

THE BEMMFISH BIO-ECONOMIC MODEL

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ABSTRACT

BEMMFISH is conceptualised as a bio-economic model for non-industrial/ artisanal fisheries, allowing for multi-species dynamics and multi-fleet dynamics, where the control variable is effort (not the catch). The aim of this paper is to give an overview of the simulation part of the BEMMFISH model and to focus on the most innovative parts on the economic side of this bio-economic model. Therefore, the multivariable price function that the model uses is analysed with several examples and the production function that relates captures with capital (vessel value). BEMMFISH is a European Project under the European Union Research Program of the V Framework Programme. Quality of Life and Management of Living Resources (Q5RS-2001-01533).

Keywords: bio-economics; modelisation, price function; production function

INTRODUCTION

One of the aims of the BEMMFISH project is to develop a bio-economic *simulation model*. A bio-economic simulation model can be understood as a set of tools designed to make projections of a set of biological and economic variables into the future (at specified time intervals t). The initial set of variables are parameterised using data for t_0 and the projection of these variables is constrained by the functional relationships established within the system. Additionally, the simulation model can be expanded to include an optimisation module to find the optimal solution of a specified objective function. Optimisation models can be seen as a generalisation of a simulation model that includes an objective function and a maximisation algorithm.

This bio-economic model is the result of two interacting sub-models: -a *biological (or stock) sub-model*, including the dynamics of the resource and their interaction with human activity in the form of fishing mortality, and -an *economic sub-model (including fleet, market and fishermen)*, accounting for the dynamics of fleets and markets, and the rules of the fishermen's behaviour. The input from the economic sub-model to the biological sub-model are mediated by fishing mortality. The outcome of the biological sub-model is fish catch, which serves as input to the economic sub-models.

The model is designed for the Mediterranean Fisheries, so it must use effort control as a management instrument, not the catch control. We consider that a realistic bio-economic model for Mediterranean fisheries has to include the specific behaviour of the individual fishing unit, or vessel; as is a control on effort model, it is necessary to measure the number of vessels in the fishery each time. For a recent review of the characteristics of Mediterranean fisheries it can be seen [1].

In Mediterranean fisheries, the catch of individual vessels is composed by numerous species and, at the same time, different types of gears target the same pool of species. Thus, it is necessary to consider a multi-species bio-economic model with technical interactions. There are various types of fisheries in the Mediterranean, both large scale and small scale. Generally, the largest part of their landings is consumed locally. Consequently, there is relatively little secondary processing, and distribution routes are short. In addition, there is no strong integration between fishing and processing activity. These characteristics differentiate the Mediterranean fishery from European Atlantic fisheries, that are characterised by the presence of large vessels with an industrial organisation strongly vertically integrated with processing and marketing, with the exception of some fisheries in the English Channel area and the North sea [2,3].

The economic sub-model is driven by the catch (converted to economic value: revenues) minus costs equation (profits or *fisheries rent*) assuming that the firm's behaviour is directed at maximising the profit constrained to the effort limitations established by the Administration or the Fishermen Associations itself.

ELEMENTS OF THE BEMMFISH SIMULATION MODEL

The BEMMFISH model aims at modelling accurately the reality of Mediterranean fisheries, where the catch of individual vessels is composed of numerous species and, at the same time, different types of gears target the same pool of species. Hence, it is a multi-species (or more accurately, multi-stock), multi-fleet model with technical interactions among fishing gears. The model allows for simulating the behaviour of Mediterranean fisheries under different management strategies. The key elements of the model are stocks and vessels (economic units or agents). The dynamics of the stocks are modelled as global, partially-age, age-structure, depending on case study or data availability. The economic units follow a single model, which includes *i)* the economic accounts, and *ii)* the decisions (behaviour) of the agents. For convenience, the economic vessels are organised (not aggregated) by fleet (a group of vessels using the same fishing gear to target the same pool of main species, at given places and times of the year), and country/area.

The model makes use of a set of biological, economic or link functions. These functions are: (1) harvesting, (2) fishing mortality, (3) price formation, (4) cost of harvesting, (5) investment, (6) modelling the dynamics of entry to the fishery or exit from the fishery, (7) modelling the dynamics of fishing effort, and (8) modelling the dynamics of catchability.

The main features of the bio-economic model are: dynamic biological model(s) for main (target) species; optional stock-recruitment relationships; optional stochastic variability of selected biological and economic parameters/variables; dynamic economic model; behavioural rules of economic units (vessels) based on Mediterranean type of fishermen; link between biological and economic box by means of a fishing mortality production function, in its simplest form $F = q \cdot E$, where F is fishing mortality, q is catchability and E is effort; flexible price formation function and simulation of alternative management actions by user-specified “events”.

