Short Communication

TEMAS: fleet-based bio-economic simulation software to evaluate management strategies accounting for fleet behaviour

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TEMAS (technical management measures) is a fleet-based bio-economic software for evaluating management strategies accounting for technical measures and fleet behaviour. It focuses on mixed fisheries in which several fleets can choose among several fishing activities to target different stocks in one or several areas. The software combines a management strategy evaluation framework, using a forward-running operating model and a management procedure with a fleet behaviour module simulating both short-term (effort allocation) and long-term (entry/exit) fleet dynamics. The suite of models behind TEMAS can be thought of as an extension of the traditional ICES forecast model. Alternative management scenarios can be compared and evaluated for their bio-economic consequences and robustness to parameter uncertainty. The software is generic and user-friendly, and can be run at several space and time scales.

Keywords: bio-economic simulation, evaluation framework, fisher behaviour, fleet dynamics, management strategies, mixed fisheries.

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Introduction

The decline of many fish stocks has led to a shift in thinking about how fisheries management might be made more effective. The traditional (single-species) biological approach is being supplemented with considerations of fleet economics and dynamics on one hand, and through wider inclusion of measures of uncertainty and errors on the other. Given the complexity, there is a need for models that encapsulate key processes to allow evaluation of management scenarios through simulation. A recently emerging trend has been towards wider use of models referred to as management strategy evaluation (MSE; IWC, 1993; de la Mare, 1998; Kell *et al.*, 2005; Aranda and Motos, 2006). Such models address the whole fisheries management process, including stock assessment and decision-making. Progress is also made towards better understanding of the implementation processes and fleet compliance, although these are still rarely included in routine modelling. Fisheries systems models aim to deal with uncertainty, not only in the dynamics of stocks and fisheries, but also in monitoring and implementation of management measures. However, the models often address stock-based scenarios and pay insufficient attention to the dynamics and economic performance of fleets.

Most mixed fisheries issues can only be addressed through fleet- or fishery-based advice rather than just through stock-based advice (STECF, 2003; Vinther *et al.*, 2004). Fleet-based approaches require explicit recognition of two major features of mixed fisheries: (i) technical interactions between gears, which imply that species cannot be harvested entirely separately, even if proper incentives and management might help reduce unwanted bycatch; and (ii) the flexibility of fishers to adapt their activity to changes in resource, management, or market conditions. Such adaptability implies that fishing practices are not easily captured by a simple mortality-multiplier as used in traditional assessments and predictions. In recent years, considerable effort has been invested in modelling this flexibility in mixed fisheries (Hilborn and Walters, 1987; Holland and Sutinen, 1999; Hutton *et al.*, 2004; Andersen and Christensen, 2006), but the use of these models in MSE is rare.

The TEMAS simulation software combines a MSE and a model of short- and long-term adaptation of fleet behaviour. TEMAS is developed as a flexible, generic tool for the bio-economic simulation of complex mixed fisheries, and follows up on several previous bio-economic, multifleet, multispecies models (Sparre and Willmann, 1992; Ulrich *et al.*, 2002; Sparre, 2003).

Main approach

Simulation models may never be able to capture all the complex interactions in fisheries systems between the marine and the human world. However, they help to integrate the existing knowledge of the various underlying processes into a single platform. In this way, they cannot be used to obtain precise quantitative predictions. They are more useful for comparing mutually the outcome of various scenarios than evaluating the unique consequences of a single one. Therefore, the overall framework of TEMAS has been designed to compare the performance measures of different

