SIMULATION MODEL
FOR
EVALUATION OF EFFORT AND CATCH QUOTA MANAGEMENT REGIMES USING THE METHODOLOGY OF ICES

(Including user's manual for the EXCEL/VISUAL BASIC application "EEQ").

Simulationsmodel til vurdering af fiskeriforvaltning ved fangstkvoter og ved indsatskvoter, baseret på ICES rådgivnings metodik (indeholdende en brugermanual til EXCEL/VISUAL BASIC programmet "EEQ")

by

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RESUME

This report documents a mathematical model and its implementation in EXCEL/Visual Basic. The purpose of the model is to simulate and compare alternative management regimes: Catch quota and effort quota management . The model is based on the methodology of ICES.

Key-words: Fisheries management. Catch Quota regime and Effort Quota regime. Stochastic simulation model. EXCEL/Visual Basic.

RESUME

Denne rapport dokumenterer en matematisk model og dens implementering i EXCEL/Visual Basic. Formålet er at vurdere fiskeriforvaltning ved fangstkvoter og ved indsatskvoter, baseret på ICES rådgivningsmetodik

Key-words: Fiskeriforvaltning. Fangstkvote and indsatskvote-regulering. Stokastisk simulerings model. EXCEL/Visual Basic.

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1. INTRODUCTION

EEQ was prepared as a part of the national project "**Effort regulation as a tool for fisheries management**" (DIFRES project No. 2088: "Indsatsregulering som redskab ved fiskeriregulering"). The Ministry of Food, Agriculture and Fisheries funds the project. The project is jointly executed by

1) DANISH INSTITUTE FOR FISHERIES RESEARCH. Department of Marine fisheries.
2) DANISH INSTITUTE OF AGRICULTURAL AND FISHERIES ECONOMICS
3) INSTITUTE FOR FISHERIES MANAGEMENT AND COASTAL COMMUNITY DEVELOPMENT (IFM).

The present version of the EEQ was developed collectively by the project members, during a number of "model-meetings", where model objectives, models specifications and implementation were discussed and collectively agreed upon. The EEQ model, as it stands here is thus not the results of the presents authors effort only.

1.1. WHAT IS EEQ ?

EEQ (pronounced "ech!") is a multi-species, multi-fleet dynamic software implementation of a stochastic simulation model, which uses a time step of one year. "**EEQ"** stands for "**Evaluation of Effort- and Quota management regimes".**

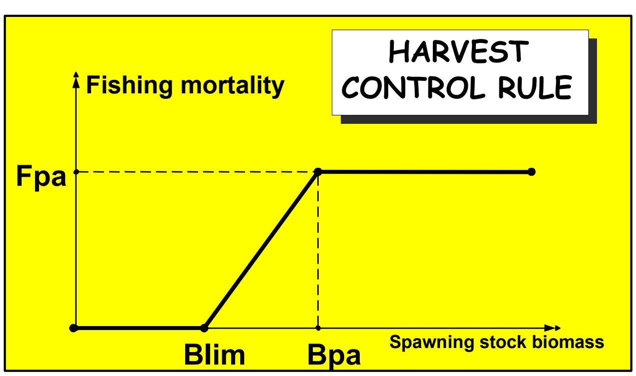
EEQ is based on the traditional ICES VPA and forecast model (reviewed in Lassen & Medley, 2000), as its purpose is to make a comparison of the current quota regime, based on ICES fish stock assessment, to the alternative: Management of fisheries by effort regulation.

In addition to the ICES component, the EEQ contains a simple bioeconomic components which computes the profit from fishing under a suite of assumptions simplifying the underlying economic model.

EEQ is a dynamic simulation model, which makes 3 dynamic simulations in parallel, for a user-specified range of years:

1) VPA on historical data (a new VPA is executed every year)
2) Forecast based on the VPA results (a new forecast is executed every year)
3) Simulation of fisheries, stock and catch (this simulation is not changed from year to year)

The catch (divided into landings and discards) takes the same values in 1) and 3) but all other variables and parameter values (such as stock numbers) may differ between 1) and 3).



The basic idea behind EEQ is to simulate a sequence of years with fish stock assessments executed by ICES working groups, and advice given by the ACFM of ICES to management bodies. The management advice of ICES is based on the Harvest Control Rule (ICES, 1998):

$$F = \begin{cases} F_{PA} \quad if \quad SSB > B_{PA} \\ \dfrac{F_{PA} * (SSB - B_{Lim})}{(B_{PA} - B_{Lim})} \ if \quad B_{Lim} \leq SSB \leq B_{PA} \\ 0 \quad if \quad SSB < B_{Lim} \end{cases}$$

SSB is the Spawning Stock Biomass, F_{pa} is the fishing mortality of the "precautionary approach". B_{pa} is the SSB corresponding to Fpa. B_{lim} is the lowest acceptable level of SSB, which allow fishing to continue. If SSB gets below B_{lim} the stock is in immediate danger of being depleted and fisheries must be stopped.

The HCR (Harvest Control Rule) of ICES is applied to all stocks for both Quota regulation as well as for Effort regulation. Thus it is assumed that ICES will not change its methodology, even if it had to give advice based on effort regulation as the management tool. Needless to say, this assumption of ICES's absolute conservatism is problematic.

The EEQ assumes a one-to-one functional relationship between Effort and fishing mortality.

Fishing Mortality = Q * Effort

where Q is the "Catchability coefficient".

As the ICES philosophy of HCR and PA (Precautionary Approach, ICES 1998, FAO, 1995,1996,1997) is the basis for both simulations of management regimes, a deterministic simulation would show exactly the same results for both management regimes.

The advice of ICES today is a catch quota, which is derived from some value of F, the fishing mortality. This strategic value is called F_{PA}, the "F of the precautionary approach".

$$Quota = \sum_{age=1}^{Number\ of\ Age\ Groups} F_{PA}(age) * \overline{N}(age) * w(age)$$

N is the stock number and w is the individual body weight of a fish.

If the FPA is derived from certain values of fishing Efforts (by fleet) to produce the same F_{PA}:

$$F_{PA}(age) = \sum_{Fleet=1}^{Number\ of\ fleets} Effort_{PA}(Fleet) * Q(Fleet)$$

we will get exactly the same catch quota. Here, following the tradition of ICES, we have ignored the fact that the fleets catch more than one species, and that F_{PA} cannot be defined in a consistent way for more than one species at a time with the expression above. ICES however, have not taken this feature of fishing into account when setting catch quotas. ICES Assessment Working Groups usually consider fishing as one homogenous fishing fleet, and does not attempt to split the F on fleets.

EEQ, however, addresses the question as will be explained below. When dealing with effort expressed in, say, days at sea, one must take into account that a sea day by a 70 meter vessel does not produce the same fishing mortality as one sea day by a 12 meter vessel.

Actually, a major problem for the present simulation is that it is not known which philosophy ICES might use if it was forced to use effort regulation. Therefore, the simplest assumption on ICES is made, namely that ICES will not change methodology of management advice.

ICES advice on fisheries management has always been based on fish stock assessment by single species VPA (Derzhavin, 1922, A review of VPA in ICES is given in Lassen & Medley, 2000) and the yield per recruit model (Beverton and Holt, 1957) in conjunction with the Thompson and Bell (1934) prediction model, and it has hardly changed since it was introduced for the first time. A few cosmetic modifications of the original VPA, has become the result of the introduction of high speed computers, but essentially ICES methodology has remained unchanged.

Taking into account the fact, that ICES has never changed methodology in giving advice on fisheries management, it appears to be a reasonable assumption that ICES will not do so in the near future, although that assumption is not very flattering for the "ICES-spirit". It is indeed very tempting to simulate some innovation in methodology of ICES, but we have no basis for assuming any change in the attitude of ACFM.

Application of EEQ to the flatfish fisheries of the North Sea was given in Ulrich C., S. Pascoe, P. Sparre, J-W. de Wilde and P. Marchal. 2002.

1.2. HOW IS EEC IMPLEMENTED?

The software implementation of EEQ, was intended to become a public software package. That is, to become of a high professional standard, with extensive documentation and user-friendly design. However, the time constraint has made it somewhat difficult to achieve these goals. The present manual is the only documentation of EEQ, and the implementation is still a β-version.

As DIFRES (like most other research institutes) uses Microsoft Office as its standard package, and all professional fisheries scientists are familiar with MS EXCEL, this commercial software was considered suitable as user-interface. However, this choice does not imply any validation of recommendation as to the qualities of MS Office. MS Office was not selected by me, but was what I had to cope with as an employee of DIFRES. Furthermore, EXCEL is also standard software in almost all Fisheries Institutes associated with DIFRES. Once EXCEL is selected, the obvious choice for computer language is VISAUL BASIC (VB), the macro language of EXCEL (and other MS Office components).

The present EEQ implementation uses the EXCEL spreadsheets for input and output only. The cells of the spreadsheets does not contain any formulas, such as "A3 = A1 + A2". All calculations are made by VB code, in the so-called VB-modules, which you can inspect, by clicking on the icon for the "VB-editor". Thus EEQ is a 100% open source software.

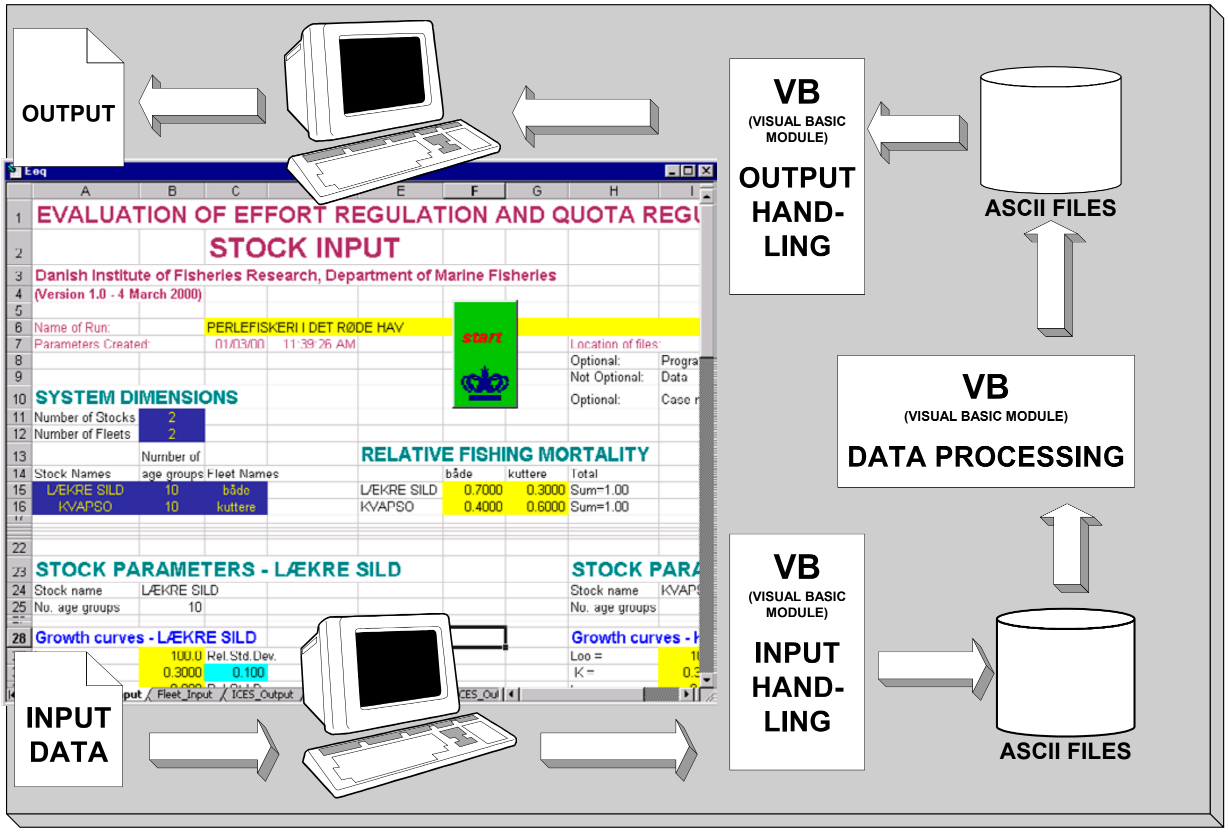


Figure 1.2.1. Flowchart for data and results of the EEQ software.

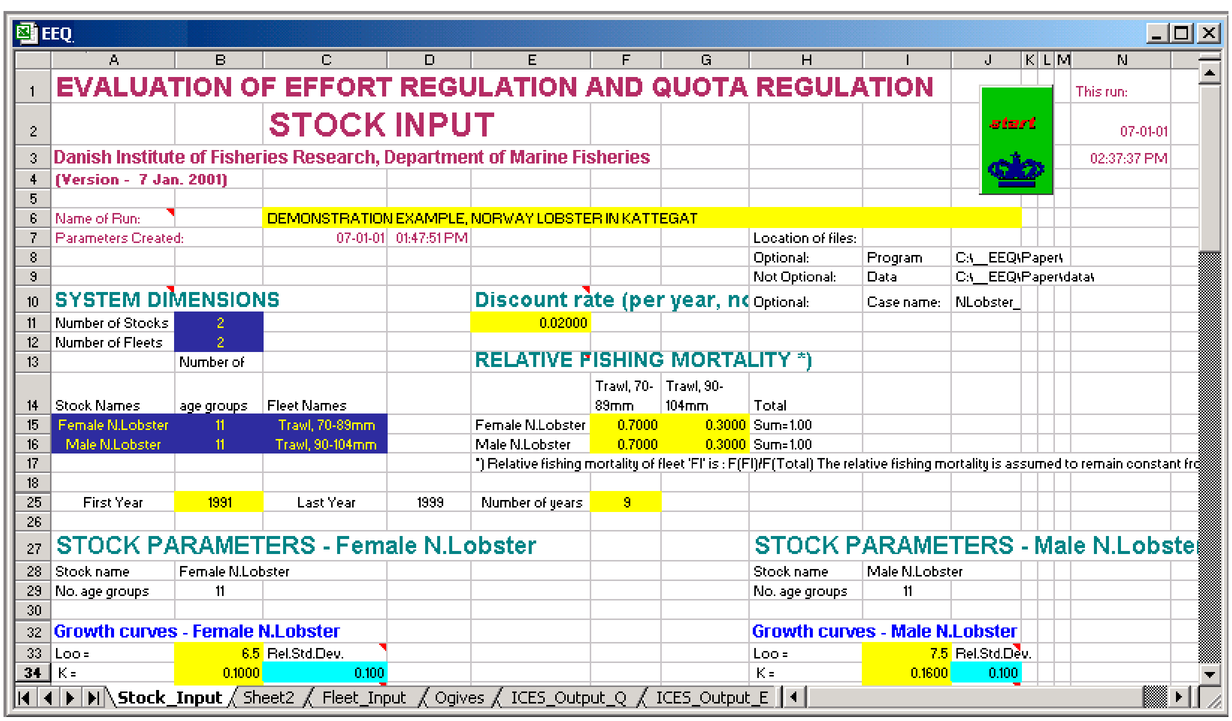


Figure 1.2.2. First worksheet of EEQ (Sheet "Stock_Input"), with the button (ministry logo) which can activate the user-forms of the EEQ

It is an experience that complicated models should not be coded as EXCEL-formulas (although this is possible), because the documentation and maintenance of large spreadsheet application becomes very cumbersome. Therefore, VB modules make all data manipulation.

.
The advantage of using EXCEL is that the user is in a well-known environment and can use all the facilities of EXCEL for entry of input, further processing and presentation of results from EEQ.

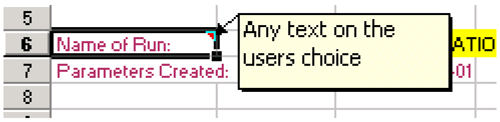
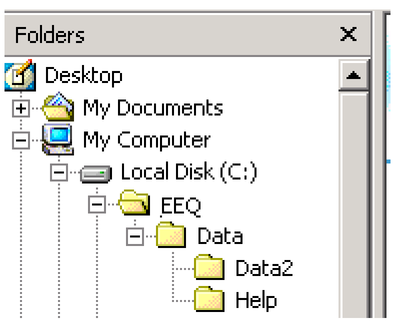


Figure 1.2.2 shows the worksheet "Stock_Input", which is the first worksheet of EEQ. This worksheet contains the "System dimensions", that is the specification of components of the case study. Note that some cell are commented (marked with a read triangle in the upper right corner). Clicking on cell displays the comment. Note that you may edit the comment.

1.3 INSTALLATION AND STARTING THE EEQ WORKSHEET

 The EEQ-programme is delivered as a ZIP-file, "EEQ.ZIP". When unzipped it becomes the directory "EEQ" with sub-directories as shown in Figure 1.3.1. To run the system without further installation, the directory must be located as shown in Figure 1.3.1. If you want to put it somewhere else, that is possible, but then you must make a few changes in the VB-program, as will be explained below.

To start the EEQ you click on the excel file: EEQ (see Figure 1.3.2). This subdirectory also contains a zipped copy of this manual (Word-file).



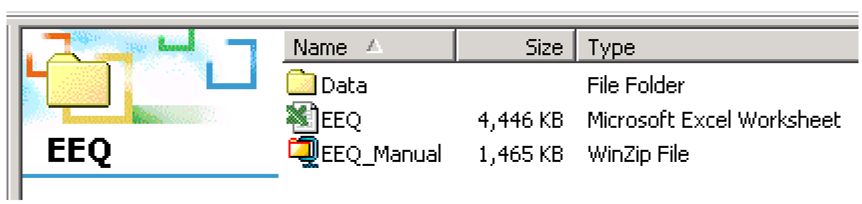


Figure 1.3.2. Location of the EEQ Excel Worksheet

Figure 1.3.1. Location of the EEQ -subdirectory

When you click the EEQ should start, and you get the opening form (Figure 1.3.3.)

To change the location of the EEQ directory (or to rename it) you must change some code in the Visual Basic Module "MO1_Declarations" (Figure 1.3.4)

To get to the module, you must go out of the form, by clicking on "X" in the right upper corner, or by clicking anywhere in the form, except for the buttons. Then you click on

which becomes activated only after you have left the user form.

This gives you the VB-window and in the "Project explorer window" (Left side in Figure 1.3.4) you click on the module "M01_Declarations"

The first part of the module contains the declarations of some text-constants.

The first text-constants id the paths for the directories, and you may change it as you please. EEQDir   = "C:\EEQ\". For example. You may change the path and the mane of the main directory to EEQDir   = "C:\Kattegat\EEQ1\".

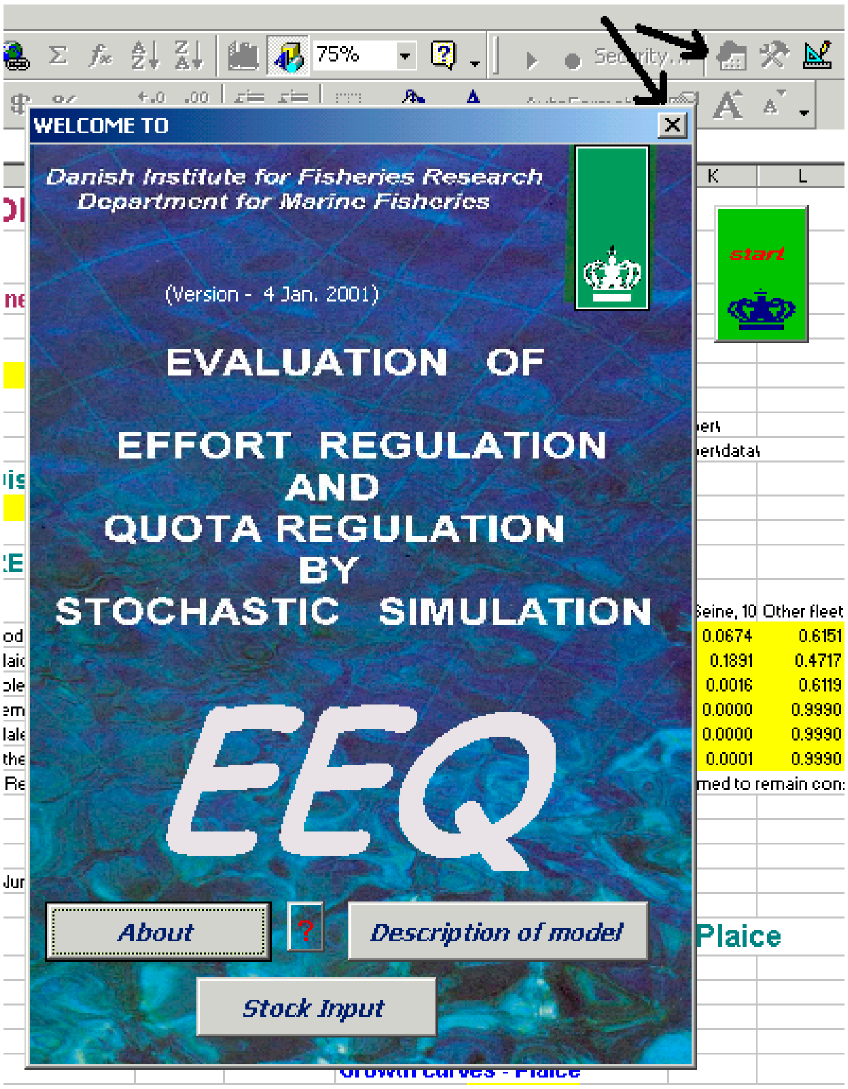


Figure 1.3.3. Opening Form of the EEQ.

But you cannot change the names “Data”, “Help” and “Data2”. Nor should you change their location relative to the main directory.

But, as long as the path-name corresponds to the actual location of the main directory, the EEQ will work. Let’s go back to the opening screen, which you only see when starting up the EEQ. To activate the main menu of EEQ you click on “Stock Input”. The menu for stock input is also the main menu of EEQ (see Figure 1.3.6). If you alternatively want to leave the menus and work in the spreadsheet, you click somewhere in the form, as mentioned above. To execute one of the options represented by the buttons of the on the menu-form, you simply click on the button. If you are in doubt about the meaning of the text on the button you may get help either from the “tip-text”, which

appear when you place the cursor over button or you may click on the question mark next to the button, which will then display a text box with further explanations.

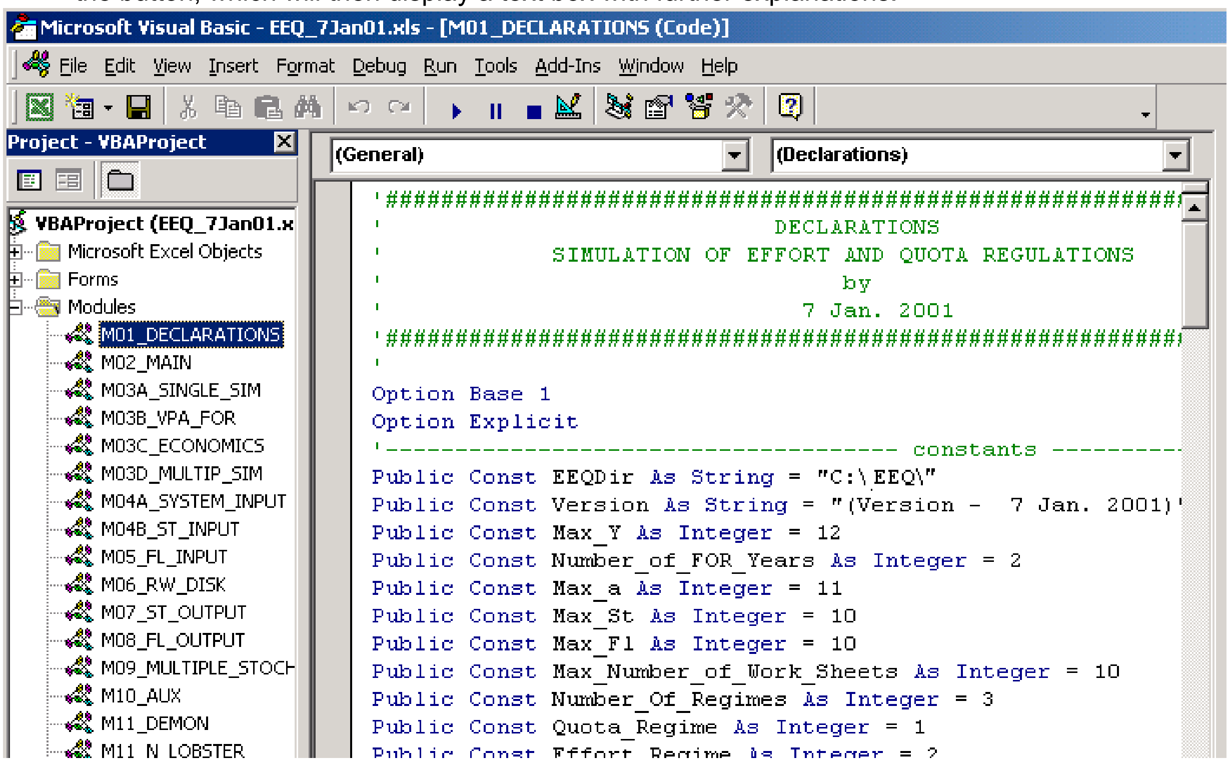


Figure 1.3.4. The first part of VB-module "M01_Declarations", which must be changed to move the directories of EEQ.

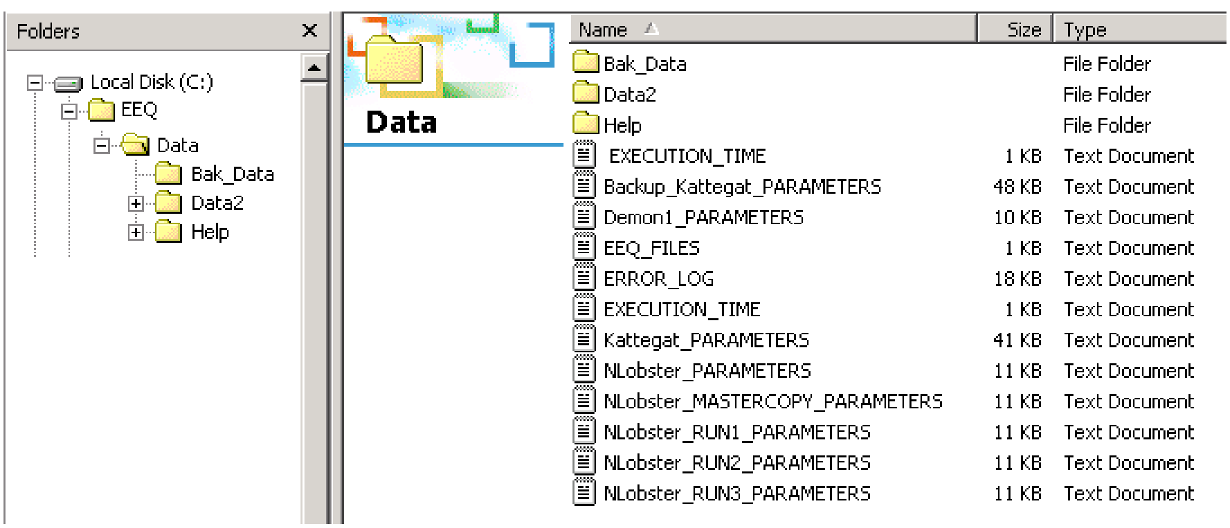


Figure 1.3.5. The content of the "data" subdirectory.

The option to "clear contents of all sheets" is not so drastic as one might think. The contents of the sheets are always backed up on a disk-file, and can easily be retrieved. For example, the button "Read stock parameters from disk file" will recreate the stock parameters.

There are other ways to recreate the worksheets. It is a good practice always to keep a master copy of your case study, and to keep copies of all the essential parameter sets you tested. The button “Backup current data set on disk file” allows you to store the current data set on disk file under separate name.

