Southern North Sea just 3%. However, around one-quarter (23%) of the number of days at sea is spent in other fishing areas than the North Sea[10].

On average, the industrial trawlers above 40 metres have the largest number of days at sea. During one year, they are on average active for 263 days, leaving only 100 days for other purposes such as maintenance. The average number of days at sea for each of the fleet segments is displayed in Table 3.2.

Table 3.2. Average days at sea for fleet segments

Fleet segment	Average number of days at sea
Trawlers 18-24m	150
Trawlers 24-40m (other)	231
Trawlers 24-40m (industrial)	223
Trawlers above 40m (other)	213
Trawlers above 40m (industrial)	263

Notes: Trawlers are classified as "other", if their catches of industrial species comprise less than 80% of their total catch value.

[9] A vessel belongs to a given county if its homeport is situated there.
[10] The total number of days spent at sea in all areas is 31,870.

3.3. Catches

The selected vessels achieve a large amount of their total catch value from the industrial fishery in the North Sea. The requirement for inclusion was 1% of the catch value, but the average vessel in the analysis far exceeds this, cf. Table 3.3. Even though the trawlers below 24 metres are the least dependent on the fishery in the North Sea, they achieve on average 20% of their catch value from the industrial fishery. The industrial trawlers between 24 and 40 meters achieve on average 75% of their total catch value from the industrial fishery in the North Sea. Altogether, an average vessel in the dataset receives 59% of total catch value from the North Sea industrial fishery.

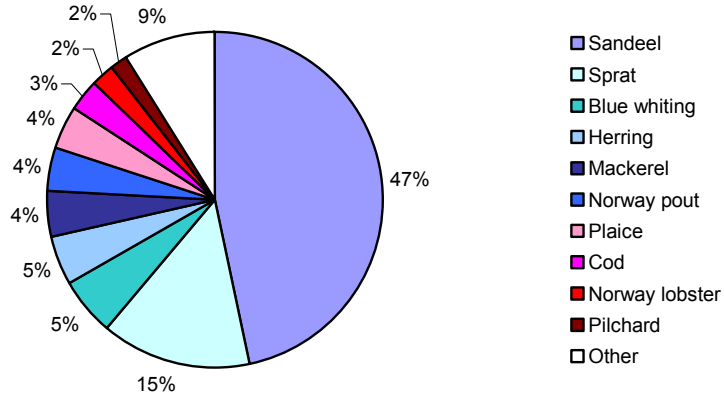
Table 3.3. Total catch value compared to value of industrial fishery in the North Sea

	------ Total catch value -----		Industrial catch value in the North Sea[1]		
Fleet segment	1,000 DKK	1,000 Euro[2]	1,000 DKK	1,000 Euro	Share of total
Trawlers 18-24m	60,325	8,119	11,979	1,612	20%
Trawlers 24-40m (other)	191,624	25,791	82,532	11,108	43%
Trawlers 24-40m (industrial)	279,549	37,624	209,537	28,201	75%
Trawlers above 40m (other)	139,466	18,771	68,346	9,199	49%
Trawlers above 40m (industrial)	120,424	16,208	91,612	12,330	76%
Total	791,388	106,513	464,006	62,450	59%

Notes: Trawlers are classified as “other”, if their catches of industrial species (all areas) comprise less than 80 percent of their total catch value. The percentage in the last column only refers to catches in the North Sea. 1) Catches in the North Sea of industrial species (blue whiting, sprat, horse mackerel, pilchard, Norway pout, sandeel); 2) The applied exchange rate is 1 Euro = 7.43 DKK.

Figure 3.1 illustrates the catch composition in the North Sea fishing areas. Sandeel and sprat are the most important species in terms of catch value. In total, 47% of the catch value in the North Sea is obtained from the sandeel fishery for the selected vessels. Sprat is also an important species, accounting for 15% of the catch value in 1999.

Figure 3.1. Composition of total catch value, for the selected vessels in the North Sea



Besides the industrial species, an array of consumption species is also caught. Amongst these are herring, mackerel, cod, plaice and Norway lobster. A distinction is made between catching these consumption species as bycatch while fishing industrial species, or as target species with a minor bycatch of industrial species. The following approach is used to classify the catches in one of the two categories: When catch weight of consumption species per day in a given month and area is less than 10%[11] of total catch weight per day, it is considered to be bycatch from industrial fishing. A catch is classified as being a consumption catch, if the opposite is the case.

3.4. Costs

The Statistics Division at FOI prepares yearly information on average costs for the vessels in the different fleet segments.

[11] 10 percent refers to the common restriction on share of target species caught using different mesh sizes, cf. (European Community) Regulation 850/98.

From this statistic eight different cost items are derived to be used in the model. These are as listed below:

a) Fuel and lubricants
b) Ice, provisions, stores
c) Maintenance
d) Sales costs
e) Rent and tax on real property
f) Insurance
g) Other services (administration, telephone etc.)
h) Crew payment

The trawlers included in the cost statistics are not stratified to describe the trawlers in this dataset and therefore the cost items are adjusted. For every fleet segment, each cost item is scaled according to the average catch value for each fleet segment, relative to the catch value of the trawlers included in the account statistics for the same fleet segment.

The adjusted average cost items are shown in Table 3.4. Not surprisingly, there is a tendency for cost to increase with increasing size of vessels.

Table 3.4. Average costs for fleet segments in 1999 (1,000 DKK)

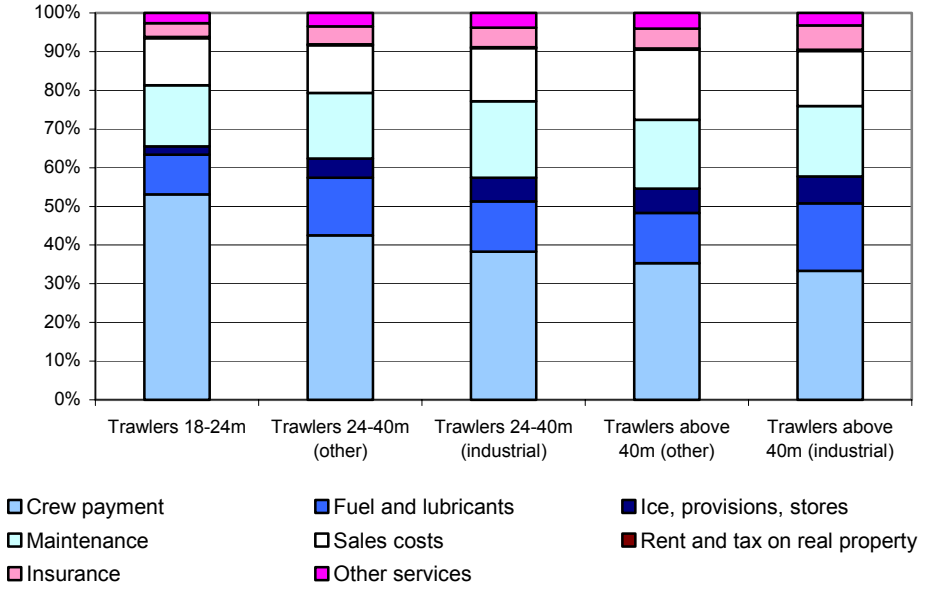
Fleet segment	Fuel and lubricants	Ice, provisions, stores	Mainte-nance	Sales costs	Rent and tax on real property	Insurance	Other services	Crew pay-ment
Trawlers 18-24m	215	46	334	256	8	75	55	1,122
Trawlers 24-40m (other)	687	233	783	570	12	211	162	1,965
Trawlers 24-40m (industrial)	578	270	873	610	10	223	170	1,694
Trawlers above 40m (other)	869	422	1,197	1,219	21	345	272	2,375
Trawlers above 40m (industrial)	1,180	471	1,234	967	20	427	220	2,261

Notes: Trawlers are classified as “other”, if their catches of industrial species comprise less than 80% of their total catch value.

The relative importance of the cost items is illustrated in Figure 3.2. Crew payment is clearly the dominant cost item followed by maintenance, sales and fuel costs. The figure reveals that the shares are not equal for the different fleet segments. The impor-

tance of crew payment decreases as the size of vessels increase. Maintenance, insurance and other services have a somewhat constant share of cost among the five fleet segments, whereas the share of costs for ice etc., sales and fuel shows a tendency to increase as the vessel size increases.

Figure 3.2. Relative share of the eight cost items of total costs in 1999



4. Implementation

In order to analyse different scenarios in the Danish industrial fishery, a programming model was set up according to the general framework and the objectives described in Chapter 2. The computer programme General Algebraic Modelling System (GAMS)[12] was the optimisation software used for the implementation. The number of dimensions included in the model defines the level of detail. This indirectly also determines the appearance of the data matrices based on the data described in Chapter 3.

The following section will therefore present the dimensions used in the Danish model. Hereafter, the calculation of the catch and cost matrices will be presented in Section 4.2 and finally the strict mathematical presentation of the model outlining the equations will be put forward in Section 4.3.

4.1. Dimensions

The level of detail is determined by five sets of dimensions, which have to some extent already been presented in Chapter 3. These are:

1. Fleet segment (5 alternatives)
2. County (3 alternatives)
3. Fishing area (8 alternatives)
4. Species (33 alternatives)
5. Month (12 alternatives)

In the following, expressions in *italic* refer to the indices associated with the model dimensions.

4.1.1. Fleet segment (*f*)

The trawlers are divided into different fleet segments, which are used by the FOI in the yearly prognosis of the economic situation of the Danish fishery. The fleet segments are constructed with length being the primary classification, but for the larger trawlers, a deduction is also made between what constitutes their primary fishery. If more than 80% of the catch value is industrial species, the trawler is classified as an industrial trawler.

[12] For a general introduction to GAMS see Brooke et al. (1998).

The five segments are as follows:

1. Trawlers 18-24m
2. Trawlers 24-40m (other)
3. Trawlers 24-40m (industrial)
4. Trawlers above 40m (other)
5. Trawlers above 40m (industrial)

4.1.2. County (*c*)

In order to perform regional studies related to local consequences of the multi-objective approach, all the included trawlers were differentiated with respect to homeport (vessel district). Since not all homeports are equally well represented, they are aggregated into three counties in order to secure anonymity. These are Ribe, Ringkøbing and Nordjylland/Viborg. More details on vessel districts and allocation to counties can be found in Appendix B.

4.1.3. Fishing area (*a*)

Eight fishing areas are considered in the model, four of which constitute the North Sea. Furthermore, the inner Danish fishing areas and "other areas" are included in the model. This serves to give a more realistic picture – and modelling – of the fishery, since some vessels are unlikely to fish only in the North Sea during one year. As mentioned earlier, including only the North Sea would leave a share of missing revenue.

The fishing areas are:

1. The Northern North Sea (4A)
2. The Central North Sea[13] (4B)
3. The Southern North Sea (4C)
4. Sandeel box[14] (subarea of 4B)
5. The Skagerrak (3AN)
6. The Kattegat (3AS)
7. The Baltic Sea, the Sound and Belts (3BCD)
8. Other areas

[13] Excluding the Sandeel box.
[14] Subarea of 4B (ICES squares: 3958, 4057, 4058, 4156, 4157, 4158, 4257, 4258, 4357, 4358, 4458). Note that areas 2 and 4 are disjointed.

4.1.4. Species (*s*)

The number of different species is 33. These are both industrial and consumption species. Most of the species are of little importance to the fishery (in terms of catch value[15]). On the other hand, a detailed description of the catch can be of interest when concerned with mixed fisheries and when discussing issues such as bycatch. Moreover, consumption species are included in the analysis for the same reason as areas, other than those of the North Sea, are included. All the species are listed in Appendix B.

4.1.5. Month (*m*)

Working on a monthly level gives an opportunity for the model to incorporate seasonal variations in the fishery.

4.2. Calculation of catches and costs per day

Every time the model is run, several data files are included. These files contain data matrices, one- or multidimensional, that are created outside the model from the data described in Chapter 3. This gives information on number of vessels and days at sea, catches, prices and costs, all for 1999, and it is possible to calculate catch per unit effort (day at sea) and variable costs per day within the model.

4.2.1. Catches

Catch per day at sea is calculated for an average vessel in each fleet segment and county. The formula for calculating the average catch per day at sea, of species *s* in area *a*, month *m*, by a vessel that has *c* as home county and belongs to fleet segment *f* ($CPUE_{f,a,m,s,c}$), is:

$$CPUE_{f,a,m,s,c} = \frac{SUMCATCH_{f,a,m,s,c}}{SUMNOFD^{99}_{f,a,m,c}} \tag{4.1}$$

where $SUMCATCH_{f,a,m,s,c}$ is the total catch in area *a*, month *m*, of species *s* for all vessels that have *c* as home county and belong to fleet segment *f*. Likewise, $SUMNOFD^{99}_{f,a,m,c}$ is the observed days at sea for these vessels in area *a* and month *m*.

[15] See the data description for a comment on catch composition.

It is now possible to define a catch equation, i.e. the catch in area *a*, month *m,* of species *s*, for vessels that have *c* as home county and belong to fleet segment *f*:

$$CATCH_{f,a,m,s,c} = CPUE_{f,a,m,s,c} \times NOV_{f,c} \times NOFD_{f,a,m,c}, \tag{4.2}$$

where $NOV_{f,c}$ is the number of vessels in fleet segment *f* from county *c* and $NOFD_{f,a,m,c}$ is the average number of days at sea in area *a*, month *m*, for a vessel that has *c* as home county and belongs to fleet segment *f*.

4.2.2. Costs

Eight matrices corresponding to the cost items a)-h) listed in Section 3.4 are used to calculate the cost components of the model. The "Sales cost" matrix contains coefficients corresponding to the share of average sales cost relative to average value of landings. The crew payment matrix also contains coefficients that correspond to a share of the revenue.

The cost items are allocated to five different cost components used in the model. Catch per day, given by the matrix of Equation 4.1 together with prices and number of days at sea[16], is used to transform costs into per-day measures. The components and corresponding relations to the cost items are outlined below:

1.	Average variable operating cost:	a) + ½×b)
2.	Average fixed cost:	c) + e) + f) + g)
3.	Average variable landings cost:	½×b)
4.	Average variable sales cost:	d)
5.	Average variable crew cost:	h)

The formulas used to calculate the five cost components are given as[17]:

1: *Average variable operating cost per day at sea:*

$$OPECOST_f = \left(FUEL_f + 0.5 \times ICE_f\right) / TNOFD_f^{99}, \tag{4.3}$$

[16] In the dataset, for 1999.
[17] Where the variable cost components are transformed into per-day measures.

where $FUEL_f$ and ICE_f are the total yearly costs of "Fuel and lubricants" and "Ice, provisions, stores" respectively, for all vessels in fleet segment *f*. $TNOFD_f^{99}$ is the total number of days at sea for all vessels in fleet segment *f*.

2: *Average fixed cost per year:*

(4.4) $$AFCOST_f = MAIN_f + RENTTAX_f + INSURANCE_f + SERVICES_f$$

where $MAIN_f$, $RENTTAX_f$, $INSURANCE_f$ and $SERVICES_f$ are average yearly costs of maintenance, rent and tax on real property, insurance and other services, for a vessel in fleet segment *f*.

3: *Average variable landings cost per day:*

(4.5) $$LANCOST_{f,a,m,c} = \sum_s CPUE_{f,a,m,s,c} \times \left(0.5 \times ICE_f / TCATCH_f\right),$$

where $TCATCH_f$ is the total catch weight for all vessels in fleet segment *f*.

