

MEFISTO 3.0

MEDiterranean FISheries Simulation TOol: A bioeconomic model for Mediterranean fisheries

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INTRODUCTION

We present a bio-economic model for Mediterranean fisheries and the software package to perform the simulations. The first objective of the model is to reproduce the bio-economic conditions in which the fisheries occur. The model is, perforce, multi-species and multi-fleet. The main management procedure is effort limitation, in terms of limits to fishing activity, but other management procedures are also available: capacity limitation, selectivity, or economic measures on productivity factors (fuel price, limits on investment, fish imports, subsidies, etc.). The model also incorporates the usual fishermen strategy of increasing efficiency, in order to increase fishing mortality, while maintaining the nominal effort. This is modelled by means of a function relating the efficiency (i.e., technological progress) with the capital invested in the fishery, and time. A second objective is to simulate alternative management strategies. The model allows operating with technical and economic management measures in the presence of different kind of events and performs stochastic simulations.

The objectives of simulating the management of fisheries can be diverse. They could be to maximize fishing production or revenues, to minimize catch fluctuations, to avoid the risk of collapse of the resource, etc. The manager has two kinds of tools available: technical (such as effort or selectivity regulations) or economic (such as subsidies and taxes). The effectiveness of each of these tools in achieving the manager's purpose varies. Complex problems require complex solutions, and the results usually are also complex. Fisheries are complex systems, hence it is not always evident how will respond to a certain management measure. Thus MEFISTO is designed as a tool to study the outcome of different management measures on a realistically simulated Mediterranean fishery.

The final users of the product are three: the scientist, the decision-maker (managers, policy-makers), and the fisherman in a broad sense (fishermen's associations, industry):

- i)* For the scientist the present model constitutes a research tool that should lead to an improved understanding of the mechanisms by which the fisheries system operates, especially in Mediterranean-type fisheries. It can also be an advisory tool, as the model acts as a test bench for analysing different management options, decision risks, sensitivity of the parameters, etc.
- ii)* For fisheries administrators and decision-makers, the model offers a way to assess the economic and biological effects of particular management measures (technical, economic or both) in the short and mid term. This could be very useful in the design of policies for mid-term objectives and for exploring the different ways to attain them. It is also important that the administrators realize the extent to which the fishery depends on the dynamics of a biological resource and not only on economic decisions.
- iii)* The model offers fishermen a new perspective on the behaviour of the system, including its temporal scale. The model should contribute to increased comprehension of the usefulness or uselessness of certain management measures, and establish the difference between short and mid term regarding earnings and losses.

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CONCEPTUAL MODEL

The objective of the model is to reproduce the fishing conditions characteristic of the Mediterranean, including several aspects that differentiate it from the models elaborated for the Atlantic fisheries. The most important particularities are:

- i) The model should necessarily be bio-economic to accommodate at the same time the dynamic nature of living resources, and the economic relationships that govern Mediterranean fisheries.
- ii) Management is mainly based on effort control, although other technical and economic measures do exist.
- iii) The management system is non-adaptive. No regular assessments are carried out and hence no adaptive management policy is implemented. TACs do not exist in these type of fisheries and the economic administrative tools acquire as much importance (or more) than the technical tools.
- iv) Increasing “catchability” (in effect, efficiency) is the mechanism of increasing fishing mortality by the fishermen: in many regions, they cannot increase fishing effort (in terms of number of boats or fishing time), as it is limited by law in the Mediterranean area. The only mechanism they have to increase catch without increasing effort is to increase their catchability by means of investment in technology. An essential point of the model is the exploration of the dependence of catchability as a function of the installed capital and time. In accordance with this hypothesis, a bio-economic model, rather than a biological one, is the more appropriate to simulate the Mediterranean fishery, since it is to a certain degree self-managed by the fishermen through economic mechanisms.
- v) The model is multi-species and multi-fleet.

The model has been built in a modular way on a system of “boxes”. A total of three boxes are defined:

1. *The stock box*. This simulates the dynamics of a particular stock. The input is the fishing effort and the catchability (these coming from *the fisherman’s box*) whose product constitutes the fishing mortality applied to the stock. The output is the catch that goes into *the market box*. The stock box can have diverse simultaneous boxes (multi-species). There are species of two kinds: the main species, whose age-structured dynamics are completely explicit, and the secondary species (or groups of species), whose dynamics are not known but whose yields are computed as a function of those of the main species.
2. *The market box*. This converts the catch into money by way of a price function. The price function includes the base price, the average fish size, and the fish offer. Additionally, sudden variations in price for exogenous reasons are also possible.
3. *The fisherman box*. This simulates the fisherman’s economic behaviour. Its input is the money coming from the market box; its output is the effort (upper-limited by law or not) and the catchability, over which the fisherman has certain control by way of function of his capital. The parameters of the fisherman’s box are contained at different levels: fleet, and vessel. The level *fleet* contains the technical and economic parameters common to a set of vessels (catchability and fishing mortality initial vectors, GT price, etc.). The level *vessel* allows particularisation of the characteristics of each boat (GT, fuel consumption, crew, etc.).

Since the model is multi-species and multifleet, it may contain several stock, market and fisherman boxes.

The simulations can also be stochastic, in that case the outputs are not a single point (deterministic process) for each time t and variable, but a set of possible outcomes, with a probability distribution.

The simulations in time are conducted by carrying a complete cycle in each time unit.

SOFTWARE COMPONENTS

Installing MEFISTO 3.0:

click the *setup.exe*³ program in the distribution CD-ROM⁴ and follow on-screen instructions. Note that the input and output data will, by default, be located in the [Program Files]/mefisto3 folder, but can be changed at installation time. MEFISTO 3.0 can be used under Microsoft 98 or later operating systems (2000, XP, but not Windows 95) and was programmed using Borland's Delphi 6.0. Currently, the software is being ported to Linux using Borland's Kylix 2.0.

To start the program, click on the *mefistob* executable or any of the Mefisto shortcuts.

Files:

The program MEFISTO works with the Excel input/output data files (*.xls)⁵. The input data files can be prepared outside the MEFISTO program, in any spreadsheet program capable of saving *.xls files. Data files can be manipulated within MEFISTO also, but to a more limited extent than in a spreadsheet program. It is recommended that the user examines the example data file provided with the installation before attempting to prepare a new data file (see also *Input Data File*, below).

Using MEFISTO:

The objective of the model is to carry projections (*SIMULATIONS*) starting from the initial conditions (*DATA* and *PARAMETERS*) forward into the future with the purpose of analyzing the behaviour of the fishery under different conditions, particularly different management situations (*SCENARIOS*).

1. A new scenario can be brought up by clicking File – Read Excel. A 7-sheet workbook appears with the data organised in the following tabs: *species*, *cohorts*, *recruitment*, *interact*, *fleet*, *vessels*, and *market*. It is important to keep the order of the sheets and the order of the variables in each worksheet, although the actual names are optional. Refer to the example data file supplied and to the table below (*Input data file*).
2. Any changes to the Excel workbook can be saved by File – Save changes.
3. Once the data is ready for the simulation, click Run – Initialize.
4. Before executing the simulations (step 5), you can change the default options (Options – Options): number of time units (years) to be projected forward, number of iterations⁶ at each projection (if the number of iterations is > 1 then the simulation is *stochastic*, otherwise it is deterministic), and the options for displaying results: mean or median, and lower / upper bounds for stochastic simulations. Initialize again (step 4) before continuing to step 5.
5. Carry out the simulation by clicking Run – Run. Once the simulation is finished, a message appears ('Simulations finished').
6. Explore the results of the simulation by clicking at Output – Standard graphs or Output – Custom graphs. See details on the use of output below (*Analysis of simulation results*).