The model does not include: biological interactions among species, optimisation, migration, handling or processing costs (because Mediterranean fisheries sell fresh product). The model is spatially structured in the sense of a fleet exploiting two or more non-overlapping areas. This is sufficient to simulate case scenarios such as protecting nursery areas or analysing the role of Marine Protected Areas (MPAs). However, the objective is not to model migration or density-dependent movement of parts of the population from one spatial unit to other, but rather to allow for the simulation of changes in fishing grounds by the different fleets. In this sense, the model will not directly be applicable to highly migratory species (i.e. large pelagics), but will be a tool to mimic the spatio-temporal changes in the allocation of effort by small-scale fleets.

SIMULATION CONSIDERATIONS

The set of biological and economic variables/parameters that represent the base bio-economic condition of the fishery are defined for year 0 (t_0). These correspond to the data obtained by a preliminary bio-economic survey and are the data entered by the case study analyst. The year 0 parameters are fixed throughout the simulation horizon (e.g. growth parameters) or change dynamically according to the equations used in the model (endogenous variables). The value of control variables can be changed by the user during the course of the simulation horizon (events).

The data set of a scenario defines the initial conditions (t_0) for both the biological and economic sub-models. The model is run through a time horizon $t=1, \dots, T$. The fraction of the population entering the economic sub-model (catch) is given by the fishing mortality (F) at each time period t . The catch of “target” species (and the input from secondary species, if any) determines the revenues (together with the fish price) and, in part, the costs. The costs are further modified by the fishing effort applied (as part of F) and possible economic controls, such as taxes, subsidies or decommission incentives. From the net result (*outcome*) of the difference between revenues and cost, the economic agent (“fisherman”) takes a decision, based on behavioural rules, on how to modify F for the following time period. This modification of F can be further altered by the manager in the form of measure controls, such as effort controls etc.

The model comprises a common set of sub-models and computer routines drawing from a standardised data set and allows the user to conduct simulation or optimisation run for a given scenario.

The model workflow is summarised in Figure 1.

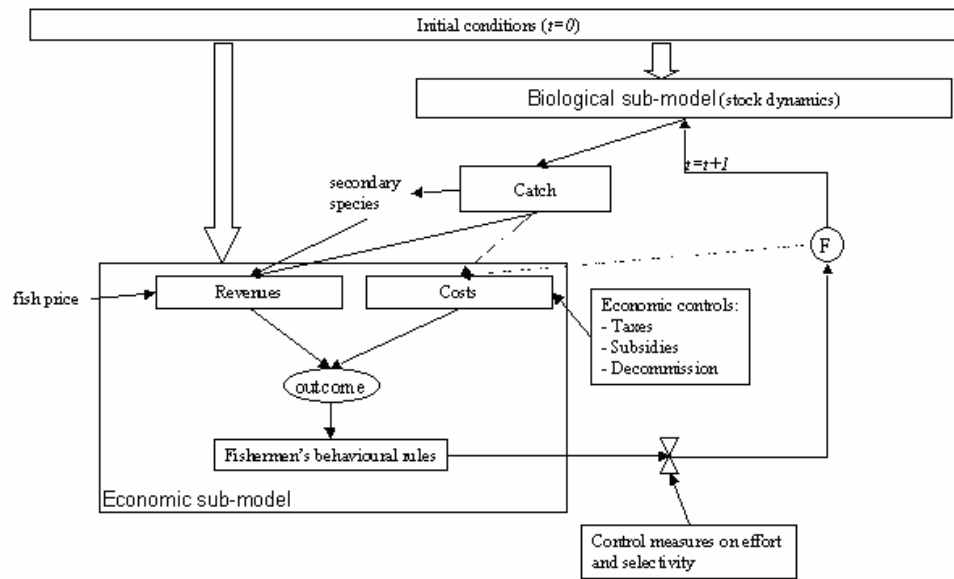


Figure 1: BEMMFISH bio-economic model Workflow, where outcome is the net profit of each economic agent.

STRUCTURE OF THE BIOLOGICAL SUB-MODEL

The stock is modelled as a generator of catches (*fish production*, Clark, 1976; Anderson, 1986; Charles, 1989; Hannesson, 1993). Three types of production models are considered: -global models (Schaefer, 1954; Schnute, 1977; their use in bio-economic models is reviewed in Seijo *et al.*, 1997); -partially age-structured models (Deriso-Schnute model: Deriso, 1980; Schnute, 1985); and -age-structured models (Beverton and Holt, 1957; Schnute, 1985; Hilborn and Walters, 1992).

The choice of an appropriate biological sub-model is constrained by the data available, but also by the management measures likely to be tested in the model: e.g. if selectivity measures are to be implemented, it is necessary to have reasonably accurate estimates of the age structure of the population. On the other hand, if measures aiming at enhancing recruitment are envisaged, it is necessary to consider time steps smaller than one year (to test seasonal closures) or a spatially-structured model that allows for simulation of area closures. It implements time steps of 1 month, 1 quarter and 1 year (as a compromise between detailed temporal resolution and data availability) and a simple spatial model that allows for the specification of different fishing areas. Although the model is multi-species, no biological interactions among species are considered, only technical interactions.

