Project no. 502289

COMMIT

Creation Of Multiannual Management Plans for Commitment

PRIORITY 8: Scientific Support to Policy (SSP)
Area 1.3 – Modernisation and sustainability of fisheries, including aquaculture-based production systems

Final Publishable Report

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Project coordinator name: Dr Laurence Kell
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PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Contents

Preface

The Final Publishable Report only contains (as specified by the EU Commission) a summary description of the full project and is only meant to briefly describe in non-technical language the: objectives, methods, results and achievements of the project in terms of impacts on the relevant sectors and research community. Therefore all the technical aspects have been excluded, and the full description of each case study, including data, models, numerical analyses have not been presented. This information is available for public use elsewhere after permission from the EU Commission and is presented in the final activity reports and/or the peer reviewed papers as outputs of this project (see Dissemination). Note: The Policy Implementation Plan as required for this project is incorporated within section 1.6 (Impact on Sectors and Research Community).

1. Project Execution

1.1 Executive Summary

The COMMIT project has made an unique contribution to fisheries management in the EU is its role in developing multi-annual management plans that explicitly take into account uncertainty about stock dynamics and the role of compliance and commitment to management regulations.

A fundamental aspect of fisheries management is to link the level of utilisation of a resource to the level of uncertainty about the system (i.e. a positive relationship between information and utilisation, so that the value of information to the fishery is positive). In this way actions that reduce uncertainty (e.g. compliance or increased scientific knowledge) will be rewarded with increased economic return. This will help managers to move away from short-term reactive management to more stable multi-annual management.

This contrasts with the conventional approach in which, in the face of the lack of information, the tendency has been not to limit harvest levels until there is sufficient information to indicate the need for such limits where information has a negative value to the fishery in the short term.

The method applied in this project requires management options to be related to management outcomes and specifically to determine how knowledge about the system and our ability to influence inputs affect outcomes such as yield per stock and sustainability.

To do this requires a rigorous treatment of uncertainty and in this project Bayesian Belief Networks (BBNs) have been used to design experimental treatments, run within the (Fisheries Libraries in R) FLR simulation framework. In this way it has been possible to integrate the probabilities of alternative uncertain outcomes (across disciplines: biological, social and economic) and to identify what elements the multi-annual management plans should contain if they are to be robust to uncertainty about system dynamics.

Three key case studies were considered representing range of fisheries in complexity and diversity of interests: North Sea Flatfish (sole and plaice), Northern Hake and Baltic Salmon. For each case study BBNs have been formulated to synthesis the results for each case study.

In the **North Sea Flatfish** case study special attention was given to the effects of effort reductions on catchability through optimisation behaviour of fishermen. The newly developed bio-economic model for the flat fish fishery in the North Sea had a direct impact on the management process, through the STECF meetings including stakeholder feedback (RAC) and advice on the flatfish multi-annual management plan in 2006 and 2007. The contradiction in the results from the COMMIT/EFIMAS model with the traditionally used EIAA model raised the issue of uncertainty in the economic outcomes of the models. Initially this highlighted the uncertainty in the model outcomes, but using the methodology developed in COMMIT, this will lead to more robust management options in the mid- and long-term.

For **Northern Hake**, the recovery plan (a multi-annual management plan) was tested within a Management Strategy Evaluation framework. The uncertainties in the biological factors (that is: the recruitment dynamics; growth, assumptions and natural mortality, cannibalism) were evaluated. However, the proposed multi-annual management plans and Harvest Control Rule (HCR) were found to be robust to alternative hypotheses as to these uncertainties associated in these biological factors.

The methodology developed in COMMIT has also been directly applied to the current advice of ICES in terms of the multi-annual management of **Baltic salmon**. Baltic salmon is the only ICES stock, for which the Bayesian approach provides the methodological background. Both the operational aims of the management, as well as the state of the stocks is given in probabilities, and thereafter it is the role of the managers to conclude, what the uncertainties mean from the management point of view.

The simulation models for the case studies are implemented within the generic FLR software framework. The framework is available at http://flr-project.org and as well as contributing to the core framework (FLCore), COMMIT has also contributed to the development of the Bayesian assessment package (FLBayes), as well as more recently the development of the economic component of the bio-economic operating model (FLEcon). Furthermore, an interactive COMMIT website was set up at: http://commit-fish.info. It allowed participants in the project to undertake project work and to share documents, data and code.

In addition, progress has been made with alternative methods to condition the models on data, the methodology associated with studies on commitment (and compliance modelling) and studies on negotiation with stakeholders. A chapter on management procedures was published as a chapter in a book (in partnership with the EFIMAS project). This Chapter is an extensive review of management procedures, including partial cataloguing of recent studies reviewing management procedures. The review provides a detailed account of what management procedures are, including a summary of their historical development. This is important as it indicates the context of their use by scientists and the utility of the approach

The uptake of the outputs by sectors and EU Commission management bodies (such as the STECF) for immediate policy advice for the long-term management of fish stocks has been considerable. Both the North Sea Flatfish and Northern Hake case studies have contributed significantly to STECF sub-group meetings during 2006/2007 both of which considered a detailed analysis of multi-annual management plans for these stocks.

1.2 Objectives

The objective of COMMIT was to provide a sound scientific basis for the long-term planning of fisheries management consistent with sustainable development, while also identifying any short-term biological and socio-economic consequences.

This was undertaken through the evaluation of multi-annual management plans that reduce annual fluctuations in exploitation strategy and ensure commitment of the stakeholders to the management plans when proposed.

Alternative strategies are based upon harvest control rules that are developed explicitly to recognise uncertainty due to process, measurement, estimation, model and implementation error. In particular socio-economic factors are identified that affect the commitment of key stakeholders and hence the level of implementation error. Robust strategies are designed that explicitly take this into account.

The stocks chosen are those of interest to the Community (Baltic Salmon, North Sea flatfish and Northern Hake) and in particularly those exploited in mixed fisheries, although the methods developed are generic and applicable to other stocks.

The development of multi-annual management plans requires us to move away from reactive ad-hoc short-term management which limits the ability to plan for the future and instead to develop long-term management objectives and plans. A key part of this must be to ensure that lack of information or our ability to implement management is explicitly taken into account in management, as consistent with the precautionary approach (FAO 1996).

This can be achieved if management strategies are tuned so that the level of utilisation of a stock depends upon the “risk of depletion” (see Figure 1 where utilisation (mean total catch) is related to information level (i.e. $1/[CV]^2$ of abundance estimates)).

This means that when the available information is low (i.e. uncertainty about stock size is greater) the TACs are low. However, as more information becomes available utilisation can be higher. Essentially there is a positive relationship between information and utilisation, so that the value of information to the fishery is positive. This is in contrast to the current approach, which tends not to limit harvest levels until there is sufficient information to indicate the limits. In this way we can provide a better basis for planning by the fishing industry and managers and for scientist to pursue long-term research aimed at resolving key uncertainties.

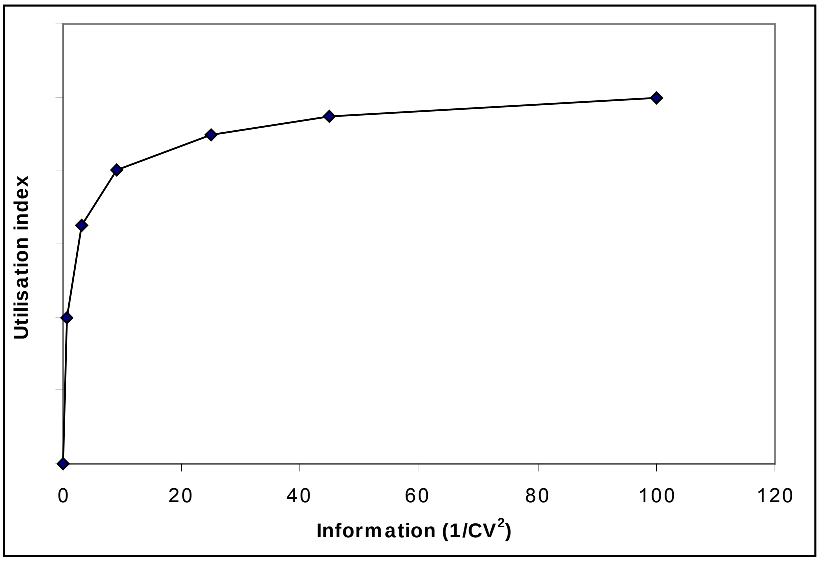


Figure 1. Relationship between an utilisation index (mean total catch) and information level ($1/[CV]^2$ of abundance estimates) for an MP, where each point along the curve represents roughly the same "risk of depletion". [Adapted from Cooke 1999.]

Bayesian Belief Nets (BBNs) are an important part of COMMIT because they allow us to link the value of information and control (e.g. alternative management options) as mentioned above. They also allow one to evaluate management objectives by integrating results from our stochastic simulation models representing alternative plausible hypothesis about the system to be managed. Thereby allowing the robustness of alternative management rules (e.g. Harvest Control Rules [HCRs], data collection regimes or other choices on how to manage the system) to be evaluated using probability distributions of variables of interest (e.g. short-, medium- and long-term yield/profit, variability in yield/profit and risk to the stock).

It also allows for improvements in our knowledge about the dynamics of the system, in the quality of data and the implementation of alternative management strategies to be quantified.

In BBNs, management objectives are represented as utility functions (which weight variables of interest representing the management objectives, e.g. risk to stock, profit, employment opportunities) enabling a systematic comparison of decision alternatives. For example, to ascertain whether better knowledge of some of the uncertain variables would lead to different management decisions or whether different management decisions would require a different understanding of the system to be made.

If the value of a decision is changed on the basis of improved knowledge of a variable, then such a variable has some value-of-information, i.e. further studies of that variable may be economically justified. Likewise with respect to control of the system, if the probabilistic dependency between a decision and a variable of interest is low then the value of information is low since any new information cannot be translated into the a positive increase in the utility function (e.g. increased profits).

One key question may be, with respect to value-of-information, is it more important to know the maximum sustainable yield (MSY) or to have perfect implementation of management? While, with respect to value-of-control, it may be more important to control the total allowable catch (TACs) or the number of fishermen. The answer will depend upon the management objectives but also the dynamics of the stocks and fleets and the implicit management procedure (i.e. the set of rules used to determine management actions including the data, assessment methods) since some management tools (i.e. control variables) may be more sensitive to some sources of uncertainty about the system than others.

Management objectives should also include social as well as economic and biological factors. For example, if management is to be achieved by controlling effort, then the same biological effect could be achieved by either reductions in fleet size or days at sea but socio-economic consequences would be very different. This can be evaluated through the use of alterative utility functions (defined functions that include and weight the variables of interest), which will enable a systematic comparison of decision alternatives, and the estimation of value-of-information.

This concept is related to whether a better knowledge of some of the uncertain variables would lead to different decisions. If a decision will be changed on the basis of a new and better estimate, that variable has potentially some value of information, i.e. the further studies of that variable may be economically justified. This is also related to the control possibilities of the system, i.e. to the probabilistic dependency between the decision node and the interest variable (which could be termed “controllability of the system”).

If this dependency is low (uncontrollable variables dominate in the uncertainties), value of information is also low, because reaction to new information through the decision variables cannot be transferred e.g. to higher profits. The option of simulating perfect information in simulation models (using the “true state” values as assessment values) may be implemented as the maximum level of knowledge, even though never achieved. The intention is also to use perfect information (i.e. using the “true state” values as assessment values) and perfect implementation (100% compliance with management regulations) as a control (i.e. the base case) to represent the maximum level of knowledge against which alternatives can be compared.

The advantages of multi-annual management are (i) to provide the industry with longer-term perspective, (ii) to remove the stress and political upheaval linked with short-term management decisions to long-term strategic choices, (iii) to manage more explicitly the long-term risks. Furthermore, multi-annual strategies do not imply major changes in data requirements, but would give more time for focused in-depths analysis of some aspects of the biological and ecological processes, which are often largely ignored in the current annual advice.

Multi-annual strategies could be either specified by setting fixed management rules for a given period of time, or be specified as adaptive approaches where effort is empirically and progressively reduced until the desired responses are observed. Criteria of expected suitability will be inspired from the literature about recovery plans (Powers 2003, Caddy and Agnew 2004), which is a specific form of multi-annual management plan, and whose criteria can be applied to any “rebuilt” stock given the weak frontier existing between recovering and recovered stocks in most groundfish fisheries. The primary set of criteria deals with the socio-economic context of the fishery, i.e. the level of heterogeneity and overcapacity of the fleets and the expected commitment from the industry (cf. Haapasaari *et al*., 2007). The second set of criteria deals with the biological sustainability of the stocks involved, given the importance of stock structure and large year classes for the stability of the stocks.

With all of the above mentioned setting the context, the main objectives of COMMIT are to provide the basis for the long-term planning of fisheries management consistent with sustainable development though the use of multi-annual management plans evaluated using a combination of Management Strategy Evaluation and novel methods such as Bayesian Belief Networks.

1.3 Contractors

The list of participant institutes is listed including a reference to their status as Principal or Assistant Contractors.

- Centre for Environment, Fisheries & Aquaculture Science (CEFAS) - Principal Contractor and Project Coordinator
- Instituto Tecnológico Pesquero y Alimentario (AZTI) - Principal Contractor
- Centre for the Economics and Management of Aquatic Resources (CEMARE) - Principal Contractor
- Danish Institute for Fisheries Research (DIFRES) - Principal Contractor
- Estonian Marine Institute (EMI) - Assistant Contractor
- Finnish Game and Fisheries Research Institute (FGFRI) - Principal Contractor
- Fisheries Research Services (FRS) - Assistant Contractor
- Imperial College of Science, Technology and Medicine (Imperial) – Principal Contractor
- Instituto de Investigação das Pescas e do Mar (IPIMAR) - Assistant Contractor
- Agricultural Economics Research Institute (LEI) – Principal Contractor
- Institute for Marine Resources and Ecosystem Studies (IMARES) – Principal Contractor

The contribution made by each contractor is shown the outline of the project management structure (Figure 2).

