Integrated modeling of fisheries

Development of a global view based on models and bioeconomic data

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Preface

BIØKOMODA was the follow-up to a conference held in autumn 2002 (Frost 2002) on fisheries economics, a conference supported by the Nordic Council of Ministers. Attendees at the conference had concluded how improved communication between researchers and the industry was needed and as a result BIØKOMODA was initiated. Like this conference the BIØKOMODA project attained financial support from the Nordic Council of Ministers.

The aim of the project was to discuss and develop existing bio-economic models in fisheries, enhance the interest in using models, focus on application of data and to disseminate knowledge among Nordic representatives.

The Institute of Food and Resource Economics was assigned to the task and this report contains a general review of the work. Two workshops have been organized. The presentations at the two workshops took in general the form of power point presentations are these are not included in this report.

However, the background material for the report has been speakers' papers, power point presentations. The report is not a scientific document as such but a summary and an appetizer. Readers who want more detailed information than provided here are referred to the papers and homepages of speakers who appear in the list of participants. The responsibility of the contents of this report is not the participants but the authors of the report.

November 2007

Jørgen Løkkegaard
Institute of Food and Resource Economics

Summary

BIØKOMODA (BIoØKOnomiske MODel Analyser) is the acronym for a series of workshops organised as a follow up to the conference about fisheries economics held in 2002 and financed by the Nordic Council of Ministers. The conference in 2002 dealt with costs and earnings statistics of fisheries, and it was concluded that there was a need for model development and application of these data to improve the advice in the crossroad between biology and economics.

A limited number of people from the academic world, the industry and the administration was invited to present and discuss the current knowledge of bioeconomic models and how these should and could be developed further.

The workshops identified a number of models, mainly economic models with larger or smaller biological components built in. The models were classified into types according to what were the exogenous and endogenous variables. Further they were divided according to if they were what-if or what's best models. The former simulates different scenarios based on a number of assumptions, while the latter finds the best size and composition of input factors in terms of fish stocks and fishing fleets with respect to maximising the profit from the fishery.

The discussion of the applicability of the models was based on a number of issues and how these issues were included in the model: production functions, prices, discard, mixed fisheries, behaviour of fishermen, model dynamics, social effects and, finally, indicators i.e. presentation of results.

Among the conclusions were that the behaviour of the fishermen was an important element in the models not least the entry/exit behaviour on which there is little information. This element was missing in most of the models. Another question was if anything could be gained from making the models work on individual fisherman level. It was concluded that the structure of the known models did not need a change to accommodate that, but the models would be significantly larger and more complex without, necessarily, producing better results. Inclusion of social aspects such as up- and down-stream effects, employment and regional impact would be useful but could be added to existing models making them larger and more demanding to work with, however, or as separate models.

Finally, the workshops noted that an institutional platform for bioeconomic modelling is absent, and that the BIØKOMODA project has acted only as a temporary platform for supporting the work with bioeconomic modelling in the Nordic Countries.

1. Introduction

The objective of BIØKOMODA (BIoØKOnomiske MODel Analyser) was elaborated on in the project description::

> The objective of the project is, on a common Nordic ground, to support development of models, which are suitable for promotion of a holistic view on a long run sustainable development of the fishery. Biological, economic and sociological aspects are included. The development of the models takes place by involvement of the fishing industry and the management authorities. The work sets out from existing models and the aim is to a) promote the development of existing models; b) to increase the interest for model construction and application; and c) to transfer knowledge between countries

Additionally, in the invitation letter to the participants it was stated how the ultimate goal of the project was eventually to formulate a "consensus" model and report. This document constitutes the latter aimed at the Nordic Council of Ministers, government officers and others interested in a general introduction to bioeconomic models and the results of the project.

BIØKOMODA was organized in workshops with attendants from the Nordic countries representing the industry, the management authorities, and the research field in terms of economists, biologist, and sociologists. Three workshops were planned in which the last one was open for all people interested in the subject. However, on the17th of May 2006 the 2nd and 3rd meeting were joined to one meeting in 2006 since useful results from a committee in the EU Commission were expected.

From the 29th to 30th November 2004 16 representatives[1] from the industry, the management authorities and the research field attended the first BIØKOMODA meeting. ICES (International Council for the Exploration of the Sea) and NEAFC (The North East Atlantic Fisheries Commission) participated the meeting as well. During the first meeting several bioeconomic models were presented and discussed. An overview of the historic development in bioeconomic modelling was presented by Ragnar Arnason from the University of Iceland and three operational models were introduced. These models were: the European EIAA-model by Hans Frost, Institute of Food and Resource Economics, Copenhagen University, the Greenland SIMGREEN-model by Hilmar Ogmundsson and Morten Sommer, University of Southern Denmark and the Norwegian Econmult by Arne Eide, Norwegian College of Fishery Science, University of Tromsø.

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[1] See Participants at the 1st BIØKOMODA Project Meeting.

During the second meeting, held November 27-29 2006, newly developed models for use in EU-projects were presented. The objective of the second meeting was to identify possibilities for improvement of existing bioeconomic models of fisheries in the Nordic countries and to form a consensus about how to construct bioeconomic models of fisheries. The group of participants[2] consisted mainly of economists while biologists and sociologists were few. The four models presented at the meeting were TEMAS by Clara-Ulrich-Rescan, Danish Institute for Fisheries Research, the Icelandic model by Olafur Klemensson, Central Bank of Iceland, SRRCMF by Anna Jonsson, Swedish Board of Fisheries and AHF-model by Ayoe Hoff, Institute of Food and Resource Economics, Copenhagen University. In addition, several issues of importance to bioeconomic models of fisheries were discussed during the meeting.

Conclusions from the first meeting (2004) included how the needs of industry and management must be taken into account in the development of models. In addition to this, different models may be needed for different purposes- possibly leading to the development of new models taking account of sociology, equity and fairness. The second meeting (2006) led to discussions of questions of huge importance in bioeconomic models: production functions, the behaviour of fishermen, indicators, mixed fisheries, discard, monitoring and enforcement, price flexibilities, dynamics and social consequences. During the meeting a common understanding was achieved and this understanding increased significantly during the discussions of the above mentioned issues.

[2] See Participants at the 2nd BIØKOMODA .

2. Bio-economic models of fishery: An overview and Usage

Bioeconomic models of fisheries give an assessment of fisheries using both economic and biological data as inputs. As such, both the economic as well as the biological aspects need to be modeled to at least some extend. The models are tools well-qualified for thorough analyses of questions related to management and regulation and despite the fact that the models often become complex and, on the face of it, cumbersome, they are most often preferable to personal judgments from experts. The main reason for this is that as opposed to models personal judgments are not capable of reproduction.

As the complexity of the bioeconomic models increases so does the need of experts and concurrently the challenge of communicating the model details to third parties. This, however, is no significant problem since the use and underlying assumptions of the models are outlined in working papers, model-documentations and -descriptions. Most of the mentioned documents are published with the very intention of supporting the democratic process of discussion and debate as well as presenting the results of applied analyses. Despite this it is unlikely that bioeconomic models themselves become directly accessible to the general public and this leaves the use of the models to the experts, who know the strengths and weaknesses of the models well.

For a model of a fishery to be a bio-economic model, it must contain information about the following elements: 1) the fish stocks included in the model, 2) the fishing fleets considered, and 3) an economic component. Interaction between the different elements is essential to make the model go beyond a mere accounting exercise.

2.1 Biological component

In its simplest form the biological component contains only the biomass of the fish stocks included in the model. More sophisticated models include age-structured biomass information. Which of the two approaches is used depends in part on the focus of the model. If the main purpose is to calculate the economic consequences of certain catch levels, it will be enough only to include the biomass as a single variable per species. If the main objective is to analyze the effects of a change in policy on the stocks of some species, an age-structured model will be preferred. In most cases, several species will be included in the model and each species can be divided after geographical area. If more than one period is considered, the biological component must also include information on stock growth and the interaction between the fishing fleet and the stock size. Biomass growth depends on the level of recruitment and on mortality. The latter consists of natural and fishing mortality. Fishing mortality is one of the elements in bio-economic models that give a direct connection between the economic part of the model and the biological part.

Several models for biomass growth exist, for example the Schaefer model, the Ricker model and the Beverton-Holt model. Each of these has specific characteristics that make it suitable in certain situations. The Schaefer-model has some very favorable qualities that ease analytical problems but the downside is a sometimes excessive simplification of the problems of interest. The quality of the Beverton-Holt model is the division of the fish stock into different year-classes, as that makes the model realistic for most fish populations. It is possible to extend the model to include dynamic optimization, gear type etc. The model was originally based on studies of the North Atlantic plaice- and haddock populations and that makes it suited of these as well as other dermersal species.