4: *Average variable sales cost per day:*

(4.6) $$SALECOST_{f,a,m,c} = \sum_s CPUE_{f,a,m,s,c} \times PRICES_{f,a,m,s,c} \times SALE_f$$

where $PRICES_{f,a,m,s,c}$ are the average price of species *s* observed (in the dataset) in area *a*, month *m*, for vessels in fleet segment *f* with *c* as home county. $SALE_f$ is the "sales cost" coefficient for a vessel in fleet segment *f*.

5: *Average variable crew cost per day:*

(4.7)
$$CREWCOST_{f,a,m,c} = \left(TREV_{f,a,m,c} - OPECOST_f - LANCOST_{f,a,m,c} - SALECOST_{f,a,m,c}\right) \times CRW_f$$

where CRW_f is the crewcost coefficient for a vessel in fleet segment *f* and $TREV_{f,a,m,c}$ is the average total revenue per day in area *a*, month *m*, for a vessel in fleet segment *f* originating from county *c*, that is

(4.8) $$TREV_{f,a,m,c} = \sum_s CPUE_{f,a,m,s,c} \times PRICES_{f,a,m,s,c} \cdot$$

The cost components in their current form have some limitations. The cost items from the account statistics are differentiated only with respect to the fleet segments. As seen above, landings, sales and crew costs are related to catch, which gives a more detailed specification of these components.

Direct relations to area, month and species are not available. One could argue that not all these issues are equally important. For example, it seems reasonable to assume that the cost of fishing one day in different areas is the same, but this is not necessarily true. Distance from homeport to fishing area could very well be influential. Seasonal variations, such as changing weather conditions, might also be relevant.

4.2.3. Mathematical representation of the model

The intention here is to present the strict mathematical formulation of the optimisation programme. Functions and equations of the programme will be outlined below, according to the three main components of the general formulation in Chapter 2.

In addition to the indices introduced earlier, the following are needed:

Indices	Description
is	Industrial species
cs	Consumption species
sn	Sandeel and Norway pout
na	North Sea areas

The index *is* corresponds to a subset of all the species (industrial species) and *cs* to its complement (consumption species). Sandeel and Norway pout are two of the industrial species.

The North Sea areas, indexed by *na*, cover the fishing areas 1-4 in Section 4.1.3.

Before the equations are stated it is pointed out that NOV and NOFD represent the endogenous variables, number of vessels and number of days at sea.

Achievement function:

Weighted sum of (scaled) deviational variables:

$$(4.9)\quad \begin{aligned} & w_1 \times \left(\frac{n_1}{MAXDEV_1} \right) + w_2 \times \left(\frac{n_2}{MAXDEV_2} \right) + w_3 \times \left(\frac{n_3}{MAXDEV_3} \right) + w_4 \times \left(\frac{n_4 + p_4}{MAXDEV_4} \right) \\ & + w_5 \times \left(\frac{p_5}{MAXDEV_5} \right) + w_6 \times \left(\frac{p_6}{MAXDEV_6} \right) + w_7 \times \left(\frac{p_7}{MAXDEV_7} \right) \end{aligned}$$

where w_i is the weight associated with objective i and n_i, p_i are under- and over-achievement from target i (i=1,..,7). $MAXDEV_i$ refers to the maximum deviation from target i (the maximum range of the objective). Recall that objectives 1-3 are maximised and 5-7 are minimised. Target values are set by maximising (minimising) one objective function at a time, disregarding the others. This way each target becomes an upper (lower) bound for a feasible objective value. Therefore, some of the deviational variables are redundant and have been omitted.

Goal constraints (short run):

Maximise profit:

(4.10)

$$\sum_{f,na,m,c} CMNOFD_{f,na,m,c} \times NOV_{f,c} \times NOFD_{f,na,m,c} + n_1 - p_1 = tPROFIT$$

Maximise employment:

(4.11)

$$\sum_{f,na,m,c} CRWCOST_{f,na,m,c} \times NOV_{f,c} \times NOFD_{f,na,m,c} + n_2 - p_2 = tEMPLOY$$

Maximise safety:

(4.12) $$\sum_{f,na,m,c} MAIN_f \times NOV_{f,c} \times NOFD_{f,na,m,c} + n_3 - p_3 = tSAFETY$$

Maintain the industrial fishery at the present level of input:

(4.13)

$$\frac{1}{2} * \left[\frac{\sum_{f,na,m,c} KW_f \times NOFD_{f,na,m,c}}{\sum_{f,na,m,c} KW_f \times NOFD^{99}_{f,na,m,c}} + \frac{\sum_{f,c} GTGRT_f \times NOV_{f,c}}{\sum_{f,c} GTGRT_f \times NOV^{99}_{f,c}} \right] + n_4 - p_4 = 1$$

Minimise catch of sandeel and Norway pout (food base for consumption species):

(4.14) $$\sum_{f,na,m,sn,c} CPUE_{f,na,m,sn,c} \times NOV_{f,c} \times NOFD_{f,na,m,c} + n_5 - p_5 = tMINCATFB$$

Minimise bycatch of consumption species:

(4.15) $$\sum_{f,na,m,cs,c} CPUE_{f,na,m,cs,c} \times BYCATCH_{f,na,m,cs,c} \times NOV_{f,c} \times NOFD_{f,na} + n_6 - p_6 = tMINBYCAT$$

Minimise impact on birds etc. in a specific area (minimise total catch of all species in a specific area of the North Sea):

(4.16) $$\sum_{f,m,s,c} CPUE_{f,'Sandeel\ subarea',m,s,c} \times NOV_{f,c} \times NOFD_{f,'Sandeel\ subarea',m,} + n_7 - p_7 = tMINCATA$$

where

$CMNOFD_{f,na,m,c}$:	Average contribution margin per day at sea
$NOV_{f,c}$:	Number of vessels
$NOFD_{f,na,m,c}$:	Average number of days at sea
$CRWCOST_{f,na,m,c}$:	Average crew cost per day at sea
$MAIN_f$:	Average maintenance cost per day at sea
KW_f:	Average kW per day at sea
$GTGRT_f$:	Average gross tonnage (gross registered tonnage when gross tonnage is unavailable)
$NOFD^{99}_{f,na,m,c}$:	Average number of days at sea in 1999
$NOV^{99}_{f,c}$:	Number of vessels in 1999
$CPUE_{f,na,m,s,c}$:	Average catch per day at sea

$BYCATCH_{f,na,m,s,c}$:	0-1 matrix, with 1 corresponding to consumption species, where total catch of consumption species per day is less than 10% of total catch per day

and

tPROFIT:	Target value for the profit objective function
tEMPLOY:	Target value for the employment objective function
tSAFETY:	Target value for the safety objective function
tMINCATFB:	Target value for the objective function to minimise bycatch of sandeel and Norway pout
tMINBYCAT:	Target value for the objective function to minimise by catch
tMINCATA:	Target value for the objective function to minimise catch in the Sandeel box

Goal constraints (long run):
Constraints (4.11)-(4.16) are the same, but the profit criterion involves fixed costs in the long run perspective. Profit is calculated as revenue less variable and fixed costs. Because of the fixed costs term, the long run profit involves all fishing areas, whereas the other objectives are only related to activities performed in the North Sea.

Therefore, the profit maximising goal constraint becomes:

$$(4.17) \qquad \sum_{f,c}\left(NOV_{f,c} \times \left(\sum_{a,m} CMNOFD_{f,a,m,c} \times NOFD_{f,a,m,c} - FCYEAR_f\right)\right) + n_1 - p_1 = tPROFIT$$

where $FCYEAR_f$ is the average yearly fixed cost for a vessel in fleet segment *f*. In the long run, not only days at sea, but also number of vessels, are endogenously determined.

Moreover, the general modelling constraints are not all the same for the short and long run scenarios. Thus, the target and anti-ideal values need to be calculated separately for the two scenarios.

General modelling constraints:

Short run:

Number of vessels equals the number in 1999:

(4.18) $$NOV_{f,c} = NOV_{f,c}^{99}$$ for all *f, c,*

Non-negative yearly contribution margin:

(4.19) $$\sum_{a,m} CMNOFD_{f,a,m,c} \times NOFD_{f,a,m,c} \geq 0$$ for all *f, c,*

Minimum number of days at sea per year:

(4.20) $$\sum_{a,m} NOFD_{f,a,m,c} \geq MINNOFDY_{f,c}$$ for all *f, c,*

Maximum number of days at sea per month:

(4.21) $$\sum_{a} NOFD_{f,a,m,c} \leq MAXNOFDM_{f,m}$$ for all *f, m, c*

Catch less than the TACs:

(4.22) $$\sum_{f,m,c} CPUE_{f,a,m,s,c} \times NOV_{f,c} \times NOFD_{f,a,m,c} \leq TAC_{a,s}$$ for all *a, s*

No fishery takes place without (any) catch[18]*:*

(4.23) $$(\sum_{s} CPUE_{f,a,m,s,c}) - NOFD_{f,a,m,c} \geq 0$$ for all *f, a, m, c*

Long run:
Constraints (4.20)-(4.23) are the same.

Non-negative profit per year:

---

[18] This is a valid formulation since the dataset fulfils the relation $\sum_{s} CPUE_{f,a,m,s,c} > 0 \Rightarrow \sum_{s} CPUE_{f,a,m,s,c} \geq 31$. Omitting this constraint would most likely result in peculiar outcomes, especially because of objective 4.

(4.24) $$NOV_{f,c} \times \left(\left(\sum_{a,m} CMNOFD_{f,a,m,c} \times NOFD_{f,a,m,c} - \right) - FCYEAR_f \right) \geq 0$$

for all *f, c*

Maximum number of vessels:

(4.25) $$NOV_{f,c} \leq MAXNOV_{f,c}$$ for all *f, c*

where

$MINNOFDY_{f,c}$:	Minimum number of days at sea for a vessel per year that belongs to fleet segment *f* and has *c* as home county - determined by the minimum observed in the dataset for 1999
$MAXNOFDM_{f,m}$:	Maximum number of days at sea in month *m* for a vessel that belongs to fleet segment *f* and has *c* as home county - determined by the maximum observed in the dataset for 1999
$TAC_{a,s}$:	Total catches of species *s* in fishing area *a* observed in 1999 (this figure is explained in an earlier footnote)
$FCYEAR_f$:	Yearly average fixed costs for a vessel in fleet segment *f*
$MAXNOV_{f,c}$:	Maximum number of vessels belonging to fleet segment *f* and has *c* as home county.

5. Scenarios

The model's ability to perform both a short run and a long run analysis divide the model-runs into two parts. The number of vessels is not considered changeable in the short run. The number of days at sea is therefore the only changeable variable, given this time horizon. In the long run, both variables can be changed and are thus assumed endogenous. Chapters 6 and 7 contain short and long run results respectively.

The model is set up to reflect the consequences and behaviour of the Danish industrial fishery conducted in the North Sea, if the preferences of various stakeholders are included separately in a multi-objective framework. Amongst the stakeholders are fishermen, managers, environmentalists and labour unions. The stakeholders, and grouping of these, are presented in Section 5.1.

The individual stakeholder's preferences have been elicited with the AHP method. Section 5.2 gives a short presentation of the weights and comments on the interests they reflect.

In Section 5.3, the consequences of stopping the Danish industrial fishery in the North Sea are considered. This subject receives special attention since the objective "Stop the industrial fishery in the North Sea" has been left out of the optimisation model. The reasons and implications of the exclusion will be discussed.

Finally, Section 5.4 contains a brief comment on validation and robustness of the model and the basis scenario is introduced.

5.1. Stakeholders

This section gives a short description of the different stakeholders and how these are manually sorted into groups.

The analysis involves 11 stakeholders that are sorted into four groups. The stakeholders' relations to the fishery determine the groups. The stakeholders and allocation into groups are shown in Table 5.1[19].

[19] The groups in Table 5.1 follow Nielsen and Mathiesen (2002).

Table 5.1. Stakeholders and groups

Groups	Stakeholders
Danish Industry	Danish Fishermen's Association (DFA) Association of Fish Meal and Fish Oil Manufactures in Denmark (AFMD) General Workers Union in Denmark – Fisheries committee (GWUD)
Environmentalists	Royal Society for Protection of the Birds (RSPB) World Wide Fund for Nature (WWF) Greenpeace International Danish Society for Conservation of Nature (DSCN)
Danish Authorities	Ministry of Food, Agriculture and Fishery – Denmark (MFAF) Danish Institute for Fisheries Research (DIFRES)
UK Authorities and Industry	Ministry of Agriculture, Fishery and Food – UK (MAFF) The National Federation of Fishermen's Organisations – UK (NFFO)

The different weights reflect different perceptions of an optimally managed fishery. Before even considering the weights, it is well known that stakeholders belonging to different groups/professions have diverging interests. For example, the perception of an optimally managed fishery seen from the Danish Industry's point of view will not coincide with the perception of the Environmentalists.

5.2. Weights

The weights results from an AHP analysis conducted by IFM without the objective "Stop the industrial fishery in the North Sea". The weights presented here are therefore slightly different from Nielsen and Mathiesen (2002), since this objective has been excluded. This section contains a representation of the different weights together with a comment on the interests they are considered to reflect.

The weights used in the optimisation model are given in Table 5.2 below. The aggregated weights cannot directly be deducted from the individual weights. This has to do with the way that AHP is used to calculate aggregated weights. It is the geometric mean approach that is applied in the present study. Every stakeholder returns a questionnaire. This gives rise to a matrix of two-by-two comparisons between objectives, that is used to calculate the given stakeholder's weighting vector. With more stakeholders, and matrices, an aggregated matrix is constructed (every entry in this aggregated matrix is the geometric mean of the corresponding entries of the stakeholders' matrices). From this matrix, an aggregated weighting vector is calculated.

It is clear that the interests are indeed diverging among the groups. The Danish Industry adds most weight on the economic objectives and maintaining the industrial fishery at present level of input, but also find it relatively important to minimise bycatch of consumption species. This leaves objective 5 and 7 with low weights.

The Environmentalists and the UK Authorities and Industry have somewhat similar preference structures with low weights on objectives 1-4 and higher weights on the biological objectives 5-7. However, the Environmentalists generally find objective 7 most important, while the UK Authorities and Industry see objective 6 as the main concern.

The Danish Authorities are especially interested in minimising the bycatch of consumption species, but also objective 4 receives a relatively high weight.

This polarisation of the weights with either high weights on objectives 1-4 or high weights on 5-7 will presumably result in extreme scenarios for the fishery. As an example, the continuing existence of the Danish industrial fishery in the North Sea is questionable, if the preferences of Greenpeace are realised. Consequences are brought forward through the presentation of output, resulting from applying different stakeholders weights, which will be given in the subsequent Chapters 6 and 7.