³ depending on the source, it may be necessary to unzip a file (e.g. *mefisto3.zip*)

⁴ Updates may be found at <ftp://cucafera.cmima.csic.es/pub/maynouf>

⁵ The Excel files are supported through the FlexCel suite of Delphi components (FlexCel v. 2.5.3), written by Adrian Gallero, and used in MEFISTO under the *Mozilla Public License* as freeware.

⁶ it is recommended that the number of iterations is 100 or more, but depending on the computer and the size of the data set this can be time-consuming.

7. Management actions must be introduced in the Events menu. After clicking Events, a form with 2 tabs appear. New events are introduced in the tab 'Add event'. The Tab 'existing events' recalls which events are introduced and will be used for the simulation. To introduce an event:

- i) select at what time unit of the projection should the management action take place,
- ii) what kind of management event (available control variables are: *change in fuel price, subsidy, change of dismissal price, change of daily fishing time, change of annual fishing time, withdrawal of vessels, species imports, sudden change in market price, or changing the selectivity pattern*),
- iii) different types of events may apply to different levels of the model components: vessels or fleets, cohorts or stocks, and market.
- iv) Enter a new value for the control variable selected
- v) Click on the button 'Add'.

To remove an event from the list, click on the button 'Delete' of the tab 'Existing events'. Note that the **Events** window cannot be closed, only minimised. This is to avoid losing the entire list of events.

Input data file:

The input data file, described below, can be the result of some data analysis and preprocessing that can be undertaken in any spreadsheet package (not necessarily MicroSoft Excel), but the final data set that will serve as input to MEFISTO must be saved in *.xls format (Biff8, *i.e.* Excel 97-2000-XP).

The input data file (Excel format) is organised in 7 worksheets comprising the following concepts:

- stock parameters for the main species (worksheet *species*)
- cohorts (or age class) parameters and data for the main species (worksheet *cohorts*)
- type and parameters of the stock/recruitment relationship for the main species (worksheet *recruitment*)
- the interaction matrix between fleets and stocks (worksheet *interact*)
- parameters of the fleets (worksheet *fleet*)
- parameters and data by individual vessel (worksheet *vessels*)
- market parameters (worksheet *parameters*)

In the following tables the names of the variables are described, together with the notation used in the formulation of the MEFISTO model.

Worksheet species

Excel name	description	notation
a	a parameter of the length-weight relationship	A
b	b parameter of the length-weight relationship	B
Linf	L_∞ parameter of von Bertalanffy growth function	L_∞
K	k parameter of von Bertalanffy growth function	k
t0	t_0 parameter of von Bertalanffy growth function	t_0
Ncohorts	number of cohorts of each stock	
stockname	name of the stock (or main species)	--

Worksheet cohorts

some data in this worksheet are estimated from VPA

Excel name	description	notation
stockname	name of the stock (or main species)	--
age	age of the cohort	index a
number	number of individuals in the cohort	N_a
mat	proportion of mature individuals at age	I_a
M	natural mortality coefficient at age	M_a

Worksheet recruitment

Excel name	description	notation
stockname	name of the stock (or main species)	--
type	integer indicating the type of recruitment function. 0: $R = N_0 e^\epsilon$, “constant” recruitment 1: $R = \alpha SSB_{t-k} e^\epsilon$, “linear” recruitment 2: $N_{0,t+1} = \frac{\alpha_1 SSB_{t-k}}{1 + \beta_1 SSB_{t-k}} e^\epsilon$, Beverton and Holt model 3: $N_{0,t+1} = \alpha_2 SSB_{t-k} e^{-\beta_2 SSB_{t-k}} e^\epsilon$, Ricker model	--
rec1	parameter N_0 , α , α_1 or α_2 in the stock – recruitment function	N_0 , α , α_1 or α_2
rec2	parameter β_1 or β_2 in the stock – recruitment function	β_1 or β_2
k	age of recruitment	k
epsilon	normally distributed random variable $N \sim (0, \sigma^2)$; e^ϵ ensures a lognormal distribution of the recruitment (where e is the base of Neperian logarithms)	ϵ

R is the recruitment at time t+1, equivalent to $N_{0,t+1}$, and SSB is the Stock Spawning Biomass at time t

Worksheet interact

Excel name	description	notation
stockname	name of the stock (or main species)	--
age	age of the cohort	index a
F1 to FG	Fishing mortality by each fleet (or 'fishing gear') by age class, from fleet 1 to fleet G	F_{ag}
S1 to SG	Selectivity factor* of each fleet by age class, from fleet 1 to G , usually 1	S_{ag}
d1 to dG	proportion of discards by each fleet by age class	d_{ag}
qa1 to qaG	initial catchability coefficient of each fleet by age class; usually 1	q_{ag}

* *selectivity* in relative terms, at year 0 of the simulation all $S_{ag} = 1$ because one of the objectives of this model is to test changes in the selectivity factor.

Worksheet fleet

g is a fleet (or gear) subindex, v is a vessel subindex

Excel name	description	notation
fleetname	fleet name	--
NV	number of vessels in the fleet	--
dismissal	price paid by the fisheries Administration for decommissioning vessels, usually in terms of €GT	dis_g
Part	share of the total revenues belonging to the owner, after discounting trade and fuel costs	$c3_g$
annincq	annual increment of catchability due to technological progress	τ_g
modKq	increment of catchability due to investment in capital	h_g
Expect	proportion of profits invested in capital	u_g
NHDmax	Activity: Maximum number of hours a day by law or physically possible	$NHD_{max, g}$
NFDmax	Activity: Maximum number of day a year by law or physically possible	$NFD_{max, g}$
NHD	Activity: Average number of hours a day	NHD_g
NFD	Activity: Average number of days a year	NFD_g
ice	daily consumption of ice, in €/day	ice_g
CommCost	Commercial or trade cost, percentage paid to the fish market for the sale of fish	$c1_g$
maxcredit	Maximum amount of money lendled by the bank, as percentage of the capital	d_g
fuelprice	price of the fuel, in €/l, paid by each fleet	fp_g
oppC	opportunity costs, i.e. cost of using the capital invested	$c6$
finC	financial costs, costs of paying the debt incurred with the bank	$c7$
varEff	proportion of effort increase when profits are positive	ΔEff_g

Worksheet vessels

Excel name	description	notation
vesselname	vessel name	--
fleetname	fleet name	--
K	capital of the vessel	K_v
gt	capacity as GT (Gross Tonnage)	GT_v
credit	debt to the bank at time 0	$D_{v,0}$
consfuel	fuel consumption in l/day	fc_v
crewsiz	crew size of the vessel, including the owner if worker	cs_v
otherDC	daily costs other than fuel and ice (e.g. net mending, food for the crew, etc.)	oDC_v
annualC	costs paid at an annual scale, disregarding all daily costs. It may include: engine repair, shipyard, mooring, fishing license, etc.	AC_g
percFC	percentage of the annual costs that are fixed or compulsory to remain in the fishery: mooring, fishing license, ...	FAC_g
percVC	percentage of the annual costs that are not compulsory, they are usually not met when the profits are negative: painting, repairs, etc. Correspond to depreciation of the capital	VAC_g
active	boolean (0-1) indicating whether the vessel was active at year 0 of the simulation	--
pEff	Effort (in terms of activity: days a year) of the vessel	E_v
q	relative catchability of each vessel, i.e. relative fishing power, where the average vessel has RFP=1	Q_v

