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FISHRENT

Bio-economic simulation and optimisation model for fisheries

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FISHRENT; Bio-economic simulation and optimisation model for fisheries

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Preface

With this publication we wish to contribute to the international research on bio-economic modelling and to preparation and analysis of fishery management options by means of bio-economic models. The structure and the specification of the model can be interpreted as an agenda for future theoretical and empirical research, in particular in areas of investment behaviour, production functions and stock-growth relations. The model shows in great detail which relations are required and which parameters must be estimated.

By the time of this publication, the model has already proven its value for practical policy preparation and evaluation. The model was developed under the EU project 'Remuneration of spawning stock biomass' and within this project the model generated almost one hundred scenarios analysing potential resource rents in seven major EU fisheries. The results of this project can be found on the website of the European Commission/DG Mare (Salz et al., 2010). The model was also used for additional empirical applications by the authors and is under further development for new applications.

We would like to thank the European Commission for its support under the above mentioned project. We would also like to encourage the readers to test the model and to provide feedback to the authors for further refinements. We are confident that the model contributes to a solid basis for future development in this area.

Prof.dr.ir. R.B.M. Huirne
Managing Director LEI

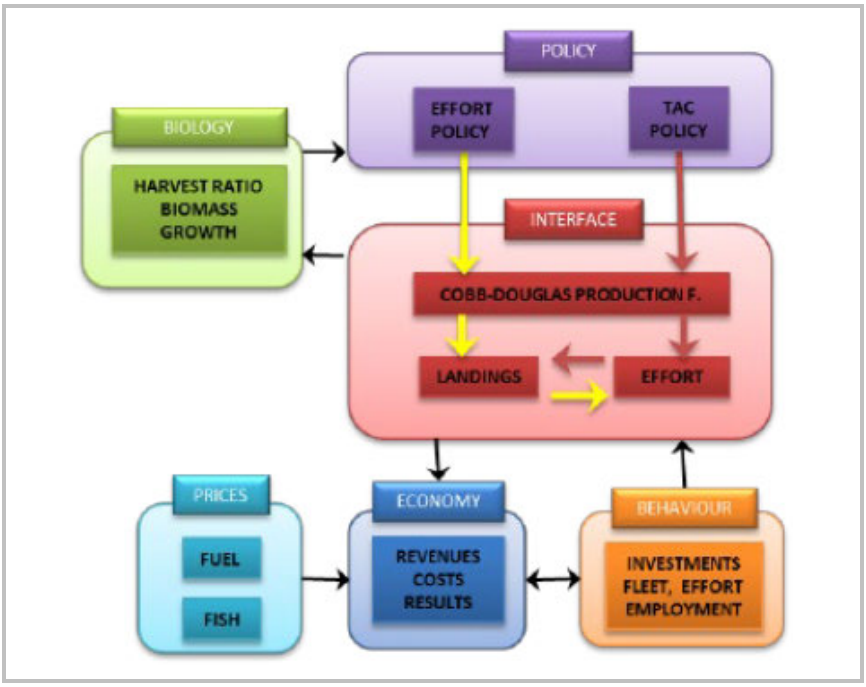
Summary

S.1 Key findings

The FISHRENT model is a major step forward in bio-economic modelling, combining features that have not been fully integrated in earlier models:

- **Incorporation of any number of species (or stock) and/or fleets**
- **Integration of simulation and optimisation over a period of 25 years**
- **Integration of effort and TAC-driven management policies**
- **Three independent relations for stock growth, production and investments.**

The feedbacks within the model allow for a dynamic simulation. The main application of the model is scenario analysis of policy options.



S.2 Complementary findings

The model formulates a complete set of mathematical relations, but it also contains a number of important assumptions, which remain to be tested empirically. Therefore the model presents a challenging agenda for empirical research, which should lead to further qualitative and quantitative improvements of the individual mathematical equations and parameter values.

S.3 Method

This model was developed during the EU-funded project 'Remuneration of spawning stock biomass'. Its aim was to generate consistent sets of scenarios for an assessment of potential resource rents in different EU fisheries.

The model comprises six modules, each focussing on a different aspect of the functioning of the fisheries system: biology (stocks), economy (costs, earnings and profits), policy (TACs, effort and access fees), behaviour (investments), prices (fish and fuel) and an interface linking the modules together. Input, calculation and output are clearly separated. The model produces a standard set of graphics, which provide a quick insight into the results of any model run. All output of the model runs can be exported to database software for further analysis.

The model has been built in Excel, which makes it accessible for most users. It has been used in new applications and even translated to other software. The model is continually further developed.

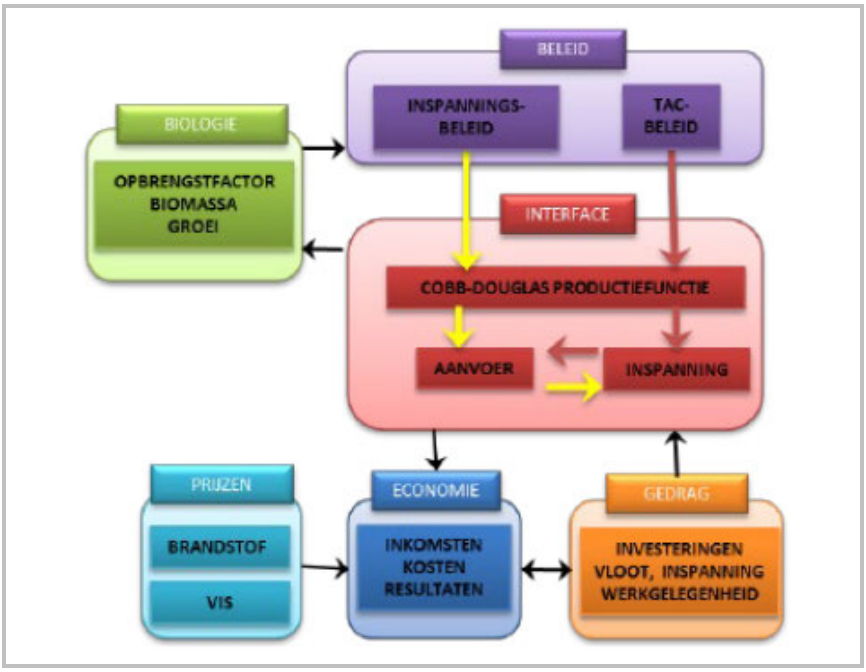
Samenvatting

S.1 Belangrijkste uitkomsten

Het FISHRENT-model is een grote stap voorwaarts op het gebied van bio-economische modellen. In dit model worden aspecten gecombineerd die in eerdere modellen niet op deze wijze waren geïntegreerd:

- **Elk willekeurig aantal soorten (of bestanden) en/of vloten;**
- **Simulatie en optimalisatie over een periode van 25 jaar;**
- **Inspanningsbeheer en management op basis van TAC;**
- **Drie onafhankelijke verbanden voor groei van het visbestand, productie en investeringen.**

De terugkoppelingen van het model maken een dynamische simulatie mogelijk. Het model wordt voornamelijk toegepast voor scenarioanalyses van beleidsopties.



S.2 Overige uitkomsten

Het model vormt een complete set wiskundige verbanden, maar omvat ook een aantal belangrijke aannames, die nog empirisch moeten worden getest. Daarom biedt het model een uitdagende agenda voor empirisch onderzoek, wat zou moeten leiden tot verdere kwalitatieve en kwantitatieve verbeteringen van de afzonderlijke mathematische vergelijkingen en parameters.

S.3 Methode

Dit model is ontwikkeld tijdens het door de EU gefinancierde project 'Remuneration of spawning stock biomass'. Het doel was om een consistente set scenario's te genereren om de potentiële 'resource rent' in verschillende visserijen in de EU te beoordelen.

Het model omvat zes modules die elk gericht zijn op een ander aspect van het functioneren van het visserijsysteem: biologie (visbestanden), economie (kosten, inkomsten en winst), beleid (TAC's, inspanning en betaling voor toegang), gedrag (investeringen), prijzen (vis en brandstof) en een interface die de modules verbindt. De input, berekening en output zijn duidelijk van elkaar gescheiden. Het model genereert een aantal standaardgrafieken die snel inzicht bieden in de resultaten van elke modelberekening. Alle outputs van de modellen kunnen worden geëxporteerd naar databasesoftware voor nadere analyse.

Het model is gebouwd in Excel, waardoor het toegankelijk is voor de meeste gebruikers. Het is gebruikt in nieuwe toepassingen en vertaald in andere software. Het model wordt voortdurend verder ontwikkeld.

1 Introduction

The FISHRENT model was developed as a part of the EU funded study 'Remuneration of spawning stock biomass[1]' (Salz et al., 2010) on the basis of earlier experiences of the team in bio-economic modelling, inter alia EIAA, BEMMFISH, TEMAS, AHF and other models which were evaluated within the project 'Survey of existing bio-economic models' (Prellezo et al., 2009). However, none of these models was appropriate to estimate resource rents under different conditions and management regimes, as required in the present project.

On the basis of the review of models and the objective of the project, it became evident that a new model had to be constructed which would meet the following requirements:

- Integrate simulation (of different management strategies) and optimisation (to determine optimum value of resource rent and other variables).
- Integrate output- and input-driven approaches, so that one model could be consistently applied to different situations in the EU, particularly the Atlantic and the Mediterranean/Black Sea areas.
- Accommodate multi-species/multi-fleet fisheries, with flexible number of species and segments.
- Close link to available economic and biological data, to allow empirical applications.
- Balanced composition between various components: biology-economics-policy.
- Dynamic behaviour over a long period, including stock-growth, investment and effort functions, to allow simulation of adjustment paths to an optimum.
- Flexibility for applications of various types of relations (e.g. different stock-growth functions, approaches to payment for access, etc.).
- Use of a well-known language (Excel) to allow a broad introduction and accessibility to different users.

The FISHRENT model contains six modules:

1. Biological module
2. Economic module
3. Interface module

[1] Available at: http://ec.europa.eu/fisheries/documentation/studies/remuneration_of_the_spawning_stock_biomass_en.pdf

4. Market module
5. Behaviour module
6. Policy module

The main characteristics of the FISHRENT model are:

- The model accounts for eight species and eight fleet segments (4*4 version is also available), but can be extended to a larger number if required, or reduced to a smaller size. The procedures for adaptations are described in Appendix 1.
- The model is a dynamic simulation model, running for a period of 25 years. Extension to a longer period is possible.
- By using the Excel Solver tool, the model can be used as an optimisation model, which is particularly relevant in relation to the estimation of the potential optimum resource rent.
- The model combines input and output based management, as well as their combinations. This has been achieved by a two stage calculation, in which first the relevant combination of effort and catch is determined and subsequently applied in the actual simulation model.
- The model contains various options for the collection of rent (payment for access), including fixed fee per unit of capacity (vessel), payment per unit of effort (day-at sea) and tax on revenues or profits.
- The model contains a large number of features, including parameter for technological progress, discards of sized and undersized fish, various options for simulation of investments, etc. Details are presented below.
- Using Excel implies that all relations are individually specified. Consequently, the specification of any relation can be easily adapted, e.g. each stock may be characterised by a different growth function and each fleet segment by a different investment function.

In Table 1.1 the FISHRENT model is compared to several major models, which have been developed and applied recently. The comparison shows that FISHRENT contains various features that have not been integrated in a similar way before.

Table 1.1 Comparison of FISHRENT with selected bio-economic models

Criteria	FISHRENT	EIAA	BEMMFISH	World Bank	EMMFID	Norwegian model
Model objective	Estimation of resource rent for specific fisheries	Economic evaluation of biologic advice	Modelling of Mediterranean fisheries	Estimation of resource rent on global level	Estimation of resource rent for the whole Danish fishery	Estimation of resource rent for the major part of the Norwegian fishery
Estimates resource rent	Per year, NPV of profits	Annual profit	Per year and NPV of profits	Point estimate of max. rent	Point estimate of max. rent	Point estimate of max. rent = net profit
Simulation/ optimisation	Simulation and optimisation	Simulation	Simulation	Optimisation by solving the profit equation	Optimisation using linear programming	Optimisation using linear programming
Input/output driven	Input and output	Output	Input	Output	Input and output	Input and output
Policy options	Free access, TAC and Effort restriction	TAC	Fishing time (effort), vessels, taxes	None	Free access, TAC and Effort restriction	Free access, TAC and Effort restriction
Fish prices elasticity	Yes	Yes	Yes	No	No	No
Accounting for exogenous fuel price changes	Yes	No	No	No	No	No
Investment function	Yes	No	Yes	No	No	No

Table 1.1	Comparison of FISHRENT with selected bio-economic models (continued)					
Criteria	**FISHRENT**	**EIAA**	**BEMMFISH**	**World Bank**	**EMMFID**	**Norwegian model**
Biological input	Biomass. Stock-growth function in a flexible format. Source: ICES and Italian institutes	Yield in terms of TACs and abundanc-es of spawning stock biomasses. Source: ICES	Stock-growth function	Single species model Logistic (=2nd degree polynomial) Fox. Sources: FAO and other	TAC/catch restrictions	TAC/catch restrictions
Economic input	Multi fleet. DCF data, distinguishing 5 cost components	Multi fleet. DCF data, distinguishing 5 cost components	DCF with minor assumptions	Distinguishes be-tween variable and fixed costs. Source: large variety of data	Detailed cost structure	Detailed cost structure
Number of years	25 years, expandable	3 point estimates Current year, next year, and long term.	40 years	Static	Static	Static
HCR/manage-ment plans	Multi-species, Six policy options: TAC min TAC max Effort min Effort max Min-Min Open access	Single species, management plans in terms of TAC/quotas	No	No	Single species, management plans in terms of TAC/quotas and effort	-

Table 1.1 Comparison of FISHRENT with selected bio-economic models (continued)

Criteria	FISHRENT	EIAA	BEMMFISH	World Bank	EMMFID	Norwegian model
Discards	Two types: undersized and over-quota	No	No	No	No	No
Software	Excel	Excel	Java	None	GAMS/Excel	Matlab
Dynamic/Static	Dynamic	Static	Dynamic	Static	Static	Static
Dimensions:						
- Fleets	Up to eight, expandable	Unlimited	Multi-fleet	Single fleet	26	25 aggregated to 11
- Species	Up to eight, expandable	25 species; 110 stocks	Unlimited	Single species	118	10
- Area unit	Fishery areas based on stock definitions	Based on stock management definition	None	Single area (Earth)	34 fishing areas based on stock definitions; 14 regions	None
- Time unit	Year	Year	Year	NA	Month	Year

Sources: Prellezo et al. (2009), World Bank (2009).