Table 5.2. AHP results/weights of all stakeholders and stakeholder groups

		1) Maximise profit	2) Maximise employment	3) Maximise safety	4) Maintain the industrial fishery at present level of input	5) Minimise catch of sandeel and Norway pout	6) Minimise by-catch of con-sumption species	7) Minimise im-pact on birds etc. in a specific area
Danish Industry	DFA	0.269	0.113	0.146	0.257	0.042	0.129	0.044
	AFMD	0.239	0.109	0.145	0.219	0.048	0.187	0.052
	GWUD	0.104	0.137	0.343	0.109	0.133	0.130	0.043
	Group of stakeholders	0.167	0.120	0.160	0.195	0.078	0.216	0.064
Environmentalists	RSPB	0.030	0.038	0.103	0.034	0.184	0.213	0.399
	WWF	0.032	0.032	0.032	0.032	0.290	0.290	0.290
	Greenpeace	0.034	0.035	0.035	0.035	0.319	0.194	0.349
	DSCN	0.025	0.034	0.079	0.025	0.316	0.212	0.309
	Group of stakeholders	0.038	0.044	0.060	0.046	0.240	0.281	0.290
Danish Authorities	MFAF	0.081	0.091	0.058	0.192	0.063	0.433	0.082
	DIFRES	0.056	0.056	0.055	0.091	0.146	0.441	0.155
	Group of stakeholders	0.070	0.074	0.059	0.138	0.100	0.443	0.117
UK Authorities and Industry	MAFF	0.039	0.040	0.064	0.049	0.190	0.348	0.271
	NFFO	0.029	0.035	0.035	0.035	0.257	0.549	0.060
	Group of stakeholders	0.047	0.053	0.056	0.069	0.187	0.457	0.132
All stakeholders:		0.075	0.073	0.093	0.095	0.174	0.327	0.163

5.3. Stop the industrial fishery in the North Sea

Initially, there were eight objectives, one of which (objective 8) was "Stop the industrial fishery in the North Sea". In the process of building the economic model, it turned out that the incorporation of this objective was not straightforward. Ultimately, it was therefore decided to exclude this objective from the economic model for reasons, which will be discussed in this section. In addition, the consequences from stopping the industrial fishery are considered.

A wish to stop the industrial fishery in the North Sea is special in the sense that it is a 0-1 objective, which is either satisfied or not. To model the objective, a reinterpretation is needed, so that it becomes a wish to reduce the industrial fishery in the North Sea, measured in catch weight. This might be somewhat in conflict with the meaning of the objective, but it is reasonable to assume that some degree of satisfaction is better than no satisfaction.

Evaluating the ranking of objectives given by the AHP analysis (and the resulting weights), it turns out that it is primarily the UK Authorities and Industry and the Environmentalists, who express great interest in stopping the Danish industrial fishery. The subsequent step is to investigate what lies behind this wish. Studying the analysis of the stakeholders' preferences (Nielsen and Mathiesen, 2002), the arguments appear to concern biological issues, such as: 1) The stock serves as food base for consumption species, 2) Protection of sea birds, 3) Bycatch of non-target consumption species and 4) Sustainability questioned in general.

It is evident that the motives for stopping the Danish industrial fishery in the North Sea are strongly connected to biological issues. Thus, the wish to stop the industrial fishery in the North Sea is to some extent covered through the biological objectives included via objectives 5, 6 and 7. Reversing the argument, the objective adds extra weight on the other biological objectives. There is a clear tendency to weight biological objectives highly, if the weight is high for the objective "Stop the industrial fishery in the North Sea", and *vice versa*.

In order to evaluate the effect of leaving out the objective, some preliminary tests were conducted to compare the results, concerning values of the other objectives,

from runs where the objective was included and where it was not[20]. The effects depend on which set of weights are applied. If the weights are high on objectives 1-4 and low on 5-8 (cf. DFA), excluding objective 8 has practically no influence. Likewise, if the weights are high on objectives 5-8 and low on 1-4 (cf. Greenpeace), objectives 1 and 2 are slightly smaller with objective 8 included, whereas the others are not significantly influenced. On the other hand, the exclusion of objective 8 seems to have greater influence, if the weights on the different objectives are more alike (cf. MFAF[21]). Of course, the above relations are loosely formulated, but they do provide indications.

To conclude, the coexistence of objectives 5,6,7 and 8 may have unintended consequences, even though the consequences appear to be diminishing, when the weights are more polarised (1-4 vs. 5-8).

When presenting the results for the different stakeholders, the resulting catch weight of industrial species in the North Sea will be calculated for each solution. Implicitly, it is therefore possible to measure the degree of satisfaction of the 8th criterion, despite that it is not directly taken into consideration, when performing the optimisations. See these results in Table C.1 and Table D.1 in Appendix C and D.

Stopping the Danish industrial fishery in the North Sea will most likely have wide-ranging consequences for the Danish fishery. This subject was treated in a report by Andersen and Løkkegaard (2002). The report calculates the consequences, if the entire Danish industrial fishery had been closed in 2001. All fleet segments, where the industrial fishery accounted for at least 10% of total catch value, were considered. These segments also included the five segments considered here.

Andersen and Løkkegaard (2002) measured the consequences of a stop of the industrial fishery with respect to the four variables: 1) catch value, 2) gross value added[22], 3) gross profit[23] and 4) profitability rate[24].

[20] The objective was modelled as minimising the total catch weight of industrial species in the North Sea areas. The tests were conducted in the short run scenario with weights of stakeholders representing different interest groups.
[21] Even though the weight on objective 8 is only 0.031 in this case.
[22] Catch value less variable and fixed costs, not including crew payment, interest and depreciation.
[23] Gross value added less crew payment.
[24] Profitability of the fishery is evaluated by assessing gross profit in relation to the size of invested capital measured in form of insurance value.

The overall effect from stopping the industrial fishery in Denmark, 2001, was estimated to imply severe reductions in catch value (23%), gross value added (31%), gross profit (57%) and average profitability will fall to 2%. The trawlers, which lose their fishing potential, will most likely change their behaviour towards participating in the consumption fishery. Because the quotas on the consumption species are more or less fully utilised, this will imply an increased pressure on the earnings of vessels in other fleet segments. A complete restructure of the Danish fishery will therefore most likely be necessary in order to account for at complete closure of the Danish industrial fishery.

Following Andersen and Løkkegaard (2002), this restructure could be in form of reducing the number of vessels in the fleet segments, which are primarily influenced by the closure. For the five fleet segments included in the multiple objective analysis, the reduction is estimated to be 58%. All industrial trawlers above 24 metres of length would be taken out, while other segments would experience reductions between 38% and 68%, with the trawlers of length between 18-24 metres being least affected.

The calculations did not consider any possible increases in the catches of consumption species due to the closure of the industrial fishery. However, if such an increase were to materialise, this will probably not be high enough to offset the reduction in the industrial fishery.

In conclusion, it should thus be clear that a stop of the industrial fishery in the North Sea would have wide-ranging consequences for the Danish fishery. The calculations made in Andersen and Løkkegaard (2002) were not restricted to the North Sea, but because of the relatively great importance of the industrial fishery that takes place in the North Sea, the statements serve as reliable indicators.

5.4. Basis scenario

The applied model is constructed to represent the fishery in 1999. This section contains a brief consideration of validation and robustness of the model. Moreover, the values of the objectives are calculated with number of days at sea and number of vessels fixed at the levels in 1999 to form a basis scenario.

Validation serves to determine whether the model gives a trustworthy representation of the system. It can be discussed, if validation of numerical models of a natural system is possible at all. According to Oreskes et al. (1994), it is not. However, the

model's ability to the replicate the values of the dataset indicate how well the model fits the system. If the model cannot replicate the values of the dataset, then it will not be able to represent the system.

Model estimates for catch weight and catch value have been compared to the values in the dataset in order to perform some kind of validation of the model. No, or very small deviations, are recorded, cf. Table 5.3.

The primary reason for the observed deviations is related to the presence of additional payments[25]. Additional payments are typically registered without any attributed catch weight. Because the applied prices are calculated by using the catch weight and catch value in the dataset, the price of additional payments therefore becomes zero in the model. Hence, the value of additional payments is also zero in the model. From Table 5.3, it is evident that the deviations are reduced to a minimum, when looking at the figures without additional payments. The remaining deviations can be attributed to rounding errors.

The exclusion of additional payments implies that the catch value in the industrial fishery is underestimated. However, at least in the short run the approach can be justified by the way these payments are paid out. Additional payments are traditionally paid out by the end of each year, when the fishmeal factories have calculated their profits. The behaviour in the industrial fishery is therefore on a monthly basis not influenced by the size of the additional payments. In the long run, the behaviour may be influenced. However, considering that the size of the additional payments for the included vessels only accounts for around 2% of the total catch value on average (or 128,000 DKK), including investment decisions probably does not have a significant influence on the behaviour.

[25] Additional payments are modelled as a separate species.

Table 5.3. Catch calculated by the model compared to catch in the dataset

	Model	Dataset	Deviation
Catch weight (tons)			
North Sea	811,006	811,006	0.00%
Other areas	162,256	162,256	0.00%
Catch value (1,000 DKK)			
North Sea	616,681	631,062	2.28%
Other areas	156,230	160,326	2.55%
Catch value[1] (1,000 DKK)			
North Sea	616,681	616,262*	-0.07%
Other areas	156,230	156,303*	0.05%

Notes: 1) Additional payments excluded (marked by *).

Besides checking the model's ability to replicate the actual dataset values, it is also important to address attention to the robustness of the model. Generally, the optimisation of a non-linear programme only guarantees a local optimum. In order to evaluate the robustness of the obtained solution, test-runs have been carried out for different starting values of the endogenous variables. The weighting vector representing all stakeholders (aggregated) was used for the tests.

Initially, the 1999 values were used as starting values. Thereafter, these were scaled up and down in order to see the effect on the obtained solutions. An array of solutions was thus compared with respect to the value of the achievement function and the seven objective values calculated from the solution. The solutions returned the same achievement function value, but the individual objectives were not always the same. There were, however, only minor deviations observed when the 1999 starting values were increased and decreased by up to 30%. The deviations may be caused by the complex nature of the set of feasible solutions. The scope of the model is large, working with a great number of endogenous variables and equations[26]. It is therefore likely that more than one combination of days at sea and number of vessels could result in the same achievement value. Another aspect is that the great number of variables and equations may challenge the optimisation software. Since the values of 1999 were found to give a robust and thus reliable solution, they were considered applicable as starting values.

[26] The number of endogenous variables is 1,455 and there are 4,449 equations (restrictions).

In order to conduct a further investigation regarding the stability of the results, and thus the trends obtained in the model, sensitivity analysis should be performed. This can be approached by allowing variation in key parameters. If the results do not change drastically, due to minor changes in the parameters, the model can be considered stable.

This has been done, where variation in two parameters was considered: 1) the weights expressed by the stakeholders and 2) the price vector. The sensitivity analysis was performed by imposing a stochastic variation in the parameters by a standard deviation of 5%[27]. With this assumption, 500 model runs were performed for a number of stakeholders.

Generally, the sensitivity analysis indicated that the model obtained stable results. The seven objectives and the achievement value were found to be insensitive to changes in weights and prices. This does however not mean that the weights (and prices) do not influence the results. It simply means that the results are reasonably reliable, because "insignificant" changes of parameters will not cause drastic changes for the results.

An approximation of the actual fishery in 1999 is found by setting the number of vessels and number of days at sea to the level of 1999. The corresponding objective values (profit, employment etc.) are all functions of number of vessels and number of days at sea and define the basis scenario. The basis scenario is useful for comparisons when evaluating the effects from applying the different sets of weights. The base values are shown in Table 5.4 together with target (ideal) and anti-ideal values. The target and anti-ideal values are upper and lower bounds for the objectives. Since the set of feasible solutions is not the same in the short and long run, the respective target and anti-ideal values are not the same. Take for example the third objective, safety, in the third column of Table 5.4. In the first row, basis scenario, it is shown that if the number of vessels and number of days at sea were fixed at the 1999 level, the value of this objective would be 96,642,000 DKK. From the subsequent rows, it follows that in the short run (long run) the upper and lower bound on safety are 131,996,000 (139,126,000) and 33,019,000 (4,060,000) DKK respectively.

[27] The assumption is that the investigated parameter is normally distributed with a mean equal to the elicited weights or the observed prices and a standard deviation 5% of each of these, respectively.

Table 5.4. Base values together with target and anti-ideal values of the objectives

	1) Profit (1,000 DKK)	2) Employment (1,000 DKK)	3) Safety (1,000 DKK)	4) Maintain the industrial fishery at present level of input	5) Catch of sandeel and Norway pout (tonnes)	6) Bycatch of consumption species (tonnes)	7) Impact on birds etc. in a specific area (tonnes)
Basis scenario (1999 values)	228,730[1]	208,357	96,642	1	553,544	4,618	7,728
Short run							
Target values (f^*)	259,004	238,283	131,996	1	0	0	0
Anti-ideal values (f_*)	91,980	77,718	33,019	0.645	553,544	4,904	7,728
Long run							
Target values (f^*)	188,251	241,969	139,126	1	0	0	0
Anti-ideal values (f_*)	10,986	12,234	4,060	0.074	553,030	4,823	7,728

Notes: 1) The definitions of short run and long run profit objectives are not the same, cf. Section 2. The short run value, i.e. contribution margin, is given in the table, whereas the long run profit estimate equals: 100,346 (1,000 DKK).

6. Short run results

As previously mentioned, the model's ability to perform both a short run and a long run analysis divide the model-runs into two parts. This chapter will describe the results obtained in the short run analysis, where the number of vessels and their characteristics are assumed fixed. Hence, number of days at sea is the only endogenous variable.

The results are generated by a series of separate model runs – one for every stakeholder, stakeholder group and *All stakeholders* (aggregated)[28]. The only difference among the runs is the weights applied. Applying the weights of a given stakeholder will supply a solution. The different solutions can be compared to each other and to the situation in the basis scenario (see Table 5.4).

The consequences of applying the different stakeholder weights in the short run will be evaluated with respect to several key indicators. First, Section 6.1 presents the consequences for the resulting seven objective values. Section 6.2 contains a description of the effort in the fishery corresponding to the different solutions. Consequences for catches and catch value are considered in Section 6.3, while costs and profits are the subjects of Section 6.4. Finally, Section 6.5 considers the likely effects upon the processing industry.

The outcome presented here is concentrated on the results obtained from applying the aggregated weights for each stakeholder group and for All stakeholders. Appendix C contains, as a supplement, a comprehensive amount of numerical material, showing the result obtained for each individual stakeholder. When the results of All stakeholders are evaluated, it is assumed that all the individual stakeholders have an equal impact on the decision making in EU fisheries management[29]. Firstly, this means that stakeholders without any economic or social risks have just as much influence as the others. Secondly, the number of stakeholders within the different groups becomes relevant. Conclusions drawn from these results must therefore be evaluated with caution.

[28] Note the distinction between *All stakeholders* (aggregated) and all individual stakeholders.
[29] This has to do with the way AHP is used to calculate aggregated weights.

6.1. Objective values

The stakeholders' weights have been applied to the model. These determine the relative importance of the seven objectives to a stakeholder and they are incorporated into the achievement function, which is the sum of the deviational variables that is minimised.

Given the optimal distribution of the number of days at sea and the fixed number of vessels, it is possible to calculate values of the objectives. This is done for the solutions resulting from applying the different stakeholders' weights. The results can be found in Table C.1 in Appendix C. Table 6.1 shows how the objective values change for the groups of stakeholders, compared to the base values of Table 5.4. The first column contains the objectives, e.g. the changes in the values of objective 1, which is maximise profit, is in the first row. This means that applying the aggregated weights of the Danish industry to the goal programme would, compared to the base values, give rise to a 1% increase of profit, 3% increase of employment, 10% improvement of safety, no changes in the level of input, 2% reduction of catches of sandeel and Norway pout, 94% reduction of bycatch and the impact on birds in a specific area completely comes to an end (is reduced to zero).