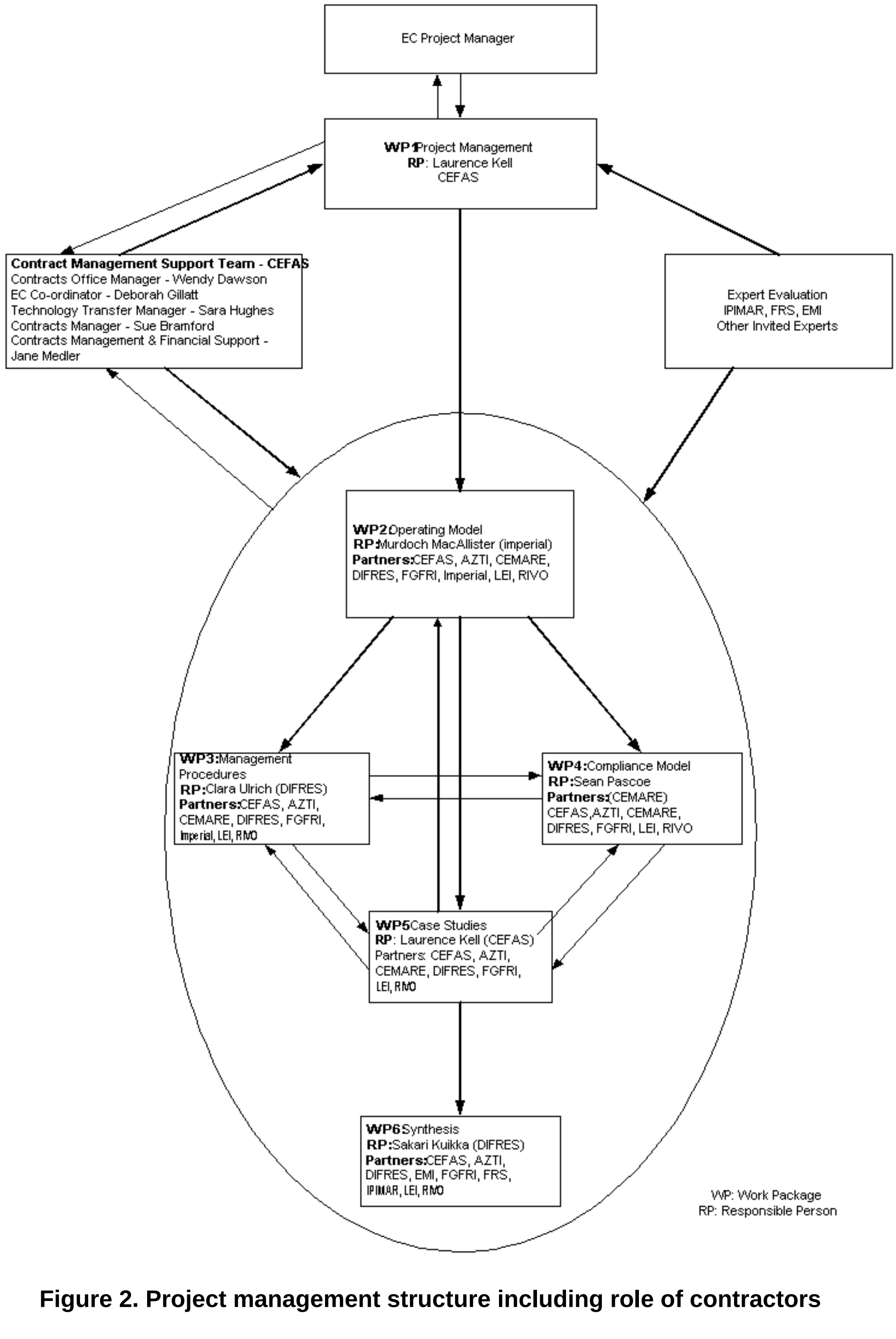


Figure 2. Project management structure including role of contractors

1.4 *Methods and Approaches*

1.4.1 Management Strategy Evaluation: the Framework

The intention was to develop simulation models in order to select management procedures that were robust to uncertainties about the dynamics of the system within which they are applied.

These have been developed explicitly recognising uncertainty due to *process error* (i.e. natural variation in dynamic processes such as recruitment, somatic growth, natural mortality), *measurement error* (generated when collecting observations from a population), *estimation error* that arises from trying to model the dynamic process (during the assessment process), *model error* (since the model used in the assessment procedure will never capture the true complexity and properties of the dynamics) and *implementation error* (since management actions are never implemented perfectly).

It is therefore possible to investigate the robustness of candidate management strategies variability in natural systems and our ability to understand, monitor and control them. This permits the selection of management strategies that are robust to uncertainties in the dynamics of the system within which they are to be applied.

The best management procedures for application tend to be ones that are fairly simple relative to the actual high degree of complexity in real world situations. The simulation models are therefore be used as part of a rigorous procedure against which the performance of alternative "simple" models that could be applied in practice are tested against the underlying “operating models” that represent the best available understanding of the actual system dynamics.

This approach has been applied in the IWC (1992) to test the potential future performance of alterative proposals for new whaling management procedures and in many other instances also (McAllister *et al*. 1999). The operating models developed in this project include biological and fleet models, a fishery model that synthesize the former two and observation error models (see Figure 3).

Simulation modelling provides the best approach available to evaluate and help identify multi-annual management plans for setting targets for the stocks concerned and harvesting rules (IWC 1992; Pelletier and Laurec 1992; Restrepo *et al.* 1992; Marchal, 1997; Kell *et al*. 1999; McAllister *et al.* 1999).

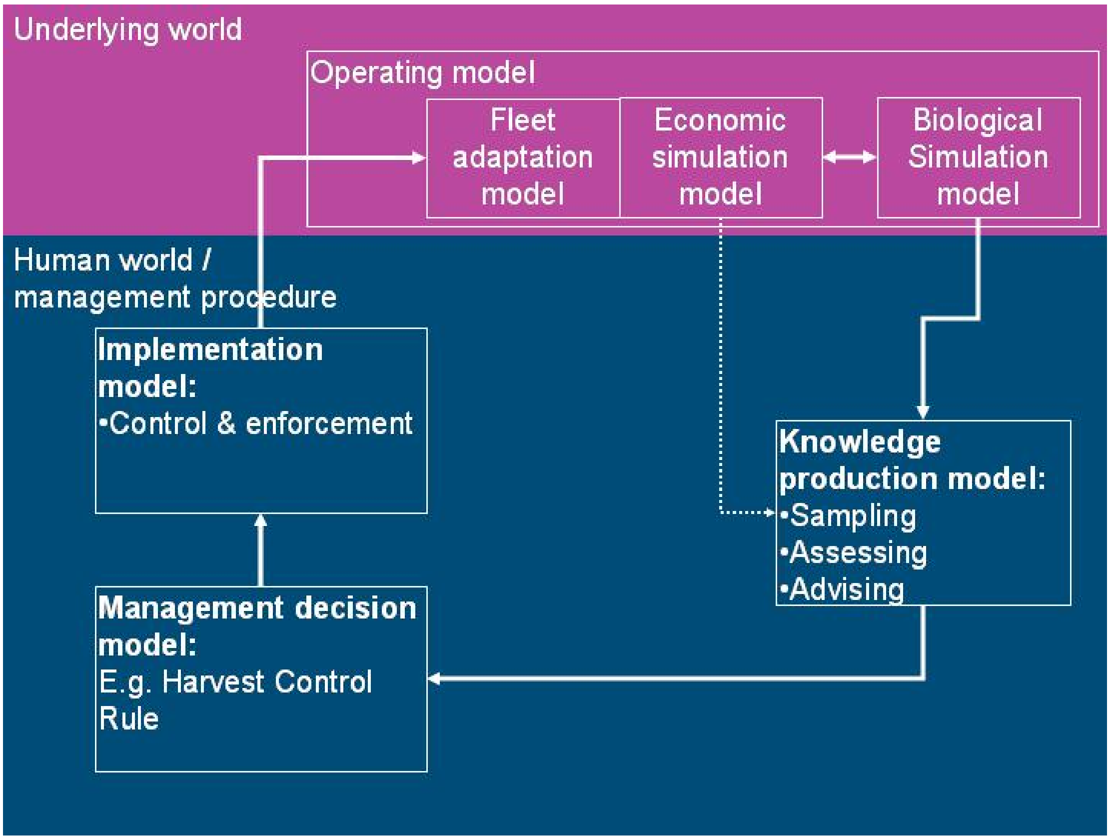


Figure 3. A conceptual diagram of the structure of the evaluation framework.

As mentioned this involves the creation of "operating models" which simulate the underlying system and then testing the consequences of alternative management actions. These simulations provide quantitative advice to fishery managers and stakeholders about the consequences of alternative fishery management processes that could be adopted. A variety of technically and conceptually different modelling approaches have emerged (Bergh and Butterworth 1987; Restrepo *et al.* 1992; McAllister *et al.* 1994; Starr *et al.* 1997; Marchal, 1997; Cooke 1999; Geromont *et al.* 1999; Kell *et al.* 1999; Ulrich *et al.* 2002).

The most suitable modelling approach to take for a given situation depends on the type of fishery (e.g., single or multi-fleet), the characteristics of the fish harvested (e.g., single or multi-stock, extent of seasonal and life history migrations), data and information available about the particular system, and existing management system (for a developing fishery vs. chronically over-fished and heavily regulated fishery).

Because mixed stock fisheries are of particular interest in the proposed research, mixed stock modelling approaches are appropriate (Punt 1993; Gillis *et al.* 1995; Cunningham 2002; Ulrich *et al.* 2002). These typically include age-structured population dynamics models with fleets that capture at least two different fish stocks (Punt 1993; Marchal, 1997; Cunningham 2002; Ulrich *et al*. 2002). Where fish stocks are migratory, the population dynamics models have been spatially structured with age-dependent and in some instances age-, and season-dependent movement vectors (Apostolaki *et al.* 2002; Cunningham 2002). Models of the capture process have been most often deterministic and very simple with either the same or different catchability and fishery selectivity functions for each stock in each area over given periods of time (Apostolaki *et al*. 2002; Cunningham 2002). However, in other instances, dynamics models for catchability for each stock by each fleet have been modelled to be functions of annual investment and changes in technology (Ulrich *et al.* 2002). In yet other instances, fleet dynamics have been likened to optimal foraging theory and the Ideal Free Distribution theory to account for potential fleet responses to new fisheries regulations (Gillis *et al*. 1995).

The approaches used to parameterise mixed stock models are also varied. Methods to parameterise the operating models typically ensure that the historic trends in stock biomass and fishing mortality rates implied by the operating model are consistent with the most recent stock assessments (Ulrich *et al.* 2002).

The methods for parameter estimation of operating models include maximum likelihood estimation, VPA methods with tuning to effort data and biomass indices, and Bayesian estimation methods and the models are commonly fitted to catch-age data, commercial catch rate data, and biomass indices (Punt 1993; McAllister and Ianelli 1997; Ulrich *et al.* 2002, Kell *et al.* 2003b). In spatially structured models, the movement vectors have been parameterised using expert judgment from a comprehensive knowledge of seasonal fleet movements tag returns (Cunningham 2002) and mark-recapture estimation methods (Punt *et al*. 2000; ICES 2002).

Methods to account for parameter uncertainty and structural uncertainty in population dynamics model formulation vary considerably among modelling approaches. Commonly applied methods to account for parameter uncertainty include bootstrapping and Bayesian methods (Restrepo *et al.* 1992; Punt and Hilborn 1997).

In the last decade, the Bayesian statistical approach is more frequently becoming the method of choice (Bergh and Butterworth 1987; McAllister *et al*. 1994; Punt and Hilborn 1997; Meyer and Millar 1999). This is partly due to its conceptual appeal, for example, the ability to assign and calculate probabilities to alternative hypotheses to reflect their relative credibility, the formalized methods offered for decision making under uncertainty (Kuikka *et al.* 1999), and the rapid growth in new computational methods to do the probability and data analysis calculations (e.g., Meyer and Millar 1999; Parma 2002).

Methods to take into account structural uncertainty in simulation modelling evaluations include scenario-based modelling where alternative operating model forms are developed based on alternative scenarios for historic and future fish and fleet population dynamics (IWC 1992). The management procedures of choice are those that are found to be robust to these structural uncertainties and provide acceptable performance with regards to agreed management target and limit reference points. A second approach goes further to assign probabilities or weights to the alternative scenarios based on their scientific credibility (Butterworth *et al.* 1993). Thus, some of the scenarios might be down-weighted for the purpose of management procedure evaluation if they are deemed to be less credible than the other scenarios.

This can help to facilitate the choice of management procedures that are robust to the most credible forms of uncertainty. A third approach is to compute Bayesian posterior probabilities for each alternative structural model, given the available data (Patterson 1999; McAllister and Kirchner 2002; Parma 2002). This is the most formal approach for taking into account structural uncertainty because it evaluates the overall goodness of fit of each operating model alternative to the available data. It also has the most stringent data requirements because the data available must be sufficiently informative to enable model discrimination.

Methods to analyse simulation results also vary considerably among applications. In most instances it involves comparisons of key indices of policy performance against various management objectives for each of the management policies evaluated. It also involves the comparison of the procedures against each other with respect to key indicators of performance. State of the art methods to facilitate the evaluation of fisheries management procedure simulation evaluation output include the production of decision tables (e.g., Punt and Hilborn 1997) and influence diagram modelling (Kuikka *et al.* 1999, that is BBNs.

In Europe, several multi-annual management systems based upon Harvest Control Rules (HCRs) have been implemented. These are for Icelandic cod, North Sea herring and Norwegian Spring Spawning Herring. Recent EU research calls to evaluate multi-annual management strategies (MATES 2003 and MATACS 2002) looked at alternative TAC management systems for a variety of demersal species where TACs were only allowed to fluctuate within specified limits.

The methodology developed within these two contracts, was further developed with the FEMS project. In one of the most recent published works, Ulrich *et al.* (2002) evaluated the influence of trends in fishing power on bio-economics in the North Sea flatfish fishery that could be regulated by either TACS or total annual effort quotas.

The research project has extended the state-of-the-art of the scientific basis for multi-annual management strategies in European mixed-stock fisheries by further developing the software that is used to undertake MSE, specify and parameterise bio-economic operating models and use BBNs in order to evaluate uncertainty within and across case studies.

1.4.2 Software development (FLR)

FLR is a generic software framework for fisheries modelling and the evaluation of management strategies. The framework allows the creation of simulation models, which can be conditioned on a range of stock and fleet assumptions, through which current and alternative management strategies can be evaluated.

The framework is able to explicitly include a variety of process and model uncertainty with respect to knowledge of the dynamics of fisheries systems, their response to management and our ability to monitor, assess and control them. This enables the development of advice that is robust to these sources of uncertainty. Currently the framework is being used to develop bio-economic models, multi-annual management plans and fishery independent assessment methods within a variety of EU Projects; however the COMMIT project has contributed significantly to FLR's development of late.

The FLR framework is implemented using object-oriented programming (OOP) by making use of the S4 classes within R. The essence of OOP is to treat data, and the procedures that act upon the data, as a single "object". These objects are of particular types, or classes, that have been developed to best represent the different elements of the system. Using this approach, different elements of fisheries systems (stocks, fleets, assessment methods etc.) are represented as predefined classes. Users do not need to know the internal structure of a class to be able to effectively use FLR. An important feature of OOP is the ability to form a new class by bundling together a collection of other classes. This approach is used extensively within FLR and it allows complicated classes to be easily built from simpler classes.

The FLR framework comprises a set of core classes and a collection of secondary packages that contain additional classes. As mentioned, the core classes represent the basic objects of fisheries systems (e.g. stocks, fleets and indices) and are contained in a single R package: *FLCore*. Secondary packages are created for specific tasks, e.g. different stock assessment methods, and use the core classes as a common interface. One is able to thus link these though a series of simple commands and undertake for any given case study a Management Strategy Evaluation.

Figure 4 represent the FLR packages and classes that comprise the elements of a full feedback Management Strategy Evaluation (MSE) (essentially the same components that are conceptually represented in Figure 3 [see above]). Figure 4 should strictly be presented in the results section as it represents progress made in this project as many of the components we either developed or further developed in this project.

Although the vast majority of programming of the FLR framework is in R, for the sake of computer speed it is necessary for some classes to have additional code written in another language. For example, solving the nonlinear equations in *FLHCR* is computationally intensive and so fast routines have been written in C++ which are then called from R. Even when classes have additional code that is written in languages other than R, R is still the front end of the FLR framework and the user is unaware of the use of other languages.

