

Fødevareøkonomisk Institut

Numerical allocation problems and introduction to the Economic Management Model for Fisheries in Denmark

EMMFID

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Preface

This report is part of the project: ‘An Economic Management Model for Fisheries In Denmark’ (EMMFID), financed by The Directorate for Food, Fisheries and Agri Business under the Danish Ministry of Food, Agriculture and Fisheries (FIFOFSJFI-5).

The report describes a model developed by the Danish Research Institute of Food Economics, and it reviews European economic models that aim at forming the basis for management decisions. The model is developed to meet management requirements by use of fisheries economics. Hence, the report considers issues within applied fisheries economics that have been demanded by managers for a long time.

The chosen approach for the Danish model is linear programming, and the model covers the whole Danish fishery. The main purpose is to serve as a tool in ‘*what-if*’ analysis and ‘*what’s best*’ analysis. It is designed to shed light on management questions such as, what is best if certain objectives are pursued subject to technological and biological restrictions.

Because of its nature the model is flexible with respect to the formulation of objectives and constraints. It is important to notice, however, that contrary to many management policies that consider certain minimum levels of fish stocks as the objective, the EMMFID model is designed to consider economic variables such as economic rent, employment and use of capital as the objectives subject to environmental constraints including minimum levels of fish stocks based on biological advice. In that way the model is in agreement with fishermen’s and society’s general objectives.

Further, it should be noted that the model is designed to make best possible use of the comprehensive databases that exist for the Danish fishery with respect to the fishing fleet, landings, catch per unit effort, and costs and earnings. It does not include development in fish stocks but it is designed to comply directly with the biological advice based on biological modelling and assessment for the North East Atlantic Ocean. On a global scale, the uniqueness of the model, is supported by the continual updating of the comprehensive Danish databases.

Danish Research Institute of Food Economics, November 2003

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1. Introduction

With respect to the Common Fisheries Policy (CFP) of the European Union (EU), revised for the next 10 years from 2003, numerical allocation problems attract significant attention. Numerical allocation issues are well known in the biological field, e.g. quota allocations, but not as much within the economic field. However, the literature about bioeconomic management policies is rather comprehensive starting with Warming (1911), Gordon (1954) and Scott (1955), see Anderson (2002). Most of the theoretical contributions are non-numerical, or if they are numerical, the analyses are based on arbitrarily constructed data. An important objective of the theoretical investigations is to compare various management measures' ability to achieve specified goals. Therefore numerical analyses are not necessary as long as the basis for the analyses of the various measures is the same.

When a problem is analysed by use of a mathematical model, the model needs to include the causal connection, parameters and variables. The parameters are defined as being constant over time while the variables can change. If parameter values are not known, e.g. from statistical sources, they could be estimated and hence provide valuable information about the system. This could be an important task in its own right. However, parameter values could also be provided without estimation (non-parametric models), either by direct extraction from statistical sources, by calculation from comprehensive data sets, or by derivation from physical relationships. Apart from the information about the system provided by the parameter values, the parameters are used to describe allocative effects and to forecast. If the results are going to be viewed as reliable it is important that the parameter values do not change or that changes are known.

Several reasons could be forwarded as to why management recommendations based on economics have been based on analytical (non-numerical) models and approaches contrary to management recommendation based on biology. One of the reasons is that the economic data required for operating and maintaining models have been sparse. Another reason is that applied economic research does not have the same institutional background as the biological research represented by e.g. the International Council for Exploration of the Sea (ICES) and the Northwest Atlantic Fisheries Organization (NAFO). Further, while the biological data, not solely but to a large extent, has to be collected independently from the fishermen, the economic data has to be delivered by the fishermen themselves, and they have so far been very reluctant to do so (Anon. 2003). Finally, it could be pointed out that the main interest of the economic research

has been devoted to what management measures would best serve to solve the market failure problem identified by Warming (1911) and Gordon (1954).

The project: '*An Economic Management Model for Fisheries In Denmark*' (EMMFID) comprises the aim to develop an all-inclusive bioeconomic allocation model for the fisheries in Denmark. The project is financed by The Directorate for Food, Fisheries and Agri Business under the Danish Ministry of Food, Agriculture and Fisheries¹ and carried out by the Danish Research Institute of Food Economics (FOI) and researchers from the Department of Environmental and Business Economics, University of Southern Denmark (SDU). EMMFID is a numerical model, set up as a linear constrained optimization programme.

Before a detailed description of EMMFID is provided the first topic to be addressed is how numerical allocation problems in EU fisheries have been solved. Various existing models are described and the provided overview of previous research in this field is used to facilitate the future work with EMMFID.

¹ Project no. FIFOF-SJFI-5

2. Bioeconomic models within the European Union (EU)

2.1. The general modelling framework

The EU fisheries are characterised by multi-species and multi-fleet fisheries (multi-output and multi-input fisheries). Therefore, attention is put on models that are designed to shed light on such types of fisheries. The inclusion of several outputs and inputs makes the model very complex and the intention with such models is not to analyse the behaviour of the fishermen, i.e. estimating parameters such as coefficients and elasticities, but to analyze the consequences of fishermen's behaviour given certain restrictions. The analytical advantages are embodied in the possibility of making calculations for large systems of the consequences if some or several of the variables and the parameters of the model change.

An important question in this respect is the question about short run and long run. In economics the distinction between short and long run is often defined as the time period required for the fixed capital to change. An important question is that if the parameter values change how long is the time period then for which the parameters could be considered constant.

Such a numerical calculation requires the specification of functional forms and all included parameters, see Conrad (1999), chapter 2. The model, including the functions and a dataset of the parameters, could be either static or a dynamic system, of which the latter includes time in one way or another. The numerical analyses could involve both simulation and/or optimization. Simulation is referred to as '*what-if*' analyses while optimization is referred to as '*what's-best*' analyses. While simulation is based on forward iteration on a specified set of parameters, optimization is not only forward iterated but also has the optimal combination of variable values subject to some pre-determined goal. In that respect it could be argued that the simulation model is a subset of the optimization model. However, if the optimal solution of large systems is pursued, the problem could be extremely difficult to solve, if any solution exists at all. Therefore, the two approaches are rather complimentary in the sense that the optimization model is applied in a comparative static way implying that the endogenous variables are determined at two different points in time and then compared. What is happening between these two points in time is considered outside the model, e.g. by use of a simulation ('*what-if*') model.

In practical fisheries management it is necessary to specify the starting point numerically, be it in terms of fish stock abundances, TAC, quota, capacity, effort (e.g. fishing days) or economic performance. From this starting point the allocation could commence either by direct allocation or by market forces subject to the use of management tools. In terms of direct allocations of individually allocated quotas, fishing days or, on member state level, the size of capacity, the overall value of a numerical calculation also depends on the value at the end point, at least in *what's best* analyses.