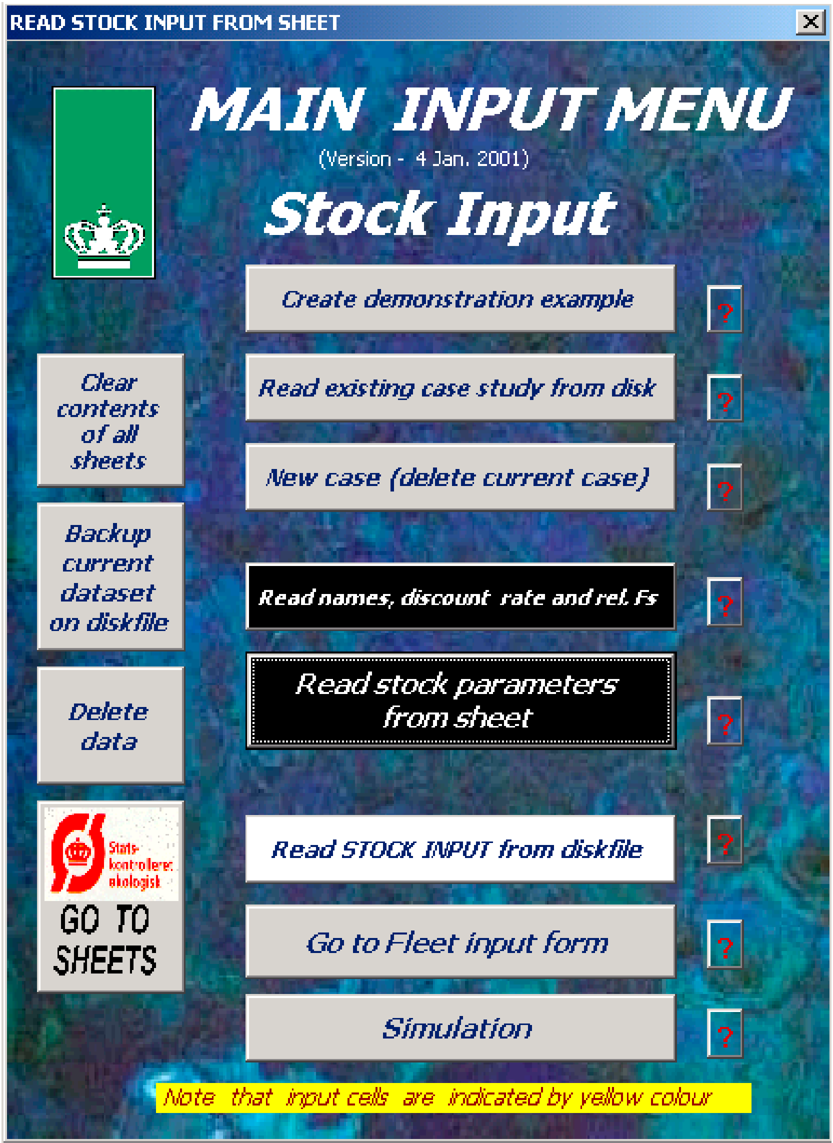
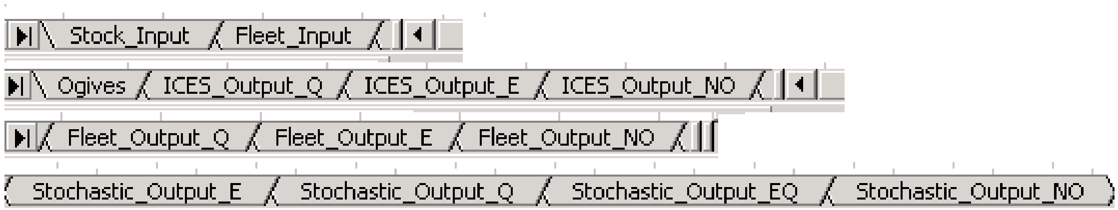


Figure 1.3.6. The stock input user form of EEQ, which is also the main menu of EEQ.

Figure 1.3.5 shows an example with 5 dataset for the same case study, here named “Nlobster”. There is a mastercopy, a “working copy” and 3 copies of “RUN1”, “RUN2” and “RUN3”, which may represent 3 runs with different assumptions about some selected parameters, for example, the gear selection parameters. As can be seen, there are two other case studies, here named “Kattegat” and “Demon1”. The parameter files all end with “PARAMETERS”. This is an extension to the name automatically made by the program, so that a parameter file can easily be identified.

The subdirectory “Bak_Data” is a subdirectory created by the user. You are allowed to create any subdirectiries you like, as lomg as you do not delete the standard directories of EEQ (See Figure1.3.1).
The button “Delete” data lets you delete data files. You may also delete data files by any other utility program, such as the “Explorer

2. INPUT AND OUTPUT OF EEQ



Input to EEQ is entered by two EXCEL worksheets, “**Stock_Input**” and “**Fleet_Input**”. Output is accessed through other EXCEL work sheets The detailed output for single simulations (deterministic or stochastic) are
given in the worksheets “**ICES_Output_X**”, with X = **E, Q** or **NO** (Effort regulation, Quota regulation or NO regulation).

Results from multiple stochastic simulations are given in the worksheets “Stochastic_Output_X”, X = “E” , “Q” , “EQ” or “NO” (Effort regulation, Quota regulation, both regulations or no regulation).

In addition there is the output-worksheet “Ogives” which presents tables with Growth curves and selection ogives (gear selection, maturity ogive and discard ogive).

Do never delete or rename any of the spreadsheets, as that action will cause the EEQ to crash. You may, however, add any number of worksheets to the workbook without damaging the EEQ.

Input to EEQ is partitioned into five main groups:

1) Dimensions of case study (or “system dimension”, see example below)
2) Relative fishing mortality (to be explained below)
3) Stock structured input (input independent of the fleet structure)
4) Fleet structured input (which may or may not be fleet structured)
5) Run options

Output is also naturally divided into the groups

1) Stock structured Output (Output independent of the fleet structure)
2) Fleet structured Output (which may or may not be fleet structured)

Each input group is further divided into:

1) Parameters
2) Relative standard deviations (used for drawing random numbers)
3) Initial conditions and model constraints

Each output group is further divided into

1) Results from single deterministic simulation
2) Results from single stochastic simulation

3) Results from multiple stochastic simulation

2.1. STOCK STRUCTURED INPUT TO EEQ

The EEQ program contains a demonstration example, and the reader is referred to this example for an illustration of the parameter list given below.

This section lists the “system-specification” and the “stock related parameters”. These inputs are stored in the spread sheet “Stock_Input”.

By the “dimensions of a case study” or “system dimensions” in EEQ is meant (see example in Figure 2.1.1).

1) The number of stocks and the name of each stock
2) Then number of age groups of each stock (time step of EEQ is one year)
3) Then number of fleets and the name of each fleet.

Once you have specified the dimensions of a new case study, the EEQ program will create a template of empty tables, which illustrates the set of parameters required to run the EEQ (see Figure 2.1.2).

	A	B	C
10	SYSTEM DIMENSIONS		
11	Number of Stocks	6	
12	Number of Fleets	7	
13		Number of	
14	Stock Names	age groups	Fleet Names
15	Cod	8	Gill Net, 90-119 mm
16	Plaice	11	Gill Net, 120-159 mm
17	Sole	11	Trawl, 70-89 mm
18	Fem. N.Lob.	11	Trawl, 90-104 mm
19	Male N.Lob.	11	Trawl, 105-120 mm
20	Other stocks	10	D.Seine, 100-120 mm
21			Other fleets

Figure 2.1.1. Example of System dimensions as input to EEQ (in worksheet “Stock_Input”).

The years for which the dynamic simulation runs is determined by the “first year”, here 1987 and the number of years, in the example 12 years, so that the last year becomes 1998. The “dimensions of case study” are stored in dark blue cells (with yellow font) in the EEQ spread sheet.

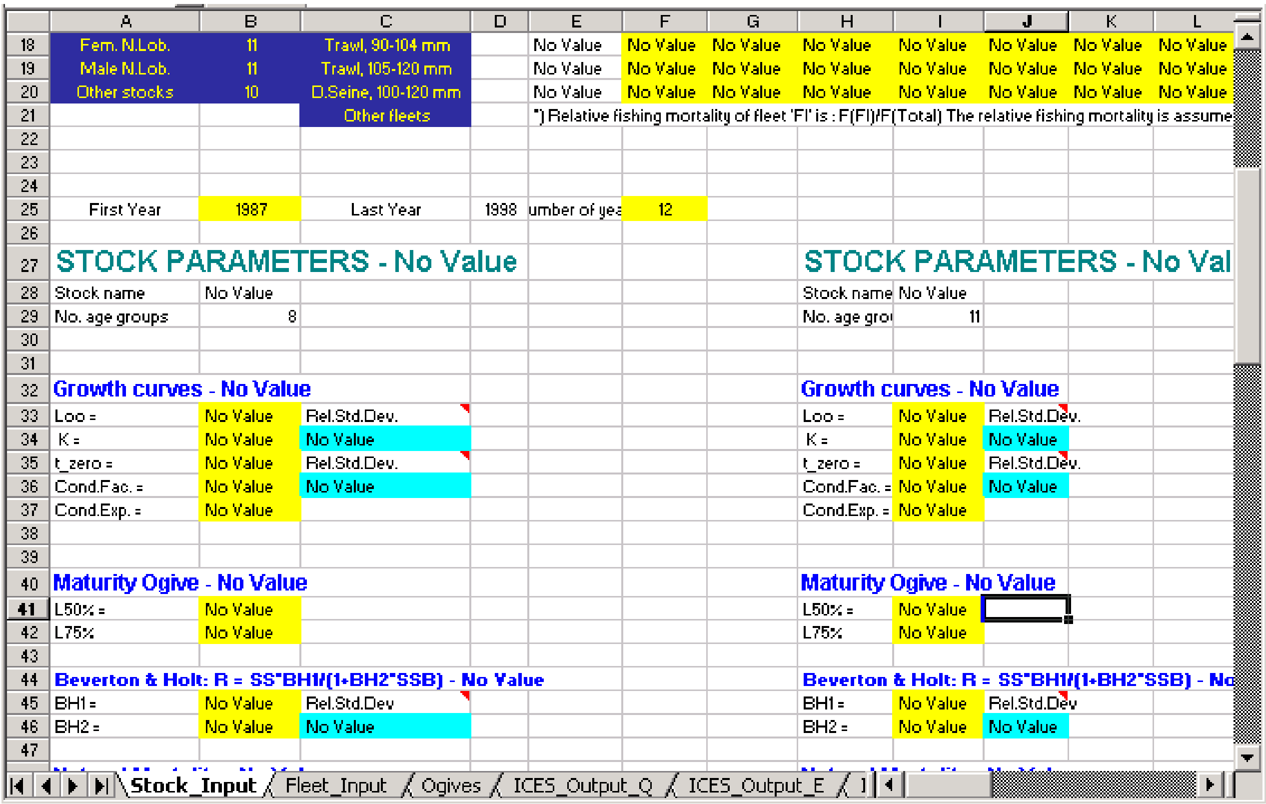


Figure 2.1.2. Table templates for new case study.

The “**relative fishing mortalities”** gives the splitting of fishing mortalities for each stock on fleet-components:

$$F_{TOTAL}(Stock) = \sum_{Fleet=1}^{Number\ of\ Fleets} F(Stock, Fleet) \quad \text{and} \quad F_{RELATIVE}(Stock, Fleet) = \frac{F(Stock, Fleet)}{F_{TOTAL}(Stock)}$$

The relative fishing mortality is assumed to remain constant. This is a necessary assumption, when you start with deciding the total F (from the harvest control rule) , and then wants to find out how much effort is needed by the fleets to produce that fishing mortality:

$$F_{TOTAL}(Stock) = \sum_{Fleet=1}^{Number\ of\ Fleets} Effort(Fl) * Q(Stock, Fleet)$$

This equation has infinitely many solutions with regards to Effort(Fl) if there are more than 2 fleets.

With the constant relative F we can allocate the F derived from the Harvest Control Rule to a fleet:

$$F_{HCR}(Stock) * F_{RELATIVE}(Stock, Fleet) = F_{HCR}(Stock, Fleet)$$

Now if we introduce a theoretical effort-concept, “$Effort_{STOCK}$”, which is the effort a fleet should exert to produce the fishing mortality:

$$F_{HCR}(Stock, Fleet) = Effort_{STOCK}(Fleet, Stock) * Q(Stock, Fleet)$$

The concept, $Effort_{STOCK}$, has no meaning except as a mathematical factor used to link F and Q.

$$Effort_{STOCK}(Fleet, Stock) = \frac{F_{HCR}(Stock, Fleet)}{Q(Stock, Fleet)}$$

To convert the set of $Effort_{STOCK}(Stock, Fleet)$ (one for each fleet) to one real effort-value one could take the mean value, or the median or whatever you can think of. Actually, in EEQ we shall convert the theoretical set of $Effort_{STOCK}$'s into one real effort value by the minimum and by the maximum.

$$Effort(Fl) = MIN_{Stock}\{\ Effort_{STOCK}(Fl, Stock)\ \}$$ and
$$Effort(Fl) = MAX_{Stock}\{\ Effort_{STOCK}(Fl, Stock)\ \}$$

Now, that sort of calculations are possible only if the relative fishing mortality is fixed.
That the relative fishing mortality remains constant is obviously a very strong assumption, which is not likely to be met if any changes of the system have happened. The assumption, however, was forced upon the EEQ, because of the problem in making assumption about the behaviour of ICES under an effort regime. The assumption of unchanged ICES methodology has the consequence that relative fishing mortality has to be assumed to remained constant. This assumption is perhaps the most critical point of EEQ (there are other weak points of EEQ).

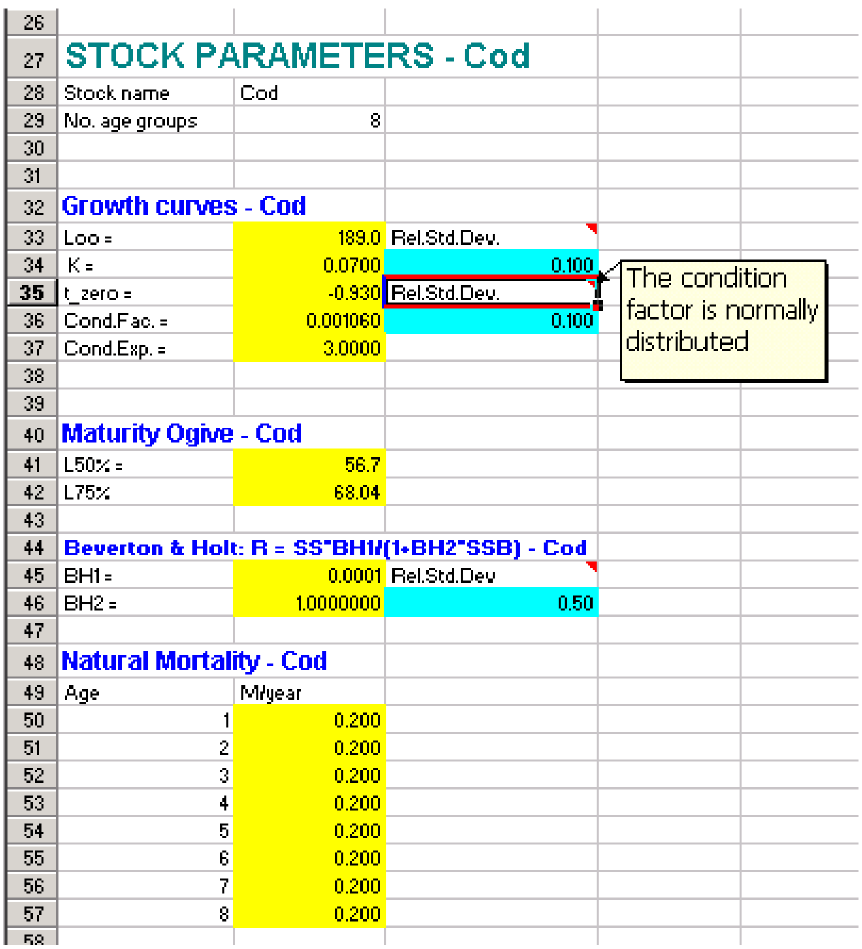


Figure 2.1.2. Stock parameters of a single stock ("Cod") from sheet "Stock_Input".

The “the relative fishing mortalities” are stored in yellow cells in the EEQ spread sheet (see example in Figure 1.2.2):.

The **discount rate** (per year). The discount rate is discussed in Section 3.7.4. It is used to compute the “present value” of quantities, which will materialise in the future.
The “stock structured parameters” are:

Von Bertalanffy growth parameters. The growth parameters in “Body length = L∞ * (1 – exp(-K*(age-to))) “ are (see example in Figure 2.1.2):

L∞: Maximum average body length
K: Curvature parameter
To: (t-zero): Initial condition parameter

The same parameters are used for “stock”, “landings” and “discards”.

Parameters in the **Length/weight relationship** (Weight = condition factor * Length ^(Condition exponent)
Condition factor
Condition exponent

Maturity ogive (see example in Figure 2.1.2):
(the logistic curve: Maturity(length) = 1/(1+epx(Mat1 + Mat2*length)), where
Mat1 = log(3)*$L_{50\%}$/($L_{75\%}$-$L_{50\%}$) and Mat2 = - Mat1/$L_{50\%}$ is used as model for maturity).
$L_{50\%}$: The length at which 50% of the fish are mature (no sexual difference is assumed)
$L_{75\%}$: The length at which 75% of the fish are mature.

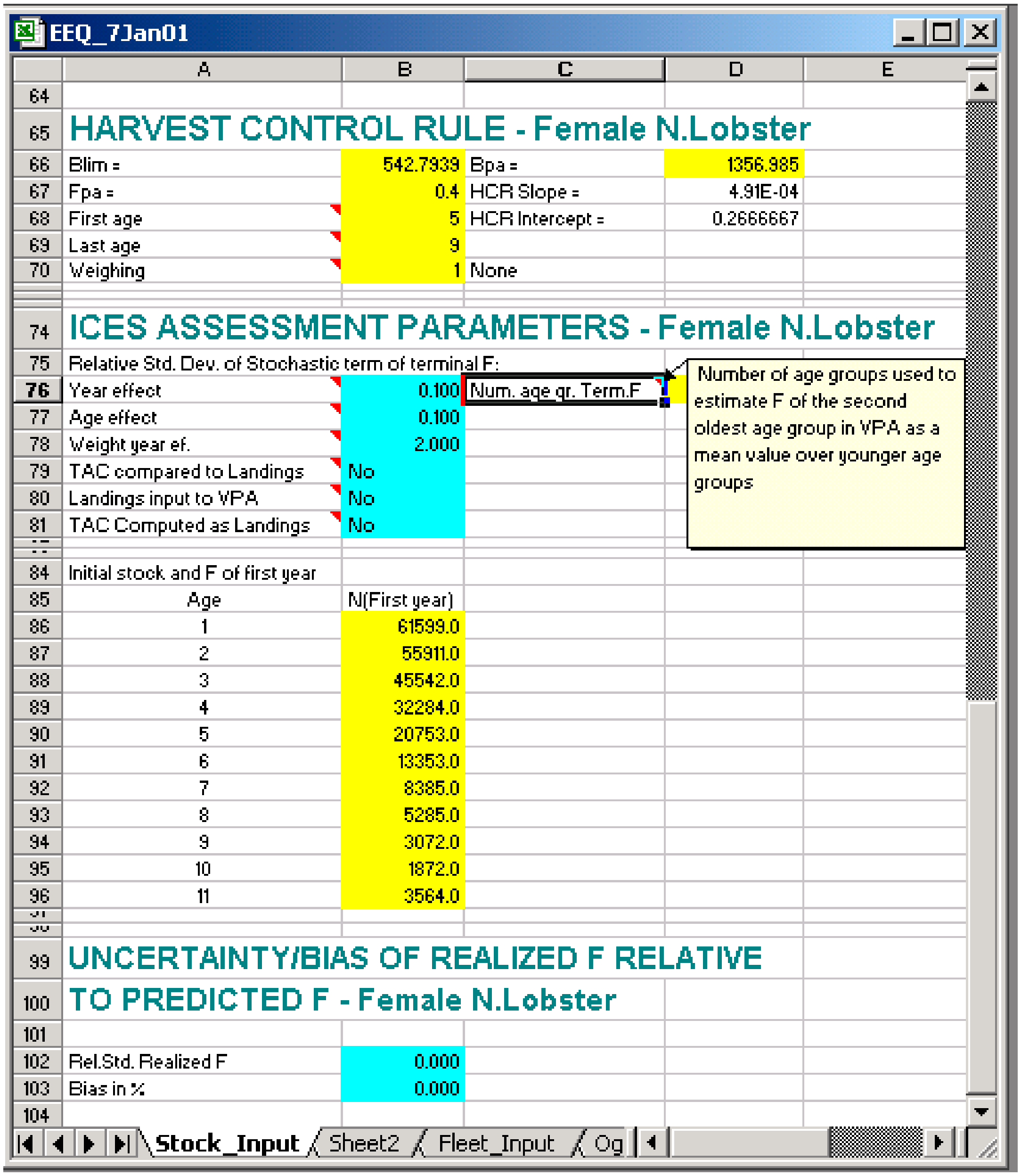
Stock/recruitment parameters (see example in Figure 2.1.2), of the Beverton and Holt model:
Recruitment = BH1/(1+BH2*SSB), where recruitment = number of 0-group fish, SSB = Spawning stock biomass.
BH1: First parameter in the B&H model
BH2: Second parameter in the B&H model.

Natural mortality by age group (see example in Figure 2.1.2). The natural mortality is assumed to remain constant from year to year.

ICES HCR (Harvest Control Rule) parameters (see example in Figure 2.1.3).

$$F_{HCR} = \begin{cases} 0 \;\; if \;\; SSB \le B_{\lim} \\ F_{pa} \dfrac{SSB - B_{\lim}}{B_{pa} - B_{\lim}} \;\; if \;\; B_{\lim} \le SSB \le B_{pa} \\ F_{pa} \;\; if \;\; SSB > B_{pa} \end{cases}$$

SSB = Spawning Stock Biomass
B_{pa}: Biomass (SSB) of the precautionary approach.
B_{lim}: The critical biomass (SSB)
F_{pa}: Fishing mortality (mean) of the precautionary approach
The first age group used to compute mean F
The last age group used to compute mean F
Option for weighing: 1 straight mean value. 2: Weighing mean value by stock numbers.



EEQ_7Jan01

	A	B	C	D	E
64					
65	HARVEST CONTROL RULE - Female N.Lobster				
66	Blim =	542.7939	Bpa =	1356.985	
67	Fpa =	0.4	HCR Slope =	4.91E-04	
68	First age	5	HCR Intercept =	0.2666667	
69	Last age	9			
70	Weighing	1	None		
74	ICES ASSESSMENT PARAMETERS - Female N.Lobster				
75	Relative Std. Dev. of Stochastic term of terminal F:				
76	Year effect	0.100	Num. age gr. Term.F		
77	Age effect	0.100			
78	Weight year ef.	2.000			
79	TAC compared to Landings	No			
80	Landings input to VPA	No			
81	TAC Computed as Landings	No			
84	Initial stock and F of first year				
85	Age	N(First year)			
86	1	61599.0			
87	2	55911.0			
88	3	45542.0			
89	4	32284.0			
90	5	20753.0			
91	6	13353.0			
92	7	8385.0			
93	8	5285.0			
94	9	3072.0			
95	10	1872.0			
96	11	3564.0			
99	UNCERTAINTY/BIAS OF REALIZED F RELATIVE				
100	TO PREDICTED F - Female N.Lobster				
101					
102	Rel.Std. Realized F	0.000			
103	Bias in %	0.000			
104					

Number of age groups used to estimate F of the second oldest age group in VPA as a mean value over younger age groups

Stock_Input / Sheet2 / Fleet_Input / Og

Figure 2.1.3. Stock parameters related to ICES assessment. From sheet "Stock_Input")

ICES assessment parameters. (see example in Figure 2.1.3). The EEQ simulates an ICES assessment each year. These parameters gives the initial conditions for the ICES assessment. This is the information, which is needed to start up the dynamic simulation over 10 years. The parameters are:

Initial stock numbers
Effort and catchability of first year (to compute Fishing mortalities of the first year)

The Effort and the catchability of first year is given as in put to work sheet "Fleet_Input".

Then there are a number of parameters (See Figure 2.1.3) which will be explained later. The last three cells contains model-options, that is, whether the TAC is matched to the landings or to the catch (= landings + discards) and the option to use catch or landings as input to VPA. The last parameter of the three is the option to let the catch prediction used to set the TAC be the landings or the catch.

The "the stock-parameters" are stored in yellow cells in the EEQ spread sheet.

Finally, we list the parameters used for stochastic simulation, what is named "Rel.Std.Dev." (Relative Standard Deviations). A parameter or a variable is made stochastic by multiplication with a "Stochastic factor", with mean value 1.0.

"Parameter" is replaced by "Parameter * (Stochastic factor)"

The value of the stochastic factor is drawn from a random number generator, which assumes either

a) A normally distributed stochastic variable with mean value 1.0

b) A log normally distributed stochastic variable with mean value 1.0

In addition to the man value, these distributions need the variance as parameter, which in EEQ is derived from the "relative standard deviation" (Standard deviation / mean value), which in this case is the same as standard deviation since the mean value is one.

The parameters, which can be made stochastic variable in EEQ are indicated by a light blue cells in the EEC spread sheet. These are:

1) Bertalanffy growth parameter, K (normally distributed) (see example in Figure 2.1.2).

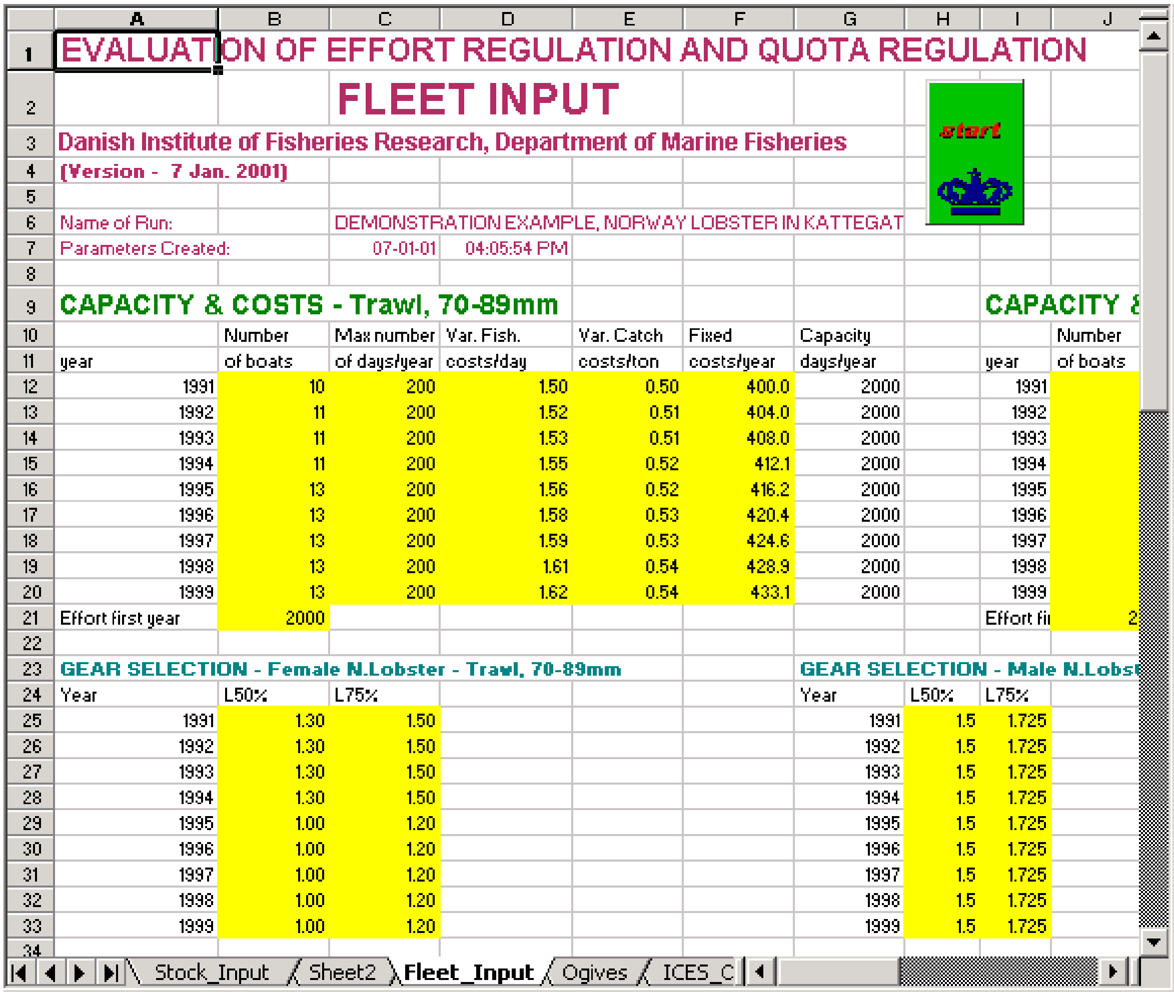
2) Condition factor (normally distributed) (see example in Figure 2.1.2).

