

EXISTING BIOECONOMIC MODELS REVIEW

Raúl Prellezo, AZTI-Tecnalia, rprellezo@azti.es
Paolo Accadia, Irepa Onlus, paoloaccadia@tiscali.it
Jesper Andersen, FOI, jla@foi.dk
Bo Andersen, DTU-AQUA, bsa@aqua.dtu.dk
Erik Buisman, LEI, Erik.Buisman@wur.nl
Alyson Little, CEFAS, alyson.little@cefas.co.uk
Rasmus Nielsen, DTU-AQUA, rn@aqua.dtu.dk
Jan Jaap Poos, IMARES – Wageningen UR, janjaap.Poos@wur.nl
Jeff Powell, LEI; Jeff.Powell@wur.nl
Christine Röckmann, IMARES – Wageningen UR, Christine.Rockmann@wur.nl

ABSTRACT

The lessons learned from a review of thirteen bio-economic models are presented. We describe and analyze how these models equal/ compare and differ in terms of the classification, their biological and economic modules, the integration between modules, the indicators they provide and indicator use. We pay particular attention to the relevance of each model as well as how a model is built, concluding that, even if the number of models is huge, the multitude of construction differences reflects the necessity of individual modelling approaches giving answers to different questions. Since real life questions in fisheries are so divers, answering them require a diversity of models.

Keywords: Fisheries; Bio-economic models; Review.

INTRODUCTION

Economy is one of the conditioning factors of fishing activity. The fish, i.e. the biological resource, can exist without the fishery, but the fishery cannot exist without fish, and what is more, there is an obvious economic interest in exploiting the biological resource. Economic analysis of the exploitation of natural resources applied to the fisheries is a relatively recent branch of economics. This speciality is known as bio-economics, and has developed since the end of the 1950's from the works of Gordon and Schaefer (Gordon 1953; Gordon 1954; Schaefer 1957).

There is a growing interest in using bio-economic models (BEM) as a tool for policy analysis to better understand pathways of development and to assess the impact of alternative policies on the natural resource base and human welfare. One of the potential benefits of these models is that one can get a better and more comprehensive indication of the feedback effects between human activity and natural resources. Modern computer power permits development of complex models far beyond what was possible only a few years ago. It has therefore become possible to make models that are theoretically more consistent and empirically more accurate.

The need to combine biology and the economics of fisheries comes from the external factors impacting on both. There is a link between the resource and the resource user that – in a simplistic way – can be seen as the fishing mortality coming from the extractive activity (even if it is broader than this). Due to this link, the external factors affecting the biological side (eg. nutrients, predators) will also impact the economic side of the system. It works also the other way around: External factor affecting the economic side (e.g., management, fuel costs) will also impact the biological side of the system. In other words the necessity of a BEM comes from the fact that both sides (biology and economy) are interrelated.

Fundamentally, a BEM is a numerical representation of biological and economic systems and is typically depicted by an economic and biological sub-model. The biological sub-model represents the natural resource (fishery/stock) whilst the economic sub-model characterizes resource users (fisher/vessel/fleet/market).

Modelling the link between fleet dynamics (catchability) and fishing mortality is critical and particularly challenging. Model complexity is predominantly driven by the underlying assumptions, data availability, relationships, interactions and feedback mechanisms.

Worldwide there is too huge a list of operational models to tackle the review of them extensively. There is also an extensive list of papers, reports and books dealing with the theory and applications of bio-economic models. Of note are the seminal paper by Smith (Smith 1969) and the most recent book by Grafton et al. (Grafton 2008).

Fisheries bio-economic models reviews are not very common in the literature. Mentionable are the review made by (Bjørndal, Lane et al. 2004) including also aquaculture, the review made by the Scientific, Technical and Economic Committee for Fisheries (STECF) of the European Union (EU) reports (SEC 2006) and (SEC 2006) and a recent review of Nordic fisheries operational models (Tjeerd-Boom, Frost et al. 2008).

There have been attempts to provide guides for bio-economic modelling, as in (FAO 1998), where apart from a review of the bio-economic theory, the ALLOC operational model is reviewed and explained. A review of models (case specific models) is also made in (Conrad 1995), and there is also a review of bio-economic models with environmental influences performed in (Knowler 2002).