2.2. European non-EU models

Research concerning economic numerical allocation topics were launched with financial support, in particular, from the EU research programmes FAR and FAIR, starting in 1990 and later from 1995 with a number of investigations carried out for English Channel, the Mediterranean, the North Sea and the Baltic Sea. All these projects have shown that it is possible to construct and operate models, and that data collection has been improved especially in Italy, Holland and Denmark.

An overview of numerical models is found in reports by Arnason and Placenti from 1997 containing a review of the models that are known to exist (at that time), although only some of them are operating (Arnason et. al. 1998).

On a worldwide level, however, it is difficult to keep track on all models – often because the models as such are not published, not even in cases where the models have been used to analyse specific subjects for which the results have been published. Another problem is that many models are not being operated continuously because of data problems and therefore become more or less forgotten. Apart from the above mentioned FAR and FAIR financed models that will be described in further detail below, two other European models should be mentioned. The first one is the ECONMULT model prepared by Eide and Flaaten at the Norwegian College of Fisheries Science, University of Tromsø, and the second one is the BEAM 4 model prepared by the FAO. These models are basically models of the *what-if* type, while most of the EU models are of the *what's best* type.

The ECONMULT is applied to the fish stocks and the fisheries of the Barent Sea, with biological and economic modules being jointly used. In the 1980s the Institute of Marine Research in Bergen (IMR) developed a biological model named MULTISPEC. In 1992 another model named AGGMULT that has almost the same structure as

the first model was built. AGGMULT is used in combination with the economic model ECONMULT.

ECONMULT includes species in the Barent Sea that have a high commercial value, e.g. cod, haddock, and saithe (and maybe capelin, herring and shrimp). In ECONMULT, there are two types of variables: structural and model variables. Structural variables are related to the structure of the fleet (number of vessel groups, number of target species and cohorts), to the global switches between ECONMULT and the biological model, and to the time unit. The model considers 'decision' and endogenous variables as the model variables. The decision variables depend on the existing regulation systems. In open access fisheries there are no decision variables while in a regulated system many variables could be activated. The endogenous variables are biomass and age structure of the stocks.

ECONMULT is a simulation model that considers one or more groups of homogeneous fishing vessels. Each group may exploit one or several fish stocks and each stock may include one or more cohorts. The introduction of cohorts is an important link between the biological and the economic structure of the model. The output of the model includes the effort, the catch, the contribution margin per vessel and the profit, while the management means that may be included in the model are taxes, closed seasons, closed areas, and limited entry. The ECONMULT model may simulate the effects on the fisheries of one of the following combinations of management means: (a) fishing effort per vessel and catch quota per vessel, (b) fishing effort per vessel and total catch quota, (c) number of vessels and fishing effort per vessel, (d) number of vessels and catch per vessel and (e) number of vessels and total catch. There is a difference between the short run and the long run scenarios. In the short run the number of vessels is considered fixed and the first two means, (a) and (b), are the most important. In the long run, the number of vessels may change and thus means (c) – (e) may show to be more useful.

BEAM 4 is primarily designed for the analysis of tropical mixed fisheries with *penaeid* shrimps as the target species and finfish as the by-catch. It is, generalised however, and in principle may be used to analyse any fishery if pertinent parameter values are available (which is often not the case). The objective of BEAM 4 (Bio-Economic Analytical Model) is to predict yield, value and a series of measures of economic performance as a function of fishery management measures, such as fishing effort control, closed season, closed areas and minimum mesh size regulation. It can deal with a fishery system of several stocks, fleets, areas (fishing grounds) and proc-

essing plants, and can account for migration of the species as well as seasonality of recruitment. The model behind BEAM 4 is an age-structured cohort-based fish stock assessment model combined with an economic model of both harvesting and processing sectors. The measures of economic performance calculated by the economic sub-model include private profit, profitability, gross value added, net value added, national net value added, resource rent, employment, costs in foreign exchange and foreign exchange earnings.

Finally before turning to the EU models it should be mentioned that under the auspices of the OECD, modelling work was carried out headed by Dan Lane who developed a generic bioeconomic model (excel spreadsheet) that has been applied to different fisheries including the cod fishery of the Baltic Sea.

2.3. EU models concerning the Mediterranean area

For the Mediterranean Sea the Italian model MOSES is well documented (e.g. www.IREPA.org, project FAIR-CT95-0561 Multi-Species Bioeconomic Models). Unfortunately, in Italy there is a lack of wide and reliable data on some fundamental aspects of fisheries, especially on migration of fleets, disaggregation of catch, biological behaviour of species and their interactions. The Italian model is specifically built to consider these aspects in an Italian context, in order to represent a management instrument to be employed by public administration. MOSES is a catch-effort model for multi-species and multi-gear fisheries, developed using time series of data of catch and fishing effort. It can be used for both simulation and optimization analysis. In the simulation case, the model offers a description of catch and effort data through the estimation of parameters (logistic and biological models). In the optimization case, it provides the optimal distribution of fishing effort over areas and gears according to different scenarios (each combining economic objectives and biological and inertia constraints). Two main parts, a biological and an economic part, compose MOSES.

For the biological part, i.e. the analysis of catch and effort data, surplus-production (non-age-structured) models and age-structured models are used. However, the use of fully age-structured models and multi-species interactions reveals to be prohibitive because of the high number of species and the lack of biological information. In MOSES, 44 species and 3 residual groups of species are considered. Therefore, the MOSES refers to the whole fishery and all stocks in the Italian fishery.

The economic part of the model reflects that more than 90% of the fishing firms are individual or small family firms, and only the remaining part consists of companies. This composition is taken into account especially in the remuneration of labour that is dominated by share contracts (80% of total cases). Therefore, the economic part of MOSES aims to maximise the value added, (i.e. the objective is to determine the optimal distribution of fishing effort that maximises the value added) compatible with the need of species preservation (biological constraint) and of socio-economic aspects such as a realistic redistribution of the productive structure (inertia constraint). The average fish prices and the fishing unit costs come from time series of data estimated by IREPA on the basis of the monitoring of how the Italian fleet has developed since 1985 through a sample methodology.

During the optimization procedure the bio-economic model looks for the optimal allocation of fishing effort (and of optimal size of the fleet) for management policy purposes, using prices and unit costs of the reference year as well as time series of catch and effort. In other words, the model suggests the best effort distribution when prices, unit costs, effort dynamics, and catch dynamics are given.

The maximisation of the value added concerns the fleet segments (divided according to fishing system and geographical area), not the individual firms. Therefore, the indirect hypothesis is that all firms behave in the same way and these actions are additive, with the consequence that the sum of these microeconomic behaviours can be now taken into consideration by the optimization algorithm. This conjecture seems to be unavoidable in Italy, where the number of fishing boats exceeds 15,000 units. As the value added represents the remuneration of the factors of production: capital and labour, which are mixed and not easily separable in Italian fisheries, the model does not consider the income distribution, but only the production aspect.