STRUCTURE OF THE ECONOMIC SUB-MODEL

The economic sub-model is driven by the catch (converted to economic value: revenues) minus costs equation (profits or *fisheries rent*) assuming that the firm's behaviour is directed at maximising the profit given by the difference between revenues and costs. The change in effort levels and introduction of new technology (investments in capital) are the instruments. In order to achieve this aim, the firm may choose the levels of the factors resulting in a better (or more efficient) combination. Limitations by management on one or more factors can incentivate the firm to find other combinations of factors, increasing the level of possible combinations. At this level, many refinements can be made.

- The revenues of the economic unit can originate from a set of target species plus a pool of accessory species.
- The direct revenues from the catch can be complemented by subsidies or decommission incentives.

-The costs can be split in fixed costs (independent of effort) and variable costs (dependent on effort or catch or both). The costs can be also be complemented by taxes.

The economic sub-model is disaggregated to the level of vessel, whenever possible. When vessel-by-vessel data is not available the individual vessels can be aggregated into fleet sub-groups. The time steps of the economic sub-model may need to be multiple, with some processes occurring at monthly or quarterly time scales, while other processes occur at larger time scales. But in any case, long-term decisions (such as when and whether to invest or divest) are carried out at a time scale of 1 year.

The results of the economic sub-model are used to modulate effort and the investment in fishing activity (affecting catchability), which in turn modulates the fishing mortality applied to the stock. The effort (expressed in fishing time) will be constrained to a maximum level of effort (legal maximum effort or physically-possible maximum effort) and can be modified by the manager by introducing events. The variations in catchability due to variations in investment are modelled empirically, by estimating the parameters of catchability functions.

MANAGEMENT MEASURES

Several performance measures are envisaged, to facilitate comparison among scenarios. However, the outcome of the simulations should be analysed in full and no pre-eminence given to a particular performance measure (some bio-economic models use only the present value of the fisheries rent as a performance measure, [1]). The analysis of the model's output must be done over the short and long term [13]. The necessary performance measures include:

-Present value of fisheries rent The present value of profits may be represented by

$$V = \int_0^{\infty} \Pi(e, x; p; m) \cdot e^{-rt} dt \quad (\text{Eq. 1})$$

-"Safe" limits of biomass for target species (i.e. 50% of virgin stock biomass) or other biological reference points ($F_{0.1}$, etc., [14])

-Fisherman's wages, number of fishermen employed, or other social measures directed at maintaining employment.

On the other hand, even if objective criteria are defined for establishing performance measures, some subjective weighting of the performance measures may inevitably develop, as the status of target stocks may have greater importance than certain economic measures, because the former will define the latter. If different combinations of parameter values define the same *optimum* some subjective analysis inevitably arises, because the manager may have *a priori* considerations over the most desirable situation: e.g., the same revenues can result from a few vessels fishing on a healthy stock or a large number of vessels fishing on a declining stock.

The management objectives are not specifically modelled; rather a set of management measures can be tested by setting up *management scenarios*. The general management policies recommended by CEC (2002), in the context of Mediterranean fisheries, are: to reduce overall fishing pressure, apply catch limitations where possible, and improve the current exploitation patterns. Based on this, the following management scenarios are given priority:

- Fishing effort limitation: Control of time at sea (hours by day, days by week and seasonal closures), maintaining limited entry (current licensing schemes), reducing fleet size.
- Fleets: Removal of boats from different fleets of a fishery, i.e. following multi-annual guidance programmes – MAGPs, including gear competition and decommissioning.
- Limitation of fishing effort by using closed areas/seasons, with an analysis of their bio-economic consequences over the short and long term.
- Analysis of fishing power increase due to technological progress and fishermen's investment.
- Selectivity (and other technical conservation measures): Mediterranean fisheries are mainly based on 0-aged individuals and juveniles caught by trawl gears with very low selectivity, resulting in very heavy growth overexploitation and putting in danger the stock by recruitment overexploitation. The model will allow exploring the short and medium term effects of selectivity changes.

- Regional approach to management: An analysis of the bio-economic effects of different fleets competing for the same resource or in the same market with different local rules will be carried out.
- Economic management tools: different kinds of subsidies, taxes and credits.
- Market: Assessments of the economic implications of technical or economical management measures on the market will be performed.
- Explore the feasibility of TAC-based management for small pelagics (as suggested in CEC, 2002) by simulation methods

The management objectives are implemented through a series of *controls*. The controls are of economic or technical nature. Among the economic control measures, the following can be researched in one or more scenarios: Taxes, Subsidies and Decommission rules. Among the technical control measures, selectivity, effort control and TACs can be considered. Effort can be controlled at several levels: as maximum fishing times, as spatial allocation of effort and as seasonal allocation of effort. Following the recommendations of CEC (2002), the application of integrated management measures is foreseen. Considering that fishermen adapt quickly and may counteract the perceived undesired effects of a management measure, more than one management measure can be simultaneously tested for each scenario.