Table 6.1. Changes in objective values compared to base values in Table 5.4 (%)

	---------- Group of stakeholders ----------				
Objectives	Danish Industry	Environmentalists	Danish Authorities	UK Authorities and Industry	All stakeholders
1) Maximise profit	1	-52	-3	-47	-38
2) Maximise employment	3	-51	-2	-46	-38
3) Maximise safety	10	-39	3	-28	-21
4) Maintain the industrial fishery at present level of input	0	-6	0	0	0
5) Minimise catch of sandeel and Norway pout	-2	-94	-7	-83	-74
6) Minimise bycatch of consumption species	-94	-99	-99	-99	-97
7) Minimise impact on birds etc. in a specific area	-100	-100	-100	-100	-100

The results in Table 6.1 present a consistent reflection of the preference structures given by the weights of the different stakeholder groups. It is evident that the optimally managed fishery is dependent on which stakeholder preferences are considered. Using the weights of either the Environmentalists or UK Authorities and Industry, the

model suggests that the contribution margin[30], in the North Sea, is reduced by 52% or 47%, respectively. This is associated with a considerable decline in catches, which is clear from the last three rows of Table 6.1. Based on the discussion in Section 5.3 concerning a stop of the industrial fishery in the North Sea, the consequences for the fishery from realising these stakeholder preferences will be wide-ranging. On the other hand, applying the weights of the Danish industry will result in increases for the first three objectives. From Table C.1 in Appendix C, it follows that the contribution margin will rise by 6% and employment by 5% for DFA (contribution margin 5% and employment 5% for AFMD). Moreover, using the weights of GWUD implies a situation were the contribution margin is reduced by 5%, but safety is increased by 23%. This opposite effect is not surprising since safety is related to maintenance costs.

Generally, it seems that objectives 4, 6 and 7 are easy to achieve. Maintaining the industrial fishery at the present level of input is related to number of days at sea and number of vessels (which is fixed at the present level). The fact that the number of vessels is already fixed at the level of 1999, and that there are numerous ways to combine the number of days at sea, explain why this objective is almost achieved for every stakeholder, even those that weight it low. For stakeholders with low weights on objective 4 and high weights on objectives 5,6 and 7, it may seem peculiar that objective 4 is almost achieved. The explanation is most likely that the effort of the industrial fishery is redirected towards vessels with a low catch per day. This redistribution maintains the effort level, but decreases the catches considerably.

For each stakeholder group, the bycatch of consumption species is reduced considerably, indicating that it is possible to conduct a profitable fishery, allocating effort to activities where the occurrences of bycatch are less common. Besides, it should be noted that the weight on this objective is relatively high for all the individual stakeholders (see Table 5.2). This high reduction in bycatches of consumption species will presumably have a positive effect on the vessels, which direct their fishery towards these species.

Solutions of all the individual stakeholders suggest that the fishery in the Sandeel box will be closed. Considering that this fishery only has a minimal importance, this result is not surprising. However, considering that the catch value per day at sea is high in this area, it may not be optimal to close this fishery from an economic point of view.

[30] Recall that the contribution margin is used as the profit objective in the short run. It is defined as revenue minus variable costs.

This reveals one of the benefits from conducting multi-objective goal programming, i.e. the ability to consider different objectives simultaneously.

The results of *All stakeholders* show considerable reductions for all objectives (except number 4) compared to the base values. Contribution margin is reduced by 38%, which is connected with reductions in catch of sandeel and Norway pout. It is questionable whether vessels will be able to stay in the fishery.

The value of the achievement function varies for the stakeholders in the analysis (see Table C.1). This can be used as an indicator of the trade-off between the objectives in the short run set-up. If the value of the achievement function is low, it means that it is relatively easy to achieve a significant degree of satisfaction (at the same time) of the goals that are weighted highly. GWUD has the highest value of the achievement function. This is also one of the stakeholders, which has the most uniform weights. Comparing the results of DFA and WWF, with the weights in mind, gives an indication that there is a greater trade-off between objectives 1-3 than between 5-7, as expected. Objective 5-7 all "pull" in the same direction – reducing catch. The trade-offs between objectives are of course dependent on the way they are incorporated into the model. A high degree of satisfaction of objectives 5-7 is generally connected with low values for profit, employment and safety. There is an obvious trade-off between these two arrays of objectives. Objectives 5-7 all seek to reduce catch which affects activity. Lower activity levels and lower catches imply decreasing earning capabilities (profit opportunities). Objectives 1-3 all increase with increasing activity, while profit decreases with costs, employment increase with crew cost, and safety increases with increasing maintenance costs.

6.2. Activity

The activity (or fishing effort) is measured in terms of number of days at sea and number of vessels. These variables are the building blocks of the optimisation model. For every model run, the optimal solution is obtained by finding the best distribution of these variables.

The total number of days at sea only increased (by approximately 12%) in the scenario based on the weights elicited from stakeholder GWUD. Applying the weights of other stakeholders result in significant reductions in the number of days at sea. A reduction in effort means that the average number of days spent at sea per vessel will be low, considering that number of vessels is fixed. If a vessel has only few days at sea

per year, it is unlikely that it can cover its fixed costs. Hence, the number of vessels is expected to fall in the long run.

The decrease in the total number of days at sea is not distributed equally between fishing areas as shown in Table 6.2 below. For the two stakeholder groups, the Danish Industry and Danish Authorities, increases are observed in the number of days in the North Sea, while significant reductions are observed in the other fishing areas. This shift may be due to several reasons, including the higher profitability in the North Sea fishery and the possibilities of conducting a fishery with little bycatch. Moreover, the objectives are related to the North Sea areas, meaning that the model seeks to find a solution that maximises profit, employment, safety etc. in the North Sea.

For the other groups of stakeholders, the number of days at sea is reduced considerably in both fishing areas. This is not surprising for two reasons. Firstly, the reduction in catches (cf. Table 6.1) is connected to the amount of effort put into the fishery. Secondly, during the optimisation process effort may be allocated more efficiently than was the case in 1999. For every species and fishing area, the catch is restricted to be less than or equal to the 1999 level. If catch is conducted by vessels at a time that enhances the average catch per day, fewer days at sea are needed before the restriction on catches becomes binding.

Looking at *All stakeholders*, the reduction in the North Sea is 22%, i.e. around one fifth of all activities in these areas are stopped. The consequences for the Danish industrial fishery will be substantial.

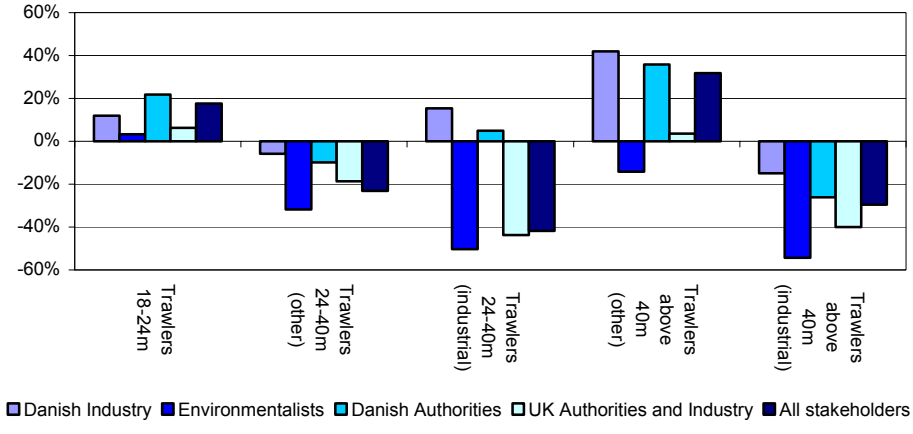
Table 6.2. Total number of days at sea for each stakeholder

	North Sea		Other areas	
Group of stakeholders	Model	Change compared to effort in 1999 dataset	Model	Change compared to effort in 1999 dataset
Danish Industry	26,858	9%	5,164	-29%
Environmentalists	15,449	-37%	5,634	-22%
Danish Authorities	25,239	2%	5,812	-20%
UK Authorities and Industry	17,899	-27%	5,802	-20%
All stakeholders	19,301	-22%	6,315	-13%

The total number of days at sea in the primary fishing area, i.e. the North Sea, with respect to the five fleet segments, is shown in Table C.3 in Appendix C. This reveals how the changes in Table 6.2 affect the different fleet segments. When considering

the Environmentalists and UK Authorities and Industry, effort is reduced within all fleet segments (with only a few exceptions). For the Danish stakeholders, the trawlers of 18-24 metres and above 40 metres (other) generally increase their effort in the North Sea. Figure 6.1 illustrates the changes in effort relative to the values in the 1999 dataset, for the four stakeholder groups and *All stakeholders*.

Figure 6.1. Changes in effort in the North Sea relative to the values in the 1999 dataset for groups of stakeholders and *All stakeholders*



6.3. Catches

The consequences from applying the stakeholder weights on catches and catch value have already been exposed by the presentation of the objectives in Section 6.1. It was clear that the magnitude of catches, as well as the value of other objectives, is indeed dependent on which stakeholder preferences are considered.

Catches in the North Sea resulting from each stakeholder group is compared with the catch in 1999 in Table 6.3. Recall that catches are restricted to be less than, or equal to, the values in 1999. If the reduction in catches of sandeel and Norway pout are compared to the results in Table 6.1, it shows that the sandeel fishery is dominant in quantity (1999). For example, the 2% reduction of sandeel and 73% reduction of Norway pout, which is the result of the Danish Authorities, corresponds to a 7% reduction of the total catch weight of both sandeel and Norway pout.

Table 6.3. Changes in catch weight in the North Sea for the stakeholder groups compared with the catch in 1999 (%)

Group of stakeholders	Sandeel	Norway pout	Other industrial species	Consumption species
Danish Industry	-2	-6	0	-3
Environmentalists	-95	-82	-9	-3
Danish Authorities	-2	-73	-8	-3
UK Authorities and Industry	-83	-85	-8	-3
All stakeholders	-74	-74	0	-3

The catch weight of sandeel in the North Sea is reduced by approximately 2% for the Danish industry and Danish Authorities. The 2% corresponds to the 1999 catch of sandeel in the Sandeel box. In fact, the restriction on sandeel is binding for the Danish stakeholders in all other North Sea areas than the Sandeel box[31]. Likewise, the results indicate that the restrictions on other industrial species are binding for the Danish industry and for *All stakeholders*. The catch of other industrial species does not vary much for the different stakeholders. The reason for this is that it is not as closely related to objectives 5 and 7 as catch of sandeel and Norway pout. The most important, and dominant in terms of quantity, of these other industrial species is sprat.

For the Environmentalists and UK Authorities and Industry, Table 6.3 displays large reductions in catches of sandeel and Norway pout (close to 100%) in the North Sea. This especially concerns sandeel in area 4B and Norway pout in 4A.

Studying the catch value in Table 6.4 gives a similar picture as seen in Table 6.3. However, it is interesting to see how the total catch value for the Danish Industry is higher than the level in 1999, even though catches are less than in 1999. This indicates a more economically efficient allocation of effort. The large reductions in catches for the Environmentalists and UK Authorities and Industry influence the catch value. From the last column, it appears that applying weights of the *All stakeholders* will cause a 37% reduction in the total catch value in the North Sea.

[31] The dominant part of the sandeel catches is caught in 4B (approximately 95%).

Table 6.4. Changes in catch value in the North Sea compared to the values in 1999 (%)

Group of stakeholders	Sandeel	Norway pout	Other industrial species[1]	Consumption species	Total
Danish Industry	1	1	3	-1	1
Environmentalists	-95	-79	-6	-9	-51
Danish Authorities	1	-72	-4	-2	-4
UK Authorities and Industry	-82	-84	-6	-10	-46
All stakeholders	-72	-71	2	-4	-37

Notes: 1) Additional payments are included in the 1999 values.

How the five fleet segments are affected by applying different stakeholder preferences can be deducted from Table C.6 in Appendix C. The catch value of industrial trawlers above 24 metres experiences most variation among the results from the different stakeholders. This is due to the fact that these fleet segments caught significant shares of sandeel (62%) and Norway pout (93%) in 1999.

6.4. Consequences for costs and profits

Costs are closely related to the fishing activity. The variable cost components used in the model are measured per day. Given an optimal solution, the number of days at sea, and number of vessels, the total costs can be calculated. The fixed costs are not included here, since they are related to the number of vessels, which is constant in the short run scenario. Tables C.7 and C.8 in Appendix C show the results for cost of the different stakeholders' preferences.

In the short run, profit is measured as total yearly contribution margin, i.e. catch value less variable costs. Table 6.5 shows how profit is divided among fleet segments for the different stakeholder groups[32]. Which is the most profitable segment depends on which stakeholder group is considered. For *All stakeholders,* industrial trawlers account for only 26% of the total contribution margin, compared to 57% in the basis scenario.

[32] Total contribution margin is compared to the value in 1999 in Table 6.1 (as objective 1). From Table C.8 and Table C.6 in Appendix C, it is possible to calculate the contribution margin within each of the five fleet segments, which will be realised for each stakeholder. Note that summarising the resulting columns for each case will not give the values of the profit objective in Table C.1, since this is only related to the North Sea (the short run profit objective value can be achieved from the last column of Tables C.5 and C.7).

Table 6.5. Total profit divided on fleet segments (%)

Group of stakeholders	Trawlers 18-24m	Trawlers 24-40m (other)	Trawlers 24-40m (industrial)	Trawlers above 40m (other)	Trawlers above 40m (industrial)
Danish Industry	9	26	30	24	12
Environmentalists	13	30	15	31	11
Danish Authorities	9	26	30	24	10
UK Authorities and Industry	12	35	16	29	8
All stakeholders	12	34	14	27	12
Dataset (1999)	8	19	26	15	31

The monetary values for all the individual stakeholders can be found in Table C.9 (in Appendix C). Together with the number of vessels within the different segments, the average contribution margin per vessel can be deduced. Low values for the contribution margin per vessel in the different fleet segments could very well indicate that the long run scenario will show a reduction in the number of vessels, due to the introduction of fixed costs.

6.5. Consequences for the processing industry

When estimating the consequences on the fishery, any side effects on the consumption fishery, onshore services or processing industry have not been considered. With respect to the first two issues, it has not been possible to calculate the consequences, this have however been possible for the latter.

There are strong links between the level of catches (landed amounts) and the level of activity and profits in the processing industry. Based on the accounts from the largest producer of fishmeal and fish oil in Denmark, which is Triple-Nine located in Esbjerg and Thyborøn, some rough estimations can be made.

Based on the accounts of Triple-Nine from 1998/1999 (Anon 1999), the gross profit before financial costs was in 1999 0.03 DKK per kilo of industrial fish landed to the factory. Using wage payments as a measure of employment, the effects upon employment can likewise be calculated. In 1999, Triple-Nine paid 0.14 DKK in wages per kilo fish landed.

If it is assumed that, the gross profit before financial costs per kilo and wage payments per kilo is the same for all the fishmeal/fish oil producers in Denmark, the consequences on the processing industry can be estimated. These are for each stakeholder group presented in Table 6.6.

Table 6.6. Total profit and employment in the processing industry from catches in the North Sea compared to values in 1999

Group of stakeholders	Profits	Employment [1]
Danish Industry	-1%	-6 persons
Environmentalists	-69%	-282 persons
Danish Authorities	-8%	- 31 persons
UK Authorities and Industry	-61%	-251 persons
All stakeholders	-53%	-216 persons
Dataset (1999)	23 mill. DKK	408 persons

Notes: 1) Average wage is assumed equal to that of a process- and machine operator working in the province in 1999, which was 266,400 DKK (Danish Employers' Confederation 1999).