When an accurate description of the dynamic processes of a fish population is needed the usual simple continuous-time models fail. One alternative are the metered models, which includes the Ricker-model. The Ricker-model is based on observations of fish species eating their own eggs and larvae. Certain salmon-species display this behavior, and Ricker curves are therefore well qualified to illustrate this. Ricker curves are too simple in many respects but it is possible to add more complex interactions and assumptions to the model (for this see Clark 1990).

2.2 Fishing fleet

The component on the fishing fleet gives a description of the fleet at some initial period and its behavior. The description of the fleet must contain all relevant information on inputs and outputs, and is often based on a period of several years in order to smooth out variability in the data. On the input side, the major division is between fixed inputs and variable inputs. Which inputs are deemed fixed depends on the time span of the model. Many models give results for one or just a few years ahead and therefore often assume that capacity, measured by number of vessels, size or tonnage, motor power, gear type, etc., is fixed. If the model runs over many years, some or all of these inputs must be assumed to be variable again. Other inputs are seen as variables, such as days at sea, number of crew, mesh size, fuel use, etc. To limit the number of variables the model works with, several inputs are assumed to be closely related to other inputs. Often, the models work only with days at sea as the variable input and all other inputs are either fixed, related to days at sea, or to total catch. Since TACs and other measures may differ between areas, models often contain information about how fishing effort is divided over fishing grounds. Besides information about the starting position of the fisheries included, the model should also contain information about the behavior of the fishing fleets. Two basic assumptions are often used here. In many cases, the model will assume behavior as usual. For example, one could assume that the catch of a certain species is divided over the fleet segments in fixed proportions. Changes in total catches then show up in similar percentage changes for every fleet segment. Alternatively, one could assume profit maximizing behavior. Other information within the fleet component of the model could be the relationship between effort and outputs. This conversion of inputs to outputs is contained in a production function that can be specified in different ways.

2.3 Economic component

The economic component contains information about prices of inputs and outputs in some initial period and how these prices change with changes in demand or supply by the fishery. Most models assume that the fishery has no influence on the price of inputs. These are therefore taken as fixed. Even more, many inputs are not explicitly taken into account in the model. Instead, the model works with costs, which basically is inputs times price. In this way, inputs can be more easily lumped together in costs that vary with a certain input. In most cases, it is convenient to use days at sea as the main input. Many costs vary with the number of days at sea and it is at the same time a major instrument of regulation. Other costs will vary with output and therefore need not be modeled explicitly either. On the output side, prices are important. A central part of all bio-economic models is the catch of fish and the revenue gained from this catch. To convert catch into revenue, the prices of all species should be known. To make economic sense, these prices should not be fixed, but should vary with output. One way of doing this is by using the price elasticity of demand. This would show how much the price changes when output changes with one percent. It would be even better to have estimations of the whole demand curve, but none of the models contain this yet.

2.4 Model categories

Bio-economic models of fisheries are used for a variety of tasks. One of the most common is to determine the repercussions of a change in management, be that a change in total allowable catch, a change in the allowable days at sea, or a change in management regime. This type of analysis gives an answer to a ‘what if’ kind of question and is a calculation of the consequences of change. In that connection, it is important to distinguish between the course of reference and the alternative course: the first is normally a projection of the present state whereas the latter is a course where the variables of interest are changed and an alternative course is calculated. The effect of a change can be calculated as the difference between the two courses i.e. a calculation of consequences (Statistics Denmark).

Another task often carried out is to determine what the fishery would look like under optimal circumstances. In this case, one wants to know optimal fishing capacity, effort and fish stock. Other tasks could be to analyze the effect of a change over a period of time, or to analyze the optimal approach path to a predetermined result at some point in time.

One could expect that one model could potentially perform all tasks. However, this turns out to be impossible. A major culprit is that the models cannot be inverted. This means that a model that uses inputs, such as days at sea, to calculate output cannot be used to calculate the needed inputs to achieve a certain output, except through trial and error. The same basically goes for optimization and projection analysis. A model that is build to give a projection of the effect of a change cannot effectively be used to determine the optimum situation for the fishery. It is possible however, at least in principle, to have dynamic versions of all models.

Table 1.1 Bio-economic models in the Nordic countries presented

Country	Model	Type	Developer	Years	Institution
Denmark	EIAA	Output based	Hans Frost	1998-	Institute of Food and Resource Economics (FOI)
	EMMFID	Optimization	Hans Frost, Jens Kjaersgaard	2002	FOI
	AHF	In-put/Output/Dyn amic	Ayoe Hoff, Hans Frost	2006-	FOI
	TEMAS	Input	Per Sparre, Clara Ulrich	2000	Danish Institute for Fisheries Re-search (DIFRES)
Iceland		Output based	Ólafur Klemensson		Central bank of Iceland, Marine Research Institute
Norway	ECONMULT	Input based	Arne Eide, Ola Flåten	1991	Norwegian College of Fishery Science
Sweden	SRRMCF	Optimization	Anton Paulrud	2006	Swedish Board of Fisheries

Bio-economic models can therefore be divided into the following categories: they can either be optimization or projection models and projection models can either be output or input based. Optimization models are used to determine a new equilibrium for the fishery that is optimal in some way. Projection models are used to evaluate the effect of a given change in the regulation of the fishery where input based models use inputs, especially effort, to determine output, while output based models reverse this process. An overview of bio-economics developed in the Nordic countries is given in Table 1.1. The table shows that all types of models are represented and that almost all models have been developed rather recently.

2.5 Uncertainty

Similar to other calculable models, the inherent uncertainty of bio-economic models is subject to discussions and sometimes criticism. Four types of uncertainty can be identified (Statistics Denmark):

- Uncertainty regarding the *future development in exogenous variables.*
- *Statistical uncertainty*.
- Uncertainty caused by *wrong or insufficient specification* of the model.
- Uncertainty in relation to the *actual application* of the exogenous information.

Uncertainty regarding the future development in exogenous variables affect the projections and in that way both the course of reference and the alternative course. It is impossible to avoid this type of uncertainty but since it is a part of both the course of reference and the alternative course, it does not affect a calculation of consequences. The same goes for statistical uncertainty, i.e. random fluctuations, which are also eliminated in a calculation of consequences. Wrong or insufficient specification is possible to take account of by adjusting results or re-specification/improvement of the model. In this, the discussions of the models are vital and critical comments are appreciated by the model-developers, who are forced to argue in favor of the model and its underlying assumptions. The actual application of exogenous information will always be a question of estimating where and how the change affects the model. Most often this is a minor problem in well-defined models where the modelers' overview easily determines this.

Results from bioeconomic models obviously contain elements of uncertainty but, again as opposed to personal judgments, the uncertainty can be disclosed and is moreover occasionally possible to quantify.

2.6 Projection models

The intention of projection models is to give an impact assessment of a change in policy. These models can typically handle a wide selection of regulation changes, such as changes in total allowable catch, allowable days at sea, selectivity of gear, gear type, switches in management regime etc. In most cases, the models use a baseline, which gives input use and output production in given year or an average over a number of years. Results of regulatory changes are then given by scaling up or down the results of the base year or period. As already mentioned, the scaling normally is not proportional to the change in the exogenous variable, but is calculated using production functions and information on price elasticities.

Two types of projection models can be distinguished: input and output models. Input models use data on inputs such as days at sea, fuel consumption and number of people employed to calculate output. Output models use a given output to calculate the inputs needed to produce that output.

2.7 Input based models

In an input-based model, exogenously given inputs are converted into outputs. In practice this almost always means that output is determined as a function of effort, where effort is given as days at sea. Days at sea are chosen as the prime input because many costs vary with it and this factor is a major policy variable. For example, the EU restricts the number of days vessels can be at sea in most fisheries.

As this type of models needs exogenous information about the inputs used in the fishery, it is suited for analyzing the effect of restrictions on inputs. So, if the number of fishing days is restricted, while there are no restrictions on catch, an input-based model can be used to calculate expected catch of the fleet.

Two of the models given in Table 1 are input based models. ECONMULT is a Norwegian model covering the most important Norwegian fisheries, mainly cod, of the Barents Sea and has been used in several analyses of fisheries in this area (see Eide and Flaaten 1998). The TEMAS model is a Danish model which consists of several components, the prime of which is the biological component (see Ulrich et al. 2006). The other components can be added to the analysis.