The FISHRENT is a full-feedback model, containing independent procedures for the development of the stock (stock-growth function), production and effort (production and investment function). Consequently, the model can shift according to the most restrictive constraint, be it the total available effort of each fleet segment or the TAC/quotas of specific species. This approach allows simulating the economic performance of individual fleet segments independently of each other over a long period of time.

2 Concepts

2.1 Modelling in general

A simulation model links a set of variables with mathematical equations in order to simulate a certain development. The solution is determined by these equations and various types of constraints to which they may be subject. In case of optimisation, the model is extended with an 'objective function' or 'objective variable'.

There are two types of variables:
- *Endogenous* (or dependent) variables - the values are determined in the model.
- *Exogenous* (or independent) variables - the values come from other sources. Two types of exogenous variables can be distinguished:
  - Equation parameters, which may have been estimated on the basis of available statistics, assumed or calibrated (i.e. determined by trial and error so that the model produces certain results, e.g. reproduces historical values);
  - Baseline data, i.e. starting values of the endogenous variables - year 1 in a dynamic model, and various constants.

The model consists of two types of relations:
- *Mathematical equations*, linking the endogenous variables. Once set, the equations do not change, unless it is concluded on the basis of additional information that the form or parameter values of the equation should be adjusted.
- *Constraints and decision rules*, steering the calculations along a certain path or constraining the endogenous variables to remain with specified boundaries. Regarding constraints and decision rules, a distinction can be made again between endogenous and exogenous:
  - Endogenous constraints and decision rules are based on specific algorithms in the model.
  - Exogenous constraints and decision rules are choices which can be made before running the model.

The model needs to be based on a set of sound theoretical and empirical *concepts*. These concepts allow distinguishing the main *modules* (components) of

the model and their relations. Modular approach to model building allows at any time to develop specific modules further, without having to adapt the model as a whole. Such development does not necessarily affect the relations between the modules.

Each model is structured around three fundamental components:

- *Input*, i.e. the values of all exogenous variables;
- *Calculation*, i.e. all relations, constraints and some decision rules;
- *Output*, i.e. the way in which the results are presented.

These components can be further sub-divided into suitable steps.

2.2 FISHRENT modules

The FISHRENT model is a generalised multi-species multi-fleet simulation and optimisation model, built in Excel. The basic version contains eight fleets and eight species and runs for a period of 25 years. The dimensions of the model can be flexibly reduced or expanded. The model is structured in six modules: biology, economy, interface, prices, behaviour and policy. In addition, the Excel model contains a module with the totals, summing variables over fleets or species. The general structure of the model and its modules is presented in Figures 2.1 and 2.2 It can be summarised as follows:

- Biological module contains the stock-growth function.
- Economic module contains the economic performance of the fleets.
- Interface module is the core of the model containing the bio-economic production functions for each combination of segment and species. This module reflects the interaction between the fishing fleet and the fish stocks.
- Price module contains fish prices, price elasticities and the possibility to adapt the price of fuel.
- Behaviour module determines the (dis)investment behaviour of the fleet, according to the realised economic performance.
- Policy module contains six policy options based on different approaches to management by TACs and effort including an option of open access fishery.

The main characteristics of the FISHRENT model are:

- Three independent relations for stock growth, production (catch) and investment.
- Integration of TAC and effort-based policies.
- Integration of simulation and optimisation.

- Flexibility to adapt forms of all relations and the values of their parameters to suit (almost) any fishery.

Figure 2.1 **Multi-species/multi-fleet relations and modules in the FISHRENT model**

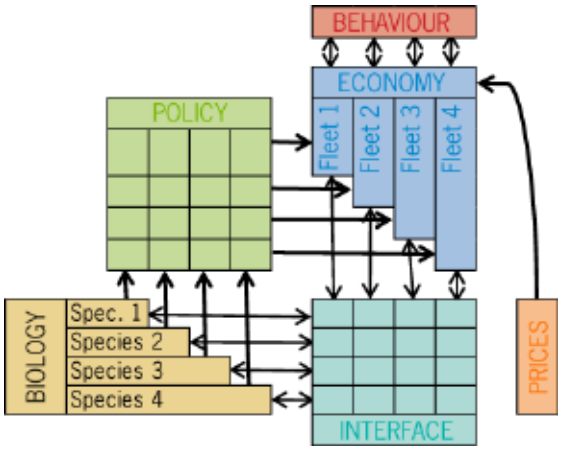


Figure 2.1 shows that all variables specified in the modules are defined in any given year by segment, species or both, which is described further in Table 2.1.

The main relations within each module are in general terms presented in Figure 2.3 and described below. Figure 2.3 presents brief qualitative descriptions of the relations and the mathematical equations, which have been shortened by using only a, b, c, or d as symbol for parameters. The mathematical description, including the precise description of the parameters, the required constraints and decision rules, is presented in Chapter 3.

Table 2.1	Definition of module dimensions a)		
Module	**Segment**	**Species**	**Explanation**
Biology	ALL	X	There is a separate stock-growth and biomass relation for each species. It is assumed that each species is composed of one stock.
Interface	X	X	Catches are determined by a production function, specified for each relevant combination of segment and species.
Economy	X	ALL	Performance of each individual segment is modelled. Performance is determined by the total catch of all species, and thus revenues, and costs, which are partly fixed and partly variable, depending on effort.
Behaviour	X	ALL	Changes of the size of each segment are driven by a segment-specific asymmetric investment function, i.e. different constraints can be imposed to investments and disinvestments.
Prices	X	X	Fish prices can change with landed volumes, based on price elasticity. Furthermore price differences attributed to individual fleet segments (gears) can be accounted for.
Policy	X	X	Output measures (TACs) are specified by species. Input measures (effort) are specified by segment. Both are generated in the model on the basis of target harvest ratios and stock-growth relations.
Totals	X	X	Included at the bottom of the sheet.

a) ALL means sum of all segments or species. X means that each individual segment or species is elaborated.

Figure 2.2 **FISHRENT modules - qualitative description**

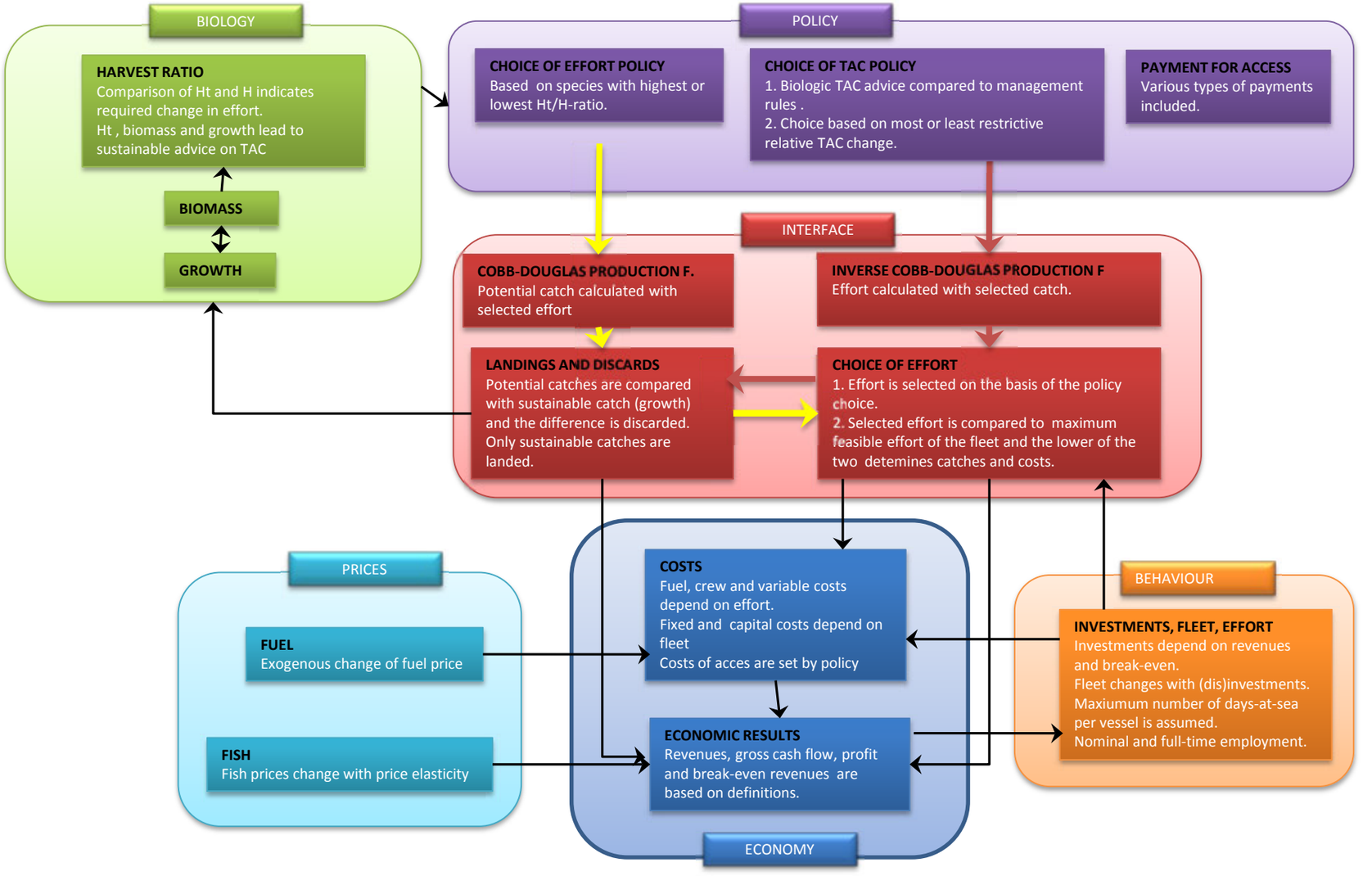
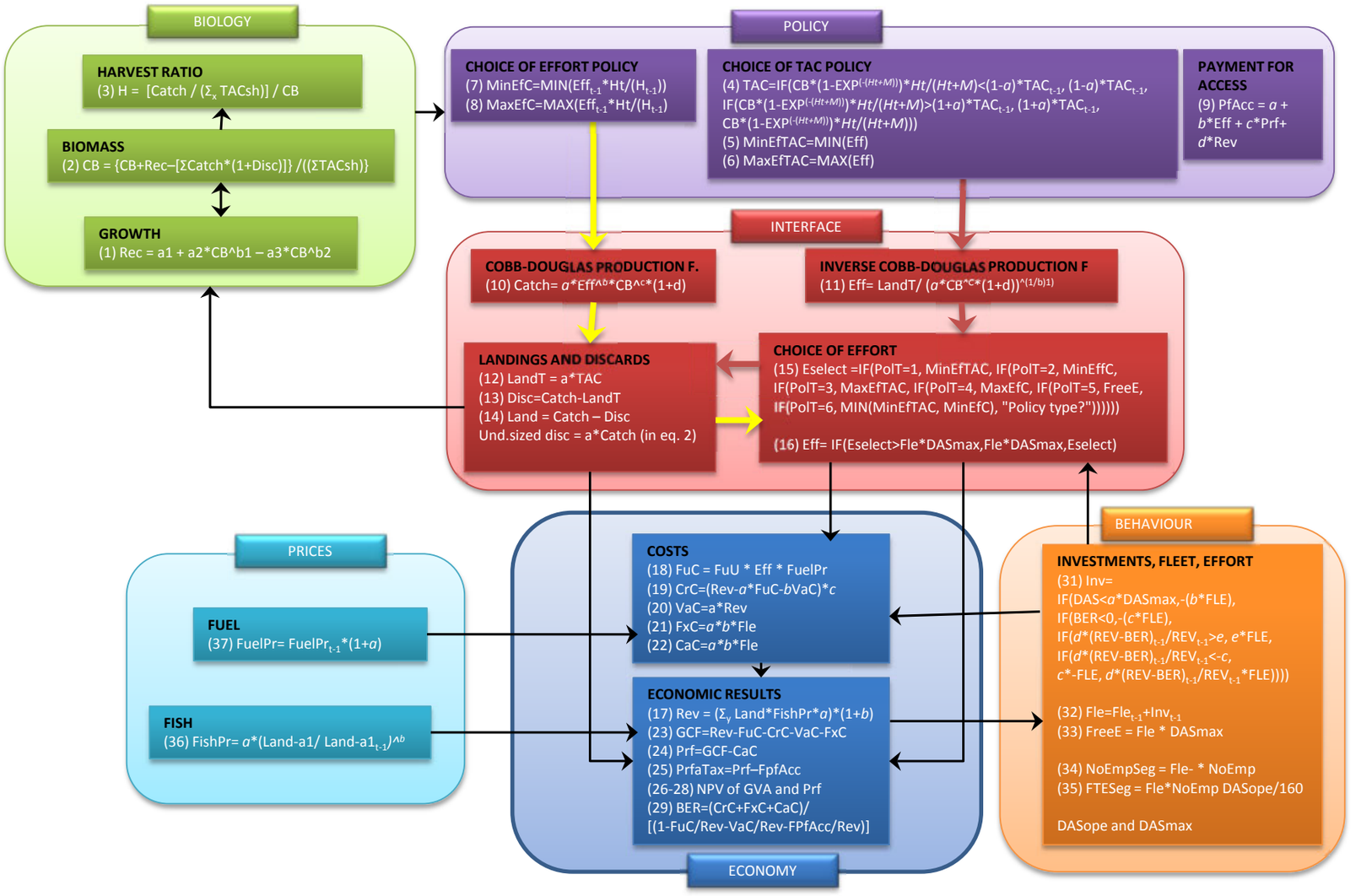


Figure 2.3 **FISHRENT model - mathematical formulation (simplified version)** [1]



[1] PIF is not presented in the formulas for simplification reasons

2.3 Biological module

The biological module contains three relations:

- Stock-growth relation (called recruitment) - a 3rd degree polynomial function, but only 2nd degree is used in the current applications.
- Biomass function - the sum of biomass in the previous period pus recruitment minus catch. Furthermore assumed discards of undersized fish are subtracted.
- Harvest ratio - ratio between biomass and total catch. Harvest ratio is a proxy for fishing mortality.