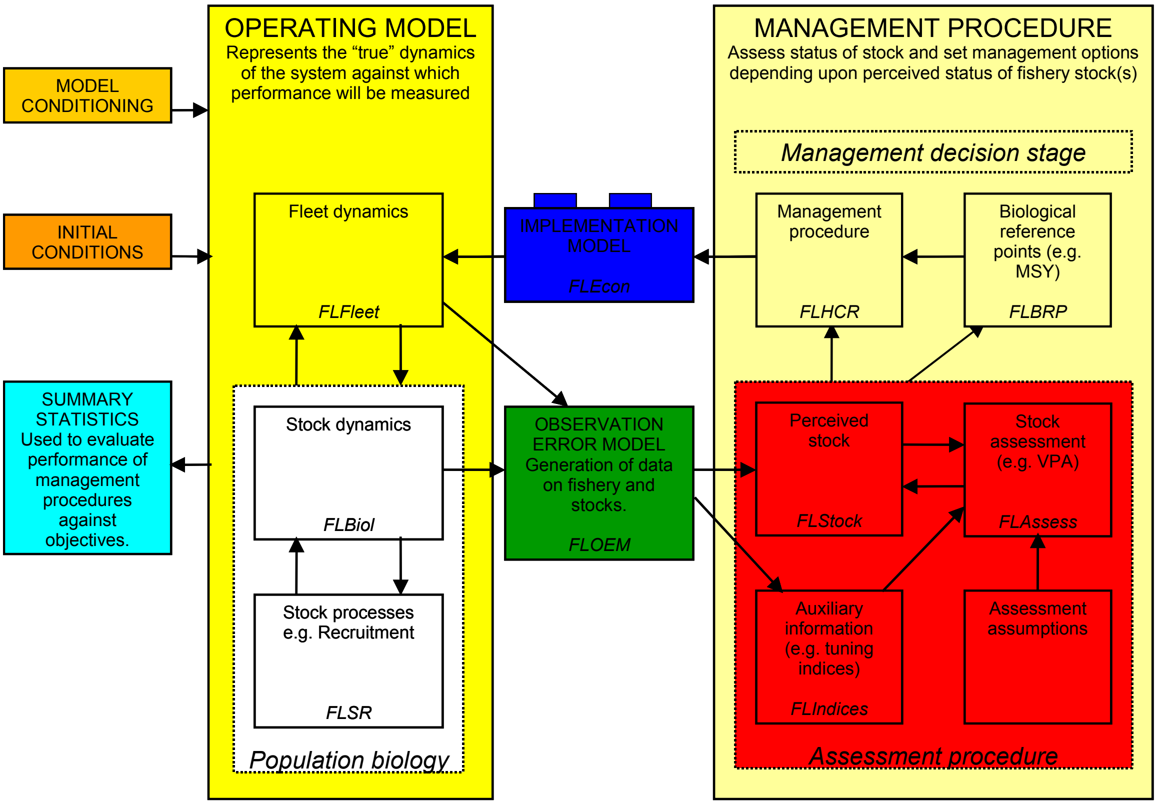


Figure 4. The FLR components that represent the elements required for the full-feed-back Management Strategy Evaluation framework.

To summarise, FLR allows one to numerically represent the complex systems this project was set out to evaluate and undertake Management Strategy Evaluation a key tool for the assessment of multi-annual management plans.

1.4.3 Application to Case studies

A range of case studies (stocks and fisheries) were chosen, in order to apply the methodology applied and further developed within the COMMIT project. The stocks are those of interest to the Community (Baltic Salmon, North Sea flatfish and Northern Hake) and in particularly those exploited in mixed fisheries, although the methods developed are generic and applicable to other stocks.

Within each case study, for each stock there is a specific combination of data, parameters and models, which embodies the best available information or understanding of that stock (e.g. the current assessment), this combination is referred to as the "base case" assessment (or null hypothesis) because it helps form a bench mark or null hypothesis against which alternative strategies or hypotheses about the system can be compared.

In terms of the presentation of case studies, the same format is followed. Firstly, the management objectives and potential utility functions are presented. Secondly, the main sources of uncertainty are presented along with the Robustness Trials to be evaluated. These are presented before or after the Bayesian Belief Networks depending on the process, as the specification of the Robustness Trials and formulation of the BBN is iterative and interactive. There is a constant feedback between the two in order to best formulate the BBNs and the Robustness Trials to be evaluated.

Lastly, for each case study there is a review of the progress made with integrating the economic and biological models, the conditioning of the operating model (based on the research in this project) and progress made with implementation in FLR. This information is available in the technical reports published as well as the peer-reviewed papers. A summary of each case study is provided below in order to provide background to readers less familiar with the stocks and fisheries within each specific case study.

1.4.3.1 Baltic Salmon:

The migratory and multi-genetic stock nature (including uncertainty over stock composition) of Baltic Salmon, plus the wide distribution of the stock means that many fleets and nations can capture fish from a single breeding population. These are general features of highly migratory and widely distributed species and therefore Baltic Salmon makes an ideal case study to ensure that the methods developed for multi-annual management strategies are applicable to a wide range of stock and fishery types.

The main problem within the salmon case study is to find management strategies, which are robust enough to assessment error and in particular the short life cycle of salmon. Especially since the total production of Baltic salmon is variable due to changes in growth rate and post smolt survival. However, it is not possible to create a buffer for the stock, as the salmon migrate to the coast when they mature, and migrate back up their natal rivers if they are not fished. In the terminal data year, the first age group, which has enough data is 1 year old salmon, which are 3 year old salmon in the TAC target year. There is very limited data for the most important spawning age group of the target year, i.e. 2-year old fish. Therefore, there is a need to identify such management elements, which decrease the need for accurate stock prediction.

Management consists of either technical measures in the coast fisheries or TACs in the offshore fishery. Coastal technical measures are not made on the basis of the yearly stock predictions, it is important to modify the time limits so, that there is high probability to get enough salmon to rivers, taking into account the uncertainty in run timing, stock size and the severity of M74 disease outbreaks.

The current advice can be remarkably improved by creating such strategic management options, which include the human behaviour as one element. If the uncertainty caused by human element can be decreased, this will also have an impact on reference points and therefore in the catch limits.

1.4.3.2 North Sea Flatfish:

Many aspects of the flatfish fishery are generic to groundfish fisheries and the projects emphasises the development of management control measures for use in a complex spatially and temporally structured system, where significant bycatch is taken and quota management currently results in substantial discarding.

North Sea flatfish are mainly taken in a mixed demersal flatfish fishery by beam trawlers in the southern and south-eastern North Sea. Although plaice and sole are the main targets in the mixed flatfish fishery, important by-catches are often taken of other flatfish species (e.g. dab, turbot, brill) and some roundfish species (cod, whiting). Directed fisheries for flatfish are also carried out with seine and gill net, and by beam trawlers in the central North Sea.

One of the main problems in the management of the North Sea flatfish fisheries can be characterized as single species TACs are problematic in a mixed-species context because of over-quota discarding and intensive control requirements.

The different flatfish species have very different selection characteristics and also very different economic values and exhibit strong seasonal migrations which have been studied extensively. Growth can change substantially over years and can in turn affect both spatial and seasonal distribution patterns and discard patterns.

In addition the large amount of economic data available and the economic properties of the fishery make it an ideal case study for multi-annual management. The fishery is of high value, accounting for approximately 40% of this the total value of landings in the North Sea (approximately €976 million in 2001). The high unit values (i.e. prices) of the main species, particularly sole, provide incentives for non-compliance. In addition many high quality socio- and economics fleet data are available and the dynamics of fleets has been already widely investigated.

1.4.3.3 Northern Hake:

Northern Hake stock is one of the most important target species for European fishing fleets whose harvest involves a large number of vessels from several European countries. The Hake fishery is an important fishery to Spain, France, UK and Ireland. In 2003 the value of the Hake TAC was estimated to be greater than £90 million. According to ICES data (ICES, 2002) five main countries contributed to 98 % of Northern Hake landings in 2002: Spain (61%), France (26%), United Kingdom (6 %), Denmark (3%) and Ireland (2%).

Northern hake is caught in a mixed fishery by a number of different gears throughout its distribution. Other species caught in the mixed-fisheries are Megrim, Monkfish, Blue whiting, Horse mackerel, and yet other species at present without TAC and quotas constrictions, which are in economic terms certainly important resources, and even more, key-species for some fleets.

The main objective is to identify elements of multi-annual management strategies that assure a level of compliance of all fishery actors and maintain sustainability of the stocks. This approach requires of multidisciplinary knowledge about biology of the main species exploited, fleets characteristics, fisheries systems, economic data (revenues and costs) involved in exploiting Northern Hake.

Uncertainties in the biological and technical parameters and structure of the operating models developed and appropriate limit and target reference points and models for discarding behaviour are formulated in developing operating models and multi-annual management procedures for the hake fishery. The long-term potential impacts of the mixed fishery on some key bycatch species is evaluated to identify sustainable multi-annual fisheries management methods for this fishery.

The focus of the research is on the current levels of compliance of fishing fleets with fisheries regulations, the various incentives and factors influencing compliance, the impacts of future new management methods on compliance, and the levels of compliance required for the management methods to work successfully in the long-term.

As noted in the preface, this format of this report as dictated by the EU Commission, is to provide a summary description of the full project and is only meant to briefly describe in non-technical language the: objectives, methods, results and achievements of the project in terms of impacts on the relevant sectors and research community. Therefore all the technical aspects of the case studies have been excluded, and the full description of each case study, including al the data, models, and numerical analyses have not been presented.

1.4.4 Bayesian Belief Networks

One of the major analytic tools in this project that was applied to the case studies were Bayesian influence diagrams, which utilize probabilistic information and enable a smooth modification of model structure, aims, and management tools.

A Bayesian belief network is essentially a probabilistic graphical model that represents a set of variables and their probabilistic independencies, and this case the variables (as nodes) can either represent some *change* in a component of the system, a decision or a utility (see Figure 5 for a simplistic conceptual diagram of a BBN).

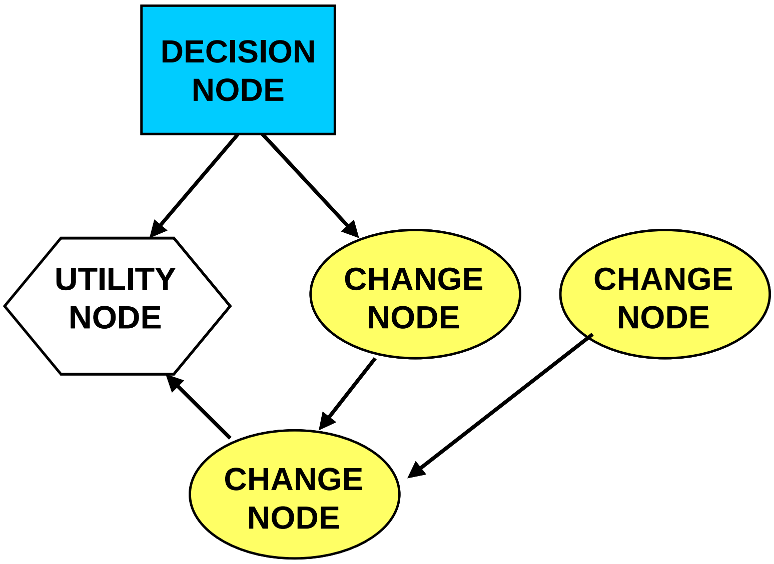


Figure 5. A simplistic conceptual diagram of a BBN

Bayesian Belief Nets (BBNs) allow us to evaluate management objectives by integrating results from our stochastic simulation models representing alternative plausible hypothesis about the system to be managed.

These allow the robustness of alternative management rules (e.g. Harvest Control Rules [HCRs], data collection regimes or other choices on how to manage the system) to be evaluated using probability distributions of variables of interest (e.g. short-, medium- and long-term yield/profit, variability in yield/profit and risk to the stock).

In BBNs, management objectives are represented as utility functions (which weight variables of interest representing the management objectives, e.g. risk to stock, profit, employment opportunities) enabling a systematic comparison of decision alternatives.

All of this work is on strategic level, whereas the yearly reactions are modelled on tactical level by the simulation modelling (see e.g. Kuikka *et al.* 1999 for the techniques). BBNs can be used as decision analysis tools, i.e. to maximize the value of objective function, and estimation of value-of-information and value-of-control, which are important tools in fisheries planning.

Value-of-information is an estimate to decide, which parts of the problem should be known more precisely, and value-of-control is the additional value of starting to use some random variable (like number of fishermen, or cost structure) as a partly controllable variable (licenses, taxes) with a certain degree of success.

The main objectives of COMMIT was to evaluate multi-annual management plans using a combination of Management Strategy Evaluation (MSE) and novel methods such as the Bayesian Belief Networks.

1.5 Results and Achievements

1.5.1 Method development: the framework and software

The further extension of the MSE framework to include bio-economic operating models was a major achievement in the COMMIT project, along with the use of Bayesian Belief Networks for the integration of uncertainty into the analysis of the case studies. In order to provide a background an extensive review of international experiences with the application of the MSE approach to fisheries evaluation was completed (see TEXT BOX 1).

The uptake by stakeholders and EU Commission bodies such as the Scientific, Technical and Economic Committee for Fisheries (STECF) of research output for an evaluation of Multi-Annual Management Plans for North Sea Flatfish and Northern Hake is evidence of a major achievement for the project, as well as the research which contribution our knowledge of Baltic Salmon and its management via the relevant ICES working group.

TEXT BOX 1

Managing without best predictions: the Management Strategy Evaluation framework

José A. A. De Oliveira[a,b], Laurence T. Kell[a], André E. Punt[c,d], Beatriz A. Roel[a] and Doug S. Butterworth[e]

a – The Centre for Environment, Fisheries and Aquaculture Science, Lowestoft Laboratory, Pakefield Road, Lowestoft, Suffolk NR33 0HT, United Kingdom
b – corresponding author
c – School of Aquatic and Fishery Sciences, Box 355020, University of Washington, Seattle, WA 98195-5020, USA
d – CSIRO Marine and Atmospheric Research, GPO Box 1538, Hobart, TAS 7001, Australia
e – Marine Resources Assessment and Management Group, Department of Mathematics and Applied Mathematics, University of Cape Town, Rondebosch 7701, South Africa

Despite consistent and extensive efforts over the last fifty years by regional management bodies and national governments to regulate fisheries, fishing capacity often remains well above that necessary to exploit marine resources at optimal sustainable levels. While the need to develop alternative novel management strategies that are able to meet their goals is widely recognised, it is almost impossible to achieve this by conducting large-scale experiments on fish populations. There has therefore been a trend towards the use of computer simulation to identify management strategies that can satisfy multiple objectives and that are robust to uncertainty. This chapter reviews the use of the Management Strategy Evaluation (MSE) framework, and explores its role in the transformation of harvest control rules into management procedures. Several examples of the implementation and use of the MSE framework around the world are given, and potential benefits and problems discussed. Finally, the paper discusses the possible role of the MSE framework in implementing agreements under the World Summit on Sustainable Development and Ecosystem-Based Fisheries Management.

The MSE framework requires software for its full implementation. The project has provided a significant contribution to the development of the software FLR (Fisheries Library in “R”): a free, open source, multi-platform, software environment for statistical computing and graphics (see http://flr-project.org).

The “R” environment provides a flexible and powerful platform for creating and enhancing stock assessment and for management strategy evaluation methodology. Thus FLR is a tool that can be used as (1) its separate components, for stock assessment and data analysis or (2) as a whole, for management strategy evaluation (MSE).

Documentation, tutorials as well as downloadable packages are available on the website (see Figure 6, 7 and 8 below).