This optimization procedure is also used for the determination of optimal distribution of fishing effort; in order to have the maximum economic result compatible with two constraints. The first is a biological constraint, introduced to avoid over fishing and depopulation for some species, as it can occur if only profit maximisation is sought; the second is an inertia constraint, introduced to select realistic solutions regarding effort redistribution. The optimal fishing effort distribution in a given area corresponds to the maximum economic outcome. The catch-effort model is composed by logistic or biological sub-models for each species/area combination. Most species can be caught by more than one gear specified by a technical matrix. The economic part considers only the

harvesting sector and makes use of unit average costs by fisheries (gear/area) and average prices (species/area), as given by the continuous monitoring of the fishing industry.

The endogenous variable of MOSES' biological sub-models is catch. The exogenous variables are: fishing effort for fishing segments and area (yearly data); a technical matrix specifying fishing segment catch of each species, recruitment age for each species, catch for each species and area. In the economic sub-model, the endogenous variables are total revenues and value added. The exogenous variables are: unit costs for fishing activity in a given year, for fishing segments and area, and average prices in a given year for species and area. In the optimization analysis, also the effort becomes endogenous, since the model is able to forecast the optimal effort distribution. Optimal allocation of fishing effort can be carried out for one or more scenarios, and is therefore endogenously determined in the model.

The authors of the model describe the strengths and weaknesses of the model in the following way. Strengths: a) provides answers useful for the drawing up of a sound management scheme, by analysing the fleet segment functioning by administrative areas b) built in such a way that it allows to overcome the possible lack of biological data, which otherwise could be difficult or expensive to obtain c) considers different possible non-equilibrium conditions in the fishing industry in terms of fishing effort allocation by gear and area, taking into account both resource exploitation and economic structure d) considers explicitly biological, social and economic constraints e) allows for evaluation of impacts emerging from the implementation of different management schemes, particularly different allocation and variation of effort. Weaknesses: a) does not consider the functioning of market (price formation, cost of factors) and demand, but only of the catching sector of the industry b) not fully age-structured and does not explicitly consider species interactions and migrations over areas as a consequence of the high number of species, as well as of the lack of many biological estimates c) objective functions of individuals are considered as given and constant d) estimates of endogenous biological parameters and relative catchability are presently calculated from the single time series for each species/area combination, no interferences with other similar cases e) optimizes fishing effort distribution only, and is not intended to offer solutions for the management of the whole industry.

In Spain bioeconomic simulation models have been constructed in cooperation between biologists, economists and information technologists at the Institute of Marine Science in Barcelona (CSIC) and the Department of Economics of the Sea at Univer-

sity of Barcelona. The models are available on the internet as well as on a CD-Rom, known as MEFISTO. MEditerranean FIsheries Simulation TOol: A bioeconomic model for Mediterranean fisheries; MECON 1.2, a bioeconomic model associated with the MEFISTO model; and VIT4WIN. VIT for windows (version: 1.2) is Software for fisheries analysis (associated with the MEFISTO and MECON 1.2 models) and a biological model. See <http://www.faocopemed.org/en/activ/infodif/mefisto.htm>.

The first objective of the model is to reproduce the bio-economic conditions in which the fisheries occur. The model is, multi-species and multi-gear. The main management procedure is effort limitation. The model also incorporates the usual fishermen strategy of increasing efficiency, in order to increase fishing mortality, while maintaining the nominal effort. This is modelled by means of a function relating the efficiency (or technological progress) with the capital invested in the fishery and time. A second objective is to simulate alternative management strategies. The model allows operating with technical and economic management measures and in the presence of different kind of events.

The manager's objective could be to maximize fishing production or revenues, to minimize catch fluctuations, to avoid the risk of collapse of the resource, etc. The manager has two kinds of tools available: technical (such as effort limitation) or economic (such as subsidies and taxes). The effectiveness of each of these tools in achieving the manager's purpose varies. In a complex system, as fisheries can be, it is not always evident what the response from the system to a certain management measure will be. Thus MEFISTO is designed as a tool to study the outcome of different management measures on a simulated, but realistic, Mediterranean fishery.

The objective of the model is to reproduce the fishing condition characteristics of the Mediterranean, including several aspects that differentiate it from the models elaborated for the Atlantic fisheries. The most important particularities are:

- The model should necessarily be bioeconomic to accommodate at the same time the dynamic nature of living resources, and the economic relationships that govern Mediterranean fisheries.
- Management is mainly based on effort control, although other technical and economic measures exist.

- The management system is non-adaptive. No regular assessments are done and hence no adaptive management policy is implemented. TACs do not exist and the economic administrative tools acquire as much (or more) importance as the technical tools.
- Increasing "catchability" (in effect, efficiency) is the mechanism of increasing fishing mortality by the fishermen: they cannot increase fishing effort, as law in the Mediterranean area defines it. Therefore they will always try to maximize fishing mortality. The only mechanism that they have to increase catch without increasing effort is to increase their catchability by means of investment in technology. An essential point of the model is the exploration of the dependence of catchability as a function of the installed capital and time. In accordance with this hypothesis, a bioeconomic model, rather than a biological one, is the more appropriate to simulate the Mediterranean fishery, since it is to a certain extent self-managed by the fishermen through economic mechanisms.
- It is multi-area, multi-gear, and multi-fleet.

The model is presented in a modern interface in the sense that it has been built in a modular way in a system of "boxes". A total of three boxes are defined that:

- *The stock box.* This simulates the dynamics of a particular stock. The input is the fishing effort and the catchability (from the fisherman's box) whose product constitutes the fishing mortality applied to the stock. The output is the catch that goes into the market box. There are two kinds of species: the main species, whose dynamics are completely explicit, and the secondary species, whose dynamics are not known but whose yields are computed as a function of those of the main species.
- *The market box.* This converts the catch into money with some price functions. One has to consider the price (or a "shadow" price), the importance of the size of the individual fish, and importance of the size of the fish supply.
- *The fisherman box.* This simulates the fisherman's economic behaviour. Its input is the money coming from the market box; its output is the effort (limited by legislation) and the catchability, over which the fisherman has certain control by way of function of his capital. The parameters of the fisherman's

box are contained at different levels: country, fleet, and vessel. The country level contains the most general economic parameters of the fleets (such as cost of fuel). The fleet level contains the technical and economic parameters that characterises each fleet segment (catchability and fishing mortality initial vectors, GT price, etc.). Finally, the vessel level, allows for the inclusion of the characteristics of each vessel.