2.4 Policy module

The policy module determines level of landings or effort. It contains a set of decision or selection rules regarding landing and effort is determined. Running the model starts with a choice of TAC (Total Allowable Catch) or effort policy. Payment for access is also a policy option, but this is incorporated in the economic module, as its effect does not pass through the interface module.

Furthermore, the policy module contains two other features:

1. Constraints on maximum change of TAC from one year to another, the +/- 15% applied in various EU recovery and management plans (harvest control rules)
2. The 'policy intensity factor' reflects the extent to which policy decisions follow the biologic advice. Value below 1 implies that the policy is more restrictive than the biologic advice. On the other hand, value above 1 means that policy concludes on higher TACs than the biologic advice proposes. This factor allows simulating the consequences of taking into account 'socio-economic dimensions' of taking restrictive management measures.

The policy choice is made within a multi-species context and therefore the policy must decide whether the most or the least restrictive biologic advice (in relation to harvest ratio of a given set of species) should be taken as a starting point. For example, species 'A' may be relatively abundant, but effort which could be allowed on this species may lead to overfishing of a species 'B'. On the other hand, if species 'B' is taken as a reference point of the policy, this will lead to underutilisation of species 'A'. The policy module contains six policy choices, which precisely highlight these policy dilemmas:

- TAC_{min} - The most restrictive TAC is used to determine the level effort which the fleet can exert. This may lead to underutilisation of other species.

- $Effort_{min}$ - Most restrictive effort level is allowed, which leads to relatively low catches.
- TAC_{max} - The least restrictive TAC is used to determine the level effort which the fleet can exert. This may lead to overfishing of other species.
- $Effort_{max}$ - Least restrictive effort level is allowed, which leads to relatively high catches.
- Open access - Fishery is driven by economic incentives. Neither TAC nor effort constraints are imposed.
- Min min - This is the most restrictive policy. In this option, $Effort_{min}$ is compared to effort level, which follows from TAC_{min} and the lower of the two is selected. This choice is made in each year separately, which means that throughout the simulation period, different species and different types of policies determine the outcomes.

Effort which follows from an 'Effort policy option' is inserted in the production function and generates catch. When a 'TAC police option' is selected, then a corresponding level of effort is calculated from an 'inverse production function', where effort is the endogenous variable.

Both effort and TACs are derived from the present and target harvest ratio in combination with other variables in the model.

Policy formulas contain a PIF-ratio (Policy Intensity Factor). PIF is included in the Drivers sheet. PIF allows the policy to be more or less restrictive than the simulated biologic advice. Distinction is made between PIF for effort or PIF for TAC based policy.

2.5 Interface module

The interface module determines the level of catch and effort, which are subsequently input to the economic module and catches form feedback to the biologic module. It contains conditional choices of effort, which are described in detail in Chapter 3.

The interface module contains seven functions for each combination of fleet segments and species:

1. Catch - based on a standard Cobb-Douglas production function. Power of 'effort'-variable contains an additional parameter which represents the technological progress.
2. Effort - inverse production function, using catch as input to determine required effort.

3. Discards - over-quota catch is discarded. Catch is confronted with 'Target landings' (segment share of TAC, see policy module) and if catch exceed Target landings, part of the excessive catch can be discarded. An assumed value of a discard parameter determines which percentage is discarded and consequently also how much is landed, albeit illegally. Discards of under-sized fish are accounted for in the catchable biomass equation, as a fixed percentage of catch. These discards occur only in case of output (TAC) driven policy.
4. Landings - difference between catch and discards.
5. Target landings - share of segment in the total sustainable catch (TAC).
6. Choice of effort in relation to policy - level of effort depends on policy choice and maximum effort which the fleet can exert. When the policy is TAC driven, then the model calculates the required effort with the inverse Cobb-Douglas production function. If the policy is effort driven, then effort is adapted proportionately with the required adaptation of the harvest ratio to the target harvest ratio.
7. Comparison of effort allowed by policy and maximum effort feasible for the fleet. After determination of the level of effort from one of the two policies, it is checked against the maximum level of effort feasible for the fleet and the lower value is selected.

The selected production function in the interface is a Cobb Douglas production function in which fishing effort in terms of days-at-sea and catchable biomass determines the catches. Technical progress is included in the production function. Through these selection procedures it is possible to integrate input and output driven policy into one model.

2.6 Economic module

The economic module contains the following relations:

- Revenues - sum of landings times prices. Prices can be adapted to qualities attained by different segments.
- Fuel costs - depend proportionately on fishing effort. Can be adapted by changing the fuel price, either once (instantaneously) or trend-wise (annual change).
- Variable costs - depend proportionately on fishing effort.
- Crew costs - based on a share of revenues and if appropriate taking account of fuel and/or variable costs.

- Fixed costs - are a fixed value per vessel. Change with the size of the fleet.
- Capital costs - as fixed costs, constant per vessel, changing with size of the fleet.
- Gross cash flow - according to definition.
- Profit - according to definition revenues minus all costs.
- Payment for access - allows for different kinds of payments:
  - Lump-sum
  - Share of profit
  - Payment per unit of effort
  - Share of revenues per species
  - Profit after payment for access
- Gross value added - according to definition.
- Fuel use - fuel costs divided by fuel price.
- Break-even revenues - according to definition. Break-even revenues drive the investment function. Therefore crew costs are considered as fixed costs, on the basis of the expectation that fishing may not be an attractive profession at a level of income lower than the level realised in a given year.

The economic module also generates net present values of profit and gross value added over 15 and 25 years. This distinction between two periods was introduced in particular in relation to the optimisation runs of the model. When a model is run for 15 years and profit or gross value added are maximised over that period, the model will tend to fish out all the stocks at the end of the period as it does not take into account what happens beyond that time horizon. This is evidently not desirable. This problem has been resolved by 'optimising' over a period of 25 years, but using the net present value of the first 15 years only. In this way destruction of stocks is avoided within the first 15 years.

2.7 Behaviour module

The behaviour module simulates the level of fishing effort trough changes of the number of vessels and/or the number of days-at-sea per vessel. It contains the following relations:

- Fleet (number of vessels) - the fleet of the preceding year plus or minus investments (fleet change).
- Days-at-sea/vessel - operational - total effort (see policy module) divided by the number of vessels.

- Days-at-sea/vessel - maximum - assumed value. This can be annually adapted by an assumed parameter. Together with the number of vessels it determines the maximum effort of a segment.
- Maximum effort (Fleet * days) - follows from fleet and maximum days-at-sea per vessel.
- Investment (number of vessels) - it is assumed that the fleet changes, i.e. (dis)investments take place, proportionately to the ratio between the break-even revenues and the realised revenues, which is adapted by the share of profits dedicated to investments. However, maximum limits to annual increase or decrease of the fleet can be imposed in terms of the percentage change of the fleet. The two limits can be different, which creates asymmetric (dis)investment behaviour[1]. Furthermore, size of the fleet is reduced when the capacity utilisation falls below an assumed level. This means that it is assumed that investments take place only when the capacity utilisation is above this level.
- Nominal employment - number of vessels times average crew.
- Full time employment - nominal employment, corrected with the ratio of operational/maximum days-at-sea.

2.8 Price module

Price module contains two equations:

1. Prices of fish, which include price elasticity for each species. Furthermore, price differentials for specific segment-species combinations can be accounted for using specific parameters.
2. Fuel price can be adapted with one-time rise or continuous annual trend.

[1] The maximum increase of the fleet from one year to next has been set at 10% and the maximum decrease at -20% of the number of vessels. These percentages are based on the EU DCF data 2002-2008, which show that 75-85% of annual changes of the size of the fleet fall in this range.

2.9 Structure of the workbook

The workbook contains six worksheets:
- Two Input sheets: Drivers and Model parameters
- Calculation sheet: Multi-year model
- Output sheet: Drivers and DB2 (DB = database)
- Two Intermediate sheets: Model input and DB1

The model contains several macros, so Excel must be run in macro-enabled mode. The different modules of the model are coloured differently for easier navigation in a worksheet with more than 800 rows.

Drivers sheet

Drivers sheet contains the following components (Figure 2.4):
- Choice of the six policy options;
- Policy intensity factor (PIF) i.e. to which extent the manager will follow the biologic advice or enforce the policy restrictions (harvest control rules);
- Input area for 'scenario number', to distinguish the results of each model run in subsequent analysis (see DB2);
- Input areas for the names of the relevant species and segments;
- Input area for setting the discount rate per segment, which may serve as a proxy for shadow valuation. For example, using a lower discount rate for small-scale fleets means that in the long run their existence gets a relative preference for 'socio-economic reasons';
- Output area with the main results regarding net present value of gross value added, profit and payment for access over 15 and 25 years;
- Output area with selected graphics showing the development of the main indicators over the simulated period of 25 years:
  - Biological: biomass, sustainable catch, stock growth;
  - Economic: Landings, revenues, gross value added and profit;
  - Technical: fleet and effort (days-at-sea).

Inclusion of main outputs allows running the model and seeing the results immediately in the same worksheet. The user inserts the main information in the light yellow cells.

Figure 2.4 **Drivers sheet (example of North Sea flatfish fishery)**

Model parameters

The Model parameter sheet contains the following information in the various columns (Figure 2.5):

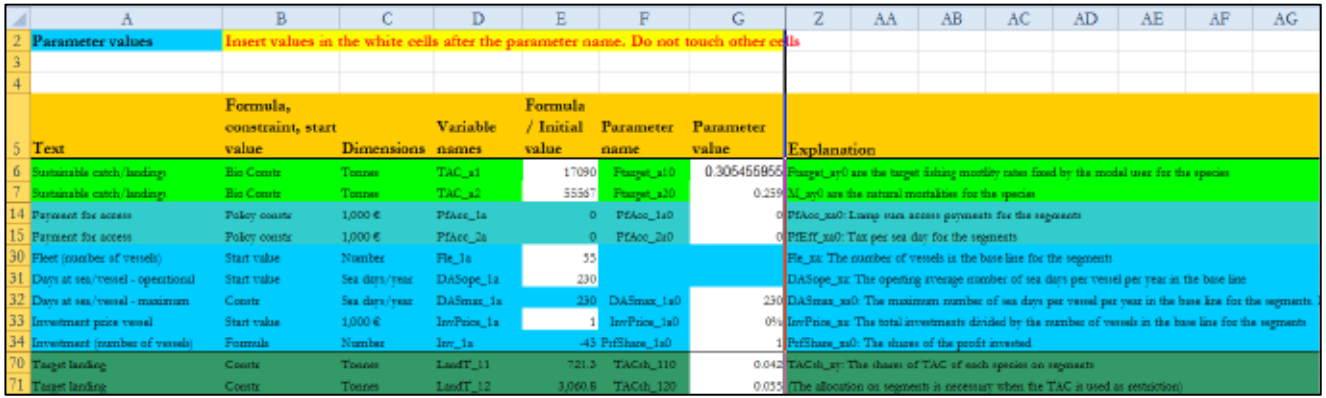
A. Full description of the variable
B. Specification whether the variable is a endogenous (result of a formula), constraint or start value, which must be filled in.
C. Dimension of the variable, clarifying the value to be entered.
D. Variable name, used in the model (see also Chapter 3). Each name is composed of '*Variable name_xy*', where x is index for fleet segment and y stand for species.
E. The cells in column E the initial values of all variables, either calculated with a formula in the cell or entered by hand.
F. Columns F-L contain names and values of parameters required to calculate specific formulas.
G. Column Z explains the meaning of each row in greater detail.

Areas where values have to or can be inserted are white, while all other areas are coloured.