Worksheet market

Excel name	description	notation
fleetname	fleet name	--
stockname	stock name	--
g1	base or average price of main species (in €/kg)	γ_1
g2	age-modifier of price, usually positive: larger fish fetch higher prices	γ_2
g3	offer-modifier of price related to catch, usually negative: when the offer on the market is high, prices diminish	γ_3
g4	offer-modifier of price related to imports, usually negative	γ_4
delta	event-modifier of price (control variable)	δ
funct2sp	type of function relating main species to secondary species: $\left\{ \begin{array}{l} 1: C_j = \mu_{ij} + \nu_{ij} C_i \\ 2: C_j = \mu_{ij} C_i^{\nu_{ij}} \end{array} \right.$	-
mu	parameter μ in the market relationship between main species (i) and secondary species (j)	μ_{ij}
nu	parameter ν in the market relationship between main species (i) and secondary species (j)	ν_{ij}
price	average price of secondary species (in €/kg)	p_j

Estimating market parameters:

The parameter $g1$ is the mean price of a main species only when $g2$, $g3$, and $g4$ are zero. When the researcher wants to investigate the effect of the size of fish ($g2$), local offer ($g3$) or imports ($g4$), then $g1$ is not exactly the mean price but the (back-transformed) intercept of the linearized equation used to estimate the parameters. In general, market parameters for a main species i for a fleet j can be estimated from empirical data as:

$$\log p_i = \log(g1) + g2 \log(\text{avg_weight}) + g3 \log(\text{local_catch}) + g4 \log(\text{imports}) + \varepsilon,$$

where *avg_weight*, *local_catch* and *imports* are given in kg. In this case, *avg_weight* and *local_catch* are those produced by fleet j , while *imports* are for the entire system (note that imports are entered as an Event).

Similarly, the parameters μ and ν of the secondary species function can be estimated from empirical data by linear regression.

Note that all quantities related to market parameters are input as €(or other monetary unit) and kg.

Initial conditions

The MEFISTO model needs good biological and economic information to run correctly. The quality of the forecasts is directly related to the quality of this information. The model is very sensitive to the values of some parameters and data: if they are unrealistic, the model may not run or can produce extravagant outcomes. This is particularly critical for some economic parameters that are uncertain or very difficult to estimate.

Biological and demographic parameters of the stock(s)

The program start-up requires, besides the biological and economic parameters, establishing an initial stock state. This implies having the vectors of mortality and the initial number of individuals by age class (F and N). In case that the user has the catch matrix C (by gear, time and age), F and N can be reconstructed by means of a VPA. If only the matrix C (by gear and age, but not time) were available, a pseudocohort analysis (hence assuming steady state), with the program VIT (available at <ftp://cucafera.cmima.csic.es/pub/maynouf>) or other VPA-based programs should be performed. The basic biological parameters (length-weight relationship parameters and von Bertalanffy growth curve parameters) must also be supplied. The parameters for a Spawning Stock Biomass / Recruitment relationship may be supplied (if known) or the user may assume different hypotheses to relate SSB to recruitment.

It should be noted that only the observable fraction of the stock, defined as the population comprised between the first and last ages with data, is analysed. The dynamics of the population segments younger than the first observed age (defined as recruitment age) or older than the last age does not exist in the model.

Sources of economic data.

Information on the economic part of the model can be obtained from four kind of sources: Data from the national statistics, data from direct consultation with the administration or institutions, data from the analysis of the researcher that uses the model and finally data from enquiries to the fishermen involved in the fisheries.

Here we present the description and make some comments on these four information sources.

1. Data from the national statistics: Some the data can be obtained from the national statistics from databases, regular publications or web sites. Some are also possible to gather from international data sources, such as the World Bank:
 - Fuel price
 - Opportunity cost: rate of public debt
 - Financial cost: average rate of bank loans

2. Data from direct consultation with administration or institutions: Some of the necessary information can be accessible from the people involved directly in the fisheries. The information marked with an asterisk can be obtained also from enquiries to the fishermen:
 - Maximum credit: is the warranty acceptable for the banks expressed as a percentage of the capital invested in the fisheries (vessel value). Lacking better information, the mortgage market can be used as reference, taking the maximum percentage of the loan over the total value acquired (normally between 50 to 80%).
 - Commercial costs *: Costs related to first sale of the catch, such as fishermen's association (*cofradía, prudhommie*) taxes, social security, tax on revenues, etc.
 - Fishing days *: Number of actual fishing days per year.
 - Fishing hours *: Number of actual fishing hours per day.
 - Dismissal price: Average price for a vessel's Gross Tonnage paid by the administration to withdraw a vessel (can be 0 if no capacity reduction plan exists for the fishery analysed).
 - Daily ice expenses *: Average daily cost of ice per boat in the fleet.
 - Owner's share *: Percentage of the revenues, after discounting commercial costs, daily costs and fuel costs, that pertain to the owner to pay for other costs incurred in the fishing operation (annual fixed costs, etc.)

3. Analyzed by the researchers: Some data can be processed before their introduction in the model as parameters and can be used by researchers to answer *what-if* questions:
 - Market Parameters: The price of target species is affected by three factors: volume of landings (produced by the model), import from other fisheries (that can be introduced as events, by default it is zero) and average size of the catch. Additionally, the price of target species can be suddenly modified by an exogenous event. See below the formulation of the price function
 - Secondary species parameters: The model is multispecies, and it admits two classes of species: the main species and the secondary species. The main species are defined as those for which their dynamics are known so they can be simulated with the stock equations. The accessory species are defined, as those that are significant in the fishery from an economic point of view but their biological and demographic parameters are unknown. Concerning their dynamics, they are associated to a main species. Each fleet derives its revenues from the sale of the main species (whose dynamics are specified in the STOCK box). Additionally, other revenues can be obtained by the sale of secondary species. The latter are treated as a group and the revenues derived from them are put in relation to the total catch derived from each main species.

4. Data from the enquiries:

MEFISTO can simulate the behaviour of each vessel. This allows a high degree of realism in its forecasting, but requires large data sets. If the data are not totally available, it is possible to establish virtual vessels, from the data of only a part of them and to suppose that the others have similar parameters. We suggest obtaining this data, from enquiries to the owners of all vessels analyzed. Here we present an example of enquiry addressed to some ship owners. The enquiry must be short and the questions easy to understand. As criterion regarding the quality of the enquiry outcome, the answers very different (two or three times) from the average can be discarded, because perhaps some owners cannot understand the questions or do not know the appropriate information.

Name of the vessel (may be coded to preserve the statistical confidentiality).

Fishing days: Number of actual fishing days per year

Fishing hours: Number of actual fishing hours per day.

GT: Gross Tonnage or, alternatively, GRT of the vessel. This information can be obtained, alternatively from fleet censuses. Note that whatever unit (GT or GRT) is used here it must be related to dismissal price.

Vessel Value (Capital): Approximate present value of the vessel including all equipment and fishing gears. High accuracy is not of too much importance here, but it is important to obtain precise and unbiased estimate of the current sale value of the vessel.

Crew size: Most frequent crew number on board.

Fuel consumption per day in liters: The fuel consumption can be obtained directly or by estimation from the tank capacity and frequency of refueling, or from engine power.