MODEL SPECIFICATIONS

Analytically, there is no material difference between heterogeneous fishing firms (or, for that matter, vessels) and different fishing fleets. In the latter case, each fleet is simply a collection of homogenous firms and can be treated as a single firm.

Even single species fisheries are generally based on distinguishable sub-stocks. These sub-stocks, in spite of belonging to the same biological species, are typically distinct in terms of economically important variables such as size and age (cohorts), genetic composition, fecundity, market value, location and catchability. Analytically, it makes no material difference whether we are dealing with distinct biological stocks or different sub-stocks of the same species. Different fleets from two or more different nations make no analytical difference in terms of fisheries modelling. Two fleets of different nationalities are analytically merely two different fleets. However, when it comes to problem of fisheries management, the obvious difference is that the management sovereignty is disjoint. This may be assumed to make the management problem less tractable.

The main link between the biology and the economics is F , fishing mortality, decomposed in effort (E) and catchability (q). The Effort (E , expressed in fishing time), is a factor for F and a factor of harvesting cost function.

The species-specific catchability function q_t includes the variation of fishing mortality related to the variability in the production factors [3]. This variability can be related *inter alia* to variations in vessel size, skipper's skill and vessel efficiency (technology). Some bio-economic models have related q_t to capital (as a proxy for investment in technology [16]), stock size [1], technical development in fishing efficiency [1], or intra- and inter-annual variation [17]. In our model, catchability depends on investment in technology (increase in capital) and temporal trends [16], although other formulations based on empirical observations are also possible. In this model the effort at time t is a fraction of the total allowable effort and q_t is a time-varying proportional constant depending on stock i and capital. For each vessel v :

$$q_{t,v} = Q_{0,v} \tau^t \frac{1 - e^{-hK_{t,v}}}{1 - e^{-hK_{0,v}}} \quad (\text{Eq. 2})$$

where $Q_{0,v}$ is the initial vessel-specific catchability constant, τ is the fraction of catchability variation with time, h is the proportion constant to capital, and $K_{t,v}$ is the capital of vessel v at time t and $K_{0,v}$ is the initial capital for vessel v . for $K_0 \neq 0$ and $h \neq 0$, where τ and h are parameters, and Q_0 and K_0 are the initial catchability and the initial capital (at $t=0$) respectively^a.

Maximum catchability (for "infinite" capital) can be: $Q_0 / (1 - \exp(-h \cdot K_0))$ ^b. The part of catchability that is influenced by fishing gear specifications (*availability*) is simply modelled by introducing a control variable S , selectivity, that can be modified by the manager as an event. Then total fishing mortality is:

$$F_{a,t,g} = q_{a,t,g} E_{t,g} S_{a,t,g} \quad (\text{Eq. 3})$$

where $S_{a,t,g}$ may vary between 0 and 1.

ECONOMIC SUB-MODEL SPECIFICATIONS

The harvest produced by the fishing mortality function from the stock (or cohort, depending on the biological model) for each fleet g , $Y_{a,g,t}$, is distributed by fishing vessels according to the relative amount of effort and fishing power (catchability) applied, assuming these can be linearly allocated by vessel:

$$Y_{a,t,v} = \frac{E_{t,v} q_{a,t,v}}{F_{a,t,g}} Y_{a,t,g} \quad (\text{Eq. 4})$$

where the subscript a refers to an age-class.

Fishing mortality results from applying fishing capital to fish stocks. By fishing capital we mean a collection of variables describing the nature of the fishing entity including the vessel, its size, engine power, equipment, fishing gear, crew size, crew quality, etc. These variables are represented by a vector k . By application of this capital we mean the total time it is applied to fishing. This time may be variably defined as the time at sea (days or hours), time searching and fishing and time actually fishing. Which measure is used depends among other things on the availability of data. The application of fishing capital to fish stocks is usually referred to as fishing effort in analytical work [6, 18]. Finally, the fish stocks to which the fishing effort is applied are not necessarily the aggregate stocks. In disaggregated work, e.g. one based on data from individual vessels or fleets, the fish stocks in question are those encountered by the vessels or fleets and fished from.

Fish price function

The value of the harvest, for each vessel and stock (or age class) is given by the general fish price equation:

$$p_{a,t,v} = f(Y_{a,t,v}, Z) \quad (\text{Eq. 5})$$

Where the vector Z refers to other possible explanatory variables, in addition to catch, including the aggregate supply of fish and substitutes. In our model, the price function of the main species (p_i) is given by the multiplicative model:

$$P_i = b_0 \cdot b_1 l \cdot b_2 o \cdot b_3 f \cdot b_4 m \cdot b_5 d \cdot b_6 \cdot \varepsilon, \quad (\text{Eq. 6})$$

Where: b_0 is the base (or average) price, b_1 is a size (length or age) modifier of price, b_2 is an offer modifier of price, b_3 is a dummy fleet modifier (different fleets may obtain different qualities of fish), b_4 is a dummy month modifier, and b_5 is a dummy daily modifier of price. While, the last two coefficients make sense only in simulations at daily or monthly scales. b_6 is an event-modifier of price, i.e., is a control variable used by the manager to simulate sudden changes in prices for exogenous reasons. ε is a normally distributed stochastic error term to account for the variability on sale price. It should be taken into account that whenever a variable is missing it should be replaced by 1 in order to be able to work with the other parameters.

