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TEMAS: fleet-based bioeconomic simulation software for evaluating management strategies accounting for fishermen behaviour.

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TEMAS (TEchnical MAnagement measureS) is a fleet-based bioeconomic software for evaluation of management strategies accounting for technical measures and fleet behaviour. Focus is on mixed-fisheries issues, where several fleets can choose between several fishing activities to target different stocks in one or several areas. The software combines a Management Strategy Evaluation (MSE) framework, using a forward running Operating Model (OM) and a Management Procedure (MP) 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 extensions to the traditional ICES forecast model. Alternative management scenarios can be compared and evaluated with regards to their bioeconomic consequences and their robustness to parameter uncertainty. The software is generic and user-friendly, and can be run at several space and time scales.

Keywords: bioeconomic simulation, evaluation frame, fishermen behaviour, fleet dynamics, management strategies, mixed fisheries.

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Introduction

The recent decline of many important fish stocks has lead to a shift in the way of considering fisheries management. The traditional single-species biological approach is being supplemented with considerations of fleet economics and dynamics on the one hand, and wider inclusion of measures of uncertainty and errors, including implementation uncertainty, on the other hand. There is a need for models that encapsulate key processes in order to evaluate management scenarios through simulation. A recent emerging trend has been towards a wider use of the models referred to as Management Strategies Evaluation (MSE) (IWC, 1993; de La Mare, 1998; Kell *et al*., 2005; Aranda and Motos, 2006). They aim at modelling the whole fisheries system, including the steps of stock assessment and management decision making. Progresses are thus made also towards better understanding of the processes of management implementation and fleet compliance, although these are still seldom included in routine modelling. Thus, fisheries systems models aim at consider uncertainty not only in the dynamics of stocks and fisheries, but also in our ability to monitor and manage them. However, these models often address stock-based scenarios, and have paid insufficient attention to the dynamics and economic performance of the fleets.

Most mixed-fisheries issues should be addressed through fleet- or fishery-based advice instead of only 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 completely separately, even if proper incentives and management might help reducing unwanted bycatch, and (ii) the flexibility of fishermen to adapt their activity to changes in resource, management or market conditions. This adaptability implies that fishing practices are not easily captured by a simple F-multiplier in the traditional assessment and prediction. Considerable effort has been invested in recent years towards 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 management scenarios is scarce.

The TEMAS simulation software is a combination of a MSE and a model of both short-term and long-term adaptation of fleet behaviour. TEMAS is a flexible generic tool for the bioeconomic simulation of complex mixed fisheries, and represents the follow-up of several previous bioeconomic, multi-fleet, multi-species models (Sparre and Willmann, 1992; Ulrich *et al*., 2002; Sparre, 2003).

Main approach

Simulation models can never capture all the complexity of fisheries systems because knowledge of many aspects of the marine and human world and all their interactions is lacking. However, they help to integrate the existing knowledge on the various underlying processes into one single platform. In this regard, they cannot be used for obtaining precise quantitative predictions. They are more useful to compare the outcome of various scenarios with each other than to evaluate the unique consequences of one single scenario. Consequently, the overall framework of TEMAS is designed for comparing the performance measures of different management regimes using the same set of inputs in the operating model.

The operating model simulates the ‘true’ system as developing according to predefined stock and fleet dynamics (Figure 1). The management procedure includes data collection with measurement error, an assessment of the ‘perceived’ status of the stock and the application of management controls. This in turn will influence the dynamics of the operating model at the next time step (Kell *et al*., 2006). The suite of models included in TEMAS can be thought of as extensions to 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 of TEMAS is the distinction between the concept of ‘fleets’ describing physical groups of vessels and the concept of ‘metiers’ (also called ‘fisheries’ or ‘riggings’) describing the activities (e.g. gear and mesh size used, fishing ground etc) of a vessel in a fleet during a given period. A fleet can thus engage in several metiers over time and space. Other new features include: (i) a user-defined time step smaller than one year to account for seasonality or periodicity, (ii) a spatial disaggregation into areas (boxes) that allows migration processes and fleet effort allocation of the fleets 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 creeping and factors of standardisation 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 that 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[1]. The code was designed to be open-access and easy to read despite its length, to ease understanding of the key processes included and facilitate the development of case-specific code such as new behaviour rules or management regimes.

The operating model

[1] Demonstration source code and further documentation is available on website: “http://www.efimas.org/”.

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 two can be specified by quarter or month rather than by year as for the older ages. This allows a more detailed description of changes in selection during the juvenile phase, the main purpose of most technical management measures. Spatial movements are accommodated by means of 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 an extensive description of the structure and dynamics of the fleets. 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 number of boats time maximum effort by boat. Realised effort cannot exceed this physical capacity.
The inclusion of metiers (fisheries) allows fleets to practice more than one activity in one or several areas, during some periods. The range of metiers a fleet can engage in is user-defined, but the relative allocation of the total effort of each fleet over the metiers and areas is either fixed or can be varied by period if the fleet behaviour module is used.