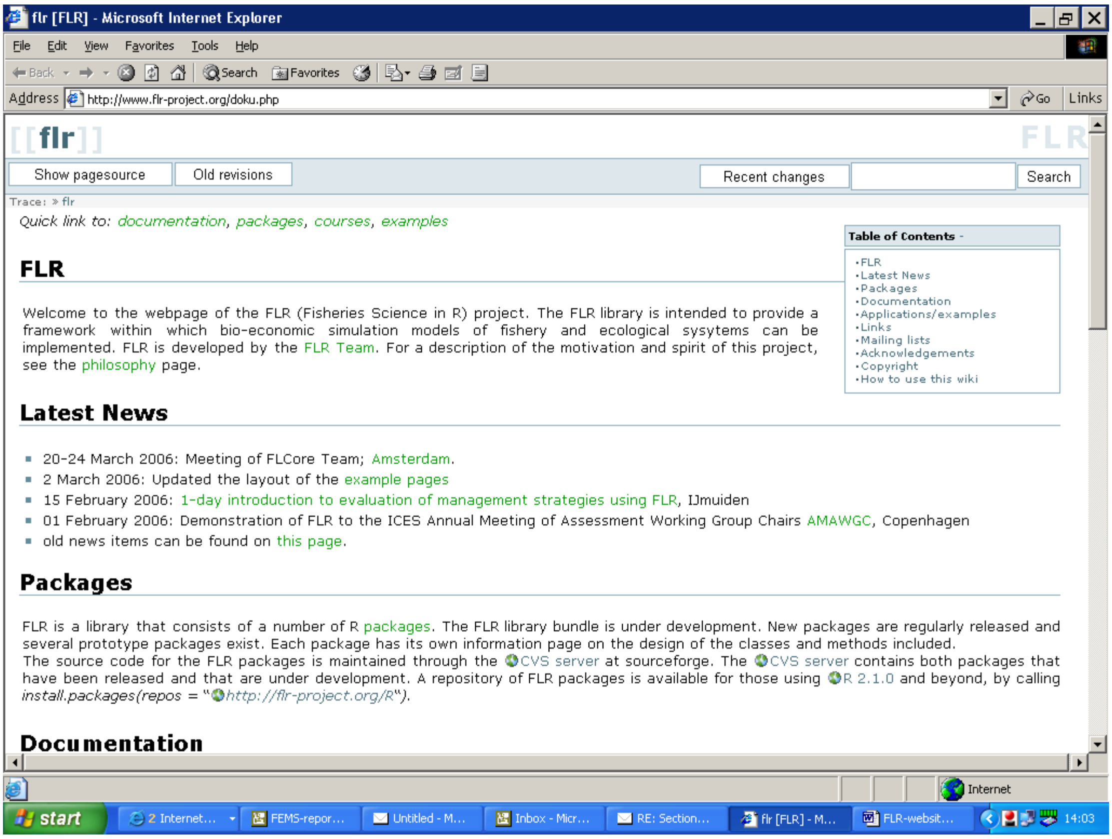


Figure 6. Introduction to FLR on the FLR website (page 1)

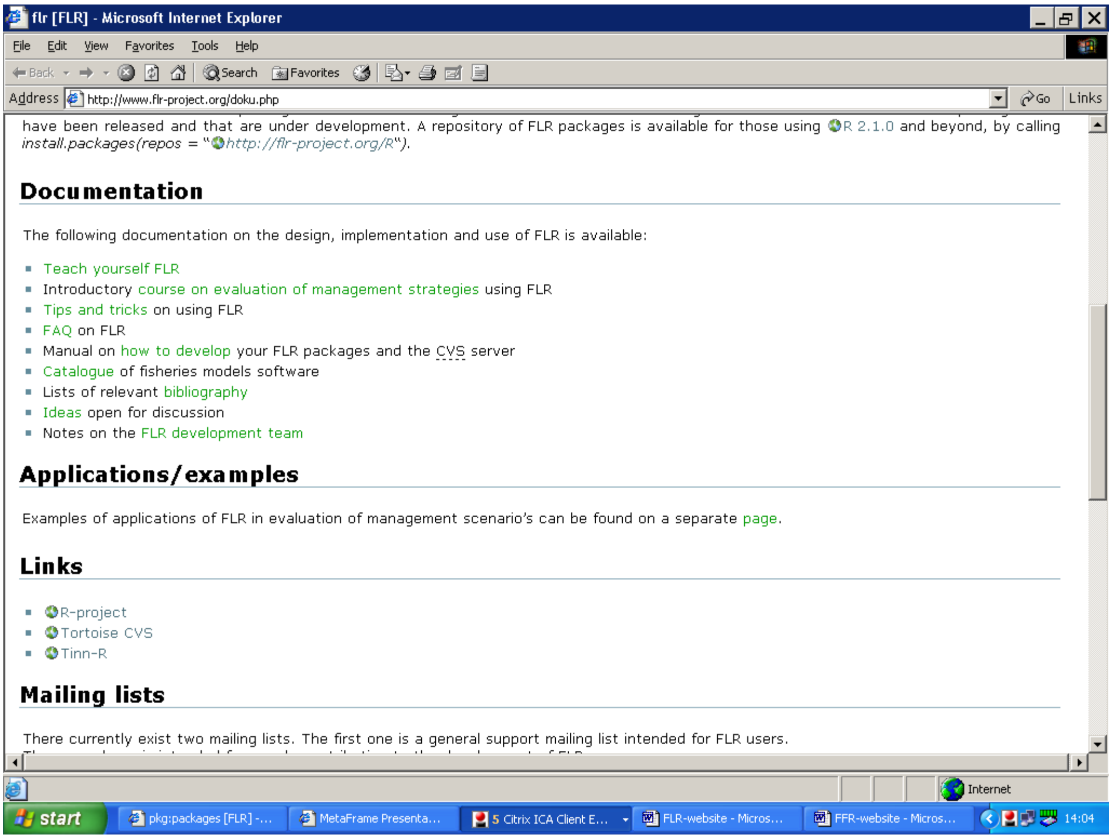


Figure 7. Introduction to FLR on the FLR website (page 2)

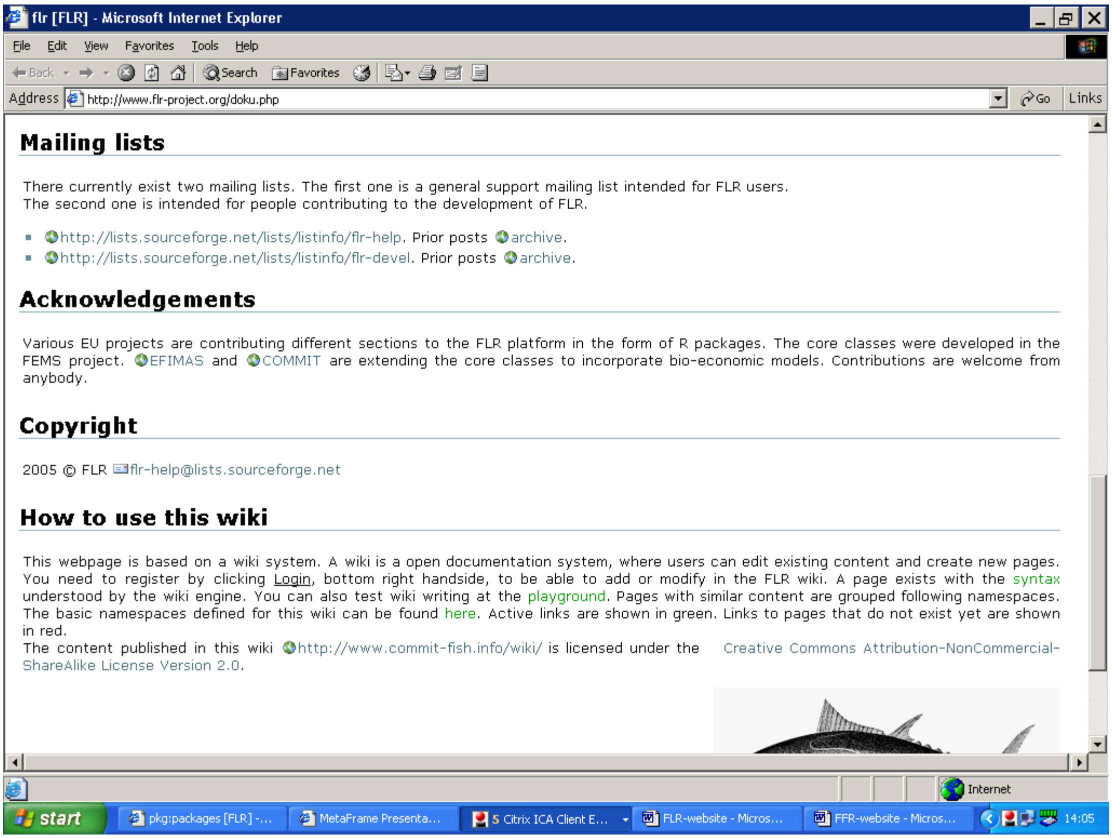


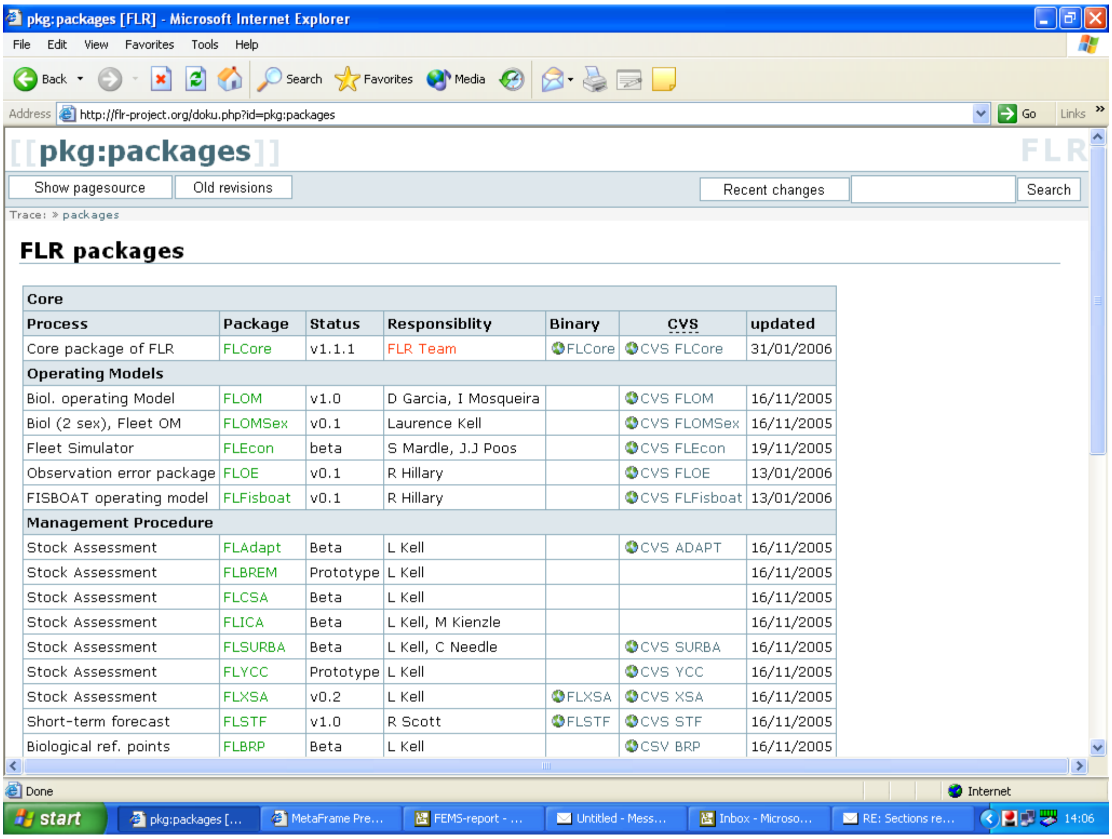
Figure 8. Introduction to FLR on the FLR website (page 3)

1.5.1.1 Software framework – FLR Packages

A number of FLR Packages have been compiled in order to complete the software framework in order to perform routine stock assessments, set up operating models and management procedures (for management strategy evaluation) and other analyses (e.g. Bayesian estimation, growth analysis etc.). These can be downloaded in various ways.

Source code is now being kept on a CVS (Concurrent Version System) server. Any interested party can access the source code of the FLR library and research, test and modify it. Suggestions for changes and bug fixes are channelled through a mailing list, and tracked by means of a bug tracking system (http://www.commit-fish.info/bugs/).

The following web-pages provide an indication of the packages that are available (Figure 9 and 10):

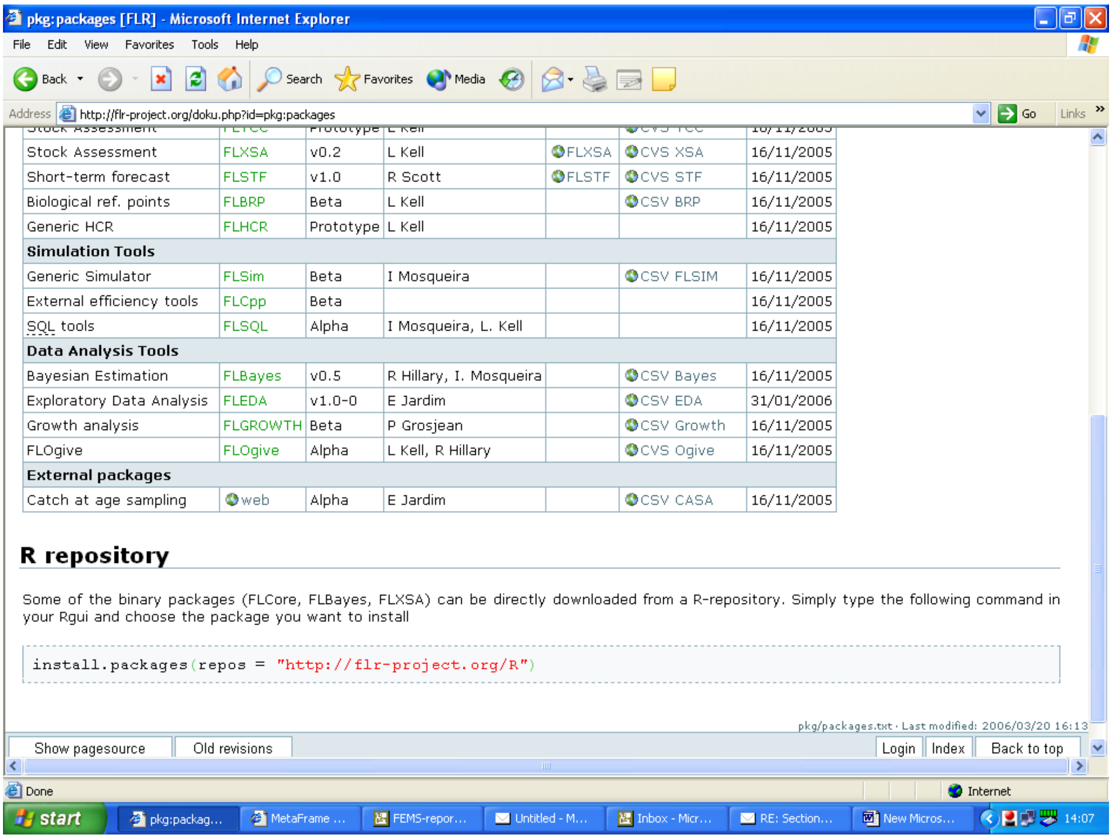


[[pkg:packages]]

FLR packages

Process	Package	Status	Responsiblity	Binary	CVS	updated
Core						
Core package of FLR	FLCore	v1.1.1	FLR Team	FLCore	CVS FLCore	31/01/2006
Operating Models						
Biol. operating Model	FLOM	v1.0	D Garcia, I Mosqueira		CVS FLOM	16/11/2005
Biol (2 sex), Fleet OM	FLOMSex	v0.1	Laurence Kell		CVS FLOMSex	16/11/2005
Fleet Simulator	FLEcon	beta	S Mardle, J.J Poos		CVS FLEcon	19/11/2005
Observation error package	FLOE	v0.1	R Hillary		CVS FLOE	13/01/2006
FISBOAT operating model	FLFisboat	v0.1	R Hillary		CVS FLFisboat	13/01/2006
Management Procedure						
Stock Assessment	FLAdapt	Beta	L Kell		CVS ADAPT	16/11/2005
Stock Assessment	FLBREM	Prototype	L Kell			16/11/2005
Stock Assessment	FLCSA	Beta	L Kell			16/11/2005
Stock Assessment	FLICA	Beta	L Kell, M Kienzle			16/11/2005
Stock Assessment	FLSURBA	Beta	L Kell, C Needle		CVS SURBA	16/11/2005
Stock Assessment	FLYCC	Prototype	L Kell		CVS YCC	16/11/2005
Stock Assessment	FLXSA	v0.2	L Kell	FLXSA	CVS XSA	16/11/2005
Short-term forecast	FLSTF	v1.0	R Scott	FLSTF	CVS STF	16/11/2005
Biological ref. points	FLBRP	Beta	L Kell		CSV BRP	16/11/2005