2.4. EU models covering the Northern Regions

The rest of the models included are all basically non-linear constrained optimization models. They are not dynamic in the sense that time is not included. They are rather static *'what's best - what-if'* models where *'what-if'* refers to changes in exogenous variables and constraints, while the *'what's-best'* element refers to the changes in the endogenous variables of the model. Some authors refer to the models as simulation models while others refer to them as optimization models. The authors have independently of one another chosen the type and layout of the models described subsequently and all the models use GAMS as the programming language (Brooke et. al. 1998). The *'GAMS-models'* are all more or less alike in the basic (generic) construction although they address different issues, which characterises the flexibility of these models.

The basic structure of the models is an objective function maximising profit (or contribution margin), and the number of vessels and fishing days specified for fleet segments are treated as endogenous variables in the models. The profit maximisation is subject to a number of constraints of biological (e.g. quotas) and technical (e.g. maximum number of fishing days per month) nature. Due to the way the models are specified the production function plays an important role and in particular the catch per day. In the four models listed subsequently the parameters in the production function are either estimated or the model is a non-parametric model (i.e. catch per day is derived from e.g. logbooks).

The model for the English Channel: Bioeconomic Modelling of the English Channel was an EU financed project (FAIR CT-96-1993) carried out by CEMARE, and has been extensively described, Pascoe (1997), Pascoe, S. and C. Robinson (1997), Pascoe, S, C. Robinson and L. Coglan (1997), Mardle, Pascoe, Tamiz, and Jones (1999), Mardle, Pascoe, and Tamiz (1999).

Another EU financed project was: A Simulation Model for the Measurement of Economic Impacts in Specific Fleet Sectors (FAIR CT-96-1454), Klepper and Lasch (1998) and de Wilde (1999). The work was carried out by Braunschweig University in Germany, Dutch Institute of Agricultural and Fisheries Economics (LEI) in Holland and Department of Economics of the Sea (GEM) at University of Barcelona. The objective of this study was to identify the economic impacts of different political and management decisions for specific German, Dutch and Spanish fleet segments. The programming model maximises the gross margin of "standard vessels" of selected, largely homogeneous fleet segments by using logbook data with regard to fishing areas, effort time, fish species and by including book-keeping data containing fixed and variable costs and prices. The model is non-parametric and optimizations are carried out to investigate the impact of changes in certain constraints and some of the parameters central to the model. In this way the model is demonstrating the impacts of different political and management decisions on the economic results of selected fleet sectors.

In Germany (Kiel University, Justus Liebig University in Giessen and University of Queensland, Australia) another project was carried out: Adjusting Fleet Size and Structure to Catch Quotas: a Mathematical Programming Model of the German North Sea and Baltic Fisheries, Brodersen, Cambell and C-H. Hanf (1998). In that project a sample of vessel catch records from four German Producer Associations for 1990-1994 was used to estimate production functions for major fishing activities in the Baltic (Area 3) and the North Sea (Area 4). The production functions, together with vessel cost information, were then used to construct a mixed-integer, non-linear mathematical programming model of the German fishery. The model is used to calculate fleet sizes and configurations which minimize cost, maximize profit, and maximize employment (as proxied by fleet size), subject to the constraint of the quotas, and, in the latter case, a non-negative profit constraint.

In Denmark, at The Danish Research Institute of Food Economics (FOI), an effort regulation model for the fisheries in the Baltic Sea, the Kattegat, and the industrial fishery, Andersen and Frost (2000 and 2001), was constructed in a collaborative project between FOI, the Danish Institute of Fisheries Economics Research (DIFER), the Danish Institute for Fisheries Research (DIFRES), and the Institute of Fisheries Management (IFM). The problem of this model was that it accounted for only part of the Danish fishery, and assumptions had to be made about the vessels' economic activities when they were operating outside the waters covered by the model.

Also in Denmark (at the former DIFER, now University of Southern Denmark) a non-linear mathematical programming model was used to calculate the benefit from ITQ management relative to non-transferable quota management: ITQs in a Danish multi-species fishery. The model concept is similar to the above-mentioned models, Vestergaard (1998), although the objective is different in the sense that two different fishery management regimes are compared. The purpose of the project was to analyse, a priori, the effects of a potential Individual Transferable Quota (ITQ) system implemented in the Danish multi-species fisheries in the North Sea and Skagerrak. By assessing each firm's production technology using Positive Mathematical Programming the empirical analysis could help to compare the current policies of the command-and-control type of regulation with the market-based instrument of ITQs.

In Holland, LEI and the Dutch Marine Institute (RIVO) the bioeconomic model FLATFISH has been developed. FLATFISH is a bio-economic spatial simulation model for plaice and sole (flatfish) in the North Sea. FLATFISH has two goals: 1) give better insight in how the biology of the fish stock and the economy are related through fishery, and 2) to use the model as a decision support tool to analyse the effects of different management scenarios. FLATFISH has been divided in a biological module (e.g. growth, migration, mortality) and an economic module (e.g. catch, fishing fleet capacity, price) and simulates the interaction and feedbacks between the modules (Pastoors, Dol and Rijnsdorp 1997).

2.5. The EIAA model

For some years a project has been conducted in cooperation between a small number of EU member states. In 1998-2000 the project was continued including all EU member states with marine fisheries, Norway and Iceland. This concerted action project: Promotion of Common Methods for Economic Assessment of EU Fisheries (FAIR CT97-3541) has been further continued in the project: Economic Assessment of European Fisheries (QLRT-2000-01502) which is an enlargement with partners including Poland, Estonia, Latvia, Lithuania and the Faeroe Islands. Part of the work in this concerted action has been to collect costs and earnings statistics for as many fishing fleets as possible. In addition to that Economic Interpretation of ACFM Advise is conducted by running the EIAA-model (Salz and Frost, 2000) that has been developed to take into account the costs and earnings statistics in conjunction with the TAC/quota recommendations forwarded from the biological assessment work.

The EIAA-model is output-driven as it calculates the costs associated with the quotas, and hence the EIAA-model calculates the value of a number of economic indicators (e.g. gross revenue, crew share, gross cash flow and net profit) from changes in quota/management areas for each included fishing fleet. The number of quota/management areas is around 130 and the number of fishing fleets is around 100 (in 2003). Quota/management areas and costs and earnings are linked by information about the catch (species) composition for each fleet segment. This type of information is, however, available for less than half of the fleet segments (in 2003), which entails that economic assessment of the biological advice can be carried out only for these segments. It is assumed that the fleet structure does not change and that the quotas are exhausted. The latter assumption implies that the catch composition is allowed to change according to quota changes, and that the up-take ratios of the quotas do not change. The model is a static short run model and apart from the costs and earnings statistics, the TAC/quota information, and stock abundance information, it includes price flexibility rates (inverse price elasticities) and catch-stock elasticities (Anon 2002). The model is available in an excel spreadsheet.