Based on Table 6.6, the repercussions on the processing industry are highly dependent upon, which stakeholder is considered. For the Danish stakeholders, the consequences are only minor, while these are more significant for the Environmentalists. These consequences would be even further influenced, if effects on the onshore services (e.g. gears, repairs) were also considered. However, no reliable figures are available, but they are presumably significant considering that the industrial vessels are primarily large and thus requires substantial maintenance etc.

7. Long run results

The long run scenario describes a system where the number of vessels can change. Both the number of days at sea and the number of vessels are considered as endogenous variables.

Three differences between the long and short run can be brought to attention: 1) In the long run the number of vessels is considered as an endogenous variable. 2) Fixed costs are taken into consideration with respect to the profit objective, and 3) vessels are restricted only to operate if profit is non-negative.

Because the number of vessels is changeable in the long run, the model is more flexible when finding an optimal solution. In the short run, the model cannot exclude vessels completely, but instead give them as few days at sea as possible. In the long run, vessels can be excluded if they are not considered the best in achieving an optimal solution. The long run scenario therefore gives insight into the possible trends in the industrial fishery, if different stakeholders have an exclusive right to manage the fishery.

As for the short run scenario, the results are generated by a series of separate model runs – one for each stakeholder, stakeholder group and *All stakeholders*. The only difference among the runs is the weights applied. Applying the weights of a given stakeholder supplies solutions that can be compared to each other and to the situation in the basis scenario (see Table 5.4).

The description of the long run results will follow along the approach as for the short run scenario described in Chapter 6. The objective values are considered in Section 7.1 and the ability to evaluate trade-offs between objectives is discussed. Section 7.2 contains a description of the fishing activity and Section 7.3 treats the consequences for catch weight and catch value. Costs and profits are the subjects of Section 7.4, while effects upon the processing industry are discussed in Section 7.5.

Like in Chapter 6, the presented outcome is concentrated on the results obtained from applying the aggregated weights for each stakeholder group and for *All stakeholders*. Appendix D contains, as a supplement, a comprehensive amount of numerical material, showing the results obtained for each individual stakeholder. As mentioned in Chapter 6, it is emphasised that the results of *All stakeholders* are evaluated assuming

that all the individual stakeholders have an equal impact on the decision making in EU fisheries management.

7.1. Objectives

As for the short run scenario, the objective values are calculated using the solutions obtained from applying the different stakeholders' weights. The values are shown in Table D.1 in Appendix D. Comparing short run and long run objective values for the profit objective value is not possible. The reason is that the profit objective value in the long run includes fixed cost and revenue obtained from all fishing areas, which is not the case in the short run. The remaining six objectives are however all measured the same way, both in the short and long run scenarios.

Table 7.1 shows how the objective values change relative to the base values in Table 5.4 for the groups of stakeholders. Generally, it can be concluded that the long run results for each stakeholder group does not reveal any unexpected results, considering their preference structures, i.e. elicited weights. Thus, the preference structures of the stakeholders are reflected in the results. The first column contains the objectives, e.g. the changes in the values of objective 1, which is maximise profit, is in the first row. This means that applying the aggregated weights of the Danish Industry to the goal programme would, compared to the base values, give rise to a 61% increase of profit, 3% increase of employment, 1% improvement of safety, 23% reduction of the level of input, 4% reduction of catches of sandeel and Norway pout, 93% reduction of bycatch and the impact on birds in a specific area completely comes to an end (is reduced by 100%).

Looking at the profit objective, applying the weights of the Danish Industry and Danish Authorities will cause increases of 61% and 40%, respectively. Allowing changes in both number of days at sea and number of vessels apparently makes it possible to conduct a more profitable fishery. For the Environmentalists and UK Authorities and Industry there is practically no catch of sandeel and Norway pout and the profit objective is reduced. Evaluating *All stakeholders,* profit is reduced by 3%. This is connected to the reductions in catches and thus revenue.

As was the case in the short run analysis, the Sandeel box is closed and bycatches are reduced significantly for all stakeholders. The statements made in Chapter 6 regarding these matters remain valid.

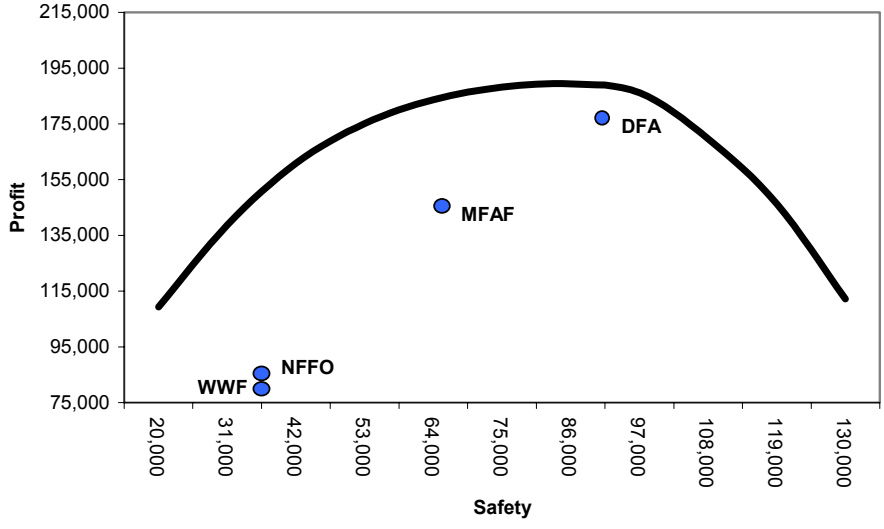
Table 7.1. Changes in objective values compared to base values in Table 5.4 (%)

Objectives	Danish Industry	Environmentalists	Danish Authorities	UK Authorities and Industry	All stakeholders
	---------- Group of stakeholders ----------				
1) Maximise profit	61	-13	40	-18	-3
2) Maximise employment	3	-51	-31	-51	-47
3) Maximise safety	1	-58	-47	-58	-55
4) Maintain the industrial fishery at present level of input	-23	-63	-57	-63	-59
5) Minimise catch of sandeel and Norway pout	-4	-99	-65	-98	-94
6) Minimise bycatch of consumption species	-93	-99	-99	-100	-99
7) Minimise impact on birds etc. in a specific area	-100	-100	-100	-100	-100

For the Danish stakeholders, the value of the achievement function is high compared to the other stakeholders in the analysis (see Table D.1). This implies that there is a higher degree of trade-off between the objectives given a high weight by the Danish stakeholders than between the most important objectives for the Environmentalists and UK Authorities and Industry. As expected, this means that the trade-off between objectives 1-3 is greater than between 5-7. Objectives 1-3 all increase with increasing activity, while objective 5-7 all seek to reduce catches and thus activity. A high degree of satisfaction of objectives 5-7 is generally connected with low values for profit, employment and safety. There is an obvious trade-off between these two arrays of objectives.

Plotting a trade-off curve as done in Pascoe and Mardle (2001) can further assess the correlation between two objectives. Figure 7.1 displays the relationship between profit and safety. For different fixed levels of safety, the model is used to maximise profit. The concave shape depicts that profit increase with safety until a given level and decreases afterwards. This is also the expected relationship, since both objectives increase with effort and only safety increases with costs. The remaining objectives are not taken into consideration. Doing this would bring down and flatten the curve. The results attained for four different stakeholders are shown in the figure. DFA is close to the maximum point, while NFFO and WWF are situated distant from the curve. This picture is consistent with the weights of the different stakeholders (see Table 5.2).

Figure 7.1. Profit / safety trade-off curve



7.2. Activity

The activity (or fishing effort), in terms of number of days at sea and number of vessels, is the core of the model. The results in this section will therefore influence catches, catch values, costs and profits described in the following sections. The number of possible solutions to the long run optimisation problem for each stakeholder is larger compared to the short run, because the number of vessels is also considered as endogenous.

In Table 7.2, the total number of days at sea is shown and compared to the total number of days at sea in the 1999 dataset[33]. The only solution where effort is increased in the North Sea is for GWUD, with an expected to increase by 17% (see Table D.2). This explains why fishing effort increases by 3% when considering the Danish industry. Otherwise, effort is reduced significantly, especially in the North Sea. The reductions in the North Sea are larger in the long run compared to the short run.

[33] The total number of days at sea in the 1999 dataset is 24,634 in the North Sea areas and 7,236 in other fishing areas.

Table 7.2. Total number of days at sea in each case and comparison with the 1999 values of the dataset

Group of stakeholders	North Sea: Model	North Sea: Change compared to effort in 1999 dataset	Other areas: Model	Other areas: Change compared to effort in 1999 dataset
Danish Industry	25,256	3%	5,878	-19%
Environmentalists	11,174	-55%	6,246	-14%
Danish Authorities	13,911	-44%	6,399	-12%
UK Authorities and Industry	11,229	-54%	6,389	-12%
All stakeholders	11,920	-52%	5,501	-24%

Table 7.3 shows the number of trawlers within each fleet segment, when applying the weights of the five groups of stakeholders. For all stakeholders the model runs suggest a reduction in the total fleet size. All stakeholder groups, except the Danish Industry, suggests that industrial trawlers of length above 40 metres are taken out of the fleet. The solution found for the Danish Industry indicates a low level of activity in this segment.

Table 7.3. Number of vessels divided on fleet segments

Group of stakeholders	Trawlers 18-24m	Trawlers 24-40m (other)	Trawlers 24-40m (industrial)	Trawlers above 40m (other)	Trawlers above 40m (industrial)	Total
Danish Industry	17	31	44	16	3	111
Environmentalists	14	19	31	8	0	72
Danish Authorities	20	22	23	7	0	72
UK Authorities and Industry	19	19	31	8	0	77
All stakeholders	16	15	31	8	0	69
Dataset (1999)	22	33	59	17	16	147

Based on Table 7.3 (or Table D.4) and the total number of days spent in the North Sea divided among fleet segments (found in Table D.3), the average activity within fleet segments can be deduced. The average number of days at sea generally increases for all fleet segments and stakeholders. This is not surprising considering that vessels with low activity are not able to cover their fixed costs. This indicates that the applied capital in form of vessels on average is more utilised.

It can be considered contradicting that profit increases with less effort and restrictions on catches. This is however due to the above comment on increased average utility of

vessels and a more profitable allocation of effort to segments, species, areas and time of year (effort in the right place and time).

It is unquestionable that implementing the management of some stakeholders will involve a restructuring of the fishery and have considerable regional effects. Severe reductions in effort and catches imply lower employment levels and decreasing earning capability. This will affect both the fishery and processing plants.

7.3. Catches

From Table 7.1 it is possible to deduce some of the consequences from applying weights of different stakeholder groups on catches of industrial species in the North Sea. It is clear that the magnitude of catches and the profit is indeed dependent on which stakeholder preferences are considered.

The catch weight in the North Sea is compared to the levels in 1999 in Table 7.4. As for the short run results, note that if the reduction in catches of sandeel and Norway pout are compared to the results in Table 7.1, it shows that the sandeel fishery in 1999 is dominant in quantity.

Table 7.4. Changes in catch weight in the North Sea for the stakeholder groups compared to the catch in 1999 (%)

Group of stakeholders	Sandeel	Norway pout	Other industrial species	Consumption species
Danish Industry	-2	-24	-2	-3
Environmentalists	-99	-92	-14	-4
Danish Authorities	-63	-81	-16	-4
UK Authorities and Industry	-99	-92	-19	-3
All stakeholders	-96	-79	-16	-3

The catch weight of sandeel in the North Sea is reduced by approximately 2 for the Danish industry. This corresponds to the 1999 catch of sandeel in area 4A and the Sandeel box. For the other stakeholder groups, the catch of sandeel and Norway pout is reduced considerably. For *All stakeholders*, the catch of sandeel is reduced by 96 and Norway pout by 79.

Looking at the different cases, the variation in catches of other industrial species is slightly more apparent than in the short run scenario, but it is still not to the extent of

sandeel and Norway pout. The reason for this is, as stated for the short run scenario, that these species are not as closely related to objectives 5 and 7 as sandeel and Norway pout. Moreover, the catch of consumption species stays approximately at the same level in all cases. With respect to consumption species, bycatch is reduced in all cases, but the reduction does not show on the total catch of consumption species for all stakeholders (see Table D.6). The consumption species are valuable, and at the same time as bycatch is reduced, the catch is increased elsewhere where bycatches are less common.

The level of catch value can be viewed in Table 7.5. The general trend herein is not significantly different considering that the reductions in catches directly influence the catch value. From the last column, the total effects on catch value can be seen. It appears that applying the weights of *All stakeholders* will cause a 53 reduction in the total catch value in the North Sea, compared to the 1999 level.

Table 7.5. Changes in catch value in the North Sea compared with the values in 1999[1] (%)

Group of stakeholders	Sandeel	Norway pout	Other industrial species	Consumption species	Total
Danish Industry	0	-21	4	-3	-3
Environmentalists	-99	-92	-12	-5	-55
Danish Authorities	-62	-80	-13	-4	-38
UK Authorities and Industry	-99	-92	-16	-4	-56
All stakeholders	-95	-78	-12	-2	-53

Notes: 1) The 1999 values of industrial catches include additional payments.

Table D.8 in Appendix D shows how the five fleet segments are affected by applying the different stakeholder preferences. Together with costs, considered in the next section, this information can be used to evaluate the profitability of the fishery within the different fleet segments. Keeping the activity levels in mind, it can (based on Table D.8) be concluded that the average catch value per vessel is generally increased, despite that the catch and catch value are reduced.

Following significant reductions in the industrial fishery, a shift towards the consumption fishery must be expected. The model does not cover this effect, and it is therefore not possible to evaluate the possible effects this may have.

7.4. Consequences for costs and profits

In addition to the variable cost components, the fixed costs will be considered in this section.

The total cost of the five cost components is displayed in Table D.9 of Appendix D. These costs are influenced by the activity of the vessels, and therefore the consequences on costs reflect the trends seen for activity when applying the different stakeholder weights. Costs are highest for the Danish Industry and lowest for Environmentalists and UK Authorities and Industry.

Table D.10 in Appendix D shows the total costs in each case with respect to the fleet segmentation. The number of vessels (cf. Table D.4) reveals that costs per vessel generally increase. This is due to the previously stated increase in average effort per vessel.

In the long run scenario, the profit is calculated as revenue minus variable and fixed costs. The changes in profit values compared to the basis scenario were stated in Table 7.1 for the different stakeholder groups (D.1 and D.11 contains numerical values for all stakeholders). Table 7.6 shows how profit is divided on fleet segments for the different stakeholder groups. Compared to the situation in 1999, the industrial trawlers become relatively less important for all stakeholder groups.

Table 7.6. Total profit divided on fleet segments (%)

Group of stakeholders	Trawlers 18-24m	Trawlers 24-40m (other)	Trawlers 24-40m (industrial)	Trawlers above 40m (other)	Trawlers above 40m (industrial)
Danish Industry	12	32	23	29	4
Environmentalists	20	27	13	40	0
Danish Authorities	14	34	23	29	0
UK Authorities and Industry	23	22	13	41	0
All stakeholders	21	28	17	35	0
Dataset (1999)	14	24	37	11	15

Comparing the total number of days at sea (cf. Table D.2 in Appendix D) with profit shows that in all cases, profit either increases more or decreases less than effort, when measuring both proportionally to the 1999 level. This indicates that the per-unit effort is allocated more economically efficient than in the 1999 basis scenario in all cases.