Figure 9. The FLR packages that are available for download from the FLR website (page1)



pkg:packages [FLR] - Microsoft Internet Explorer

http://flr-project.org/doku.php?id=pkg:packages

Stock Assessment	FLXSA	v0.2	L Kell	FLXSA	CVS XSA	16/11/2005
Short-term forecast	FLSTF	v1.0	R Scott	FLSTF	CVS STF	16/11/2005
Biological ref. points	FLBRP	Beta	L Kell		CSV BRP	16/11/2005
Generic HCR	FLHCR	Prototype	L Kell			16/11/2005
Simulation Tools						
Generic Simulator	FLSim	Beta	I Mosqueira		CSV FLSIM	16/11/2005
External efficiency tools	FLCpp	Beta				16/11/2005
SQL tools	FLSQL	Alpha	I Mosqueira, L. Kell			16/11/2005
Data Analysis Tools						
Bayesian Estimation	FLBayes	v0.5	R Hillary, I. Mosqueira		CSV Bayes	16/11/2005
Exploratory Data Analysis	FLEDA	v1.0-0	E Jardim		CSV EDA	31/01/2006
Growth analysis	FLGROWTH	Beta	P Grosjean		CSV Growth	16/11/2005
FLOgive	FLOgive	Alpha	L Kell, R Hillary		CVS Ogive	16/11/2005
External packages						
Catch at age sampling	web	Alpha	E Jardim		CSV CASA	16/11/2005

R repository

Some of the binary packages (FLCore, FLBayes, FLXSA) can be directly downloaded from a R-repository. Simply type the following command in your Rgui and choose the package you want to install

```
install.packages(repos = "http://flr-project.org/R")
```

pkg/packages.txt · Last modified: 2006/03/20 16:13

Figure 10. The FLR packages that are available for download from the FLR website (page2)

An interactive COMMIT website (Figure 11 and 12 below) has been set up at: http://commit-fish.info. It allows participants in the project to undertake project work and to share documents, data and FLR code and apply the packages to the case studies.

Figure 11. The COMMIT website providing links to project methodology and case study specific information (page 1)

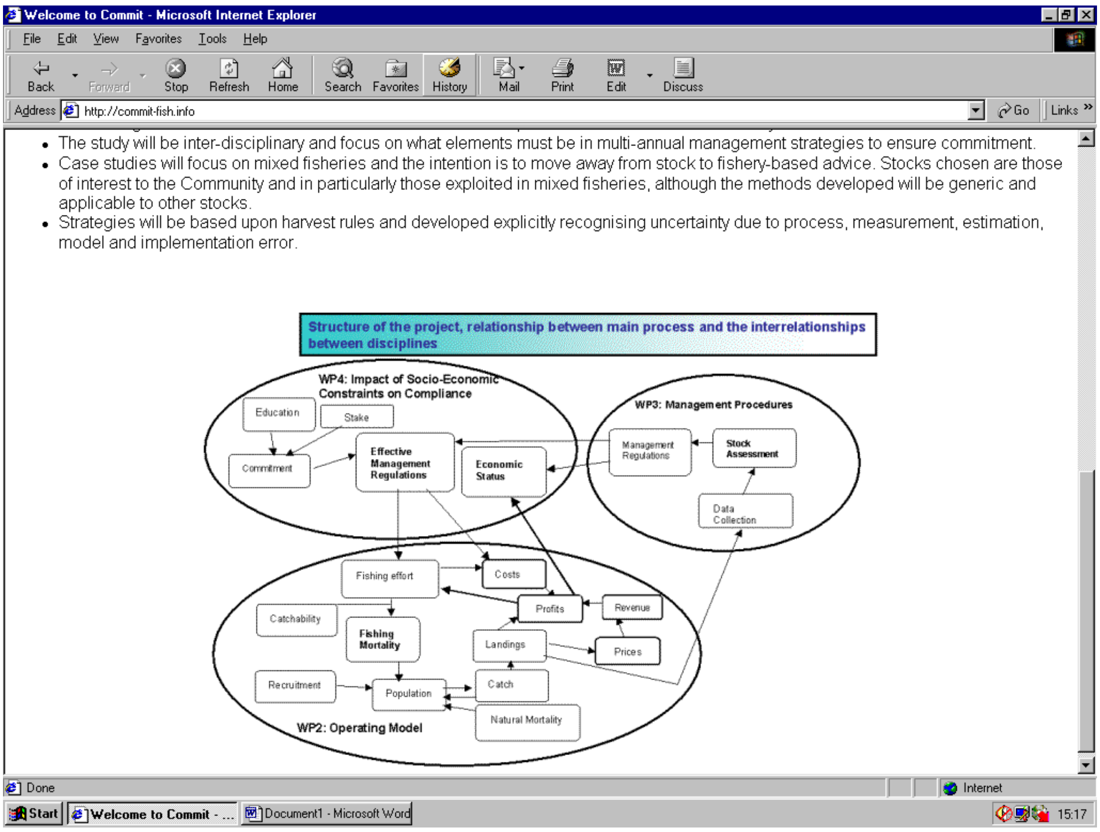


Figure 12. The COMMIT website providing an overview of the project (page 2)

The results illustrate the flexibility and utility of the simulation framework. These are reviewed under the case studies, however a key aspect was to review progress with the development of FLR at a generic level across the project and a paper was published to disseminate knowledge to the wider scientific community (see TEXT BOX 2).

TEXT BOX 2

FLR: an open-source framework for the evaluation and development of management strategies

Kell, L. T., Mosqueira, I., Grosjean, P., Fromentin, J-M., Garcia, D., Hillary, R., Jardim, E., Mardle, S., Pastoors, M., Poos, J. J., Scott, F., and Scott, R. D. 2007. FLR: an open-source framework for the evaluation and development of management strategies. – ICES Journal of Marine Science, 64.

The FLR framework (Fisheries Library for R) is a development effort directed towards the evaluation of fisheries management strategies. The overall goal is to develop a common framework to facilitate collaboration within and across disciplines (e.g. biological, ecological, statistical, mathematical, economic, and social), and in particular to ensure that new modelling methods and software are more easily validated and evaluated, as well as becoming widely available once developed. In particular, the framework details how to implement and link a variety of fishery, biological, and economic software packages so that alternative management strategies and procedures can be evaluated for their robustness to uncertainty before implementation. The design of the framework, including the adoption of object-orientated programming, its feasibility to be extended to new processes, and its application to new management approaches (e.g. ecosystem affects of fishing) is discussed. The importance of open source for promoting transparency and allowing technology transfer between disciplines and researchers is stressed.

One key aspect of the further development of FLR was the integration of packages and software that included other disciplines, such as economics and the modelling of fishermen's behaviour. These are reviewed in the next section.

1.5.1.2 Including economic variables and modelling behaviour

Following the involvement of the COMMIT project in the extensive development of FLR and the requirement for the inclusion of economic variables and relationships substantial changes have been made to the core classes of FLR, in particular to the fleet class (FLFleet) and the FLEcon class.

Due to the open source nature of the code, it is an ongoing process and updates are consistently being made (in partnership with the relevant work-packages in EFIMAS). A brief review of progress with FLEcon is provided below. The economics, in a summary form, is included in the FLFleet class. Four slots have been made available for crew-share, variable costs and fixed costs, as well as a measure of capacity. In order to provide detail to the economics capability within the FLR framework, a new FLEcon class was set up. This disaggregates variable costs and fixed costs, in particular, into the key components in which cost data is collected.

A slot (i.e. *list.fixed*) denoting whether a parameter is variable (F), fixed (T) or neither (NA) is also included (default values for this classification are included). In the case of crew, there may be a requirement in specific case studies to have a fixed and variable component. The cost structure is designed to be compatible with the new economic cost data collection regulation in mind. The structure of FLEcon is defined as such that included slots for a break-down in the cost structure (costs for fuel, bait, ice, food, insurance, management, quota leasing, crew costs [if not part of crew share], maintenance, depreciation, opportunity costs, interest, and other).

Functions prepared to provide the link between FLEcon and FLFleet are available. Simply, these sum the elements of variable and fixed costs and place the results into the associated FLFleet object. A summary function for the object is also provided. Functions for FLEcon are:

- Sum Variable Costs (links to slot in FLFleet)
- Sum Fixed Costs (links to slot in FLFleet)
- Summary

An input routine which reads in cost data into a FLEcon object is provided. This reads in the cost data from a structured text file (in the format of the 'VPA-type' structure). This is consistent with the needs and use of data input in other components of the FLR.

In addition to the basic costs aggregation functions, extended fleet methods are also provided. These are designed to give the capability to calculate a suite of economic indicators. Three main indicators have been included are for the calculation of intermediate consumption, gross value added and gross cash flow (see Table 1). The basic link to the FLFleet object is made where the "catches" slot contains information on landings and price. The links between objects to allow the calculation of some of the economic indicators is a non-trivial task, which confirms the need for availability of these indicators in the core.

Table 1. Economic indicators and their "meaning".

Average vessel productivity	Landed weight (or value) / No vessels (or GT or HP or Days fished or Employment)
Total invested capital	Average vessel value * No vessels
Variable costs (i.e. running costs – vary with effort)	Sum of variable costs
Fixed costs (not varying with effort, often summarised on a yearly basis)	Sum of fixed costs
Gross margin	Revenues - variable costs
Intermediate consumptions	Landing costs + Fuel costs + Other running costs + Gear + insurance + Management + Maintenance + Other
Gross value added (expresses the remuneration of labour and capital)	Revenue - Intermediate consumptions
Net value added	Gross value added - Taxes
Gross cash flow (income available to the vessel to pay interest	Gross value added - Crew share - Social insurance cost

and instalments (depreciation) on loans)	(paid by the vessel owner) -Taxes
Full equity profit	Gross cash flow - Depreciation
Interest (opportunity cost of capital)	Interest rates to be defined
Net profit	Gross cash flow - Depreciation - interest
Skipper-owner remuneration	Skipper wage + Full equity profit

(Note: different countries and 'fleets' even calculate crew/skipper remuneration differently! e.g. percentage of gross revenue / net revenue).

In order to provide a model with more detailed price capability, such as how price (and its obvious relevance to the calculation of fleet revenues) may react to changes in landings, an FLPrice class is defined, that includes slots for parameters for estimating then predicting price elasticities, the models thereof, residuals and the link back to the landings, that is consistent with the elements of the FLFleet "catches" slot. Imports and their prices are not currently incorporated – but is an issue that must be addressed. Two price 'models' are included, currently tagged as "constant" and "simple". Functions to calculate the price relationship are available, the results of which are stored in a "parameters" slot, where

- "constant" relates to the long run average price, and
- "simple" relates to the calculation of a short run price flexibility (i.e. the percentage change in price given a percentage change in landings).

To reiterate, the economic aspects of the MSE simulation were handled by the *FLR* package *FLEcon*. *FLEcon* comprises classes with associated methods and functions that can be used to calculate and store economic information and model fleet behaviour, essentially the simulation of fleet behaviour under an effort-controlled fishery. The latter is described below.

A variety of economic indicators can be calculated using the cost, price, effort and landings data. These indicators can be used to measure the economic performance of the management strategy. The indicators are stored using the *FLEcon* class *ComInd* which comprises a series of slots of type *FLQuant*, enabling the indicators to be stored by year. The indicators are calculated using the function *CommitIndicators*().

The MSE simulations produce effort and landings data for all future years. However, price and cost data is not available for the future years and so these must be estimated where necessary. Price data in the future simulation years is assumed to be same as the last year that real data is available for multiplied by an increase if necessary. The same is true for the costs classified as fixed or other. Costs that are classified as variable (e.g. fuel) are assumed to vary with effort. Variable costs in the future simulation years are therefore calculated as the cost in the last year that real data is available for, scaled by the relative effort.

Table 2. The indicators calculated are:

Indicator	Description
Total variable costs	The total of the variable costs, as defined by the *FLCost* class.
Total fixed costs	The total of the fixed costs, as defined by the *FLCost* class.
Value landings	Calculated per species caught. The total of the product of the landings numbers, the landing weights and the price, all at age.
Total value landings	The total value of the value landings per species plus an additional user set value for the value from other, non-simulated, species.
Crew share	Calculated as the total value landings multiplied by the argument crew.share.prop.
Gross cash flow	The total value landings minus the fixed and variable costs and crew share.
Net profit	The gross cash flow minus depreciation and interest (taken from the *FLCost* object).
Gross value added	The total value landings minus the fixed and variable costs

The indicators for all years are calculated at the end of the simulation (Table 2). This means that they have no impact on fleet behaviour during the simulation. They simply measure the performance of the fishery.

The inclusion of models of fishermen's behaviour has been constrained to the estimation of the effects of changes the relationship between nominal fishing effort and fishing mortality with an effort control system (e.g. days-at-sea restrictions as imposed within the North Sea). The specification of the relationships and the modelling thereof is detailed below.

<u>Modelling changes in fishermen's behaviour: a non-linear F-E relationship</u>

In an MSE, the relationship between fishing mortality (*F*) and effort (*E*) is generally assumed to be linear ($F = q \cdot E$), where *q* is the catchability at age. This relationship assumes that all effort is equal, that is, if effort is halved, so is *F*.

An alternative non-linear relationship has been included in *FLEcon* to act as a proxy for fleet behaviour under an effort controlled management regime. This is represented by $F = K \cdot q \cdot E^{\alpha}$; where α and *K* are constants that need to be specified and α is less than 1. This relationship has the general shape as shown in Figure 13).

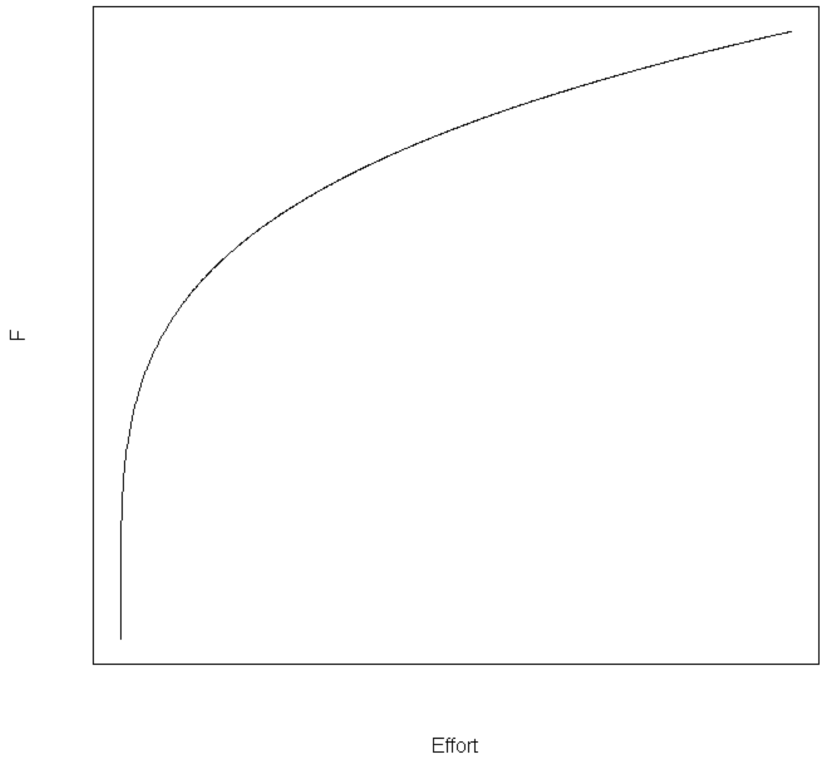


Figure 13. The expected relationship between effort and fishing mortality estimated in the case when days-at-sea becomes restrictive and fishermen reduce their number of less efficient trips.