2.8 Output based models

The starting point of an output based model is the output of the fishing fleet, which can be harvest or landings. This makes this type of model especially suited for modeling the effect of restrictions on landings or harvest although other types of analysis can be performed too.

Two of the models given in Table 1 are output-based. The oldest is the Icelandic model that has been used to determine the optimal catch level of cod for the Icelandic fleet (see Danielsson et al. 1997, and Klemensson 2006). The model does not work with a specific (inverted) production function, but brings it in through the backdoor by making costs dependent on output and the size of the stock. Although we had said that it is hard to use projection models to calculate the optimum for a fishery that is what the Icelandic model has been used for. This is somewhat easier for the Icelandic model since it only takes cod into account. The other model is the EIAA (Economic Impact of ACFM Advice) model (see SEC(2004) 1710). Work on this model started already in the mid 1990s, but the model first got its current form around 2000. The model is used annually to give an economic assessment of the quota proposals to the European Commission. It is also used for other tasks however..

2.9 Dynamic models

Static models picture the fishery at a certain point in time and there is no succeeding time period. This image of fishery can seem unlikely but come in handy when describing a fishery in steady-state or when keeping the model simple in order to assess complex impacts. Dynamic models on the other hand are capable to show how the fishery develops over a longer period of time. To do so, the model must be able to determine how fleet capacity and the fish stocks develop over time. For fleet development, this means that an investment function must be added. In principle, investments will depend on the expected profits over the coming years in the fishery. As no information is available on expectations, dynamic models normally assume that past profits are a good predictor of future profits. Hence the investment decision is made a function of average profits over some past period of time. To this, one can add policies that will affect (dis)investments, such as decommissioning schemes.

For the growth of the fish stocks in the model, the model has to contain information about recruitment to and mortality of the biomass. Mortality here can be split up into natural and fishing mortality. Fishing mortality is affected by the fishing activity of the fleets. This part therefore gives a connection between the fleet component and the biological component. A major problem in giving the development of the fish stocks is that biologists are rather uncertain about how fish stocks develop over time. Fish stock development is influenced by many factors such as fishing activity and climate, but there seems to be a large stochastic component.

Dynamic models are not a different class of models, as both input- and output-based models can be made dynamic. In a sense, dynamic models are just a further development of these projection models. However, real dynamic models are scarce. The only operational dynamic model is the AHF model recently developed at FOI (Hoff and Frost 2006). This model consist of two parts: an input based model and an output based model. The reason for constructing the model like this is that fisheries policy often sets limitations on both inputs and outputs. For example, the EU sets both TACs and a limit on the number of days a vessel; can be at sea. Total output from the fishery is then determined by which factor is the most restrictive; days at sea or total allowable catch. One could then use the model as follows. First start with the input-based model and calculate total catch when the total allowable number of days at sea has been exhausted. If it turns out that catch is lower than the TACs set, this is where the analysis stops. However, if catch exceeds the TACs, one should move to the output-based model and recalculate. Besides combining output- and input-based models, the model can be made dynamic as biomass growth and investment behavior is included..

2.10 Optimization models

The objective with optimization models is different from that of projection models. Instead of showing the effect of a change in policy with the fleet as it is now, an optimization model shows a new equilibrium when all effects have been taken into account. This means that optimization models also assume that fleet capacity and fish stocks can change. Optimization models are then especially suited to analyze effect of policy on fleet capacity in the long run. They show how large the fishing fleet should be, under certain circumstances, to achieve maximum profits in for the fleet.

Two of the models mentioned in Table 1 are optimization models; the Danish EMMFID model and the Swedish SRRMCF model. The EMMFID model has been developed to analyze long-run effects of policy changes on the Danish fishing fleet (see Frost and Kjærsgaard 2003). It is also used annually in the forecasts made for the publication 'Fiskeriets Økonomi' (The Economic State of the Danish Fisheries). The SRRMCF model has been developed to assist in the long-run management of the Swedish fisheries (see Paulrud 2006). It is designed to maximize the resource rent of the fisheries modelled..

3. Bio-economic modeling of fisheries

In the following sections elements important in the construction and running of bioeconomic models of fisheries are discussed. Therefore, these elements are presented in some detail.

3.1 Production functions

A central element in virtually all bio-economic models is the production function. This function gives the relationship between the inputs used in the fishery and the outputs produced. The production function is especially essential when regulation of production factors is used as management instrument for instance restrictions on days at sea, gear type, mesh size etc. However, when the management instrument is a TAC or a tradable quota system, a production function is not strictly necessary, as witnessed by the Icelandic model for cod. In this model, revenue is estimated from an inverse demand function and costs are estimated. Profit is then maximized and in this way the production function is bypassed.

There is a number alternative production functions available, and the choice of functional form can have significant influence on the outcome of the model. Well-known examples of production functions are described in the following sections.

3.1.1 The Translog production function

A very general formulation of the production function is the translog function. Basically, any production function can be approximated by the translog function and it is often referred to as “flexible”.

Christensen et al. (1971) were among the first to describe the translog function, which can be regarded as a 2nd order logarithmic Taylor polynomial approximation (Thomsen 1999). With two production factors, the translog production function can be given as:

$$\log Y = \log A + \alpha 1 S + \beta 1 E + \alpha 2 (\log S) 2 + \beta 2 (\log E) 2 + \delta \log S \log E \qquad (1)$$

A major advantage of the translog function is that it allows for changes in the returns to scale as output changes. Often the long run average cost function is assumed to have a U-shape so that there first are increasing then constant and finally decreasing returns to scale.

3.1.2 Constant Elasticity of Substitution (CES) production function

The CES production function can be regarded as a generalization of production functions and it contains the Cobb-Douglas function, the linear function and the Leontief function as "special cases" (Varian 1992). With two production factors and constant returns to scale the CES production function is given by:

$$Y = \kappa \left[\alpha S^{\frac{\sigma-1}{\sigma}} + (1-\alpha) E^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \quad \kappa > 0 \, , \, \sigma > 0 \, , \, 0 < \alpha < 1 \qquad (2)$$

where κ, σ and α are parameters. The CES function exhibits constant elasticity of substitution between the two production factors i.e. the curvature of the isoquants is constant[3]. Production is represented more generally than in the Cobb-Douglas function but in spite of this the CES-function can exhibit constant, increasing or decreasing returns to scale depending on the value of , like the Cobb-Douglas production function. The CES production function is non-linear and unlike the Cobb-Douglas function it cannot be linearized analytically (Hoff 2004). Since estimation of functional parameters for the CES function includes complicated non-linear fitting techniques, linear approximations of CES functions are very useful (Hoff 2004). Such approximations based on Taylor expansions are only suitable for certain ranges of parameters i.e. the elasticity of substitution and the returns to scale. However, when an n-input technology is assumed to show constant elasticity of substitution close to unity, the observed values may be fitted to the n-dimensional translog form described earlier. For a thorough analysis of this see Hoff (2004).

3.1.3 Cobb-Douglas production function

A Cobb-Douglas is a widely used type of production function and it can be stated as:

Y=A•SαEβ (3)

Here α and β are parameters and the choice of these reflects the economies of scale in production: When α+β=1, there are constant returns to scale, implying that a certain percentage increase in both production factors gives the same percentage increase in output. When α+β>1, there are increasing returns to scale, and with α+β<1 there are decreasing returns to scale. The Cobb-Douglas production function has many useful and well known attributes such as linearity of the logarithm and elasticity of sub-

[3] "…the elasticity of substitution measures the percentage change in the factor ratio divided by the percentage change in the TRS (Technical Rate of Substitution) , with output being held fixed." (Varian, 1992).

stitution equal to one. Further, α and β shows the output elasticity of the fish stock and the fishing effort i.e. how much output is increased once the input is increased. Finally, α and β also shows the shares of fish stocks and effort of the output (landings). All these features help specifying α and β on an empirical level.

It is possible to derive the Cobb-Douglas function from a translog function. The Cobb-Douglas function is log-linear (or ln-linear) since ln Y is a linear function of ln to the input variables. The following conversion illustrates this:

$$\ln Y = \ln A + \alpha \ln S + \beta \ln E \quad (4)$$

In addition to the abovementioned modification and as mentioned earlier, the Cobb-Douglas function is a special case of the CES function when equals zero, see Annex 1 Production function features..