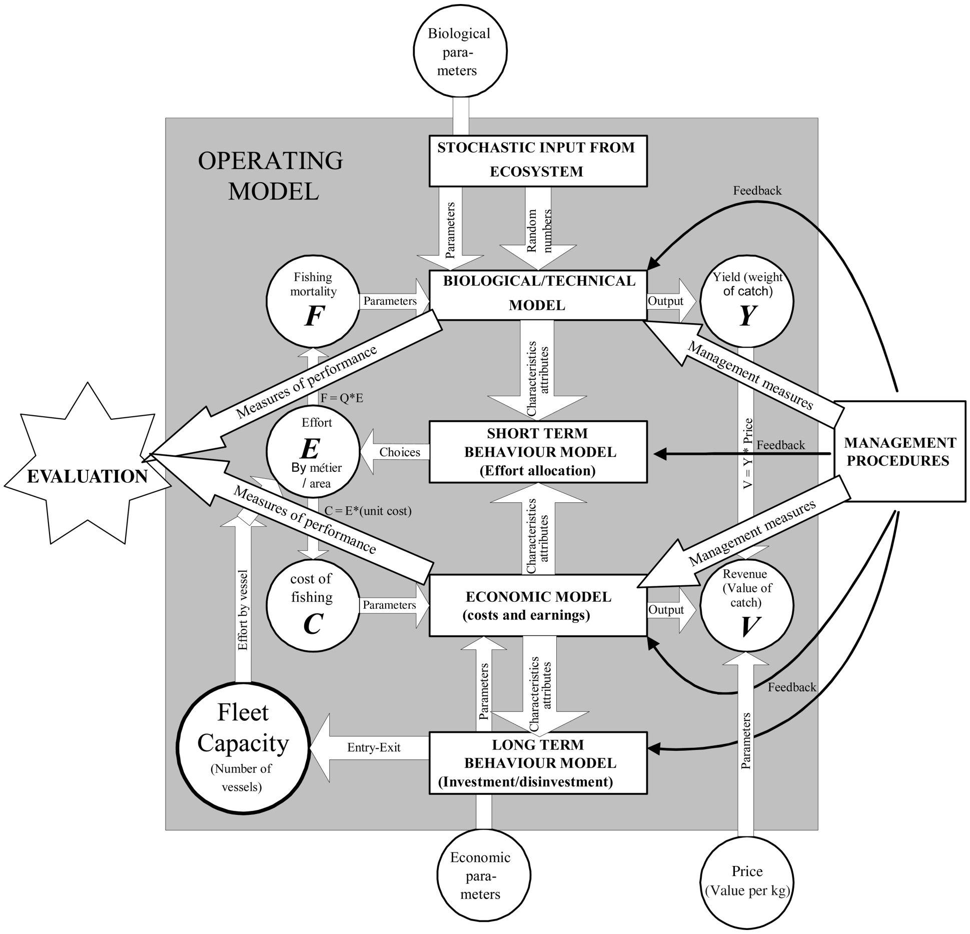

Figure 1. The OM of the TEMAS software.

management regimes using the same set of inputs in the operating model (OM).

The OM simulates the "true" system as it develops according to predefined stock and fleet dynamics (Figure 1). The management procedure (MP) includes data collection with measurement error, assessment of the perceived status of the stock, and application of management controls. This in turn influences the dynamics of the OM at the next time-step (Kell *et al.*, 2006). The suite of models included can be thought of as an extension of the traditional ICES forecast model (Thompson and Bell, 1934).

Since the previous version of the model detailed in Ulrich *et al.* (2002), considerable improvements have been made (Sparre, 2003). A cornerstone is the distinction between the concept of fleets describing physical groups of vessels and the concept of métiers (also called fisheries or riggings) describing the activities (e.g. gear and mesh size used, fishing ground) of a vessel in a fleet during a given period. Therefore, a fleet can engage in several métiers over time and space. Other new features include: (i) a user-defined time-step smaller than 1 y to account for seasonality or periodicity; (ii) spatial disaggregation into areas (boxes) allowing migration processes and fleet effort allocation to be included; (iii) a fleet-adaptation module based on discrete short-term (effort allocation among fisheries and areas) and long-term (entry/exit) choices; (iv) a catchability model to account for potential technical creep and standardization factors (from nominal to effective effort); and (v) a vessel age distribution for potential linkages with fishing power and capacity dynamics. All new features are optional. Several parameters can be assigned probability distributions, so the main error types can be simulated in stochastic runs.

TEMAS is coded in Visual Basic, and uses Microsoft Excel as a convenient and user-friendly interface for data input and export of results (some demonstration source code and further documentation is available at http://www.efimas.org/). The code was designed to be open access and easy to read (despite its length), to support understanding of the key processes included, and to facilitate the development of case-specific code such as new behaviour rules or management regimes.

The operating model

Equations used to model the age- and length-based processes of the biological, harvest, and catch modules are described in Ulrich *et al.* (2002) and Sparre (2003).

Biological module

The growth of juveniles up to age 2 can be specified by quarter or month, rather than by year, as for higher ages. This allows more detailed description of changes in selection during the juvenile phase, the main purpose of many technical management measures. Spatial movements are accommodated using a box model (Quinn *et al.*, 1990), allowing exchanges between areas through instantaneous migration at the end of each time-step.