This relationship implies that not all effort is equal and that if effort is reduced, fishermen will stop fishing in the least productive areas, i.e. those that result in the least F for a given effort. This means that a reduction in effort may not always result in the expected reduction in F.

This relationship is not used in the management stage of the MSE (managers are assumed to always use the linear F-E relationship) but is used in the operating model section of the MSE to act as a proxy for fleet behaviour. TEXT BOX 3 provides the details for the research undertaken in *COMMIT* and the work completed as applied to the North Sea Flatfish case study.

Understanding and modelling economic factors is critical to the full specification of bio-economic models.

TEXT BOX 3

Linking Catchability and Fisher Behavior under Effort Management

J.A.E. van Oostenbrugge, J.P. Powell, J.P.G. Smit, J.J. Poos, S. B. M. Kraak and F.C. Buisman (in press – Living Aquatic Resources)

Catchability is crucial for the economic performance of fisheries and their management. However, in many bio-economic simulation models it is assumed to be either constant or it is largely ignored, despite the fact that it is known to vary due to technical, environmental and behavioral factors. Such variation can cause the relationship between effort and fishing mortality to be nonlinear. This paper provides evidence for the possibility of nonlinear optimizing behavior from the Dutch beam trawl fishery, provides a methodology for estimating the curvature of the resulting relation, and a simple way of implementing these processes within a bio-economic model. Moreover, it shows the influence of a nonlinear relationship between effort and fishing mortality in a model of effort management (EU long-term flatfish management plan).

In addition, including compliance and non-compliance of stakeholders within the framework in order to provide context for the evaluation of multi-annual management plans was essential to the project. The following sections summarise progress made on reviewing the background knowledge on negotiation and compliance (and the modelling of compliance). Again, as in previous sections the technical details are excluded.

1.5.2 Negotiation framework for fisheries management

The negotiation framework was developed under the theory of Distributed Artificial Intelligence systems is used in modelling of some important elements of fisheries management. Negotiation is defined as a form of interaction in which stakeholders, with conflicting interests and a desire to cooperate, try to come to a mutually acceptable agreement on the conservation of fishery ecosystem and allocation of fishery resources.

That interaction aims to resolve a conflict of interest between two or more stakeholders through the use of a defined protocol and the strategies of the stakeholders. The main goal is to achieve an agreement over defined issue(s) of contention. Usually stakeholders *negotiate* in order to reach agreement on *conservation and division of shared fishery resources* or on a *mutually useful exchange* of their own resources. Argument-based negotiation frameworks allow stakeholders to exchange, in addition to proposals and indications of their acceptance or rejection, meta-information about them, such as the reasons for their proposals, and for accepting or rejecting them.

Negotiation is seen as grounded, firstly, on a *joint commitment* among the members of a group of stakeholders to achieving a certain state of the fishery ecosystem, and secondly, aimed at generating a *joint commitment* among the negotiating stakeholders to acting according to *a joint plan of action* (e.g. fisheries management plan, recovery plan etc.). Transformation of commitments is what constitutes the essence of negotiation. Coming to an agreement transforms a joint commitment towards a state into a joint commitment to performing a plan for achieving that state.

Commitment is defined as a pledge or promise negotiating parties can make both about actions and beliefs. *Conventions* describe circumstances under which a negotiating party should reconsider its commitments and indicate the appropriate course of action to: either retain, rectify or abandon the commitment. Commitments (pledges to undertake a specified course of action) and conventions (means of monitoring commitments in changing circumstances) can be seen as the foundation of coordination in fisheries management systems.

Coordination model elements are seen as follows: 1) structure within which negotiating parties can interact in predictable ways, 2) flexibility so that negotiating parties can operate in dynamic environments, 3) appropriate knowledge (joint knowledge base) and reasoning capabilities to intelligently use the structure and flexibility. An application of the theory presented above to an actual the project case study was undertaken in this project (see TEXT BOX 4).

TEXT BOX 4

Negotiation framework for Baltic fisheries management: striking the balance of interest

Aps, R., Kell, L. T., Lassen, H., and Liiv, I. 2007. Negotiation framework for Baltic fisheries management: striking the balance of interest. – ICES Journal of Marine Science, 64(4): 858–861.

The issue of balancing of stakeholder interests in translating science-based advice into agreed management measures is explored. The outcome of negotiations within the International Baltic Sea Fishery Commission (IBSFC) for setting the TAC for Baltic herring, sprat, cod, and salmon between 1977 and 2004 is analysed. Given the political and economic pressure inherent in fishery management, IBSFC Contracting Parties, as maximizers of economic value, often set the TAC by unit stock in excess of what is considered sustainable. TACs set in excess of sustainable levels of exploitation (decision-overfishing) reflect the relative importance attributed by negotiating parties to the interests of multiple groups participating in the fishing industry. Such decision-overfishing can be seen as management failure to secure public interest in the long-term health of fish populations. The potential political and social causes of overfishing have to be addressed and removed before measures can be implemented that might reach the goal of sustainable development.

1.5.3 Modelling compliance

The Common Fishery Policy (CFP) embodies a multitude of objectives in its resource conservation and management system for fisheries in European Union (EU) waters. The stated objective for the conservation and sustainable exploitation of fisheries resources under the CFP (Council Regulation (EC) No. 2371/2002: Article 4) is "to provide for sustainable exploitation of living aquatic resources and of aquaculture in the context of sustainable development, taking account of the environmental, economic and social aspects in a balanced manner".

Under the CFP, specific conservation and management measures are defined. For example, in northern European waters a system of total allowable catches (TACs) for targeted stocks form the basis of the system. In addition, minimum landing sizes are implemented. There are also restrictions in place concerning the use of different sizes of mesh and the accompanying percentage of given species that are allowed to be caught in given areas.

The effectiveness of management regulations in achieving the desired objectives depends on fishermen's compliance with those regulations. Previous studies on fishery management have demonstrated that management failure in many fisheries was due to imperfect compliance with regulation. In particular, management measures imposing restrictions on catch and effort are generally subjected to a degree of violation, which can reduce their effectiveness in preserving stocks biomass.

As reported by Hatcher and Pascoe (2006), the negative impact of non-compliance on policy formulation are related as well to the divergence between expected outcomes and the actual outcomes as to the distortion of the information on which policy is based. Violation behaviour is obviously not declared and its magnitude is generally unknown. Under output control regime, underestimating the actual landings can result in a wrong estimate of the size of the resource and consequently in a too restrictive quotas system. Under input control, instead, an effective fishing effort higher than the observed fishing effort can result in an apparent increase of productivity (measured in terms of catch per unit of effort), which may be incorrectly interpreted as an improvement in stocks status.

In the last 10 years, bio-economic models have been increasingly adopted to indicate and predict the effects of management measures on fisheries. Within these models, it is particularly important to check that the model output has an 'error' within reasonable bounds. In bio-economic models, perfect compliance with regulations is generally assumed and a specific compliance model is not incorporated in the general model scheme. This assumption is likely to increase the model outputs error.

Recently, some attempts to model compliance with fishery regulations have been published in few papers. Among others, an EU funded project on "*Fishery Regulation and the Economic Responses of Fishermen: Perceptions and Compliance*" (FISHREG) has investigated the reasons determining non-compliance with fisheries regulation through discrete choice models. The results of this project have shown that choices on compliance or violation depend on the interaction of economic, sociological and psychological factors. The identification of variables affecting the most non-compliance behaviour is of particular interest for improving the effectiveness of fisheries management regimes and the predictive capacity of bio-economic models.

Firstly, a literature review of fisher management response behaviour is reported and has been published (part funded by COMMIT and part by EFIMAS: Chapter 14 of the EFIMAS book “The Knowledge Base for Fisheries Management” by Hatcher and Pascoe (2006)). Secondly, in the COMMIT project research was focused on compliance with how fishery regulations can be modelled. Variables potentially affecting compliance and the use of discrete choice model are described. Note that in this report the equations for modelling compliance have not been presented in this report due to their technical nature. The approach suggested has been implemented in the FLR (Fishery Library in R) framework by defining a new class called “FLCompliance”. Finally a discussion on the effects deriving from the incorporation of the compliance model into the framework of bio-economic modelling is reported.

An understanding of the reasons why fishers do not comply with policy regulations is an important part of the fisheries policy knowledge base. Foremost, it allows for the possible extent of non-compliance to be estimated given the set of environmental, economic and social conditions under which the policy is being imposed. This enables better estimates of the outcomes from management policies to be derived a priori, enabling more reliable policy evaluations. It also enables consideration of factors that could improve compliance during the policy formulation process.

According to the standard (neoclassical) economic model of rational behaviour, individuals maximise their utility subject to constraints and firms (whose decisions are controlled, we assume, by utility-maximising individuals) maximise profits, again subject to constraints. In situations of risk or uncertainty where individual outcomes or states can be assigned a distinct probability of occurrence, in the rational model *expected* utility is maximised.

Based on this utilitarian model of behaviour, economic models of crime have been developed which focus on the expected gains and losses associated with a rational choice between committing an offence and not committing an offence (see Becker, 1968; Stigler, 1970; Ehrlich, 1972, 1973; Brown and Reynolds, 1973; Block and Heineke, 1975; Heineke, 1978a; for reviews see Heineke, 1978b; Pyle, 1983; Eide, 1994; Fielding et al., 2000). This type of *deterrence* model is generally associated with Becker (1968) and is widely used to model compliance with regulations, including fishery regulations.

The essential policy prescriptions that stem from this type of model relate to the optimal choice of the probability of detection and sanction, which depends upon enforcement effort, and the size of the penalty. Since the expected penalty is a product of the (subjective) probability of detection and the penalty if sanctioned, and since enforcement is usually costly, the general conclusion is that deterrence should as far as possible be achieved by increasing the penalty (Polinsky and Shavell 1979 and 1992, Shavell 1993). Ehrlich (1973) considered the possibility that *p* was related to the amount of time spent by the individual in illegal activity, i.e. habitual offenders have a biased assessment of their risk of getting caught. Thus habitual offenders may have a lower assessment of the risk of detection, for example because they have developed techniques for avoiding detection, or because they have been lucky enough to avoid detection in the past. Alternatively, it is plausible that persistent offenders have a higher assessment of their risk of getting caught, because they know that enforcement is being targeted at them, or perhaps because they think they are 'running out of luck'.

This basic approach has been widely used in order to model regulatory enforcement and compliance in environmental management problems such as pollution control (e.g., Downing and Watson, 1974; Harford, 1978; Beavis and Walker, 1983; Malik, 1990; Keeler, 1991; see also Heyes, 1998, 2000) as well as in the regulation of commercial fisheries (Sutinen and Andersen, 1985; Milliman, 1986; Anderson and Lee, 1986; Anderson, 1989; Charles *et al.*, 1999).

Implicit in most economists' rational model of behaviour is that preferences are exhibited over, and utility derived from, only those 'goods' that can be consumed in the ordinary sense, or, indirectly, from the income or wealth that enables consumption of such goods. Some modifications or extensions to the strictly rational maximising or *optimising* model of economic behaviour do not fundamentally challenge the standard utilitarian assumptions. Risk aversion, for example, is often modelled by assuming a diminishing marginal utility for wealth or income, or with a utility function that is sensitive to the *variance* of expected wealth or income (see Hirshleifer and Riley, 1992). In either case, the utility function is assumed to have some particular form without any explicit modelling of what produces that form.

Theories of 'bounded rationality' and 'satisficing' (Simon 1955, 1957, 1972) focus principally on the idea that individuals have limited access to, and limited ability to process, information relevant to their choices, so that the model of rational 'optimisation' is unrealistic in describing both process and outcome in decision-making behaviour. Related theories argue that the ability to optimise is also compromised by uncertainty (e.g., Kahneman and Tversky 1979, Heiner 1983). These and similar 'cognitive' theories of decision-making allow for non-cognitive influences such as emotions or behavioural norms as guides or 'stopping rules' (heuristics) in the decision process, but they remain essentially theories of utilitarian rational choice (see, for example; Connolly *et al.*, 1999).

In the non-economic social sciences more attention is devoted to the influence of personal and social norms, social influences of a more instrumental nature, as well as more or less contemporaneous judgements about the 'legitimacy' of regulations, in determining individuals' behaviour under regulation. Although theories of behaviour in sociology and social psychology place considerable emphasis on such factors, there is no conventional or generally accepted *economic* model of behaviour that explicitly incorporates moral norms or other behavioural norms, for example.

Although there appears to be little consistency on this in the social sciences literature, a distinction can be made between *moral* norms and *social* norms. According to Elster (1989b) social norms are shared norms which relate to appropriate conduct within a specific group of people and which are at least partly sustained by the approval and disapproval of others, while moral norms are personal norms concerning ethical values relating principally to the *rights* of other people in general and are largely independent of extrinsic influence. A key concept in sociology and social psychology is that moral norms are obligations that have become *internalised* so that they influence behaviour even in the absence of external pressures (Hoffman 1977). The extent to which social norms may be regarded as internalised, however, is not always clear from the literature (see, for example, Elster 1989b and Tyler 1990).

Norms, particularly norms of fairness and cooperation, may depend critically on observance by a sufficient number of others, or they may break down (Elster 1989a). Norms may be undermined by external coercion, even though the norm may have encouraged the very behaviour desired by the external authority (Frey 1994, Kreps 1997). Individuals may also personally evade the influence of norms in various ways.

Social influences are not always considered as normative. The behaviour and attitudes of others may be influential simply through close relationships between individuals in a group and through identification with the group. Granovetter (1985) emphasises the importance of social relations (‘embeddedness’) in addition to what he calls ‘generalised morality’ (i.e., norms) in determining cooperation and trust within groups. Aronson (1984, p.35) categorises responses to social influences in terms of “compliance, identification or internalisation”. In other words, individuals may act in response to the threat of formal or informal sanctions, or the example provided by significant others, or internalised norms. Sugden (1989) views ‘conventions’ as the precursors of social norms that may become internalised through the human desire to obtain approval and avoid disapproval. Young (1979) identifies six types of incentives that may act to determine compliance behaviour. These he lists as self-interest, enforcement, inducement, social pressure, obligation, and habit or practice, the last two of which would appear to include moral and social norms in the sense discussed above.

Modern views of legitimacy in the social sciences derive from Weber (1947) and suggest that acceptance of the legitimacy of an authority will encourage compliance with its laws even where those laws conflict with an individuals’ own self-interest (see Sternberger, 1968). In other words, legitimacy represents a perceived obligation to obey that is necessarily linked to political authority and is distinct from the influence of moral norms (indeed personal morality and legitimacy may conflict). The separation between legitimacy, morality and self-interest is not straightforward, however, nor is legitimacy a singular or absolute concept. To the extent that legitimacy is enduring it may approach the normative status of morality, for example, whereas legitimacy judged contemporaneously in terms of outcome may be said simply to reflect self-interest (Tyler 1990).