3.1.4 Leontief production function

Of the flexible functions, the Leontief and the translog functions are the most frequently used (Thomsen 1999). In case of two production factors the function can be stated as:

Y=min(a1S, a2E) (5)

Linear production models and linear programming often involve the Leontief production function, which opposed to the neoclassical production functions is associated with L-shaped isoquants. These shapes indicate substitution among production factors is not possible and production factors are used in a fixed ratio. It is off course possible to produce a certain amount of output using more input but the relevant production possibility frontier is the "corners" of the L-shaped isoquants. Consequently, the relative lowest amount of input available restricts production.

In addition to the lack of substitution, the Leontief production function is homogenous of first degree indicating constant returns to scale. However, these immediate restrictions can be relaxed when several Leontief production functions are combined suggesting more complex models.

As mentioned earlier, the Leontief production function can be regarded as a special case of the CES-function, see Annex 1 Production function features.

3.1.5 Linear production function

Yet another production function is the linear production function possibly given as:

Y=A+a1S+a2E (6)

Where Y is output, S is biomass, E is effort, A is a constant and the a's are parameters. Both S and E can be composite variables and all elements in (5.1) can be vectors.

Like the Cobb-Douglas and the Leontief production functions, the linear production function can be regarded as a special case of the CES-function, see annex 1. A linear production function is very specific since it does not allow for many different representations of the fishery. Furthermore, output can be produced even when one of the inputs is not available, which in the case of the fishery above is impossible.

3.1.6 Comments on production functions

Productions functions can be depicted in "a family tree of linearly homogeneous production functions", see Färe et al. (1989). All functional forms of the production functions have some advantages and disadvantages. The more general the representation, the more complicated the function becomes to work with. At the same time, the more general representations of the production functions also allow for more flexibility and thereby for more different representations of the production process. Hence ideally, one should start with a translog production function. If this shows to be identical to a Cobb-Douglas, one can shift to the latter. However, insofar a production function is used in bio-economic models of fisheries it is almost always a Cobb-Douglas type. This is the case in all models mentioned in Table 1.1.

A major problem with production functions is to determine which representation depicts the real situation best. There are two paths, which are not mutually exclusive, the theoretical and the empirical. Through economic theory, one can determine what properties the production function should have. This will lead us some way and will for example lead to a rejection of the linear model. However, this still leaves us with several options. Empirical estimation of production functions is therefore needed to gain insight into the functional form of the production function for fisheries, and also to determine the values of the parameters in the model.

Furthermore, it will be useful, to disaggregate the production function as much as possible, so that there is a separate production function for each fleet segment.

The amount of data needed to run a model with a production function depends on the level of detail needed. For most models working on an annual basis, data is available, at least in the Nordic countries. If shorter time periods are required for the analysis, more data is needed.

4. Prices

In most bioeconomic models of fisheries it is assumed that fishermen seek to maximize profits (which is not the same as maximization of the resource rent). Important variables in the context of profit maximization are the prices of landed fish and the implicit price development.

In the analytical linear fishery models it is often further assumed that catch does not affect the prices of landed fish i.e. the demand curves are infinitely elastic. This assumption can be realistic for some (smaller) fisheries whereas the prices in (larger) more important fisheries are dependent on supply and demand of world markets.

One of the reasons why constant prices are assumed is that the investigated problems often become non-linear and consequently more difficult when prices become dependent on supply and demand. Another reason is that bioeconomic models often are static and fishermen are assumed to have myopic expectations i.e. they expect future prices to correspond to historic prices.

Prices of fish products are rarely constant though, but it is possible to obtain estimates of future fish prices. The estimates of the price development for example in the Danish fisheries are conducted by the Institute of Food and Resource Economics. The analyses are based on assumptions regarding:

- The EU Commissions' estimated rate of inflation for the EU (1.6% in 2006)
- Expected supply of fish products nationally as well as in the EU and globally. The aggregate supply for the European market is multiplied by a price-flexibility coefficient, which illustrates the relative change in prices in response to a supply change. Moreover is the supply adjusted for "special conditions" applying to Danish fishery, the quotas decided upon and the utilization of the national quotas.
- Foreign exchange quotations.
- Expected supply of fish products to the markets in the EU. Price-estimates are based on whether the fish products are essential commodities, easy to substitute or inferior goods. Furthermore, prices are affected by consumers' purchasing power and preferences.

Some bioeconomic fishery models apply the estimated future fish prices via price flexibilities and the EIAA-model is one of them. The benefit of this is a more complete and true analysis of earnings in the fishery of interest but the downside is a more complex and data demanding model.

Furthermore, price estimates and price flexibilities are often not available for several years and that limits the application.

5. Discard

Discard can generally be defined as (by)-catch that is put back to sea. The problem with discard is that fish that are caught and put back to sea have a low survival rate. Therefore, discard will contribute to fishing mortality without giving any economic benefit.

The general definition covers several types of discard. First of all, there will often be a minimum legal landing size of the fish species in question. Within the EU, it is mandatory to discard fish that are below this minimum landing size. However, in Norway and in Iceland all catch, including individuals below minimum landing size have to be landed. Another type of discard is quota-determined discard. This type of discard takes place in mixed fisheries (see below) where a vessel at every point in time catches more than one species of fish. It may then happen that the vessel has no quotas for one (or more) species, while it still has quotas for others. As the vessel is not allowed to land species for which it has no quotas, it will have to discard these species, no matter whether they are below or above the minimum landing size. A third type of discard is highgrading, which means that a low value part of the catch is discarded in order to be able to store and land more valuable fish. The discarded low value fish will be above the minimum legal landing size, but the fisherman has an economic incentive to discard it. Highgrading can refer to both the discard of smaller fish that usually fetch a lower kilo price than larger fish and to the discard of less valuable species in favor of more valuable species. A fourth type of discard is discarding of non-marketable species or sizes. It is a result of the limited selectivity of fishing gear and consumers preferring some species to others. Consequently not all of these are demanded equally – for instance will by-caught starfish, jellyfish, sea mammals, birds etc. not often be demanded.

Discarding is not a problem for the individual fisherman. After all, discarding takes place in order to increase profits. However, discarding carries with it several problems. First of all discarded fish often do not survive their return to the sea and hence, a large part of the discarded fish is wasted. This is seen as an ethical problem in that food resources are spoiled while they could have been consumed. Another problem is that discarding makes it more difficult to assess the fish stock. Normally, only landings are reported, while the level of discarding is unknown. Hence, only using landings data will underestimate fishing mortality of the stock. The stock assessments for the basis of fisheries policies, especially the total allowable catch. Therefore, more uncertain stock assessments may cause TACs to be set too high or too low.

Discard should be included in bio-economic models for two main reasons. First of all, as mentioned above, neglecting discard will lead to wrong stock assessments. If then one wants to assess the effect of a (change in) policy measure on fish biomass within a bio-economic model, discard should be included in some way. Furthermore, reducing discard is one of the major policy aims in many countries. Hence, a bio-economic model should be able to address the effect of a policy measure on discard.

However, the relationship between harvest and discard is not a simple one and data on discards are not readily available. Since discarding occurs for several reasons, as discussed above, several relationships should be modeled. For example, discard because fish are below the minimum legal landing size is affected by gear type and mesh size as well as by total harvest. Quota determined discarding is affected by the composition of quotas a vessel holds, the catch composition of the vessel and the economic incentives to keep fishing when one of the quotas is fully utilized. Hereby it should be noted that catch composition to some extend can be controlled by the individual fisherman. The same holds for the composition of catch quotas if the fishery is regulated through an ITQ system. The level of highgrading is dependent on the relative price of the fish caught and on the relative amount caught. The larger the difference in price between the low value and the high value fish, the larger the incentive to highgrade. Furthermore, the larger the proportion of high value fish in harvest, the more it pays to highgrade.

Although the main theoretical issues regarding discarding are well understood, it remains hard to model discarding because there is so little data available that can show the actual relationship between the various variables. Some data does exist though. Biologists have made many test hauls to determine the catch composition with specific gear type and mesh size in a certain area at some time period. However, it is uncertain how representative these tests are compared to real fishing behavior. Furthermore, several countries such as Norway and Iceland have restrictions on discarding so that all harvest should be landed. This should make it easier to include discard in models for these countries, although discarding still can take place in these countries.

6. Mixed fisheries

A major challenge in modeling fisheries is that they are mostly mixed fisheries. With this we mean that in most cases, several species are caught at the same time. This presents the modeler with several problems.