7.5. Consequences for the processing industry

The estimated long run consequences does not, as in the short run, include any side effects due to changing patterns in the industrial fishery. The side effects are primarily related to changing catch levels in the consumption fishery, the industrial fleets demand for onshore services and the supplies delivered to the processing industry.

As mentioned in Section 6.5, it has only been possible to estimate possible side effects for the processing industry. By using the accounts from 1999 for the largest Danish producer of fishmeal and fish oil, it has been possible to evaluate the possible consequences for the processing industry.

From the accounts of Triple-Nine, the gross profit before financial costs was in 1999 0.03 DKK per kilo of industrial fish landed to the factory, while wage payments was 0.14 DKK per kilo fish landed. Based on these figures, the consequences for the processing industry can be calculated using the weights expressed by each stakeholder. These are presented in Table 7.7 for each group of stakeholders. The assumption made in Section 6.5, that the gross profit before financial costs and wage payments per kilo is the same for all the fishmeal/fish oil producers in Denmark, remain valid.

Table 7.7. Total profit and employment in the processing industry from catches in the North Sea compared to values in 1999

Group of stakeholders	Profits	Employment [1]
Danish Industry	-3%	-13 persons
Environmentalists	-74%	-303 persons
Danish Authorities	-51%	-206 persons
UK Authorities and Industry	-75%	-308 persons
All stakeholders	-72%	-293 persons
Dataset (1999)	23 mill. DKK	408 persons

Notes: 1) Average wage is assumed equal to that of a process- and machine operator working in the province in 1999, which was 266,400 DKK (Danish Employers' Confederation 1999).

Serious consequences are thus estimated for the processing industry, if the management of the industrial fishery is based upon the weights of the stakeholder groups, except for the Danish Industry. The size of these consequences makes it doubtful that this industry will be able to survive in the long run. A consequence following thereof is increased unemployment in regions, which in some cases are highly dependent upon the fishery.

8. Implications for management

This chapter will discuss the implications for fisheries management of using a multi-objective framework. The discussion will primarily be based on the present analysis. Some remarks therefore only apply to fisheries with the same characteristics as the Danish industrial fishery in the North Sea, while others are more applicable in general.

For a multi-objective management model to be applicable, managers need to deduce their objectives and establish a ranking/weighting between these.

Specifying relevant and unambiguous objectives and obtaining preferences from relevant stakeholders is a prerequisite for the analysis in general. Determining all objectives in the analysed fishery is essential in order to produce a reasonable description of the stakeholders' interests. However, the more objectives that are included, the more troublesome the modelling part becomes. It is therefore necessary to critically review the objectives, and only include the relevant ones. Effort must be made to avoid several objectives representing the same concerns, which would artificially add extra weight hereon.

In the present analysis, seven objectives have been included. Working with so many objectives brings forward the multifarious nature of the system, i.e. the many different aspects of the Danish industrial fishery, and makes it easier to differentiate among stakeholders. The model is considered to function reasonably well, despite the many objectives.

The present model of the Danish industrial fishery has a high level of detail. It is of course valuable to include comprehensive information, because it gives a more realistic description of the system and the ability to achieve results on regional, seasonal and fleet levels. The only concern, from a modelling perspective, is that the complexity grows with the level of detail. Many variables and restrictions imply that the dimension of the set of feasible solutions is high, and each model run calls for extensive computations challenging the optimisation software.

Meaningful weights are also fundamental to the analysis. As became apparent during the model runs, the results are indeed dependent on the distribution of the weight. The value of joining the elicitation of objectives and the corresponding preference structures with GP modelling needs to be emphasised. The modelling part is a natural fol-

low-up on the elicitation of preferences. Doing the modelling with "artificial" weights will not be quite as fruitful, considering that selected weights tend to be somewhat arbitrary (Drynan and Sandiford, 1985).

When discussing the implications for management, a distinction seems necessary between implications related to the weights expressed by the stakeholders and implications associated with the bioeconomic model.

The analysis in Chapters 6 and 7 revealed that the weights have an important influence on the results. If managers use such weights to manage fisheries, it is therefore crucial that the expressed weights are reliable. Stakeholders can for instance have incentives to express preferences, which are not alone related to the analysed fishery. They could have other non-relevant objectives in mind that influence their weights. If management is based on such weights, the outcome is not very useful.

Given reliable weights, managers still have some important decisions to make. The results from applying the weights expressed by the various stakeholders differed quite substantially and it is therefore not straightforward how managers should translate the results into the most advantageous management decision, paying attention to the different perceptions of how the fishery should look. Hence, using a multi-objective framework with several stakeholders is not only dependent on reliable weights of the individual stakeholders, but also on a way to combine the results.

A management based on only one stakeholder would of course simplify the situation. However, this is most likely only possible in very few fisheries. This fact therefore calls for a way to obtain a set of weights, which account for the preferences of all stakeholders. Two questions can be asked in that respect: 1) what would be the best way to achieve it? and 2) does it make sense to try evaluating a joint preference structure?

Ideally, the best way to obtain an overall set of weights would be a situation where all stakeholders agreed on a set of weights to be used in the management. In fisheries, where stakeholders have very diverging interests, it may not be possible to obtain overall weights through negotiations[34]. This also questions the validity of a joint preference structure.

[34] In relation with acquirering weights to perform the analysis of the Danish fishery, it was tried to arrange a workshop on this issue. However, it was never realised due to lacking interest from the stakeholders.

If the power structure between stakeholders was known, it could be used to weigh the different weights. This way the stakeholders' weights are used to obtain a joint preference structure. The power structure is meant to represent how the different stakeholders presently affect management decisions. In the analysis of the Danish industrial fishery, results were also obtained using weights related to an aggregated preference structure. These results are calculated under the assumption that all stakeholders have the same power/ influence on the management.

The bioeconomic model is important when managers seek quantitative information about the consequences on the analysed fishery. Unfortunately a biological model was not available. Inclusion of this would of course improve the description of the Danish industrial fishery. It is important that the model gives the best possible description of the fishery. Quantifying the objectives expressed by the stakeholders is one crucial part of the model set-up. Using an incorrect measure to describe an objective can give the wrong advice to the managers.

The model used in this project to describe the Danish industrial fishery was very detailed and objectives are described in the best possible way. It is therefore considered to give a reliable picture of the expected consequences related to the different stakeholders weights. However, it does demand access to detailed data to set up such a model, and this may not always be the case for other fisheries.

The weights alone may give indications of what the fishery would look like, if management were to be optimal from each of the stakeholders' perspectives. However, building an optimisation model makes it possible to formulate the system properties and evaluate consequences for key factors such as the objective, activity, catches, catch value and profit with respect to relevant dimensions (fleet segment, fishing area etc.). However, managers should not use the exact figures as management targets, but instead focus on the trends reflected in the results[35]. Using the exact numbers is, despite the high level of realism in the model, too insecure.

Given a stakeholder's ranking of the seven objectives, it is possible to get an idea of what is expected for the objective values, activity of fishermen, catches and earning capabilities, etc. Within the system, it is thus possible to deduce in which direction the number of vessels, days at sea, catches and profit on an aggregated level and per ves-

[35] The actual figures can to some extent be used to get an idea about the level of the different key factors.

sel (including regional, seasonal and fleet segmentation) will develop for the different stakeholders.

Other valuable information from the model include the possibility to obtain information about the trade-off between objectives. This is also possible on individual stakeholder level. It is for instance possible to assess how much a stakeholder would be willing to reduce profits by in order to increase safety, employment and reduce by-catch.

In order to investigate the stability of the results and thus the trends obtained in the model, sensitivity analysis has been performed. Variation in two key parameters (prices and weights) was considered, and the sensitivity analysis indicated that the model obtained stable results. The seven objectives and the achievement value were found to be insensitive to changes in the parameters. This does however not mean that the weights (and prices) do not influence the results. It simply means that the results are reasonably reliable, because "insignificant" changes of parameters will not cause drastic changes for the results.

With the above discussion in mind, can this type of analysis give any new insights into fisheries management? And should the use of these insights be increased in the future?

With respect to the first question, the answer is yes. The inclusion of several objectives gives a more realistic description of the management of fisheries that are characterised by having many different stakeholders with diverging objectives. Although the results should be interpreted with caution, the indicated trends are considered valuable to managers.

Regarding the second question, the answer is more uncertain. As with other types of models, it is very important to obtain trustworthy results. This demands reliable data and an all-inclusive model. If this is not the case, managers should evaluate the results from a critical point of view. This indirectly implies that the use of multi-objective bioeconomic models is easier to implement in fisheries, which do not have significant effects on other people, i.e. the number of stakeholders are limited and the fishery is simple to describe.

9. Conclusion and final remarks

The Danish industrial fishery in the North Sea is not only an important fishery for many Danish fishermen, but draws attention from numerous types of stakeholders. These stakeholders range from fishermen and managers to environmentalists and labour unions and are not only from Denmark, but do also include stakeholders from United Kingdom and international organisations. This wide international interest is coexistent with the fact that the fishery is considered to have an influence on the consumption fishery and feeding grounds for birds. The stakeholders' perceptions of, and interests towards, the fishery are characterised by being very different from each other, and therefore makes the fishery interesting to study in a multi-objective framework.

The primary aim of the present study has therefore been to assess the applicability and effectiveness of a multi-objective model as a tool in the EU fisheries management. This was done by analysing the case of the Danish industrial fishery in the North Sea. Even though the analysis was performed on this specific fishery, some of the experiences and remarks made will undoubtedly remain relevant in other fisheries and in general as well.

The analysis was divided into a two-step procedure.

First, a set of qualitative methods was applied to determine the objectives of relevant stakeholders regarding the Danish industrial fishery in the North Sea. This was followed by a quantification of the individual stakeholders' preferences to express these as a weight vector for each stakeholder. The weight vector is characterised by containing a weight for every objective and the weights sum to unity.

The second step was considered in this report. This step involved setting up a bio-economic model of the Danish industrial fishery, incorporating the weights, and thereafter analysing the management consequences for the fishery. The management considerations were analysed for each stakeholder and for groups of stakeholders.

The model is a non-linear constrained optimisation programme and has been set up in a multi-objective goal-programming framework. The objectives were incorporated in goal constraints and deviational variables determine the respective distances to target values. It is the weighted sum of the deviational variables that is minimised, and therefore the solution represent the optimal achievement of all objectives simultane-

ously. The analysis consisted of a comparative study of the optimally managed Danish industrial fishery in the North Sea, seen from the perspective of individual stakeholders, groups of stakeholders and all stakeholders (on an aggregated level). The model seemed to be operational and provide reliable results. To avoid extreme and non-realistic solutions, care was taken to formulate the objective functions and the set of allowable solutions, i.e. including sensible restrictions on fishing effort and catches.

Seven objectives were included in the objective function ranging from profit and safety costs to bycatch and closure of feeding grounds. The analysis was performed using a short run and long run time perspective for each stakeholder. The difference between these is the number of endogenous variables. In the short run, the number of days at sea was assumed to be the only variable changeable by managers, while in the long run, the number of vessels also becomes changeable.

An extensive amount of figures was therefore available with respect to the consequences upon the industrial fishery, if the weights from each stakeholder were used to determine the optimally managed fishery. Not surprisingly, the results supplied by the model correspond to the preference structures elicited for the different stakeholders. For the stakeholders with large weights upon economic factors (primarily Danish stakeholders), the activity and thus catches in the industrial fleet should only decrease marginally, while the economic objectives are improved. The opposite was estimated to be the case for stakeholders with large weights on biological factors (primarily stakeholders from United Kingdom and environmentalist groups). Significant reductions in activity and therefore catches and profits were to be realised, if the weights of these stakeholders were used to manage the fishery. It should be mentioned that the objectives practically consist of two types, each pointing in opposite directions. Both the objectives and the preferences of the stakeholders are polarised, which explains the trends shown in the results. There is a clear trade-off between the economically related objectives on one hand and the biological on the other.

Considering that the consequences for the optimal management of the Danish industrial fishery in the North Sea were seen to be highly dependent on which weights were applied, the importance of meaningful and reliable weights is evident. When performing multi-objective optimisations, it must therefore be emphasized that the process will benefit from joining the qualitative elicitation of preferences with the quantitative analysis. The results of a goal programme with arbitrary weights would not have been as fruitful.

Consequences besides those directly related to the industrial fishery were also to a minor extent considered. However, due to lack of information on the consequences related to the consumption fishery and onshore industry, only the processing industry were considered. Again, the size of the effects was greatly dependent upon the specific stakeholder.

Based on the experiences derived from the multi-objective analysis of the Danish industrial fishery in the North Sea, several implications on management were finally discussed. The importance of obtaining meaningful and reliable weights was stressed, including how these are measured in the model set-up. This is due to the high influence these have on the obtained results. The presented model is detailed and based on reliable data. Moreover, sensitivity analysis on key parameters showed that the trends in the presented case study are reliable. Despite this, managers should not focus upon the exact figures, but instead focus upon the obtained trends.

There are areas where further development and investigation would be possible. This includes issues as choice of method to scale the deviational variables, a more comprehensive analysis of the trade-off among objectives, which again would involve experimenting with the number of objectives. In addition, further sensitivity analyses could be performed. For example, the sensitivity with respect to the catch per day parameter and the functional formulation of the objectives could be examined. Finally, it would be interesting to look into other multi-objective approaches, such as the lexicographic (preemptive), MinMax goal programmes and interactive procedures (Steuer, 1986).

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Appendix A. Construction of dataset

The data was obtained from FD and DIFRES. The latter contains information about the level of activity, i.e. the number of days at sea. This variable is fundamental to the optimising model, since days at sea is an endogenous variable.

Unfortunately, there was a mis-match between the catches registered in the DIFRES database and the FD database[36]. The activity measure in form of number of days at sea was therefore scaled with respect to the fraction of FD catch weight relative to DIFRES catch weight. This approach secured that the number of days at sea was in reasonable agreement with the catches as registered by FD.

Table A.1 summarises the consequences of performing the adjustment of the dataset. Overall, 7 percent of the observations were deleted, which accounted for only 3 of the catch value. Almost 90 percent of this deleted catch value was due to discrepancies in October, November and December, the primary reason being the presence of additional payments.

Table A.1. Observations and deleted catches

	Before[1]	After[2]	Deleted	Deleted (%)
In total 1999				
Observations	2,294	2,123	171	7
Catch Value (1,000 DKK)	816,046	791,388	24,658	3
Catch Value (1,000 Euro)[3]	109,831	106,513	3,319	
Month 10,11,12				
Observations	689	584	105	15
Catch Value (1,000 DKK)	187,445	165,379	22,066	12
Catch Value (1,000 Euro)	25,228	22,258	2,970	

Notes: 1) FD dataset; 2) Adjusted dataset; 3) The applied exchange rate is 1 Euro = 7.43 DKK.

The industrial vessels obtain a given price for their catches during the year. When the industrial fishery stops towards the end of the year due to seasonality, the profits from the processing plants are calculated and divided among the vessels as additional payments. These payments are registered at the end of the year and account for 76 of the deleted catch value. Thus, the used data underestimates the income in the industrial fishery to some extent.

[36] While the FD database is a continuously updated database, the part of the DIFRES database, which FOI has access to, is not. Corrections are therefore not accounted for in the DIFRES database.

Currently, a new large general fisheries database DFAD (Danish Fisheries Analytical Database) is under construction in collaboration between the Danish Fisheries Directorate, The Danish Institute for Fisheries Research, and the Danish Research Institute of Food Economics. This work is, at this moment, not fully accomplished. However, it is possible to implement the new data in the model as soon as they are available.