In this paper we present the lessons learned from reviewing thirteen bio-economic models, namely AHF, BEMMFISH, BIRDMOD, COBAS, ECOCORP, ECONMULT EMMFID, FLR, EIAA, MEFISTO, MOSES, TEMAS and SRRMCF (see Table 1). These lessons derive from the work carried by a contract between the authors and the EU Commission (Prellezo et al. 2009).

MODEL CLASSIFICATION

Bio-economic models can be classified into two categories, simulation (what if) or optimization (what's best). Simulation models strive to simulate a system by projecting a set of biological and economic variables or parameters into future scenarios to evaluate alternative management strategies. Optimization models are designed to find an optimal solution of an objective function under certain economic and/or biological constraints. The objective function is to be maximized when looking at e.g. revenue, profit, harvest, days at sea, employment, fleet size, welfare, or minimized when looking at e.g. costs. The constraints can be e.g. limitations on quota, days at sea, biological stock status, effort distribution, catch dynamics or parameter values. Normally constraints are constructed by using inequalities instead of equalities. In that sense the restrictions define a flexible area, and a solution is found within this area, given a pre-defined objective. Simulation models rely on the same set of boundaries and parameter values, but these can be seen as a set of rules that determine the dynamic consequences of a fishery.

All models reviewed, with the exception of MOSES, are able to conduct simulations (see Table 1), while in some models (EIAA, EMMFID, FLR, SRRMCF) it is possible to conduct both types of analyzes. What function is optimized varies per model, possibilities include profit, harvest, sea days, number of vessels, value added, and employment. With respect to the simulation models, all are capable of assessing management policies and many include economic indicators. Incidentally, some of the simulation models include optimizing routines, although their overall objective is not to maximize or minimize a particular objective function. For instance, in some of the FLR based models there are routines to maximize catch given harvest control rules, but the intent of these models is to simulate rather than optimize the economic performance of the fishery in question.

Consideration must be given to model orientation (see Table 1), that is, whether the fishery is input (effort, gear restrictions, area closures) or output driven (quota, catch composition, minimum landing size). There are operational differences concerning the data requirements of input and output orientated models. Input driven models demand data resolution at the level of vessel activity or assimilation of technical characteristics such as mesh size or gear attributes. In contrast output driven models must comprise of quota or catch data. Bio-

economic models BIRDMOD, BEMMFISH, COBAS and MOSES solely model input controlled fisheries, the remaining models encapsulate both input and output regulated fisheries.

Bio-economic models are developed to capture either short-run (i.e. fleet and population dynamics) or long-run structural behaviour (i.e. investment or entry/exit decisions) on a temporal or spatial scale. Furthermore, bio-economic models can be classified as either deterministic, or stochastic through implementation of uncertainty (process, observation, estimation, model or implementation error).

Table 1. List of models reviewed, type and orientation

Acronym	Name	Type (T) and Orientation (O)	Fishery	Based on an assessment model
AHF	The Dynamic Capacity Change Model	T: Simulation O: Input / Output	Atlantic	Yes
BIRDMOD	Methodological Support for a Bio-economic Model of Population Analysis of Demersal Resources	T: Simulation O: Input	Atlantic	No
BEMMFISH	Bio-economic Modelling of Mediterranean Fisheries	T: Simulation O: Input	Mediterranean	No
COBAS	A Dynamic bio-economic model of the fisheries of the South West to determine the costs and benefits of sustainable fisheries management	T: Simulation O: Input	Atlantic	No
EcoCoRP	Economic effects of the cod recovery plan on the mixed fisheries in the North Sea.	T: Simulation O: Input / Output	Atlantic	Yes
ECONMULT	Bio-economic multispecies model of the Barmet Sea fisheries	T: Simulation O: Output / Input	Atlantic	No
EIAA	Economic Interpretation of ACFM advice	T: Simulation O: Output / Input	Atlantic	Yes
EMMFID	Economic Management Model of Fisheries in Denmark	T: Optimization or Simulation O: Output / Input	Atlantic	No
FLR	Fisheries Library in R	T: Simulation O: Output/input	Atlantic and Mediterranean	Yes
MEFISTO	Mediterranean Fisheries Simulation Tool	T: Simulation O: Input / Output	Mediterranean	Yes
MOSES	Models for Optimal Sustainable Effort in the Seas	T: Optimization O: Input	Mediterranean	No
SRRMCF	Swedish Resource Rent Model for Commercial Fishery	T: Optimization (Simulation possible) O: Output / Input	Atlantic	No
TEMAS	A fleet-based bio-economic simulation soft-ware for management strategies accounting for fishers behaviour	T: Simulation O: Output / Input	Atlantic	Yes