3) The Beverton and Holt stock recruitment relationship (log-normally distributed) (see example in Figure 2.1.1).

4) The terminal F used in ICES stock assessment by VPA. The stochastic effect is split into a year effect and age effect, as is customary in ICES (Separable VPA). (see example in Figure 2.1.2).

5) The "realised F", that is the F in the simulation (compared to the F predicted in the ICES forecast). (see example in Figure 2.1.3).

6) Bias in the "realised F". It is often observed that ICES underestimate the F in its prediction, indicating that ICES is biased in its F-estimation. EEQ contains an option for bias of the realised F compared to the F predicted predicted by ICES (see example in Figure 2.1.3).



EVALUATION OF EFFORT REGULATION AND QUOTA REGULATION

FLEET INPUT

Danish Institute of Fisheries Research, Department of Marine Fisheries

(Version - 7 Jan. 2001)

Name of Run: DEMONSTRATION EXAMPLE, NORWAY LOBSTER IN KATTEGAT

Parameters Created: 07-01-01 04:05:54 PM

CAPACITY & COSTS - Trawl, 70-89mm

year	Number of boats	Max number of days/year	Var. Fish. costs/day	Var. Catch costs/ton	Fixed costs/year	Capacity days/year
1991	10	200	1.50	0.50	400.0	2000
1992	11	200	1.52	0.51	404.0	2000
1993	11	200	1.53	0.51	408.0	2000
1994	11	200	1.55	0.52	412.1	2000
1995	13	200	1.56	0.52	416.2	2000
1996	13	200	1.58	0.53	420.4	2000
1997	13	200	1.59	0.53	424.6	2000
1998	13	200	1.61	0.54	428.9	2000
1999	13	200	1.62	0.54	433.1	2000
Effort first year	2000					

CAPACITY &

year	Number of boats
1991	
1992	
1993	
1994	
1995	
1996	
1997	
1998	
1999	
Effort fi	2

GEAR SELECTION - Female N.Lobster - Trawl, 70-89mm

Year	L50%	L75%
1991	1.30	1.50
1992	1.30	1.50
1993	1.30	1.50
1994	1.30	1.50
1995	1.00	1.20
1996	1.00	1.20
1997	1.00	1.20
1998	1.00	1.20
1999	1.00	1.20

GEAR SELECTION - Male N.Lobst

Year	L50%	L75%
1991	1.5	1.725
1992	1.5	1.725
1993	1.5	1.725
1994	1.5	1.725
1995	1.5	1.725
1996	1.5	1.725
1997	1.5	1.725
1998	1.5	1.725
1999	1.5	1.725

Stock_Input / Sheet2 / Fleet_Input / Ogives / ICES_C

Figure 2.2.1. Flet dependent input and some fleet and stock dependent input from sheet "Fleet_input".

2.2. FLEET DEPENDENT INPUT TO EEQ

This input is structured by fleet, and some times also by stock. The input in question is stored on EEQ spreadsheet "Fleet_Input". As for the stock input, parameters are indicated by yellow cells and parameters for stochastic simulation by light blue cells.

The fleet structured input is either independent of stocks or stock-structured.

2.2.1. FLEET STRUCTURED STOCK INDEPENDENT INPUT TO EEQ

This group of input parameters relates mainly to the economics of fleets. They are

1) Number of boats in the fleet
2) Max number of days/year a boat can possible fish
3) Variable costs of Fishing per boat day (effort dependent costs). This cost is independent of the catch.

4) Variable costs of handling and selling the Catch per weight unit (independent of fishing effort)
5) Fixed costs per boat per year.

The product of 1) and 2) gives the capacity of the fishing fleets (the upper limit of effort that can be exerted).

The parameters are all year specific.

	A	B	C	D	E	F	G	H	I	J	K
35											
36	DISCARD - Female N.Lobster - Trawl, 70-89mm						DISCARD - Male N.Lobster - Trawl, 70-89mm				
37	Year	D.L50%	D.L75%				Year	D.L50%	D.L75%		
38	1991	1.95	2.535				1991	2.25	2.925		
39	1992	1.95	2.535				1992	2.25	2.925		
40	1993	1.95	2.535				1993	2.25	2.925		
41	1994	1.95	2.535				1994	2.25	2.925		
42	1995	1.95	2.535				1995	2.25	2.925		
43	1996	1.95	2.535				1996	2.25	2.925		
44	1997	1.95	2.535				1997	2.25	2.925		
45	1998	1.95	2.535				1998	2.25	2.925		
46	1999	1.95	2.535				1999	2.25	2.925		
47											
48											
49	CATCHABILITY - Female N.Lobster - Trawl, 70-89mm						CATCHABILITY - Male N.Lobster - Trawl, 70-8				
50	year	Q	Rel.St.Dev(Q)				year	Q	Rel.St.Dev(Q)		
51	1991	0.00005	.1000				1991	0.00005	.1000		
52	1992	0.00005025	.1000				1992	0.00005	.1000		
53	1993	5.0501E-05	.1000				1993	0.00005	.1000		
54	1994	5.0754E-05	.1000				1994	0.00005	.1000		
55	1995	5.1008E-05	.1000				1995	0.00005	.1000		
56	1996	5.1263E-05	.1000				1996	0.00005	.1000		
57	1997	5.1519E-05	.1000				1997	0.00005	.1000		
58	1998	5.1776E-05	.1000				1998	0.00005	.1000		
59	1999	5.2035E-05	.1000				1999	0.00005	.1000		
60											

Stock_Input / Sheet2 / Fleet_Input / Ogives / ICES_C

Figure 2.2.2. Fleet and stock structured input to EEQ, from sheet "Fleet_Input".

2.1.1. FLEET AND STOCK STRUCTURED INPUT TO EEQ

These parameters are all year specific. As indicated by the title of the section they also vary from stock to stock.

Gear selection ogive (the logistic curve: Selection(length) = 1/(1+epx(S1 + S2*length)), where S1 = log(3)*L50%/(L75%-L50%) and S2 = - S1/L50% is used as model for gear selection).
L50%: The length at which 50% of the fish entering the gear is retained
L75%: The length at which 75% of the fish entering the gear is retained
.

Discard selection ogive (the logistic curve: DiscardOgive(length) = 1/(1+epx(D1 + D2*length)), where D1 = log(3)*L50%/(L75%-L50%) and D2 = - D1/L50% is used as model for discarding).
L50%: The length at which 50% of the fish caught, are discarded.
L75%: The length at which 25% of the fish caught, are discarded

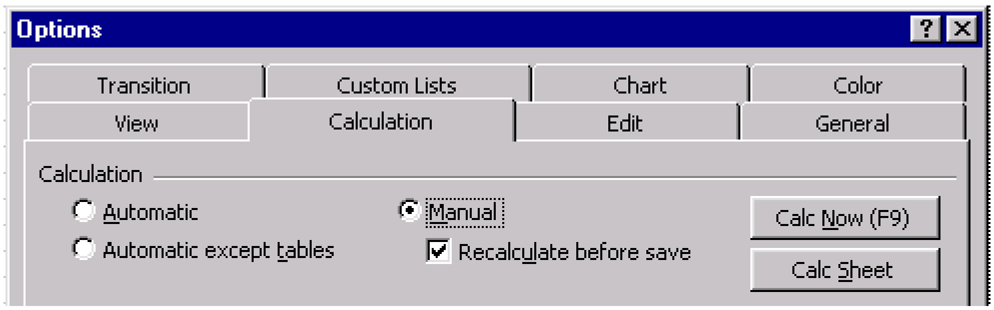
Catchability coefficients.
That is the relationship between fishing mortality and effort:
Fishing mortality = Effort * Catchability coefficient.

Price per kg. The price is modelled as a "year factor" multiplied by an "age factor"

Price per kg of age group a = (Maximum price) * ((Price of age group a)/ (Maximum price))
The maximum price (among age groups) is year dependent, whereas the relative price ((Price of age group a)/ (Maximum price)) remains constant over years.

Of the fleet structured parameters, only the catchability can be made a stochastic variable. It is assumed to be log-normally distributed.

2.3. RUNNING THE EEQ



It should be kept in mind that the EEQ does not automatically execute the computations as in a ordinary spreadsheet. Actually, there is an option in EXCEL for “manual calculation”. If you select this option, calculations will be made only when you press the “F9-key”.

Figure 2.3.1. EXCEL-Option: Calculation.

The EEQ will only execute when you request it to do so, corresponding to pressing the “F9” key. You give the commands to EEQ by clicking on buttons in the “User forms”.

Once you are in the scope of userforms, you loose access to the spreadsheet, but you can at any time easily toggle between userforms and spreadsheets. You go from sheets to userforms by clicking on the green button with the ministry logo and “Start” on it. You leave the userforms by clicking on the “Go to Sheets” button. As an example of a userform, Figure 1.3.5. shows the form for entry of stock structured input.

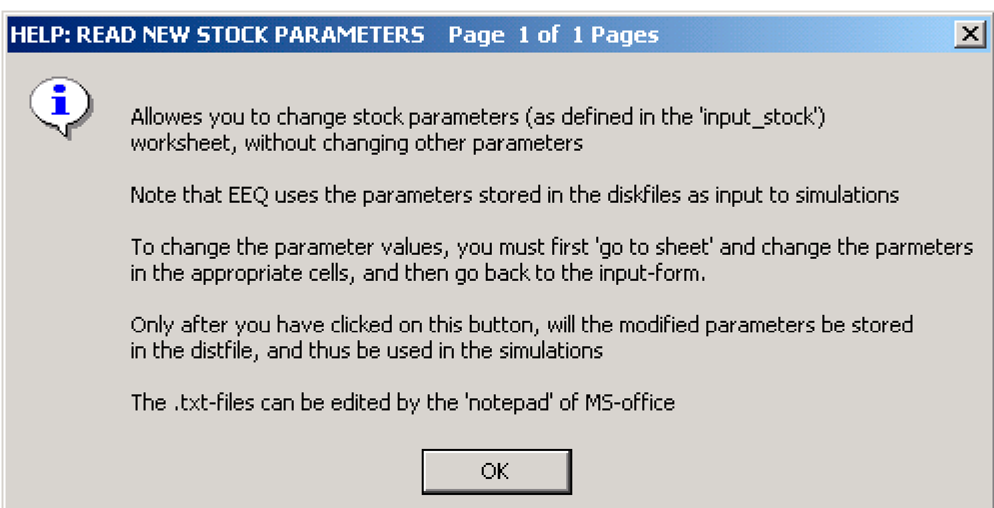


Figure 2.3.2. Example of help message (here for “Read stock parameters).

Next to each button is a small “?”-button, which can provide further explanation on the text on the buttons. As an example is shown the help message of the “Read ICES assessment parameters”-button. Actually, this help massage is the first in a suite of four messages, each one adding more information to the foregoing.
As the user forms thus is supposed to be self-explanatory, we shall not here go further in a “user’s manual”.

2.4. RUN OPTIONS OF EEQ

The run option relates to management regime and type of stochastic/deterministic simulation.

The options for management routines are

1) Quota management
2) Effort management
3) Both management regimes together
4) No management regime
5)

Options 1) and 2) does not produce the same output as 3). In three the two set of results are scaled the same way, to make comparison easy. Options 1) and 2) executed separately, will usually give different scaling of the results.

Note that EEQ does not contain a “hybrid option”, that is an option with both effort and quota regulation. This is due to the fact that the present state of the art of fisheries management evaluation does not allow for anything else but the most distinct and crude assumptions to be compared.

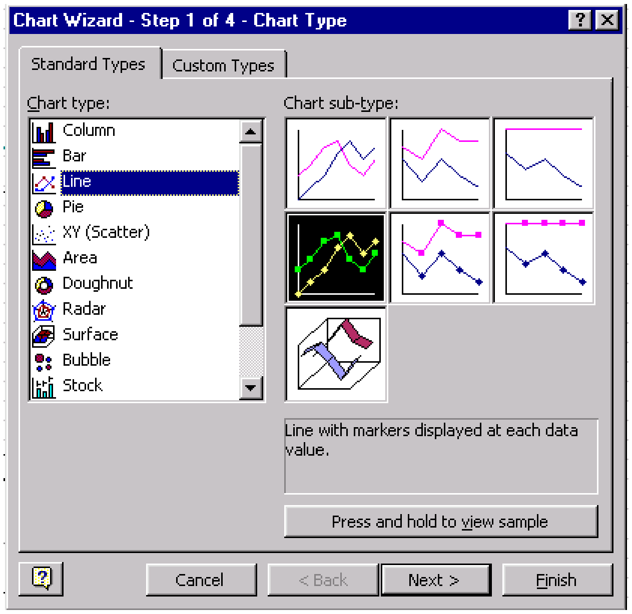
The options for stochastic/deterministic simulation are.

1) Single deterministic simulation
2) Single stochastic simulation
3) Multiple stochastic simulation of selected management regime
4) Multiple stochastic simulation of both management regimes
5) To compare TAC to landings or to catch
6) To use landings or catch as input to VPA

In cases 3 and 4 you are also requested to enter the number of simulations you want to run with EEQ.

2.5. OUTPUT FROM EEQ

As input to EEQ, the Output is also separated into stock structured output and fleet structured output, as indicated by the names of the three output worksheets: “ICES_Output”, “Fleet_Output” and “Stochastic_Output”. The names “ICES” is used for the output sheet to indicate the close relationship between “ICES” and “Fish stock assessment”. The “ICES_Output”- sheet might as well have been given the names “Stock_Output“.
There are two versions of each regime-specific output sheet, depending on the management regime selected:



1) Catch quota regime: “ICES_Output_Q”, “Fleet_Output_Q” and “Stochastic_Output_Q”.
2) Effort regulation regime: “ICES_Output_E”, “Fleet_Output_E” and “Stochastic_Output_E”.

and there is a sheet which compares the multiple result from the two management regimes, “Stochastic_Output_EQ”

This should facilitate the comparison of the two management regimes.

The output from EEQ consists only of tables with numbers. EEQ does not produce any graphs. It is up to the user of EEQ to apply the facilities of EXCEL to produce whatever graphs she/he considers usefull.
Some tables are designed to make the transformation into a graph easy. Figure 2.5.1.a and b, for example, shows a typical output from a multiple stochastic simulation.

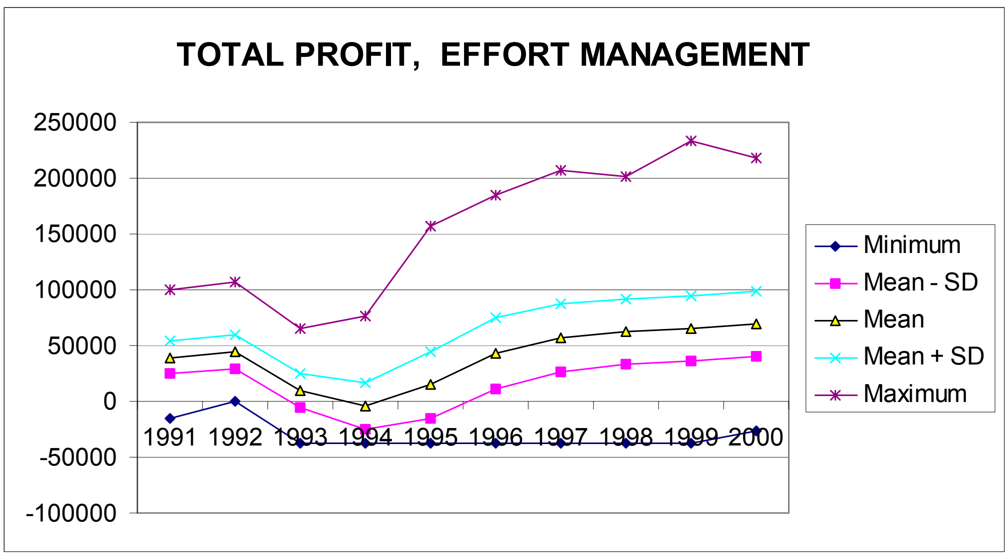


Figure 2.5.1.a. Example of graph produced from the output tables of EEQ.

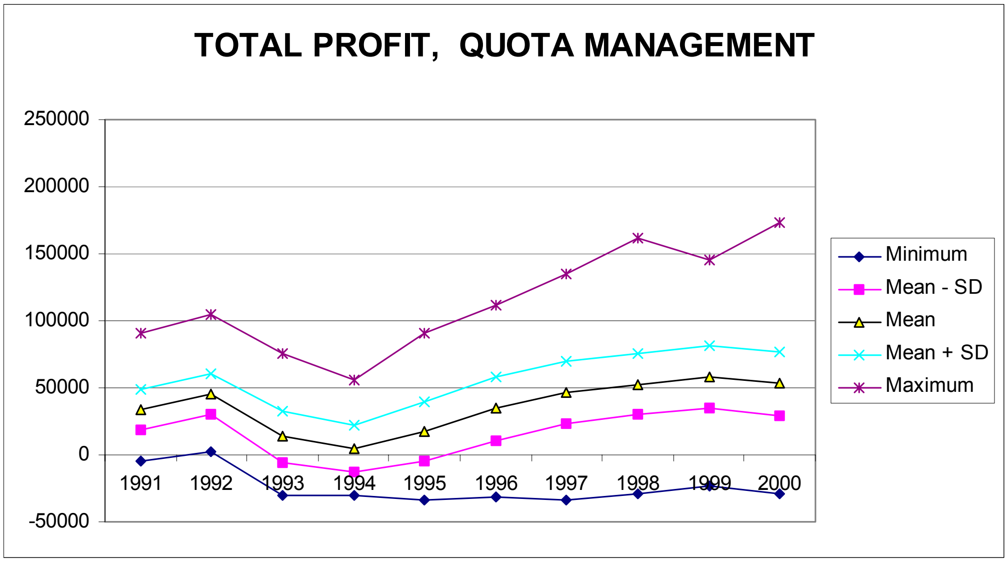


Figure 2.5.1.b. Example of graph produced from the output tables of EEQ.

The EXCEL table from which Figure 2.5.1.b was produced looks like:

Eq

	AI	AJ	AK	AL	AM	AN	AO	AP
37								
38		EFFORT REGULATION - Grand Total Profit						
39		Year	Minimum	Mean - SD	Mean	Mean + SD	Maximum	
40		1991	-14807	24724	39484	54244	100227	
41		1992	684	29198	44661	60124	107012	
42		1993	-37896	-5529	10051	25631	65000	
43		1994	-37905	-24971	-3810	17350	76241	
44		1995	-37806	-15011	14839	44690	157243	
45		1996	-37651	11154	43075	74996	184515	
46		1997	-37529	26020	56644	87268	206866	
47		1998	-37366	32852	62226	91599	201950	
48		1999	-37035	36646	65743	94839	233227	
49		2000	-26208	40806	69826	98846	218621	
50								
51								

Fleet_Output_E | Stochastic_Output_E | ICES_Output_Q | Stochastic_Output_EQ | Fle

Figure 2.5.2 shows some details behind the graphs in Figures 2.5.1.a and b. Figure 2.5.2 compares the distributions of profit from the two management regimes. In this case, 3000 simulations were made for each management regime, and Figure 2.5.2 shows the frequencies of the profit (with arbitrary x-scale).

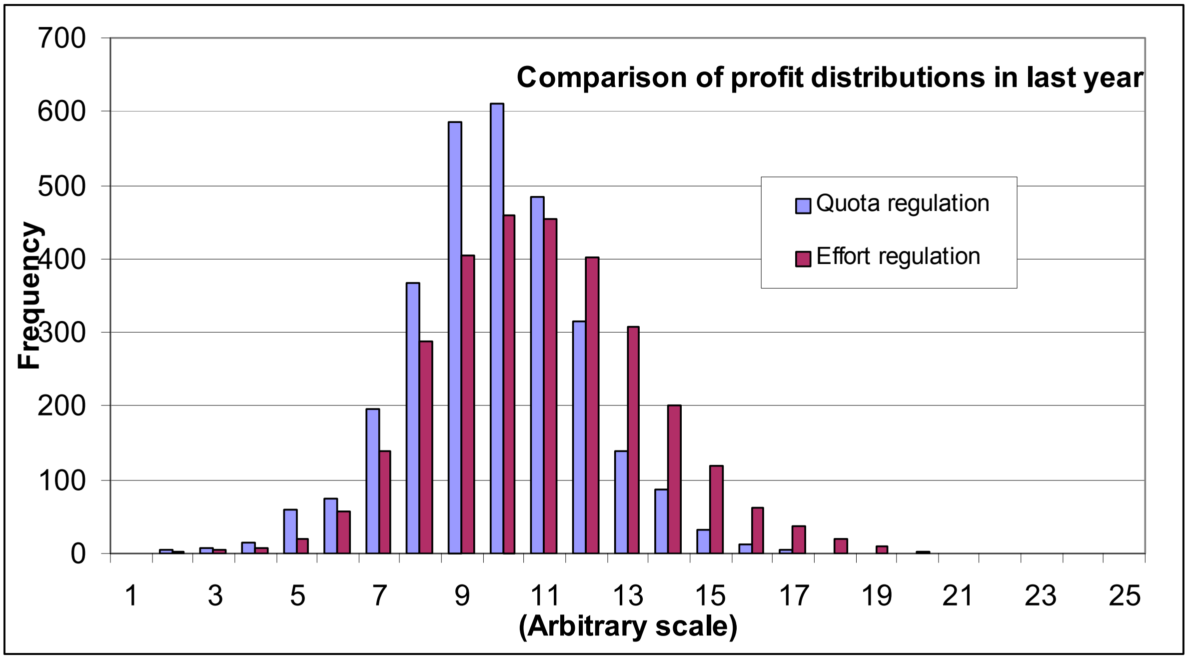


Figure 2.5.2. Example of graphical presentation of EEQ results.

The outputs produced by the EEQ is rather extensive, and the reader is referred to the demonstration example of EEQ to see further details.

3. THE MODEL BEHIND EEQ

Figure 3.1 illustrates the 3 parallel models of EEQ. The figure also indicates the way the EEQ has been made a stochastic simulation, but we shall come back to that aspect in various sections below.

Figure 3.0.1 is thought of as a reference when going through the following sections. Therefore, there shall be no comprehensive explanation of Figure 3.0.1 at this stage.

Probably the most concise and comprehensive description of the model behind EEQ is the VB (Virtual Basic) program, which implements the EEQ. The names of variables and the structure of the VB program are designed to make the algorithms easy to grasp. The reader, who really wants to know what EEQ does, is recommended to study the VB program To get access to the code of the VB-modules you click on the icon VB-button.

Although the reader may not be familiar with the VB-language, it still makes some sense to study the codes, as it is often intuitively clear what the codes means. Figure 3.0.2 shows an example of VB-code, namely the “corner stone of EEQ”, the subroutine, which executes a single simulation over a time series of years. Figure 1.3.4 shows the list of VB modules as it appears in the so-called “Project window” of the VB system.

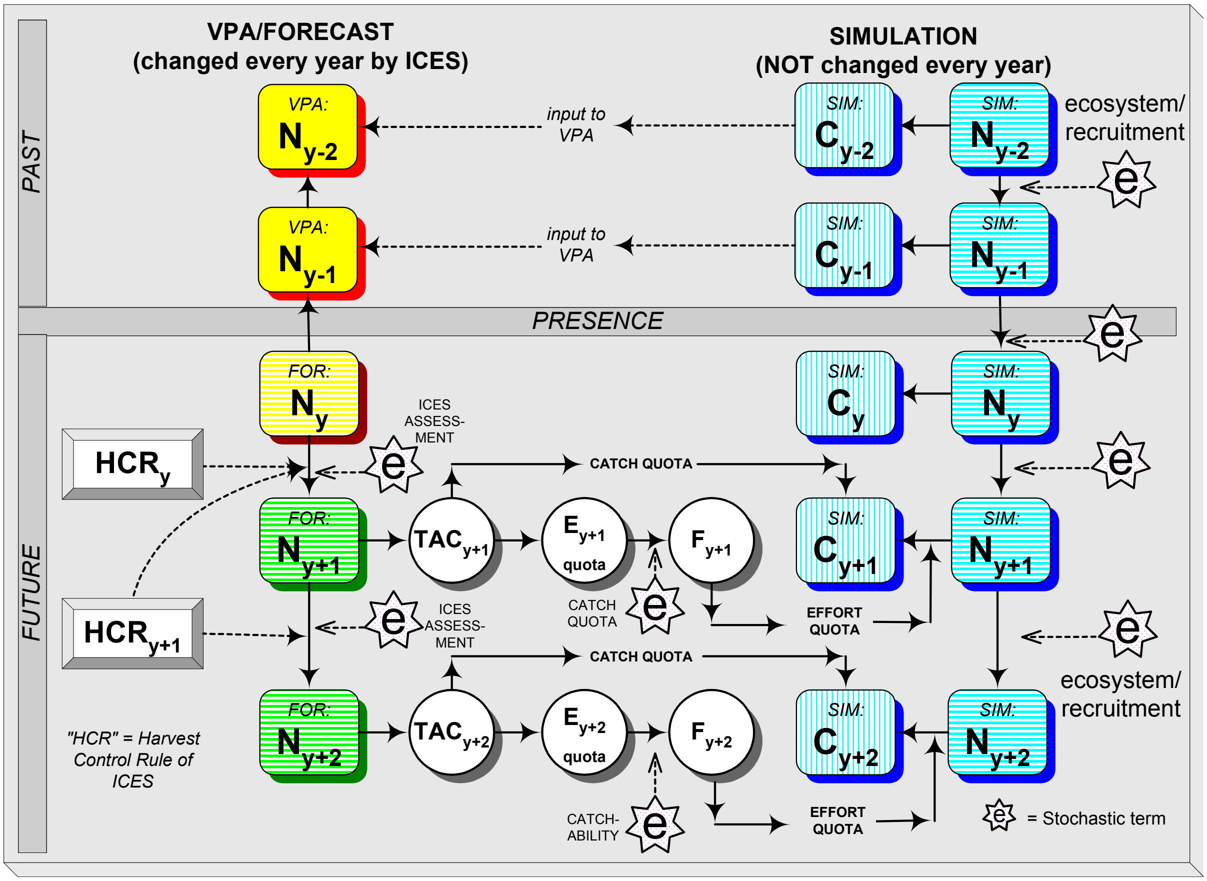


Figure 3.0.1. The components of the EEQ.

```
Sub MAIN_DYNAMIC_SIMULATION
Call INITIALIZE_DYNAMIC_SIMULATION_MAIN
For Year = 2 To Number_of_Years
    For St = 1 To Number_of_Stocks
        Call PERFORM_THE_VPA(1, Year, Draw_Stochastic)
        Call MAKE_ICES_FORECAST_AND_APPLY_HCL(1,Year)
        For a = 1 To Number_Of_Age_Groups(St)
            F(St, Year + 1, a) = FOR_F(St, 2, a)
        Next a
    Next St
     Call COMPUTE_EFFORT_AND_ADJUST_F_FOR_ALL_FLEETS(Year + 1,
Draw_Stochastic)
    For St = 1 To Number_of_Stocks
           Call SIMULATE_BASIC_STOCK_DYNAMICS_FOR_ONE_YEAR(Year + 1, False)
    Next St
Next Year
Call MAKE_FLEET_ECONOMICS_AND_TOTAL_SUMMED_OVER_STOCKS(1,Number_of_Years)
Call MAKE_TIME_DISCOUNTED_SUMS_OF_FLEET_ECONOMICS(1,Number_of_Years)
End Sub
```

Figure 3.0.2. Example of Visual Basic code. Here the (simplified) central algorithm for a single simulation over a time series of years. (for further details on the VB-program, see Annex A)

A very large part of the EEQ-code (say 90%) deals with the administration of input and out put (The "Handling boxes" in Figure 1.2.1), and that part of the code is of interest only to the VB-programmer. The subroutines of interest to the model are all stored in the two modules "M02A_Algorithms" and "M20B_Main_Multi_Simulation".