In the literature on local management or ‘co-management’ approaches to fisheries governance, it is often suggested that greater involvement of fishers in the management process will lead to increased levels of compliance because regulations will then be accorded greater legitimacy as a result (see, for example, Jentoft 1989, Nielsen 1994, Jentoft and McCay 1995, Nielsen and Vedsmand 1997). In the non-economic social sciences, even in the context of ‘commons’ problems like the fishery studies of compliance tend to focus away from deterrence, often to the point of ignoring economic forces altogether. But fishers seek economic returns; they have fixed factor costs, labour opportunity costs, etc., and hence will necessarily be sensitive to expected financial gains and penalties. On the other hand, even in fisheries enforcement studies based on the rational economic model, the importance of non-pecuniary factors is recognised. For example, Anderson and Lee (1986, p.690) noted that “there are many issues of moral values and ethics involved. First, all fishers may not cheat even though it is financially profitable to do so. Also, the suggestion that policies be implemented assuming that people will not comply with them has the potential for eroding social capital which depends on respect for the law.” Sutinen *et al* (1990) recognised that conventional economic models frequently fail to explain actual patterns of compliance seen in fisheries. In practice the high costs of enforcing regulations usually result in relatively low probabilities of detection, while at the same time penalties are not usually high enough to produce a strong deterrent effect. Nevertheless, these authors observed, in many cases a significant proportion of fishers do comply with regulations.

Despite the strict rationality assumptions of the standard economic model, the influence of non-pecuniary or non-instrumental factors such as behavioural norms has been incorporated, for example, into theoretical economic models of tax compliance (e.g., Gordon, 1989; Alm *et al.*, 1992; Cullis and Lewis, 1997), as well as models of compliance with fishery regulations (Sutinen and Kuperan 1999, Hatcher *et al* 2000, Hatcher and Gordon 2005).

There does exist a considerable and growing literature within economics on the desirability and possibility of including norms in the economic model of preferences. The literature on norms and the economic theory of utility and preferences has been extensively reviewed by Goldfarb and Griffith (1991), Hausman and McPherson (1993) and Dowell *et al* (1998), with particular reference to ‘moral norms’. These authors distinguish between models which incorporate norms and those which model concern for others by including the income or utility of others in the own utility function (‘interdependent utility’). Dowell *et al* (1998) reject multiple or hierarchical utility models (see, for example, Etzioni, 1988) in favour of a set of models in which moral or immoral behaviour results in a shift in utility from goods associated with that behaviour. As the authors note, these models are formally similar to the concept of ‘state-dependent’ utility in the literature on risk and uncertainty (see Hirshleifer and Riley, 1992). One version of their model allows for continuous rather than discontinuous effects on utility of behaviour that may be perceived as neither 'completely moral' or 'completely immoral'.

Empirical studies of compliance in fisheries
Sutinen and Kuperan (1999) developed an extended compliance model that included, alongside monetary incentives and deterrence variables, variables relating to social influence, moral norms and the perceived legitimacy of the regulator and the regulations. Kuperan and Sutinen (1995, 1998) estimated a similar supply of violations model using data from a survey of fishers in Malaysia and their compliance with fishery zoning regulations. They found certain social, moral and legitimacy variables to be significant in determining levels of compliance.

Hatcher *et al* (2000) estimated an empirical model of compliance with quota restrictions among fishers in the UK. Significant explanatory variables for compliance in their model were the perceived risk of detection and the size of the expected fine if detected, but also the feeling of involvement in the design and implementation of regulations, an indicator of a norm of compliance and the perceived attitude of others. Gezelius (2002) found that compliance by Norwegian fishers was associated with an informally enforced (i.e. by other fishers) set of norms. These norms themselves permitted violation of some regulations that were not considered legitimate. Social factors were found to be major influences of compliance in Italian fisheries. Gambino *et al*. (2003) found that violation behaviour of the Italian fishers interviewed was mainly affected by (in order of importance) social pressure, their judgement about legitimacy, moral influence and their judgement about the effectiveness of the enforcement system.

In a study of Danish fishers (Nielsen and Mathiesen, 2003), economic benefits from non-compliance were demonstrated to be the most important single factor influencing compliance of the fishers. However, norms, inclusion in the decision-making process (affecting legitimacy), beliefs about the behaviour of others and belief (or disbelief) that the system would provide conservation benefits were all found to be contributing factors.

A more recent UK study by Hatcher and Gordon (2005) collected more detailed data on fishers' perceptions and experience of enforcement and, in addition, sought to measure the financial incentive to cheat. A more sensitive econometric model was used which enabled the influences on *degrees* of violation to be investigated. Although the authors still found some evidence of normative influences on quota violation levels, their results suggested that "conventional" economic incentives predominated. Interestingly, fishers in this survey sample appeared not to form their subjective risk of getting caught on the basis of their past experience of either landings inspections or logbook inspections at sea. It appeared that frequency of inspections *per se* had little effect on the perceived chance of detection, perhaps because violators were skilled at concealing over-quota fish from inspectors, or because the standard of inspections was simply inadequate. There was, however, a strong association between the subjective risk of detection and past experience of successful convictions. Levels of quota violations in the fishery appeared to be driven mainly by financial incentives. Higher violations were positively associated with perceptions of greater constraints on earnings and negatively associated with the perceived risk of getting caught. No social influence appeared to be significant in the determination of violation levels in this study, but there was some evidence of a normative influence on violations, with the recognition of the conservation value of quotas being more associated with lower levels of violation (although it was acknowledged that violators might seek to justify their actions by negating the utility of quota controls in interview).

Model

As previous studies on fishery management have demonstrated, non-compliance represents one of the factors of management systems failure in many fisheries. The effectiveness of management measures in stock conservation can be significantly compromised by non-compliance behaviour, especially when it is widely spread among fishermen. Hatcher *et al*. (2000) found that less than 30% of fishers interviewed declared to have completely complied with quotas regulation. As discussed in the previous section, compliance decisions depend on many factors, which can be summarized in economic factors (including monetary costs and benefits of violation), perceptions of regulation legitimacy, moral and social influences. In particular, the relevance of non-economic factors in the determination of compliance behaviour is generally recognized in empirical compliance models. For example, both Sutinen and Gauvin (1989) and Furlong (1991) hypothesised that compliance is influenced by personal characteristics, and Sutinen and Kuperan (1999) included in their model variables relating to social influence, moral norms and the perceived regulations legitimacy.

Non-incorporation of fishermen's compliance in bio-economic models can result in a specification error in the model, which can determine an increase in the model stochastic error and consequently in model uncertainty.

Nevertheless, bio-economic models developed to predict the evolution in the status of fisheries generally assume that fishers perfectly comply with regulations. For example, Ulrich *et al*. (2002) assumed that fishing activity ceases when quota of one of the several species is achieved. However, a few attempts to consider non-compliance in bio-economic models have been proposed in literature. For example, in a bio-economic simulation model for a South African fishery (Hutton *et al*., 2001), the effects of perfect compliance versus perfect non-compliance with minimum size and effort restrictions were compared. Such an approach, simulating the two extremes of compliance, produces a range of possible values for the relevant bio-economic model's outcomes, but does not have an effective improvement in their estimations.

In order to improve model outputs estimations and reduce model uncertainly, a more suitable incorporation of compliance in the general structure of bio-economic models for fisheries can be obtained through the measurement of the probability of compliance. Based on some papers recently published on compliance modelling (Hatcher *et al*., 2000; Gambino *et al*., 2003; Hatcher and Gordon, 2005) and the results of the EU funded project FISHREG, an explicit model to predict probabilities of compliance and non-compliance has been developed for incorporation in bio-economic simulation models. As much of the data used to measure views and attitudes of fishermen towards regulations are necessarily binary or categorical in nature, discrete choice models, like Logit or Probit model, have been employed. This model can be incorporated in bio-economic models scheme for a more correct evaluation of the effects of different management measures on fisheries status.

Variables affecting compliance

As described in the literature review above, the choice between compliance and non-compliance with regulation should be related not only to the expected monetary benefits and costs, but also to other non-pecuniary factors. Violation gains and possible fines represent only one of the factors influenced compliance decisions. Others factors can be associated to personal and social norms as well as perceptions of regulatory legitimacy. Compliance-violation decisions depend on the interaction of many sociological, psychological and economic factors. As reported in the FISHREG project, a generic violation behaviour model can be represented as a function of different factors, these being: Personal characteristics; Incentives; Deterrence; Moral influences; Social influences; and Legitimacy.

The personal characteristics are measurable variables describing the fisherman and the vessel. As for the fisherman, they can be expressed in terms of skipper age, years of experience, level of instruction, knowledge of regulation, etc. As for the vessel, variables like vessel size, status of vessel ownership, gross earnings, etc. can be included in the model.

According to the standard neo-classical economic model of rational behaviour, incentives and deterrence represent the main factors in determining the probability of violation. Obviously, the probability of violation is assumed to be positively associated with financial incentives to violate and negatively with the deterrence, which is intended as the perceived probability of detection. Financial incentives are generally measured through the perceived earnings reduction from complying with the regulation or the expected financial gains from violating. On the contrary, the perceived probability of detection can be associated and measured in terms of number of convictions, number of landings inspections in port, number of logbook inspections at sea, level of fines, etc. or collecting direct information on the subjective probability of detection.

Financial incentives and deterrence are relatively easy to be measured compared to moral and social influence. In this case, the identification of specific variables is not so straightforward. As reported in Gambino *et al*. (2003), “moral influence (M) concerns the personal ethical view on what is right or wrong. Moral norms are obligations, which have been internalised. They are individual values, which influence a person even in the absence of external pressure. On the contrary, social influence (S) represents the pressure exerted by specific groups of persons (family, organisation, and community) on fisher’s behaviour and relates to appropriate conduct within a specific group of people, and is sustained by the approval and disapproval of others".

Moral influence has been investigated as the personal normative judgements about violation. For example, Hatcher and Gordon (2005) asked the interviewees their agreement with sentences like "quotas should be complied with because they are the law" or "quotas should be complied with because otherwise you are taking more than your fair share".

Social influence has been analysed as the perceived behaviour and opinions of significant others, like the perceived violation behaviour of peers, the opinion of family, the perception of association, etc. For instance, Gambino *et al*. (2003) submitted to the survey questions on the opinions of their family, fisherman's association and their community about non-compliance behaviour.

Legitimacy represents the perceived obligation to obey to a political authority. It concerns the judgement about the regulation both in terms of effectiveness of regulatory system in reaching management objectives and in terms of opinion on regulatory institutions. Normative judgements about the legitimacy of the regulatory system, such as effectiveness of regulation, fairness of inspections, and opinion about regulatory institutions can be investigated to analyse these factors.

Standard linear regression model cannot be used to estimate the probability of non-compliance as violation is generally measured through binary or ordered categorical data. Statistical techniques, like Probit and Logit models, have been developed to allow for a regression-type approach to model the discrete nature of a dependent variable. In general, this approach produces a probability distribution for each possible outcome of the dependent variable.

In these models, the dependent variable V can be modelled either as a binary variable, where V equals to 1 in the event of violation and 0 otherwise, or as an ordered variable, where more than two discrete values are associated with the individual's violation rate. For example, Hatcher and Gordon (2005) adopted an ordered Probit model to investigate compliance with quota regulation, where different levels of violation are associated to increasing percentages of over-quota landings. Ordered responses models can be considered as an extension of binary response models.

FLCompliance Class

A compliance model has been developed for incorporation into the FLR framework. The model is designed as a FLR class, called FLCompliance, and is aimed to consider the probability of non-compliance with different management regimes. Compliance is modelled by ordered responses models as described and three different probability distributions for the error terms are available: logistic (Logit model), standard normal (Probit model) and Cauchy distributions. By using discrete choice models, a FLCompliance object is able to predict and simulate fisherman compliance behaviour both at individual and aggregate level. Specific functions have been developed to simulate the effects of changes in the variables affecting compliance on the probability of violation of fisheries regulations. FLCompliance is also designed to verify the reliability of the specified regression model and the relevance of the variables selected to explain compliance-violation decisions. Once all the input data have been stored and the model's options have been set, a number of functions (i.e. "methods" in R) are available to produce regression outputs.

Compliance implementation
A bio-economic model can never be a completely accurate description of the real system. Some amount of simplification is inevitable in any model. However, a few key components should be introduced in the model to capture the essence of the phenomenon under investigation, while all minor influences can be relegated as random effects to the stochastic error term.

The necessary approximation and abstraction included in any bio-economic model produces a degree of uncertainly in model outcomes. When the model is correctly specified, model uncertainly can be straightforward managed as a stochastic error term with a known distribution. Otherwise, a model misspecification can produce, among others negative effects, an error which will be added to the stochastic error term increasing its magnitude and making unknown its distribution.

As reported in the literature review, the level of compliance with regulation represents a relevant component in measuring the outputs coming from the implementation of management measures. This component should be incorporated in bio-economic models, especially when they are devoted to evaluate fisheries regulations. Non-incorporation of fishermen's compliance in bio-economic models can determine a specification error in the model, increasing model stochastic error and consequently model uncertainty.

Within the COMMIT project, a compliance model has been incorporated in the structure of the bio-economic model used to measure the effects of management measures on fisheries status. In that scheme, commitment is supposed to be influenced by a group of variables related to *economic status*, *education* and *stake*. The direct effects of management regulations on the variables belonging to the operating model are then corrected taking into account the simulated level of compliance.

The structure of the compliance model presented in this report is very similar to that proposed in the literature. However, a few changes have been introduced with respect to the definition of the variables affecting compliance and to the impact of management procedures on the level of compliance. As discussed previously, six groups of variables are supposed influencing compliance in this model. Actually, only *legitimacy* is introduced ex novo, while *personal characteristics* substitutes *economic status* integrating that group with other potential explanatory variables, *moral and social influences* seem to be more directly associable to compliance than *education*, while the use of *incentives* and *deterrence* allows for identifying better stakes affecting fishermen's behaviour.

A significant change is related to the description of the effects of management procedures on the variables affecting compliance. Compliance is not independent from the typology of management measure imposed. Some typologies of regulations are subjected to violation more than others for a multiplicity of factors. These factors can be measured in terms of *incentives*, *deterrence* and *legitimacy*. The vessel's earnings reduction from complying with the regulation, the perceived probability of detection when violating, the legitimacy associated to the measure are all factors depending on the specific management regulation adopted. Furthermore, one management measure can be implemented in different ways. For example, modifying the value of TACs in quotas regulation could reduce the financial incentives to violate, and setting TACs in agreement with fisheries industry could increase the legitimacy associated to the measure.

The incorporation of compliance in the bio-economic model eliminates the specification error, but not the stochastic error associated to the estimation of the level of compliance. However, if the compliance model is correctly specified, this error can be measured and opportunely managed.

Within the structure of the bio-economic model, a compliance model should produce a correction factor for the effects of management regulations on the variables included in the operating model. Actually, the described compliance model can estimate the probabilities of violation on an interval percentage scale. When a binary probit or logit model is employed, the model calculates the probabilities for two possible choices, compliance and violation. These probabilities can be used to measure the number of vessels which violate the regulation, but are unable to provide information about the level of violation.

A possible measure of the level of violation and the related correction factor applicable to management regulations can derive from the adoption of an ordered responses model. Assume that probabilities of violation p_i are calculated for a four ordered responses model, where responses are labelled V_i (Table 3).

Table 3. Probabilities of violation p_i are calculated for a four ordered responses model.

Response	Probability	Level of violation
$V_1 = 0$	p_1	<=0% TAC
$V_2 = 10$	p_2	>0% and <=10% TAC
$V_3 = 20$	p_3	>10% and <=20% TAC
$V_4 = 30$	p_4	>20% TAC

If the model estimation is obtained by a random sample representative of the population under analysis, probabilities p_i are equivalent to the percentage of vessels which violate at V_i level. Even if an ordered responses model is more detailed than a binary model, a discrete choice model cannot directly produce a specific value for the level of violation. Probabilities p_i are not associated to a single value, but to an interval of possible values. For example, p_2 is associated to a level of violation between 0% and 10% of TAC. This approximated measure includes an additional error whose magnitude depends on the robustness of the hypotheses assumed. However, data used to estimate the compliance model can be employed to reduce as much as possible the error associated to its incorporation in the bio-economic model. This could be obtained by setting appropriate intervals, identifying the distribution of data within the classes and testing the relative hypotheses.