Effort module

The effort module links all other modules of harvest, economics, and fleet behaviour and can be used for producing an extensive description of fleet structure and dynamics. Capacity is expressed as the maximum number of effort units (e.g. fishing days) that a fleet can exert during a time-step, and is the product of the number of boats multiplied by the maximum effort by each boat. Realized effort cannot exceed the physical capacity.

The inclusion of métiers allows fleets to practise more than one activity in one or several areas during a specified period. The range of métiers in which a fleet can engage is user-defined, but the relative allocation of the total effort of each fleet over the métiers and areas is either fixed or can be varied by period if the fleet behaviour module is used.

Fleet behaviour module

Two modules define the short-term (tactical) and the long-term (structural) behaviour, respectively. The short-term module covers the allocation of effort across métiers and areas for each fleet at each time-step. Effort allocation is expressed by a discrete choice structure, where a choice is defined as a combination of a métier and an area. The effort allocated to each choice is given by the product of the overall effort by fleet multiplied by the probability of selecting a given choice.

The overall effort is either user-defined or derived endogenously according to the various quota shares by fleet and stock, using the so-called Fcube method (ICES, 2006). The choice probability for a given fleet is derived from the theory of the utility-maximizing behaviour, which assumes that a fleet (or a fisher) will choose the alternative that gives the greatest utility among a finite number of alternatives (Train, 2003). This approach, better known as a random utility model, has been applied in several empirical studies modelling trip-based choice behaviour in terms of fishing location and/or métier for individual fishers (Bockstael and Opaluch, 1983; Holland and Sutinen, 1999; Wilen *et al.*, 2002). Similar methodology has been applied to long-term behaviour (capacity dynamics), where the choices for a vessel correspond to entering, staying in, or exiting a fleet annually (Ward and Sutinen, 1994; Pradhan and Leung, 2004).

The observed utility for a given choice is expressed by a set of explanatory variables describing "characteristics" (terms related to the fleet) and "attributes" (terms related to the choice; McFadden, 1974). These variables often include expected profit or revenue, but other factors such as tradition, habit, seasonal variations in resource availability, information flow among fishers, skipper skills, or management regulations may also affect a short-term decision. For long-term behaviour, explanatory variables such as annual revenue, fleet size, biomass index, vessel age, residence of the vessel owner, and captainship may be used. However, including a behaviour model in a fleet-based simulation framework often requires a reduction in the set of choices because of limitations imposed by both temporal and spatial dimensions of the model, and a reduction in the set of explanatory variables because of limitations in data and degrees of freedom. Although information on fleet activities (landings and effort) is often available at a trip and ICES rectangle level through logbook data, biological information is often only available annually at a stock unit and management area level.

The restrictive resolution of the biological component, as well as the aggregation of individual vessels into fleets (reducing the number of observations available), may lead to simplification of the observed utility function to few significant explanatory variables, which can be modelled as state variables in the simulations. Moreover, many important decision factors in the observed utility function cannot be measured directly from traditional fishery data (Smith, 2000), so proxies often have to be used. For example, a reduced set of explanatory variables has been used for the North Sea flatfish fishery, including the average value per unit of effort during the previous time-step (as proxy for economic attractiveness of alternative choices), and information on the fleet's fishing pattern during the previous time-step (as proxy for recent knowledge) and one year earlier (as proxy for seasonality and tradition).

Harvest module

Harvesting relates to both the fleet and the métier by area. The total fishing mortality (F) generated is related to effort, catchability, and age-specific selectivity by métier and area. Selectivity represents the combined effect of gear selection and species availability. F by métier is divided into landings mortality and discard mortality, using length-based discard ogives. The latest developments of the catchability model include optional results of recent analyses on the link between nominal and effective catchability through tactical choices and technical creep (Marchal *et al.*, 2006). An option for an exponential relationship between catchability and biomass (Fox, 1974; MacCall, 1999) has also been implemented.

Economics module

TEMAS allows for an optional number of economics models, each representing a group of stakeholders (fishing industry, government treasury, society, etc.). The economics module is adapted from Sparre and Willmann (1992). The core is a microeconomic description of costs and earnings by métier. Variable costs are defined by area to account for spatial differences in, for instance, fuel costs.