3. Economic Management Model for Fisheries In Denmark (EMMFID)

3.1. The objective of EMMFID

The basic goal for the fishery, in context of the project, is that society aims to achieve a balanced economic use of resources while maintaining fish stocks at a sustainable level. This means that biological limitations on yield from the fish stocks are taken into consideration.

In this perspective, the aim of the project is to:

Be able to describe and model fishing activities in such a way that economic consequences due to interaction of industry activities and regulation of fishing resources considering sustainability of stocks can be clarified.

With the processing power possessed by computers as of today, it is possible to construct complex numerical models. An all-inclusive and detailed model can contribute with valuable information on the economics of the fishery in focus. The potential of numerical models and endogenous optimization is emphasised in Arnason (2001). The EMMFID model takes as many as possible of Arnason's suggestions into account with a view to make the model operational. Arnason suggests that instead of specifying behavioural relationships explicitly, the decision process giving rise to that relationship is modelled, i.e. fishermen maximise profit subject to a number of constraints imposed by the management regime. This is the approach used in the EMMFID model context. Arnason suggests that the individual fisherman maximises his profit while the EMMFID model maximises profit for the whole industry. However, if Arnason's approach allows for trade among fishermen in terms of quotas or effort the two model approaches converge. If trade is not allowed in Arnason's approach the dynamics of the model is very limited. Arnason further suggests the inclusion of time, fish stocks, investment dynamics, and fish prices, the latter to secure equilibrium. Time, in term of infinite time horizon, and fish stock dimensions are not included in the EMMFID approach, as the model comprises numerous stocks with unknown time/stock interactions, especially in the long run. Instead the EMMFID model uses fish stock inputs based on biological scientific models and advice. It is assumed that the Danish supply does not affect fish prices; therefore the Danish fishermen are price-takers and adapt the supply. Inclusion of 'dynamic' prices would require inclusion of a global demand function for fish. The 'investment dynamics' is included, but

as the model does not optimize over time because of the fish stock complexity but rather at points in time, possible paths towards a new equilibrium is investigated outside the model.

The model is set up in a static framework as a linear constrained optimization programme, programmed in the optimization software GAMS² (General Algebraic Modelling System). Fleet size and fishing effort, measured in number of vessels and number of days at sea respectively, are endogenous variables.

A former model constructed at FOI to evaluate the effects of regulating activity for the Baltic Sea and the Kattegat serves as inspiration for the structure of this model (Frost and Andersen, 2001). Moreover the model started from a non-optimization model used in the report: Economic Situation of the Danish Fishery 2001 (and 2002, 2003) (Danish Research Institute of Food Economics, 2001a).

The model covers the entire commercial fishery in Denmark, disaggregated with respect to fleet segments, homeports, fishing areas, species and seasons (by month). The level of detail is remarkably high which widens the analysing prospects. Consequently, the scope of the model is very large and every run demands for extensive computations. In the following a thorough description of the model is provided.

3.2. The generic model

Linear vs. non-linear models

Generally, the optimization of a non-linear programme only guarantees a local optimum, whereas linear models are deterministic in the sense that if an optimal (bounded) solution exists, the model can be solved to find such a solution. Linear models are often criticized of giving ‘extreme corner solutions’, and that very different solutions may be the result of minor changes in parameter values. These issues are connected with the way constraints are formulated. If the model allows for extreme solutions, such solutions can be achieved. EMMFID operates with many constraints and effort has been put into constructing these in a way, so model is able to represent a reliable framework for agents given the current production technology and management system. Some preparatory arrangements have been made to ensure linearity of the model. Fleet size and activity are the decision (endogenous) variables of the model. Modelling fishermen’s behaviour implies determining which vessels are going

² For a general introduction to GAMS, see Brooke et al. (1998).

to be operating and the scale of operation. Intuitively this would mean that the number of vessels and the number of days at sea per vessel would be the endogenous variables. In the present set-up, however, it is instead the number of vessels together with the number of days at sea for all vessels³ that are endogenous. The average number of days at sea is determined implicitly and can be subsequently derived.

This section is meant to demonstrate the general aspects of the model formulation. The model is static, which means that a model-run will cover the behaviour in a given year and there are no built-in dynamics. Different states of the system (scenarios) are compared for analyses, i.e. comparative static analyses are performed.

The model formulation consist of two main components:

- A. Objective function
- B. Constraints (delimit the set of feasible solutions)

Given a set of feasible solutions, the model seeks a combination of number of vessels and days at sea that maximises the value of the objective function. In other words, the model presents the optimal fishing behaviour given that certain conditions are valid.

The general mathematical formulation is as follows:

$$(A) \quad \text{maximise } \mathbf{c} \begin{bmatrix} \mathbf{x} \\ \mathbf{y} \end{bmatrix}$$

subject to:

$$(B) \quad A \begin{bmatrix} \mathbf{x} \\ \mathbf{y} \end{bmatrix} \leq \mathbf{a},$$

$$\mathbf{x} \in \mathfrak{R}_+^n, \mathbf{y} \in \mathfrak{R}_+^m.$$

Where:

- \mathbf{x} and \mathbf{y} are non-negative vectors of number of vessels and number of days at sea
- $\mathbf{c} \in \mathfrak{R}^{n+m}$ and $\mathbf{a} \in \mathfrak{R}^I$ are parameters and A a $(n+m) \times I$ real valued matrix.

³ With respect to the relevant grouping of vessels. This will become clear later on.

The model is meant as an analysing tool of fleet and effort behaviour. It is not necessarily the exact solutions, as such, that are needed (and going to be implemented) but rather the comparative static that makes it possible to compare solutions and indicate directions with respect to future fleet structure adjustments.

3.2.1. Choice of objective function

The choice of objective function depends on which scenario is analysed. The objective function represents the criterion that is optimized. An optimal solution is found as a feasible combination of number of vessels and number of days at sea where the value this function is at maximum. Examples of different objectives could be:

1. Maximise contribution margin / profit
2. Maximise employment
3. Maximise fleet size.

The first objective is generally used, when setting up (bio-) economic models. Nevertheless the other two non-monetary objectives are interesting because these are objectives of certain political interest not least with respect to distributional impact.

3.2.2. Choice of constraints

Constraints describe the set of feasible solutions for the system. For a realistic system framework, these would include restrictions on:

1. Catch (e.g.: Catch must be less than TACs)
2. Profit (e.g.: Minimum constraints on yearly profit/contribution margin per vessel)
3. Days at sea (e.g.: Maximum/minimum number of days at sea per vessel)
4. Fleet behaviour (such as: Fishing ground and species to be exploited).

Excluding such restrictions in the maximisation problem could imply a solution that is impossible to realise in the 'real' world.