The structures of bio-economic models generally reflect the main features of the fisheries under analysis. Fisheries in the EU are very heterogeneous. Single species and multi-species fisheries, pelagic and demersal fisheries, single gear and multi-gear fisheries need different modelling approaches. Moreover, different management regimes are in force in different areas. The modelling approaches used to simulate the effects of output control measures, like Total Allowable Catch (TAC), diverge substantially from those used to simulate input control measures, like fishing effort limitations, or technical measures, like mesh size restrictions or area and season closed. Perhaps surprisingly, many features of the models are not, in principle, specific to a particular area, perhaps indicating that aspects of these models share similar algorithms. That said, the models do vary widely as to the scale used, with some models driven by a single target species and a majority applicable to a mix of species, depending on the type of fisheries analyzed. This is not surprising given the wide diversity in the number of target species facing European fisheries. In addition, most of the models are not bound to yearly steps, but are flexible in terms of the time periods over which they can be applied. The sophistication of the biological components varies greatly across models. Many of the models include routines for stock recruitment, growth and maturity, but few provide a complete biological overview; the only exception being one version of the EIAA model. Four models, SRRMCF, ECONMULT, EIAA and EMMFID, provide no biological information, but are used in combination with historical catch data or separate biological models.

THE BIOLOGICAL MODULE

Availability of stock assessment

Bio-economic models in fisheries can focus on a single species or multi-species (also in sequential fisheries) depending on the assessment they are provided. In either case, they require at least some measure of the stock(s)' evolution. The situations where stock assessments are available and those where they are not, should be distinguished.

Stock assessment is available for the main species

That stock assessment is available has the advantage that it allows a deep (but not always complete) understanding of the stock dynamics. Approaches to the treatment of the "biological box" differ greatly among models and range from simple surplus models to complex age and/or size structured models normally based on Virtual Population Analysis (VPA) (Cushing 1981). There is a large diversity among the models reviewed in type of biological module. Some of them are oriented towards giving advice for a single, primary stock and thereby largely ignoring interactions with other stocks. Other models evaluate several stocks, e.g. stocks included in a mixed fishery. This can be in form of several single species assessments (multi-stock) or assessments taking into consideration biological interactions between stocks such as predation (multi-species models, e.g. MSVPA) (see review of ecological models in (Plagányi 2007)).

Some models have an actual biological module where they perform a population dynamic evaluation, e.g. separate VPA or cohort analyses, i.e. integrate a stock assessment, inside the model itself, while other models simply use input from separate biological models and lift in output such an external assessment-model. A trade off appears to exist between the generality and the complexity of the models. For example SRRMCF, EIAA, ECONMULT and EMMFID do not have a biological module. They are designed for advising, providing scenarios given a catch or/and a TAC as advice to the overall fishing sector of one country and the overall ICES Advisory Committee (ACFM or ACOM) advice affecting EU fleets, respectively. ECONMULT has been used in combination with two biological models, MULTSIMP and AGGMULT. BIRDMOD has its own biological model component ALADYM (Age Length Based Dynamic model). Some other models present limitations in terms of the dimensions they are capable of handling. The BEMMFISH model is a paradigmatic example, a maximum of 4 species and 3 fleets can be conditioned. On the contrary there are models whose strength lies in among other the biological component (FLR based models and BIRDMOD with ALADYM, for example).

There is a clear distinction between Atlantic and Mediterranean oriented models. The source and type of these assessments are case dependent, originating from the relevant body. The link between the economic module and the biological stock assessment is direct in respect of the biological assessment itself is directly made and included within the actual model. The FLR can for example, simulate alternative assessments, and simulate the full procedure of assessments carried out by different bodies. Additionally, TEMAS can operate an independent VPA, i.e. it does not directly require an assessment, but it does require the estimation of typical biological parameters. EcoCoRP has similar requirements, but in this case the assessment is based on the MSVPA. The EIAA and the EMMFID models require only the output of an external assessment, and the link with the bio-economic module is made through the TAC advice and Spawning Stock Biomass (SSB). MEFISTO is an exception for the Mediterranean oriented model since it requires biological assessment. The rest of the models, including those oriented towards the Mediterranean, are not linked to an assessment. This does not necessarily imply that biological parameters are not required. In fact, BIRDMOD, MOSES and BEMMFISH require a certain extent of biological data).