An application of this price function has been test with monthly ex-vessel hake prices from the Barcelona auction, for the period from January 1992 until December 2001. The data used for the analysis did not provide any differentiation on size and day, but it could be disaggregated by fleet/gear (trawl, long-line and minor gears), quantity landed and month. Even all parameters could not be modelled in this case, we obtain that the common model using the average price has a standard deviation of the 21.2%, while the multi-variable function proposed here has an adjusted R-square of 70.1%, with a standard deviation of the 11.5%.

Harvest cost function

The cost function for each vessel may be represented by a cost function of the general form:

$$Co_{v,t} = f(k, Y_{v,t}, w) \quad (\text{Eq. 7})$$

where w refers to the vector of input prices.

Before modelling in detail the cost structure of each vessel, we need to consider the aggregate catches of each vessel, i.e. including the catches from target and accessory species. The catches from accessory species are modelled in relation to the catch of the main species C_i (corresponding to $Y_{v,t}$ in the previous equation) with the following empirical relationships between C_i and C_j and the parameters μ and ν estimated from available data series:

$$\begin{cases} C_j = \mu_{ij} + \nu_{ij} C_i \\ C_j = \mu_{ij} C_i^{\nu_{ij}} \end{cases}, \quad (\text{Eq. 8})$$

Then the total revenues (or Gross Value of Production) is:

$$P_v = \sum_{i=1}^I C_i p_i + \sum_{j=1}^J C_j p_j + O_v, \quad (\text{Eq. 9})$$

where O_v are other sources of income to the vessel, such as subsidies. Then for each firm or operating unit, the net revenues (RT_v) over a period t are:

$$RT_v = P_v - Co_v, \quad (\text{Eq. 10})$$

where P_v are the total revenues and Co_v are the operating costs.

For the analysis of costs, we use the methodology adopted to produce the Annual Economic Report of European Union Fisheries (2000), applied to the specific conditions of the Mediterranean. The expenses that the fishermen may incur are divided into 7 groups, summarised on table I:

Table I: Possible costs that fishermen may incur^c

Term		Name	Variable	Explanation
Short-term costs	Variable costs	Trade costs	Co1	function of catch
		Labour costs	Co3	function of effort
		Daily costs	Co2	
	Fixed costs	Maintenance costs	Co5	function of profits (1)
		Compulsory costs	Co4	constant (2)
Long-term costs		Opportunity costs	Co6	price of money
		Financial costs	Co7	interest rates

Co1 Trade costs. All costs that are possible to express as a percentage of the Total Revenues (P_v). (VAT, Fishermen's association taxes, labour taxes, local taxes, sale process, etc.) This is a percentage of the total of the Total Revenues.

Co2 Daily costs. These are the costs caused by the fishing activity (fuel consumption, net mending, daily food expenses, etc.), excluding labour costs. They are a function of the daily cost of fishing by effort and include a part of maintenance costs, such as net mending, which are proportional to effort.

When the initial P_v is reduced by $Co1_v$ and $Co2_v$, the remainder is known in Spain as *monte menor* (MM). MM is divided in parts, one for the owner and another for the crew (including the owner, when the owner is a worker). The "part" (share) is a percentage that can vary among fleets, but it averages around 50% ($c3_g$), once the trade costs and the daily costs have been deducted.

Co3 Labour costs. These are composed of the share (“part”) corresponding to the crew as a function of function of *MM*. The average wage of the crew can be used also as a control measure in the model, in the sense that high wages can incentivate interests in this economic activity and low wages (or wages below a minimum level) can hamper this economic activity for want of workforce.

Co4 Compulsory costs (harbour costs, license, insurance, etc.). Yearly costs incurred by the fisherman for keeping his business legal. We suppose that they are constant as they are not dependent upon effort (number days at sea) or catch. They are considered to be an exogenous variable in the model and are expressed per vessel.

Co5 Maintenance costs (flexible costs). These are the costs required to maintain the vessel at its maximum performance level. They are included in the reinstatement of the used capital, repairs, etc. They are considered as an exogenous variable in the model and are expressed per vessel.

Co5 is divided in two parts by a percentage per vessel. The first part is the operating costs that are indispensable to meet in order to remain in activity. The second part is the other maintenance cost, which is avoidable (*Coa*) but reduces the catchability when modelling the catchability as a function of capital (C5.2: painting, maintenance of electronic devices, maintenance of engine, etc.). This percentage (*ca*) is also considered per vessel.