Different scenarios can be formulated in terms of both the objective function and the constraints. Consider for instance the differentiation between a short and long run scenario, e.g. maximisation of contribution margin/profit. It is reasonable to assume that the number of vessels is constant in the short run, but not in the long run perspec-

tive. Regarding the objective function, in the long run fixed costs are taken into consideration when profit is maximised. This may not be the case in the short run.

3.3. Data for the specific model

Currently, a new large general fisheries database DFAD (Danish Fisheries Analytical Database) is under construction in collaboration between the Danish Fisheries Directorate (FD), the Danish Institute for Fisheries Research (DIFRES), and the Danish Research Institute of Food Economics (FOI). This work is still in progress. However, it will be possible to apply the new data in the model as soon as they are available. Therefore, for the specific model presented below data from year 2000 serve as input, and the two primary data sources are:

1. Databases prepared and maintained by Danish Fisheries Directorate (FD).
2. Account statistics prepared by the Statistical Department at The Danish Research Institute of Food Economics (FOI)

The FD databases supply information on vessel characteristics, activity, catch and catch value, whereas FOI delivers data on costs. The contents of the dataset and conditions on which vessels are included will be described below. Note that in the ongoing work with the model, data are considered temporary as a new up dated dataset is being prepared each year.

3.3.1. Vessel characteristics and catches

A dataset is necessary to construct the data matrices and parameters that are used in the model. Hence, the dataset describes the system that is being modelled. Catch weight, catch value and various characteristics of the vessels such as length, tonnage, engine power, insurance value and homeport are examples of the information contained in the dataset. Together with information about the number of days at sea and prices, catch per day can be calculated.

The analysis of the commercial fishery in Denmark is based on active vessels with revenue in 2000 above 195,598 DKK⁴ (named FOI-vessels). This is the minimum amount used in the account statistics at FOI and determines which vessels form the basis for costs and earnings statistics for the Danish fishery.

⁴ This figure is updated each year by the increase in the wage index.

The number of vessels in the dataset, divided among different length groups and use of gear⁵, is shown in Table 1. The presentation reveals the segmentation used in the model (model dimensions are treated in Section 3.4.1).

Tabel 1. Number of vessels		
Length	Gear	Vessels
<12m	Liners and gill netters	323
	Trap setters etc.	87
	Danish seiners/netters/trawlers	43
	Trawlers	37
12-15m	Liners and gill netters	92
	Danish seiners/netters/trawlers	40
	Danish seiners	23
	Trawlers	181
15-18m	Liners and gill netters	52
	Danish seiners/netters/trawlers	8
	Danish seiners	27
	Trawlers	134
18-24m	Liners and gill netters	35
	Danish seiners/netters/trawl	8
	Danish seiners	51
	Trawlers	107
24-40m	Beam trawlers	10
	Danish seiners/netters/trawlers	5
	Trawlers, other	79
	Trawlers, industrial	62
>40m	Purse seiners	11
	Trawlers, other	16
	Trawlers, industrial	17
Specialised fisheries	Northern prawn	25
	Mussels	65
	Common shrimp	1
Total		1,539

Clearly the main part consists of smaller vessels below 18m in length, but measuring the fleet in terms of capacity or catch value gives a somewhat different picture (see Table 2). The larger vessels have a dominant share of both capacity and total catch value.

⁵ Determined by the registration used in the vessel register at the Danish Fisheries Directorate.

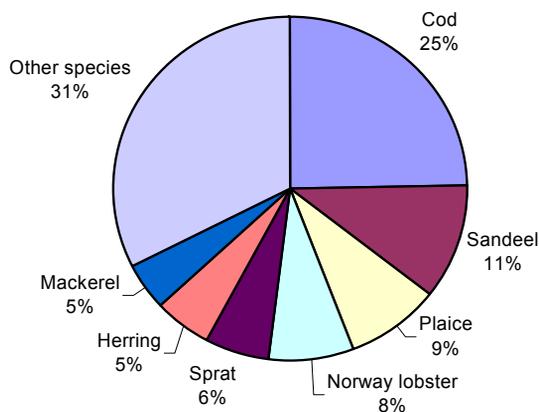
Tabel 2. Tonnage and catch value (% of total)		
Length	Gross tonnage	Catch value
<12m	3%	10%
12-15m	5%	11%
15-18m	2%	13%
18-24m	6%	16%
24-40m	46%	28%
>40m	33%	15%
Specialised fisheries	5%	7%
Total	78,160	3,277,964¹

Note: 1) In thousands DKK. The exchange rate between DKK and Euro is approximately 1 Euro = 7.43 DKK.

3.3.2. Catches

Figure 1 below enlightens the relative importance of the different species, in the 2000 dataset, in terms of catch value. It shows that cod is the most important single species followed by sandeel, plaice, Norway lobster and sprat. The dataset holds sufficient information to work out a much more detailed treatment of the catch composition, but that would be beyond the scope of this report.

Figur 1. Composition of total catch value, for the included vessels



3.3.3. Activity (Days at sea)

This subsection contains a short comment on how average days at sea in 2000 are determined within fleet segments. The expected correspondence between fleet segments, landings and days at sea, partitioned with respect to the management areas on which quotas are set, is not present so far. As mentioned at the beginning of section 3.3, FD, DIFRES and FOI are collaborating on a new linkage of records at the DFAD database, expected to be ready in the end of 2003.

Days at sea are available on a trip-basis. During a trip a vessel most likely catches several different species, some of which are not related (via quotas) to the same management areas. Activity is then allocated to catches and management areas according to the respective share of the total catch value.

3.3.4. Costs

The statistical department at FOI prepares information on costs. The minimum amount of revenue mentioned earlier, 195,598 DKK, is used in the account statistics to determine which vessels form the basis for reporting earnings in the Danish fishery.

The account statistics (Anon. 2001b) includes information on average costs per vessel, such as the following: Fuel and lubricants, maintenance, sales cost, insurance and crew payment. Assets and liabilities are calculated, and activity is related to capacity. Furthermore it contains information on family income, consumption and savings, for participants of the fishery. The specific cost items and their use in the model will be dealt with later on.

3.4. Implementation of the specific model

Before introducing the strict mathematical representation outlining the equations of the model, the dimensions and calculations of catches and costs per day will be described.

3.4.1. Dimensions

The level of detail is determined by five sets of dimensions. These are:

1. Fleet segment (26 alternatives)
2. County (14 alternatives)
3. Fishing area (34 alternatives)
4. Species (118 alternatives)
5. Month (12 alternatives)

Letters expressed in parenthesis and *italic* refer to the indices associated with the model dimensions.

3.4.2. Fleet segment (*f*)

Vessels are divided into 26 segments depending on length and use of gear. Use of gear is determined by the registration used in the vessel register at the Danish Fisheries Directorate.