Other daily costs: The total of the daily cost, excluding fuel, ice, bait or any cost deduced before establishing the share of the income between owner and crew members. It is possible to consider in this cost aspects such as lamps, crew food, water, etc.

Daily ice expenses: Average daily cost of ice per boat in the fleet. The value of this concept may be very different among different gears.

Annual costs: Total annual costs incurred by the vessel paid from the owner's share. This concept covers aspects such as license, mooring, vessel insurance, engine repair, shipyard, gears repair, painting, etc. Given that some costs are produced at irregular intervals (e.g., engine repair every 5 years), it is very important to obtain a yearly average.

Percentage of "fixed costs": What part of the annual cost is inevitable and paid for every year, if the owner is to remain in the fishing activity (license, mooring, minimal repairs, etc.).

Owner's share: Percentage of the revenues, after discounting commercial costs, daily costs and fuel costs, that belong to the owner to obtain their incomes and pay for other costs incurred in the fishing operation (annual fixed costs, etc.). Normally it is the same or very similar in a fleet.

Commercial costs: Costs related to first sale of the catch, such as fisherman's association (*cofradía, prudhommie*) taxes, social security, tax on revenues, etc. This is a percentage of Total Revenues from the fish sale. Normally it is the same or very similar in a fleet.

Catchability

In a scenario in which the fishing effort is limited, fishermen can increase fishing mortality increasing the efficiency of fishing. Efficiency is a component of the catchability, and depends mainly on the ability of fishermen to detect fish, localizing fishing grounds, carrying out precise hauls, etc. these goals could be achieved with technology. Increasing the catchability the fishing mortality will growth according to the equation $F=qE$ even when the effort remains constant.

Technological progress has, at least, two components: investment and time.

- Investment. Technology can be bought: The more money the fishermen invest in technology, the more efficient fishing becomes. The relationship capital invested (~value of the boat) - catchability is direct but not lineal. We assume that starts at the trivial point [0,0] and has an asymptote which represents the current level of technology available in a particular time unit. The model proposed has a single parameter to be estimated.
- Time. Technology progresses with time. The price of any particular instrument decreases with time, and usually it becomes more precise and user-friendly, hence more available to fishermen. Furthermore new apparatuses enter the market constantly. As a result fishermen can get more technology with the same investment, so the efficiency growths steadily with time. This component is also incorporated in the model in terms of percentage of catchability increase by time unit (year) with one single parameter.

Therefore the catchability depends on two independent variables: capital and time, with two parameters to be estimated. However this estimation remains very difficult because good series of [capital, catchability, time] would be needed to fit the model, and the variables capital and catchability are not easy to obtain.

Analysis of simulation results

1. Standard output

The program allows the user to examine the result of the simulation by producing a “standard output”⁷ that includes the main indicators of the simulation: *Stock mean biomass*, *Spawning stock biomass*, *Number of recruits*, *Average fishing mortality*, *Catch by stock or by fleet*, *Effort*, *Catchability*, *Capital*, *Number of vessels*, *Profits*, *Revenues* and *Costs*. These indicators are shown at an aggregated level, by fleet or stock and can be computed for all fleets and stocks.

Access the standard output by clicking **O**utput – **S**tandard output. A window appears with a list for selecting the indicator and a dropdown list for selecting the level of aggregation: fleet or total for economic variables and stock or total for biological variables. Clicking the ‘New’ button on the left panel will produce a new graph, while clicking ‘Add’ will add a new indicator to the same graph. In the case of stochastic simulations, the upper and lower bounds can be drawn (default) or not, by checking the appropriate tick box.

Each graph can be saved by clicking “Save graph” in Enhanced Metafile Format (*.emf), which is readily imported in major office applications.

The entire standard output can be produced as a spreadsheet containing one worksheet per indicator. Each worksheet contains the location of the indicator (mean or median) and the lower and upper bounds, if selected. The spreadsheet can be saved (in Excel format) for further analysis and preparing new graphs.

Note that the user can examine as many “Standard output” windows as desired.

The “Standard output” window is closed by clicking the button “OK”.

2. Custom output

This menu allows the user to create analyze any indicator related to stock, cohort, fleet or vessel, at any level of aggregation and for any iteration in the simulation. The use of “custom graphs” is similar to the use of Standard graphs. Note that the option “Export data” can create very large data files.

FORMULATION : STRUCTURE AND MATHEMATICAL MODEL

The MEFISTO bio-economic model is conceptualised primarily as a *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. A 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

⁷ The graphic output of the MEFISTO program uses the TeeChart libraries developed by David Berneda for Delphi 3 and later versions.

-an economic sub-model (including fleet, market and fishermen), accounting for the dynamics of fleets and markets, and the rules of fishermen's behaviour.

The input from the economic sub-model to the biological sub-model is mediated by fishing mortality. The outcome of the biological sub-model is fish catch, which serves as input to the economic sub-models.

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 multi-gear interactions.

There are two types of fisheries in the Mediterranean, both large scale and small scale. A socially and economically very important sector of the Mediterranean fisheries, however, consists of small scale, artisanal fleets. 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 (*cf.* Ulrich *et al.*, 2002; Sparre and Willmann, *mimeo*).

The different economic and productive structure of the Mediterranean fishery causes also differences in fisherman⁸ behaviour. There can be important differences about the objective functions of the fishermen and the social and cultural controls under which they operate. For these reasons, we consider that a realistic bio-economic model for Mediterranean fisheries has to include the specific behaviour of the individual fishing unit, or vessel. For a recent review of the characteristics of Mediterranean fisheries, see Leonart and Maynou (2003).

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.

Elements of the model

The model allows for simulating the behaviour of Mediterranean fisheries under different management strategies. The key elements of the model are:

- Stocks
 - Main species
 - Cohorts
 - Secondary species
- Fleets
 - vessels (economic units or agents)

The dynamics of the main species is modelled as an age-structured model. 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 (corresponding closely to the concept of "métier", *see definitions*), and country/area.

The model makes use of a set of biological, economic or link functions. These are:

⁸ Considering the individual fisherman, or more exactly a vessel, as the basic economic agent

1. the harvesting function,
2. the fishing mortality function,
3. the price formation function,
4. the cost of harvesting function,
5. the investment function,
6. a function modelling the dynamics of entry to the fishery or exit from the fishery,
7. a function modelling the dynamics of fishing effort, and
8. a function modelling the dynamics of catchability.

Features

The main features of the bio-economic model are listed below, many are specific to our model, while others are common to any bio-economic model:

- dynamic biological model(s) for main (target) species
- stock-recruitment relationships (one type should be chosen)
- optional stochastic variability of selected biological (stock-recruitment relationship) and economic parameters (price). Specifying stochastic variability is only necessary for stochastic simulations, not for deterministic ones.
- 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 endogenous price formation function
- simulation of management actions by user-specified “events”

The model does not include: biological interactions among species, optimisation, migration, handling or processing costs.

Spatial considerations

Space is not specified in the model, hence any spatial issue, constraint or limitation cannot be included either in the simulation or in the management considerations. The stock is defined out of space, and it is assumed that all of its components are equally available to fishing through the fishing mortality vector. If this assumption were not true the model should not be applied. So the model is applicable to any fishery (large pelagic, coastal, etc.) fulfilling this condition, otherwise the results would be misleading. Implementation of MPAs could be analysed if it can be simulated as changes on effort or fishing mortality vector (exploitation pattern).

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 (*see above, Input data*). 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).