Costs:
Table A.2 shows how well the vessels of the dataset are represented in the account statistics.

Table A.2. Number of vessels in dataset and the number of these represented in the account statistics

Fleet segment	All vessels in dataset	Vessels in the account statistics
Trawlers 18-24m	22	8
Trawlers 24-40m (other)	33	12
Trawlers 24-40m (industrial)	59	20
Trawlers above 40m (other)	17	8
Trawlers above 40m (industrial)	16	3
Total	147	51

Notes: Trawlers are classified as “other”, if their catches of industrial species comprise less than 80% of their total catch value.

With exception of industrial trawlers above 40 metres, the fleet segments are represented by more than one-third of the vessels in the account statistics.

Appendix B. Dimensions

Table B.1. The counties and corresponding vessel district and related registration letters

County	District	Registration letters	Most important ports
Nordjylland and Viborg county	Aalborg	A*	
	Frederikshavn	FN*, LN*	
	Hirtshals	HG	Hirtshals
	Hanstholm	HM	Hanstholm
	Skagen	S	Skagen
	Skive	SK*	
	Thisted	T	Hanstholm
Ribe county	Esbjerg	E	Esbjerg
Ringkøbing county	Lemvig	L	Thyborøn, Thorsminde, Lemvig
	Ringkøbing	RI	Hvide Sande

Notes: Homeports marked with * are not represented in the dataset.

Table B.2. The 33 species[1]

1.	Other species (C)	12.	Common dab (C)	23.	Plaice (C)
2.	Blue whiting (I)	13.	Hake (C)	24.	Lemon sole (C)
3.	Tusk (I)	14.	Haddock (C)	25.	Herring (C)
4.	Sprat (I)	15.	Ling (C)	26.	Witch flounder (C)
5.	Cuttlefish (C)	16.	Pollack (C)	27.	Flounder (C)
6.	Norway lobster (C)	17.	Mackerel (C)	28.	Brill (C)
7.	Northern prawn (C)	18.	Saithe (C)	29.	Norway pout (I)
8.	Catfish (C)	19.	Turbot (C)	30.	Sandeel (I)
9.	Angler (C)	20.	Picked dogfish (C)	31.	Sole (C)
10.	Halibut (C)	21.	Pilchard (I)	32.	Cod (C)
11.	Horse mackerel (I)	22.	Redfish (C)	33.	Additional payments

Note: 1) Additional payments are treated as a species. Species marked with *I* and *C* are considered as industrial and consumption species, respectively.

Appendix C. Output tables from the short run scenario[37]

Table C.1. Value of Achievement function and the objectives

		Achievement function value	1) Maximise profit (1,000 DKK)	2) Maximise employment (1,000 DKK)	3) Maximise safety (1,000 DKK)	4) Maintain the industrial fishery at present level of input	5) Minimise catch of sandeel and Norway pout (tonnes)	6) Minimise bycatch of consumption species (tonnes)	7) Minimise impact on birds etc. in a specific area (tonnes)	8) Stop the industrial fishery in the North Sea[1] (tonnes)
Danish Industry	DFA	0.141	243,518	219,749	98,659	1.000	545,816	480	0	767,845
	AFMD	0.148	240,920	218,008	99,412	1.000	545,554	347	0	767,582
	GWUD	0.244	217,644	208,247	118,809	1.000	543,549	614	0	765,577
	Group of stakeholders	0.175	231,694	215,227	106,477	1.000	542,949	296	0	764,977
Environmentalists	RSPB	0.152	116,742	108,162	73,290	0.995	88,631	94	0	297,350
	WWF	0.104	106,012	97,539	52,672	0.873	10,530	43	0	212,473
	Greenpeace	0.112	106,189	97,694	52,849	0.879	10,948	54	0	212,892
	DSCN	0.132	100,553	94,112	57,964	0.863	9,686	52	0	212,797
	Group of stakeholders	0.143	109,825	102,243	59,203	0.939	35,937	58	0	239,088
Danish Authorities	MFAF	0.119	226,512	209,179	98,139	1.000	527,718	72	0	731,743
	DIFRES	0.154	133,011	123,206	72,162	1.000	128,381	48	0	333,545
	Group of stakeholders	0.148	221,027	204,905	99,201	1.000	513,307	45	0	717,347
UK Authorities and Industry	MAFF	0.140	116,521	108,356	67,699	0.983	76,050	58	0	281,356
	NFFO	0.108	101,890	95,057	55,456	0.889	17,864	13	0	205,773
	Group of stakeholders	0.153	120,692	111,762	69,516	1.000	93,432	58	0	298,718
All stakeholders		0.208	141,660	129,848	76,184	1.000	144,191	124	0	365,180

Notes: 1) The last column contains the catch weight of industrial species in the North Sea. This criterion is not included in the model and has no influence on the optimisations.

[37] Monetary values are presented in Danish kroner (DKK). The exchange rate between DKK and Euro is approximately 1 Euro = 7.43 DKK.

Table C.2. Total number of days at sea for each analysed stakeholder

		-------- North Sea --------		-------- Other areas -------	
		Model	Change compared to effort in 1999 dataset	Model	Change compared to effort in 1999 dataset
Danish Industry	DFA	24,982	1	5,533	-24
	AFMD	25,232	2	4,695	-35
	GWUD	30,123	22	5,721	-21
	Group of stakeholders	26,858	9	5,164	-29
Environmentalists	RSPB	18,496	-25	6,156	-15
	WWF	13,745	-44	5,387	-26
	Greenpeace	13,783	-44	5,443	-25
	DSCN	15,038	-39	5,562	-23
	Group of stakeholders	15,449	-37	5,634	-22
Danish Authorities	MFAF	24,993	1	5,777	-20
	DIFRES	18,495	-25	5,994	-17
	Group of stakeholders	25,239	2	5,812	-20
UK Authorities and Industry	MAFF	17,535	-29	5,758	-20
	NFFO	14,387	-42	5,925	-18
	Group of stakeholders	17,899	-27	5,802	-20
All stakeholders		19,301	-22	6,315	-13

Table C.3. Total number of days at sea divided on fleet segments in the North Sea

		Trawlers 18-24m	Trawlers 24-40m (other)	Trawlers 24-40m (industrial)	Trawlers above 40m (other)	Trawlers above 40m (industrial)
Danish Industry	DFA	3,155	4,960	10,078	3,680	3,108
	AFMD	3,171	5,221	10,338	3,855	2,646
	GWUD	2,539	5,705	15,659	3,438	2,782
	Group of stakeholders	2,989	4,891	12,145	3,796	3,038
Environmentalists	RSPB	2,679	3,971	6,023	3,126	2,697
	WWF	2,543	3,336	4,286	2,237	1,343
	Greenpeace	2,543	3,336	4,292	2,240	1,371
	DSCN	2,505	3,438	5,227	2,223	1,645
	Group of stakeholders	2,758	3,541	5,224	2,294	1,632
Danish Authorities	MFAF	3,304	4,477	11,042	3,582	2,587
	DIFRES	3,203	3,828	5,949	3,040	2,475
	Group of stakeholders	3,253	4,679	11,040	3,630	2,637
UK Authorities and Industry	MAFF	2,782	4,243	6,023	2,616	1,871
	NFFO	2,549	3,064	5,099	2,300	1,374
	Group of stakeholders	2,836	4,223	5,929	2,767	2,145
All stakeholders		3,142	3,993	6,131	3,522	2,513
Dataset (1999)		2,670	5,195	10,526	2,673	3,570
Number of vessels		22	33	59	17	16

Table C.4. Catch weight in the North Sea (tonnes)

		Sandeel	Norway pout	Other industrial species	Consumption species
Danish Industry	DFA	501,526	44,290	222,029	34,705
	AFMD	501,526	44,028	222,029	34,516
	GWUD	501,526	42,022	222,028	34,594
	Group of stakeholders	501,526	41,423	222,029	34,493
Environmentalists	RSPB	80,502	8,129	208,719	34,271
	WWF	10,484	46	201,943	34,181
	Greenpeace	10,565	383	201,944	34,205
	DSCN	6,462	3,223	203,111	34,212
	Group of stakeholders	27,810	8,127	203,151	34,216
Danish Authorities	MFAF	501,526	26,192	204,025	34,412
	DIFRES	117,030	11,352	205,164	34,406
	Group of stakeholders	501,526	11,780	204,041	34,371
UK Authorities and Industry	MAFF	69,453	6,597	205,306	34,268
	NFFO	14,959	2,905	187,908	34,169
	Group of stakeholders	86,628	6,803	205,286	34,310
All stakeholders		132,839	11,352	220,989	34,472
Dataset (1999)		509,254	44,290	222,069	35,393

Table C.5. Catch value in the North Sea (1,000 DKK)

		Sandeel	Norway pout	Other industrial species	Consumption species	Total
Danish Industry	DFA	298,866	29,123	165,252	155,068	648,309
	AFMD	298,830	28,545	164,026	151,903	643,304
	GWUD	289,864	26,368	161,708	146,824	624,764
	Group of stakeholders	296,699	26,863	163,246	150,544	637,352
Environmentalists	RSPB	50,067	5,461	150,666	134,506	340,700
	WWF	5,786	31	147,963	137,658	291,438
	Greenpeace	5,817	217	147,959	138,041	292,034
	DSCN	3,557	1,864	147,702	134,025	287,148
	Group of stakeholders	16,002	5,459	148,635	138,020	308,116
Danish Authorities	MFAF	296,960	16,764	151,760	149,118	614,602
	DIFRES	71,257	7,686	150,842	144,746	374,531
	Group of stakeholders	296,927	7,354	151,693	148,529	604,503
UK Authorities and Industry	MAFF	43,082	4,075	149,525	135,905	332,587
	NFFO	8,151	1,690	138,972	137,731	286,544
	Group of stakeholders	53,023	4,215	149,740	136,946	343,924
All stakeholders		81,384	7,686	161,845	146,314	397,229
Dataset (1999)		293,778	26,540	158,489[1]	152,256	631,063

Notes: 1) Including additional payments.

Table C.6. Total catch value divided on fleet segments (1,000 DKK)

		Trawlers 18-24m	Trawlers 24-40m (other)	Trawlers 24-40m (industrial)	Trawlers above 40m (other)	Trawlers above 40m (industrial)
Danish Industry	DFA	64,536	198,069	217,868	183,375	117,550
	AFMD	64,266	182,284	219,344	169,017	118,678
	GWUD	52,937	164,348	322,354	126,076	74,349
	Group of stakeholders	61,406	177,565	255,733	164,057	98,310
Environmentalists	RSPB	48,735	135,686	106,835	116,408	47,932
	WWF	46,979	117,542	76,744	124,245	57,300
	Greenpeace	46,403	122,888	76,198	124,604	57,606
	DSCN	48,014	110,102	88,578	122,157	56,178
	Group of stakeholders	50,179	123,591	88,482	123,040	60,620
Danish Authorities	MFAF	61,753	185,073	246,661	163,233	89,589
	DIFRES	59,079	164,147	98,514	104,992	73,459
	Group of stakeholders	61,980	176,859	251,205	160,217	83,868
UK Authorities and Industry	MAFF	51,392	142,545	93,720	115,408	57,439
	NFFO	46,769	109,026	85,520	124,351	58,385
	Group of stakeholders	51,814	150,665	97,566	123,811	54,090
All stakeholders		58,330	167,106	103,551	134,855	75,029
Dataset (1999)[1]		60,317	184,127	276,525	122,013	107,451

Notes: 1) Including additional payments.

Table C.7. Variable costs divided on selected components (1,000 DKK)

		Operating costs	Landing costs	Sales costs	Crew costs	Total	Total in the North Sea
Danish Industry	DFA	111,141	19,067	94,946	261,905	487,060	404,791
	AFMD	108,647	18,658	91,561	252,640	471,506	402,385
	GWUD	127,859	18,372	90,320	245,336	481,887	407,120
	Group of stakeholders	116,097	18,474	92,343	253,511	480,426	405,658
Environmentalists	RSPB	89,924	9,332	54,708	144,238	298,202	223,959
	WWF	70,748	7,926	51,177	138,363	268,214	185,425
	Greenpeace	71,375	8,148	51,667	140,085	271,275	185,845
	DSCN	75,574	8,136	51,625	138,102	273,438	186,595
	Group of stakeholders	77,220	8,561	53,800	145,610	285,191	198,291
Danish Authorities	MFAF	110,816	18,157	90,772	251,009	470,753	388,090
	DIFRES	88,594	10,125	58,748	163,253	320,720	241,520
	Group of stakeholders	111,574	17,845	89,438	246,450	465,308	383,477
UK Authorities and Industry	MAFF	84,885	9,190	54,927	148,454	297,456	216,066
	NFFO	74,711	7,948	51,601	137,896	272,155	184,654
	Group of stakeholders	86,801	9,783	57,109	154,140	307,834	223,232
All stakeholders		93,624	11,210	64,256	174,600	343,690	255,567

Table C.8. Total variable costs divided on fleet segments (1,000 DKK)

		Trawlers 18-24m	Trawlers 24-40m (other)	Trawlers 24-40m (industrial)	Trawlers above 40m (other)	Trawlers above 40m (industrial)
Danish Industry	DFA	38,543	117,695	147,358	109,322	74,143
	AFMD	38,359	108,460	148,682	101,443	74,562
	GWUD	31,546	100,578	220,234	77,515	52,014
	Group of stakeholders	36,637	106,873	172,988	98,773	65,155
Environmentalists	RSPB	29,274	82,963	77,947	71,750	36,268
	WWF	28,156	71,042	54,451	73,636	40,930
	Greenpeace	27,836	74,100	53,857	74,307	41,175
	DSCN	28,805	67,123	63,989	73,194	40,328
	Group of stakeholders	30,067	74,686	64,092	73,458	42,888
Danish Authorities	MFAF	36,889	110,426	166,171	97,649	59,617
	DIFRES	35,406	98,959	71,359	64,574	50,422
	Group of stakeholders	37,063	106,293	169,351	96,123	56,478
UK Authorities and Industry	MAFF	30,850	86,385	68,391	70,697	41,132
	NFFO	28,067	66,206	62,045	74,228	41,608
	Group of stakeholders	31,014	91,068	70,861	74,955	39,936
All stakeholders		34,903	100,308	75,383	82,301	50,795

Table C.9. Total profit divided on fleet segments (1,000 DKK)

		Trawlers 18-24m	Trawlers 24-40m (other)	Trawlers 24-40m (industrial)	Trawlers above 40m (other)	Trawlers above 40m (industrial)
Danish Industry	DFA	25,992	80,374	70,510	74,054	43,407
	AFMD	25,908	73,823	70,661	67,575	44,115
	GWUD	21,391	63,770	102,119	48,561	22,335
	Group of stakeholders	24,769	70,692	82,746	65,285	33,154
Environmentalists	RSPB	19,461	52,723	28,887	44,658	11,664
	WWF	18,822	46,500	22,293	50,610	16,370
	Greenpeace	18,568	48,788	22,341	50,297	16,430
	DSCN	19,210	42,980	24,590	48,963	15,850
	Group of stakeholders	20,111	48,905	24,389	49,583	17,732
Danish Authorities	MFAF	24,864	74,647	80,490	65,583	29,972
	DIFRES	23,673	65,188	27,155	40,418	23,037
	Group of stakeholders	24,917	70,566	81,854	64,094	27,391
UK Authorities and Industry	MAFF	20,542	56,161	25,329	44,711	16,306
	NFFO	18,702	42,820	23,475	50,122	16,777
	Group of stakeholders	20,800	59,597	26,705	48,856	14,154
All stakeholders		23,427	66,798	28,169	52,554	24,234