Firstly, we can no longer assume that a vessel can freely determine its catch but have to assume some relationship between catches of certain species. However, there is some flexibility in choice of catch composition as this can change depending on catch area and season, gear type and mesh. It is not easy though measuring how easy it is for a vessel to change catch composition and therefore, it is not immediately clear how to model catches in a mixed fishery. The usual method to deal with this problem is to take catch composition either as fixed or as totally flexible. It should be clear that these methods do nothing to solve the problem. It is necessary to establish links between the catches of different species in a more flexible manner. One method would be to assume that catch composition is at least partly determined by the price of the different species. Another method would be to have a more detailed model that operates on shorter periods of time, weeks for example, and smaller geographic areas, ICES squares for example. If at the same time data was available at this level, a model could be constructed that allows for switches between time periods and geographical areas. This does not fully solve the problem however, because observed catch compositions do not necessarily represent all possible catch compositions. Furthermore, it is not necessarily so that all vessels within a certain fleet segment can obtain the same catch composition as a specific vessel, purely because of a limited amount of fish available in a certain area at a certain time period. The main problem however remains the one of data availability.

A problem closely related to the above one is how to determine the effect of quota restrictions within the model. In modeling quota restrictions one has to determine when the fleet stops fishing: Is it after the most restrictive quota is reached, will the fishermen deplete all quotas or will they do something in between? The answer depends in part on how successful the fleets are in changing their catch compositions. The more flexible, the easier it will be for the fleet to adjust its catch so that it matches its quota composition. A partial solution to this problem is to observe the catch composition of various vessels within a fleet segment. Catch composition will differ between vessels and over time. One could then assume that all vessels within the segment can at least adjust their catch composition so much that they can achieve all catch compositions observed within the fleet segment. If quotas are set on catches, one can compare the quota composition with the catch composition of the vessels within the fleet segment and use the catch compositions that most closely resemble the quota composition. However, as before, this still leaves the problem, that vessels could change their catch composition even more than the range that has been observed.

This issue is closely related to the problem of including discard in the model. In a single species fishery, discard only consists of individuals below the legal minimum landing size, or of individuals above that size that have too low economic value to be landed. However, in a mixed fishery discard can occur because the species has low value compared to that of another species in the catch or because the vessel has used up all its quotas for a specific species, while it still has quotas for the other species. Since discard is a major management issue, it would be relevant to evaluate management changes with respect to changes in discard.

Furthermore, in determining the optimum for the fishery one now has to take into account that certain fish species are caught together. This makes it hard to maximize resource rent while at the same time safeguarding all different stocks. To deal with this problem, one could maximize resource rent under the constraint that no stock should be lower than a certain biologically given level. The problem remains however that it is unknown how flexible fishing vessels are in altering their catch composition.

Dealing with this issue requires detailed information about fishing activities. As mentioned, one approach to determine the flexibility of vessels to control their catch composition would be to observe variations in catch composition over time and at different places. Ideally, such data should be collected at tour level or even at the haul level. Currently, the EU has regulations on logbook registrations by fishing vessels that make collection of catch data at tour level and ICES square level mandatory. Hence, in principle, data is available. However, it is uncertain whether the data collection at this level is enforced in al Member States and furthermore, even if data is collected it is not always readily available for research activities.

7. Behaviour of fishermen

A bio-economic model should include the behavior of fishermen to at least some extend. Fishermen will change their fishing behavior when conditions, such as prices for inputs, prices for outputs, and regulation, change. Changes can occur in fishing capital stock, effort, fishing area, fishing season and fishing gear.

Within the bio-economic model, the behavior of the fishermen needs to be formalized. Here, a basic issue is what drives the behavior of the fishermen. The normal assumption is that fishermen, like all firms, try to maximize profits. This drive for highest possible profits should lead fishermen to choose the optimal combination of all the elements mentioned above. To include this behavior into the model, an explicit profit function that comprises all possible choices for the vessel has to be included. It should be clear that including these aspects in a bio-economic model would greatly complicate the model. Therefore, such amendments should only be made when necessary. This is most likely the case when the regulatory system gives fishermen the opportunity to adjust their behavior, as would be the case under an ITQ system and when there are major shifts in the regulatory system. Whenever the system is rather rigid and the shifts are small, it would be better to assume behavior as usual instead of modifying the model to include changes in behavior.

If there is a need to include the behavior of fishermen in the model, data on several aspects is needed. Partly, this is the same data as is needed as described in the section on mixed fisheries; we need to know how fishermen can adjust their catch composition. Furthermore, all input and output prices should be available and demand curves for both inputs and outputs should be included in the model. If demand functions cannot be estimated, there should at least be some information about the price elasticities. Finally, the model should include information about the investment behavior of the fishing fleet in order to assess changes in fishing capacity as a result of regulatory changes.

Some of the data is readily available in most Nordic countries. Prices for landed fish are well documented and so are input prices. Estimates of demand curves for fish are widely available. However, the great majority of these estimates concern the demand for fish within one country. Fish markets are, however, highly integrated at the international level so that country level estimates are likely to show a too low elasticity. Hence what are needed are estimates of demand functions best at world level. Such estimates are not readily available though. Data on catch composition and the flexibility of fishermen to alter this composition exists to some extend, but is not always readily available. Furthermore, information on investment behavior by fishermen is sparse.

Including fishermen behavior explicitly in bio-economic models of fisheries could greatly improve the predictive power of the model but also greatly complicates the model. This aspect should therefore only be included in the model when it can be reasonably assumed that it will affect the outcome of the analysis substantially. Otherwise, it is better to assume that the fishermen will behave as they have in the past, with slight modifications, if these are easy to include.

8. Monitoring and enforcement

There is a tendency within most fisheries to employ effort and invest in capital to the point where socio economic profits are zero and the fishery is overcapitalized and overemployed. At this point fish stocks are easily overexploited and the returns to society are significantly lower than in optimum. Hence there is a good case for government policy. However, without monitoring and enforcement fishery policy would be meaningless as the policy would not be respected. But monitoring and enforcement is costly, so there is a trade-off between compliance and costs of enforcement.

There are two reasons to include monitoring and enforcement of fisheries policy in bio-economic models. The first one is that monitoring and enforcement affects the levels of illegal practices in fisheries, such as illegal landings and discard, and thereby affects the total level of catch, landings and fishing mortality. This in turn will affect prices, profits and stock levels. The other reason is that policymakers would like to know the effect of different monitoring and enforcement regimes on fisheries before implementing them. Included in this is the issue of what the optimal level of enforcement is. Since monitoring and enforcement are costly, it may be that the monitoring agency would not want to monitor and enforce the policy perfectly. Furthermore, the government may want to adjust the TACs it sets when it knows that illegal fishing takes place.

To model these issues, several components should be included. With respect to the monitoring and enforcement agency, a function should be included that determines how it reacts. This function could show how the agency reacts or could be modified to test alternative monitoring and enforcement behavior. How the agency should behave under different circumstances has been widely discussed in the literature, both in general and more applied for environmental and resource economics. However, not much is known about how agencies act in reality. Hence, data is needed to be able to model this behavior. Among the data needed is information about the monitoring and enforcement level by the agency. This would include the number of inspections and some measure of the thoroughness of the inspections. However, agencies typically monitor in different ways. Inspections at sea are combined with inspections during landings and inspections of logbooks and administration, both of the vessels, but also of distributors and retailers of fish and fish products. It may be hard to capture all these different types of monitoring behavior within the model, although man-years used on monitoring and enforcement would be a first crude measure that could be included in the model. Besides this, the penalty level should be included. Data on this should be available from the monitoring and enforcement agency. Furthermore, there should be some measure of the probability of detection. This may actually be hard to ascertain. A simple measurement may be number of detections of noncompliance divided by the number of inspections. However, two problems arise here. The number of inspections may be hard to observe and because of the diversity of inspections, adding up inspections may not be viable. Besides that, the agency may not monitor randomly, but target specific fleet segment where non-compliance is more likely. A simple measure of detection may then overestimate the probability of detection. This is to say that although data may be available, that does not mean that modeling monitoring and enforcement is straightforward.

Fishermen reactions to monitoring and enforcement should be included too. Ideally, a profit function should be included that takes monitoring and enforcement effort by the agency into account. As most models assume profit maximization by fishermen, modeling compliance along the same lines would be rather straightforward. This would imply that fishermen weight the benefits of illegal behavior against the probability of being detected times the fine they have to pay if caught. Refinements can be included that make it possible for the fishermen to adjust behavior, for example by making it more difficult for the agency to detect non-compliance. Finally, if management reacts to illegal fishing practices by adjusting the TACs or effort restrictions, such behavior should be included too. Again, the main problem is that good information about such behavior is lacking.