Model input

Model input (MI) sheet contains all equations for one year (Figure 2.6). It is constructed parallel to the following Multi-year model sheet. It presents information entered in the preceding three sheets. It serves as a guideline to the use of the model and an intermediate sheet for input in the Multi-year model sheet. An important aspect is that the cells in columns I, K, M, etc. bear names indicated in the columns H, J and L. The formulas in the MYM-sheet refer to these names. No data needs to be entered on this sheer.

Figure 2.5 **Model parameters sheet**



	A	B	C	D	E	F	G	Z	AA	AB	AC	AD	AE	AF	AG
2	**Parameter values**	Insert values in the white cells after the parameter name. Do not touch other cells													
3															
4															
5	**Text**	**Formula, constraint, start value**	**Dimensions**	**Variable names**	**Formula / Initial value**	**Parameter name**	**Parameter value**	**Explanation**							
6	Sustainable catch/landings	Bio Constr	Tonnes	TAC_a1	17090	Ftarget_a10	0.305455955	Ftarget_ay0 are the target fishing mortality rates fixed by the model user for the species							
7	Sustainable catch/landings	Bio Constr	Tonnes	TAC_a2	55567	Ftarget_a20	0.259	M_ay0 are the natural mortalities for the species							
14	Payment for access	Policy constr	1,000 €	PfAcc_1a	0	PfAcc_1a0	0	PfAcc_xa0: Lump sum access payments for the segments							
15	Payment for access	Policy constr	1,000 €	PfAcc_2a	0	PfAcc_2a0	0	PfEff_xa0: Tax per sea day for the segments							
30	Fleet (number of vessels)	Start value	Number	Fle_1a	55			Fle_xa: The number of vessels in the base line for the segments							
31	Days at sea/vessel - operational	Start value	Sea days/year	DASope_1a	230			DASope_xa: The opening average number of sea days per vessel per year in the base line							
32	Days at sea/vessel - maximum	Constr	Sea days/year	DASmax_1a	230	DASmax_1a0	230	DASmax_xa0: The maximum number of sea days per vessel per year in the base line for the segments							
33	Investment price vessel	Start value	1,000 €	InvPrice_1a	1	InvPrice_1a0	0%	InvPrice_xa: The total investments divided by the number of vessels in the base line for the segments							
34	Investment (number of vessels)	Formula	Number	Inv_1a	-43	PrfShare_1a0	1	PrfShare_xa0: The shares of the profit invested							
70	Target landing	Constr	Tonnes	LandT_11	721.3	TACsh_110	0.042	TACsh_xy: The shares of TAC of each species on segments							
71	Target landing	Constr	Tonnes	LandT_12	3,060.8	TACsh_120	0.053	The allocation on segments it necessary when the TAC is used as restriction)							

Figure 2.6 **Model input sheet**

	A	B	C	D	E	F	G	H	I	J	K	L	M
5	Policy type	Module	Segments	Spec	Text	Formula, constraint, start value	Dimensio	Variable names	Time0/year1	Parameters	and	Restrictior	
6	TAC MIN	Policy TAC	All	Sp1	Sustainable catch/landings	Bio Constr	Tonnes	TAC_a1	17090	Ftarget_a10	0.305	M_a10	0.1
14	TAC MIN	Policy 1	Sg1	All	Min effort computed from TAC	Policy Constr	Sea days	MinEffTAC	13510				
22	TAC MIN	Policy 2	Sg1	All	Min Effort from target F	Policy constr	Sea days	MinEffC_1:	9315				
30	TAC MIN	Policy 3	Sg1	All	Max effort computed from TAC	Policy Constr	Sea days	MaxEffTA(	18059				
38	TAC MIN	Policy 4	Sg1	All	Max Effort from target F	Policy Constr	Sea days	MaxEffC_1	18949				
46	TAC MIN	Policy 5	Sg1	All	Effort free	Policy constr	Sea days	FreeE_1a	12650				
54	TAC MIN	Policy choice	Sg1	All	Effort selection	Policy constr	Sea days	ESelect_1a	12650				
62	TAC MIN	Policy tax	Sg1	All	Payment for access	Policy constr	1,000 €	PfAcc_1a	0	PfAcc_1a0	0	PfEff_1a0	0
70	TAC MIN	Policy tax	All	Sp1	Payment for fish	Policy constr	1,000 €	PfFish_a1	0	PfFish_a10	0		
78	TAC MIN	Beh 1	Sg1	All	Fleet (number of vessels)	Start value	Number	Fle_1a	55				
79	TAC MIN	Beh 1	Sg1	All	Days at sea/vessel - operational	Start value	Sea days/year	DASope_1	230				
80	TAC MIN	Beh 1	Sg1	All	Days at sea/vessel - maximum	Constr	Sea days/year	DASmax_:	230	DASmax_1a0	230	DASmax_1a1	0%

Multi-year model sheet

Multi-year model (MYM) contains the calculation for a 25-year period (Figure 2.7). It also contains the calculation of the net present values of gross value added and profit over 15 years, 25 years and infinity. Inclusion of the calculation of net present values is necessary on this sheet in order to allow the use of the Excel Solver. The Solver can be run on one sheet only and cannot refer to objectives or constraints on other sheets.

Database 1 sheet (DB1)

This sheet copies the MYM sheet for database use (Figure 2.8). It contains a macro 'Convert' which converts a 2-dimensional table (variables * years) to a 1-dimensional table and writes it in sheet Database 2 (DB2), generating a database format. The sheet contains precise description how the macro should be run.

The column E merges all dimensions of each variable into one composite name, in order to create a simple 2 dimensional table.

Database 2 sheet (DB2)

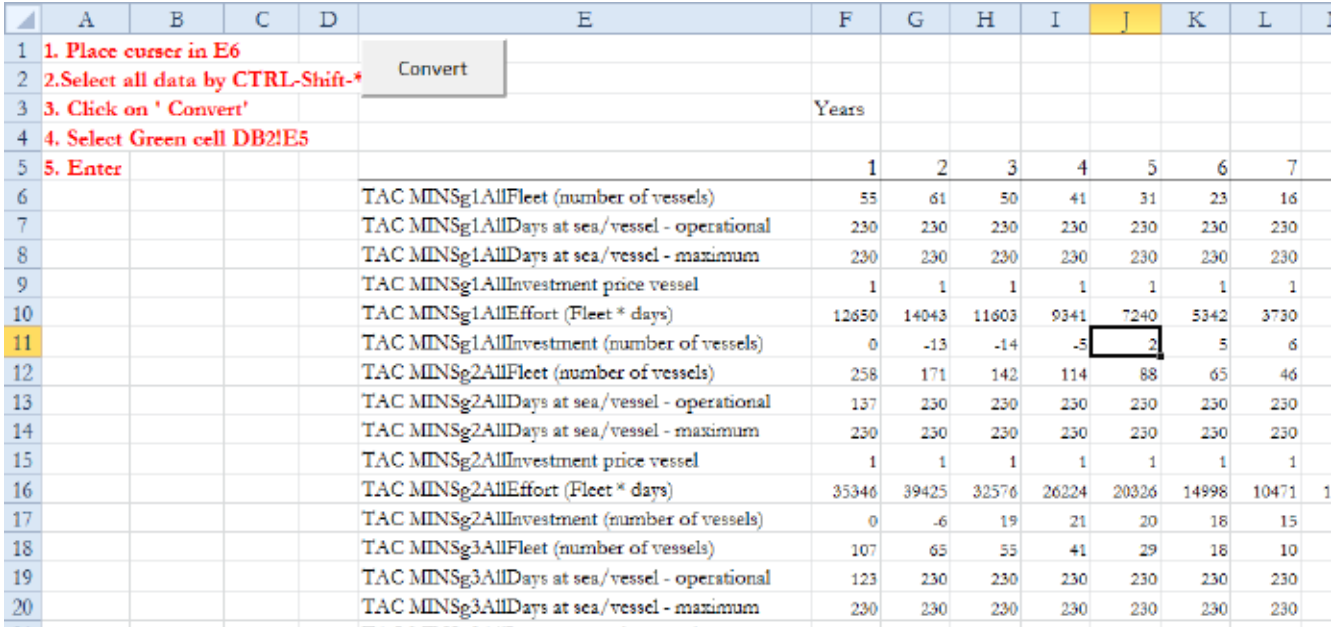
DB2 contains the complete MYM sheet in a database format, which then can be analysed using Pivot table(s), MS Access or another database software (Figure 2.9). The results of each scenario (model run) can be copied from DB2 into a new database or workbook and compared, as each run bears a different number.

Columns A-D rewrite the dimensions of each variable in their original form, on the basis of column E. Columns I-L rewrite the information entered on the Drivers sheet. This is useful so that later dataset output can contain the actual names of segments and species, instead of only Sg1 etc. Inclusion of scenario number allows to run different scenarios of one policy, e.g. if it is desirable to use different equation parameters.

Figure 2.7 **Multi-year model sheet**

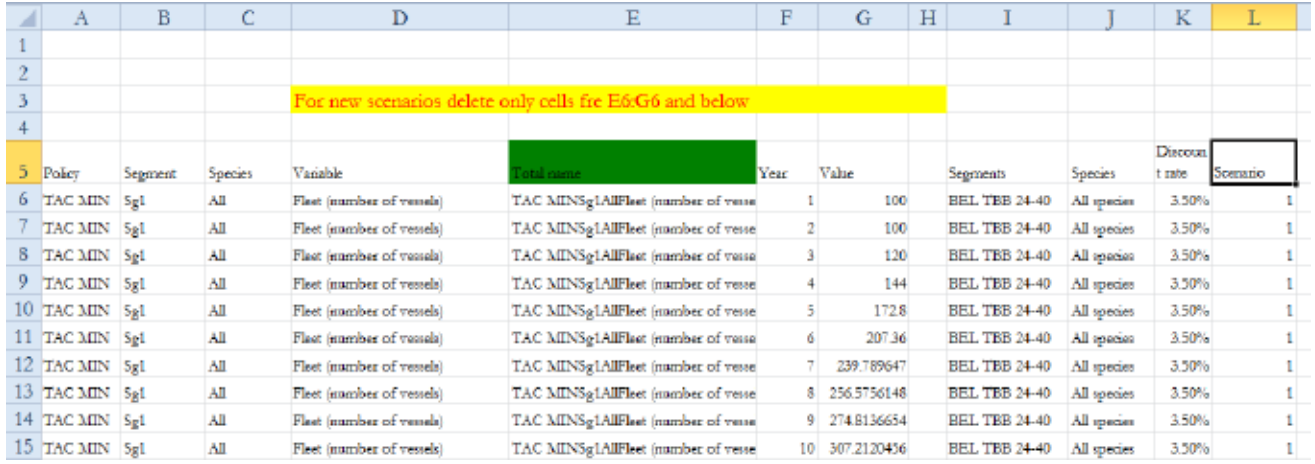
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
2	Multi year model					Npv_aa	3068766	NPV15_aa	921297	GVA15_aa	2,758,477	FpAcc15_a	0	
3								NPV25_aa	1573475	GVA25_aa	5,136,421	FpAcc25_a	0	
4									TimeByyear1					
5	Policy type	Module	Segments	Species	Text	Formula, constraint, start value	Dimension	Variable names	1	2	3	4	5	6
6	TACMN	Policy TAC	All	Sp1	Sustainable catch/landings	Bio Constr	Tonnes	TAC_a1	17090	14527	12348	10495	8921	7583
14	TACMN	Policy 1	Sg1	All	Min effort computed from TAC	Policy Constr	Sea days	MinEFTAC_1a	13510	14043	11603	9341	7240	5342
22	TACMN	Policy 2	Sg1	All	Min Effort from target F	Policy constr	Sea days	MinEfC_1a	9315	7387	7365	6342	5540	4931
30	TACMN	Policy 3	Sg1	All	Max effort computed from TAC	Policy Constr	Sea days	MaxEFTAC_1a	18059	14474	16885	18889	21366	24114
38	TACMN	Policy 4	Sg1	All	Max Effort from target F	Policy Constr	Sea days	MaxEfC_1a	18849	15112	16997	16997	17033	16929
46	TACMN	Policy 5	Sg1	All	Effort free	Policy constr	Sea days	FreeE_1a	12650	14043	11603	9341	7240	5342
54	TACMN	Policy choic	Sg1	All	Effort selection	Policy constr	Sea days	ESelect_1a	13510	14043	11603	9341	7240	5342
62	TACMN	Policy tac	Sg1	All	Payment for access	Policy constr	1,000	PfAcc_1a	0	0	0	0	0	0
70	TACMN	Policy tac	All	Sp1	Payment for fish	Policy constr	1,000	PfFish_a1	0	0	0	0	0	0
78	TACMN	Beh1	Sg1	All	Fleet (number of vessels)	Start value	Number	Fle_1a	55	61	50	41	31	23
79	TACMN	Beh1	Sg1	All	Days at sea/vessel - operational	Start value	Sea days/year	DASope_1a	230	230	230	230	230	230
80	TACMN	Beh1	Sg1	All	Days at sea/vessel - maximum	Constr	Sea days/year	DASmax_1a	230	230	230	230	230	230
81	TACMN	Beh1	Sg1	All	Investment price vessel	Start value	1,000	InvPrice_1a	1	1	1	1	1	1
82	TACMN	Beh1	Sg1	All	Effort (Fleet * days)	Formula	Sea days	Eff_1a	12650	14043	11603	9341	7240	5342
83	TACMN	Beh1	Sg1	All	Investment (number of vessels)	Formula	Number	Inv_1a	0	-10	-14	-5	2	6
126	TACMN	Inter1-1	Sg1	Sp1	Target landing	Constr	Tonnes	LandT_11	721	613	521	443	377	320
190	TACMN	Bio1	all	Sp1	Catchable biomass	Start value	Tonnes	CB_a1	26294	24913	22895	20977	19390	20904
191	TACMN	Bio1	all	Sp1	Recruitment	Formula	Number fish	Rec_a1	13749	13142	11894	11059	10327	11308