Note that the variables of the VB-program has been given names, which should immediately tell the reader what it is about. The VB program is conveniently structured by "Subroutines" ("Sub") which can "Call" each other. The subroutines are started from the spread sheet by clicking on the "Simulate"-button in the userforms.

This manual gives both a conventional description of the mathematical model behind the EEQ as well as a description by "pseudo VISUAL BASIC" and a flowchart (see Annex A). It is recommended to compare this mathematical description to the worksheets and the VB modules of the EXCEL implementation of EEQ.

It should continuously be kept in mind that the EEQ is not a single model, but three parallel models: Some variable and parameters are specific to the model, and some variables are shared by all three models. The model specific parameters are indicated by the subscripts "FOR", "SIM" and "VPA" whenever there are doubts about which model the symbol refers to.

3.1 LIST OF SYMBOLS

Below follows a complete list of all variables of the EEQ model. The symbols are grouped, and in alphabetical order within each group.

Note that dot "." instead of an index means summation over the index in question. Thus
$X(i,.,j) = \sum_u X(i,u,j)$

3.1.1. INDICES IN ALPHABETICAL ORDER.

A	Age group	$a = 0,1,\ldots,a_{max}(st)$
Fl	Fleet	$Fl = 1,2,\ldots,NU_{Fleet}$
Y	Year	$y = y_{first},y_{first}+1,\ldots,y_{last}$
St	Stock	$St = 1,\ldots,NU_{Stock}$

3.1.2. TIME VARIABLES IN ALPHABETICAL ORDER:

Y_{first}	First year
y_{last}	Last year

3.1.3. BIOLOGICAL VARIABLES (VARIABLES RELATED TO STOCKS) IN ALPHABETICAL ORDER:

B_{total}(St, y)	Total biomass of stock "St" at the beginning of year "y"
a_{max}(st)	Oldest age group of stock St
BH1(St)	First Parameter in the Beverton and Holt Stock/Recruitment model for stock "St"
BH2(St)	Second Parameter in the Beverton and Holt Stock/Recruitment model for stock "St"
C(St,.,y,a)	Numbers caught (landed or discarded) by all fleet combined of stock "St" during year "y", age group "a" , Input to VPA.
F_{FOR}(St, y, a)	Fishing mortality created (by all fleets) on stock "St" during year "y", age group "a". of forecast model, $F = F_{land} + F_{disc}$

$F_{SIM}(St,.,y, a)$	Fishing mortality created (by all fleets)on stock "St" during year "y", age group "a". of simulation model, $F_{SIM}(St,.,y, a) = \Sigma_{Fl}F_{SIM}(St, Fl,y, a)$
$F_{VPA}(St, y, a)$	Fishing mortality created (by all fleets) on stock "St" during year "y", age group "a". of VPA, $F = F_{land} + F_{disc}$
$F_{SIM\text{-}Realised}$ (St,.,y, a)	Realised fishing mortality = $F_{SIM}(St,.,y, a)^* \varepsilon_F(St,Fl,y)^*(1+\beta(St,Fl,y))$
K (St)	Von Bertalanffy curvature parameter of stock "St".
Lgt(St, a)	Mean Body length in stock of stock "St", age group "a"
$LGT_{50\%Mat}(St)$	Length at which 50 % of stock "St" is mature
$LGT_{75\%Mat}(St)$	Length at which 75 % of stock "St" is mature
$L_\infty(St)$,	Von Bertalanffy parameter, L-infinity of stock "St".
M(St, a)	Natural mortality of stock "St" age group "a"
Mat(St,a)	Maturity ogive of stock "St", age group "a"
$N_{FOR}(St, y, a)$	Stock number of stock "st", at the beginning of year "y" of simulation model.
$N_{SIM}(St, y, a)$	Stock number of stock "st", at the beginning of year "y" computed by simulation model.
$N_{VPA}(St, y, a)$	Stock number of stock "st", at the beginning of year "y" computed by VPA
$N_{Init}(St, a)$	Initial stock number, that is the stock number in year Y_{first}
$N_{SIM\text{-}Mean}(St, y, a)$	Average Stock number of stock "st", during year "y"
NU_{Stock}	Number of stocks
QE(St)	Condition exponent of stock "St". (Wgt = QF * Lgt ^{QE})
QF (St),	Condition factor of stock "St". (Wgt = QF * Lgt ^{QE})
Rec(St,y)	Recruitment number of stock "St" in year "y".
$SSB_{FOR}(St, y)$	Spawning stock biomass of stock "St" at the beginning of year "y" of forecast model
$SSB_{SIM}(St, y)$	Spawning stock biomass of stock "St" at the beginning of year "y" of simulation model
$SSB_{VPA}(St, y)$	Spawning stock biomass of stock "St" at the beginning of year "y" of VPA
$T_o(St)$	Von Bertalanffy initial condition parameter, t-zero of stock "St".
Wgt(St, a)	Mean Body weight in stock of stock "St", of age group "a"
Z(St, y, a)	Total mortality of stock "St" in year "y", age group "a"

3.1.4. TECHNICAL VARIABLES IN ALPHABETICAL ORDER (VARIABLES RELATED TO FLEETS):

C(St,Fl,y,a)	Numbers caught (landed or discarded) by fleet "Fl" of stock "St" during year "y", age group "a" , $C = C_{Landing} + C_{Disc}$
$C_{Land}(St,Fl,y,a)$	Numbers landed by fleet "Fl" of stock "St" during year "y", age group "a"
$C_{Disc}(St,Fl,y,a)$	Numbers discarded by fleet "Fl" of stock "St" during year "y" , age group "a"
DIS(St, Fl, y, a)	Discard selection ogive of fleet "Fl" catching stock "St", age group "a", that is, the fraction of fish caught, which are discarded.
E(Fl, y)	Effort of fleet "Fl" during year "y".
$F_{SIM}(St, Fl,y, a)$	Fishing mortality created by fleet "Fl" on stock "St" during year "y", age group "a". of simulation model, $F = F_{land} + F_{disc}$
$F_{REL}(St, Fl,y, a)$	Relative fishing mortality = $F_{SIM}(St, Fl,y, a)/ F_{SIM}(St,.,y, a)$ of simulation model
$F_{REL\text{-}Max}(St, Fl,y)$	Relative max fishing mortality = $Max_a\{F_{SIM}(St, Fl,y, a)\}/ Max_a\{F_{SIM}(St,.,y, a)\}$ of simulation model
$F_{land}(St, Fl,y, a)$	Landing mortality" created by fleet "Fl" on stock "St" during year "y", age group "a". (only in simulation model)
$F_{disc}(St, Fl,y, a,)$	Discard mortality created by fleet "Fl" on stock "St" during year "y", age group "a". (only on simulation model)

$SEL(St, Fl, y,a)$	Gear selection ogive of fleet “Fl” catching stock “St”, age gr. “a”
$LGT_{50\%}(St,Fl,y)$	Body Length at which 50% of the fish entering the gear are retained, Fleet “Fl” catching stock “St” in year “y”
$LGT_{75\%}(St,Fl,y)$	Body Length at which 75 % of the fish entering the gear are retained, Fleet “Fl” catching stock “St” in year “y”
$LGT_{50\%Disc}(St,Fl,y)$	Body Length at which 50% of the fish caught are discarded, Fleet “Fl” catching stock “St” in year “y”
$LGT_{75\%Disc}(St,Fl,y)$	Body Length at which 25% of the fish caught are discarded, Fleet “Fl” catching stock “St” in year “y”
$EY_{MAX}(Fl,y)$	The maximum number of effort units per vessel per year
NU_{Fleet}	Number of Fleets
$NU_{Vessel}(Fl, y)$	Number of vessels in fleet “Fl” in year “y”
$Q(St, Fl, y)$	catchability coefficient of fleet “Fl” catching stock “St” during year “y”.
$Y_{GrTotal}(Fl,y)$	Grand total (all stocks combined) Yield caught by fleet “Fl” during year “y”
$Y_{Total}(St,Fl,y)$	Total Yield of stock “St” caught by fleet “Fl” during year “y”
$Y_{GrTotal\text{- }Land}(Fl,y)$	Grand total (all stocks combined) Yield landed fleet “Fl” during year “y”
$Y_{Total\text{-}Land}(St,Fl,y)$	Total Yield of stock “St” landed by fleet “Fl” during year “y”

3.1.5. ECONOMIC VARIABLES IN ALPHABETICAL ORDER(VARIABLES RELATED TO FLEETS)

$COST_{FISHING}(Fl,y)$	Cost of fishing per unit of effort (independent of catch) of fleet “Fl” in year “y”
$COST_{CATCH}(Fl,y)$	Cost of handling catch per weight unit (independent of effort) of fleet “Fl” in year “y”
$COST_{FIXED}(Fl,y)$	Fixed costs per vessel (independent of effort and catch) of fleet “Fl” in year “y”
$PROFIT(Fl,y)$	Profit of fleet “Fl” in year “y”
$COST_{Total}(Fl,y)$	Total costs of fleet “Fl” in year “y”
$P_{max}(St, Fl, y)$	Maximum Price per weight unit (over age groups) of stock “St” landed by fleet “Fl” in year “y”,
$P_{Rel}(St, Fl, a)$	Relative price (=Price/Maximum Price) of age group a of stock “St” landed by fleet “Fl” in year “y”,
$P(St, Fl,y, a)$	Price per weight unit (over age groups) of stock “St”, age group a, landed by fleet “Fl” in year “y”, $P(St, Fl, y,a) = P_{max}(St, Fl, y)* P_{Rel}(St, Fl, a)$
r	Discount rate. Percent per year.
$V_{GrTotal}(Fl,y)$	Grand total Value (all stocks combined) from fleet “Fl” during year “y”
$V_{Total}(St,Fl,y)$	Total Value of stock “St” from fleet “Fl” during year “y”

3.1.6. ICES ASSESSEMNET AND MANAGEMENT VARIABLES IN ALPHABETICAL ORDER:

$a_{Fmaen\text{-}first}$	First age group used to compute the mean F_{VPA} for as the mean of $F_{VPA}(a_{Fmaen\text{-}first})$, $F_{VPA}(a_{Fmaen\text{-}first}+1),\ldots, F_{VPA}(a_{Fmaen\text{-}last})$
$a_{Fmaen\text{-}last}$	Last age group used to compute the mean F_{VPA} for as the mean of $F_{VPA}(a_{Fmaen\text{-}first})$, $F_{VPA}(a_{Fmaen\text{-}first}+1),\ldots, F_{VPA}(a_{Fmaen\text{-}last})$
$a_{TF\text{-}first}$	First age group used to compute the F_{VPA} for second oldest age group as the mean of $F_{VPA}(a_{TF\text{-}first})$, $F_{VPA}(a_{TF\text{-}first}+1),\ldots, F_{VPA}(a_{TF\text{-}last})$
$a_{TF\text{-}last}$	Last age group used to compute the F_{VPA} for second oldest age group as the mean of $F_{VPA}(a_{TF\text{-}first})$, $F_{VPA}(a_{TF\text{-}first}+1),\ldots, F_{VPA}(a_{TF\text{-}last})$
$B_{lim}(St)$	Lowest spawning stock biomass for stock “St” allowing for fishing according to the precautionary approach (given by the ACFM, Advisory Committee of Fisheries Management of ICES)
$B_{pa}(St)$	Spawning stock biomass for stock “St” corresponding to the

	precautionary approach (given by the ACFM, Advisory Committee of Fisheries Management of ICES)
$E^*_{HCR}(St,Fl,y)$	Stock-dependent Effort corresponding to the Harvest Control Rule of ICES. $E^*_{HCR}(St,Fl,y) = F_{HCR}(St,y)*F_{REL-Max}(St,Fl,y)/Q(St,Fl,y)$
$E_{HCR}(St,Fl)$	(Stock-independent) Effort corresponding to the Harvest Control Rule of ICES. The definition depends on the management regime.
$F_{HCR}(St,y)$	Fishing mortality of the ICES harvest control rule ($F_{HCR}(St,y) = F_{FOR-Mean}(St,y)$).

$$F_{HCR}(St, y+2) = \begin{cases} 0 \;\; if \;\; SSB(St.y) \le B_{\lim}(St) \\ F_{pa}(St)\dfrac{SSB(St,y)-B_{\lim}}{B_{pa}(St)-B_{\lim}(St)} \;\; if \;\; B_{\lim}(St) \le SSB(St,y) \le B_{pa}(St) \\ F_{pa}(St) \;\; if \;\; SSB(St,y) > B_{pa} \end{cases}$$

$F_{pa}(St)$	Fishing mortality for stock "St" corresponding to the precautionary approach (given by the ACFM, Advisory Committee of Fisheries Management of ICES)
TAC(St, y)	Catch quota of stock "St" in year "y"

3.1.7. PARAMETERS USED TO CREATE STOCHASTIC AND BIASED VARIABLES

$\beta(St,Fl,y)$ %	Bias (in units of percentage) of realised F, a year fleet and stock dependent variable indicated the relative magnitude of bias introduced by the ICES methodology
$\varepsilon_F(St,Fl,y)$, σ_F	Stochastic factor of realised F, a year fleet and stock dependent normally distributed stochastic variable with mean value 1.0 and standard deviation σ_F .
$\varepsilon_K(St,y)$, σ_K	Stochastic factor of von Bertalanffy parameter K, of stock "St" and year "y" dependent normally distributed stochastic variable with mean value 1.0 and standard deviation σ_K .
$\varepsilon_Q(St,Fl,y)$, σ_Q	Stochastic factor of catchability, a year, fleet and stock dependent normally distributed stochastic variable with mean value 1.0 and standard deviation σ_Q .
$\varepsilon_{QF}(St,y)$, σ_{QF}	Stochastic factor of condition factor, of stock "St" and year "y" dependent normally distributed stochastic variable with mean value 1.0 and standard deviation σ_{QF} .
$\varepsilon_{SR}(St)$, σ_{SR}	Stochastic factor of stock/recruitment relationship, of stock "St", a stock dependent log-normally distributed stochastic variable with mean value 1.0 and standard deviation σ_{QF} .
$\varepsilon_{TF-Age}(St,a)$, σ_{TF-Age}	Stochastic factor of terminal F in VPA accounting for the age-group-effect, of stock "St", a stock dependent normally distributed stochastic variable with mean value 1.0 and standard deviation σ_{TF-Age} .
$W_{\varepsilon-Year}$	Weight of year effect the stochastic factor for terminal F in VPA
$\varepsilon_{TF-Year}(St)$,$\sigma_{TF-Year}$	Stochastic factor of terminal F in VPA accounting for the year-effect, of stock "St", a stock dependent normally distributed stochastic variable with mean value 1.0 and standard deviation $\sigma_{TF-Year}$.

3.2. GROWTH AND MATURITY OF INDIVIDUALS AND NATURAL MORTALITY

3.2.1. VON BERTALANFFY GROWTH MODEL

Mean Body length in stock of stock "St", in year "y" of age group "a", LGT(St,a,y) Bertalanffy equation:

$$Lgt\ (St, a, y) = L_{\infty}(St) * (1 - \exp(-(K\ (St) * \varepsilon_K (St, y)) * (a + 0.5 - T_0(St))) \quad (3.2.1.1)$$

where
a = 0,1,2,…, a_{max}(st), age group
K (St) = Von Bertalanffy curvature parameter of stock "St".
L_{∞}(St) = Von Bertalanffy parameter, L-infinity of stock "St".
T_o (St) = Von Bertalanffy initial condition parameter, t-zero of stock "St".
ε_K(St,y) = A year and stock dependent normally distributed stochastic variable with mean value 1.0 and standard deviation σ_K .

Body length is assumed to be the same for stock, landings and discards. "Lgt" is shared by all three sub-models.

3.2.2. LENGTH/WEIGHT RELATIONSHIP

Mean Body weight in stock "St", age group "a":

$$Wgt\ (St, a, y) = QF\ (St) * \varepsilon_{QF}(st, y) * Lgt(St, a, y)^{QF\ (St)} \quad (3.2.2.1)$$

where
QE(St) = Condition exponent of stock "St".
QF(St) = Condition factor of stock "St" .
ε_{QF}(St,y) = (ε_K(St,y) +ε'_{QF}(St,y))/2
where ε'_{QF}(St,y)) is a year and stock dependent normally distributed stochastic variable with mean value 1.0 and standard deviation σ_{QF}. Note that the K and the condition factors are positively correlated, so that a fast growth is associated with a good condition.

Body weight is assumed to be the same for stock, landings and discards. The length weight relationship is shared by all three sub-models.

3.2.3 MATURITY OGIVE

Maturity ogive of stock "St" in age group "a", that is the fraction of mature fish as a function of body length.

$$Mat(St, a, y) = \frac{1}{1 + exp(Mat1 + Mat2 * Lgt_{Stock}(St, a, y))} \quad (3.2.3.1)$$

where
Mat1 = ln(3)* $LGT_{50\%Mat}$(St)**/(** $LGT_{75\%Mat}$(St) - $LGT_{50\%Mat}$(St)**)**
Mat2 = ln(3)**/(** $LGT_{75\%Mat}$(St) - $LGT_{50\%Mat}$(St)**)**
$LGT_{50\%DMat}$(St) = Length at which 50 % of stock "St" are mature
$LGT_{75\%Mat}$(St) = Length at which 75 % of stock "St" are mature
As the length at age vary from year to year so does the maturity ogive.
The maturity ogive is shared by all three sub-models.

The natural mortality is assumed to remain constant from year to year, and depend only on stock and age group.

M(St, a) = Natural mortality of stock “St” age group “a”

The natural mortality is shared by all three models.

3.3. GEAR- AND DISCARD SELECTION OGIVES

3.3.1. DISCARD SELECTION OGIVES

Discard ogive of stock “St” in year “y” of age group “a” , that is the fraction of fish discarded (for any reason) as a function of body length.

$$DIS(St,Fl,a) = 1 - \frac{1}{1 + exp(Dis1 + Dis2 * Lgt_{Stock}(St,a))} \qquad (3.3.1.1)$$

where

Dis1 = ln(3)* $LGT_{50\%Disc}$(St,Fl,y)**/(** $LGT_{75\%Disc}$(St,Fl,y) - $LGT_{50\%Disc}$(St,Fl;y)**)**
Dis2 = ln(3)**/(** $LGT_{75\%Disc}$(St,Fl,y) - $LGT_{50\%Disc}$(St,Fl,y)**)**
$LGT_{50\%Disc}$(St,Fl,y) = Body Length at which 50% of the fish caught are discarded, Fleet “Fl” catching stock “St” in year “y”
$LGT_{75\%Disc}$(St,Fl,y) = Body Length at which 25% of the fish caught are discarded, Fleet “Fl” catching stock “St” in year “y”

The discard selection model applies only to the simulation model.

3.3.2. GEAR SELECTION OGIVES

Gear selection ogive of fleet “Fl” catching stock “St” in year “y” of age gr. “a”

$$SEL(St,Fl,y,a) = \frac{1}{1 + exp(Sel1 + Sel2 * Lgt_{Stock}(St,a))} \qquad (3.3.2.1)$$

where
Sel1 = ln(3)* $L_{50\%}$**/(** $L_{75\%}$ - L_{50}**)** and Sel2 = ln(3)**/(** $L_{75\%}$ - $L_{50\%Disc}$**)**
$LGT_{50\%}$(St,Fl,y) = Body Length at which 50% of the fish entering the gear are retained, Fleet “Fl” catching stock “St” in year “y”
$LGT_{75\%}$(St,Fl,y) = Body Length at which 75 % of the fish entering the gear are retained, Fleet “Fl” catching stock “St” in year “y”

The discard selection model applies only to the simulation model.

3.4. EFFORT AND CAPACITY

3.4.1. FISHING DAYS OR SEA DAYS

The variable Effort relates to two purposes: 1) To convert fishery activity into fishing mortality and 2) to convert fishing activity into costs of fishing.
The concept of effort (and concept of “fleet” in general) applies only to the simulation model, as ICES does not operate with it in it.

Effort of fleet “Fl” fishing during in year “y” is **E(Fl, y).**

The unit may be fishing days, or days away from port (sea days), depending on the availability of information from logbooks**.**

3.4.1. FLEET CAPACITY

The capacity is the maximum number of fishing units (fishing days or sea days) that a fleet can exert. It is given by the variables:

$NU_{Vessel}(Fl, y)$ = Number of vessels in fleet "Fl" in year "y"

$EY_{MAX}(Fl,y)$ =The maximum number of effort units per vessel per year

Thus: $\mathbf{E(Fl, y) \leq NU_{Vessel}(Fl, y)^{*} EY_{MAX}(Fl,y)}$ (3.4.1.1)

3.5. FISHING MORTALITY IN SIMULATION MODEL

Fishing mortalities in the simulation model, are derived from the VPA and the subsequent application of the ICES forecast model. The F and the corresponding TAC is computed by aid of the ICES Harvest control rule, which will be introduced in Section5. In case of a Quota-based management regime, the F will be reduced if the catch exceeds the quota. How the F is controlled under the two alternative management regimes will be discussed in Section 4 Here we shall only define the fishing mortalities without discussing how they are assigned their values.

3.5.1. ABSOLUTE AND RELATIVE FISHING MORTALITY IN SIMULATION MODEL

Fishing mortality in the present context mean the mortality created by landing and discard: $F = F_{land} + F_{disc}$

There are four F-concepts in the simulation model:

1) Fleet specific fishing mortality (related to effort)
2) Total (all fleets combined) fishing mortality related to VPA
3) Relative fishing mortality (Constant input parameters to EEQ)
4) Relaized F (the stochastic F generated from the FORECAST F)

Fleet specific fishing mortality (related to effort as explained in the following subsection) is

$F_{SIM}(St, Fl,y, a)$ = Fishing mortality created by fleet "Fl" on stock "St" during year "y", age group "a",

This does not compare to the F of VPA and the ICES forecast model as these models do not split on F on the contributions from each fleet. The sum over fleets compares to the ICES F-concept:

The combined fishing mortality is the sum of the fleet-specific "partial"-Fs:
$F_{SIM}(St,.,y, a)$ = Fishing mortality created (by all fleets) on stock "St" during year "y", age group "a".

$$\mathbf{F_{SIM}(St,.,y, a) = \Sigma_{Fl} F_{SIM}(St, Fl,y, a)} \quad (3.5.1.1)$$

Due to the fact that our knowledge is limited by the limitations of the ICES methodology, we were forced to assume that the relative distribution of F on fleets remain constant, that is we assume that

$$\mathbf{F_{REL}(St, Fl,y, a) = \text{Relative fishing mortality} = F_{SIM}(St, Fl,y, a)/ F_{SIM}(St,.,y, a)} \quad (3.5.1.2)$$

remains constant. This is a very critical assumption in EEQ, which however cannot be replaced by a proper model as long as the ICES methodology remains the standard of fisheries assessment.

The "Realised F" is the stochastic variable:

$$\mathbf{F_{SIM\text{-}Realised}(St,.,y,a) = F_{SIM}(St,.,y,a)^{*}\,\varepsilon_F(St,Fl,y)^{*}(1+\beta(St,Fl,y)/100)} \qquad (3.5.1.3)$$

where

$\boldsymbol{\varepsilon_Q}$**(St,Fl,y)** = Stochastic factor of realised F, a year fleet and stock dependent normally distributed stochastic variable with mean value 1.0 and standard deviation σ_F .

$\boldsymbol{\beta}$**(St,Fl,y) %** = Bias (in units of percentage) of realised F, a year fleet and stock dependent variable indicated the relative magnitude of bias introduced by the ICES methodology.

It is $F_{SIM\text{-}Realised}$ which is used to simulate the stock and the fisheries. F_{SIM}, which is derived from the ICES FORECAST model is mean value of the distribution from which $F_{SIM\text{-}Realised}$ is drawn by the random number generator.

3.5.2. THE RELATIONSHIP BETWEEN EFFORT AND FISHING MORTALTY IN SIMULATION MODEL

The simulated fishing mortality is derived from the effort and the selection ogive in the case of management based on effort regulation. The relation between effort and fishing mortality is assumed to be subject to stochastic variation:

$$\mathbf{F_{SIM}(St, Fl,y, a) = E(Fl,y)^{*}\, Q(St, Fl,y)\, {}^{*}\varepsilon_Q(St,Fl,y)\, {}^{*}\, SEL(St, Fl,y, a)} \qquad (3.5.2.1)$$

E(Fl, y) = Effort of fleet "Fl" fishing during in year "y"
SEL(St, Fl,y, a) = Gear selection ogive of fleet "Fl" catching stock "St" in year "y" of age gr. "a"
Q(St, Fl,y) = Catchability coefficient of fleet Fl catching stock "St" in year "y"
ε_Q(St,Fl,y) = Stochastic factor of catchability, a year fleet and stock dependent normally distributed stochastic variable with mean value 1.0 and standard deviation σ_Q .

3.5.3. LANDING AND DISCARD MORTALITY

Fishing mortality is the sum of landing mortality and discard mortality:

$$\mathbf{F_{SIM}(St, Fl,y, a) = F_{land}(St, Fl,y, a) + F_{disc}(St, Fl,y, a,)} \qquad (3.5.3.1)$$

where

F_{land}(St, Fl,y, a) = Landing mortality" created by fleet "Fl" on stock "St" during year "y", age group "a".
F_{disc}(St, Fl,y, a,) =Discard mortality created by fleet "Fl" on stock "St" during year "y", age group "a".

F_{SIM}(St, Fl,y, a) = Fishing mortality created by fleet "Fl" on stock "St" during year "y", age group "a",

They are defined by :

$$\mathbf{F_{land}(St, Fl,y, a) = F_{SIM}(St, Fl,y, a)\, {}^{*}\, (1 - DIS(St, Fl, y, a))} \qquad (3.5.3.2.a)$$
$$\mathbf{F_{disc}(St, Fl,y, a,) = F_{SIM}(St, Fl,y, a)^{*}\, DIS(St, Fl, y, a)} \qquad (3.5.3.2.b)$$

where

DIS(St, Fl, y, a) = Discard selection ogive of fleet “Fl” catching stock “St”, age group “a”, that is, the fraction of fish caught, which are discarded.

3.6. STOCK NUMBERS AND STOCK BIOMASS IN SIMULATION MODEL.

3.6.1. STOCK NUMBERS AT BEGINNING OF YEAR IN SIMULATION MODEL

N(St, y, a) = Stock number of stock “st”, at the beginning of year “y” age group a, a = 0,1,…,. a_{max}(St).

Rec(St,y) = N(St, y, 0) (3.6.1.1)

is called the “Recruitment” and N^{+}(St, y, a_{max}(St)) is the “plus-group”, that is

N^{+}(St, y, a_{max}(St)) = N(St, y, a_{max}(St)) + N(St, y, a_{max}(St)+1) + N(St, y, a_{max}(St)+2) + …(3.6.1.1)

The number of survivors in the oldest age group, N(St, y, a_{max}(St)), is not used in EEQ, only the plus group, N^{+}(St, y, a_{max}(St)) is used.

3.6.2. THE EXPONENTIAL DECAY MODEL

The stock number of stock “st”, at the beginning of year “y” is computed in different ways, depending on the index values. Indices y = y_{first}, a = 0 or a = a_{max}(St) require special treatment:

Number of age group a+1 of stock “St”, at the beginning of year “y+1” is.