No stock assessments are available

In case no stock assessment is available, some models do require a certain level of data for at least one of the species considered (MEFISTO) and others do have limitations in terms of the number of species that can be incorporated (BEMMFISH). Other alternatives are the use of a surplus model (time series of catch and effort are collated to construct a dynamic projection model) or the division of species into main species and secondary ones, where the latter are just a proportion of the main species. Other possible solutions are random realizations of past abundances and landings.

As concerns the distinction between target and non-target species, usually landings are used as a proxy to determine future catch compositions. Selecting the complexity of the model is another solution. Normally models allow using a simpler surplus model for the non-target species, which requires parameterization. In all of the models analyzed some knowledge of the accompanying species is required. The least data demanding situation is the case in which only the landings composition of the fleets is required, even if such an approach assumes that availability of the landed species is not limited and that the fleets will not change catch composition. In the short term this can be a reasonable assumption, but in the long term it can cause problems. A small improvement is to consider the catch composition as stochastic. Finally, the rest of the solutions are more data demanding and require previous estimations or at least an endogenous biological module to perform those estimations given a time series of effort and catches (cf. MOSES).

Link with stock assessment system

Another important issue is the link that a model has with the system that provides the biological assessment. The most complex link is the direct one, that is, when the model itself incorporates the assessment system of the stocks. The main advantage of this kind of model is that it can incorporate all the uncertainties arising from the biological system. A less complex biological module is when the model requires the assessment of the stock but only to parameterize the “stock box”, e.g. obtained from an externally performed biological assessment. Finally, there are other models that parameterize the biological module just using a limited number of parameters and data types such as landings, effort or an initialization biomass. In the latter case, the model is not based on an actual stock assessment even if a preliminary assessment could be required for obtaining an initialization biomass.

THE ECONOMIC MODULE

The structures of European bio-economic models can be very heterogeneous. Despite this, three economic components can be considered common to all models: fleet and effort dynamic, price dynamic and costs dynamic. In addition, there is a fourth component, the landings dynamic, which can either be modelled using a biological or economic approach.

The incorporation of these components in bio-economic models and the approaches used for simulating their dynamics through time depend on many factors. However, model's purposes, data availability and their structure, and the features of the fisheries under modelling can be considered as the main drivers in the modelling process.

The type of model can determine the relevance of each economic component and the approach used for its implementation. Furthermore, input or output driven models (which reflect the management regimes in force in the fisheries under modelling) show different model structures. Input variables in one model can be outputs in another model. This affects the choice of the functional forms adopted in the economic components.

Production functions for landings dynamic

The inclusion of landings dynamic in a bio-economic model depends on the management system implemented (or potentially implementable) in the fisheries under modelling. Where output restrictions, like TAC or other quota regimes, are in force, landings (equivalent to quotas) dynamic are usually defined by harvest control rules (HCR). In these fisheries, the levels of TAC represent generally an input to the bio-economic models. This is commonly true in models like EIAA and AHF developed for the fisheries in Northern European countries. On the contrary, in Mediterranean fisheries, where the management system is mainly based on input restrictions, landings dynamic represents an endogenous component of the model.

Where landings or catches dynamic is incorporated in the model, this is simulated by either a biological or economic approach. However, there are also models, like BIRDMOD, adopting both biological and economic sub-models depending on the data available by species. As biological models are very data demanding, the use of production functions or surplus production models represents an acceptable alternative for reproducing landings dynamic when biological data are not available. This is particularly true in multi-species fisheries where biological data are available only for a limited number of stocks.

The Cobb-Douglas function (Cobb and Douglas 1928) is used in models like AHF, ECONMULT and EMMFID to estimate the level of landings, while BEMMFISH uses a Cobb-Douglas function to estimate the fishing mortality.

A different approach based on logistic models is adopted in MOSES to estimate the level of landings in the long term given a constant level of fishing effort. The use of the equilibrium Schaefer (Schaefer 1954; Schaefer 1957) or exponential (Fox 1970) model is suitable for optimization models to find optimal solution in the long term.