Co6 Opportunity cost. This is the cost of using the capital invested. It is a function of the capital invested by the rate of the “Public Debt” (*c6*). It allows the determination of what the capital's alternative profitability would be if it were invested elsewhere for a fixed term. It indicates the revenues lost (or “opportunities” lost) to the fisherman by investing in the fishing activity. This rate is fixed by country.

Co7 Financial cost. Interest and capital return on bank loans. In case of negative profits, debts arise and any further investment necessitates bank loans. *Co7* depends on banking interest rates (*c7*) and the individual debt incurred (*D_v*).

D_v has an upper limit (maximum debt accepted by banks) depending on the total capital invested, as the bank is not willing to lend more than $d_m \cdot K_v$, where d_m is a maximal percentage of lend authorised by the bank, and K_v the total vessel investment.

In addition to the costs defined above, taxes (*T*) can be deducted from the total revenues.

where x_e are the effort components and \square_0, \square_I and t_e are parameters relative to the tax rate ($0 \leq \square_0, \square_I; t_e \leq 1$).

Capital dynamics and investment

The firm's capital (*K*, disregarding subscript *v*) is altered over time by investment and deterioration or depreciation. The basic dynamic identity is:

$$K_{t+1} = K_t - \delta_t K_t + I_t, \quad (\text{Eq. 11})$$

where δ_t is the deterioration function and I_t is the investment in capital, that is a function of profits.

The fundamental investment rule is to invest (positive or negative) when expected profits with the investment taking due account of uncertainty and risk are higher than the expected profits without the investment. More formally:

Let $V(K)$ represent the firm's value function, i.e. the maximal attainment of its objectives, with capital K . Let $V(K+\Delta K)$ represent the value function with a new investment (positive or negative) of ΔK . Both expected profits include the appropriate risk premiums. The optimal investment rule then is:

Undertake ΔK if and only if $V(K+\Delta K) > V(K)$.

When the firm's objective is profit maximization, the value function, $V(K)$, represents maximal expected profits by the firm. Applying this rule in fisheries modelling requires the calculation of the expected present value of the objective function for two or more levels of capital. This clearly involves a substantial dynamic calculation where not only the firms's capital but biomass and other dynamic endogenous variables evolve over time and affect the firm's objective function. It follows that the firm will have to form expectations about the path of these variables and their impact on the objective function. Possible existence of lags and conspicuous consumption has been considered. In the special case where capital is fully malleable (it can be bought and sold in any amounts at a given market

price), the optimal investment rule reduces to the rule for purchasing normal flow inputs, namely that the capital level at each point of time is:

$$\Pi_K(K) = w_i, \tag{Eq. 12}$$

where Π represents current profits and w_i denotes the use or rental price of capital.

The relationship between capital and catches is obtained as the catches in the spatial unit for the specie and the vessel i at time t are (Schaefer, 1954):

$$C_t = q_t * E_t * B_t \tag{Eq. 13}$$

$$C_{it} = q_{it} * E_{it} * B_t \tag{Eq. 14}$$

$$CPUE = C_{it} / E_{it} = q_{it} * B_t \tag{Eq. 15}$$

So, differences in the CPUE of the vessels during the same period should be due to catchability. And catchability should be dependent of the value of the ship, so that higher value vessels fish more, as they are bigger or better equipped. A linear relationship between catches (in monetary terms) and the vessel value (capital) for some red shrimp Mediterranean vessels is shown on figure 2.

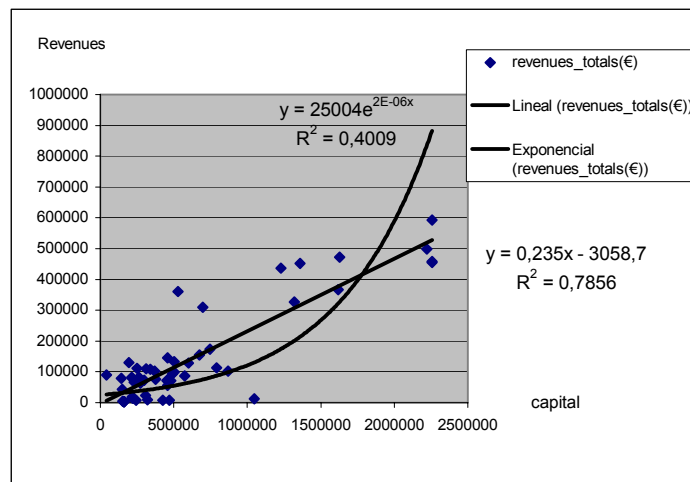


Figure 2: Relationship between catches in revenues and vessel value (capital)

Behavioural rules of the firm

The firms' behaviour may in general be assumed to follow from the maximization of some objective subject to the biological constraint of the fishery. In its most general form this objective function would involve all of the variables in the fishery. However, more restricted objectives seem more realistic. In economic theory it is usually assumed that firms seek to maximise profits. Indeed, under a degree of competition there are good reasons to believe that this must be the case. The basic economic hypothesis is that the firm attempts to maximise the profits obtained from the activity (fisherman's behaviour based on profit maximisation). If the profits are positive (over the social average) the firm will invest more in the activity to obtain more profits. We consider that the possibility of investment is limited by institutional restrictions (e.g. legislation banning the increase in the number of vessels) and by budget limitations: the resources available are the previous profits obtained from the activity, or part of them. If the profits are negative (over the social average) the fishermen will try to leave the activity but also will try to obtain revenues from the previously invested capital, that otherwise have no alternative value.