If y > y_{first} and a < a_{max}(st) then N(St, y, a) is computed by the exponential decay model for the plus group.

$$N(St, y+1, a+1) = N(St, y, a) * \exp(-Z(St, y, a)) \qquad (3.6.2.1)$$

where
Z_{SIM}(St,y,a) = Total mortality on stock “St” in year “y”, age group “a”.
N_{SIM}(St, y, a) = Stock number of stock “st”, at the beginning of year “y”

If y > y_{first} and a = a_{max}(st) then N(St, y, a) is computed by the exponential decay model for the plus group.

$$\begin{aligned} N(St, y+1, a_{Max}(St)) &= N(St, y, a_{Max}(St)-1) * \exp(-Z(St, y, a_{Max}(St)-1)) + \\ &N(St, y, a_{Max}(St)) * \exp(-Z(St, y, a_{Max}(St))) \end{aligned} \qquad (3.6.2.2)$$

If y > y_{first} and a = 0 and then N(St, y, 0) is computed by the Beverton and Holt stock/recruitment model, as will be explained in Section 3.6.6.
If y = y_{first} then N(St, y_{first}, a) = N_{Init}(St, a). The “Initial stock number “N_{Init}(St, a)” are input parameters to EEQ.

3.6.3. MEAN NUMBER OF SURVIVORS IN SIMULATION MODEL.

Average Stock number of stock “st”, during year “y” :

$$N_{SIM-Mean}(St,y,a) = N_{SIM}(St,y,a)\frac{1-\exp(-Z_{SIM}(St,y,a))}{Z_{SIM}(St,y,a)} \qquad (3.6.3.1)$$

where
Z_{SIM}(St,y,a) = F_{SIM}(St,.,y,a) + M(St,a) = Total mortality" on stock "St" in year "y" of age group "a".
N_{SIM}(St, y, a) = Stock number of stock "st", at the beginning of year "y" .

3.6.4. MEAN NUMBER CAUGHT IN SIMULATION MODEL.

The number caught is computed by:

C(St,Fl,y,a) = F_{SIM}(St, Fl,y, a)* $N_{SIM\text{-}Mean}$(St, y, a) (3.6.4.1)

where

C(St,Fl,y,a) = Numbers caught (landed or discarded) by fleet "Fl" of stock "St" during year "y", age group "a"

F_{SIM}(St, Fl,y, a) = Fishing mortality created by fleet "Fl" on stock "St" during year "y", age group "a",

Note that the numbers caught are shared by the simulation model and the VPA.

3.6.5. MEAN STOCK BIOMASS AND SPAWNING STOCK BIOMASS

Mean stock biomass of the year is

$$B_{SIM}(St,y) = \sum_{a=0}^{a_{\max}(St)} N_{SIM-Mean}(St,y,a) * Wgt(St,a) \qquad (3.6.5.1)$$

where

$N_{SIM\text{-}mean}$(St,y,a) = Mean Stock number of stock "st", during year "y" :
Wgt(St, a) = Mean Body weight in stock of stock "St", age group "a"

$$SSB_{SIM}(St,y) = \sum_{a=0}^{a_{\max}(St)} N_{SIM-mean}(St,y,a) * Wgt(St,a) * Mat(St,a) \qquad (3.6.5.2)$$

where Mat(St,a) = Maturity ogive of stock "St" age group "a"

3.6.6. STOCK AND RECRUITMENT MODEL

The recruitment of stock St in year "y", Rec(St,y) = N_{SIM}(St, y, 0) is modelled by the Beverton and Holt model:

$$\mathrm{Re}c(St,y) = \frac{BH1(St)}{1+BH2(St)*SSB_{SIM}(St,y-1)} * \varepsilon_{SR}(St) \qquad (3.6.6.1)$$

where

BH1(St) = First Parameter in the Beverton and Holt Stock/Recruitment model for stock "St"

BH2(St) = Second Parameter in the Beverton and Holt Stock/Recruitment model for stock “St”

ε_{SR}(St) = Stochastic factor of stock/recruitment relationship, of stock “St”, a stock dependent log-normally distributed stochastic variable with mean value 1.0 and standard deviation σ_{SR} .

Rec(St,1) is given as input to EEQ.

3.6.7. NUMBER LANDED AND DISCARDED

Numbers landed by fleet “Fl” of stock “St” in year “y” age group “a”

$$\mathbf{C_{Land}(St,Fl,y,a) = F_{land}(St, Fl,y, a) * N_{SIM\text{-}mean}(St, y, a)} \qquad (3.6.7.1)$$

Where

F_{land}(St, Fl,y, a) = “Landing mortality” created by fleet “Fl” on stock “St” in year “y” age group “a”.

$N_{SIM\text{-}mean}$(St, y, a)= Average Stock number of stock “st”, in year “y” .

Numbers discarded by fleet “Fl” of stock “St” in year “y” age group “a”

$$\mathbf{C_{Disc}(St,Fl,y,a) = F_{Disc}(St, Fl,y, a) * N_{SIM\text{-}mean}(St, y, a)} \qquad (3.6.7.2)$$

Where

F_{land}(St, Fl,y, a) = “Landing mortality” created by fleet “Fl” on stock “St” in year “y”, age group “a”.

$N_{SIM\text{-}mean}$(St, y, a)= Average Stock number of stock “st”, in year “y”

3.6.8. WEIGHT OF LANDED AND DISCARDED FISH

Weight of fish landed by fleet “Fl” of stock “St” in year “y”, age group “a”

$$Y_{Land}(St,Fl,y,a) = N_{Land}(St,Fl,y,a) * Wgt(St,Fl,a)$$

(3.6.8.1)

Where
C_{Land}(St,Fl,y,a) = Numbers landed by fleet “Fl” of stock “St” in year “y”, age group “a”
Wgt(St, Fl, a) = Mean Body Weight of stock “St”, age group “a”

The total annual fleet specific yield:

$$Y_{Land}(St,Fl,y,.) = \sum_{a=1}^{a_{\max}(St)} Y_{Land}(St,Fl,y,a) \qquad (3.6.8.2)$$

Numbers discarded by fleet “Fl” of stock “St” in year “y”, age group “a”

$$Y_{Disc}(St,Fl,y) = \sum_{a} C_{Disc}(St,Fl,y,a) * Wgt\ (St,Fl,a) \qquad (3.6.8.3)$$

Where
C_{Disc}(St,Fl,y,a) = Numbers discarded by fleet “Fl” of stock “St” in year “y”, age group “a”
Wgt(St, Fl, a,) = Mean Body Weight of stock “St”, age group “a” (von Bertalanffy)

$Y_{GrTotal-Land}$(Fl,y) = Grand total (all stocks combined) Yield landed fleet "Fl" during year "y"
$Y_{Total-Land}$(St,Fl,y) = Total Yield of stock "St" landed by fleet "Fl" during year "y"

The total weight of landings (all stocks combined) by fleet "Fl" in year "y" is:

$$Y_{Land}(.,Fl,y,.) = \sum_{St=o}^{NU_{Stock}} Y_{Land}(St,Fl,y,a) \qquad (3.6.8.4)$$

3.7 BIOECONOMIC SUBMODEL OF EEQ

The bio-economic sub-model of EEQ is based on so many simplifying assumption that it hardly deserves the name of an economic model. However, EEQ, being a multispecies model, must use some common unit which allow for the aggregation of landings, and the comparison of fleet performances. The obvious choice for a common unit is the unit of value, the introduction of which is the first step into bioeconomics.

3.7.1. EX-VESSEL PRICES

In order to make the provision of input easy, the ex-vessel prices has been modelled as a year effect (maximum price over age groups) and an age-effect (relative price):

P_{max}(St, Fl, y) = Maximum Price (over age groups) of stock "St" landed by fleet "Fl" in year "y",
P_{Rel}(St, Fl, a) = Relative price of age group a of stock "St" landed by fleet "Fl" in year "y",

The product becomes the age-dependent absolute price:

P(St, Fl,y, a) = Price per weight unit of stock "St", age group a, landed by fleet "Fl" in year "y",

P(St, Fl, y,a) = P_{max}(St, Fl, y)* P_{Rel}(St, Fl, a) (3.7.1.1)

3.7.2. VALUE OF LANDINGS

V_{Total}(St,Fl,y) = Total Value of stock "St" from fleet "Fl" during year "y"

$$V_{Total}(St,Fl,y) = \sum_{a=0}^{a_{max}(St)} N_{Land}(St,Fl,y,a) * Wgt(St,Fl,a) * P(St,Fl,y,a) \qquad (3.7.2.1)$$

$V_{GrTotal}$(Fl,y) = Grand total Value (all stocks combined) from fleet "Fl" during year "y"

$$V_{GrTotal}(Fl,y) = \sum_{St=1}^{NU_{Stocks}} V_{Total}(St,Fl,y,) \qquad (3.7.2.2)$$

3.7.3. COSTS

The costs are divided into three groups:

1) Costs of fishing, proportional to the sea days. Includes oil, lubrication, ice, food, repair of gear, maintenance in general.

2) Cost of handling and selling the fish (dependent on the landings). This may include taxes, auction fee, handling of catch, cost of selling fish. It also contains the divisible earnings (salaries to crew which is a share of the revenue from fishing)

3) Fixed costs (independent of fishing activity, only dependent on number of vessels). Fixed costs are instalments, interests, depreciation, fee, overheads, insurance, etc.

$COST_{FISHING}(Fl,y)$ = Cost of fishing per unit of effort (independent of catch) of fleet "Fl" in year "y"
$COST_{CATCH}(Fl,y)$ = Cost of handling catch per weight unit (independent of effort) of fleet "Fl" in year "y"
$COST_{FIXED}(Fl,y)$ = Fixed costs per vessel (independent of effort and catch) of fleet "Fl" in year "y"

The total costs of fleet "Fl" in year "y" then becomes

$$\mathbf{COST_{Total}(Fl,y) = COST_{FISHING}(Fl,y)*E(Fl,y) + COST_{CATCH}(Fl,y)*Y_{land}(.,Fl,y,.) + COST_{FIXED}(Fl,y)*NU_{vessel}(Fl,y)} \quad (3.7.3.1)$$

A major shortcoming of in this simple description of costs is that it ignores the costs of management, including surveillance, enforcement, control and management related research (such as the cost of developing of EEQ). It appears that on overage (worldwide) the cost of management constitutes around 10 % of the value of the cost. Thus, the cost of management is far from negligible, and in case the cost of one management regime is, say, only 25 % of the other, it makes a big difference on the overall revenue from the fishing sector. If is believed that effort-based management is cheaper and easier to implement. It is postulated to be easier to implement effort regulation, because the compliance by the industry to effort regulation would be bigger that that of quota regulation. However, this feature in comparison of alternative regulations is not covered by EEQ.

3.7.4. PRIVATE PROFIT

The "private profit" of fleet "Fl" in year "y" becomes the difference between revenue and costs:

$$\mathbf{PROFIT(Fl,y) = VGrTotal(Fl,y) - COST_{Total}(Fl,y)} \quad (3.7.4.1)$$

The usual objective of ICES when giving advice is to control the SSB, the spawning stock biomass. In a fleet oriented management system, it would (to the present authors opinion) be natural to consider also objectives related to the fleets. Most fleets however, catches a mixture of stocks, and any fleet centred objective has to combine the landings of stocks into a unit, which compares to other characteristics of the fleet performance. One obvious choice is the value of the landings and to compare the revenue to the costs of fishing. That is the very first step into bio-economics. This in addition to the traditional stock-centred objective, the EEQ offers a fleet centred objective of management, namely the private profit from fishing.

The profit is just one possible measure for the performance of fisheries. Other bio-economic measures for the performance of fisheries could be the profitability, that is, the profit relative to the investment. A third measure could be the contribution of fisheries to the national gross domestic product. There is no limit to the measures of performance one might suggest. Thus, the profit presented by the EEQ is just an example of a bio-economic measure of performance.

The profit considered here is called the "Private profit" to the fishing industry, as it looks at the economics from the point of the industry's view only. The private profit, however, is not suggested as a replacement of the biological management measures suggested by the ICES. Quoting Hannesson (2000): *"The maximisation of private profit, however, is not an obviously legitimate social goal. It would make perfect sense for somebody who owned the resource, but it would not be a primary goal from a social point of view. What makes sense from a social point of view is to maximise the value produced by the resources at society's disposal. This occurs when the last unit of any productive resource produces the same value irrespectively of where it is used. This implies,* *however, that the profit in the fishery is being maximised. This profit is a bit special, as it is due to the limited productivity of the fish stock and can be seen as the cost of using that productivity. In economic jargon this goes under the name of "Resource Rent", or "Fishing Rent", due to its analogy with land rent. Like land rent, the fishery rent is a residual that remains after all factors of production (labour, capital and other inputs) have been paid. The rent reflects the differences in productivity between different "Quality" categories of a resource".*

So should an alternative to the ICES reference points be suggested it would rather be the "resource rent" that the "private profit", but the EEQ does not go that far into an economic analysis of the fisheries. The private profit is to be considered as one of the components you need to arrive at the "resource rent", or whatever ultimate measure of performance you may choose.

The profit concept introduced above does not account for the time discounting. That is, the EEQ assigned the same importance to what happens today as what will happen 1, 2, 3 …. years from now. Should profits be summed over years, a discount rate, r (percent per year), should be applied, to weight the profits relative to "to day", for example.

$$PROFIT_{Present}(Fl,.) = \sum_{Y=1}^{NU_{Years}} PROFIT(Fl,y) * \exp(-(y-1)*r/100)) \qquad (3.7.4.2)$$

By this equation the sum of profits will become the "present value" in year y. The EEQ contains am option to apply a discount rate. Any other quantity expressed in monetary units can converted to "present values", and the EEQ does use a discounting for all monetary output. For example:

$$VGrTOTAL_{Present}(Fl,.) = \sum_{Y=1}^{NU_{Years}} VGrTOTAL(Fl,y) * \exp(-(y-1)*r/100)) \qquad (3.7.4.3)$$

4 SIMULATION OF VPA BY ICES

Together with each year-step of the simulation model simulates a VPA executed by ICES, as well as a catch prediction for the next two years. A major problem, however, for the designer of EEQ was to simulate the FSA (Fish stock Assessment) of ICES in a reasonable way. Eventually it was decided to take the most simple approach, namely the simple VPA as it was executed when the present author attended an ICES working group meeting some 25 years ago. The reasoning for this choice is elaborated below. If you are only interested in how the EEQ works and not so much why it does what it does you may well skip the entire subsection 4.1.

4.1. HOW TO SIMULATE ICES ASSESSMENT?

The methodology of ICES has (more or less) remained unchanged since the very start of the advisory function of ICES. I see only one attempt to create a milestones in the ICES FSA (Fish Stock Assessment) methodology since 1956 (Here, I define a "milestone" as a major new methodology relative to the single species VPA, which exploits a type of data which was not previously exploited for FSA). The attempted milestone was the multispecies model by Andersen and Ursin (1977), which exploited stomach content data. The multispecies model was implemented by ICES in the form of the "MSVPA" (Multi-Species VPA, Sparre 1991) and Multispecies Forecast "MSFOR". Although MSVPA & MSFOR have had some limited use in ICES, they never developed into an ICES standard methodology, and that is why I use the term "attempted milestone". MSVPA and MSFOR did not become the milestone it should have been. If there is a "next version of EEQ", it should contain the species interaction of MSVPA.

Then there was a second major event involving the use of new data in ICES FSA, which however, does deserve to be called a “milestone”. That was the introduction of the so-called “VPA-tuning”. Unlike the MSVPA, the “Single-Species Tuned VPA” has become the standard methodology of ICES FSA. Numerous scientific papers on VPA-tuning were published, and a suite of different versions were applied in ICES.

I am not aware of any other candidate for a “milestone”. The introduction of “reference points” may be claimed by some people to be a milestone. However, as I define the concept, the “reference points” do not qualify, as they do not utilise new data sources. Somehow, all the reference points are derived from the yield/recruit concept, and thus only represent modifications of the old theory. Nor do I consider the suite of stochastic simulation models, which has become so popular in ICES circles, for milestones in FSA. The various bootstrapping, Bayesian simulations etc., are more linked to the development of fast speed computers and statistical theory, whereas they do not represent innovation in the field of FSA. These general methods are used to estimate the confidence limits of parameter estimates and predictions under the assumption that the model applied reflects the reality. This is a valuable contribution to the fisheries science, but it does not solve the basic problems of FSA.

The most striking feature of ICES’s inability to introduce innovation in its system is the fact that ICES is still operating with single species FSA. The multispecies VPA was an attempt to overcome the single-species limitation, but it was turned down by the “tradition of ICES”, which has blocked for the development for so many years.

My experience from many different VPA-tunings, is that one can get almost any desired result out of a VPA tuning, by “fiddling” with the optional (not observed) input parameters and/or the assumptions behind the underlying model. The VPA-tunings I exercised were not robust methods in any sense.

The simplest predictor of the future landings is the observed historical landings. The FSA as implemented in ICES did not add much to this simple predictor. I believe that, what we WG-members actually did were to use the simple predictor, and then we “pretended” to have used the sophisticated FSA methodology. That is, the VPAs were tuned and tuned and tuned until they gave the expected results. If one tuning software refused to “collaborate” it was exchanged with another more co-operative tuning software. Most often, the limited time available did not allow the working group to discuss the theory and rationality behind the various VPA-tuning software.

The above considerations give another reason why I do consider it worthwhile to do a lot out of simulating the ICES version of VPA.

4.2 TYPE OF VPA SIMULATED IN EEQ

The VPA of EEQ is the traditional VPA of ICES. Input is the numbers caught by all fleets (landings + discards) and terminal Fs, as is illustrated by the example:

Age/year	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
0	C(1994,0)	C(1995,0)	C(1995,0)	C(1997,0)	C(1998,0)	C(1999,0)
1	C(1994,1)	C(1995,1)	C(1995,1)	C(1997,1)	C(1998,1)	C(1999,1)
2	C(1994,2)	C(1995,2)	C(1995,2)	C(1997,2)	C(1998,2)	C(1999,2)
3	C(1994,3)	C(1995,3)	C(1995,3)	C(1997,3)	C(1998,3)	C(1999,3)
4	C(1994,4)	C(1995,4)	C(1995,4)	C(1997,4)	C(1998,4)	C(1999,4)
5	C(1994,5)	C(1995,5)	C(1995,5)	C(1997,5)	C(1998,5)	C(1999,5)
6+	C(1994,6)	C(1995,6)	C(1995,6)	C(1997,6)	C(1998,6)	C(1999,6)

Age/year	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
0						**F(1999,0)**
1						**F(1999,1)**
2						**F(1999,2)**
3						**F(1999,3)**
4						**F(1999,4)**
5	**F(1994,5)**	**F(1995,5)**	**F(1995,5)**	**F(1997,5)**	**F(1998,5)**	**F(1999,5)**
6+						

Ideally, the input should be catch (Landings + Discards), but in practice, often the catch is not know, only the landings are observed. Therefore, EEQ contains the option to let input to VPA be catch or landings. The option is fleet specific in EEQ. (see example in Figure 2.1.3, which shows that this option-parameters is entered in Cell B73 of worksheet “Stock_Input”).

Actually, the Fs of the second oldest age group is not really input, but is computed by the VPA as the mean value of some younger age groups (to be explained in Section 4.2.1). The specification of this mean value calculation (which age groups) is made by the input parameters in Cell D70 of sheet “Stock_Input”, see Figure 2.1.3.

Outputs are Fishing mortalities and stock numbers as illustrated by the example:

Age/year	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
0	F(1994,0)	F(1995,0)	F(1995,0)	F(1997,0)	F(1998,0)	
1	F(1994,1)	F(1995,1)	F(1995,1)	F(1997,1)	F(1998,1)	
2	F(1994,2)	F(1995,2)	F(1995,2)	F(1997,2)	F(1998,2)	
3	F(1994,3)	F(1995,3)	F(1995,3)	F(1997,3)	F(1998,3)	
4	F(1994,4)	F(1995,4)	F(1995,4)	F(1997,4)	F(1998,4)	
5						
6+	*F(1994,6)*	*F(1995,6)*	*F(1995,6)*	*F(1997,6)*	*F(1998,6)*	*F(1999,6)*

Age/year	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
0	N(1994,0)	N(1995,0)	N(1995,0)	N(1997,0)	N(1998,0)	**N(1999,0)**
1	N(1994,1)	N(1995,1)	N(1995,1)	N(1997,1)	N(1998,1)	**N(1999,1)**
2	N(1994,2)	N(1995,2)	N(1995,2)	N(1997,2)	N(1998,2)	**N(1999,2)**
3	N(1994,3)	N(1995,3)	N(1995,3)	N(1997,3)	N(1998,3)	**N(1999,3)**
4	N(1994,4)	N(1995,4)	N(1995,4)	N(1997,4)	N(1998,4)	**N(1999,4)**
5	**N(1994,5)**	**N(1995,5)**	**N(1995,5)**	**N(1997,5)**	**N(1998,5)**	**N(1999,5)**
6+	*N(1994,6)*	*N(1995,6)*	*N(1995,6)*	*N(1997,6)*	*N(1998,6)*	*N(1999,6)*

The F_{VPA}s are found by solving the “backward” VPA equation for F, cohort by cohort:

$$\frac{C(St,y,a)}{N_{VPA}(St,y+1,a+1)} = \{\exp[\ F_{VPA}(St,y,a) + M(St,a)\ ] + 1\} * \frac{F_{VPA}(St,a,y)}{F_{VPA}(St,y,a) + M(St,a)} \quad (4.2.0.1)$$

The EEQ uses ordinary Newton iteration to solve the non-linear equation. Thus, the EEQ does not use, say, "separable VPA", as is customary in some ICES methods, the reason being that it would not matter much in the present context if one method or another method is used.

4.2.1. TREATMENT OF OLDEST AGE GROUPS

The F of the two oldest age groups are not computed by solving the VPA equation (as indicated by the arrows on the N-table above). For the second oldest age group is used:

$$F_{VPA}(St,y,a_{\max}(st)-1)) = \frac{1}{a_{TF-last} - a_{TF-first} + 1} \sum_{a=a_{TF-first}}^{a_{TF-last}} F_{VPA}(St,y,a) \quad (4.2.1.1)$$

where a_{first} and a_{last} are input parameters to EEQ.

The oldest age group, the plus-group gets the same fishing mortality as the second oldest age group.

$$F_{VPA}(St,y,a_{\max}(st))) = F_{VPA}(St,y,a_{\max}(st)-1)) \quad (4.2.1.2)$$

4.2.2. TERMINAL F OF LAST DATA YEAR

The terminal F, that is, the F of the last data year is in ICES assessment usually derived from some indices of F or indices of N (e.g. young fish survey results). Taking into account the uncertainly involved in predicting F (or N) from survey indices, the EEQ does something similar to using an F index. It uses the F predicted by the forecast program multiplied by a stochastic factor:

$$F_{VPA}(St,Y_{Last},a) = F_{FOR}(St,2,a) * \frac{\{\ \varepsilon_{TF-Year}(St) * W_{\varepsilon-Year} + \varepsilon_{TF-age}(St,a)\ \}}{(W_{\varepsilon-Year} + 1)} \quad (4.2.2.1)$$

ε_{TF-Age}(St,a) = Stochastic factor of terminal F in VPA accounting for the age-group-effect, of stock "St", a stock dependent normally distributed stochastic variable with mean value 1.0 and standard deviation σ_{TF-Age} .
$W_{\varepsilon-Year}$ = Weight of year effect the stochastic factor for terminal F in VPA (input parameter).
$\varepsilon_{TF-Year}$(St) = Stochastic factor of terminal F in VPA accounting for the year-effect, of stock "St", a stock dependent normally distributed stochastic variable with mean value 1.0 and standard deviation $\sigma_{TF-Year}$. The randomly drawn year effects is the same for all age groups.

The F predicted in the forecast is the F predicted in year Y_{last} –1. The forecast is always one year "behind" as the prediction is made for last data year + 1.

4.2.3. CALCULATION OF MEAN F AND SSB

The mean fishing mortality to be used in the ICES Harvest Control Rule may either co computed as the straight mean value (on the EEQ-user's choice)

$$F_{VPA-MEAN}(St,y) = \frac{1}{a_{Fmen-last} - a_{Fmean-first} + 1} \sum_{a=a_{Fmean-first}}^{a_{Fmean-last}} F_{VPA}(St,y,a) \quad (4.2.3.1)$$

or it may be computed as the weighted mean, where the weighing factors are the stock numbers.

$$F_{VPA-WMEAN}(St,y)=\frac{\sum_{a=a_{Fmean-first}}^{a_{Fmean-last}} F_{VPA}(St,y,a)*N_{VPA}(St,y,a)}{\sum_{a=a_{Fmean-first}}^{a_{Fmean-last}} N_{VPA}(St,y,a)} \qquad (4.2.3.2)$$

where
$a_{Fmean\text{-}first}$ = First age group used to compute the mean F_{VPA}
$a_{Fmean\text{-}last}$ = Last age group used to compute the mean F_{VPA}

The spawning stock biomass in VPA is computed as the biomass at the beginning of the year:

$$SSB_{VPA}(St,y)=\sum_{a=0}^{a_{\max}(St)} N_{VPA}(St,y,a)*Wgt(St,a)*Mat(St,a) \qquad (4.2.3.3)$$

5 HARVEST CONTROL RULE OF ICES

The Harvest control rule is in EEQ implemented by assigning a value F_{HCR} to the mean fishing mortality in the forecast program $F_{FOR\text{-}Mean}$(St,y+2), The forecast is made in year y+1 (this year) , based on data in last data year, y, for next year, "y+2" : F_{HCR} (St,y-2) = $F_{FOR\text{-}Mean}$(St,y+2). The mathematical expression for the ICES harvest control rule, with all indices, reads (compare section 1.1)

$$F_{HCR}(St,y+2)=\begin{cases} 0 \;\; if \;\; SS(St.y)\le B_{\lim}(St) \\ F_{pa}(St)\dfrac{SSB(St,y)-B_{\lim}}{B_{pa}(St)-B_{\lim}(St)} \;\; if \;\; B_{\lim}(St)\le SSB(St,y)\le B_{pa}(St) \\ F_{pa}(St) \;\; if \;\; SSB(St,y)>B_{pa} \end{cases}$$

That means that the F dictated by the HCR is used in the catch prediction "next year". The same HCR dictated fishing mortality derived foregoing year is used in the simulation model for the "current" year, that is the year of the ICES assessment.

The F_{HCR} is also used as a parameter (the mean value) in the distribution from which F_{SIM} is drawn, as was explained in Section 3.5.1.

When converting the above harvest control rule for F into a harvest control rule for effort, we are in deep problems, as ICES never expressed any thoughts about this question. The problem is, of course, that F_{HCR}, refers to the stocks and Effort refers to the fleets. ICES never made any attempt to relate fishing fleets to fish stocks. ICES have made a few isolated attempts to relate stocks to hypothetical fleets, but to my knowledge, never to real (physically identifiable fleets). How the HCR is implemented in EEQ in the two alternative management regimes will be explained in the Section 6 in connection with the forecast model.

6 SIMULATION OF ICES FORECAST

6.1. TYPE OF FORECAST MODEL

The traditional ICES forecast model (the Thompson & Bell Model) is the same as the simulation model, but with no stochastic factors. It predicts the stock and the fishery of all combined fleets for two years. The predicted yield is based on F derived from the harvest control rule for each stock, the predicted yield is used as TAC in the simulation model.

Figure 6.1.1. illustrates the interaction between the VPA, the FORECAST and the SIMULATION in EEQ. The first logical step in EEQ is the VPA, which is followed by the FORECAST and subsequent application of HCR (Harvest Control Rule) to compute the F_{HCR} and the corresponding TAC for next year. In the EEQ, however, the F_{HCR} is also used as a parameter in the stochastic simulation of the F in the SIMULATION model. The solid arrows indicates that the simulation is stochastic, where the mean value of the stochastic fishing mortality is derved from the forecast model. The philosophy behind this (somehow weird approach) is that we assume some relationship between ICES assessment and the real world.