Even though different approaches are available to simulate landings dynamic, these need a minimum data set to be adopted. When data on some species do not exist some ad hoc solutions have been suggested by models developed for the Mediterranean fisheries. In particular, BIRDMOD uses a modified Schaefer model to estimate landings dynamic for the group of species not included in the biological module. MEFISTO uses a linear or an exponential relationship between the landings of secondary species and those of the target species.

Price dynamic

In bio-economic models fish prices are generally differentiated by species and by fleet (or fleet segment). The price of a species can be affected by fleet nationality (production can be sold at different prices in different countries) and by the fishing gear used by the fleet (fishing gears determine differences in the quality and size of the product and hence in its price). However, when differences in prices related to the fleets are negligible, the same price can be used for the total landings of a stock.

Fish prices can be assumed either constant or variable. Generally a constant price is assumed in the optimization models, like MOSES and EMMFID. These models estimate optimal solutions in the long term. On such time horizon, price dynamic can be affected by a number of exogenous factors which cannot be suitably incorporated in a bio-economic model. On the contrary, year by year projections produced by simulation models generally incorporate potential changes in fish price. However, depending on the features of

the fisheries under analysis, different functional forms and different independent variables can be used in price functions. Almost all simulation models simulate price dynamic by using elasticity functions where fish price is depending on the level of landings given a price flexibility coefficient. Exceptions are represented by ECONMULT where a linear relationship between price and landing is used and MEFISTO where, in addition to the level of landings, also the average weight of the fish and the level of imported product are used to simulate price dynamic.

Fleet and effort dynamic

The distinction between long term and short term decisions in fisher's behaviour is incorporated in most of the bio-economic models reviewed. Long term decisions are generally simulated by investment/disinvestment functions, which can be directed to buy a new vessel (increasing the fleet size) or improve the efficiency of the existing ones (investments in technology). Short term decisions can be seen as tactical adaptations producing variations in fishing effort. For instance, changing the number of fishing days or their duration in hours, changing the fishing area and switching among different fishing gears (for polyvalent vessels) can be considered as short term decisions. Different approaches have been used to incorporate fleet and effort dynamics. Some of the models allow the possibility for fishers to adjust their behaviour to different target species, but very few allowed fishers to change fishing grounds or gear, perhaps reflecting either the complexity of modelling such changes or certain well-established patterns of behaviour.

As for the fleet dynamics, the main approaches are rules based on a qualitative approach, as a function of profits or by optimization. A qualitative rules-based approach consists of the use of a set of rules for defining the probability for vessels to enter a fleet, to remain within that fleet or to exit the fleet. For example, AHF includes the possibility to transfer the vessel to another fleet by selling it in the second hand market as an alternative to the decommissioning.

The use of specific functions based on profits to simulate fleet dynamics has been applied in the models for Mediterranean fisheries. An elasticity function where fleet size depends on the last two years' variations in profits is proposed in BIRDMOD. Also the approach adopted in MEFISTO is based on the level of profit. When profits are positive the firm will make further investment. On the contrary, when profits are negative the vessel may leave the sector. In BEMMFISH the number of vessels is estimated as a linear function of profits. Investments are calculated as a percentage of profits both in MEFISTO and BEMMFISH.

The optimization approach is based on the micro-economic theory where fishers are expected to maximize profits by setting an optimal level of fishing effort. Even though fishermen do not act to optimize effort, policy makers should do it. Optimization models, like MOSES, have been developed to advice policy makers on the optimal levels of effort and capacity. Following this approach, the number of vessels in a fleet is obtained as an output from the model.

Fishing effort is calculated as the product of two components: capacity, expressed in terms of number of vessels, gross tonnage or engine power; and activity, expressed in terms of days or hours at sea. Variations in capacity are simulated in bio-economic models by the approaches reported above. Variations in activity are related to short term decisions, which can change the spatial/temporal allocation of effort units.

BIRDMOD uses this approach to simulate variations in capacity and activity: An elasticity function is applied where the total number of days at sea depends on the last two years' variations in profits and a flexibility coefficient.

Costs dynamic

Based on the needs of the analysis and the structure of the model's outputs, costs are differentiated by fleet or fleet segment. The only exception is represented by MEFISTO where costs dynamic is simulated for each of the vessels involved in the fisheries.