Figure 2.8 **DB1 sheet**



	A	B	C	D	E	F	G	H	I	J	K	L
1	1. Place curser in E6				Convert							
2	2.Select all data by CTRL-Shift-*											
3	3. Click on ' Convert'					Years						
4	4. Select Green cell DB2!E5											
5	5. Enter					1	2	3	4	5	6	7
6					TAC MINSg1AllFleet (number of vessels)	55	61	50	41	31	23	16
7					TAC MINSg1AllDays at sea/vessel - operational	230	230	230	230	230	230	230
8					TAC MINSg1AllDays at sea/vessel - maximum	230	230	230	230	230	230	230
9					TAC MINSg1AllInvestment price vessel	1	1	1	1	1	1	1
10					TAC MINSg1AllEffort (Fleet * days)	12650	14043	11603	9341	7240	5342	3730
11					TAC MINSg1AllInvestment (number of vessels)	0	-13	-14	-5	2	5	6
12					TAC MINSg2AllFleet (number of vessels)	258	171	142	114	88	65	46
13					TAC MINSg2AllDays at sea/vessel - operational	137	230	230	230	230	230	230
14					TAC MINSg2AllDays at sea/vessel - maximum	230	230	230	230	230	230	230
15					TAC MINSg2AllInvestment price vessel	1	1	1	1	1	1	1
16					TAC MINSg2AllEffort (Fleet * days)	35346	39425	32576	26224	20326	14998	10471
17					TAC MINSg2AllInvestment (number of vessels)	0	-6	19	21	20	18	15
18					TAC MINSg3AllFleet (number of vessels)	107	65	55	41	29	18	10
19					TAC MINSg3AllDays at sea/vessel - operational	123	230	230	230	230	230	230
20					TAC MINSg3AllDays at sea/vessel - maximum	230	230	230	230	230	230	230

Figure 2.9 **DB2 sheet**



	A	B	C	D	E	F	G	H	I	J	K	L
1												
2												
3				For new scenarios delete only cells fre E6:G6 and below								
4												
5	Policy	Segment	Species	Variable	Total name	Year	Value		Segments	Species	Discount rate	Scenario
6	TAC MIN	Sg1	All	Fleet (number of vessels)	TAC MINSg1AllFleet (number of vesse	1	100		BEL TBB 24-40	All species	3.50%	1
7	TAC MIN	Sg1	All	Fleet (number of vessels)	TAC MINSg1AllFleet (number of vesse	2	100		BEL TBB 24-40	All species	3.50%	1
8	TAC MIN	Sg1	All	Fleet (number of vessels)	TAC MINSg1AllFleet (number of vesse	3	120		BEL TBB 24-40	All species	3.50%	1
9	TAC MIN	Sg1	All	Fleet (number of vessels)	TAC MINSg1AllFleet (number of vesse	4	144		BEL TBB 24-40	All species	3.50%	1
10	TAC MIN	Sg1	All	Fleet (number of vessels)	TAC MINSg1AllFleet (number of vesse	5	172.8		BEL TBB 24-40	All species	3.50%	1
11	TAC MIN	Sg1	All	Fleet (number of vessels)	TAC MINSg1AllFleet (number of vesse	6	207.36		BEL TBB 24-40	All species	3.50%	1
12	TAC MIN	Sg1	All	Fleet (number of vessels)	TAC MINSg1AllFleet (number of vesse	7	239.789647		BEL TBB 24-40	All species	3.50%	1
13	TAC MIN	Sg1	All	Fleet (number of vessels)	TAC MINSg1AllFleet (number of vesse	8	256.5756148		BEL TBB 24-40	All species	3.50%	1
14	TAC MIN	Sg1	All	Fleet (number of vessels)	TAC MINSg1AllFleet (number of vesse	9	274.8136654		BEL TBB 24-40	All species	3.50%	1
15	TAC MIN	Sg1	All	Fleet (number of vessels)	TAC MINSg1AllFleet (number of vesse	10	307.2120456		BEL TBB 24-40	All species	3.50%	1

3 Model definition

The Model parameters sheet contains all input, including the values of year 1, as the baseline for the Multi-year model sheet. The following sections present the mathematical formulation and discuss their meaning, justification and assumptions.

Variable names are composed as follows:

Name_xy, x = segment index, y = species index;
when index = a this means, sum of *all* species and/or segments

Parameter names are composed as:

Name_xyz, x = segment index, y = species index and
z = sequential number of the parameter in a relation;

This notation and the names of the variables and parameters is used throughout the model. In the following text, parameters are written in italics, variables in normal. In most equations, only variables of the same year are related, so that time denomination is not required. When referring to the preceding year, time denomination (t-1) is stated.

The model makes a distinction between 'target' and 'non-target' species. Target species are species included explicitly in the model with their biological functions. Non-target species are all other species caught/landed by the segment. Non-target species must be included to obtain the total revenues of the segment.

The model distinguishes segments specified in the Drivers sheet and one segment called 'Other'. Segments are explicitly included in the model with their economic functions. Segment 'Other' represents all remaining fleets which also catch (some of) the target species. 'Other' segment must be included to obtain the correct catches and harvest ratio of each target species.

Catches of 'non-target species' by the segment 'Other' are not included in the model. This may require a significant amount of additional data and it would increase the size of the model even further, while it generates little relevant additional information for later analysis.

3.1 Biological module

Growth function

The biological module simulates the growth for each species using 3rd degree polynomial stock-growth function.

(1) $\text{Rec-ay} = \text{Rec-ay0} + \text{Rec-ay1} * \text{CB-a1}^{\wedge\text{Expo-ay1}} - \text{Rec-ay2} * \text{CB-a1}^{\wedge\text{Expo-ay2}} + \text{Rec-ay3} * \text{CB - a1}^{\wedge\text{Expo-ay3}}$

Where: CB = catchable biomass[1]
Rec = parameters
Expo = exponents/parameters

The advantage of the 3rd degree polynomial is that it is easy to estimate using Excel standard functions.

It is well known that stock-growth and stock-recruitment functions are statistically weak. The function selected in the model is just one of many possibilities and may be replaced by functions like Ricker or hockey-stick. By using the RANDBETWEEN function in Excel, it is also possible to run the model stochastically, with random growth (only limited by the known minimum and maximum values). This would require running the model many times and subsequently analysing the boundaries of such 'chaotic' system.

Biomass function

The biomass function contains the following elements:
- Biomass of the preceding year;
- Growth;
- Catch of the individual segments, upgraded for discards of undersized fish (not part of TAC);
- Upgrade of the catch of specified segments for catch by segments 'other', expressed as (1/sum of TAC shares);
- The production function (15) may lead to a catch which is greater than the biomass, which is evidently not possible. Furthermore, reducing the biomass to zero implies that complete extinction, making later recovery impossible.

[1] SSB has been used as a proxy.

In order to avoid fishing out a species completely (or even negative values) a minimum size of the catchable biomass must be set. The CB is set at a very low value of 0.000001. In this way the catches are also reduced to a very low value, having little or no impact on the final result. The problem that Catch may exceed CB could be also resolved by introducing a CBproxy, which would first check whether Catch<CBproxy and, if this condition would not be met, adapt the Catch with another theorem. However, this would further complicate the model and the numerical results would not significantly improve.

(2) $\text{CB-ay} = \text{IF } \{(\text{CB-ay}_{t-1} + \text{Rec-ay}_{t-1} - [\Sigma_x \text{ Catch-xy}_{t-1} * (1+\textit{Disc_xy0})]) / (\Sigma_x \textit{ TACsh_xy0})\} < 1, 0.000001, \{(\text{CB-ay}_{t-1} + \text{Rec-ay}_{t-1} - [\Sigma_x \text{ Catch-xy}_{t-1} * (1+\textit{Disc_xy0})]) / (\Sigma_x \textit{ TACsh_xy0})\}$

Where CB_{t-1} = catchable biomass in year t-1
Rec_{t-1} = growth in year t-1
Catch = catch in year t-1
Disc = discards of undersized fish
TACsh = TAC share of the segment

Harvest ratio

The harvest ratio is calculated as catch divided by biomass. However, as the segments in the model do not necessarily catch the whole TAC, their catch is extrapolated to total catch by dividing by their aggregate TAC share.

(3) $\text{H-ay} = [\text{Catch-ay} / (\Sigma_x \textit{ TACsh-xa})] / \text{CB-ay}$

Where CB_{t-1} = catchable biomass in year t-1
TACsh = TAC share of the segment
Catch = catch

3.2 Policy module

Policy choice

The fisheries management pursues the achievement of long-term sustainable exploitation of fish stocks at MSY level. There are in principle two approaches:

the output (TAC) driven approach and the effort-driven approach. Although in some fisheries constraints in both areas exist, one of them is always more binding. However, in a multi-species multi-fleet situation, it is usually impossible to achieve the MSY level for all species concurrently. This gives rise to two situations:

- One species is fished at MSY level, while other species are overfished. Policy focusing on this species will be least restrictive, using the TAC or effort related to that species as benchmark for the overall activity of the fleet.
- One species is fished at MSY level, while other species remain underutilised. Policy focusing on this species will be most restrictive, using the TAC or effort related to that species as benchmark for the overall activity of the fleet.

These two options have been included in the model. A third option, which would take some 'average' value as a starting point has not been modelled, as it is not clear how such 'average' should be determined and because the two 'extreme' options provide information about the 'limits of the system' within which all other options fall.

The model requires determining a unique and consistent composition of three elements:

- catches, which affect biomass,
- landings, which together with prices determine revenues, and
- effort, which determines part of the costs.

This is achieved in the policy module as follows:

1. The MSY level of biomass and growth (sustainable harvest) of each species is calculated from the 2nd degree polynomial stock-growth function, by setting the first derivative equal to zero.
2. The resulting harvest ratio $(Catch/Biomass)_{msy}$ is interpreted as Hmsy or Htarget.
3. Current harvest ratio (H) realised in each year is compared to Hmsy and the ratio (Hmsy/H) determines the biologic advice: either effort or TAC is adjusted proportionately by that ratio. Evidently, the ratios are different for each species, which creates the need to select from the most or the least restrictive approach.
4. The level of Htarget may be adapted by the policy maker with the Policy intensity factor (PIF). Setting PIF>1 will lead to higher TAC or effort than advised by science. This allows to account for 'socio-economic considerations'. Setting

PIF<1 implies that more severe restrictions are imposed, e.g. to protect other parts of environment, net reflected in the TAC or effort proposals.

5. It is then a policy choice whether output or input driven policy should be implemented and whether the most or the least restrictive approach should be followed. This leads to four possible choices, which have been supplemented by further two choices: open access (free fishing) and pursuit of most restrictive policy possible. Consequently the model contains six policy choices:
   a. TAC_{min}: leads to effort required to catch the most binding TAC/quota;
   b. $Effort_{min}$: choose the lowest effort determined by comparing the ratio Htarget/H for all species;
   c. TAC_{max}: choose the effort required to catch the least binding TAC/quota
   d. $Effort_{max}$: choose the highest effort determined by the ratio H target/H for all the species;
   e. Open access: no restrictions imposed;
   f. Min-min: choose the lower of the effort levels defined by TAC_{min} and $Effort_{min}$.

The selected policy is applied every year of the model separately. This means that in different years different species may be used as a min or max restriction. In the min-min policy, it is possible that effort constraint is used in one year and TAC constraint in another.

Sustainable catch and selected TAC

Sustainable catch is calculated as the growth of the biomass, including natural mortality and adapted to the ratio harvest ratio divided by total harvest. The model uses the Baranov function (Lassen, 2000). In some EU fisheries it has been agreed that the TACs would change at most by X% from one year to another (e.g. 15% in the flatfish recovery plan). Therefore, this constraint has been also incorporated. The constraint can be lifted by setting TAC-ay0=0.

$$
\begin{aligned}
(4)\ \text{TAC-ay} = \text{IF}(\text{CB-ay} * (1 - \text{EXP}^{(-(\text{PIF-TAC} * \mathit{Htarget_ay0}+\mathit{M_ay0}))}) * \text{PIF_TAC} * \mathit{Htarget_ay0} / \\
(\text{PIF_TAC} * \mathit{Htarget_ay0} + \mathit{M_ay0}) < \\
(1 - \mathit{TAC_ay0}) * \text{TAC-ay}_{t-1}, (1 - \mathit{TAC_ay0}) * \text{TAC-ay}_{t-1}, \\
\text{IF}(\text{CB-ay} * (1 - \text{EXP}^{(-(\text{PIF-TAC} * \mathit{Htarget_ay0}+\mathit{M_ay0}))}) * \text{PIF_TAC} * \mathit{Htarget_ay0} / \\
(\text{PIF_TAC} * \mathit{Htarget_ay0} + \mathit{M_ay0}) > \\
(1 + \mathit{TAC_ay0}) * \text{TAC-ay}_{t-1}, (1 + \mathit{TAC_ay0}) * \text{TAC-ay}_{t-1}, \\
\text{CB-ay} * (1-\text{EXP}^{(-(\text{PIF-TAC} * \mathit{Htarget_ay0}+\mathit{M_ay0}))}) * \text{PIF_TAC} * \mathit{Htarget_ay0} / \\
(\text{PIF_TAC} * \mathit{Htarget_ay0} + \mathit{M_ay0}))
\end{aligned}
$$

Where CB-ay = catchable biomass
Htarget-ay0 = target (msy) harvest ratio
M-ay0 = natural fishing mortality
TAC-ay0 = maximum change of TAC from one year to another
$TAC\text{-}ay_{t-1}$ = TAC preceding year
PIF-TAC = Policy intensity factor applied to TAC policy

Equation (4) simulates biological advice (i.e. proposed TAC: CB-ay * (1 - EXP(-(Htarget_ay0+M_ay0))) * Htarget_ay0/(Htarget_ay0 + M_ay0) and compares it to the TAC of the preceding year, checking whether the change does not exceed the maximum change agreed in the management plan. After the comparison the appropriate value of the new TAC is selected. PIF-TAC factor allows the policy maker to increase or decrease the biologically proposed target harvest ratio, based on other political considerations.