Furthermore the segmentation separates vessels that are participating in a licensed fishery with limited entry. This includes the mussel, common shrimp and northern prawn fisheries.

Main groupings of the fleet are:

- Vessels less than 12m in length
- Vessels between 12 and 15m in length

- Vessels between 15 and 18m in length
- Vessels between 18 and 24m in length
- Vessels between 24 and 40m in length
- Vessels above 40m in length
- Special vessels in licensed mussel, common shrimp or northern prawn fisheries.

In the first six groups, vessels are separated with respect to type of gear. The 26 fleet segments appear from Table 1⁶.

3.4.3. County (*c*)

Vessels are differentiated with respect to homeport. To simplify matters and to limit the scope of the model, homeports are aggregated to county level. Moreover, not all homeports are equally well represented. There are 14 counties in total.

3.4.4. Fishing area (*a*)

Quota regulation operates with several so-called management areas. These are combinations of species and fishing areas (in general). Therefore the model works with more areas than the usual partition of the North Sea, Skagerrak, Kattegat, Baltic Sea and the Sounds and Belts. In total, the model includes 34 areas covering the traditional areas for non-quota species and management areas for the quota species.

The fact that the model covers all areas gives a realistic picture – and modelling – of the fishery, since some vessels most probably fish in several areas and target different species during a whole year. Excluding some areas would mean that possible opportunity costs are left out, implying that a share of the revenue (profit) disappears, and peculiar fleet behaviour would be observed.

3.4.5. Species (*s*)

The Danish fishery is characterised by primarily being a multi-species fishery. The number of different species is 118. This is a very detailed breakdown of species. Most

⁶ In the present set-up, vessels less than 12 metres of length have been excluded from the optimization. These vessels often operate with a deficit (with respect to socio-economics) and would therefore be omitted.

are individual species (quota restricted and non-quota restricted), while five are combinations of two or more because of the quota determination. Most of the species, though, are of little importance to the fishery (in terms of catch value). On the other hand, a detailed description of the catch can be of interest concerning mixed fisheries and in the evaluation of issues such as bycatch.

3.4.6. Month (m)

Working on a monthly level gives an opportunity for the model to incorporate seasonal variations in the fishery, both in terms of catch per day and catch composition that varies considerably over the year.

3.5. Calculation of parameters of the specific model

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 dataset described previously. These files give information on the number of vessels and days at sea, catches, prices and costs, all for 2000, and makes it possible to calculate catch per unit effort (catch per day at sea) and variable costs per day, in the model.

3.5.1. 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:

$$(1) \quad CPUE_{f,a,m,s,c} = \frac{SUMCATCH_{f,a,m,s,c}}{NOFD_{f,a,m,c}^{data}},$$

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 $NOFD_{f,a,m,c}^{data}$ is the observed days at sea in area a , month m , for all vessels that have c as home county and belong to fleet segment f .

It is now possible to state 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 :

$$(2) \text{ CATCH}_{f,a,m,s,c} = \text{CPUE}_{f,a,m,s,c} \times \text{NOFD}_{f,a,m,c},$$

where $\text{NOFD}_{f,a,m,c}$ is the endogenous variable number of days at sea in area a , month m , for all vessels that have c as home county and belong to fleet segment f .

3.5.2. Costs and cost per day

Data matrices included by the model are used to calculate the cost per day components.

The following cost items are in the fishery account statistics at FOI⁷:

- 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
- h) Crew payment

Eight matrices corresponding to the items a)-h) are included in the model. The “Sales cost” matrix contains coefficients corresponding to the share of the average sales cost relative to average value of landings. Likewise the crew payment matrix contains coefficients corresponding to a share of revenue.

The cost items are allocated to four different cost components that are used in the model. Catch per day (the matrix of equation (1)) together with prices and days at sea in the dataset, are used to transform costs into per-day measures. The components and corresponding relations to the cost items appear from the table below and the formulas for calculating these are given subsequently.

⁷ Average cost per vessel (in the different fleet segments).

1.	Average variable operating cost per day at sea	a) + b)
2.	Average fixed cost	c) + e) + f) + g)
3.	Average variable landings cost per DKK per day	d)
4.	Average variable crew cost per day	h)

Calculation of cost components used in the model:

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

$$(3) \quad OPECOST_f = (FUEL_f + ICE_f) / TNOFD_f^{data},$$

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

Component 2: Average fixed cost (within fleet segments):

$$(4) \quad \text{Sum of average fixed cost items, i.e. c) + e) + f) + g).}$$

Component 3: Average variable landings cost per DKK per day:

$$(5) \quad LANCOST_{f,a,m,c} = \sum_s CPUE_{f,a,m,s,c} \times PRICES_{f,s} \times SALE_f,$$

where $PRICES_{f,s}$ are the average price of species s observed in the dataset for vessels in fleet segment f . $SALE_f$ is the “sales cost” coefficient for a vessel in fleet segment f .

Component 4: Average variable crew cost per day:

$$(6) \quad CREWCOST_{f,a,m,c} = TREV_{f,a,m,c} \times CRW_f,$$

where CRW_f is the “crew cost” coefficient for a vessel in fleet segment f . $TREV_{f,a,m,c}$ is the average total revenue in area a , month m , for a vessel in fleet segment f originating from county c , that is:

$$(7) \quad TREV_{f,a,m,c} = \sum_s CPUE_{f,a,m,s,c} \times PRICES_{f,s}.$$

The cost components in their current form have some limitations. The cost items from the account statistic are differentiated only with respect to the fleet segments. As seen

above landing 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 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, would probably also be relevant.

3.6. Objective function and constraints of the specific model

The outlining of the objective function and the constraints will be given in accordance with the main components of the optimization programme shown in section 3.2. Before the equations are introduced, the optimization problem is restated in words, i.e. to determine the number of fishing days and vessels that best satisfy the objective:

- Maximise the economic rent, i.e. the contribution to the margin (in the short run) or the net profit (in the long run)

Subject to the following constraints:

1. Constraints depending on catches and profit
2. Constraints depending on number of vessels allowed
3. Constraints depending on the number of days at sea possible for technical reasons
4. Non-negativity constraints.

Endogenous variables:

- $NOV_{f,c}$: Number of vessels in fleet segment f originating from county c .
- $NOFD_{f,a,m,c}$: Number of days at sea in area a , month m , for all vessels in fleet segment f originating from county c .

The objective function:

Choice of objective function depends on which scenario is analysed. Assuming that the contribution margin is being maximised, the objective function is:

$$(8) \quad CM = \sum_{f,a,m,c} CMNOFD_{f,a,m,c} \times NOFD_{f,a,m,c}$$

where $CMNOFD_{f,a,m,c}$ is the contribution margin per day in area a , month m , for a vessel in fleet segment f , originating from county c . i.e.,

(9)

$$CMNOFD_{f,a,m,c} = TREV_{f,a,m,c} - OPECOST_f - LANCOST_{f,a,m,c} - CREWCOST_{f,a,m,c}$$

Constraints:

The constraints are formulated as a collection of equations (or inequalities). Recall that several different set-ups are available just by including different sets of equations or by strengthening/relaxing equations. In other words, the set-up given here is not final.