While costs dynamic is simulated by using linear functions in all the models reviewed, differences can be found in the level of detail used to represent and include the fleet costs structure. A minimum approach consisting in the differentiation between fixed and variable costs, is adopted in AHF, BEMMFISH, ECONMULT and MOSES. Fixed costs are supposed to be constant through time or depending on fleet capacity expressed in terms of number of vessels or GT, while variable costs dynamic is generally associated to variations in fishing effort.

Other models use a more detailed approach where specific cost components are extrapolated from fixed or variable costs and simulated by specific functions. Among these components, crew share (or labour cost), commercial cost, fuel cost and capital cost are specifically simulated in many models.

The simulation of the labour cost is particularly relevant to estimate the effects of management measures from a social point of view. This variable allows some social indicators, like the average salary per man employed, to be evaluated through time. In the models developed for Mediterranean fisheries, like BIRDMOD and MEFISTO, the labour cost is estimated as a percentage (generally equal to 50%) of the difference between revenues and variable costs (including fuel costs), while in the other models it is generally calculated as a percentage of revenues. This is due to the prevalence of different work contracts in different European regions.

Commercial costs (related to the operations of selling) are normally estimated as a linear function of revenues. An exception is represented by the use of total landings instead of revenues in BIRDMOD.

Fuel cost represents the most relevant cost item in fishing activity for most of the European fleets. Recently, significant increases in fuel price have represented one of the most critical factors for the profitability of fishing activities. Calculating fuel cost as the product of fuel consumption and fuel price allows bio-economic models, like ECOCORP and MEFISTO, to estimate the effects of potential variations in fuel price.

Capital costs represent the costs associated to the use of capital. These are explicitly simulated in ECOCORP and MEFISTO by linear functions of the capital value.

INTEGRATION

The manner in which the biological and economic subcomponents of fisheries models are linked is crucial to the success of a fisheries model. Fish production arises from the application of labour and capital to the natural resource in a fishery. This fishery system comprises a dynamic interplay between the biological part of the system and the economic part. Integrating different disciplines allows us to take into account possible feedbacks between the biological and economic components. If those feedbacks within a fishery system are disregarded, there is a danger that the analysis of fisheries will be at best misleading and at worst incorrect (Cunningham 1985).

Changes in an economic variable will affect fishing mortality through modifications of fishing behaviour; and fishing mortality directly affects the stock size and ultimately stock dynamics in the biological component. Vice versa, changes in a biological variable will affect stock size and translate into changes in fishing mortality and in turn effort and catchability, thus ultimately affecting fishing behaviour. Hence, in modelling language, the core integration node that connects feedback loops between fisheries biology and economy is fishing mortality.

Depending on model objectives, the types and amount of feedback incorporated in a model vary with the structure of the individual model sub-components; feedback loops are thus model specific. On the biological model side, fishing mortality reflects the decrease of the stock size due to fishing; from the economic point of view, fishing mortality links to revenues through the value of the landings as well as to the costs of the fishing operations. Fishing mortality is a resultant of the applied fishing activity that depends on various economic input factors such as vessel size, power, applied gear, fishing time, etc. The degree of effectiveness of the

applied activity depends in turn on biological characteristics of the targeted fish species and stocks, e.g. the amount of fish in the sea, but also whether the fish is homogeneously distributed in the water or concentrated in schools, when fished. Following that we find models with or without full, cyclic feedback between and within the components of the biological and economic modules. For example AHF and ECONMULT are able to implement two management regimes such as the effort limitation and TACs (whatever is binding) by affecting the biological component.

Of the 13 bio-economic models reviewed, 4 were actually purely economic (ECONMULT, EIAA, EMMFID, SRRMCF). The feedback considered on the economic side is remarkable, looking at how a change in employment, rent, capital use subject to environmental/biological constraints affects fleet size (number of vessels) or fleet activity (number of days at sea). The biological side is restricted to basic catch input, estimated or derived from ICES stock assessment output. ECONMULT can be coupled to a separate biological model, AGGMULT, to account for biological feedback. The remaining nine have both an economic as well as a biological component. The degree of feedback in both compartments varies, depending on the model objectives and degree of model complexity.

With respect to the biological side, the biological situation of the targeted fish stock(s) represents the core part. In data-poor stock situations, mostly a surplus production function is applied to estimate stock biomass, depending on growth and mortalities. In settings with more detailed biological data, usually a standard equation of fish population dynamics is applied, assuming exponential decay of fish (in numbers, structured by age or length), linked to the classical “Baranov catch equation” that describes the output from the stock as a function of natural and fishing mortality and stock numbers. There are various possibilities to account for growth and recruitment.