Including monitoring and enforcement in bio-economic models will give better information about illegal landings and improve stock assessments. It will also make it possible to assess the effects of different monitoring and enforcement regimes. However, modeling this issue is not straightforward and is therefore only justified if illegal landings or illegal fishing behavior in general is a problem in the fishery concerned, or if the aim of the model is to assess the effects of monitoring and enforcement.

9. Dynamics

A central element in bio-economic models is the connection between the economic and the biological components. In its most simple form it may just give fishing costs as a function of biomass within a certain year. This is satisfactory if the model is intended only to give the results for one year and the main focus is on economics. However, if more than one year is considered, the model should describe how the fleet and the biomass interact with each other.

Dynamic models are of interest if one wants to assess the effects of policy measures over a longer period of time. This will be the case if the management plan considered affects fleet capacity and/or the fish stock. Normally, effects on fish stocks and fishing fleet capacity take time to emerge. To include these effects in the model, two functions are needed. For the dynamics of the fishing fleet, it is necessary to know the investment behavior of fishermen and potential entrants. Investment can pertain to adding vessels to the fleet or to improvements to the existing fleet that increase capacity defined broadly. In general, the existing fleet will be modernized continuously to improve the effectiveness of current vessels. This is often termed as technological creep. It can be modeled by assuming that fishing fleets become more efficient by a certain percentage every year, so that less effort is needed to catch the same amount of fish. Large changes in fishing capacity will have to be modeled through a specific investment function. Investments in any sector are always assumed to be correlated with expected future profits in the sector. Since it is hard to model expectations about the future, it is common to assume that investment depend on past profits, where several years can be included as lagged variables. This may be an adequate method when no major changes are expected in the near future. However, major alterations in policy, for example a shift to ITQs, may trigger a change in investment behavior. In that case, assuming business as usual is not adequate. A possible solution is to determine the equilibrium outcome of such a policy change in an optimization model. This will give some indication about the final size of the fleet and possible also fish stocks. With knowledge, or some good assumptions, about how fast the fleet will adapt to the new situation, investment can be modeled in a dynamic model. Investment or disinvestment decisions also depend on the existence of decommissioning schemes. Hence, these have to be taken into account in the model.

Besides an investment function to determine the behavior of the fleet, a growth function for the fish stock is needed. In some cases, it will be sufficient to have an aggregate growth function that shows the growth of the biomass. However, in many cases it will be necessary to include an age-structured model of the stock. Assessments are then needed about recruitment, natural, fishing and discard mortality.

There is a danger in modeling both investment decisions and the dynamics of the biomass in a deterministic manner. Since both are uncertain, it may be wise to make this clear in the model and its output. One way of doing so is by including stochastic elements in the investment and biomass growth functions. In that way, and by doing a number of runs of the model, a spread can be determined within which the outcome is likely to lay. Another method would be to do a sensitivity analysis where several key parameters are given different values in different runs. Again, repeating the model calculations with different assumptions about certain key parameters will give insight in the possible outcome of a change in policy.

A major problem in modeling the dynamics of a fishery is that very little data is available. Not only is information on future prices, policies and stock recruitment scarce, information about past investment behavior and fish stock dynamics is limited too. Furthermore, there is a difference in attitude towards dynamic models between biologists and economists. Whereas economists are used to dynamic models that run over a longer period of time, biologists are very reluctant to give stock assessments for more than one or maximum two years ahead. The result may be that dynamic models will find little acceptance among fishery biologists, while these are needed to construct valid long term models. Hence, cooperation between the two professions is needed to come to an agreement on how biomass dynamics over a longer period should be modeled.

Making bio-economic models dynamic greatly enhances their usefulness as a policy evaluation tool. It gives the possibility to see the long-run effects of a policy proposal and not only shows the eventual outcome, but also the path toward that outcome. The obvious disadvantage of including dynamics in models is that they become much more complicated to work with. Furthermore, the longer the time horizon used, the more uncertain the outcome will be. Therefore, either stochastics should be added, or a sensitivity analysis of the results should be provided to give insight into the uncertainty of the outcomes. To our knowledge, the only model capable of giving a dynamic analysis over a longer period of time is the AHF model developed by Hans Frost and Ayoe Hoff at the Institute of Food and Resource Economics in Denmark.

10. Social effects

The existing bio-economic models of fisheries focus rather narrowly on the fishery itself. But other things may be relevant to take into account too. First of all, social opportunities, such as alternative job opportunities, affect fishermens' reactions to changes in their environment. Another factor in this respect is the strength of the social ties with the community. Those with strong ties will be more reluctant to move away than those with more loose ties. The existence and size of unemployment benefits will also affect the decision whether to stay in the fishery or not.

Another issue that could be taken into account is the processing industry. There are different effects possible on the processing industry from changes in fishery policy. Changes in total allowable catches may lower the supply to industry and may have a negative impact on their profitability. This may also lead processors to diversify away from local fish to the global market of fish. Another affect of a change in fishery policy may be a change in the quality of the fish supplied. It may for example enable fishermen to supply fresh fish for direct consumption instead of frozen fish to the processing industry. The processing industry will have to adapt to the change in supply and restructuring may take place. Another effect may be that catches can be spread out more evenly over the year. This will also spread out employment in the processing industry over the year and decrease seasonal work. All these effects may also give changes in the price of fish, which again may affect profits. It should be recognized though that the fish processing industry already is oriented at the global market and outsourcing takes place on a large scale. Information about the processing industry is available. This issue has however not received much attention in the form of modeling within a bio-economic model. Therefore, it will take some time to develop such a new component to these models. One could even take things a step further and include all the markets for inputs and outputs explicitly in the bio-economic model (see Arnason, 2000). This would imply building a kind of computable general equilibrium model for the fisheries sector. The advantage of such a model is that there are relatively few exogenously given factors, which should improve the predictive power of the model. However, this improvement comes at a large computational cost. Normally, such models cannot be solved analytically, but the solution has to be found through iteration, which can involve several runs of the model.

Although economists normally focus on efficiency, politicians are often at least as much interested in distribution. Here we can distinguish between two types: distribution between persons, in our case fishermen, and regional distribution. There is a tendency that large inequalities, both between people and regions, are unwanted. These issues could be addressed within bio-economic models. To show the effect of fishery policy in income distribution between fishermen, one would ideally need a model that gives results per vessel. This is virtually impossible because of data restraints, but also because results at that level of detail will be highly uncertain. However, distribution between fishermen could be addressed by showing the effect of policies per average vessel per fleet segment.

Another issue is the regional aspect of fisheries. In many cases, the fishery industry is large in regions with few other employment opportunities. Hence, reductions in the fisheries may have large regional consequences. These effects may be only of a transitional character and not affect national social welfare negatively in the long run, but politically, these effects are often seen as a problem. Therefore policy makers will want to know the regional effects of a policy before it is implemented. The regional effects do not only pertain to the direct effect on changes in catch, but also to changes in employment associated with fishery in general. This includes all supplies to the fishery and all processing industry. To include this aspect in a model, information is needed about the supply stream to the fishing fleet and the flow of fish after they have been landed. Although some of this information may be available, there is a general lack of studies showing the patterns within the different countries. Furthermore, there is too little information about how supply to the fleet and the processing industry react to changes in fishery policy.

The proposed extension will not interfere with the structure of current models. However, they do present a major enlargement of the models. Not only will this affect the complexity of the models, time, data and research is needed to develop the new components of the models and how to integrate them in the current models. The usual caveat applies here too: including the extensions is only worthwhile if the expected changes are rather big. If not, then it is better to leave them out of the model and assume behavior as usual.

11. Indicators

Bio-economic models can deliver a whole range of outputs. These outputs can give information about biological aspects, such as the size and growth rate of biomass, economic aspects, such as profitability and size of the fleet, or social, such as employment. Bio-economic models are mainly used to evaluate policy alternatives. Hence, the output of the models is of direct interest for policy makers and all those affected by fishery policy. It is therefore important to present results that matter in the policy decision process and to present them in a way that is comprehensible for non-specialists. A prime way of doing so would be by developing some indicators that convey the results from the bio-economic model in an understandable and consistent way.

What indicators are needed may differ between models and between policy objectives, but all indicators should be constructed such that they convey information about the central aspects that are analyzed. Furthermore, they should be clear and concise and avoid ambiguity. Another important factor is that the indicators chosen should be consistent over time, so that the indicators can be used over a long time interval.

Biologists already have some indicators that signal whether a stock or catch is sustainable or not. Furthermore, their advice to the EU is given in a rather simple form namely maximum fishing mortality. Even this latter indicator is not directly useable in the political process. Therefore, it is converted to catches per area within the EU. Since bio-economic models contain a biological component, these same measures could be used as indicators within these models. Other biological and ecological indicators could contain information about biodiversity and the quality of the ecosystem if such information is given by the model.