Data: initial values of the variables and parameters

Parameter: fixed value throughout the simulation horizon. Normally coefficients of equations

Variable: can change during the simulation

Endogenous: change according to the equations

Control or exogenous: changeable by the user (“events”)

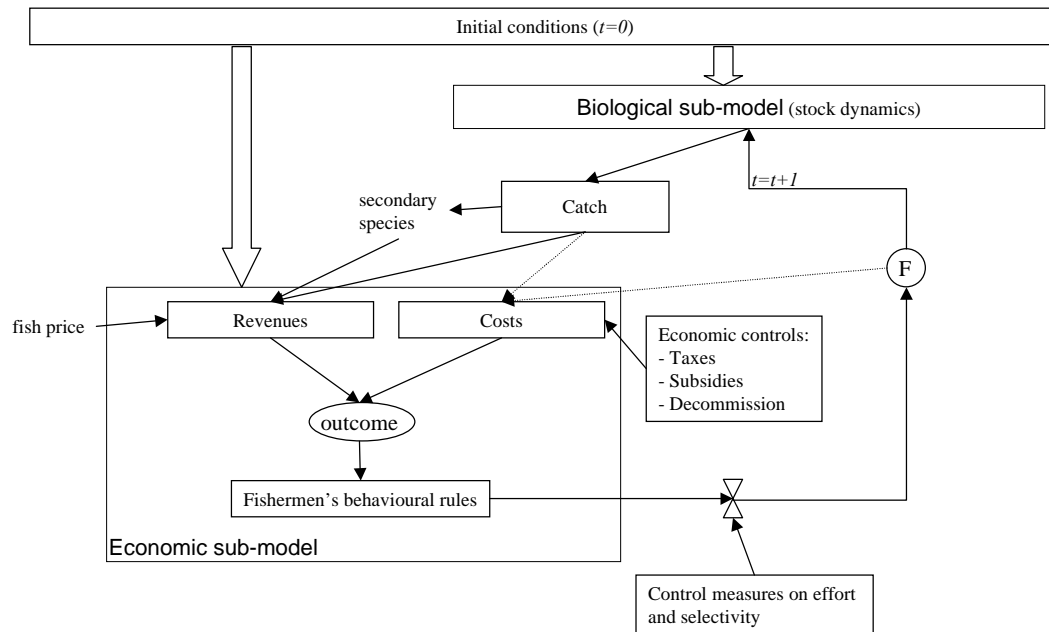
Control: simulates management actions

Exogenous: simulates not controllable externalities

Stochastic value subject to random variability following a user-specified distribution functions

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 general structure of the MEFISTO bio-economic model is shown in Chart 1. Chart 1: Workflow in the BEMMFISH bio-economic model, 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) by way of fishing mortality, following age-structured models (Beverton and Holt, 1957; Schnute, 1985; Hilborn and Walters, 1992).

The choice of the 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.

Although the model is multi-species, no biological interactions among species are considered, only technical interactions. Likewise, the influence of environmental effects on the stock dynamics is not explicitly considered (although such effects can approximately be incorporated as stochastic variability on recruitment or natural mortality or as point events in time).

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 at short term (one unit time) 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 encourage 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.

Additionally, the fisheries rent includes salaries paid to workers, with a minimum acceptable wage below which fishing will not be possible for want of workers.

Links between the biological and the economic sub-models

The revenues of catches are the input to the economic sub-model. Fishing mortality vectors are the output to the biological model.

The results of the economic sub-model are used to modulate effort and catchability (through investment in fishing activity), which define the fishing mortality applied to the stock. The effort (expressed as fishing time and number of boats) will be upper-limited to a maximum level (legal maximum effort or physically possible maximum effort) and can be modified by the manager by introducing events (modifying the number of boats or the allowed fishing time). The variations in catchability due to variations in investment and time are included in the model. The parameters should be assumed or estimated empirically from independent data.

Performance measures

Performance measures are indicators that can be compared with those of other simulations or with standard or agreed reference points.

Several performance measures can be computed from the simulation results. However, it would be advisable to analyse the outcome of the simulations in full and not give pre-eminence to any particular performance measure (some bio-economic models use only the present value of the fisheries rent as a performance measure, Sparre and Willmann, *mimeo*). The analysis of the model’s output must be done over the short and long term (Mardle and Pascoe, 1999). The performance measures may include:

-Present value of fisheries rent. The present value of profits may calculated as:

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

-“Safe” limits of biomass for target species (*i.e.*, 50% of virgin stock biomass) or other biological reference points ($F_{0.1}$, etc., Caddy and Mahon, 1995)

-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.

Management objectives

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 the project's Technical Annex and CEC (2002), 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. This scenario can be simulated only if there are clear differences in age composition inside and outside the closed area (i.e. nursery area), so the exploitation pattern (F vector profile) changes after closure
- Analysis of fishing power increase due to technological progress and fishermen's investment, by exploring the Capital / Catchability function.
- 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 endangering the stock by recruitment overexploitation. The model allows to explore 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 can be carried out.
- Economic management tools: different kinds of subsidies, taxes and credits.

The management objectives are implemented through a series of *controls* or *events*. The controls are of economic or technical nature. Among the economic control measures, the following can be investigated in one or more scenarios: Taxes, Subsidies and Decommission rules. Among the technical control measures, selectivity and effort control can be considered. 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. In this way, if a management measure fails for any reason, a second, complementary management measure can help implement the specified management policy.

The bio-economic modelling framework

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 biologically important variables such as size and age (cohorts), genetic composition,

fecundity, 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.

In this model, a stock is defined as a population whose individuals share all the biological parameters and the individuals of every cohort have the same probability to be caught.

Fleets from different states are not different in terms of modelling. Two different state fleets are considered merely as two different fleets that might be managed under different rules and parameters (i.e. fuel price, taxes, costs, etc).

Fishermen's behaviour is based on profit maximisation, while management objectives may be different from the fishermen's.

The biological sub-model

The dynamics of the number of individuals of a cohort in an age-structured model responds to the following equations (for $N_{0,t+1}$ see below, Recruitment):

$$N_{a+1,t+1} = N_{a,t} e^{-Z_{a,t}}, \quad 1 \leq a < m \quad (8.1)$$

In the case of initial data with class +, the following equation is employed

$$N_{a+1,t+1} = N_{a,t} e^{-Z_{a,t}} + N_{a+1,t} e^{-Z_{a+1,t}}, \quad a+1 = m \quad (8.2)$$

where the total mortality $Z_{a,t}$ corresponding to age-class a is

$$Z_{a,t} = F_{a,t} + (M_{a,t} + \varepsilon), \quad \varepsilon \sim U, \quad \text{or} \quad Z_{a,t} = F_{a,t} + (M_{a,t} e^{\varepsilon}), \quad \varepsilon \sim N, \quad (8.3)$$

where $M_{a,t}$ is the instantaneous natural mortality rate at age-class a and $F_{a,t}$ is the overall fishing mortality rate at age-class a . The fishing mortality at age-class a generated by fishing gear g is defined as:

$$F_{a,g,t} = q_{a,g,t} E_{g,t}, \quad (8.4)$$

where $E_{g,t}$ is the effort applied by gear g , and $q_{g,t}$ is the catchability that corresponds to gear g and age-class a .