On the economic side, the crucial endogenous variable is fishing effort where effort is defined in terms of, simply, the ability of a fleet or ship to catch fish. For instance, all else equal, a fleet with engines producing more power will have the ability to exert greater effort. There are different ways of relating fishing effort to a particular fishing mortality (in turn determining catch). The type of relationship depends, for example, on the particular gear and mesh size characteristics, but it is also strongly affected by the biology, e.g. the life history of the target fish species, or by stock age structure. These factors thus influence the “catchability”. Catchability appears in different types, either as a parameter, as an exogenous variable, or as an endogenous variable. In the models surveyed, effort is generally taken into account in a linear relationship with catch, i.e. a doubling of effort, all else equal, will lead to a doubling in catch. This simplifying assumption is replaced in some of the models by a Cobb-Douglas production function in which inputs can be substituted.

However, the catch in itself is only a proxy of the economic output, which is mostly determined by the landings, being the total catch minus a part of this, which e.g. is thrown overboard for reasons of economy and legislation. EIAA, TEMAS, AHF, ECOCORP and EFIMAS are designed to be able to account for discarding, and these models can thus be applied to analyse the effects for example of a discard ban.

Finally the link between components is made at the lowest common denominator. For instance, as shown above, many of the economic components can be disaggregated to the ship level, however, that aggregation is appropriate only if it can be linked to biological data at the same level. All of the models link economic and biological components at the fleet level, some at the metier level (TEMAS, BIRDMOD, MEFISTO, AHF, COBAS, and possibly EMMFID and EFIMAS). Only one model is linked at the ship level (MEFISTO). About half the models are linked at the same spatial dimension and most economic models are resolved at a yearly level. The time horizons of the biological and economic components of all the models generally correspond with one another.

INDICATORS AND REFERENCE POINTS

Bio-economic indicators are the main point of contact between a model and its users. In general, indicators are used to provide evidence as to how well pursued objectives are being achieved. In the case of European

fisheries research, the objectives are generally well-defined because the issues facing these fisheries are similar, which explains why the models considered in this paper produce very similar indicators. The common objectives to all models considered in this paper are to assess and compare the status of one or more stocks with biologically sustainable levels and assess and compare the catch capabilities of fleets that need to remain economically profitable. The indicators included in the models follow from those objectives with the overarching objective of obtaining sustainable fisheries in biological, economic and social terms.

Indicators used in fisheries are defined by the FAO (FAO 1999) in relationship to sustainable development as: "A variable, pointer, or index related to a criterion". Its fluctuation reveals variations in key elements of sustainability, and their position and trend in relation to reference points indicate the present state and dynamics of the system. Indicators provide a bridge between objectives and actions.

Although the models under consideration vary in terms of purpose or emphasis, all of them provide information on four types of indicators, namely, biological indicators, capacity indicators, economic indicators, and sociological characteristics.

Given the overall objective of building sustainable fisheries, it is not surprising that models typically provide biological data on measures of SSB in comparison to the biomass reference points, as well as mortality rates and catches. The capacity characteristics of fleets generally include measures of the catch capabilities of individual vessels including the number of vessels, fishing effort and landings per fleet, vessel productivity, vessel horsepower and gross tonnage. In addition, both biological and capacity characteristics are often available as time series. Economic indicators can be either short-term or long-term. Typical short-term indicators are market price, income, and various profit indicators. Long-term indicators include net present value, return on investment and, less frequently, remuneration of biomass. Social indicators are often limited to measures such as employment, usually measured as full time equivalents (FTE), and crew share. Social interests are not well developed in the models reviewed, and those that are available are closely related to economic indicators and none of the models produce detailed results on the social impact of fisheries policies.

Building sustainable fisheries requires a combined analysis and understanding of all four types of indicators and their interactions. The four types of indicators are complementary which means that indicators lose much of their meaning when analyzed in isolation.

Indicators focused at the vessel level are rare (MEFISTO, EMMFID), while all the models can perform multi-fleet and multi-species analyzes, reflecting the nature of European fisheries. Given the generic structure of economic indicators discussed above, it is not surprising that all of the models include measures of fixed and variable costs, and in many models, prices are variable and include the possibility to adjust them. However, in contrast to the biological components, few of the economic indicators allow the possibility to model uncertainty, perhaps reflecting the belief that such indicators are non-stochastic.