When considering economic indicators we have to distinguish between private and social benefits and costs. If we only look at the economic situation of the fleet, we will be interested in the revenue, costs and profitability of the vessels. Instead of just giving numbers, these could be put in categories. For example, the EIAA model gives information on profitability in the categories ‘not profitable’, ‘stable’, and ‘profitable’. Other indicators could give information about the number of vessels, the employment in the fleet and the pay to crew. From a social point of view, the most interesting indicator is the resource rent. A fishery is managed at its social optimal when the resource rent is at its maximum. An indicator on resource rent could for example say how far from the optimal position the fishery is.

What is needed most of all though, is an assessment of which indicators are needed by policymakers and other interested parties. Since they are the ones requesting the results from the bio-economic models, they are also the ones that know how the information should be presented so that it is useful for them.

12. Conclusion

In the BIØKOMODA project a number of models was presented and discussed with the intention of developing models further, inspire the stakeholders in fishery and increase the interest in bioeconomic modelling. Through the workshop participants' knowledge between countries and organizations was shared and transferred levelling insight and understanding. Whether the intended effects have become visible yet demands a study beyond the scope of this report but the BIØKOMODA project has undoubtedly supported the development of models in the Nordic countries significantly.

This report in itself constitutes one of the goals of the project since it highlights the issues of utmost importance in bioeconomic modelling of fisheries in the Nordic countries.

At the BIØKOMODA-meetings bioeconomic models were categorized and comparisons between and within categories made. The main groups established were projection models, further dividable in input- and output models, and optimization models. The importance of the production function in a bioeconomic model was underlined and a selection of possible functional forms and the consequences of using these discussed. Output-prices i.e. the price of fish and the frequent assumption of these being constant were considered followed by the possibilities and consequences of altering this.

Types and problems of discard and the possibilities of discard-management were examined during the meetings. It was agreed that ideally discard is included in bioeconomic models and different ways of estimating discards were presented. Problems modelling mixed fisheries are well-established but still highly relevant since most fishing gear employed shows limited selectivity. The participants at the BIØKOMODA meetings discussed this in relation to regulation, discard, optimization of the fishery and data availability since mixed fishery is a multifaceted feature of most commercial fisheries.

It was agreed that fishermen's behaviour is an important aspect of bioeconomic models. From an economic viewpoint profit maximisation is considered the driving force for the behaviour which is included in many of the models on fleet segment level. Further, disaggration to individual level would not change the general structure of the models but make them much more complicated and data demanding.

The challenges modelling monitoring and enforcement and obtaining reliable data were studied at several points during the meetings. It was established that monitoring and enforcement studies are needed but not necessarily included in all models. Connections between the biological and economic component in the models are needed when several years are considered. This calls for models capable of dynamic analyses- for instance of changes in management and regulation.

Of considerable importance and a challenge in this context is describing the investment behaviour of fishermen and the growth function of fish since substantial uncertainties are present here. Poor data availability amplifies the uncertainties and especially biological data and estimated parameters are lacking. To solve this problem additional cooperation between biologists and economists are needed in order to reach unity on how to model dynamic growth functions of stocks. The models AHF and TEMAS are models capable of dynamic analyses and they stand out since such models are rarely operational.

Downstream- and social effects from fishery as well as fishing-externalities are frequently relevant to include. Typically, this leads to an enlargement – and not change – of the model to shed light on the distribution among fishermen and regions. Using indicators increases understanding and consistency when results from models are presented to third parties. Biological indicators are well-established but economic indicators need an appropriate set up. Work on this is in progress in the EU and will be interesting to follow in the Nordic countries too.

The achievements of the BIØKOMODA-project support a continued collaboration and exchange of experience between the fishing industry, the management authorities and the researchers in the Nordic countries. This also applies within the research field that is between the different groups of researchers. At the same time, it is important to notice how an essential spin-off from BIØKOMODA is the attention drawn to the fact that an institutional platform for fishery economists is absent. In the light of this the project has to some extent acted as a temporary platform supporting bioeconomic modelling in the Nordic countries. No further activities are planned under the auspices of the BIØKOMODA project. Similar future projects, however, are considered highly relevant in order to develop bioeconomic modelling in the Nordic countries further.

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Sammenfatning

BIØKOMODA (BIoØKOnomiske MODel Analyser) er akronymet for en række seminarer organiseret som en opfølgning til konferencen i 2002 om fiskeriøkonomi og finansieret af Nordisk Ministerråd. Konferencen i 2002 omhandlede omkostnings- og indtjeningsstatistik for fiskeriet, og det blev konkluderet, at der var behov for modeludvikling og anvendelse af data med henblik på at forbedre rådgivningen I krydsfeltet mellem biologi og økonomi.

Et begrænset antal mennesker fra den akademiske verden, industrien og administrationen blev inviteret for at præsentere og diskutere den eksisterende viden inden for bioøkonomiske modeller, og hvordan disse burde og kunne udvikles yderligere.

Der blev på seminarerne fremlagt et antal modeller, hovedsageligt inden for økonomi, med større eller mindre komponenter af biologi. Modellerne blev klassificerede i typer med hensyn til, hvad der var udefra givne variable (eksogene), og hvad der blev bestemt i modellen (endogene). De blev endvidere opdelt I hvad-nu-hvis og hvad-er- bedst modeller, hvor førstnævnte simulerer forskellige scenarier under bestemte antagelser, mens sidstnævnte finder den bedste størrelse og sammensætning af fiskebestande og fiskeflåder med henblik på at maksimere den økonomiske gevinst i fiskeriet.

I diskussionen om modellernes anvendelighed blev der taget udgangspunkt I en række emner, og hvordan disse var inkluderede i modellerne: produktionsfunktioner, priser, udsmid, blandede fiskerier, fiskernes adfærd, dynamikken I modellerne, sociale effekter og endelig indikatorer dvs. hvordan resultaterne præsenteres.

Blandt konklusionerne kan nævnes, at fiskernes adfærd var vigtig ikke mindst med hensyn til tilgang/afgang fra fiskeret, og at dette element var dårligt dækket i modellerne. Et andet spørgsmål var, om der kunne vindes noget ved at formulere modellerne helt ned på enkeltfartøjsniveau. Konklusionen var, at der ikke behøvedes ændringer I modelstrukturen i eksisterende modeller for at inkludere dette, men at modellerne ville blive betydeligt større og mere komplekse, uden at der nødvendigvis ville tilvejebringes bedre resultater. Indarbejdelse af sociale aspekter, op- og nedstrømseffekter, beskæftigelse og regionale påvirkninger ville være nyttige og ville kunne føjes til eksisterende modeller, som imidlertid ville blive store og dermed mere krævende at arbejde med. Alternativt kunne disse spørgsmål belyse med separate modeller.

Endelig blev det noteret på seminarerne, at der ikke findes nogen institutionel platform for bioøkonomisk modellering, og at BIØKOMODA projektet kun har fungeret som en midlertidig platform med hensyn til at understøtte arbejdet med bioøkonomisk modellering i de Nordiske lande.

Annex 1 Production function features

1. The Cobb-Douglas function is a special case of the CES function when

•

$\rho = \frac{\sigma - 1}{\sigma}$ equals zero. Production expressed as

$Y = \kappa\left[\alpha S^{\frac{\sigma-1}{\sigma}} + (1-\alpha)E^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}$ is not defined for $\rho = 0$ since ρ is a

denominator. Nevertheless, as ρ approaches zero, the isoquants of the Cobb-Douglas and the CES function are very much alike (Varian 1992).

When *ρ=1* simple substitution in the CES-function yields a linear production function:

$$Y = \kappa\left[\alpha S^{\frac{\sigma-1}{\sigma}} + (1-\alpha)E^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} \text{ where } \rho = \frac{\sigma - 1}{\sigma},$$

$$Y = \kappa\left[\alpha S^{1} + (1-\alpha)E^{1}\right]^{1/1} = \kappa\left[\alpha S + (1-\alpha)E\right],$$

which is a linear function.