Appendix D. Output tables from the long run scenario[38]

Table D.1. Value of Achievement function and the objectives

		Achievement function value	1) Maximise profit (1,000 DKK)	2) Maximise employment (1,000 DKK)	3) Maximise safety (1,000 DKK)	4) Maintain the industrial fishery at present level of input	5) Minimise catch of sandeel and Norway pout (tonnes)	6) Minimise bycatch of consumption species (tonnes)	7) Minimise impact on birds etc. in a specific area (tonnes)	8) Stop the industrial fishery in the North Sea[1] (tonnes)
Danish Industry	DFA	0.139	176,574	219,911	91,336	0.758	538,890	667	0	759,264
	AFMD	0.149	172,744	218,258	91,399	0.760	538,779	488	0	759,151
	GWUD	0.260	127,058	213,960	114,255	0.915	540,433	516	0	762,459
	Group of stakeholders	0.179	161,378	214,742	97,627	0.773	531,739	342	0	749,955
Environmentalists	RSPB	0.119	81,487	104,285	43,983	0.402	9,475	39	0	207,560
	WWF	0.066	82,968	99,422	35,259	0.351	2,756	2	0	180,400
	Greenpeace	0.071	88,331	101,346	35,958	0.359	2,880	39	0	191,551
	DSCN	0.098	78,282	102,796	41,776	0.373	5,991	29	0	198,938
	Group of stakeholders	0.097	87,003	103,062	40,875	0.369	8,263	31	0	199,307
Danish Authorities	MFAF	0.120	146,661	172,323	66,474	0.556	351,573	22	0	529,833
	DIFRES	0.111	87,938	100,723	39,623	0.369	13,823	2	0	184,454
	Group of stakeholders	0.127	140,360	143,646	50,776	0.433	196,053	29	0	383,025
UK Authorities and Industry	MAFF	0.100	83,227	97,862	37,269	0.318	9,305	2	0	187,118
	NFFO	0.068	85,358	98,803	35,398	0.355	4,131	2	0	175,856
	Group of stakeholders	0.105	82,037	101,838	40,552	0.369	9,318	2	0	190,171
All stakeholders		0.159	97,232	109,491	43,762	0.410	30,473	40	0	217,617

Notes: 1) The last column contains the catch weight of industrial species in the North Sea. This criterion is not included in the model and has no influence on the optimisations.

[38] Monetary values are presented in Danish kroner (DKK). The exchange rate between DKK and Euro is approximately 1 Euro = 7.43 DKK.

Table D.2. Total number of days at sea in each case and comparison with the 1999 values of the dataset

		---------- North Sea ----------		---------- Other areas --------	
		Model	Change compared to effort in 1999 dataset	Model	Change compared to effort in 1999 dataset
Danish Industry	DFA	23,861	-3	5,676	-22
	AFMD	23,879	-3	5,634	-22
	GWUD	28,907	17	5,390	-26
	Group of stakeholders	25,256	3	5,878	-19
Environmentalists	RSPB	12,241	-50	6,181	-15
	WWF	9,696	-61	6,340	-12
	Greenpeace	9,863	-60	5,596	-23
	DSCN	11,517	-53	6,313	-13
	Group of stakeholders	11,174	-55	6,246	-14
Danish Authorities	MFAF	17,435	-29	6,030	-17
	DIFRES	10,771	-56	5,554	-23
	Group of stakeholders	13,911	-44	6,399	-12
UK Authorities and Industry	MAFF	10,352	-58	6,346	-12
	NFFO	9,772	-60	5,654	-22
	Group of stakeholders	11,229	-54	6,389	-12
All stakeholders		11,920	-52	5,501	-24

Table D.3. Total number of days at sea in the five fleet segments (in the North Sea)

		Trawlers 18-24m	Trawlers 24-40m (other)	Trawlers 24-40m (industrial)	Trawlers above 40m (other)	Trawlers above 40m (industrial)
Danish Industry	DFA	2,842	7,101	9,963	3,544	409
	AFMD	2,851	7,156	9,848	3,524	500
	GWUD	3,011	4,055	15,952	3,863	2,026
	Group of stakeholders	2,898	6,574	11,390	3,864	529
Environmentalists	RSPB	2,786	3,469	4,502	1,484	0
	WWF	2,545	2,072	3,528	1,551	0
	Greenpeace	2,360	2,431	3,568	1,504	0
	DSCN	2,688	2,706	4,603	1,521	0
	Group of stakeholders	2,396	2,698	4,589	1,490	0
Danish Authorities	MFAF	3,480	3,123	7,510	3,322	0
	DIFRES	2,530	2,028	4,604	1,609	0
	Group of stakeholders	2,996	3,776	5,207	1,932	0
UK Authorities and Industry	MAFF	3,251	1,019	4,492	1,590	0
	NFFO	2,557	2,152	3,572	1,492	0
	Group of stakeholders	2,865	2,296	4,555	1,513	0
All stakeholders		2,874	2,182	5,082	1,782	0
Dataset (1999)		2,670	5,195	10,526	2,673	3,570

Table D.4. Number of vessels divided on fleet segments

		Trawlers 18-24m	Trawlers 24-40m (other)	Trawlers 24-40m (industrial)	Trawlers above 40m (other)	Trawlers above 40m (industrial)	Total
Danish Industry	DFA	17	34	39	16	2	107
	AFMD	17	35	38	16	3	108
	GWUD	20	20	64	15	9	128
	Group of stakeholders	17	31	44	16	3	111
Environmentalists	RSPB	19	23	31	8	0	81
	WWF	22	17	30	8	0	77
	Greenpeace	17	16	31	8	0	72
	DSCN	23	20	31	9	0	83
	Group of stakeholders	14	19	31	8	0	72
Danish Authorities	MFAF	23	16	32	15	0	87
	DIFRES	14	15	31	8	0	68
	Group of stakeholders	20	22	23	7	0	72
UK Authorities and Industry	MAFF	21	12	30	8	0	72
	NFFO	18	15	31	8	0	72
	Group of stakeholders	19	19	31	8	0	77
All stakeholders		16	15	31	8	0	69
Dataset (1999)		22	33	59	17	16	147

Table D.5. Number of vessels in the different counties

		Nordjylland and Viborg	Ribe	Ringkøbing	Total
Danish Industry	DFA	20	53	34	107
	AFMD	22	53	34	108
	GWUD	7	54	67	128
	Group of stakeholders	18	53	39	111
Environmentalists	RSPB	15	40	27	81
	WWF	11	38	28	77
	Greenpeace	5	39	28	72
	DSCN	12	40	31	83
	Group of stakeholders	10	39	23	72
Danish Authorities	MFAF	14	50	23	87
	DIFRES	4	39	25	68
	Group of stakeholders	9	36	27	72
UK Authorities and Industry	MAFF	12	39	21	72
	NFFO	5	39	28	72
	Group of stakeholders	13	39	24	77
All stakeholders		6	38	25	69
Dataset (1999)		33	52	62	147

Table D.6. Catch weight in the North Sea (tonnes)

		Sandeel	Norway pout	Other industrial species	Consumption species
Danish Industry	DFA	498,158	40,733	220,374	34,569
	AFMD	498,158	40,621	220,372	34,429
	GWUD	498,840	41,593	222,026	34,601
	Group of stakeholders	498,158	33,581	218,216	34,375
Environmentalists	RSPB	5,935	3,540	198,085	34,264
	WWF	2,729	26	177,644	34,046
	Greenpeace	2,822	59	188,671	34,088
	DSCN	2,573	3,418	192,947	34,130
	Group of stakeholders	4,664	3,600	191,043	34,118
Danish Authorities	MFAF	343,200	8,373	178,261	33,544
	DIFRES	9,406	4,417	170,631	34,188
	Group of stakeholders	187,755	8,299	186,971	33,941
UK Authorities and Industry	MAFF	5,968	3,337	177,814	33,400
	NFFO	4,041	90	171,725	34,194
	Group of stakeholders	5,743	3,575	180,853	34,240
All stakeholders		21,327	9,146	187,144	34,332
Dataset (1999)		509,254	44,290	222,069	35,393

Table D.7. Catch value in the North Sea (1,000 DKK)

		Sandeel	Norway pout	Other industrial species	Consumption species	Total
Danish Industry	DFA	295,365	25,437	165,145	152,782	638,729
	AFMD	295,131	25,434	164,954	149,350	634,869
	GWUD	291,727	25,885	166,967	150,105	634,684
	Group of stakeholders	294,710	20,969	164,042	147,982	627,703
Environmentalists	RSPB	3,515	2,064	144,624	144,793	294,996
	WWF	1,556	18	130,951	143,892	276,417
	Greenpeace	1,591	39	139,043	142,102	282,775
	DSCN	1,495	1,983	141,594	143,900	288,972
	Group of stakeholders	2,668	2,093	140,089	144,457	289,307
Danish Authorities	MFAF	207,784	5,468	138,098	139,381	490,731
	DIFRES	5,510	2,642	128,022	146,239	282,413
	Group of stakeholders	112,862	5,381	137,120	146,856	402,219
UK Authorities and Industry	MAFF	3,497	1,935	129,636	136,144	271,212
	NFFO	2,316	60	128,167	144,620	275,163
	Group of stakeholders	3,253	2,078	133,568	146,010	284,909
All stakeholders		13,274	5,885	138,975	148,519	306,653
Dataset (1999)		293,778	26,540	158,489[1]	152,256	648,309

Notes: 1) Including additional payments

Table D.8. Catch value divided on fleet segments (1,000 DKK)

		Trawlers 18-24m	Trawlers 24-40m (other)	Trawlers 24-40m (industrial)	Trawlers above 40m (other)	Trawlers above 40m (industrial)	Total
Danish Industry	DFA	68,967	268,462	246,243	185,897	22,674	792,243
	AFMD	70,111	269,678	239,413	182,373	25,548	787,122
	GWUD	66,742	137,162	340,328	184,708	60,599	789,539
	Group of stakeholders	68,555	221,555	277,844	183,828	32,032	783,814
Environmentalists	RSPB	64,925	125,860	151,500	108,943	0	451,229
	WWF	62,040	100,466	152,662	114,839	0	430,007
	Greenpeace	59,496	107,944	151,731	112,712	0	431,883
	DSCN	62,463	110,472	155,235	113,115	0	441,285
	Group of stakeholders	59,158	115,933	155,469	113,004	0	443,563
Danish Authorities	MFAF	82,354	128,404	223,064	203,603	0	637,425
	DIFRES	61,489	96,540	156,848	115,456	0	430,332
	Group of stakeholders	71,057	182,540	179,324	123,167	0	556,088
UK Authorities and Industry	MAFF	73,842	74,106	157,941	115,501	0	421,390
	NFFO	62,102	97,050	151,908	112,855	0	423,915
	Group of stakeholders	68,556	103,846	153,313	112,996	0	438,712
All stakeholders		67,929	106,667	169,345	111,674	0	455,615
Dataset (1999)[1]		60,317	184,127	276,525	122,013	107,451	750,433

Notes: 1) Including additional payments.

Table D.9. Total costs in all areas divided on cost components (1,000 DKK)

		Operating costs	Landing costs	Sales costs	Crew costs	Fixed costs	Total
Danish Industry	DFA	100,727	18,842	94,908	271,456	129,736	615,669
	AFMD	100,829	18,804	94,072	269,344	131,329	614,378
	GWUD	119,477	18,950	98,345	266,521	159,188	662,481
	Group of stakeholders	106,719	18,682	95,164	267,134	134,737	622,436
Environmentalists	RSPB	58,640	7,835	54,148	158,410	90,708	369,742
	WWF	51,330	7,312	52,420	152,006	83,971	347,039
	Greenpeace	49,540	7,479	52,479	153,386	80,668	343,552
	DSCN	57,043	7,630	53,515	154,827	89,988	363,003
	Group of stakeholders	56,157	7,642	53,756	156,010	82,994	356,559
Danish Authorities	MFAF	78,079	14,393	79,355	219,842	99,095	490,764
	DIFRES	52,220	7,359	52,616	152,263	77,937	342,394
	Group of stakeholders	65,286	11,231	65,982	196,029	77,201	415,729
UK Authorities and Industry	MAFF	51,854	7,419	51,714	149,278	77,897	338,162
	NFFO	49,004	7,195	51,698	150,591	80,069	338,557
	Group of stakeholders	55,708	7,497	53,166	154,585	85,718	356,675
All stakeholders		55,361	7,984	55,256	161,791	77,992	358,383

Table D.10. Total costs divided on fleet segments (1,000 DKK)

		Trawlers 18-24m	Trawlers 24-40m (other)	Trawlers 24-40m (industrial)	Trawlers above 40m (other)	Trawlers above 40m (industrial)
Danish Industry	DFA	49,319	198,624	212,032	137,314	18,380
	AFMD	49,784	201,225	206,961	135,430	20,978
	GWUD	49,464	105,210	313,163	137,386	57,258
	Group of stakeholders	49,153	169,576	240,445	137,329	25,933
Environmentalists	RSPB	47,808	103,199	141,473	77,262	0
	WWF	47,119	80,996	138,885	80,040	0
	Greenpeace	43,480	82,155	139,582	78,335	0
	DSCN	48,003	90,539	143,990	80,471	0
	Group of stakeholders	41,920	92,207	144,128	78,305	0
Danish Authorities	MFAF	60,229	96,084	186,882	147,570	0
	DIFRES	43,140	74,042	145,018	80,194	0
	Group of stakeholders	51,675	134,401	146,764	82,888	0
UK Authorities and Industry	MAFF	54,174	58,923	144,396	80,669	0
	NFFO	45,446	75,145	139,693	78,272	0
	Group of stakeholders	49,619	85,440	142,634	78,982	0
All stakeholders		47,890	79,742	152,630	78,121	0

Table D.11. Total profit divided on fleet segments (1,000 DKK)

		Trawlers 18-24m	Trawlers 24-40m (other)	Trawlers 24-40m (industrial)	Trawlers above 40m (other)	Trawlers above 40m (industrial)	Total
Danish Industry	DFA	19,648	69,838	34,210	48,583	4,294	176,574
	AFMD	20,327	68,453	32,452	46,942	4,570	172,744
	GWUD	17,278	31,952	27,165	47,323	3,341	127,058
	Group of stakeholders	19,401	51,979	37,399	46,499	6,100	161,378
Environmentalists	RSPB	17,117	22,660	10,027	31,682	0	81,487
	WWF	14,921	19,470	13,777	34,799	0	82,968
	Greenpeace	16,016	25,789	12,149	34,377	0	88,331
	DSCN	14,460	19,933	11,245	32,644	0	78,282
	Group of stakeholders	17,237	23,726	11,341	34,699	0	87,003
Danish Authorities	MFAF	22,125	32,320	36,183	56,033	0	146,661
	DIFRES	18,349	22,498	11,830	35,261	0	87,938
	Group of stakeholders	19,383	48,139	32,560	40,278	0	140,360
UK Authorities and Industry	MAFF	19,668	15,183	13,544	34,832	0	83,227
	NFFO	16,656	21,905	12,215	34,582	0	85,358
	Group of stakeholders	18,937	18,407	10,680	34,014	0	82,037
All stakeholders		20,039	26,925	16,715	33,553	0	97,232