Minimum and maximum effort computed from TAC

As elaborated above, when TAC policy is selected, the TAC resulting from equation (4) is inserted in the inverse production function to determine the effort required to catch each species. The effort levels are compared and the lowest or highest effort level is selected to be used in the model for the calculation of catch of other species and costs.

(5) MinEfTAC-xa = MIN{[(LandT-xy / (*Catch_xy0* * CB-ay ^ (*Catch_xy2*(1+Catch_xy3)*)^(1/Catch_xy1)}

(6) MaxEfTAC-xa = MAX{[(LandT-xy / (*Catch_xy0* * CB-ay ^ (*Catch_xy2*(1+Catch_xy3)*)^(1/Catch_xy1)}

Where LandT-xy = target landings
CB-ay = catchable biomass
Catch-xy0, Catch-xy1, Catch-xy2, Catch-xy3 = parameters of the production function

Minimum and maximum effort from Htarget

When effort policy is selected, allowable effort for each species is adjusted by the ratio between target harvest ratio and partial harvest ratio caused by the

segment. The ratios regarding all species are compared and minimum or maximum is selected according to the policy choice. Adjustment from one year to the next is not constrained by an X% limit, as in case of TACs. PIF-Eff allows the policy maker to deviate from biological advice.

(7) MinEfC = MIN(Eff-xa$_{t-1}$ * PIF-Eff*Htarget-ay0 / (H-ay$_{t-1}$))
(8) MaxEfC = MAX(Eff-xa$_{t-1}$ * PIF-Eff*Htarget-ay0 / (H-ay$_{t-1}$))

Where	Eff-xa$_{t-1}$	= effort preceding year
	Htarget-ay0	= target harvest ratio
	H-ay$_{t-1}$	= harvest ratio in preceding year
	PIF-Eff	= Policy intensity factor applied to effort policy

Payment for access

The formula for payment for access contains four different types of payments, all being segment specific so that in principle different segments could be 'taxed' differently:
- Lump sum;
- Payment per unit of effort;
- Profit tax;
- Payment as percentage of value of landed fish.

By setting the parameters at 0 or a non-0 value, various combinations of payments can be simulated.

(9) PfAcc-xa = *PfAcc_xa0* + *PfEff_xa0* * Eff-xa + *ProTax_xa0**Prf-1a + Σ_x(*PfFish_ay0* * Land-ay * FishPr-ay)

Where	*PfAcc_xa0*	= lump sum payment
	PfEff_xa0	= payment per unit of effort
	Eff	= effort
	ProTax_xa0	= profit tax
	Prf	= profit
	PfFish_ay0	= payment for landed value
	Land	= landings
	FishPr	= fish price

3.3 Interface module

The purpose of the Interface module is to generate a consistent set of landings and effort, taking into account the policy choice and the maximum effort which can be exerted by the fleet. The possible combinations are presented in Table 3.1. The first two columns determine the policy choice: TAC of Effort and Min or Max. Third and fourth column shows which effort level is selected for the model. The last column shows how the catch is calculated.

Table 3.1 Policy choice in relation to effort and resulting model values

Policy	Max/ Min	Relation between required effort and maximum effort	Effort used in the model	Model catch
TAC	Min	Required eff < Max. eff	Required eff	TAC
		Required eff > Max. eff	Max. eff	Catch=f(Max. eff)
	Max	Required eff < Max. eff	Required eff	TAC
		Required eff > Max. eff	Max. eff	Catch=f(Max. eff)
Effort	Min	Required eff < Max. eff	Required eff	Catch=F(Required eff)
		Required eff > Max. eff	Max. eff	Catch=f(Max. eff)
	Max	Required eff < Max. eff	Required eff	Catch=F(Required eff)
		Required eff > Max. eff	Max. eff	Catch=f(Max. eff)

Catch - production function

The core equation of the model is the Cobb-Douglas production function and its inverse. Two situations are distinguished:

- Equation 10: The catch (excluding undersized discards) is a function of effort, stock abundance and technological progress. In this case effort is the exogenous variable, which means that the policy determines how much effort is allowed and subsequently catch can be determined. In this case the normal form of the Cobb-Douglas production function is used. This could be called effort driven production function.
- Equation 11: When the policy is determined by TACs, then the required effort level can be calculated using an inverse Cobb-Douglas production function.

(10) Catch-xy = *Catch-xy0* * Eff-xa^Catch-xy1 * CB-ay^Catch-xy2 * (1+Catch-xy3)

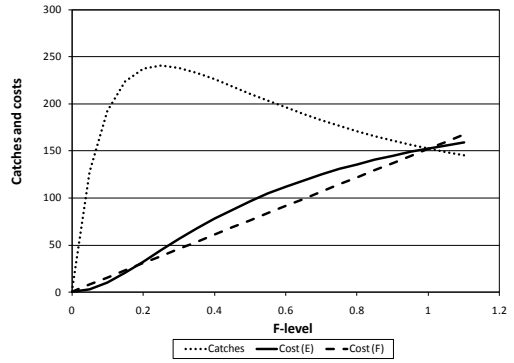
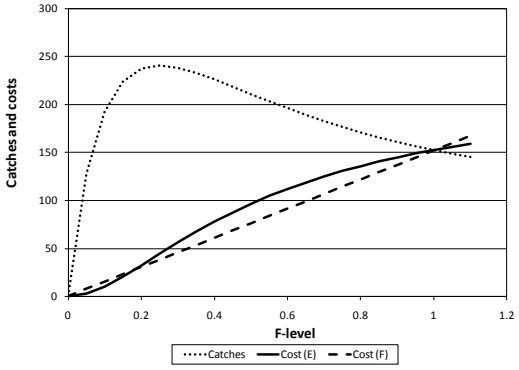
(11) Eff-xy = LandT-xy / (*Catch-xy0* * CB-ay$^{\text{Catch-xy2}}$ * (1+Catch-xy3))$^{(1/\text{Catch-xy1})}$

Where Eff = Effort
CB = Catchable biomass
LandT = Target landings based on segment share in TAC
Catch_xy3 = Rate of technological progress
Catch_xy0, Catch_xy1, Catch_xy2 = estimated parameters
Catch_xy1 + Catch_xy2 = 1

The total catch of a species includes the catch by 'other' segments, which has been accounted for in the biomass function (2) using the sum of TAC shares of the specified segments.

The parameters of the function are estimated based on theory and few empirical studies. The technological progress is hardly above 1.5% per year (Frost et al., 2009). For trawlers that are less impacted by stock abundance than by technology the exponent for effort is between 0.6-0.9 while the exponent for the stock is between 0.1-0.4. For gillnetters the opposite is to be expected. For pelagic and demersal species with schooling behaviour the exponent for the stock is low while it is higher for dispersed demersal species. Setting the values of these parameters makes it possible to estimate the Catch-xy0 parameter.

The importance of the exponents is significant, as shown in Figure 3.1 in which the catch and the fishing costs (being a function of the effort) are shown for different harvest ratios. For further explanation see Frost et al. (2009). It is seen that the optimal fishing mortality rate may not differ in the two examples but the size of the resource rent, and what could be gained by optimal adaptation differs significantly.

Figure 3.1	Catches and costs under different assumptions about the relationship between harvest ratio and effort
	2.1 Cobb-Douglas production function α= 0.4 β=0.6 Low catch-effort flexibility High stock-catch flexibility
	2.2 Cobb-Douglas production function α= 0.9 β=0.1 High catch-effort flexibility Low stock-catch flexibility
Source: Frost et al. (2009), Figure 7. Costs (E) = assumes linear relation between costs, effort and mortality. Costs (F) = assumes non-linear relation between costs, effort and mortality.	

Target landings

Target landings are equal to the historical segment share in the TAC. Target landings allow calculation of the effort level required to exploit the set TACs and the over-quota catches.

(12) LandT-xy = TAC-ay * *TACsh_xy0*

Where TAC = total allowable catch
TACsh = historical segment share in the EU TAC

Over-quota discards

The landings are derived from the catches after subtraction of over-quota catches, which must be discarded.

(13) Disc-xy = IF(Catch-xy > LandT-xy, *Disc_xy1* * (Catch-xy - LandT-xy), 0)

Where Catch = catch
LandT = target landings, based on segment share in TAC (see policy module)
Disc = share of over-quota catch which is discarded

Landings

Landings of a segment are catches minus over-quota discards.

(14) Land-xy = Catch-xy - Disc-xy

Where Catch = catch
Disc = over-quota discards

Effort selection

Appropriate level of effort is selected on the basis of the policy choice. The last term 'Policy type?' is included as a warning should an invalid number of policy type be inserted.

(15) Eselect = IF(PolT=1, MinEfTAC-xa, IF(PolT=2, MinEffC-xa,
IF(PolT=3, MaxEfTAC-xa, IF(PolT=4, MaxEfC-xa,
IF(PolT=5, FreeE-xa, IF(PolT=6, MIN(MinEfTAC-xa, MinEfC-xa),
'Policy type?'))))))

Where PolT = Policy type

Effort choice - policy versus fleet

Effort is measured as the total number days-at-sea for each fleet segment. This is the product of the number of vessels and the operational number of days-at-sea per vessel per year. Total effort which a segment can exert depends on the selected policy option (see policy module). However, the effort level allowed by the policy may be higher than the maximum effort which the segment can generate. Therefore, the appropriate effort level has to be selected.

(16) Eff-xa = IF(Eselect-xa>Fle-xa * DASmax-xa, Fle-xa * DASmax-xa, Eselect-xa)

Where Eselect = effort selected in the policy module
Fle = fleet
DASmax = maximum number of days-at-sea per vessel

The model also operates with the maximum number of days-at-sea per vessels per year.

3.4 Economic module

Revenues

Gross revenue is estimated for each fleet segment taking the landings net of discards and multiplied with fish prices. Specific price differential of the segment from the average is included. Revenues from target species are upgraded by revenues from other species, either by a lump sum or a percentage. This choice can be made in the model parameter sheet with appropriate values of the parameters.

(17) $Rev\text{-}xa = (\Sigma_y\ Land\text{-}xy * FishPr\text{-}ay * \mathit{PrSeg_xy0}) * (1 + \mathit{OtSpR_xa0}) + \mathit{OtSpF_xa0} * Eff\text{-}xa$

Where Land = landings
FishPr = fish price
PrSeg = price differential for the segment from the average price
Eff = effort
OtSpR = revenues from non-target species as a percentage of target

species

OtSpF = revenues from non-target species per unit of effort

Fuel costs

The fuel costs depend on fuel use per unit of fishing effort, effort and fuel price. Fuel price may be differentiated between segments.

(18) FuC-xa = *FuU_xa0* * Eff-xa * *FuelPr_1a0*

Where *FuU* = fuel use per unit of fishing effort
Eff = effort
FuelPr = fuel price (may be segment specific)

Crew costs

Crew costs are often calculated as a share of the gross revenues after deduction of fuel costs and/or variable costs.

(19) CrC-xa = (Rev-xa - *CrC_xa1**FuC-xa - *CrC_1a2* * VaC-xa) * *CrC_xa0*

Where Rev = revenues
FuC = fuel costs
VaC = variable costs
CrC_xa0 = crew share
CrC_xa1 and *CrC_xa2* are either 0 or 1 to take the fuel costs or variable costs into account.

Variable costs

Variable costs, being e.g. costs of landings, auction and harbour fees, depend on gross revenues.

(20) VaC-xa = Rev-xa * *VaC_xa0*

Where Rev = revenues
VaC_xa0 = variable costs as percentage of gross revenues

Fixed costs

The fixed costs, also named vessel costs or semi-fixed costs are administration, insurance, maintenance, etc. It is assumed that these costs depend implicitly on the value of the vessel and are constant per vessel. The value of the segment is separated in a value index per vessel and the number of vessels. In this way fixed costs will change with the changing number of the vessels in the segment. If the value index is set at a different value than 1, then changes in construction costs can be accounted for.

(21) FxC-xa = *FxC_xa0* * Fle-xa * *InvPrice_xa*

Where	Fle	= number of vessels
	FxC_xa0	= fixed costs per vessel
	InvPrice_xa	= value index

The fixed costs per vessels (FxC_xa0) are determined taking the total fixed costs for a segment in the base year divided by the number of vessels. Using the value index (InvPrice) may be appropriate when the size of the fleet would be significantly expanded and construction costs of new vessels would be expected to be above the value of the existing vessels.

Capital costs

Capital costs are calculated in the same way as fixed costs.