We try to simplify this hypothesis in a quantitative process whereby the input is the profits obtained in the previous year and the output is the effort (and modifications in catchability in some cases) to be applied the following year. In fact, we simulate the decision process in a box that converts the total revenues to the fishing effort that will be applied by the vessel in the following unit of time, measured as number of days at sea, and variations in catchability, in some cases. The assumptions on the behavioural rules of the fisherman (*fishermen's decision*) are: 1) Fishermen

assume that fish production depends on the effort (and catchability in some cases). 2) The revenues at the end of one period are used to cover the different costs of the fishing activity for the next period. Investment is a function of the profits. 3) There is a maximum legal limit for the number of days at sea. The number of ships, as well as their engine power, is also limited by the administration. 4) The fisherman intends to go fishing for the maximum number of days that the law and revenues allow.

A large body of literature reports that only effective institutional controls (provided by the administration or by the fishermen organisations) can result in a reduction of effective fishing time. If this control is not effective in Mediterranean conditions (high price, reduced catch, weak financial capacity and proximity of fishing grounds) the total fishing time is all the time technically possible (including summer holidays and Sundays).

The difference between fishermen revenues and costs, may lead to different situations in the profits of each individual vessel. Figure 3 reproduces the deduction of costs from the total revenue to arrive to the final profit level, which is the outcome of the economic box.

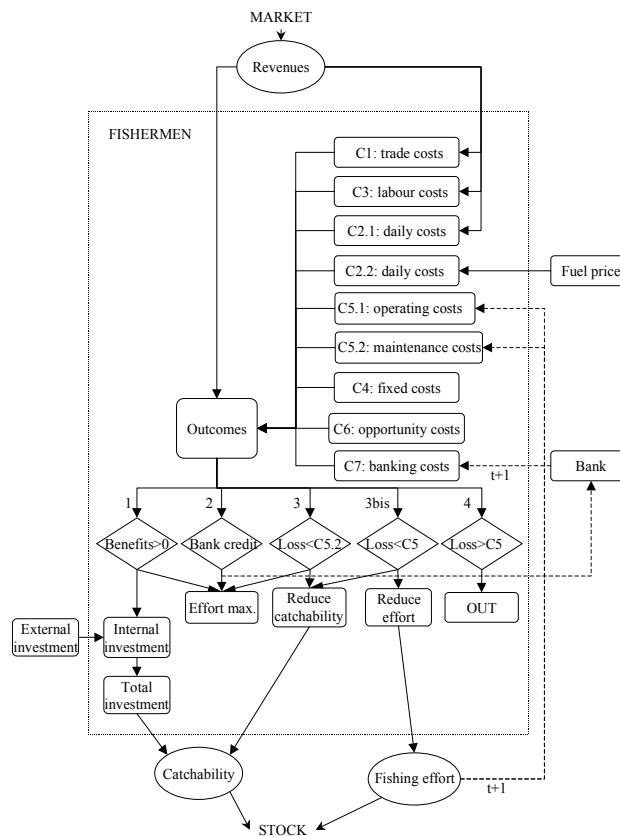


Figure 3: The behavioural rules of fishermen

The manager's control variables (taxes, subsidies, decommission, price of effort, allocation of effort, etc.) can modify directly or indirectly the result of the fishermen's behavioural rules.

Regarding the fishermen's "financial health" after one time-unit period, there exist 4 possible results.

1st Positive Profits

The profits in the model are totally reinvested. There exists a technical limitation establishing a restriction: how much of the catchability is increased by a new introduction of investment. This limitation is incorporated in the catchability modifier. The profits explain a part of investment (the Internal Investment, I_i), but the total investment is also affected by subsidies. Then the total investment (I) is defined as:

$$I = I_i + I_e \tag{Eq. 16}$$

where I_e are the subsidies that the fishing sector can receive from institutions (External Investment). However, the destination of investment is conditioned in the model, just as it is in the Mediterranean reality, where there is a maximum number of ships that can be based at a port, a maximum number of days of fishing, etc. The fisherman can invest to improve the catchability of the boat and fishing gear by acquiring fish detection systems, navigation aids, improving fishing machinery, modernizing the ship, etc. In this sense, investment is a concept restricted to the possibility of improving catchability and not extending to the possibility of increasing effort (as time at sea and number of vessels) beyond a maximum level set by the legislation. Investment in the present period influences catchability across the fleet in the following period through variation in total fleet capital. The value of the capital of the fleet increases with the investments $K_{t+1}=I_t+K_t$. The result of positive profits is, therefore, to increase in the following period catchability for the vessel them, while maintaining fishing effort at its maximum level.