The model calculates cash flow (revenue minus costs) and profit for each time-step, and offers a suite of performance measures for the system. A key performance measure is the current net value, equal to the discounted net cash flow. Other measures are resource rent, contribution to gross domestic product, and employment.

Economic incentives are important for short- as well as long-term fleet behaviour. The short-term decisions include tactical adaptations to prevailing conditions as framed by spatial resource availability, spatial differences in the cost structure, prices, and management settings. The long-term decisions are on the strategic choices of entry/exit and on the developments through investments.

The management procedure

The management module contains all steps of the perceived system, from data collection to management. A suite of options is available for pre-prepared evaluations of management regimes. The natural reference for comparison is the current assessment procedure and the current management regime, which are simulated proxies of the true observed regime.

Current assessment procedure

The link between the OM and the MP is made through the sampling procedure, in which samples are taken from the true catches of the OM to provide the catch-at-age matrix used in assessment. The assessment is a simplified virtual population analysis procedure (Ulrich *et al.*, 2002). The user might choose to run an assessment with perfect inputs, or to run an assessment with uncertainty, e.g. based on landings only, with noisy random deviation from the true catches, or with bias.

Current management regime

The current management goal in European waters is to preclude spawning-stock biomass (SSB) falling below a certain limit reference point. The current regime is a case-specific combination of a set of management measures implemented to reach this goal. For many stocks, precautionary levels of F have been specified (F_{PA}), which in practice are used as management objectives (F_{target}). The simplest model is to assume that F is proportional to effort. Therefore, the ultimate goal would be to fix the effort of all fleets so that F summed over fleets equalled F_{target} for all species caught. However, in a mixed fisheries context, it may not be possible for the vector of all species-specific F to match exactly their respective F_{target}s, because each fleet catches a typical mix of several species. TEMAS allows for various options for handling this problem.

The current management regime in northern European waters is based on setting annual total allowable catches (TACs) that are distributed among countries according to fixed quota shares. In TEMAS, TACs are set using harvest control rules (HCRs) based on assessment results. Default rules use the precautionary reference points (ICES, 2005), but any HCR based on recovery plans or reference points based on maximum sustainable yield considerations can be implemented in the code. TACs are allocated to fleets using the historical average as a proxy for conservative allocation rules at international (relative stability) and national (e.g. ITQ) levels. In mixed fisheries, the default TAC regime is simulated by assuming that fleets continue fishing until all quota has been exhausted, discarding any over-quota catches (no revenue). However, alternative assumptions and rules may be implemented (ICES, 2006). In recent years, the TAC system has been combined with fleet-based effort restrictions for some demersal fisheries. This can be simulated by fixing for each period a fleet- and métier-specific maximum number of fishing days. The number of vessels is accounted for explicitly, which makes TEMAS suitable for simulating management scenarios aimed at reducing fleet capacity, such as licence regulations, taxes, subsidies, and decommission programmes. Finally, closed areas and closed seasons can also be simulated through time and space (given the level of disaggregation), and so can additional technical measures through selectivity and catchability parameters (gear regulations) and discard ogives (minimum landing sizes).

Alternative management regimes

The simulation of alternative management regimes requires understanding of, or assumptions about, how the regimes will work in practice and how they interact with fleets and stocks in the OM. One alternative management strategy of current interest is an effort control system that would replace the TAC system (Nielsen *et al.*, 2006; Rijnsdorp *et al.*, 2007). Another more adaptive strategy is being considered by CEC (2006) that approaches F_{target} gradually by reducing effort on some stocks by 10% annually until the target is achieved. Such approaches have been accounted for in the design, and it should be possible to simulate changes in paradigm of EU management strategies, where monitoring of fleet activity becomes more important than accurately predicting F and SSB.

Application and implementation

So far, the TEMAS software has been applied mainly in the North Sea mixed flatfish fisheries to determine the importance of accounting for fleet behaviour (Vermard *et al.*, 2005), in the Baltic cod (*Gadus morhua*) fisheries to evaluate the impact of seasonal fishing closures, and in the Kattegat flatfish fishery to evaluate alternative management objectives. The software proved reasonably capable of reproducing some past observed fleet and stock pattern predictions of fleet and stock effects, and of implementing alternative and case-specific scenarios, demonstrating its generic applicability and user-friendliness.

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