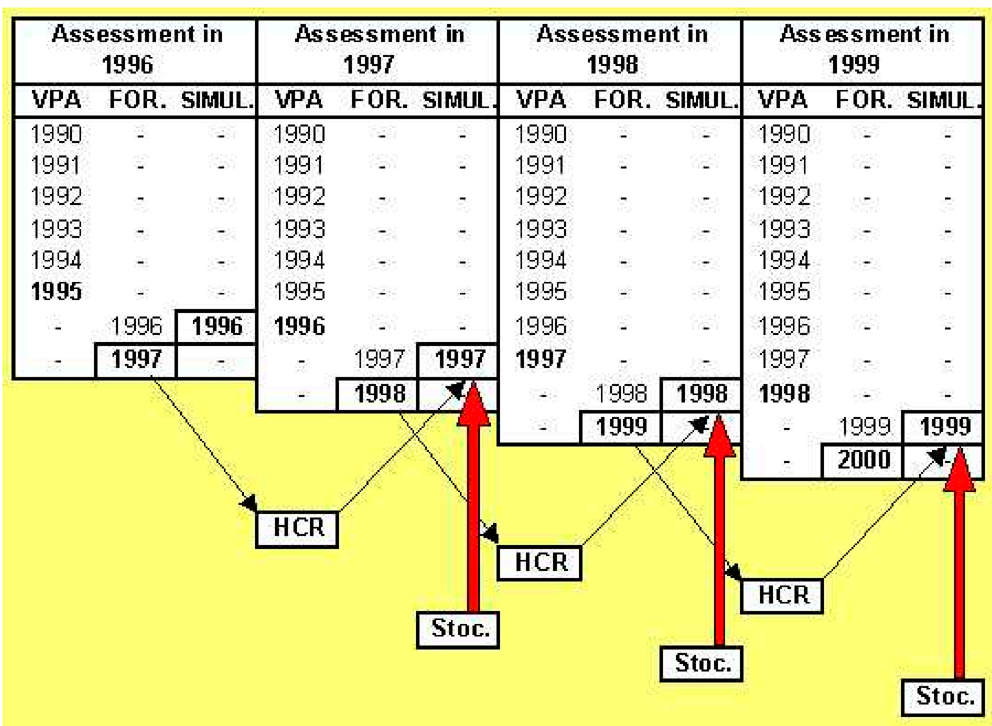


Figure 6.1.1. The years for which new results are produced by EEQ in each year-step (each assessment year).

The recruitment of the two future years, are derived from the VPA-estomates of recruitment, as the “overage historical recruitment”.

$$\mathrm{Re}\,c(St, Future\ \ year) = \frac{1}{Last\ \ VPA\ \ year - First\ \ VPA\ \ year + 1} \sum_{y=FirstVPAyear}^{LastVPAyear-1} N_{VPA}(St, y, 0) \qquad (6.1.1)$$

The same recruitment is used for both forecast years.

6.2. APPLICATION OF HARVEST CONTROL RULE UNDER CATCH QUOTA REGIME

The F_{HCR} of the HCR is converted into a TAC for the quota management regime

$$TAC(St,y) = \sum_{a=o}^{a_{Max}(St)} C_{FOR}(St,y,a) * w(St,y,a) \tag{6.2.1.a}$$

which will be applied in the simulation model to stop the fishery under quota regime, if the TAC is exceeded.

In practice, the TAC is counted against the landings, so the TAC should have been

$$TAC(St,y) = \sum_{a=o}^{a_{Max}(St)} LANDINGS_{FOR}(St,y,a) * w(St,y,a) \tag{6.2.1b}$$

but the forecast model in EEQ does not split catches into landings and discards. This is an inconsistency the EEQ inherited from ICES, and which we don't really know what to do about. But when we are in the simulation model, the catch is split into landings and discards, and the condition for quota management now becomes

$$TAC(St,y) \geq \sum_{a=o}^{a_{Max}(St)} \sum_{Fle=1}^{NU_{Fleets}} C_{Land}(St,Fl,y,a) * w(St,y,a) \tag{6.2.2}$$

A reduction in the fishing mortality then (naturally) has the consequence of a proportional reduction in the effort.

If the condition is not met, then all the Fs (of all fleets) are reduced until the TAC equals the landings.

F is also reduced if it exceeds the capacity of the fleets. That is no F can be bigger than Eq. 3.4.1.1. allows for (that is: $E(Fl, y) \leq NU_{Vessel}(Fl, y) * EY_{MAX}(Fl,y)$). The capacity conditions converted into fishing mortality becomes:

$F_{SIM\text{-}Max}(St,Fl,y) = E(Fl, y) * Q(St,Fl,y) \leq NU_{Vessel}(Fl, y) * EY_{MAX}(Fl,y) * Q(St,Fl,y)$.

where "SIM-Max" refers to maximum over age groups. By summation over fleets:

$$F_{SIM-Max}(St,y) \leq \sum NU_{Vessels}(Fl,y) * EY_{MAX}(Fl,y) * Q(St,Fl,y) \tag{6.2.3}$$

This constraint on fishing mortality, although very easy to accept, has always (to my knowledge) been ignored in ICES assessments and ICES advice. ICES has in recent years often overestimated the F, with the result that catch quotas were not taken. Thus, Eq. 6.2.3 has great practical importance.

Although the quota regime does not bother about the effort corresponding to the F_{HCR}, the EEQ need to care for it. This is because the EEQ contains the bioeconomic submodel, and a bioeconomic model must have the Effort as input to the cost-calculations.

The first step in converting the F_{HCR} into effort is rather hypothetical, in that introduce the concept of "Stock dependent-effort". The is a rather hypothetical definition. The stock dependent effort is the effort you need to produce a certain fishing mortality on a given stock, disregarding all other activities of the fleet. Only in real clean, one-stock fisheries, one can observe "Stock-dependent-effort" in reality. Anyway, the stock dependent effort is defined as

$$\mathbf{E^*_{HCR}(St,Fl,y) = F_{HCR}(St,y)^*F_{REL\text{-}Max}(St,Fl,y)/Q(St,Fl,y)} \qquad (6.2.1).$$

Thus, the fishing mortality is divided into fleet secments (partial fishing mortalities) by multiplication with the relative fishing mortality, $F_{HCR}(St,y)^*F_{REL\text{-}Max}(St,Fl,y)$. The partial fishing mortality is then converted into stock-specific effort by dividing with the catchability coefficient.

Eq 6.2.1 allocates an effort value for each stock to a given fleet. To get a unique effort valye, E(Fl,y) of a fleet, we must assume some rule for how the stock-dependent efforts are combined into one effort value. Unfortunately, ICES, give us no guidance on this matter. We need therefore, to suggest a functional relationship between the stock-independent effort and the stock dependent effort:

$$\begin{aligned} &E_{HCR}(Fl,y) = \\ &Functional\quad \mathrm{Re}\,lationship\,(E_{HCR}(1,Fl,y), E_{HCR}(2,Fl,y),...., E_{HCR}(NU_{Stocks}, Fl, y) \end{aligned} \qquad (6.2.2)$$

One such functional relationship could be the minimum value of the stock-dependent efforts:

$$E_{HCR}(Fl,y) = Min\{\ E_{HCR}(1,Fl,y), E_{HCR}(2,Fl,y),...., E_{HCR}(NU_{Stocks}, Fl, y)\ \} \qquad (6.2.3a)$$

another one is the maximum value:

$$E_{HCR}(Fl,y) = Max\{\ E_{HCR}(1,Fl,y), E_{HCR}(2,Fl,y),...., E_{HCR}(NU_{Stocks}, Fl, y)\ \} \qquad (6.2.3b)$$

The first approach would mean that fisheries is reduced or stopped as soon as the precautionary approach is exceeded for one stock, and the other one that fishing is reduced or stopped only when the precautionary approach is exceeded for all stocks.

Actually we don't know what ICES thinks about these two extreme alternatives. Perhaps ICES would go for something in between (we don't know). One could imagine that fishery would be stopped when on average the precautionary approach was exceeded, which would lead to the definition of Eq 6.2.4, in gave we used the straight aritmetric mean value

$$E_{HCR}(Fl,y) = \frac{1}{NU_{Stocks}} \sum_{St=1}^{NU_{Stocks}} E_{HCR}(St,Fl,y) \qquad (6.2.4a)$$

However, one might want to weight the stock-dependent efforts with the yield the represent, which would give the defininition:

$$E_{HCR}(Fl,y)=\frac{\sum_{St=1}^{NU_{Stocks}} E_{HCR}(St,Fl,y)*Y_{Total}(St,Fl,y-2)}{\sum_{St=1}^{NU_{Stocks}} Y_{Total}(St,Fl,y-2)} \qquad (6.2.4b)$$

One could also weigh by the stock biomass or by the value of the yield. In that case we would have to use the yield of an earlier year as weighing factor, as the effort is related to the yield. One can think of more options. The point here is that there are many options, and we have no idea on which one would be chosen in case ICES was forced to make a choice.

In EEQ, we have (more or less) arbitrarily chosen Eq. 6.2.4a for effort calculation in the case of catch quota management, because it is simple, and because it is a kind of compromise between the two extremmes. But there is no real convincing argument for using that option.

6.3. APPLICATION OF HARVEST CONTROL RULE UNDER EFFORT REGULATION REGIME

In the case of effort regulation as management regime, no TAC is required. In this case we therefore need to convert the F_{HCR} also for management purposes. As for the catch quota regime, we start with calculating the stock-dependent effort (Eq. 6.2.1): $E^*_{HCR}(St,Fl,y) = F_{HCR}(St,y)*F_{REL-Max}(St,Fl,y)/Q(St,Fl,y)$.
Here we assume that ICES is aware of the effort, and therefore has formulated a harvest control rule in terms of effort. We assume that this effort HCR is exactly the same as that for fishing mortality in the sense, that the “Effort-HCR “ cannot violate the “F-HCR” for any stock. The logical consequence of this demand for the “Effort-HCR” is that:

$$\mathbf{E_{HCR}(Fl,y) = Min_{St}\{E^*_{HCR}(St,Fl,y)\}} \qquad (6.2.3.1)$$

This approach will guarantee that the HCR is not exceeded for any stock. Eq. 6.2.3 represents the view that ICES will continue to let the current implementation of the precautionary approach be the strategy for fisheries management. It is hard, however, to believe that any advisory group would show so little ability to adopt to a changing world. Any suggestion for a prediction of a more intelligent future attitude of ICES is welcomed.

The effort defined by Eq. 6.2.3 is then turned into fishing fishing mortality Eq 3.5.2.1, that is

$$F_{HCR}^{After}(St,y)*F_{REL-Max}(St,Fl,y)=E_{HCR}(Fl,y)*Q(St,Fl,y) \qquad (6.2.3.2)$$

and summing over fleets:

$$F_{HCR}^{After}(St,y)=\sum_{Fl=1}^{NU_{Fleets}} E_{HCR}(Fl,y)*Q(St,Fl,y) \qquad (6.2.3.3)$$

where $F_{HCR}^{After}(St,y)$ stands for the fishing mortality modified after the minimisation.
To explore the equation of (6.2.3.3), (which to the authors knowledge is new in the world of ICES) we shall make a few derivation, and study some special cases of it. By combining the equations it is seen that:

$$F_{HCR}^{After}(St,y) = \sum_{Fl=1}^{NU_{Fleets}} Min_U \left\{ F_{HCR}^{Before}(u,y) * F_{REL-Max}(u,Fl,y) / Q(u,Fl,y) \right\} * Q(St,Fl,y) \tag{6.2.3.4}$$

Which reduces to $F_{HCR}^{After}(St,y) = F_{HCR}^{Before}(St,y)$ as $\sum_{Fl=1}^{NU_{Fleets}} F_{REL-Max}(St,Fl,y) = 1.0$ in the trivial case of one stock and one fleet

In the case of only one fleet we get:

$$F_{HCR}^{After}(St,y) = Min_U \left\{ F_{HCR}^{Before}(u,y) * Q(u,Fl,y) \right\} * Q(St,Fl,y) \tag{6.2.3.5}$$

Obviously, the capacity constraint (Eq. 6.2.3) also applies to the case of effort-regulation.

$$F_{SIM-Max}(St,y) \le \sum NU_{Vessels}(Fl,y) * EY_{MAX}(Fl,y) * Q(St,Fl,y)$$

in case the capacity constraint is exceeded the Fs are reduced correspondingly.

7 COMPARISOM OF MANGEMENT REGIMES

There are many ways one could compare the performance of the two alternative management regimes, and again ICES leaves us with little guidance, so we will have to invent a methodology of our own. One approach of ICES, is possible to transfer to problem of comparison of management regimes, namely the performance measure often used by ICES.

The form of the principal output from EEQ is illustrated by Table 7.1.2, which shows the frequency diagrams of the total profit from fisheries, each year. EEQ will in one run produce 2 + 2*(NU_{stocks} + NU_{Fleets}) similar tables with the content as specified in Table 7.1.1. EEQ will produce a total of 2*(2 + 2*(NU_{stocks} + NU_{Fleets})) tables as there there will be a table for each management regime.

Table No.	Number of tables	Table content
1	1	Grand Total Value of landings
2	1	Grand Total Profit
3	NU_{stocks}	SSB – by stock
4	NU_{stocks}	Mean F – by stock
5	NU_{Fleets}	Value of landings by fleet
6	NU_{Fleets}	Profit by fleet

Table 7.1.1. The principal tables produced by EEQ after a multiple stochastic simulation.

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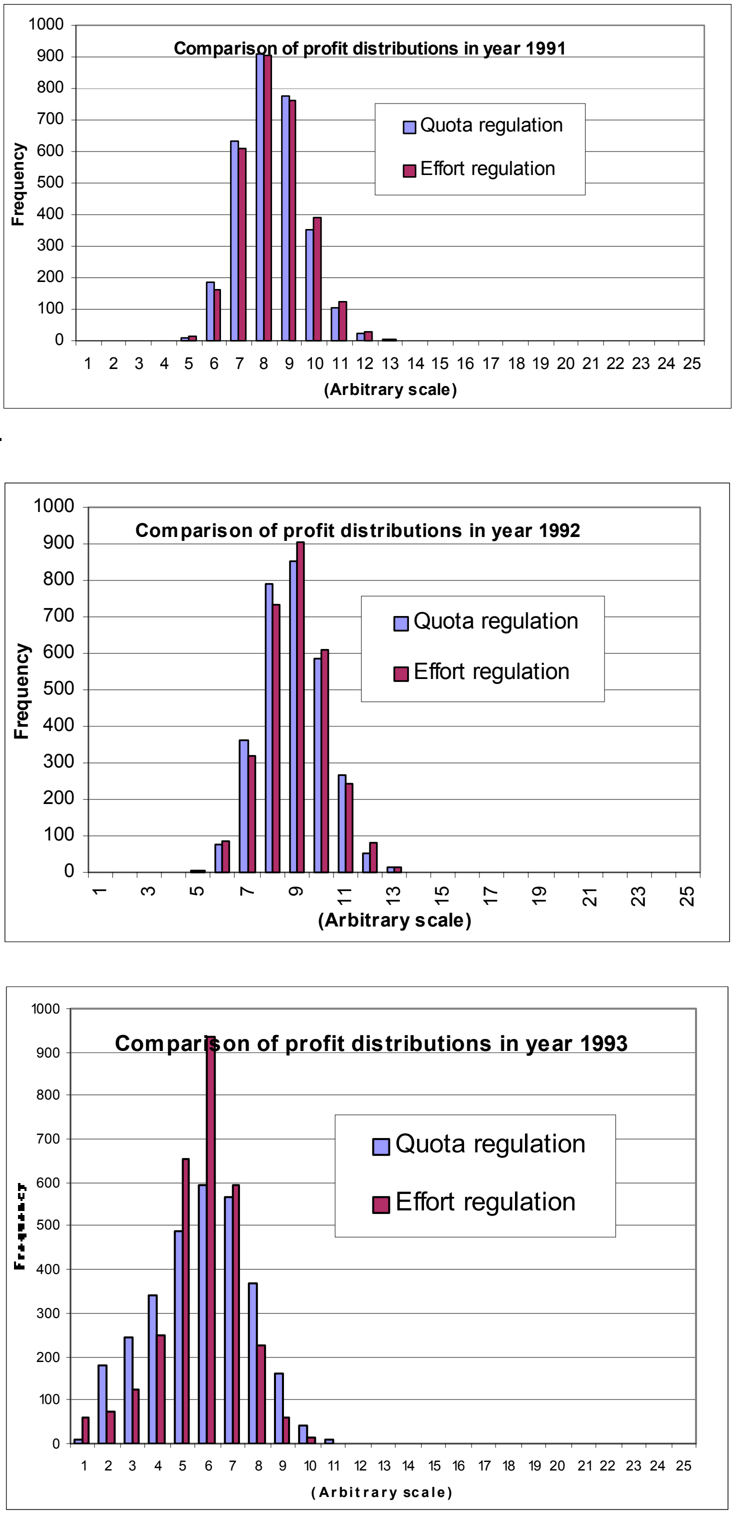

Figure 7.0.1. Comparisons of distributions of performance measures for three consecutive years.

EFFORT REGULATION - Grand Total Profit											
Year		**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
Mean	Profit	39484	44661	10051	-3810	14839	43075	56644	62226	65743	69826
Std.dev.	Profit	14760	15463	15580	21161	29851	31921	30624	29373	29096	29020
Min	Profit	-14807	684	-37896	-37905	-37806	-37651	-37529	-37366	-37035	-26208
Max	Profit	100227	107012	65000	76241	157243	184515	206866	201950	233227	218621
Rel.St.d. %	Profit	37.38	34.62	155.01	555.35	201.16	74.11	54.06	47.20	44.26	41.56
Frequency in 3000 simulations: - Grand Total Profit											
Index :	lower limit:	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
1	-38284	0	0	67	507	279	51	11	4	3	0
2	-27331	0	0	106	385	203	52	16	5	0	2
3	-16377	2	0	230	508	279	92	23	12	9	8
4	-5423	14	8	659	562	384	143	58	32	17	7
5	5531	120	85	941	531	437	246	139	85	49	44
6	16484	503	299	639	294	434	342	239	175	149	92
7	27438	831	651	268	148	382	398	353	291	255	230
8	38392	794	874	75	46	232	428	438	394	412	368
9	49346	492	627	13	16	179	389	407	498	485	450
10	60299	179	300	2	2	84	329	421	471	460	448
11	71253	50	124	0	1	52	225	329	350	368	403
12	82207	13	25	0	0	27	125	218	266	304	347
13	93161	2	5	0	0	17	75	159	169	208	247
14	104114	0	2	0	0	4	60	79	114	119	153
15	115068	0	0	0	0	3	25	55	55	63	94
16	126022	0	0	0	0	2	8	28	41	43	49
17	136975	0	0	0	0	1	9	17	18	33	29
18	147929	0	0	0	0	1	1	3	13	7	14
19	158883	0	0	0	0	0	1	2	4	10	10
20	169837	0	0	0	0	0	0	2	2	3	2
21	180790	0	0	0	0	0	1	2	0	1	0
22	191744	0	0	0	0	0	0	0	1	0	2
23	202698	0	0	0	0	0	0	1	0	1	0
24	213652	0	0	0	0	0	0	0	0	0	1
25	224605	0	0	0	0	0	0	0	0	1	0

Table 7.0.2. Example of measures for the performance of the Effort management regime.

These principal tables are considered measures for the performance of the management regime. However, one might well have selected more measures or different measures for the performance. But for the time being we assume, these are the performance measures available in EEQ

Figure 7.0.1 compares the distributions of performance measures in the first three years of the simulation period. A full comparison of management regimes should consider all 10 years, and derive a single figures which indicates the difference, and thus allowing us to conclude that one management regime is better than the other. However, the present author will leave it to the user to decide which measure should be used to compare management regimes.

8. DISCUSSION

The present author considers the EEQ one of the simplest possible approaches, which is capable of addressing the problem of comparing two alternative management regimes. For example, the ability of EEQ to make stochastic simulations was a minimum requirement. As a deterministic model, the EEQ would not detect any difference between the alternative management strategies, should it be based on the assumption of a relationship between effort and fishing mortality.

8.1. FEATURES OF EEQ, WHICH MAKE EEQ UNREALISTIC

Taking into account the present state of the art on fisheries management research and the availability of data for management research, the goal of the EEQ model-makers, was indeed to make it as simple as possible, and with the minimum data requirement. This approach naturally leads to a suite of simplifying assumptions and questionable assumptions behind EEQ, some of which will be listed below. The list is not complete, - as for most other parents, the author is not aware of all the oddities and deformities of his “baby”.

1) **Compliance**: The present version of EEQ does not address the degree of compliance of the industry to management by effort regulation relation to management by quota-regulation. It is believed that the industry would prefer effort-regulation compared to quota-regulation, and the degree of compliance would consequently be higher. This in turn should result an easier and cheaper control and surveillance.

2) **Cost of management**: The cost of management (control, surveillance, advisory bodies, administration and research) is not accounted for in EEQ. If the expectations expressed under 1) turn out to hold in practice, the cost of effort-based management should be lover that that of quota management. As the cost of management on average (world-wide) is around 10 % (ref. Hanneson *et al*., 2000), this component of the sector economy may be considerable, and constitute a large fraction of the profit.

3) **Bioeconomics**. In general, the bio-economic submodel of EEQ is too simple to reflect the reaction of the industry on a change in management regime. For example: Prices are influenced by the production, investments are influenced by the profitability of the industry. These mechanisms are kept constant in the EEQ.

4) **Investments.** The investments in the fishing sector are ignored. There are two principal ways in which effort can be controlled (1) By restrictions on the number of fishing days (2) By restriction on the capacity (The number of boats. Restrictions on the capacity will make the restrictions on the fishing days less important. In the extreme, with a very low capacity, there will be no need for restrictions on the fishing days. To reduce the capacity may imply lost investments to be compensated by decommission schemes. However, the EEQ is not able to address this question as it does deal with investments.

5) **Sector:** Only the harvesting sector is considered in EEQ, disregarding the relationships between the harvesting and the processing sectors. The behaviour of the fishermen (e.g. discarding) is influenced by the demands from the industry.

6) **Number of fishers**. As is tradition by ICES experts, no account is made to the fishers in EEQ. The EEQ does not even account for the number of fishers per boat, and does thus ignore the employment aspect of fisheries. The bio-economic model does not account for the “divisible earning”, that is the part of the revenue given as remuneration to the crew. This is usually a certain share of the revenue minus certain costs (the divisible earning).

7) **Discard-practice**. The EEQ does not simulate a change in discard-practice with a change in management regime. With effort regulation, there would be no legal reason for discarding fish (for doing “high-grading” due to quota exceed). Under effort regulation there would be only an economic reason for discard (low price and high costs of handling). However, this important issue is not dealt with by EEQ.

8) **Spatial features**: There are no spatial features build into the EEQ. Thus the stocks in question are supposed to be evenly distributed over the sea area of EEQ. What happens outside the sea area of EEQ is not accounted for. Fish stocks as well as fishing fleets are mobile, and there

rarely exists a sea area in the world where stocks and fisheries are isolated from neighbouring areas. The three case studies of EEQ do certainly not belong to this category of isolated fishing systems.

9) **Nation and area coverage**: Only the fishing fleets of one nation, namely the Danish fleets, are accounted for in EEQ. However, in all three cases, the fish stocks are exploited by other nations. Ideally, any fisheries model should cover the entire distribution area of the stock, it should cover all stocks and all fleets fishing in the area. Ideally, the combination of areas, stocks and fleets should be so that the stocks and the fleets operate in the area only. This may in practice lead to the demand that all seas and all stocks of the globe be included in the model, so some compromise is required for practical reasons.

10) **Seasonality:** Seasonality of fishing (e.g. seasonality of catchability coefficients) is disregarded in EEQ. The catchability is known to be highly variable during the year. One way to overcome this problem would be to let the EEQ work with time steps of one month or a quarter of the year rather than with a time step of one year. The main reason for choosing the time step of one year, is that the ICES assessments are made with a time step of one year.

11) **Only one area**: Some vessels may during the year leave the "EEQ sea-area" to fish elsewhere. This is not accounted for in the EEQ. This weak point of the EEQ makes it very problematic to handle the economics of the fleets, since some costs and some revenues remain unknown. In the EEQ they are assigned the value of zero, which technically can be made by assigning a lower value to the annual effort, than the annual one which was actually exerted, when fishing in all areas was accounted for.

12) **Gear change**: Some fishing vessels change gear rigging during the year (for example from 70 mm Norway lobster trawl to 90 mm cod trawl in the Kattegat). Change of rigging and gears are not accounted for in the EEQ.

13) **Vessel size**: Sizes of vessels are not directly accounted for in EEQ. It can be accounted for indirectly by definition of fleets, where the definition also accounts for the size of the vessel (say, small, medium and large trawlers).

14) **Conservatism of ICES**: The advisory body (ICES) is assumed to maintain their methodology (VPA, FORECAST and the Harvest Control Rule) under an Effort regulation regime. This is indeed a very negative assessment of the ability of ICES to adopt to new conditions.

15) Behaviour of ICES: It is not known how ICES would transfer fishing mortalities into effort quotas (which in principle can be done in infinitely many different ways). A very simple rule of the thump has been introduced in EEQ to give the problem a "mathematical solution", namely the assumption of constant relative fishing mortality.

16) **Allocation of effort quotas to areas and seasons.** As the present version of EEQ does not consider spatial or seasonal aspects, it is also blind to the problem of allocating effort quotas to sea areas and to seasons of the year. It is well known, even to ICES experts, that the distribution of resources vary in space and time. Also the catchability is known to vary spatially and seasonally. The fishing fleets adopt to the variations of the resources. Therefore, it is very important to which degree effort quotas are linked to areas and seasons, but the current version of EEQ ignores this problem.

17) **Behaviour** of fishers. Fishermen may change behaviour as a reaction to management measures. It is believed that fishers' behaviour will be closely linked to the economics. The change in behaviour will materialise primarily in the choice of fishing grounds, gear rigging and

fishing season. However, as the present version of the EEQ is blind to these phenomenons, it also ignores all aspects of fishers' behaviour.

18) **Stochastic modelling**: There is no rational justification for the way stochasticity was implemented in the EEQ. Stochastic factors, following either a normal- of a log-normal distribution were introduced to the modelmakers liking. This could have been done in many other ways. For example, a stochastic factor has been assigned to the curvature parameter, K, in the von Bertalanffy growth equation, but we might as well have assigned the stochastic factor it to L_∞, or to both parameters. It is not known what the effect of an alternative stochastic modelling would have been.

19) **Technical management measures**: Technical management measures, such as minimum mesh size, closed areas, closed seasons and minimum landing size are not accounted for in EEQ. It is expected that effort regulation would be combined with technical management measures, so any complete analysis should consider the combined effect of technical management measures and effort regulation.

20) **Relationship between F and Effort**: The EEQ uses the simple model linear model for the relationship (proportionality) between effort and fishing mortality "F = Q* Effort". The model implies that (forgetting about a number of details) that yield is Y = F*B, where B is the biomass This model is believed to a apply mainly for demersal (non-schooling species). A more realistic and versatile model would read $Y = F*B^{\beta}$,where the exponent β reflects the relationship between catchability and abundance of the stock. This model leads to $Y = Q * B^{\beta-1*} * Effort * B$, or catchability equals a constant, Q, multiplied by the biomass raised to the power 1-β, $Q * B^{\beta-1}$. It would be a relatively easy thing to extend the model, but the extra requirement to parameter estimation would be considerable.

21) **Hybrid management regime**: The EEQ does contain an option for a "hybrid management regime". A hybrid solution would be a management regime, which uses both Quota regulation and Effort regulation. An introduction of effort management regime would probably in the first turn appear as a hybrid solution. However, with the current state of the art of fisheries management science, it is probably too ambitious to attempt to detect any difference unless one goes to the extremes.

8.2. CONCLUSION

The EEQ is based on a long suite of simplification and strong assumptions, some of which are not likely to be met in reality. Some problems stem from the fact that there is no tradition for working with fleets and effort in ICES (or any other fisheries advisory body in Europe). The philosophy of EEQ thus represents a true innovation in fisheries assessment in ICES, and could represent a true milestone in the development. Perhaps the most important feature of EEQ that it through light on some central problems in fisheries assessment, which so far has been ignored in by the scientific bodies and advisory bodies of ICES. One major omission in the ICES methodology is the use of fishing capacity as a major tool for fisheries management. The ICES perspective is probably that capacity is not a "biological concept", and consequently should not be dealt with by ICES. If that is the viewpoint of ICES, it should also accept the perspective that fisheries management is not only a matter of biology, and therefore should not be dealt with by ICES.

The EEQ, however, does certainly not deal with all the gabs of the ICES approach of fisheries assessment, such as ICES's ignoring of spatial and seasonal aspects.

If the EEQ is further developed, it is obvious to extend it to cover spatial aspects and seasonality of fishing. That would mean to divide the sea area into sub-areas and year into shorter time periods, say quarters or months.