Quota-restriction: Total catch in area a of species s must not exceed the total allowable catch (TAC).

$$(10) \quad \sum_{f,m,c} CPUE_{f,a,m,s,c} \times NOFD_{f,a,m,c} \leq TAC_{a,s},$$

where $TAC_{a,s}$ is the total allowable catch of species s in area a . This is not necessarily equal to the TAC at the end of the year that may be affected by quota swaps. Neither is it the actual catch that is affected by quota interactions or various kinds of slacks.

Minimum profit condition: Active vessels must have at least a given level of profitability. The profitability of the fishery is measured by assessing the contribution margin in relation to the size of invested capital. Insurance value is used as basis for the evaluation of the size of capital.

(11)

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

where $MINRENT_f$ is the minimum rent percentage for a vessel in fleet segment f and $INSU_f$ the average insurance value in 2000. This condition also ensures that the fishing effort/behaviour of vessels is somewhat realistic. If it is left out, solutions with vessels having very few (say 10) days at sea per year could arise. That would not be the case in reality.

Maximum number of vessels: Currently a 20% increase relative to the number in 2000 sets the upper bound.

$$(12) \quad \sum_{f,c} NOV_{f,c} \leq 1.2 \times \sum_{f,c} NOV_{f,c}^{data} .$$

Maximum number of days at sea per vessel per year:

$$(13) \quad \sum_{a,m} NOFD_{f,a,m,c} \leq MAXNOFDY_f \times NOV_{f,c} ,$$

where $MAXNOFDY_f$ is the maximum number of days at sea per year, for a vessel in fleet segment f . This value is currently equal to the maximum values observed in the dataset, with the additional restriction to be less than or equal to 320.

Maximum number of days at sea per vessel per month: Logical conditions say that the maximum number of days at sea in month m must be less than the actual number of days in month m .

$$(14) \quad \sum_a NOFD_{f,a,m,c} \leq MAXNOFDM_m \times NOV_{f,c} ,$$

where $MAXNOFDM_m$ is the number of days in month m .

To follow-up upon the comment given before describing the equations, the modeller could choose to change the parameter values in one or more of (10)-(14) - or even exclude some equations and introduce new ones. The model is very flexible to adjustments and the analysing potential seems evident.

4. Concluding remarks and discussion

In a European Union context most of the identified models comprising large fisheries systems are of the type *what's best*, i.e. optimization models. Only one (MEFISTO) is of type *what-if*, i.e. a simulation model. Of the two European non-EU models, the ECONMULT is a simulation model that has been developed as an optimization model, while BEAM 4 is a simulation model. Further it is common for the EU optimization models that the fish stocks are considered exogenous variables, i.e. the models do not calculate the optimal input of fish stocks. That is left to the biological field of research.

The Danish fishery is characterised by primarily being a multi-species fishery. Hence each vessel exploits several fish stocks deliberately or under compulsion at the same time. Smaller vessels, less than 18m in length, are dominant in terms of number, whereas more than half of total catch value stems from larger vessels. The relative importance of the different species shows that cod is the most important single species followed by sandeel, plaice, Norway pout, and sprat.

It has been considered important to construct a type of model that is able to handle multi-species fisheries, aiming at partly to provide a realistic estimate of the economic outcome and partly to reflect the fishing technology that in most cases makes it impossible or at least non-feasible to exploit one species at a time. The economic management model has been constructed to describe and model the fishing activities in such a way that economic consequences, due to interaction of industry activities and regulation of fishing resources considering sustainability of fish stocks, can be clarified.

The choice is a model set up as a linear optimization programme in the optimization software GAMS. The two main components are the objective function and the constraints that implicitly have the advantage that the operator needs to consider what are the objectives in the system and what are the constraints. The objective function represents the criterion that is being maximised, while the modelling constraints describe the set of feasible solutions. One could actually say that the constraints describe the system, since they determine the admissible degree of variation for a solution. It is worth noticing that biological models are in almost all cases formulated with the size of the fish stock as the objective (function) while in the economic model the target stock is included as a constraint which is, basically, in agreement with what should be the political thinking.

The model provides an optimal combination of number of vessels and days at sea, i.e. the optimal fishing behaviour within the given feasibility area. Different scenarios can be analysed and compared – with each other or the actual fishery in 2000. A set of equations works as building blocks of the model and various set-ups are available just by simple adjustments. Moreover, the model covers the entire commercial fishery in Denmark with a remarkably high level of detail. It should be clear that there is a great analysing potential.

In comparison with other types of models, mainly simulation models, the model provides information about the consequences *if* a target is reached, but it does not tell *how* the target is reached. Further, linear programming (LP) or non-linear programming (NLP) models are criticized for the lack of inclusion of behaviour of the agents, for working with fixed production technologies (short run), for the sensitivity to changes in constraints, for producing local optima rather than global optimum (only NLP), and for being very data demanding.

Compared to a simulation model in which behaviour is often an important feature controlled by the inclusion of elasticities, behaviour is included in our LP model by giving the same fleet segments different options with respect to gear use and hence catch composition. The real problem in LP/NLP and simulation models is to determine the number of feasible options among a long list of options. That needs to be done outside the model. Fixed production technology may be accounted for in the comparative static analyses, where technological progress could be included by e.g. changes in catch per day rates.

If too many constraints are invoked the model is of little use because it will only reflect the current situation. On the other hand if the number of constraints is too small the solutions are inclined to change dramatically subject to changes in certain parameter values in the objective function, i.e. prices of fish. Some kind of compromise is necessary, and the model itself is of no help here. It has to be determined outside the model.

LP/NLP models and comparable simulation models are very data demanding. In the Danish case a substantial amount of information is available and one useful application of all that information is to try to structure it in the way it is done in an LP model. The lack of data and not least of continuous updating of data is considered to be a drawback for the application of LP/NLP models in fisheries. This is however, not a restriction in the Danish case.

Simulation models do not optimize but describe developments based on assumptions about behaviour and technology. These models are “positivistic” in the sense that they do not inflict judgement into the system but only describe what happens subject to certain impacts from outside. The LP model is “normative”. If a certain objective is specified, the model calculates the “solution” of the system to achieve the objective. However, the objective is almost always a value judgement that is not usually agreed upon by everybody. In fisheries, however, politics determine the objectives, rational or not, and an LP model is a feasible instrument to calculate consequences, which is not the case with a simulation model.

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