The overall fishing mortality corresponding to age a is:

$$F_{a,t} = \sum_{g=1}^G F_{a,g,t}, \quad (8.5)$$

The fraction of the catches discarded (d) at sea can be estimated empirically from available data sets and used to split the fishing mortality into two fractions: F' (landings mortality) and F'' (discard mortality):

$$\begin{cases} F'_{a,g,t} = F_{a,g,t} - F''_{a,g,t} \\ F''_{a,g,t} = F_{a,g,t} d_{a,g,t} \end{cases} \quad (8.6)$$

The average number of individuals during the age-class interval a is:

$$\bar{N}_{a,t} = N_{a,t} (1 - e^{-Z_{a,t}}) / Z_{a,t}. \quad (8.7)$$

Individual growth:

The von Bertalanffy growth model is assumed:

$$l_a = L_{\infty} (1 - e^{-k(a-t_0)}) e^{\varepsilon}, \quad (8.8)$$

and the relative growth in weight is:

$$w_a = A l_a^B e^\varepsilon . \quad (8.9)$$

Biomass and catches

The mean biomass by age-class can be calculated with the mean weights at age (\bar{w}_a as given by Leonart and Salat, 1997):

$$\bar{B}_{a,t} = \bar{N}_{a,t} \bar{w}_a . \quad (8.10)$$

The total mean biomass for the whole cohort is then:

$$\bar{B}_t = \sum_{a=1}^m \bar{B}_{a,t} . \quad (8.11)$$

The catch of age-class a individuals by gear g is:

$$C_{a,g,t} = F_{a,g,t} \bar{B}_{a,t} , \quad (8.12)$$

and the catch by age-class, gear, and total catch are given by the following equations:

$$C_{a,t} = \sum_{g=1}^G C_{a,g,t} , \quad (8.13)$$

$$C_{g,t} = \sum_{a=1}^m C_{a,g,t} , \quad (8.14)$$

$$C_t = \sum_{a=1}^m \sum_{g=1}^G C_{a,g,t} . \quad (8.15)$$

Recruitment

A recruitment model is necessary in simulation studies to link the state of the population at time t with the population at time $t+1$. Except for the case of constant recruitment, the number of recruits is a function of the spawning stock biomass ($SSB_{a,t}$) that is calculated as the proportion of mature fish by age ($I_{a,t}$) of the mean biomass:

$$SSB_{a,t} = \bar{B}_{a,t} I_{a,t} , \quad (8.16)$$

$$SSB_t = \sum_{a=1}^m SSB_{a,t} . \quad (8.17)$$

Three different procedures for generating recruits are used:

- Constant recruitment, where for each simulation the same number of recruits $N_0 = R e^\varepsilon$ is generated;
- Beverton and Holt's model:

$$N_{0,t+1} = \frac{\alpha_1 SSB_{t-k}}{1 + \beta_1 SSB_{t-k}} e^\varepsilon , \quad (8.18)$$

- Ricker's model

$$N_{0,t+1} = \alpha_2 SSB_{t-k} e^{-\beta_2 SSB_{t-k}} e^\varepsilon , \quad (8.19)$$

where k is the age of recruitment and ε is a normally distributed random variable.

Links between the biology and the economy:

The links between biological and economic boxes is F , fishing mortality, decomposed in effort (E) and catchability (q).

Effort

Effort (E , expressed in fishing time), is a factor for F . For the dynamics of E , see *Behavioural rules of the firm*.

Catchability

The species-specific catchability function q_t includes the variation of fishing mortality related to the variability in the production factors (Ulrich *et al.*, 2002). 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: Leonart *et al.*, 1996, 1999), stock size (Sparre and Willmann, *mimeo*), technical development in fishing efficiency (Sparre and Willmann, *mimeo*), or intra- and inter-annual variation (Eide *et al.*, 2003).

There are a large number of elements that relate fishing effort with fishing mortality (catches), and they are all contained within catchability. Laurec and Le Guen (1981) give the following outline:

1) *availability*: depends on the fish and the fishing gear and is independent of the fisherman's behaviour.

- i) *accessibility*: geographical component, displacement from and to the fishing areas.
- ii) *vulnerability*: related to fish behaviour.

2) *efficiency*: this depends, among other factors, on the fishing strategy or fishing tactics.

Of all these elements, the one that the fishermen clearly can modify is efficiency for a particular gear. In our model, catchability depends on investment in technology (increase in capital) and temporal trends (Leonart *et al.* 1996, 1999).

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 :

$$q_{v,t} = Q_{v,0} \tau^t \frac{1 - e^{-hK_{v,t}}}{1 - e^{-hK_{v,0}}} \quad (8.20)$$

where $Q_{v,0}$ is the initial vessel-specific catchability constant, τ is the fraction of catchability variation with time, h is the proportion constant to capital, and $K_{v,t}$ is the capital of vessel v at time t and $K_{v,0}$ 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 $t=0$) respectively⁹.

Maximum catchability (for “infinite” capital) is: $Q_0 / (1 - \exp(-h \cdot K_0))$.¹⁰

⁹ 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).

¹⁰ 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.

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.

The part of catchability that is influenced by fishing gear specifications (*availability*) is simply modelled by introducing a control variable S , selectivity, which can be modified by the manager as an event. Then total fishing mortality is:

$$F_{a,g,t} = q_{a,g,t} E_{g,t} S_{a,g,t} \quad (8.21)$$

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

Economic sub-model

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

$$Y_{v,t} = \frac{E_{v,t} q_{v,t}}{\sum_v E_{v,t} \sum_v q_{v,t}} Y_{g,t}, \text{ for vessels } v \text{ in fleet } g \quad (8.22)$$

Fishing mortality results from applying fishing capital to fish stocks. By fishing capital 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. is implied. These variables are represented by a vector \mathbf{k} . By application of this capital, the total time that it is applied to fishing is implied. 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.

Fish price function

The value of the harvest, for each fleet and stock is given by the general fish price equation:

$$p_{g,t} = f(Y_{g,t}, \mathbf{Z})$$

where the vector \mathbf{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 ($p_{i,g,t}$) for each fleet g is given by the multiplicative model:

$$p_{i,g,t} = \gamma_1 \bar{w}_{i,g,t}^{\gamma_2} C_{i,g,t}^{\gamma_3} imp_{i,t}^{\gamma_4} \delta_{i,g,t} \cdot e^\varepsilon, \quad (8.23)$$

where:

- γ_1 is a theoretical price when all the other variables are 1,
- γ_2 is a size modifier of price with the average weight of a fish caught by this fleet. The average weight of an individual of stock i caught by fleet g is $\bar{w}_{i,g,t} = \frac{C_{i,g,t}}{N_{i,g,t}}$
- γ_3 is an offer modifier of price with local catch, whereby price varies with catch of stock i for gear g : $C_{i,g,t}$,
- γ_4 is an offer modifier of price with imports, whereby price varies with the imports of stock i : $imp_{i,t}$,
- $\delta_{i,g,t}$ is a sudden price modifier by fleet, simulating the effect of a sudden price change due to exogenous reasons.

Note that τ is conceptually easier to understand than h . This is because τ is independent and has no dimensions while the value of h depends on the magnitude and dimensions of the capital, hence no easy guidelines can be provided to assess its value.

- ε is an error term (centered around 0), simulating stochastic variation in prices. The stochastic variation follows a log-normal distribution, while $\varepsilon \sim N(0, \sigma^2)$.