• *Fleet behaviour module*
Two behaviour modules are defined, for the short-term (tactical), and the long-term (structural) behaviour, respectively. The short-term module covers the allocation of effort across metiers and areas for each fleet at each time step. The effort allocation is expressed by a discrete choice structure, where a choice is defined as a combination of a metier 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 choosing 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, Ulrich *et al.*, unpublished). The choice probability for a given fleet is derived from the theory of the utility-maximising behaviour, which assumes that a fleet (or a fisherman) will choose the alternative that gives the highest utility among a finite number of alternatives (see e.g. Train, 2003). This approach, better known as the Random Utility Model (RUM), has been applied in several empirical studies modelling trip-based choice behaviour in terms of fishing location or/and fishery for individual fishermen (Bockstael and Opaluch, 1983; Holland and Sutinen, 1999; Wilen *et al*., 2002). A similar methodology has been applied for the long-term behaviour (capacity dynamics) where the choices for a vessel correspond to entering, staying in or exiting a fleet on yearly basis (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). They 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 fisherman short-term decision. For long-term behaviour, explanatory variables such as annual revenue, fleet size, biomass index, vessel age, residency of the vessel owner and captainship may be used. However, including a behaviour model into a fleet-based simulation framework may often require a reduction in the set of choices due to limitation of both temporal and spatial dimensions of the model, and a reduction in the set of explanatory variables, due to limitations in data and degree of freedom. While information on fleet activities (landings and effort) is often available at the trip and ICES square level through log-books data, biological information is often available at the stock and management area level on a yearly basis only. 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 a simplification of the observed utility function to few significant explanatory variables that can be modelled

as state variables in the simulations. Furthermore, many important decision factors in the observed utility function cannot be measured directly from usual fishery data (Smith, 2000), and often proxies are used.

For example, a reduced set of explanatory variables was used for the North Sea flatfish fishery (Andersen et al., 2006), 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 metier by area. The total fishing mortality generated is related to effort, catchability and age-specific selectivity by metier and area. Selectivity represents the combined effect of gear selection and species availability. The fishing mortality by metier is divided into landings mortality and discard mortality using length-based discard ogives. The last 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). TEMAS also allows optionally for an exponential relationship between catchability and biomass (Fox, 1974, MacCall, 1999).

• *Economic module*

TEMAS allows for an optional number of economic models, each representing a group of stakeholders (e.g., fishing industry, government treasury, society). The economic module is adopted from Sparre and Willmann (1992); the core is a microeconomic description of costs and earnings by metier. Variable costs are defined by area to account for spatial differences in e.g. fuel cost.

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

Economic incentives are important for short-term as well as long-term fleet behaviour. The short-term decisions include tactical adaptations to the 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. TEMAS contains a suite of options for pre-prepared evaluations of management regimes. The natural reference for comparison is the "current assessment procedure" and "current management regime", which are simulated proxies of the true observed regime.

• *Current assessment procedure*

The link between the operating model and the management procedures is made through the sampling procedure, where samples are taken from the "true" catches of the operating model to provide the catch-at-age matrix used in assessment. The assessment is a simplified VPA procedure (Ulrich *et al.*, 2002). The user might choose to run an assessment with perfect inputs, or to run an assessment with uncertainty, for example 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, based on the Precautionary Approach, is to avoid that SSB falls below a certain limit reference point. The current regime is a case-specific combination of existing management measures implemented to reach this goal. In many cases, precautionary levels of fishing mortality are specified for each stock, which are used in practice as management objectives. Let F_{Target} designate a desired stock-specific fishing mortality (e.g. F_{PA} or F_{MSY}). The simplest model is to assume that F is proportional to effort. Thus, the ultimate goal would be to fix the effort of all fleets so that F summed over fleets equals F_{Target} for all species caught by the fleets in question. However, usually, there will be no solution for making the vector of all species-specific F exactly match their respective F_{target} because each fleet catches a typical mix of several species. TEMAS allows for various options for handling this problem.

The current management regime in North European waters is setting annual Total Allowable Catches (TAC), which are distributed among countries according to fixed quota shares. In TEMAS, TACs are set using Harvest Control Rules (HCR) based on assessment results. Default rules are the precautionary approach reference points (ICES, 2005), but any HCR based on recovery plans or MSY reference points can further be implemented in the code. TACs are allocated to fleets using historical average, as a proxy for conservative allocation rules at the international (relative stability) and national level (ITQs, rations etc) level. In mixed-fisheries, the default TAC regime is simulated by assuming that fleets go on fishing until the last single-stock quota have been exhausted, discarding the over-quota catches of other stocks (no revenue). But alternative assumptions and rules can be implemented (ICES, 2006). In recent years, the quota system has been combined with fleet-based effort restrictions for some demersal fisheries. This can be simulated by fixing for each period fleet- (and fishery-) specific maximum number of fishing days. TEMAS explicitly accounts for the number of vessels, which makes it suitable for simulating management scenarios aiming 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 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 on, how these regimes will work in practice, and how they interact with fleets and stocks in the operating model. One alternative management strategy of current interest is an effort control system that would replace TAC (Nielsen *et al*., 2006; Rijnsdorp *et al.,* 2006). Also a more adaptive attempt to approach F_{Target} gradually by reducing effort on some stocks by 10% each year until the target is achieved is being considered by the Commission of the European Commission (EEC, 2006). Such approaches have been taken into account in the design and TEMAS should be able to simulate changes in paradigm of EU management strategies, where monitoring of fleet activity becomes more important than the accurate prediction of fishing mortality and spawning stock biomass.