2nd Negative Profits (losses), but bank credits are still available

In case of negative profits, the fisherman shall try to maintain the same level of activity by borrowing money from the bank. The new loan has to be added to non-redeemed loans of previous years, if any. The total debt incurred with the bank is always limited to a percentage of the value of the capital (d_m), as banks lend money on a personal guarantee. In the model, this guarantee is the value of the ship, but the bank (as in any mortgage) does not accept as guarantee something that has the same value as the loan. When this limit is exceeded, the possibility of obtaining new loans disappears, and we must examine the 3rd possibility, below. If credit is obtained, the result is that the catchability and the effort are maintained, but the following year a new added cost will exist: the financial cost (Co7), which is unavoidable.

3rd Negative Profits (losses), it is not possible to borrow more money, but the unavoidable costs can still be met.

If the fisherman cannot cover the costs and can no longer borrow money to maintain maximum catchability and fishing effort, he will have to reduce other costs. In this case, the fisherman will reduce all the costs that are avoidable in the short term: the avoidable part (Coa) of maintenance costs (Co5) in the first place. This will consequently reduce the maintenance, and thus the catchability, but still maintain maximum effort. The maintenance costs (Co5) are necessary to maintain the vessel in top operative condition. If these costs cannot be covered the value of the vessel decreases and the catchability falls. The fisherman will try to fish the legal maximum of days, but if the losses are larger than the maintenance costs he will be forced to reduce other costs, the only option being to reduce the variable daily costs (Co2). In this way, by consuming less fuel the fisherman is being forced to reduce fishing effort (in fishing days) so as to limit the variable daily expenses incurred (option 3bis).

4th Negative Profits (losses) and unavoidable costs cannot be met.

If losses become larger than the avoidable costs (Co2+Coa), the fisherman can no longer make it in the face of these unavoidable expenses and he ceases fishing. In this case, not only the catchability decreases but also the effort, and the vessel disappears from the fishery. The decrease of fishing mortality will profit the remaining ships. Then our model supposes that: 1) All profits obtained from the fisheries are invested in this activity; 2) The only financial possibilities for the fisherman are the outcomes of the activity to increase investment (or public subsidies); 3) The fisherman tries to fish as much as possible; 4) The crew accept to work for any wage, although some restrictions on this can be easily implemented, such as a minimum salary; 5) In the area of analysis only the vessels analysed can fish; 6) There is not income from other activities (agriculture, services, etc.); 7) Only the investment in catchability is allowed, due to administrative restriction on maximum effort. It is not possible to introduce new vessels or increase fishing time.

DEVELOPMENT AND SPECIFICATION OF THE MODEL

This model profit from the experience of similar models developed before as MEFISTO [16]. At present different institutes involved in the BEMMFISH project collecting and processing information on different Mediterranean Fisheries to specify the value of variables, contrast the model functions and testing the outcomes of the model. These institutions are, with the ones that present this paper, IFREMER (France), the Greek Ministry of Fisheries, IREPA (Italy), INRH (Marroc), CNDPA (Alger), INSTM (Tunis), MBRC (Libya) and Pernambuco University (Brazil). The work in progress shall be reported in the web page of the project, where is possible to find more information available: www.bemmfish.net

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^a To make q_t constant, and equal to Q_0 , it is necessary that $\tau = 1$ and $h \rightarrow \infty$. To make q_t only depend on time it is necessary that $\tau \neq 1$ and $h \rightarrow \infty$. To make q_t increase at an annual p %, $\tau = 1+p/100$. If $\tau < 1$, the catchability decreases with time. To make q_t only depend on capital it is necessary that $\tau = 1$ and $h > 0$, but not $h \gg 0$ (in order for the effect to be seen, $h \cdot K$ should be smaller than 5 and is recommended to be of the order of 1).

^b Thus, the two parameters have the following meaning: τ (condition: $\tau > 0$, reasonable $\tau \geq 1$) Expresses the dependence on time, for example if we assume an annual catchability growth of 2%, $\tau = 1.02$. If $\tau = 1$ time doesn't intervene. While, h (condition: $h > 0$). This is a modifying influence on capital in the calculation of catchability. If h is high, capital doesn't affect catchability. If h is very near 0 the weight of capital is substantial (even excessively so). h cannot be 0.

^c A part of the maintenance costs is function of benefits. These costs are devoted to improve the vessel, leading to an increase of capital and are avoidable. Another part of the maintenance costs are held constant and represent a minimum unavoidable maintenance of the vessel.