Another natural extension of EEQ would be a "behaviour algorithm" foe the fishing vessels, predicting the reaction of the fishers to regulations.

A model which accounts for the list of omissions and gabs in EEQ listed in Section 8.1 is the so-called, FA (Fisheries Assessment) model and software, developed by the present author. The FA is also implemented as an EXCEL application, and contains the EEQ as a subset. The FA is based on experience achieved by the author while working as an FAO fishery resources officer in countries like Tanzania, Madagascar, Malaysia, Thailand and Morocco, starting in the mid eighties until 1992. This work is being continued in FAO under the name of BEAM (Bio-Economic Analytical Model).

One may claim that a major problem with the FA is its demand for data. However, all the data that is needed to run the FA should be available in principle (through the log-books and the sales slip databases all EU member countries, and it neighbour countries maintain in their fisheries). The main problem may be to break the ICES tradition to ignore these invaluable mountains of data.

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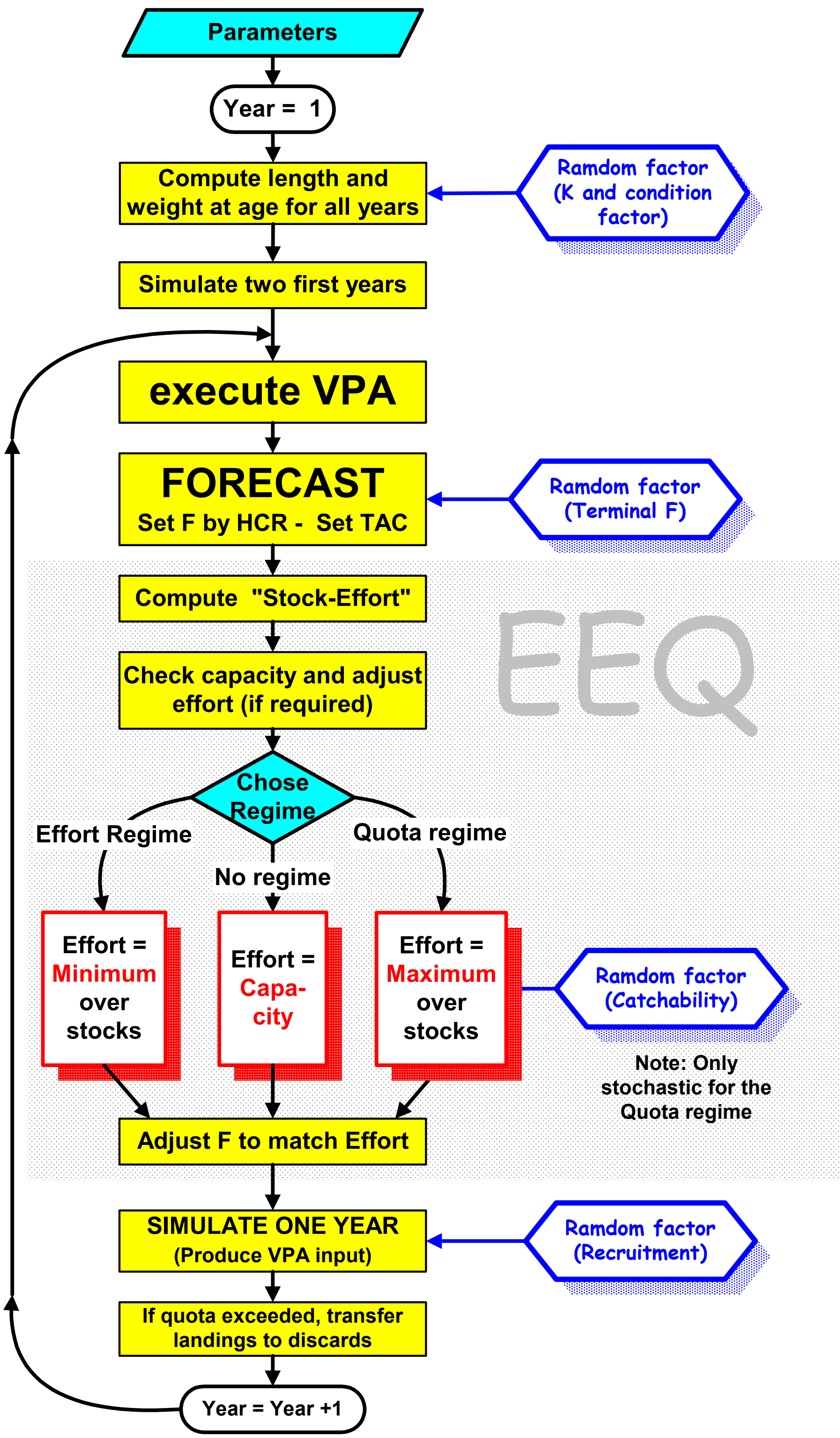
ANNEX A: THE CENTRAL ALGORITHM OF EEQ.



The flowchart illustrates the basic algorithm of one single simulation of a time series with EEQ. It also illustrates the stochastic simulation.

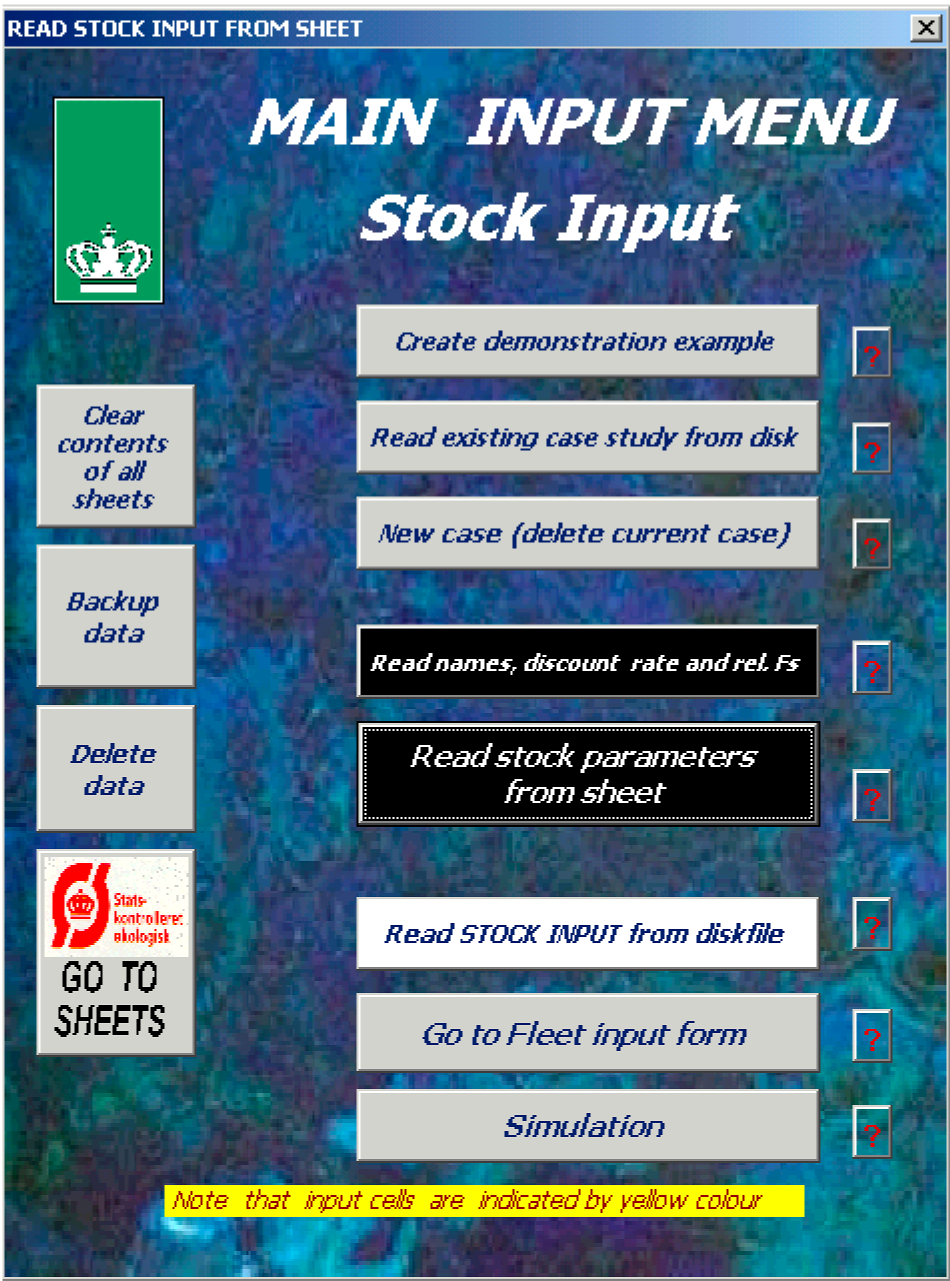
The details of the flowchart are explained in the "pseudo" VB-program given below.

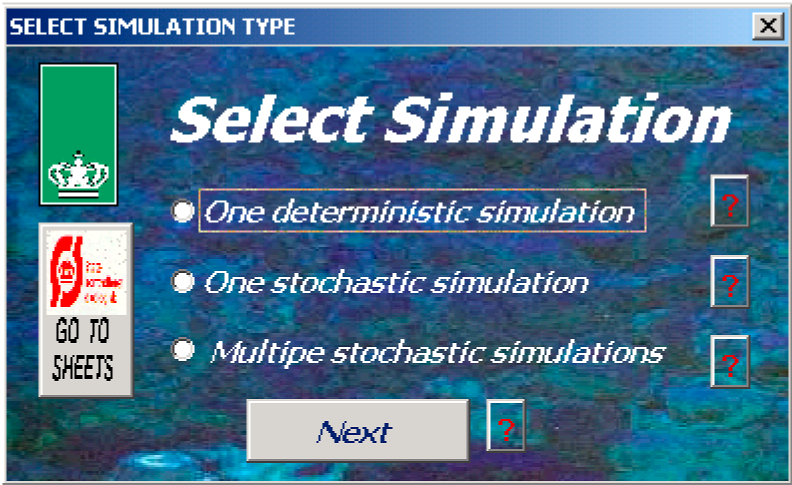
The shaded box indicates the parts of the model, which is specific to EEQ, whereas the ofter model components are the traditional models applied by ICES assessment working groups.

Note the differences between the conversions of F (derived from the HCR) to effort in the three alternative management regimes.

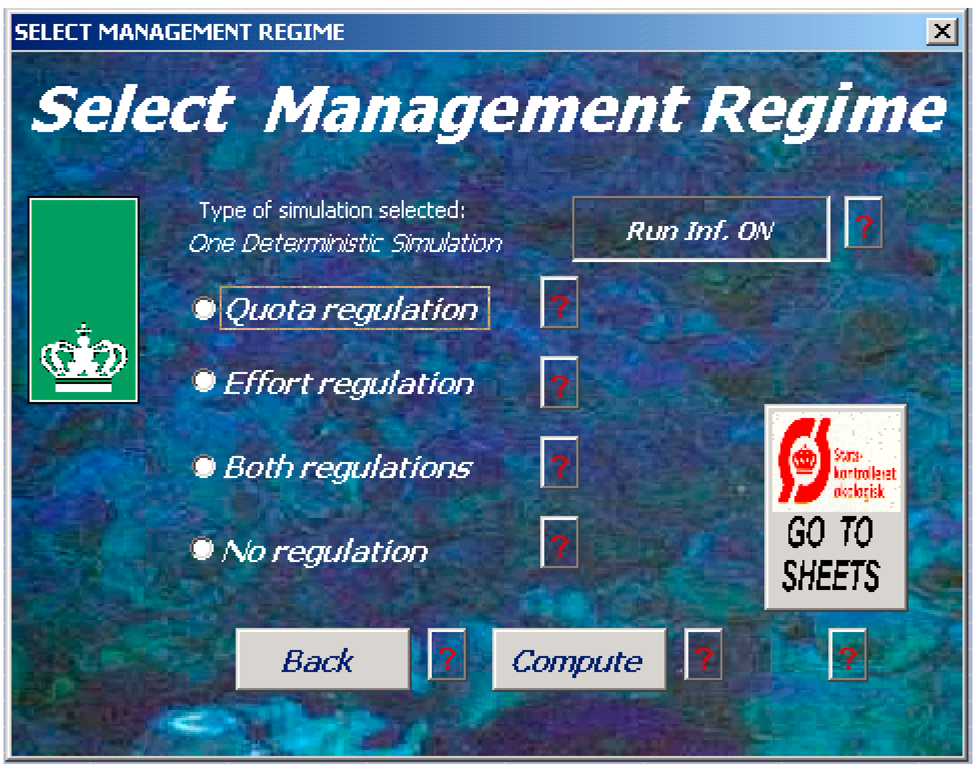
This “VISUAL BASIC” program would not run on a computer. The intension is to explain the logic of the algorithm. However, the pseudo-VB-program shown here has exaxtly the same design as the real program. All non-essential statements have been removed.

The algorithm is started by clicking on “Simuation” in the main menu. Then comes the menu for selection of simulation type: (Single deterministic, single stochastic or multiple stochastic):





Once you have selected the simulation type you select the management routine:



When you after the selection of management click on "Compute" you actrivate the routine SELECT_SIMULATION_OPTION, which in turn activates one (or two) of the routines:

1) MAIN_EXECUTE_QUOTA_REGIME
2) MAIN_EXECUTE_EFFORT_REGIME
3) MAIN_EXECUTE_NO_REGIME

Sub SELECT_SIMULATION_OPTION

```
'
Select Case Selected_Run_Option
    Case 1
        Call MAIN_EXECUTE_QUOTA_REGIME
    Case 2
        Call MAIN_EXECUTE_EFFORT_REGIME
    Case 3
        Both_Management_Regimes = True
        Call MAIN_EXECUTE_EFFORT_REGIME
        Call MAIN_EXECUTE_QUOTA_REGIME
    Case 4
        Call MAIN_EXECUTE_NO_REGIME
End Select
End Sub
'
```

Sub MAIN_EXECUTE_QUOTA_REGIME

```
`
Management_Regime = 1 ' -- (1) Quota regulation
Select Case Simulation_Type
Case 1
    Call MAIN_DYNAMIC_SIMULATION(False, 1, False) ' -- (1) Quota regulation
Case 2
    Call MAIN_DYNAMIC_SIMULATION(False, 1, True) ' --- (1) Quota regulation
Case 3
    Call MAIN_STOCHASTIC_MULTIPLE_SIMULATION(1) ' ---- (1) Quota regulation
End Select
End Sub
'
```

Sub MAIN_EXECUTE_EFFORT_REGIME

```
`
Management_Regime = 2 ' -- (2) effort regulation
Select Case Simulation_Type
Case 1
    Call MAIN_DYNAMIC_SIMULATION(False, 2, False) ' -- (2) effort regulation
Case 2
    Call MAIN_DYNAMIC_SIMULATION(False, 2, True) ' --- (2) effort regulation
Case 3
    Call MAIN_STOCHASTIC_MULTIPLE_SIMULATION(2)  ' --- (2) effort regulation
End Select
End Sub
'
```

Sub MAIN_EXECUTE_NO_REGIME

```
'
Management_Regime = 3 ' -- (3) no regulation
Select Case Simulation_Type
Case 1
    Call MAIN_DYNAMIC_SIMULATION(False, 3, False) ' -- (3) no regulation
Case 2
    Call MAIN_DYNAMIC_SIMULATION(False, 3, True) ' --- (3) no regulation
Case 3
    Call MAIN_STOCHASTIC_MULTIPLE_SIMULATION(3)  ' --- (3) no regulation
End Select
End Sub
```

Sub MAIN_DYNAMIC_SIMULATION

```
'
' --------------------- make simulation for first year ---------------
'
Call INITIALIZE_DYNAMIC_SIMULATION(Mult_Stoch_Simul, Draw_Stochastic)
'
For Year = 2 To Number_of_Years
    ' -------------------------- SIMULATION OF ICES W.G. -----------------------
    For St = 1 To Number_of_Stocks
        '
        ' ---------- (First_VPA_Year, Last_VPA_Year, Stochastic) --------------
        Call PERFORM_THE_VPA(1, Year, Draw_Stochastic)
        ' ---- the VPA routine does not contain behaviour algorithms -
        ' ----- the next routine contains the HCR behaviour algorithms
        '
        ' ----- This routine contains the HCR behaviour algorithms -----------
        ' ----------------------------------(First_VPA_Year, Last_VPA_Year)---
```

```
        Call MAKE_ICES_FORECAST_AND_APPLY_HCR_AND_SET_TAC(1, Year)
        '
        ' -------- Use ICES Forecast F as input to simulation -------------
        ' -------- (As mean value in probability distribution) ------------
        For a = 1 To Number_Of_Age_Groups(St)
            If Year < Number_of_Years Then _
            F(St, Year + 1, a) = FOR_HCR_F(St, 2, a)
            ' --- Note that FOR_HCR_F (derived by sub "MAKE_ICES_FORECAST")
            ' --- is subject to the HCR. ---------------------------------
        Next a
    Next St
    '
    '---------- SIMULATION OF STOCK AND FISHERY (Year + 1) ---------
    '
    If Year < Number_of_Years Then
        '
        '--------- Convert the Fs from HCR into Effort by fleet: ------------------
        ' ------------ If effort regime: Effort = Minimum (Over stocks) HCR-Effort
        ' ------------ If quota regime:  Effort = Maximum (Over stocks) HCR-Effort
        ' ------------ If no regime:     Effort = Capacity
        ' -------- Also check that capacity is not exceeded. In case the computed
        '
        Call COMPUTE_EFFORT_AND_ADJUST_F_FOR_ALL_FLEETS(Year + 1, Draw_Stochastic)
        '
        ' --- Use the Fs created by the HCR and later modified as input to the simulation
        Call SIMULATE_BASIC_STOCK_DYNAMICS_FOR_ONE_YEAR(Year + 1, False)
        '--- Note: This routine transfers quota exceed to discards ----
        '
      End If
Next Year
'
' ------- These routines contains no behaviour rules ----------------------
Call MAKE_FLEET_ECONOMICS_AND_TOTAL_SUMMED_OVER_STOCKS(1, Number_of_Years)
Call MAKE_TIME_DISCOUNTED_SUMS_OF_FLEET_ECONOMICS(1, Number_of_Years)
'
End Sub
```

Sub INITIALIZE_DYNAMIC_SIMULATION

```
`
call READ_PARAMETERS_FROM_DISK
'
'----------------- Compute ogives for all years: ----------------------------
Call MAKE_GROWTH_SELECTION_DISCARD_AND_MATURITY_CURVES(Draw_Stoc)
'
For St = 1 To Number_of_Stocks
    '
    '--- Nstart(St, year=1, a) and Effort_Days(year=1, Fl) are input parameters ---
    '--- Input are also: Q_Ref(St, year=1, Fl) and M(St,a) --------------------
    '
    F1 = Zero '------ compute fishing mortality first year --------------
    '---------------- in other years F are set by the HCR of ICES --------
    For Fl = 1 To Number_of_Fleets
        F1 = F1 + Q_Ref(St, 1, Fl) * Effort_Days(1, Fl)
    Next Fl
    '------------------ compute mean stock numbers first year -------------
    For a = 1 To PlusGr
        F(St, 1, a) = Zero
        For Fl = 1 To Number_of_Fleets
            F(St, 1, a) = F(St, 1, a) + _
            F1 * Relative_F(St, Fl) * Selection(St, 1, a, Fl)
        Next Fl
        ZZ = F(St, 1, a) + M(St, a)
        Nmean(St, 1, a) = Nstart(St, 1, a) * (1# - Exp(-ZZ)) / ZZ
    Next a
    '
    '------------ COMPUTE CATCH, YIELD AND BIOMASS YEAR ONE --------------
    '
    TY = Zero ' --- total yield (in weight) -----------
    TB = Zero ' --- total stock biomass ---------------
    TS = Zero ' --- total spawning stock biomass ------
    For a = 1 To PlusGr
        Catch(St, 1, a) = Nmean(St, 1, a) * F(St, 1, a)
```

```
        TY = TY + Catch(St, 1, a) * w(St, 1, a)
        Biom = Nstart(St, 1, a) * w(St, 1, a)
        TB = TB + Biom
        TS = TS + Biom * Mat_Ogive(St, 1, a)
    Next a
    Total_Yield(St, 1) = TY
    Total_Biom(St, 1) = TB
    Total_SSB(St, 1) = TS
    '
    ' ------- Compute Recruitment next (second) year -----------------
    '
    Nstart(St, 2, 1) = BH1(St) * Total_SSB(St, 1) / _
    (1# + BH2(St) * Total_SSB(St, 1)) '---- * LogNormal_Recruit_Fac(St)
    '
    Call COMPUTE_DISCARDS_LANDINGS_VALUE_AND_MEANF(1)
    '-----------------------------------(First_VPA_Year, Last_VPA_Year)------
    Call MAKE_ICES_FORECAST_AND_APPLY_HCR_AND_SET_TAC(1, 1)
    '
    For a = 1 To PlusGr
        F(St, 2, a) = FOR_HCR_F(St, 2, a)
        ' ----- It takes 3 years of data to make the first prediction ---------
        TAC(St, 1) = 9.9E+35 ' ---- No TAC for first year (TAC = infinite) ----
        TAC(St, 2) = 9.9E+35 ' ---- No TAC for second year (TAC = infinite) ---
        TAC(St, 3) = 9.9E+35 ' ---- No TAC for Third year (TAC = infinite) ----
    Next a
    '
    '----------------- Compute Stock Numbers year 2 ------------
    For a = 1 To PlusGr - 1
        Nstart(St, 2, a + 1) = _
        Nstart(St, 1, a) * Exp(-F(St, 1, a) - M(St, a))
    Next a
    Nstart(St, 2, PlusGr) = Nstart(St, 2, PlusGr) + _
    Nstart(St, 1, PlusGr) * Exp(-F(St, 1, PlusGr) - M(St, PlusGr))
    '
    '-------------- Same fishing mortality years 1 and 2 ------
    For a = 1 To PlusGr
        F(St, 2, a) = F(St, 1, a)
    Next a
    '
Next St
' ------- These are not computed in routine MAIN_DYNAMIC_SIMULATION for year 2 --
' ------- The first calculation in MAIN_DYNAMIC_SIMULATION is for year 3 --------
Call COMPUTE_EFFORT_AND_ADJUST_F_FOR_ALL_FLEETS(2, False)
Call SIMULATE_BASIC_STOCK_DYNAMICS_FOR_ONE_YEAR(2, False)
'
End Sub
```

Sub SIMULATE_BASIC_STOCK_DYNAMICS_FOR_ONE_YEAR (y, Stochastic)

```
'
' ------------------------- input Fs to this routine are the "F(St, y, a)" -------------
If Stochastic Then
    LogNormal_Recruit_Fac(St) = LogNormal_Dist(RelStDev_Recruit(St))
    Q_Normal_Factor(St, Fl) = NormalDist(RelSTD_Q(St, y, Fl))
Else ' --------------------------------- deterministic simulation: ---------------------
    LogNormal_Recruit_Fac(St) = 1#
    Q_Normal_Factor(St, Fl) = 1#
End If
'-------------------------------------- Beverton & Holt Stock/Recruitment ---------------
'
Nstart(St, y, 1) = LogNormal_Recruit_Fac(St) * _
BH1(St) * Total_SSB(St, y - 1) / (1 + BH2(St) * Total_SSB(St, y - 1))
'
' ---------------- N for 1+ age groups (except oldest age group) ------
For a = 1 To Number_Of_Age_Groups(St)
    ZZ = F(St, y, a) + M(St, a)
    ExpZ = Exp(-ZZ)
    Nmean(St, y, a) = Nstart(St, y, a) * (1 - ExpZ) / ZZ
Next a
'----------------------------------- compute biomass -----------------------
TY = Zero
TB = Zero
TS = Zero
For a = 1 To Number_Of_Age_Groups(St)
    Catch(St, y, a) = Nmean(St, y, a) * F(St, y, a)
    Biom = Nmean(St, y, a) * w(St, y, a)
    TY = TY + Catch(St, y, a) * w(St, y, a)
    TB = TB + Biom
```

```
    TS = TS + Biom * Mat_Ogive(St, y, a)
Next a
Total_Yield(St, y) = TY
Total_Biom(St, y) = TB
Total_SSB(St, y) = TS
'
Quota_Exceed_To_Discards(St, y) = Zero
'
Call COMPUTE_DISCARDS_LANDINGS_VALUE_AND_MEANF(y)
'
'------- Reduce F if quota is exceeded (only for quota-regulation) -----
'------- Then the quoata exceed is transferred to "discards" -----------
'------- The fraction of the catch exceeding the TAC is "Quota_Exceed_To_Discards"
If (Management_Regime = Quota_Regime) And (y > 3) Then

    If TAC_Compares_To_Landings(St) Then
        TAC_Match = Total_TAC_Yield_Landings(St, y)
    Else
        TAC_Match = Total_Yield(St, y)
    End If

    If TAC(St, y) < TAC_Match Then
        ' -------- The fraction of landings, which should be transferred to ----
        ' -------- discards is "Quota_Exceed_To_Discards" --------------------
       Quota_Exceed_To_Discards(St, Y) = 1  -  TAC(St, y) / TAC_Match
        '
        Call COMPUTE_DISCARDS_LANDINGS_VALUE_AND_MEANF(y)
        '
    End If
End If
'
' ---------------- compute N at beginning of next year (except for last year) ----------
`
If y < Number_of_Years Then
    `---------------------------------------------- all true age groups ------------
    For a = 1 To Oldest_Age - 1
        Nstart(St, y + 1, a + 1) = Nstart(St, y, a) * Exp(-F(St, y, a) - M(St, a))
    Next a
    `---------------------------------------- plus-group -----------------------------
    Nstart(St, y + 1, Oldest_Age) = Nstart(St, y + 1, Oldest_Age) + _
    Nstart(St, y, Oldest_Age) * Exp(-F(St, y, Oldest_Age) - M(St, Oldest_Age))
End If
'
End Sub
'
'
```