Application and implementation

The TEMAS software has been mainly applied so far in the North Sea mixed-flatfish fisheries, investigating the importance of accounting for fleets behaviour (Vermard et al., 2005, Andersen et al., 2006), in the Baltic cod fisheries, evaluating the impact of seasonal fishing closures (Nielsen *et al.*, unpublished, Sparre *et al.*, unpublished), and in the Kattegat flatfish fishery, evaluating alternative management objectives (Vermard, unpublished). The software proved able to reproduce reasonably well some past observed fleet and stock patterns predictions of fleet and stock effects, and to implement alternative and case-specific scenarios, emphasising its genericity and user-friendliness.

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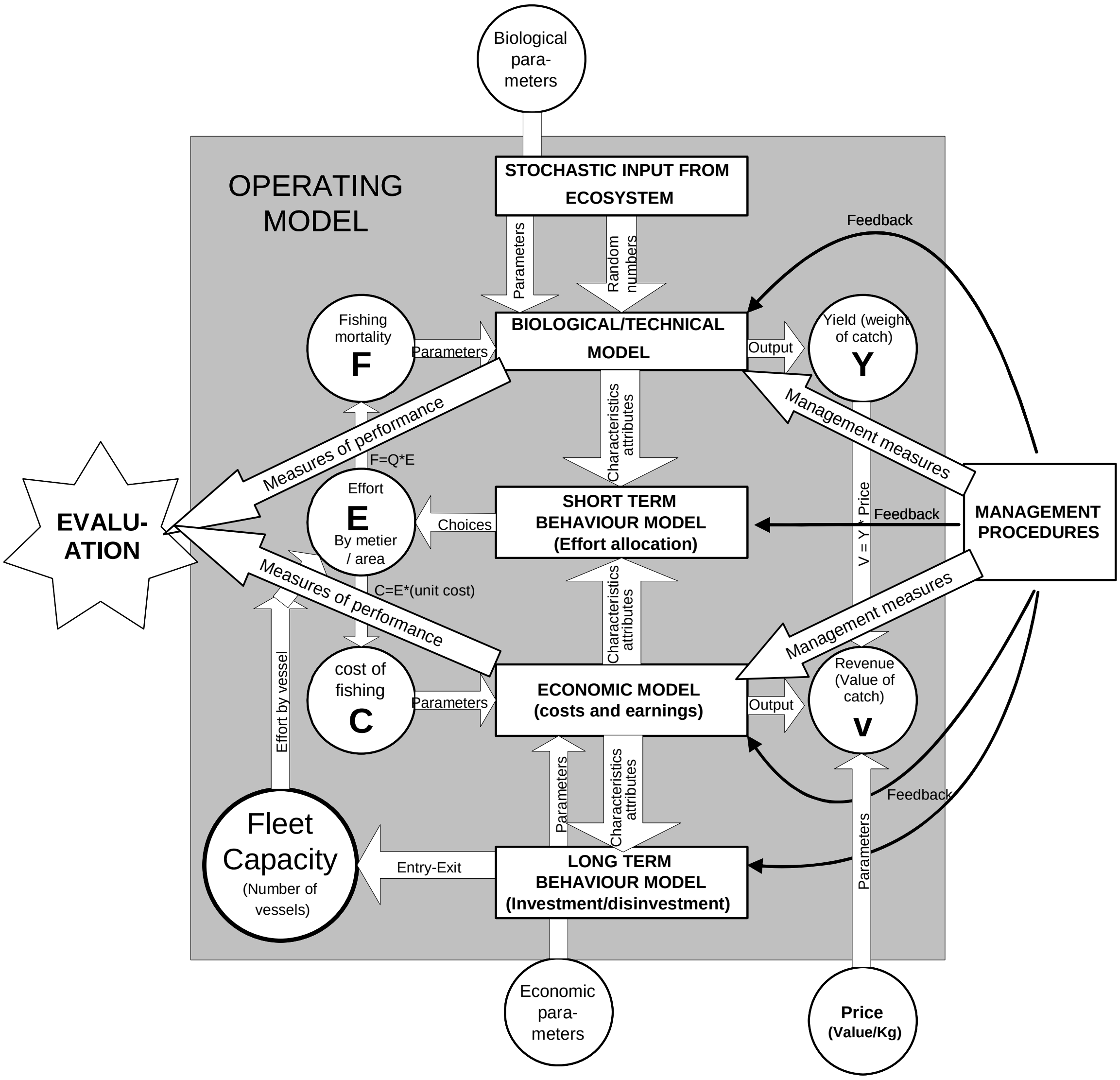

Figure 1. The Operating Model of the TEMAS software.