Harvest cost function

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

$$Co_{v,t} = f(k, Y_{v,t}, w),$$

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, hereafter the subscripts v and t are dropped, except when necessary to avoid confusion) with the following empirical relationships between C_i and C_j and the parameters μ and ν , estimated from available data series:

$$\begin{cases} C_j = \mu_{ij} + \nu_{ij} C_i \\ C_j = \mu_{ij} C_i^{\nu_{ij}} \end{cases}, \quad (8.24)$$

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

$$P_v = \sum_{i=1}^I C_i p_i + \sum_{j=1}^J C_j p_j + O_v, \quad (8.25)$$

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:

$$RT_v = P_v - Co_v, \quad (8.26)$$

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

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 the following table:

Possible costs that fishermen may incur

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	Co5.1	function of profits ¹¹ (1)
		Compulsory costs	Co5.2	constant (2)
	Co4		constant	
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 Revenues:

$$Co1_v = cl_g \cdot P_v \quad (8.27)$$

where cl_g is a constant for each group of vessels in the same fleet g .

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. For each vessel v we have (see *Input data file*, worksheet fleet and vessels, above):

$$Co2_v = NFD_v (fp_g \cdot fc_v + ice_g + oDC_v). \quad (8.28)$$

When the initial P_v is reduced by $Co1_v$ and $Co2_v$, the remainder (known in Spain as “monte menor”) is:

$$MM_v = P_v - Co1_v - Co2_v. \quad (8.29)$$

MM is divided in parts, one for the owner and another for the crew (including the owner, when the owner is a worker). The 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 corresponding to the crew as a function of function of MM :

$$Co3_v = c3_g (P_v - Co1_v - Co2_v). \quad (8.30)$$

It is also possible to obtain the average wage as:

$$AW_g = Co3_g / \text{crew number} \quad (8.31)$$

The average wage of the crew can be monitored as a performance measure in the model, in the sense that high wages can encourage 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. They are entered in the model as *annual costs*.

$Co5$ is divided in two parts by a percentage per vessel. The first part is the operating costs that are indispensable (“unavoidable”: $Co5.1$) to meet in order to remain in activity, given by the proportion FAC_g (“Fixed Annual Costs”). The second part is the other maintenance cost, which is avoidable but reduces the catchability when modelling the catchability as a function of capital ($Co5.2$: painting, maintenance of electronic devices, maintenance of engine, etc.). This percentage (VAC_g) 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.

$$Co6_v = c6 \cdot K_v \quad (8.32)$$

where K_v is the total investment in vessel v .

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).

$$Co7_v = c7 \cdot D_v \quad (8.33)$$

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 $d_g \cdot K_v$, where d_g is a maximal percentage of lend authorised by the bank, and K_v the total vessel investment.

Some parameters determine the level of each cost. To facilitate data input, the model assumes that some of them are equal for any vessel of the fleet (e.g., $c1$, $c3$, $c6$ and $c7$), and others for each vessel.

Capital dynamics and investment

The firm’s capital (K) is altered over time by investment and deterioration or depreciation. The basic dynamic identity is:

$$K_{t+1} = K_t - \delta_t \cdot K_t + I_t, \quad (8.34)$$

where δ_t is the deterioration parameter function and I_t the investment in capital.

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 firm’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.

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:

$$\Pi_K(K) = w_i,$$

where Π represents current profits and w_i denotes the use or rental price of 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 fishery¹². 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.

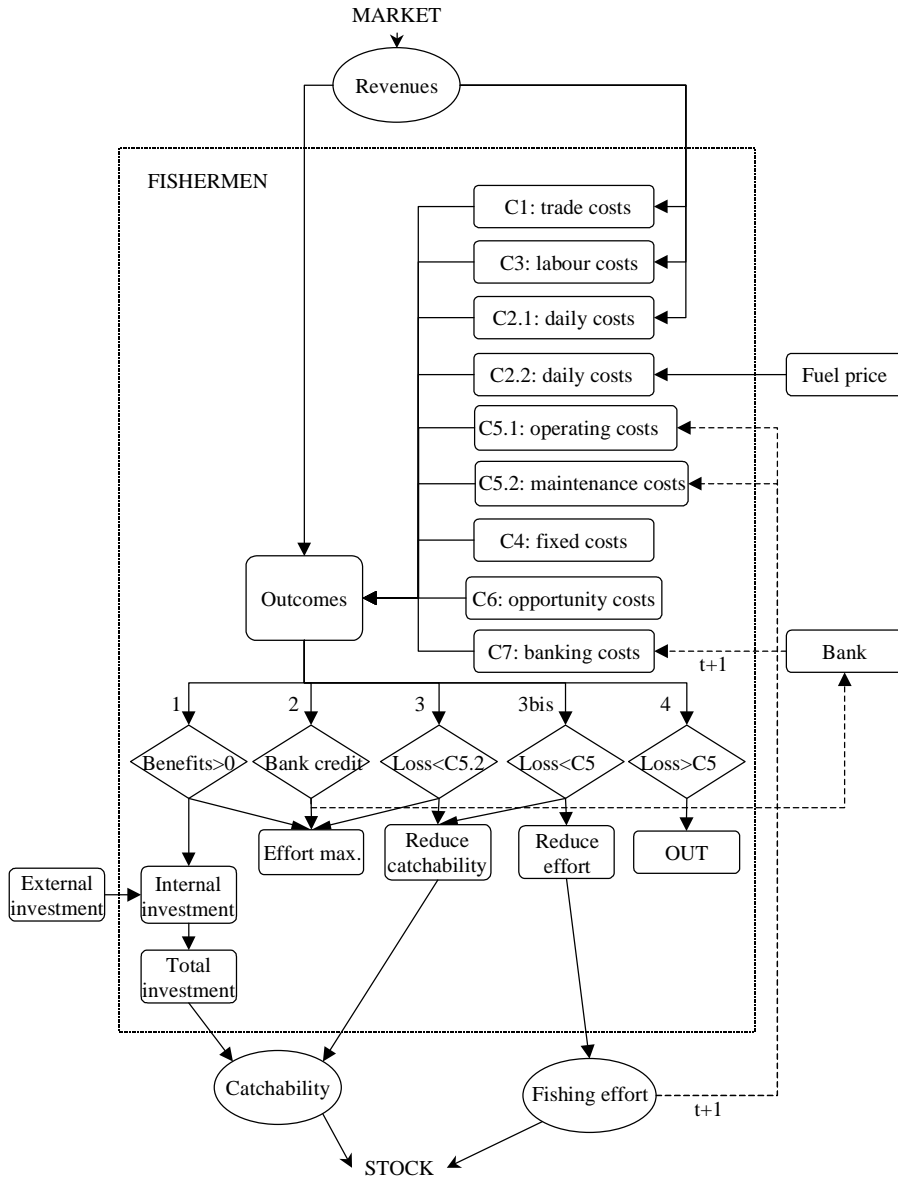
The assumptions on the behavioural rules of the fisherman (*fishermen's decision*) are:

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.
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. Chart 2 reproduces the deduction of costs from the total revenue to arrive to the final profit level, which is the outcome of the economic box.