Sub COMPUTE_EFFORT_AND_ADJUST_F_FOR_ALL_FLEETS (y, Stochastic)

```
`
` --- This routine is called from "MAIN_DYNAMIC_SIMULATION" after the execution of
` ---       PERFORM_THE_VPA   and
` ---       MAKE_ICES_FORECAST_AND_APPLY_HCL
` --- But before the execution of
` ---   SIMULATE_BASIC_STOCK_DYNAMICS_FOR_ONE_YEAR
`
` ---  Two adjustments of Effort are made:
` ---  1) If the effort derived from F(HCR) exceeds the capacity (number of boats times max
number of
` ---      days/year), the effort is reduced accordingly.
'  ---  2) Effort (of each fleet) is adjusted as follows:
` ---       Quota regime: Effort = Maximum effort over stocks
` ---       Effort regime:  Effort = Minimum effort over stocks
` ---        No Regime:    Effort = Capacity
` ---    subsequently, the Fs are recalculated from the adjusted effort-values.
`
For St = 1 To Number_of_Stocks
    '
    F_Max = F(St, y, 1) ' --- find x1 = MAX{F(a)} over age groups ----
    For a = 1 To Number_Of_Age_Groups(St)
         If F_Max < F(St, y, a) Then F_Max = F(St, y, a)
    Next a
    '
         ' ---- FIND (Stock-specific) Effort corresponding to F for  Stock 'St' ----------
    For Fl = 1 To Number_of_Fleets
        If Stochastic Then
            Q_Normal_Factor(St, Fl) = NormalDist(RelSTD_Q(St, y, Fl))
```

```
        Else '
            Q_Normal_Factor(St, Fl) = 1#
        End If
          `
        QR = Q_Ref(St, y, Fl)  `---- Reference Q is an input parameter ------
        Q(St, y, Fl) = QR * Q_Normal_Factor(St, Fl)
                 `
        ' ------------- capacity checked on nominal effort -----------
                  ' ---------------- Relative_F is an input parameter ------------
        Nominal_Effort = F_Max * Relative_F(St, Fl) / QR
        '
        Capacity_Multiplier = 1 `--- intial value of effort reduction factor ----
        '
        If Nominal_Effort > Fleet_Effort_Capacity(y, Fl) Then
           '-------- effort reduction factor to account for capacity -----------
           Capacity_Multiplier = Fleet_Effort_Capacity(y, Fl) / Nominal_Effort
        End If
        '
        Select Case Management_Regime
            Case Quota_Regime
                  '
                  '----------------- Note: Q is stochastic ----------------
                    `------------------- under quota regime ------------------
                Effort_Stock_Days(St, y, Fl) = _
                Capacity_Multiplier * F_Max * Relative_F(St, Fl) / Q(St, y, Fl)
                '
            Case Effort_Regime   ' ------ effort management ---------------
                ' ---- Here the effort is set by managers by a given ------
                ' ---- catchability, Q_Ref, so no stochastic factor -------
                '
                Effort_Stock_Days(St, y, Fl) = Capacity_Multiplier * Nominal_Effort
                '
            Case No_Regime ' ------ NO management -------- No adjustment required ------
         End Select
     Next Fl
Next St
'
' -------------- Find combined EFFORT (not stock-specific) ----------
'
Select Case Management_Regime
    case quota_regime ' ------ management regime = quota regime -------
        '
        ' ------ Here Effort = MAXIMUM effort over stocks -------------
        '
        For Fl = 1 To Number_of_Fleets
            Max_Effort = Effort_Stock_Days(1, y, Fl)
            For St = 2 To Number_of_Stocks
                If Max_Effort < Effort_Stock_Days(St, y, Fl) Then _
                Max_Effort = Effort_Stock_Days(St, y, Fl)
            Next St
            Effort_Days(y, Fl) = Max_Effort
        Next Fl
    case effort_regime  ' ------ management regime = effort regime -------
         `
        ' ------ Here Effort = MINIMUM effort over stocks ------------
        '
        For Fl = 1 To Number_of_Fleets
            Min_Effort = Effort_Stock_Days(1, y, Fl)
            If Number_of_Stocks > 1 Then
                For St = 2 To Number_of_Stocks
                    If Min_Effort > Effort_Stock_Days(St, y, Fl) Then _
                    Min_Effort = Effort_Stock_Days(St, y, Fl)
                Next St
            End If
            Effort_Days(y, Fl) = Min_Effort
        Next Fl
    case no_regime ' ------ management regime = no regime ------------
        '
        '----------------- Same effort all ys (= capacity) --------
        For Fl = 1 To Number_of_Fleets
            Effort_Days(y, Fl) = Fleet_Effort_Capacity(y, Fl)
        Next Fl
End Select
'
'--------- Recalculate all Fs with new combined effort -------------
'
For St = 1 To Number_of_Stocks
```

```
    For a = 1 To Number_Of_Age_Groups(St)
        '
        Sum_F = Zero
        For Fl = 1 To Number_of_Fleets
            '
            '---------------------------- F by fleet -----------
            F_Fleet(St, y, a, Fl) = Effort_Days(y, Fl) * _
            Q(St, y, Fl) * Selection(St, y, a, Fl)
            '
            Sum_F = Sum_F + F_Fleet(St, y, a, Fl)
        Next Fl
        '------------ F summed over fleets ----------
        F(St, y, a) = Sum_F
        '
    Next a
Next St
'
End Sub
```

Sub COMPUTE_DISCARDS_LANDINGS_VALUE_AND_MEANF (y)

```
'
` --- this routine is called from SIMULATE_BASIC_STOCK_DYNAMICS_FOR_ONE_YEAR
`
For Fl = 1 To Number_of_Fleets
    TL = Zero
    TD = Zero
    VAL = Zero
    For a = 1 To Number_Of_Age_Groups(St)
        '
        F_Fleet(St, y, a, Fl) = F(St, y, a) * Relative_F(St, Fl)
        '
        Discard(St, y, a, Fl) = Relative_F(St, Fl) * _
        Catch(St, y, a) * Discard_Ogive(St, y, a, Fl)
        '
        Landings(St, y, a, Fl) = Relative_F(St, Fl) * _
        Catch(St, y, a) * (1# - Discard_Ogive(St, y, a, Fl))
        '
                 ' ------ if quota excedded then the exceed is transferred to discards ---
        X1 = Quota_Exceed_To_Discards(St, y)
        '
        If X1 > 0 Then
            '
            Discard(St, y, a, Fl) = _
            Discard(St, y, a, Fl) + X1 * Landings(St, y, a, Fl)
            '
            Landings(St, y, a, Fl) = (1# - X1) * Landings(St, y, a, Fl)
            '
        End If
        '
        Biom = Landings(St, y, a, Fl) * w(St, y, a)
        TL = TL + Biom
        TD = TD + Discard(St, y, a, Fl) * w(St, y, a)
        '
        VAL = VAL + Biom * Price_Max(St, y, Fl) * Price_Rel_by_Age(St, a, Fl)
    Next a
    Total_Landings(St, y, Fl) = TL
    Total_Discard(St, y, Fl) = TD
    Total_Value(St, y, Fl) = VAL
Next Fl
' -------------------------- Landings (in weight) summed over fleets --------------------
' ---------------------- these are the quantities counted against the TAC ----------------
TL = Zero
TD = Zero
For Fl = 1 To Number_of_Fleets
    TL = TL + Total_Landings(St, y, Fl)
    TD = TD + Total_Discard(St, y, Fl)
Next Fl
Total_TAC_Yield_Landings(St, y) = TL
Total_TAC_Yield_Discards(St, y) = TD
'
' --------- number landed which can be used as input to VPA ------
For a = 1 To Number_Of_Age_Groups(St)
    TL = Zero
    For Fl = 1 To Number_of_Fleets
        TL = TL + Landings(St, y, a, Fl)
    Next Fl
    Landings_VPA_Input(St, y, a) = TL
```

```
Next a
'
'-------------------- compute weighted mean F ----------------------
MF = Zero
WW_Sum = Zero
For a = 1 To Number_Of_Age_Groups(St)
    If (a >= First_age_Mean_F(St)) And (Last_age_Mean_F(St) >= a) Then
        If Mean_F_Weighting(St) = 2 Then
            MF = MF + F(St, y, a) * Nstart(St, y, a)
            WW_Sum = WW_Sum + Nstart(St, y, a)
        Else
            MF = MF + F(St, y, a)
        End If
    End If
Next a
If Mean_F_Weighting(St) = 2 Then
    Mean_F(St, y) = MF / WW_Sum
Else
    Mean_F(St, y) = MF / (Last_age_Mean_F(St) - First_age_Mean_F(St) + 1)
End If
'
End Sub
`
‘
```

Sub PERFORM_THE_VPA (First_VPA_Year,Last_VPA_Year, Stochastic)

```
'
' ------------------------------------- Terminal F,  last data year --------------------
If Stochastic Then
    Terminal_F_Stochastic_Year_Effect = _
    NormalDist(Rel_SD_TerminalF_Year_Effect(St))
Else
    Terminal_F_Stochastic_Year_Effect = 1#
End If
' ---------------------------------------- select input to VPA (Landings or Catch) --------
For Y = 1 To Last_VPA_Year
    For a = 1 To Oldest_Age
        If Landings_Input_To_VPA(St) Then
            VPA_input(Y, a) = Landings_VPA_Input(St, Y, a)
        Else
            VPA_input(Y, a) = Catch(St, Y, a)
        End If
        If (VPA_input(Y, a) <= Zero) Then _
        Call VPA_Input_ERROR(a)
    Next a
Next Y
'
For a = 1 To Oldest_Age
    ' ------------------ age dependent stochastic F-term -----------
    If Stochastic Then
        Terminal_F_Stochastic_Age_Effect = _
        (VPA_Weight_Of_Year_Effect(St) * Terminal_F_Stochastic_Year_Effect + _
        NormalDist(Rel_SD_TerminalF_Age_Effect(St))) / _
        (VPA_Weight_Of_Year_Effect(St) + 1#)
    Else
        Terminal_F_Stochastic_Age_Effect = 1#
    End If
    '
         '-------------------------------------------- F(St, Last_VPA_Year, a) is
predicted in the FORECAST ----
    F6 = F(St, Last_VPA_Year, a) * Terminal_F_Stochastic_Age_Effect
    '
    VPA_F(St, Last_VPA_Year, a) = F6
    Z6 = F6 + M(St, a)
    VPA_Nstart(St, Last_VPA_Year, a) = _
    VPA_input(Last_VPA_Year, a) * Z6 / (1 - Exp(-Z6)) / F6
Next a
`
` --------------------- other years -----------------------------
'
For Y = Last_VPA_Year - 1 To First_VPA_Year Step -1
    '
    '--------- age groups younger than odest age gr.- 1 ----------
    '
    For a = Oldest_Age - 2 To 1 Step -1
        If VPA_input(Y, a) > 0 Then
            VPA_F(St, Y, a) = _
            Solve_For_FVPA(VPA_input(Y, a), _
```

```
            VPA_Nstart(St, Y + 1, a + 1), M(St, a))
        Else
            VPA_F(St, Y, a) = 0#
        End If
        '
        VPA_Nstart(St, Y, a) = _
        VPA_Nstart(St, Y + 1, a + 1) * _
        Exp(VPA_F(St, Y, a) + M(St, a))
    Next a
    '
         '--------------- odest age group - 1 ------------------------
         `  -------- F(+Group) = F(oldest real age group = age1) -----------
         '  -------- F(oldest real age group = age1) = Mean F over the -----
         '  -------- age groups: "age1 - Age_TF, ..., age1" ----------------
    F6 = Zero
    age1 = Oldest_Age - 1   ' --- second oldest age groups (oldest real age group)
    If age1 - Number_Of_VPA_Ages_For_Terminal_F(St) < 1 Then _
    Number_Of_VPA_Ages_For_Terminal_F(St) = age1 - 1
    '
    For a = age1 - Number_Of_VPA_Ages_For_Terminal_F(St) To age1 - 1
        F6 = F6 + VPA_F(St, Y, a)
    Next a
    F6 = F6 / Number_Of_VPA_Ages_For_Terminal_F(St) ' ----- mean F -------
    '
    VPA_F(St, Y, age1) = F6 '---- F(oldest real age group) -----
    Z6 = F6 + M(St, age1)
    '
    VPA_Nstart(St, Y, age1) = VPA_input(Y, age1) * Z6 / (1 - Exp(-Z6)) / F6
         '------------- oldest age group ----------------------------
    VPA_F(St, Y, Oldest_Age) = F6 ' ---- F(+group) ----------------
    Z6 = F6 + M(St, Oldest_Age)
    VPA_Nstart(St, Y, Oldest_Age) = _
    VPA_input(Y, Oldest_Age) * Z6 / (1 - Exp(-Z6)) / F6
Next Y
'------------------------- BIOMASS, SSB AND MEAN F -----------------
' ---- Mean_F_Weighting = 1: Not Weighted
' ---- Mean_F_Weighting = 2: Weighted by stock numbers
For Y = First_VPA_Year To Last_VPA_Year
    TY = Zero
    TB = Zero
    TS = Zero
    MF = Zero
    WW_Sum = Zero
    For a = 1 To Number_Of_Age_Groups(St)
        TY = TY + Catch(St, Y, a) * w(St, Y, a)
        Biom = VPA_Nstart(St, Y, a) * w(St, Y, a)
        TB = TB + Biom
        TS = TS + Biom * Mat_Ogive(St, Y, a)
        If (a >= First_age_Mean_F(St)) And _
        (Last_age_Mean_F(St) >= a) Then
            If Mean_F_Weighting(St) = 2 Then
                MF = MF + VPA_F(St, Y, a) * VPA_Nstart(St, Y, a)
                WW_Sum = WW_Sum + VPA_Nstart(St, Y, a)
            Else
                MF = MF + VPA_F(St, Y, a)
            End If
        End If
    Next a
    VPA_Total_Yield(St, Y) = TY
    VPA_Total_Biom(St, Y) = TB
    VPA_Total_SSB(St, Y) = TS
    If Mean_F_Weighting(St) = 2 Then
        VPA_Mean_F(St, Y) = MF / WW_Sum
    Else
        VPA_Mean_F(St, Y) = MF / _
        (Last_age_Mean_F(St) - First_age_Mean_F(St) + 1)
    End If
Next Y
End Sub
```

Sub MAKE_ICES_FORECAST_AND_APPLY_HCL (First_VPA_Year,Last_VPA_Year)

```
'
'------------- Recruitment = mean VPA recruitment ---------------
'
Recruitment = Zero
For Y = First_VPA_Year To Last_VPA_Year
    Recruitment = Recruitment + VPA_Nstart(St, Y, 1)
```

```
Next Y
Recruitment = Recruitment / (Last_VPA_Year - First_VPA_Year + 1)
'
'------------ same recruitment in all future years ---------------
'
For Y = 1 To Number_of_FOR_Years
    FOR_Nstart(St, Y, 1) = Recruitment
Next Y
'-------------------------- Harvest control rule: -----------------
'
' ----- If SSB > Bpa then F = Fpa.
' ----- If SSB < Blim then F = 0.
' ----- If  Blim < SSB < Bpa, then F = Fpa*(SSB-Blim)/(Bpa-Blim) =
' -----                          = HCR_Intercept + HCR_Slope * SSB
' ----- where
' -----        HCR_Intercept = Fpa*Blim/(Bpa-Blim)
' -----        HCR_Slope     = - Fpa/(Bpa-Blim)
'
SSB1 = VPA_Total_SSB(St, Last_VPA_Year)
'
If SSB1 > Bpa(St) Then
    Fmax_HCR = Fpa(St)
Else
    If SSB1 <= Blim(St) Then
        Fmax_HCR = 0
    Else
        Fmax_HCR = HCR_Intercept(St) + HCR_Slope(St) * SSB1
    End If
End If
' --------- Multiply Fmax_HCR by selection ogive and sum over fleets -----
' --------- Note: Same F both forecast years ----------------------------
'
For Y = 1 To Number_of_FOR_Years
    For a = 1 To Number_Of_Age_Groups(St)
        X1 = Zero
        For Fl = 1 To Number_of_Fleets
            X1 = X1 + Fmax_HCR * Relative_F(St, Fl) * Selection(St, Last_VPA_Year, a, Fl)
        Next Fl
        FOR_F(St, Y, a) = X1
    Next a
Next Y
'-------------- N_start first Forecast year -----------------------------
'
For a = 2 To Oldest_Age
    FOR_Nstart(St,1,a) = VPA_Nstart(St, Last_VPA_Year, a - 1) * _
    Exp(-VPA_F(St, Last_VPA_Year, a - 1) - M(St, a - 1))
Next a
'------------- plus-group ----------------------------------------------
FOR_Nstart(St, 1, Oldest_Age) = _
FOR_Nstart(St, 1, Oldest_Age) + VPA_Nstart(St, Last_VPA_Year, Oldest_Age) * _
Exp(-VPA_F(St, Last_VPA_Year, Oldest_Age) - M(St, Oldest_Age))
'
'---------- N of second and later Forecast years -----------------------
'
For Y = 2 To Number_of_FOR_Years
    For a = 2 To Oldest_Age
        FOR_Nstart(St, Y, a) = _
        FOR_Nstart(St, Y - 1, a - 1) * Exp(-FOR_F(St, Y - 1, a - 1) - M(St, a - 1))
    Next a
         '------------- plus-group ------------------------------------------
    FOR_Nstart(St, 1, Oldest_Age) = FOR_Nstart(St, Y, Oldest_Age) + _
    FOR_Nstart(St, Y - 1, Oldest_Age) * Exp(-VPA_F(St, Y - 1, Oldest_Age) - M(St,
Oldest_Age))
Next Y
'---------------------- compute catch -------------------------------
'
For Y = 1 To Number_of_FOR_Years
    For a = 1 To Oldest_Age
        ZZ = FOR_F(St, Y, a) + M(St, a)
        ExpZ = Exp(-ZZ)
        FOR_Catch(St, Y, a) = FOR_Nstart(St, Y, a) * FOR_F(St, Y, a) * (1 - ExpZ) / ZZ
    Next a
Next Y
' ------------------- compute biomass ------------------------------
'
For Y = 1 To Number_of_FOR_Years
    TY = Zero
```

```
    TB = Zero
    TS = Zero
    For a = 1 To Oldest_Age
        Biom = FOR_Nstart(St, Y, a) * w(St, Y, a)
        TY = TY + FOR_Catch(St, Y, a) * w(St, Y, a)
        TB = TB + Biom
        TS = TS + Biom * Mat_Ogive(St, Y, a)
    Next a
    FOR_Total_Yield(St, Y) = TY
    FOR_Total_Biom(St, Y) = TB
    FOR_Total_SSB(St, Y) = TS
Next Y
' ----------------------- set TAC for next year ----------------------
If Last_VPA_Year + 2 <= Number_of_Years Then _
TAC(St, Last_VPA_Year + 2) = FOR_Total_Yield(St, Number_of_FOR_Years)
'
End Sub
`
```

SUB MAKE_FLEET_ECONOMICS_AND_TOTAL_SUMMED_OVER_STOCKS (Y_Start As Integer, Y_Stop As Integer)

```
'
For Y = Y_Start To Y_Stop
    For Fl = 1 To Number_of_Fleets
        '
        Total_Fleet_Value(Y, Fl) = Zero
        For St = 1 To Number_of_Stocks
            Total_Fleet_Value(Y, Fl) = _
            Total_Fleet_Value(Y, Fl) + Total_Value(St, Y, Fl)
        Next St
        '
        Total_Fleet_Fishing_Costs(Y, Fl) = _
        Effort_Days(Y, Fl) * Var_Fishing_Cost_per_day(Y, Fl)
        '
        Total_Fleet_Catch_Costs(Y, Fl) = _
        Total_Fleet_Value(Y, Fl) * Var_Catch_Cost_per_Money_Unit(Y, Fl)
        '
        Total_Fleet_Fixed_Costs(Y, Fl) = _
        Number_Of_Boats(Y, Fl) * Fixed_Annual_Cost_per_Boat(Y, Fl)
        '
        Total_Fleet_Profit(Y, Fl) = _
        Total_Fleet_Value(Y, Fl) _
        - Total_Fleet_Fishing_Costs(Y, Fl) _
        - Total_Fleet_Catch_Costs(Y, Fl) _
        - Total_Fleet_Fixed_Costs(Y, Fl)
    Next Fl
Next Y
'
For Y = Y_Start To Y_Stop
    Grand_Total_Value(Y) = Zero
    Grand_Total_Fishing_Costs(Y) = Zero
    Grand_Total_Catch_Costs(Y) = Zero
    Grand_Total_Fixed_Costs(Y) = Zero
    Grand_Total_Profit(Y) = Zero
    For Fl = 1 To Number_of_Fleets
        Grand_Total_Value(Y) = _
        Grand_Total_Value(Y) + Total_Fleet_Value(Y, Fl)
        Grand_Total_Fishing_Costs(Y) = _
        Grand_Total_Fishing_Costs(Y) + Total_Fleet_Fishing_Costs(Y, Fl)
        Grand_Total_Catch_Costs(Y) = _
        Grand_Total_Catch_Costs(Y) + Total_Fleet_Catch_Costs(Y, Fl)
        Grand_Total_Fixed_Costs(Y) = _
        Grand_Total_Fixed_Costs(Y) + Total_Fleet_Fixed_Costs(Y, Fl)
        Grand_Total_Profit(Y) = _
        Grand_Total_Profit(Y) + Total_Fleet_Profit(Y, Fl)
    Next Fl
Next Y
'
End Sub
'
```

Sub MAKE_TIME_DISCOUNTED_SUMS_OF_FLEET_ECONOMICS (Y_Start As Integer, Y_Stop As Integer)

```
'
Time_discounted_Grand_Total_Value = Zero
Time_discounted_Grand_Total_Fishing_Costs = Zero
Time_discounted_Grand_Total_Catch_Costs = Zero
```

```
Time_discounted_Grand_Total_Fixed_Costs = Zero
Time_discounted_Grand_Total_Profit = Zero
'
For Fl = 1 To Number_of_Fleets
    Time_discounted_Total_Fleet_Value(Fl) = Zero
    Time_discounted_Total_Fleet_Fishing_Costs(Fl) = Zero
    Time_discounted_Total_Fleet_Catch_Costs(Fl) = Zero
    Time_discounted_Total_Fleet_Fixed_Costs(Fl) = Zero
    Time_discounted_Total_Fleet_Profit(Fl) = Zero
    For St = 1 To Number_of_Stocks
        Time_discounted_Total_Value(St, Fl) = Zero
    Next St
Next Fl
'
For Y = Y_Start To Y_Stop
    Discount_Factor = Exp(-(Y - 1) * Discount_Rate)
    '
    Time_discounted_Grand_Total_Value = Time_discounted_Grand_Total_Value + _
    Grand_Total_Value(Y) * Discount_Factor

    Time_discounted_Grand_Total_Fishing_Costs =
    Time_discounted_Grand_Total_Fishing_Costs + _
    Grand_Total_Fishing_Costs(Y) * Discount_Factor

    Time_discounted_Grand_Total_Catch_Costs = Time_discounted_Grand_Total_Catch_Costs + _
    Grand_Total_Catch_Costs(Y) * Discount_Factor

    Time_discounted_Grand_Total_Fixed_Costs = Time_discounted_Grand_Total_Fixed_Costs + _
    Grand_Total_Fixed_Costs(Y) * Discount_Factor

    Time_discounted_Grand_Total_Profit = Time_discounted_Grand_Total_Profit + _
    Grand_Total_Profit(Y) * Discount_Factor
    '
    For Fl = 1 To Number_of_Fleets
        Time_discounted_Total_Fleet_Value(Fl) = Time_discounted_Total_Fleet_Value(Fl) + _
        Total_Fleet_Value(Y, Fl) * Discount_Factor

        Time_discounted_Total_Fleet_Fishing_Costs(Fl) =
        Time_discounted_Total_Fleet_Fishing_Costs(Fl) + _
        Total_Fleet_Fishing_Costs(Y, Fl) * Discount_Factor

        Time_discounted_Total_Fleet_Catch_Costs(Fl) = _
         Time_discounted_Total_Fleet_Catch_Costs(Fl) + _
        Total_Fleet_Catch_Costs(Y, Fl) * Discount_Factor

        Time_discounted_Total_Fleet_Fixed_Costs(Fl) = _
        Time_discounted_Total_Fleet_Fixed_Costs(Fl) + _
        Total_Fleet_Fixed_Costs(Y, Fl) * Discount_Factor

        Time_discounted_Total_Fleet_Profit(Fl) = Time_discounted_Total_Fleet_Profit(Fl) + _
        Total_Fleet_Profit(Y, Fl) * Discount_Factor

        For St = 1 To Number_of_Stocks
            Time_discounted_Total_Value(St, Fl) = _
            Time_discounted_Total_Value(St, Fl) + _
            Total_Value(St, Y, Fl) * Discount_Factor
        Next St
    Next Fl
Next Y
End Sub
```

Sub MAKE_GROWTH_SELECTION_DISCARD_AND_MATURITY_CURVES (Stochastic As Boolean)

```
'
' ----- Growth is made stochastic through K (curvature parameters) and
' ----- the condition factor (W = Cond.fac* L ^ cond.exp) ------------
' ----- As maturity, gear and discard selection is derived from the
' ----- length at age, these ogives are also stochasticlic drawn
'
For St = 1 To Number_of_Stocks
    ' --------- maturity selection parameters (S1Mat and S2Mat) -----------
    S1Mat = Ln3 * LgtMat50(St) / (LgtMat75(St) - LgtMat50(St))
    S2Mat = -Ln3 / (LgtMat75(St) - LgtMat50(St))
    '
    eps_K = 1# ' ---- stochastic factor for K (Bertalanffy parameter)
    eps_Cond_Fac = 1# ' ---- stochastic factor for condition factor
    '
    For Y = 1 To Number_of_Years
```

```
        For Fl = 1 To Number_of_Fleets
            ' ------------ gear selection parameters (S1 and S2) -----------
            X = (Lgt75(St, Y, Fl) - Lgt50(St, Y, Fl))
            S1(Fl) = Ln3 * Lgt50(St, Y, Fl) / X
            S2(Fl) = -Ln3 / X
            ' ------ Discard selection parameters (DS1 and DS2) -----------
            X = (Dis_Lgt75(St, Y, Fl) - Dis_Lgt50(St, Y, Fl))
            DS1(Fl) = Ln3 * Dis_Lgt50(St, Y, Fl) / X
            DS2(Fl) = -Ln3 / X
        Next Fl
        '
        ' ---------- Draw stochastic term in growth and lgt/w ----------
        ' ------------------- Note: Independet of age ------------------
        If Stochastic Then
            eps_K = NormalDist(Rel_Std_Dev_K_Bert(St))
            eps_Cond_Fac = (eps_K + NormalDist(Rel_Std_Dev_Cond_Fac(St))) * 0.5
        End If
        '
        For a = 1 To Number_Of_Age_Groups(St)
            ' ---------------- body length and weight -------------------
            '
            Stochastic_K_Bert = K_Bert(St) * eps_K
            Stochastic_Cond_Fac = Cond_Fac(St) * eps_Cond_Fac
            ' ------------------- body length -----------------------
            Lgt1 = Loo(St) * (1 - Exp(-Stochastic_K_Bert * (a - 0.5 - t_zero(St))))
            '
            ' ------- correct for possible negative growth ------------
            If Y > 1 Then
                If a > 1 Then
                    If Lgt1 > Lgt(St, Y - 1, a - 1) Then
                        Lgt(St, Y, a) = Lgt1
                    Else
                        Lgt(St, Y, a) = Lgt(St, Y - 1, a - 1)
                        Lgt1 = Lgt(St, Y, a)
                    End If
                Else '------ first age group ----------
                    Lgt(St, Y, 1) = Lgt1
                End If
            Else ' ------------ first year ---------------
                Lgt(St, 1, a) = Lgt1
            End If
            '------------------- body weight -----------------------
            w(St, Y, a) = Stochastic_Cond_Fac * Lgt1 ^ Cond_Exp(St)
            ' ----------------- maturity ogive ---------------------
            Mat_Ogive(St, Y, a) = 1# / (1 + Exp(S1Mat + S2Mat * Lgt1))
            For Fl = 1 To Number_of_Fleets
                ' ---------------- gear selection ogive -------------
                Selection(St, Y, a, Fl) = 1# / (1# + Exp(S1(Fl) + S2(Fl) * Lgt1))
                ' ------------- discard selection ogive -------------
                Discard_Ogive(St, Y, a, Fl) = _
                 1# - 1# / (1# + Exp(DS1(Fl) + DS2(Fl) * Lgt1))
            Next Fl
        Next a
    Next Y
Next St
'
If Not Stochastic Then Call WRITE_OGIVES
End Sub
'
```

Sub MAIN_STOCHASTIC_MULTIPLE_SIMULATION (Management_Regime As Integer)

```
'
Call MAKE_GROWTH_SELECTION_DISCARD_AND_MATURITY_CURVES(True)
Call INITIALIZE_DYNAMIC_SIMULATION_MAIN(True, True)
'
Number_Of_Simulations = _
InputBox("Give number of simulations", "STOCHASTIC SIMULATIONS", 1)
'
' --------------- number of stochatic variables --------------------
Number_of_Variables = 2 + 2 * Number_of_Stocks + 2 * Number_of_Fleets
'
Call WRITE_FIRST_PART_OF_SIMUALTION_RESULTS(Name_Of_Management_Regime)
'
For Stochastic_Iteration = 1 To Number_Of_Simulations
    ' -------------------- Mult_Stoch_Simul, ---------------------------
    ' ------------------------------------ Management_Regime, ---------------
    ' ---------------------------------------------- Draw _Stochastic ----
    Call MAIN_DYNAMIC_SIMULATION(True, Management_Regime, True)
```

```
    '
    Call WRITE_SECOND_PART_OF_SIMUALTION_RESULTS(Stochastic_Iteration)
    '
Next Stochastic_Iteration
'
Call READ_FIRST_TIME_MULTIPLE_SIMULATION_DATA_FROM_DISK(Management_Regime)
Call READ_SECOND_TIME_MULTIPLE_SIMULATION_DATA_FROM_DISK(Management_Regime)
'
Call WRITE_MULTIPLE_STOCHASTIC_OUTPUT_ONE_REGIME_ON_SHEET
'
End Sub
```