The Technical Rates of Substitution of the two indicate this in case of two input factors:

$$TRS_{CES} = -\frac{\partial f / \partial x_1}{\partial f / \partial x_2} = -\frac{1/\rho\left[a_1 x_1^{\rho} + a_2 x_2^{\rho}\right]^{(1/\rho)-1} \rho a_1 x_1^{\rho-1}}{1/\rho\left[a_1 x_1^{\rho} + a_2 x_2^{\rho}\right]^{(1/\rho)-1} \rho a_2 x_2^{\rho-1}} = -\left(\frac{x_1}{x_2}\right)^{\rho-1}$$

When ρ approaches zero, $-\left(\frac{x_1}{x_2}\right)^{\rho-1}$ approaches $-\left(\frac{x_1}{x_2}\right)^{-1} = -\frac{x_2}{x_1}$

This is the TRS for the Cobb-Douglas function:

$$TRS_{CD} = -\frac{\partial f / \partial x_1}{\partial f / \partial x_2} = -\frac{a_1 \alpha x_1^{\alpha-1} a_2 \alpha x_2^{1-\alpha}}{a_1 x_1^{\alpha} (1-\alpha) a_2 \alpha x_2^{-\alpha}} = -\frac{\alpha}{(1-\alpha)} \frac{x_2}{x_1}$$

2. The Leontief production function can be regarded as a special case of the CES-function.

TRS for the CES-function is given by $TRS_{CES} = -\left(\frac{x_1}{x_2}\right)^{\rho-1}$ and as ρ approaches -∞, TRSCES approaches $-\left(\frac{x_1}{x_2}\right)^{\infty}$. If x2> x1 the TRSCES is zero and if x2< x1 the TRSCES is infinite.

Consequently, as *ρ* approaches -∞, the CES isoquants look like the isoquants associated with the Leontief technology (Varian 1992).

Annex 2: Agenda for 1’st BIØKOMODA workshop.

Institute of Food and Resource Economic (FOI), Copenhagen, 29-30 November 2004

Agenda

Monday, November 29

12.00	Introduction to BIØKOMODA
12.45	Lunch
	Presentation and discussion of models:
	Hans Frost (EIAA model), Ragnar Arnason (Review of models)
15.00	Break
15.15	Presentation and discussion of models:
	Christen Sørensen, Hilmar Ogmundsson and Morten Sommer (SIMGREEN)
	Arne Eide and Ola Flaaten (ECONMULT)
Tuesday 30 November	
09.00	Synthesis report of 2002 Conference on Fisheries Economics
	Data availability and application
10.00	Break
10.15	Constructing a consensus management model for Nordic countries
	Future work plan
	Conclusion of the meeting

Participants at the 1st BIØKOMODA Project Meeting

Name	Country	Affiliation	Admin istration	Econ omist	Biol ogist	Industry
Christen Sørensen	Greenland	University of Southern Denmark		x		
Hilmar Ogmundsson	Greenland	University of Southern Denmark		x		
Morten Sommer	Greenland	University of Southern Denmark		x		
Arne Eide	Norway	Norwegian Fisheries College, University of Tromsø		x		
Per Sandberg	Norway	Fisheries Directorate, Bergen		x		
Hans Frost	Denmark	Institute of Food and Resource Economics		x		
Erik Lindebo	Denmark	Institute of Food and Resource Economics		x		
Kjartan Høydal	UK	NEAFC	x		x	
Ragnar Arnason	Iceland	University of Iceland		x		
Jarno Virtanen	Finland	Finnish Game and Fisheries Research Institute		x		
Anders Carlberg	Sweden	Swedish Fisheremen's Association				x
Marianne Raben Olrik	Denmark	Danish Fishermen's Association		x		x
Hans Lassen	Denmark	ICES			x	

Presentations at the 1st BIØKOMODA Project Meeting

1. Hans Frost (EIAA model)
2. Ragnar Arnason (Review of models)
3. Arne Eide (ECONMULT)
4. Hilmar Ogmundsson and Morten Sommer (SIMGREEN)

Annex 3: Agenda for 2'nd BIØKOMODA workshop

Hotel Hvide Hus, Køge, November 27-29 2006

Agenda

Monday, November 27

13.30	Welcome, introduction and resume of last meeting		Jan Tjeerd Boom (FOI)
14.00	General introduction to bioeconomic models		Hans Frost (FOI)
15.00	An overview of some bioeconomic models		
	15.15	TEMAS	Clara Ulrich-Rescan (DIFRES)
	15.45	Icelandic model	Olafur Klemensson (Central Bank of Iceland)
16.15	break		
	16.30	SRRMCF	Anna Jonsson (Swedish Board of Fisheries)
	17.00	EIAA/BIF	Hans Frost (FOI)
17.30	Bioeconomic models in fishery policy		

Tuesday, November 28

09.00	Production function
10.30	break
10.45	Behavior of fishers
11.45	Indicators
12.45	Lunch
13.45	Mixed fisheries
14.45	Discard
15.45	break
16.00	Monitoring and enforcement
17.00	Price flexibility
18.00	Dynamics

Wednesday, November 29

09.00	Social consequences
10.30	*break*
11.00	Summary and conclusions
13.00	Closure

Subjects for discussion:

- *Bioeconomic models in Fishery Policy*
  The goals of bioeconomic models are to gain insight into fisheries and to advice policy makers on fishery policy. Then what output should bioeconomic models of fisheries be able to produce and how can we produce that output?
- *Production functions*
  The production function is the central equation in a bioeconomic model. Depending on the type of model, the production function translates inputs into outputs or vice versa.
- *Behavior of fishermen*
  What is the behavior of fishermen and how can it be captured in the model.
- *Indicators*
  The advice given to policymakers should be easily understandable. Here, some simple indicators could be helpful. What kind of indicators would be useful and how can bioeconomic models provide those.
- *Mixed fisheries*
  In most fisheries, more than one type of fish is caught. How can one model fishing activities under these circumstances. A related issue is, how fishermen can alter their behavior to diminish the catch of certain species.
- *Discard*
  Discard is one of the focal points of policy. How can discard be modeled in bioeconomic models?
- *Monitoring and enforcement*
  Should monitoring and enforcement costs be included in the model and if so, how
- *Price flexibility (price elasticity)*
  Changes in output can lead to changes in prices. The price changes are typically found by using price flexibilities (or price elasticities). How are price flexibilities used in the model and what are they based on?
- *Dynamics*
  A major issue is the interaction between fishing activities and fish stocks over time. This is especially important when one wants to consider how to bring back fish stocks to sustainable levels. How can such dynamics be modeled and how realistic are the outcomes?
- *Social consequences*
  Most bioeconomic models focus on the direct effects of regulation on fishing fleets and stocks. However, other effects could be included as well. Examples could be the effect on the fish processing industry, effects on unemployment in regions with fishing activity, etc.

Participants at the 2nd BIØKOMODA workshop

Name	Country	Affiliation	Admin istration	Econ omist	Biol ogist	Industry
Miguel Ángel Peña Castellot	Belgium	DG-Fish	x			
Alberto Spagnolli	Belgium	DG-Fish	x			
Tobias Kerrn-Jespersen	Denmark	Baltic RAC				
Marianne Raben Olrik	Denmark	Danish Fishermen's Association				x
Clara Ulrich Rescan	Denmark	Danish Fisheries Research Institute			x	
Jan Tjeerd Boom	Denmark	Institute of Food and Resource Economics		x		
Jesper Levring Andersen	Denmark	Institute of Food and Resource Economics		x		
Thomas Thøgersen	Denmark	Institute of Food and Resource Economics		x		
Ayoe Hoff	Denmark	Institute of Food and Resource Economics		x		
Hans Frost	Denmark	Institute of Food and Resource Economics		x		
Jarno Virtanen	Finland	Finnish Game and Fisheries Research Institute		x		
Soile Kulmala	Finland	University of Helsinki		x		
Carl Christian Schmidt	France	OECD		x		
Michael Kingsley	Greenland	Nature Institute			x	
Karen Bjarney Johannsdottir	Island	University of Iceland		x		
Sveinn Agnarsson	Island	University of Iceland		x		
Olafur Klemensson	Island	Central Bank		x		
Anna Jonsson	Sweden	Swedish Board of Fisheries		x		
Staffan Waldo	Sweden	SLI		x		
Lars-Christian Sørensen	Denmark	Master student		x		
Kim Bjørn Nielsen	Denmark	Master student		x		
Søren Eliasen	Denmark	Institute of Fisheries Management		x		

Presentations at the 2nd BIØKOMODA Project Meeting

1. Hans Frost (FOI) (General introduction to bioeconomic models)
2. Clara Ulrich-Rescan (DIFRES) (TEMAS)
3. Olafur Klemensson (Central Bank of Iceland) (Icelandic model)
4. Anna Jonsson (Swedish Board of Fisheries) (SRRMCF)
5. Hans Frost (FOI) (EIAA/BIF)