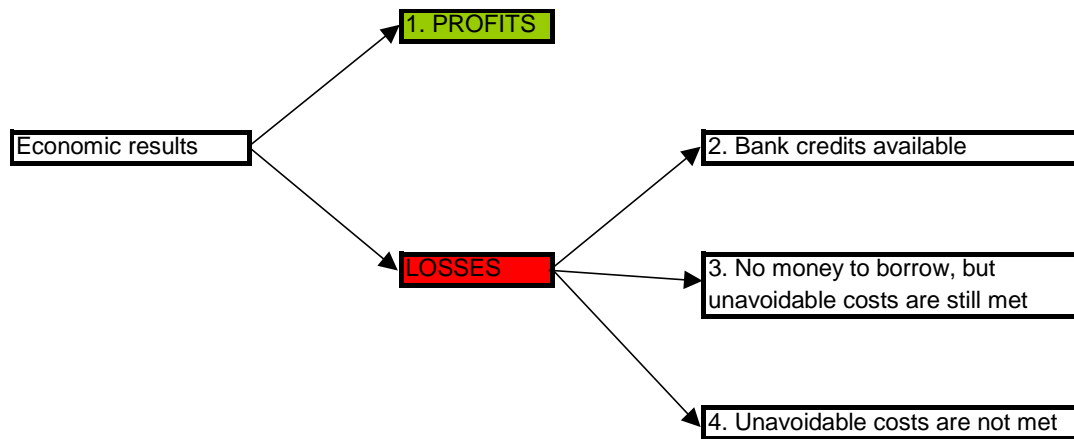
The manager's control variables (taxes, subsidies, decommission, price of effort, allocation of effort, etc.) can modify directly or indirectly the result of the fishermen's behavioural rules.

Chart 2: The behavioural rules of fishermen



Regarding the fishermen's "financial health" after one time-unit period, there exist 4 possible results. We model the fishermen's priorities in response to these economic results in Chart 3.

Chart 3: Fishermen possible economic results



1st Positive Profits

The profits in the model are reinvested by a factor u_g of expectative ($u_g = 1$, total reinvestment, $u_g = 0$ no internal investment). 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 (equation 8.20 above). The profits explain a part of investment (the Internal Investment, I_i), but the total investment is also affected by subsidies (entered as a manager's event). Then the total investment (I) is defined as:

$$I = I_i + I_e \tag{8.35}$$

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_g), as banks lend money on a personal guarantee. In the model, this guarantee is the value of the vessel, but the bank (as in any mortgage) would 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 ($Co5.I$) 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 ($Co5.2$) of the maintenance costs 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 in capital of the vessel decreases as well as the catchability (according to the equation 8.20).

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 ($Co2+Co5.2$), 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 assumes that:

- 1) Profits obtained from the fisheries are internally 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 exert as much effort 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 fleets analysed can fish
- 6) There is no 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.

Definitions

Accessory or Secondary species: In the age-structured model, a secondary species (or pool of species) is a part of the catch of the fleet whose dynamics are not known, but it generates significant amounts of revenues for the fleet. The catches from secondary species are determined in relation (positive or negative) to a main species catches.

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). This definition of fleet is close to the definition of *fishing tactic* or *métier* (e.g. Biseau, 1998). An alternative definition, on economic grounds could be “a group of vessels sharing the same cost structure and exploitation pattern (fishing mortality vector profile)

Main species or target species: In the age-structured model, a main species is a stock unit with well-defined population dynamics.

Scenario: It is the combination of a data set with a management policy. Hence, for each case study, several scenarios can be defined according to the management policies to be tested.

Vessel: basic economic unit; economic agent; firm.

Notation

M: mass, L: length, T: time, MU: monetary units

<i>symbol</i>	<i>description</i>	<i>units</i>	<i>dimension</i>
α_1	parameter of the stock-recruitment relationship in B&H model	ton ⁻¹	M ⁻¹
α_2	parameter of the stock-recruitment relationship in Ricker model	ton ⁻¹	M ⁻¹
β_1	parameter of the stock-recruitment relationship in B&H model	ton ⁻¹	M ⁻¹
β_2	parameter of the stock-recruitment relationship in Ricker model	ton ⁻¹	M ⁻¹
δ	depreciation of capital	-	-
ε	random variable, generic term of stochastic error	-	-
τ	parameter in the time-catchability relationship		-
μ	parameter in the revenue-catch relationship for secondary species	ton	M
ν	parameter in the revenue-catch relationship for secondary species	ton ⁻¹	M ⁻¹
a	age	year	T
AC	annual costs other than daily costs	€year	MU·T ⁻¹
AW	average wage	€year	MU·T ⁻¹
A	parameter in the length-weight relationship	g/cm ^B	M·L ^{-B}
B	parameter in the length-weight relationship	-	-
B	biomass	ton	M
\bar{B}	mean biomass	ton	M
γ_1	base price	€year	MU·T ⁻¹
γ_2	size (weight) price modifier	-	-
γ_3	offer (catch) price modifier	-	-
γ_4	offer (imports) price modifier	-	-
δ	exogenous price modifier (controlled by manager)	-	-
C	catch	ton/year	M·T ⁻¹
Co	costs	€year	MU·T ⁻¹
$Co1$	Trade costs	€year	MU·T ⁻¹
$Co2$	Daily costs	€year	MU·T ⁻¹
$Co3$	Labour costs	€year	MU·T ⁻¹
$Co5.1$	Compulsory maintenance costs (unavoidable to remain in the activity)	€year	MU·T ⁻¹
$Co5.2$	avoidable maintenance costs (to offset depreciation of capital)	€year	MU·T ⁻¹
$Co6$	Opportunity costs	€year	MU·T ⁻¹
$Co7$	Financial costs	€year	MU·T ⁻¹
D	Debt incurred by vessel	€year	MU·T ⁻¹
d_g	Maximum percentage of lend	-	-
d	Fraction of discards	-	-
E	Effort	-	T
F	Fishing mortality	year ⁻¹	T ⁻¹
FAC	percentage of the annual costs (AC) that are unavoidable	%	-
fc	fuel consumption	l / day	M T ⁻¹

G	number of fishing gears (“fleets”)	-	-
g	index of fishing gears	-	-
h	parameter in the capital-catchability relationship	€ ¹	MU ⁻¹
I	Proportion of maturity in biological models	-	-
I	level of investment in economic models	€	MU
i	stock index		
K	capital	€	MU
K_0	initial capital	€	MU
k	growth rate in the von Bertalanffy growth model	year ⁻¹	T ⁻¹
k	age of recruitment in the stock-recruitment relationships	year	T
l	size (weight) in the price formation function	g	M
l	individual length	cm	L
L_∞	maximum length in the von Bertalanffy growth model	cm	L
M	natural mortality rate	year ⁻¹	T ⁻¹
m	maximum age	year	T
MM	“monte menor”	€year	MU·T ⁻¹
N	number of individuals	indiv.	
\bar{N}	mean number of individuals	indiv.	-
O	other income (e.g. subsidies)	€year	MU·T ⁻¹
oDC	other daily costs used in Co2	€day	MU·T ⁻¹
imp	imports in the price formation function	g	M
P	Total revenues (Gross Value of Production)	€year	MU·T ⁻¹
p	price (of main i or secondary j species)	€kg	MU·M ⁻¹
q	catchability	day ⁻²	T ⁻²
Q_0	initial (relative) catchability of a vessel	day ⁻²	T ⁻²
R	recruitment	indiv.	
RT	rent, net revenues	€year	MU·T ⁻¹
S	selectivity		-
SSB	spawning stock biomass	ton	M
T	maximum index of time in the simulations	year	T
t	time	year	T
t_0	age at length 0 in the von Bertalanffy growth model	year	T
t_0	initial time of simulations	year	T
VAC	percentage of the annual costs that are avoidable	%	-
v	index of vessel		
w	individual weight	g	M
\bar{w}	mean individual weight	g	M
Z	total mortality rate	year ⁻¹	T ⁻¹

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