(22) *CaC*-xa = *CaC_xa0* * Fle-xa * *InvPrice_xa*

Where	Fle	= number of vessels
	CaC_xa0	= capital costs per vessel
	InvPrice_xa	= value index

Gross cash flow

The gross cash flow is the difference between revenues and all operational costs.

(23) GCF-xa = Rev-xa - FuC-xa - CrC-xa - VaC-xa - FxC-xa

Where Rev = revenues
FuC = fuel costs
CrC = crew costs
VaC = variable costs
FxC = fixed costs

Profit

Profit is calculated before and after payment for access.

(24) Prf-xa = GCF-xa - CaC-xa

Where GCF = gross cash flow
CaC = capital costs

(25) PrfaTax-xa = Prf-xa - FpfAcc-xa

Where Prf = profit
FpfAcc = full payment for access

Payment for access is a policy (control) variable and the function form is included under the policy module (equation 9).

Net present value of profit and gross value added

The discounted net profit and gross value added have meaning only in the dynamic model working for a number of years. Different discount rates are allowed for the different segments to reflect different time preferences although it seems most meaningful to use the same discount rate for all segments as default.

The net present values are computed for a 15 and 25-year period and for infinity. As already explained earlier, this distinction between the two periods of 15 and 25 years was introduced in particular in relation to the optimisation runs

of the model. When a model is run for 15 years and profit or gross value added are maximised over that period, the model will tend to fish out all the stocks at the end of the period as it does not take into account what happens beyond the set time horizon. This is evidently not desirable. This problem has been resolved by 'optimising' over a period of 25 years, but using the net present value of the first 15 years only. In this way destruction of stocks is avoided within the first 15 years.

The net present value of net profit for infinity (equation 28) may be also used to estimate the maximum resource rent from a fully adjusted fishery. As a 15-year period normally is long enough to expect full adjustment it is assumed that the profit in year 15 will continue infinitely.

(26) NpvPrf15_xa = Σ_t Prf-xa$_t$ * [1 - (1+*Dis_xa0*)^-{DisPeriod-xa1/*Dis_xa0*}]

(27) NpvGVA_xa = Σ_t GVA-xa$_t$ * [1 - (1+*Dis_xa0*)^-{DisPeriod-xa1/*Dis_xa0*}]

(28) NPV-xa = Npv15-xa + Prf$_{t=15}$/*Dis_xa0* * (1+*Dis_xa0*)^-{15+1}

Where Prf = profit
GVA = gross value added
Dis_xa0 = discount rate
DisPeriod-xa1 = year t

Break-even revenues

The break-even revenue shows the gross revenue with given capital costs that yields a zero profit. Break-even can be used for different analytical purposes. It is an indicator of profit and it provides an indication of economic overcapacity.

The break-even revenue is used in the model as a driver of investments (equation 29). Ratio of break-even revenues to realised revenues determines the level of investments in the following period. Therefore the break-even revenues consider crew costs as fixed costs. This is justified on the basis of three mutually related arguments:

- Skipper ownership is commonplace is in the EU fisheries. This implies that there is no clear distinction between remuneration of labour and capital.
- Crews are remunerated on share basis. Break-even revenues may imply an unacceptably low crew share, making fishing an unattractive occupation. Then it would be unrealistic to expect that operation at break-even level could be continued indefinitely, while that is precisely the principle of break-even.

- Inclusion of crew costs among 'fixed costs' reduces the fluctuations of investments throughout the simulated period.

(29) BER-xa = (CrC-xa + FxC-xa + CaC-xa) /
[(1 - FuC-xa / Rev-xa - VaC-xa / Rev-xa - FPfAcc-xa / Rev-xa)]

Where CrC = crew costs
FxC = fixed costs
CaC = capital costs
FuC = fuel costs
Rev = revenues
VaC = variable costs
FPfAcc = full payment for access

Fuel use

Fuel use is for some fisheries an important indicator. Therefore a fuel use relation has been included in the model.

(30) FuU = Eff-xa * *FuU_xa0*

Where Eff = Effort
FuU_xa0 = Fuel use per unit of effort

3.5 Behaviour module

The behaviour module determines the (dis)investment and changes in effort level (days-at-sea per vessel).

Investment function

Theoretically the investments are determined by expectations of future profit, but there is no empirical data, which could be used to support such theorem in the model. Instead, perceived profitability in the preceding year, expressed as ratio between break-even revenues minus realised revenues divided by realised revenues is used to determine the (dis)investments in each year. When break-even revenues exceed realised revenues, the ratio is positive and the fleet will expand and vice versa.

This leads in some years to quite substantial changes in the number of vessels in a fleet segment, which could occur as vessels from other segments may enter the given fishery. At the same time, it was recognised that the inertia of the system (licensing, knowledge of skippers, etc.) does not allow such full flexibility. Consequently, parameters have been introduced to limit the maximum annual (dis)investments. As different parameters have been applied to investments and disinvestments, asymmetric investment and disinvestment behaviour can be simulated.

Furthermore, it has been assumed that the active fleet will first achieve a certain minimum number of days-at-sea per vessel before the number of vessels will be expanded. This assumption was introduced to avoid continuous growth of the fleet, while at same time the number of days-at-sea per vessel could be proportionately falling[1], as long as break-even revenues exceed realised revenues.

(31) Inv-xa = IF(DASope-xa < *InvDays_xa3* * DASmax-xa, -(*InvLimd_xa2* * FLE-xa),
IF(BER-xa < 0, -(*InvLimd_xa2* * FLE- xa),
IF(*PrfShare_xa0* * (REV-xa - BER-xa)$_{t-1}$/REV-xa$_{t-1}$ > *InvLimu_xa1*,
InvLimu_xa1 * FLE- xa,
IF(*PrfShare_xa0* * (REV-xa - BER-xa)$_{t-1}$/REV-xa$_{t-1}$ < -*InvLimd_xa2*,
InvLimd_xa2 * -FLE- xa,
PrfShare_xa0 * (REV-xa-BER-xa)$_{t-1}$/REV-xa$_{t-1}$ * FLE- xa))))

Where
Rev = revenues
BER = break-even revenues
FLE = fleet, number of vessels
DASope = operational (actual) number of days-at-sea per vessel
DASmax = maximum number of days-at-sea per vessel
PrfShare_xa0 = share of profit dedicated to investments,
InvLimu_xa1 = upper limit for investments, as a relative change of the fleet
InvLimd_xa2 = lower limit for investments, as a relative change of the fleet
InvDays_xa3 = minimum level of capacity utilisation, under which no investments take place

[1] Such situation has occurred in practice in the past, e.g. the king crab fishery in Alaska.

The behaviour module assumes that only segments which historically participated in the fishery will be able to do so also in the future. While the size of these segments may be reduced almost to zero, there is no provision to allow new types of vessels (technologies) to enter into the fishery.

Fleet (number of vessels)

Number of vessels in a segment is equal to the fleet of the preceding year (t-1) plus the (dis)investments in the preceding year (t).

(32) $Fle\text{-}xa = Fle\text{-}xa_{t-1} + Inv\text{-}xa_{t-1}$

Where Fle = fleet
Inv = (dis)investments

The number of vessels is constant if the investment function is turned off e.g. by setting the profit investment share, PrfShare-xa0, at zero. Changes in the number of vessels affect the number of days-at-sea, fixed and capital costs and ultimately the profit.

In case of free fishery it can be expected that the fleet will exert the maximum number of days-at-sea per vessel.

(33) FreeE-xy = Fle-xa * DASmax-xa

Where Fle = fleet (number of vessels)
DASmax = maximum number of days-at-sea per vessel

Employment

Distinction is made between nominal and full time employment. Nominal employment is based on average crew per vessel.

(34) NoEmp_xa = Fle-xy * Crew-xa

Where Fle = fleet (number of vessels)
Crew = *average crew per vessel*

Full time employment is based on the notion that a full time crewman would be also continuously on board when a vessel would be operating the maximum number of days-at-sea.

(35) FTESeg = Fle-xa * NoEmp-xa * DASope-xa */FTE-norm-xa*

Where Fle = fleet (number of vessels)
NoEmp = average crew per vessel
DASope = operational number of days-at-sea
FTE-norm = assumed FTE standard of number of days-at-sea

The FTE-norm is set for each segment, according to the national definition of FTE and interpretation of FTE in the specific fishery. The approach should be consistent with the definition of FTE under DCF.

3.6 Price module

Fish prices

Fish prices are based on the prices of the baseline year, possibly adapted by price elasticity. However, this is only relevant if the fishery lands a significant share of the total supply of a species. Setting price elasticity at zero leads to constant prices. If required, the formula could be easily adapted to include a price trend.

(36) FishPr-ay = *FishPr_ay0* * (Land-a1 / Land-a1_{t-1})$^{\wedge(\text{-PrEl_a11})}$

Where FishPr = fish price
Land = landings
PrEl = price elasticity

Fuel price

The fuel price can be adjusted by an annual percentage change (FuelPr-xa0), which can be also differentiated between fleet segments. Fleet performance at a generally higher level of fuel price can be simulated by setting the FuelPr at a desired initial level.

(37) FuelPr-xa = FuelPr-xa_{t-1} * (1 + *FuelPr_xa0*)

Where *FuelPr_1a0* = is annual percentage change of fuel price

3.7 Totals

At the bottom of the worksheet, totals of all relevant variables are calculates as sums of segments.

(38)	Catch	Catch-ay	= Σ_x Catch-xy
(39)	Discards	Disc-ay	= Σ_x Catch-xy
(40)	Landings	Land-ay	= Σ_x Land-xy
(41)	Target landing	LandT-ay	= Σ_x LandT-xy
(42)	Revenues	Rev-aa	= Σ_x Rev-xa
(43)	Fuel costs	FuC-aa	= Σ_x FuC-xa
(44)	Crew costs	CrC-aa	= Σ_x CrC-xa
(45)	Variable costs	VaC-aa	= Σ_x VaC-xa
(46)	Fixed costs	FxC-aa	= Σ_x FxC-xa
(47)	Capital costs	CaC-aa	= Σ_x CaC-xa
(48)	Gross cash flow	GCF-aa	= Σ_x GCF-xa
(49)	Profit	Prf-aa	= Σ_x Prf-xa
(50)	Full payment for access	FPfAcc-aa	= Σ_x FPfAcc-xa
(51)	Profit after access payment	PrfaTax-aa	= Σ_x PrfaTax-xa
(52)	Profit discounted	PrfDis-aa	= Σ_x PrfDis-xa
(53)	NPV 25 years	Npv25-aa	= Σ_x Npv25-xa
(54)	NPV infinity	Npv-aa	= Σ_x Npv-xa
(55)	Break-even revenues	BER-aa	= Σ_x BER-xa
(56)	Gross value added	GVA-aa	= Σ_x GVA-xa
(57)	Fuel use	FuU-aa	= Σ_x FuU-xa
(58)	Fleet (number of vessels)	Fle-aa	= Σ_x Fle-xa
(59)	Days-at-sea/vessel - operational	DASop-aa	= Eff-aa/Fle-aa
(60)	Effort - segment	Eff-aa	= Σ_x Eff-xa
(61)	Total investment	TotInv-aa	= Σ_x TotInv-xa
(62)	Investment (number of vessels)	Inv-aa	= Σ_x Inv-xa
(63)	Nominal employment	NoEmp-aa	= Σx NoEmp-xa
(64)	Full-time employment	FTEmp-aa	= Σx FTEmp-xa

3.8 Other indicators

Three other indicators are calculated as well, although they are not used in the model.

(65) Partial harvest ratio	Hpar-xy	= Catch-xy/CB-ay
(66) Catchability	Catchability	= Fpar-xy/Eff-xy
(67) Catch per unit effort	CPUE-xy	= Catch-xy/Eff-xy

4 Adaptation of the model to fewer fleet segments and species

The model is constructed for eight fleets segments and eight species (8x8 version) but it is also available in smaller versions (4x4 and 2x2). These versions can be used for fewer fleet segments and species.

When an 'oversized' model is used, i.e. specified number of segments or species is smaller than the model size, then two types of error will arise:

- Division by zero.
- Choosing effort according to the policy choice of effort determined by the most restrictive TACs or effort.

Division by zero

Number of vessels set at zero for a segment implies zero revenue, but as revenue is used as denominator in the break-even and hence in the investments calculations this leads to an error. Therefore, the number of vessels for segments that are not used must be set close to zero e.g. 0.0001.

Species in terms of fish stocks set at zero imply an error in the number of days-at-sea as stocks are used as denominator in some of the effort equations depending on H and Htarget. Therefore the stocks that are not used must be set close to zero, e.g. 0.0001.

In the model the stocks are not allowed to go below 1 (or another small number close to zero) to make sure that the model does not work with negative stocks and that a stock can grow again after having been depleted. Therefore the stocks will always be 1 even if set close to zero in the Parameter sheet. This will cause a very small error (over estimation) in the in the results (profit, GVA) of the fleet segments. This error is well within the margins of error which can be expected in such a model.

Choosing effort according to minimum TAC or effort

This adjustment is related to the choice of policy and is only needed if fewer species are used than the dimension of the model. If species are omitted by setting the initial stocks at zero the model still takes these species into account in the choice of TAC or effort in the policy equations. As the model in the MIN case chooses effort according to the most restrictive quota of the species or the most restrictive effort, the effort will be determined by the 'empty' species and hence the effort will be zero.