USE AND IMPLEMENTATION OF MODELS

Going from the theoretical setup of a bio-economic model to the actual implementation of this is often a cumbersome and time-consuming process.

The availability of data can restrict what can be modelled in practice, and if sufficient data is not available, assumptions are needed in order to proceed from the theoretical setup. The primary part of the thirteen models covered in our analysis can apply fisheries related economic data collected through the DCR/DCF. Only two models (BEMMFISH and MEFISTO) are using more detailed data, which are not available within the DCR/DCF. Using the DCR/DCF economic data secures that common definitions are used and that the data format is known, thus giving reliable data and easy applicability. However, often other data sources must also be consulted, primarily when collecting biological data. Some biological data may originate from the DCR/DCF as well, but very often the models include data from ICES, ICCAT, NAFO or GFCM working groups. Some models, e.g. EIAA, apply various stock estimates directly, while for instance FLR based models

as well as TEMAS, BIRDMOD and ECOCORP to a varying degree utilise the parameter values related to recruitment, natural mortality etc. The dependency on other data will have an effect on the ease for which updates of a model can be implemented.

In several of the thirteen models, the data collection must be supplemented with estimation of various relationships and parameter values. Often these estimations are only needed the first time the model is empirically setup and not each time new years of the DCR/DCF data become available. However, if the analysed fleets or fisheries are changed, or the circumstances for the fleets or fisheries significantly change, for instance due to management changes, this may require new estimation of the model parameters.

CONCLUSIONS

We have reviewed thirteen bio-economic models and found that they do handle specific tasks for which they were originally created. They are characterised through case studies to address specific management scenarios. However, often a degree of flexibility is built into models to allow appropriate control to adapt the model to address other case studies or management scenarios. The natural and anthropogenic interactions in the marine ecosystems are complex; hence it is challenging to encapsulate the interactions, dynamics and relationships into a model framework.

When a model is built initial recognition must be given to the fisheries management problem because this will dictate the nature of the model developed. In that sense, input-output orientation is highly correlated with the fishery analyzed. In particular all the models developed for providing advice in the Mediterranean are input oriented, as a reflection of the management system existing in this sea. On the contrary, simulation/optimization selection is just a matter of the research question (what if, what's best) but looks like an independent decision which is a prior step to the management problem and responds more to the problem of designing a management option (optimization) or testing it (simulation).

In addition, the distinction between Mediterranean and Atlantic also affects the biological module in which generally speaking Mediterranean models do not have an assessment model integrated (neither an assessment system) while some of the Atlantic models do. It implies that those models not having an assessment model have to solve the biological part using previously estimated biological parameters or using production models. The range of possibilities (solutions) incorporated in the models are even higher when non target (main) species are considered.

Economic modules are fairly well developed, probably because these models have been at a large extent constructed by economists. Optimization models normally consider fixed prices while simulation models adopt elasticity functions to simulate their dynamics.

Integration among biological and economic models has by contrast space for its development. Four of the models do not need it (they are purely economic models) and the remaining models propose production functions that are either linear or of the Cobb Douglas type.

Simulation of fishermen behaviour is not extensively included in the models analyzed. The obvious exception is the capital dynamic (entry-exit, investment behaviour), but even in this case the principles driving the investment functions are not shared among the models. Short term behaviour (changes in gears, areas), reaction to changes in the enforcement system or intensity, and even spatial or temporal management measures are difficult to find in the models and still require some further development.

Indicators for the biological and economic side are extensively provided by the models. However it has to be noticed that the stochastic approach of the biological indicators is in contrast with the deterministic approach of the economic ones. Some of the models also give social indicators, but in general these are closely related to the economic ones (Gross value added, crew share, employment).

Integration is important to avoid discrepancies between the biological and economic advice, coming from the use of different models. Secondly, that a trade off between simplicity and usefulness of the model arise when integrated models are used. Biological and economic assessments are just parts of the same fisheries management advice, and models should work in this direction.

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ACKNOWLEDGMENTS

The work has been carried out under the financial support of the Studies and Pilot Projects for Carrying out the Common Fisheries Policy of the European Commission's Directorate General for Maritime Affairs and Fisheries (under contract FISH/2007/07 – Lot 5).