Therefore it is necessary to delete the species not used from the policy equations in the model. This is done in the Policy module of the model, which comprises four sub-sections - choice of the most restrictive or the least restrictive TAC and choice of the most restricted or the least restrictive effort. There is one equation for each fleet segment i.e. 32 equations must be adapted when 8 segments are specified. However, only the equations for the most restrictive TACs or effort constraints (the MIN cases) need to be adjusted and only for the equations including the active fleets segments.

For example, if the 8x8 version is used for six fleet segments and eight species no adjustment is necessary as all species are used. But if the model is used for 6 species 12 equations need adjustment in order to delete the two species 'positions' not used in the equations for the six fleet segments.

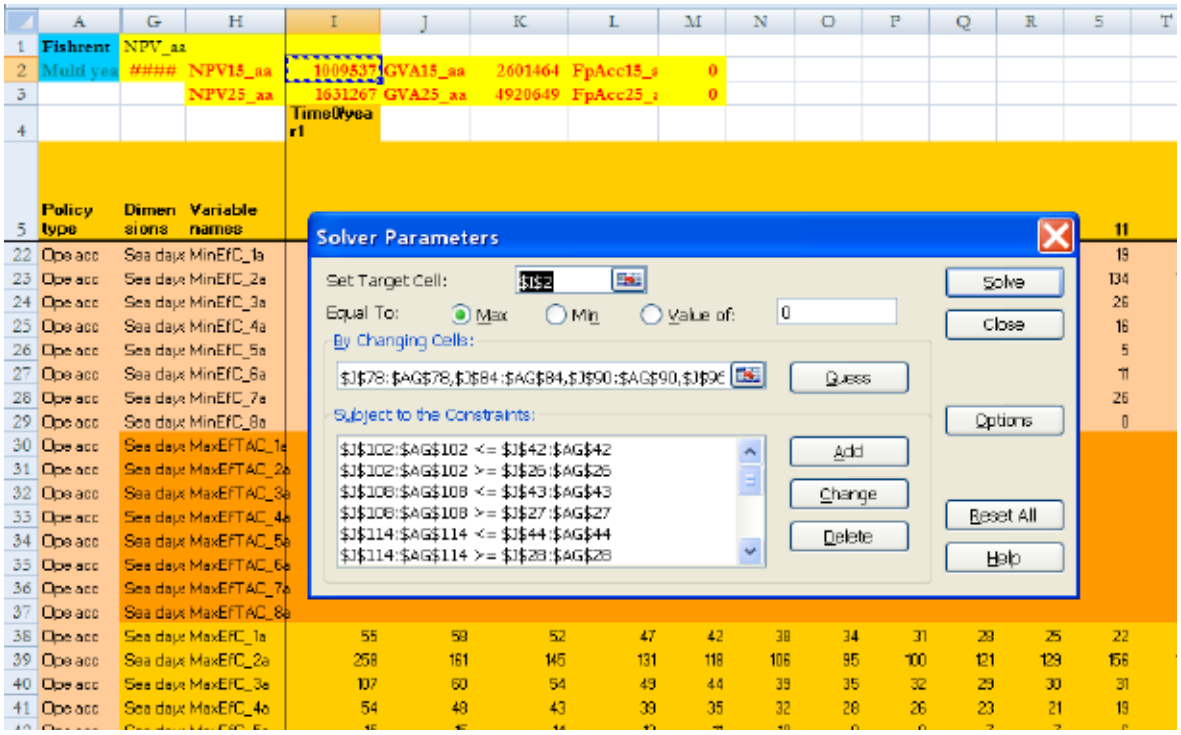
5 Running the Excel Solver

When using the FISHRENT model for optimisation it must be born in mind that the Solver may not produce optimum results in its first run (Figure 5.1). The default settings of the Options are set at maximum time of 100 seconds and maximum 100 iterations, which may not be sufficient. Increasing the default settings does not provide a guarantee that the optimum values will be found. Therefore it is recommended to run the Solver in several consecutive steps until the results do not change any more. After each run the Excel file must be stored under a new name and the Solver must be run again in this new file.

The Solver must be set according to the desired values, on the sheet 'Multi-year model', example being presented in the following figure:

- Target set points to required value in column I or K
- Changing cells are the rows containing the number of vessels
- Constraints reflect values which cannot be exceeded, i.e. minimum or maximum effort.

Figure 5.1 Example of setting values to run the Excel Solver



References

Frost, H., J. Levring Andersen, A. Hoff and Th. Thøgersen, *The EIAA Model Methodology, Definitions and Model Outline*. FOI Report no. 200. Institute of Food and Resource Economics, Copenhagen, 2009.

Frost, H., J.L. Andersen, A. Hoff and Th. Thøgersen, *The EIAA Model.* FOI report 200, 2009.

Holt, S., 'Sunken Billions - But how many?' . In: *Fisheries Research* 97 (2009): pp. 3-10.

Hoff, A. and H. Frost, 'Modelling combined harvest and effort regulations: the case of Dutch beam trawl fishery for plaice and sole in the North Sea.' In: *ICES Journal of Marine Science* 65 (2008) 6: pp. 822-831.

Lassen, H. and P. Medley, *Virtual Population Analysis - A Practical Manual for Stock Assessment.* Fisheries Technical Paper 400. FAO, Rome, 2000.

Nielsen, M., B.L. Cozzari, G. Eriksen, O. Flaaten, E. Gudmundsson, J. Løkkegaard, K. Petersen and S. Waldo *Focus on the economy of the Nordic fisheries*. FOI report 186. 2007.

Prellezo, R., A. Little, R. Nielsen, J. Levring Andersen, Ch. Rockmann, P. Accadia, E. Buisman and J. Powell, *Survey of existing bio-economic models*. Final report, 2009.

Salz, P. and H. Frost, *Model for economic interpretation of the ACFM advice (EIAA).* Presentation at the XI EAFE Annual Conference, Esbjerg, 2000.

Salz, P., E. Buisman, H. Frost, P. Accadia, R. Prellezo and K. Soma, *Study on the remuneration of spawning stock biomass*, Final report to EC contract MARE/2008/11 - Lot 3. 298 pages, 2010.

SGECA - SGRST, *Meeting on bio-economic modelling, Commission staff working paper*. Ispra 4-6 October 2005 and 7-9 March 2006.

World Bank (The) and FAO, *The Sunken Billions, The economic Justification for Fisheries Reform*. 2009.

Nielsen M., B. L. Cozzari, G. Eriksen, O. Flaaten, E. Gudmundsson, J. Løkkegaard, K. Petersen and S. Waldo, *Focus on the economy of the Nordic fisheries*. FOI report 186, 2007.

Appendix 1

List of parameters and their initial settings

Name	Acronym	Units	Value	Comment
Target harvest ratio	Htarget-ay0	Coefficient	Calculated	From the relevant advisory body (ICES)
Mortality - natural	M-ay0	Coefficient	Species specific	From the relevant advisory body (ICES)
TAC constraint	Tac-ay0	Coefficient	Species specific	From the relevant advisory body (ICES)
Payment - lump sum	PfAcc-xa0	1000 euro	0	Is the payment for the license
Payment per unit of effort	PfEff-xa0	Coefficient	0	Related to the effort
Payment - profit tax	ProTax-xa0	Coefficient	0	Related to the effort
Payment - fish value	PfFish-ay0	Coefficient	0	Related to the landings
Fleet (no. of vessels)	Fle-xa	Number	Segment specific	Number of vessels of the segment
Days-at-sea/vessel - operational	DASope-xa	Number	Calculated	Operational days-at-sea per vessel
Days-at-sea/vessel - maximum	DASmax-xa	Number	Assumed	Maximum number of operational days-at-sea per vessel
Days-at-sea/vessel - maximum	DASmax-xa1	Percentage	0	Potential percentage increase of the maximum number of fishing days. Not used
Nominal employment	NoEmp	Number	Calculated ex-ante	Based on historical data

Name	Acronym	Units	Value	Comment
Investment price vessel	InvPrice-xa	1000 €	1	Total investment of the total segment divided by the number of vessels in 1000 €. Not used
Investment (no. of vessels)	InvPrice-xa0	Percentage	0	Not used
Investment (no. of vessels)	PrfShare-xa0	Coefficient	0.2	It is a Boundary coefficient. The share between the (Rev-BER)/Rev.
TAC share	TACsh-110	Coefficient	Calculated	It is the share of the landings made by the segment to the total landings of the stock
Catchable biomass	CB-ay	Tonnes	Species specific	Spawning stock biomass used as a proxy.
Growth	Rec-ay	Tonnes	Species specific	Growth is estimated by recruitment (number of fish) multiplied by yield per recruit. The function include M and r
Growth	Rec-ay0	Coefficient		Estimated (intercept)
Growth	Rec-ay1	Coefficient		Estimated (order 1)
Growth	Rec-ay2	Coefficient		Estimated (order 2)
Growth	Rec-ay3	Coefficient		Estimated (order 3)
Growth	Expo-ay1	Coefficient	1	
Growth	Expo-ay2	Coefficient	2	
Growth	Expo-ay3	Coefficient	3	
Catch	Catch-110	Coefficient	Estimated	Constant in the production function
Catch	Catch-111	Coefficient	0.2 or 0.6	Exponent of effort
Catch	Catch-112	Coefficient	0.8 or 0.4	Exponent of biomass

Name	Acronym	Units	Value	Comment
Catch	Catch-113	Percentage	0	The annual technical progress, (note that the function is not linear)
Discards - undersized fish	Disc-110	Percentage	0	Percentage of the discards
Discards - quota fish	Disc-111	0 to 1	0	1: can land all caches 0: cannot land over-quota catch
Fuel price	FuelPr-xa	Coefficient	1	It is the nominal increased of the fuel cost relative to base case year: =1: Fuel cost as in the base case >1 Fuel cost higher than in the base case <1 Fuel cost lower than in the base case. Not used
Fuel price	FuelPr-xa0	Percentage	0	Annual growth of the fuel cost relative to the previous year
Fish prices	FishPr-ay	€/kg	Calculated	
Fish prices	PrEl-ay1	Coefficient	0	
Fish prices	PrSeg-110	Coefficient	1	If >1 the price of this segment /species is increased
Revenues	OtSpR-xa0	Percentage	Calculated	Percentage of the revenue obtained by the other species.
Revenues	OtSpF-xa0	1000€	Calculated	Fixed amount of the other species by vessel
Revenues	Related to the effort	1000€/fishing day	Calculated	Not done yet Not used
Fuel costs	FuC-xa0	Coefficient	Calculated	Total fuel cost in 1000 € divided by total fishing days
Crew costs	CrC-xa0	Coefficient	Calculated	Depends on the drivers (CrC-1a1 and CrC-1a2)

Name	Acronym	Units	Value	Comment
Crew costs	CrC-xa1 and CrC-xa2	0 or 1	Calculated	If (0,0) total crew cost divided by total revenues (1,0) total crew cost divided by (total revenues - fuel cost) (0,1) total crew cost divided by (total revenues - variable costs) (1,1) total crew cost divided by (total revenues - variable costs –fuel costs)
Variable costs	VaC-xa0	Coefficient	Calculated	Total variable costs divided by total revenues
Fixed costs	FxC-xa0	1000€/vessel	Calculated	Fixed costs divided by number of vessels
Capital costs	CaC-xa0	1000€/vessel	Calculated	Capital costs divided by number of vessels
Discount rate	Dis-xa0	Coefficient	3.5%	At a first stage. Common for all the fleets but with a sensitive analysis of it
Fuel use	FuU-xa0	1000 liters /sea day	Calculated	Not a role in the model but the result is calculated. Not used
Policy intensity factor	PIF	0 to 1	1	=1: strictly follows biologic advice >1: less strict than biologic advice <1: more strict than biologic advice

Appendix 2

List of variables and symbols

Biological module	
Catchable stock biomass	CB
Yield per recruit	YpR
Recruitment	Recr 3rd degree polynomial or Ricker
Parameters	Rec (4 coefficients) and Expo (3 exponents)
Policy module	
TAC constraint	TAC
Effort constraint	EfC
Payment for access	PfAcc
Payment for fish	PfFish
Target harvest ratio	Htarget
Natural fishing mortality	M
Tac band	Tac
Economic module	
Revenues	Rev
Fuel costs	FuC
Crew costs	CrC
Variable costs	VaC
Fixed costs	FxC
Capital costs	CaC
Gross cash flow	GCF
Profit	Prf
Payment for access	FPfAcc
Profit after tax	PrfaTax
Profit discounted	PrfDiS
NPV 15 years	Npv15
NPV infinity	Npv
Break-even revenues	BER
Fuel use	FuU
Discount factor	Dis

Discount period	DisPeriod
Interface	
Target landings (TACs)	LandT
Catch including under- and oversized discard	CatchT
Catch excl. undersized discards	Catch
Discards oversized fish	Disc
Landings	Land
Catch-xy0	catch coefficient
Catch-xy1	exponent for effort (days-at-sea)
Catch-xy2	exponent for stock size
Catch-xy3	coefficient for technical progress (%)
Prices	
Fuel price	FuelPr
Fish prices	FishPr
Price elasticity	PrEl
Behaviour	
Effort (Fleet * days)	Eff
Investment (number of vessels)	Inv
Fleet (number of vessels)	Fle
Days-at-sea/vessel - operational	DASope
Days-at-sea/vessel - maximum	DASmax
Investment price vessel	InvPrice
Investment share of profit	PrfShare
Interest rate	Int
Time horizon for investment	Period
Average crew per vessels	Crew
Nominal employment	NoEmp
Full time employment in segment	FTESeg
Norm for FTE	FTE-norm

Appendix 3

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