Another source of model uncertainly can be associated to the simulation step. In any standard bio-economic simulation model, like that proposed in the project, the measurement of the error should be distinctly evaluated during the estimation and simulation steps. While during the estimation step all data are available, during the simulation only the endogenous variables can be estimated and updated by the model. The exogenous variables, instead, are generally supposed as constant or simulated through parametric approach (changing arbitrarily their values to verify the resultant effects on relevant outputs).

In the compliance model, only a limited number of explanatory variables can be effectively internalised in the bio-economic model. Within the group *personal characteristics*, variables related to the economic status of the vessel can be internalised because profits are estimated in the operating model. Variables associated to *incentives*, *deterrence* and *legitimacy* can be partially updated along the simulation because influencing by management procedures. On the contrary, variables measuring *social and moral influences* cannot be updated. They are exogenous variables which can be managed as constant in the model.

Exogenous variables affect not only the compliance model, but each bio-economic model component. For example, fuel price is an exogenous variable in the economic component. It cannot be internalised in the model even if fuel represents the most relevant cost in many fisheries. As changes in exogenous variables cannot be simulated, their variability reduces the model predictive capacity and increases the model error.

Discussion
Compliance with fisheries regulations depends on the interaction of many sociological, psychological and economic factors. These factors have been summarised in those describing the fisherman and the vessel, factors relating to financial incentives and deterrence, factors concerning moral norms and social influence, and factors concerning the legitimacy of regulation. The objective of modelling compliance is to understand the causes of non-compliance by identifying the factors affecting the most fishermen's behaviour. This is undertaken by collecting survey data by questionnaires and employed discrete choice models, like Logit or Probit model, which are widely used in econometric analysis to evaluate categorical variables.

This approach has been used in few studies to evaluate the probability of compliance and the variations in these probabilities due to changes in the explanatory variables. For example, Hatcher and Gordon (2005) showed that the level of compliance with quotas regulation in UK is driven mainly by economic incentives; while Gambino *et al*. (2003) identified social influence, judgement about the regulatory system, moral influence and judgement about the enforcement system as the variables more affecting compliance with the regulation on minimum distances from the coast in Italy.

As these studies have demonstrated, probabilities of compliance are strictly related to the management measure under investigation. Some typologies of regulations are subjected to more violation than others for a multiplicity of factors. For example, the complexity in the activity of deterrence or the higher costs of enforcement, the lower degree of legitimacy associated to the measure, which incentives fishermen to violate, etc. When evaluating different management measures, especially by using bio-economic models, the degree of compliance with these measures cannot be ignored. A bio-economic model cannot be used for producing scientific advice if it is not considered a valid depiction of the system modelled, and compliance is a relevant part of this system. Nevertheless, to date, compliance models have not been incorporated in any fisheries bio-economic model.

Within the models used for management purposes, it is particularly important to check that the model output has an 'error' within reasonable bounds. Ignoring compliance in bio-economic models can increase the model error, measured by comparing simulated and actual outcomes, and so the uncertainty in the model outputs. Non-incorporation of compliance behaviour in bio-economic models is one of the factors determining model risk and uncertainty. When perfect compliance is assumed, the simulated outcomes from a management policy are likely different from the actual outcomes. This represents a typical case of implementation error as fishermen respond differently than is assumed in the model. The analysis of compliance with UK fishing quotas by Hatcher and Gordon (2005) showed that only 20% of the sample fully complied with regulation. In this case, assuming perfect compliance determines inevitably an increase in model error and consequently in model uncertainty. The non-incorporation of a compliance model can be interpreted also as a misspecification of the bio-economic model, and therefore as a modelling error.

A second potential impact on the model bias can be derived from the measurement error. For example, under output control regime, non-compliance can result in underestimates of landings because of not declared illegal landings. For the same reason, under input control regime, it can determine an underestimation of the effective fishing effort. The use of underestimated data in bio-economic models can lead to an incorrect parameter estimation and, potentially, incorrect model results. A compliance model, like any other component in a bio-economic model, can be also be affected by process error. This type of error can be associated to the presence of exogenous variables, whose variability cannot be simulated by the model. As models are unable to capture the effects of changes in exogenous variables on the real system, their variability reduces the model predictive capacity and increases the process error. Variables measuring moral and social influences are examples of exogenous factors within the compliance model. However, variables belonging to other groups, like incentives, deterrence and legitimacy can be significantly affected by exogenous effects.

1.5.4 Methods for conditioning models to data

COMOD is an acronym that stands for **c**onditioning **o**perating **m**odels **o**n **d**ata. Alternative terminology in use includes: specifying operating models, seeding operating models, fitting operating models to data.

We need to condition operating models on data for two reasons: so that we can run forward projections of the population dynamics that provide plausible predictions of the potential outcomes of alternative policy options and so that we can explore responsiveness of the management measures to our uncertainty about the true state of the real world and quantitatively take into account the weight of evidence in support of the plausible alternative hypotheses.

There are various approaches in use. Below, we summarise different methods to condition operating models on data, discuss practicalities involved, such as data requirements, cite advantages and drawbacks of different conditioning methods and give examples of their use. Furthermore, we present and discuss developments within FLR that might facilitate conditioning operating models on data during the course of this project and in the future use of FLR.

Methods: Operating models usually are more complex than population models used in stock assessment, albeit this is not the case with the Baltic salmon. Operating models hence contain more parameters than population models in stock assessment, and bio-economic operating models may contain parameters that are hard to estimate, for example because of insufficient economic data. We distinguish between two types of approaches that produce parameter values for the operating models: direct and indirect. Furthermore, the indirect approach is subdivided into statistically consistent and inconsistent.

We state that the direct approach is taken when the fully-fledged operating model is fitted to data directly. When operating model is complex it may be an impractical route to take, demanding too much time and resources from the researchers. Nor is it necessarily the best in a statistical sense, as it could mean fitting an over-parameterised model to an insufficient set of data.

Alternatively, we could rely on analysis of simpler model or models to provide a measure of uncertainty for the corresponding parameters in the operating model. For instance, we could use a VPA based stock assessment output, in combination with economic analysis and/or stock-recruit analysis. These methods to specify an operating model we classify as indirect.

Why differentiate between the two approaches?
The answer is for both theoretical and pragmatic reasons. Theoretical reasons include the issue of consistency. In the indirect approach, the model

assumptions in a separately conducted data analysis could differ from the assumptions in the operating model. For example, in VPA, XSA, ICA, CSA and other similar methods the catch-age data are utilized in an algorithm that projects the cohorts backwards in time and the stock-recruit relationship is not modelled within the cohort analysis.

Pragmatic reasons are that fitting different models by different methods to the same data can yield different estimates. For instance, the estimates of number at age, fishing mortality at age, spawning stock biomass under standard ICES methodology could differ from the same things estimated in a direct approach of fitting operating model to data via either frequentist or Bayesian statistical catch at age or mark-recapture analysis.

These differences could affect the conclusions of the management strategy evaluations. There could be unforeseen implications for the management strategy evaluation performed under different conditioning methodologies for the same operating model. Using FLR comparisons can be made between the outcomes that result from conditioning operating models on data in different ways.

Next we describe various methods to achieve statistical consistency between operating models and available data. We present methodology in order of difficulty.

Methods currently available:
Conditioning of models based on stock assessment methods such as tuned VPA could be augmented by stock – recruit analysis such as MLE or bootstrap methods (these can actually use tuned VPA series output as input). In FLR, we could use MCMC or other Bayesian techniques to incorporate uncertainty about stock-recruit relationship into simulation evaluations. The tuned VPA results could be viewed as prior beliefs about abundances, etc; S-R analysis helps to better characterize the potential relationship between recruitment and spawning stock, the potential variability in recruitment and potential autocorrelation in recruitment that may be useful in predicting future recruitments. In FLBayes, there are Bayesian stock-recruit routines for all the S-R models in the FLSR class in FLCore; FLSR employs only MLE methods when using FLCore alone.

In FLBayes, there is also a class called FLSP, for fitting both MLE and Bayesian MCMC Pella-Tomlinson production models. We urge fitting an MLE model and looking at the diagnostics before fitting a Bayesian one. The age-structured Bayesian MCMC assessment models are the latest aspect of FLBayes, utilising various types of relative/absolute abundance data, and hopefully mark-recapture data later on.

The future:
Statistical catch at age methodology can be used as a stock assessment or to fit operating models to data directly. (References for statistical catch at age methodology: Quinn/ Deriso Quantitative Fish Dynamics, Dave Fournier, Archibald, John Sibert). There is particular software called CASAL (that uses

Bayesian statistical methods as well as frequentist) that is good at catch at age and there are discussions with the developers to incorporate CASAL into FLR. CASAL can provide point estimates as well as Bayesian probabilistic estimates that are particularly useful in taking into account parameter and model uncertainties for management strategy evaluation.

Finally, there are Bayesian approaches ranging in complexity. Baltic salmon is an extreme case, where a very complex operating model has been fit to a variety of data sources in sequential, but integrated analysis. The preference has been for statistically consistent conditioning of operating models using Bayesian methods, examples include: Mackerel, Baltic Salmon, and Irish Sea Plaice.

Evaluating plausibility of alternative operating models

Having discussed how to condition individual operating model on data, we move on to consider several alternative operating models at once. Conditioning models on data is linked with the problem of evaluating plausibility of different models. There are also many approaches to this problem, we describe several. It is hard to recommend a particular approach as it depends on the information available and on the statistical analysis undertaken for the purpose of specifying operating models.

The simplest approach is to assign equal probability to alternative models. This is a straightforward option if there is no information that suggests that some models are more plausible than others. If there is biological knowledge, for example information about the habitat, behaviour (such as cannibalism or schooling behaviour), but no data that could enable to statistical analysis, it is possible to rely entirely on expert opinion.

It is sometimes possible to utilize criteria such as DIC, BIC, AIC which could be computed by various software packages - these calculate relative goodness of fit of the model to data, and hence enable comparisons among alternative models. However, these values are usually employed to choose the best model. It is difficult to interpret these values for the purpose of assigning weight to alternative operating models. At best, goodness of fit criteria can serve as guidance to expert opinion on judgement of weights.

The formal Bayesian way of evaluating plausibility of alternative models fitted to the same data is to calculate probability of the model given the data. The marginal posterior probability of the model given the data can be approximated using a few different numerical methods.

The probability of the data given the model which is required to compute the posterior of the model can be obtained by, for example:

- Under MCMC, the harmonic mean of the likelihood function (as used in Michielsens and McAllister 2004, hierarchical meta analysis of stock-recruit data to provide marginal posterior probabilities for the Beverton Holt and Ricker stock recruit models)
- Under MCMC, reversible jump, such that the chain is set up to jump across the different models (applied by Patterson 1999)

- Under SIR, average of the importance ratios computed for each model (used by Cunningham 2002 (Atlantic mackerel management strategy evaluation), McAllister and Kirchner 2002 (Risk analysis of Namibian orange roughy exploitation)).

In the Baltic salmon analysis of which stock-recruitment function describes the data better – Ricker or Beverton and Holt, Michielsens used the harmonic mean approach to calculate the probability associated with these two model assumptions. This is the easiest to implement since all you need to do is record the likelihood function in each MCMC iteration and then take the harmonic mean of all likelihoods in the chain. The main problem with this approach is the tendency for numerical instability when very tiny likelihoods are encountered within the Markov chain.

Data quality:
Other issues that arise during conditioning operating models on data include data quality concerns. An issue that arises often is that scientists may suspect or belief that the quality of time series data changes significantly overtime. It is also often difficult to estimate such changes using available data. One suggestion is to incorporate different hypothesis about the biases in data into alternative operating models.

In some North American fisheries concerns over deteriorating quality of fishery dependent data were alleviated by calibration of the fishery data series using fishery data gathered by on board government sponsored observers (the data in question was fisher log books). Moreover, in Alaskan fisheries, catch misreporting is minimized because it is a requirement for all trawlers to have on board government sponsored scientific observers.

1.5.5 Case studies

Various results from all the case studies have been presented at ICES working groups as well as dedicated STECF study group meetings focussing specifically on the evaluation of multi-annual management plans for North Sea sole and plaice (the flatfish) and Northern Hake. Furthermore, various presentations have been made at international conferences.

Only a brief explanation is provided for each case study in terms of progress, as this is a final publishable report that does not contain detailed technical information. For each case study the management objectives and potential utility functions are presented. Secondly, the main sources of uncertainty are presented together with the Robustness Trials to be evaluated along with the Bayesian Belief Networks. The aim of the robustness trial is to investigate the behaviour of alternative management procedure under a range of operating conditions and assumptions about stock and fleet dynamics.

Therefore to re-iterate, setting up the operating models and evaluating the robustness trials required us to:

i. specify appropriate management objectives and utility functions

ii. specify the control options
iii. identify the main sources of uncertainty
iv. integrated the economic and biological models
v. condition the operating models and assign appropriate prior probabilities to them
vi. implement appropriate models in the FLR framework
vii. build the Bayesian Belief Nets

Please note in the outline of the operating models for each case study numerous options are presented for evaluation as there are an infinite number of alternative possibilities in terms of types of models, their specification, options for observation error models and various means uncertainty can be included and evaluated. In reality only a sub-set of the above was evaluated for each case study, thus interested parties should read the published analyses in each example to see the exact form of the model, all the inputs and assumptions made.

Before the final BBNs are presented a precise description of each case studies' current management procedure is provided. Each Management Strategy Evaluation (MSE) for each case study (Baltic Salmon North Sea Flatfish and Northern Hake) has a potential infinite set of alternative candidate management procedures.

The basis of choosing a combination of alternative management procedures (where each includes the option for alternative assessments, harvest control rules as a sub-set of management strategies) is based on the overall objectives of the project: to evaluate multi-annual management plans. D7 outlines the *current management procedures* in detail. Often alternative management procedures are deviations (often not extreme) of current management procedures. Therefore they are only outlined in brief.

More importantly in two cases (Flatfish and Northern Hake) alternative management procedures are those that have recently been proposed by the Commission, and followed up by a RAC meeting (NSRAC and NWWRAC). Furthermore, the results of the analyses were presented at STECF meetings (see Dissemination and use).

1.5.5.1 North Sea Flatfish

1.5.5.1.1 <u>Objectives, Operating Model and Robustness trials</u>

Management objects and utility functions
The relative value of the different objectives is a management decision and BBNs are used to allow managers evaluate the outcomes of different actions. Generic management objectives are to maximise profit or yield from the two fisheries, ensure relative stability between fleets, maintain employment levels, reduce discarding of plaice in the Southern North Sea fishery, reduce overcapacity in the sole directed fleets and to ensure sustainability of the sole and plaice stocks. Utility functions allow for the evaluation of these multiple

objectives in the short-, medium- and long-term as well and the trade offs between them. Utility functions are based upon the following statistics

- Biological: lowest and average ratio to the carrying capacity or virgin biomass. (with equal weight sole and plaice)
- Economic: NPV (used in dynamic models with indication of the number of years used. 3 measures: STA, MTA and LTA with equal weight for all (STA: short-term average, MTA: medium-term average and LTA: long-term average).
- Commitment: reflecting a balance between resource and capacity (e.g. STECF WG). Include probability of non-compliance, with a functional that is: benefits subtract the probability of detection multiplied by the expected fine plus an additional factor to account for social norms.

Note the details of the management objectives were modified after consultation with the RAC. It did not affect the final robustness trials.

The biological part of the Flatfish operating model is based upon the ICES WG perception (i.e. stocks numbers, and weight-at-age etc. are taken from the ICES North Sea WG) and the operating models developed in projects such as FEMS. The economic/fleet model for the North Sea flatfish case study is based upon the Netherlands, Danish and the United Kingdom fleets. A simple fleet structure of two fleets, corresponding to a Northern fleet large mesh fleet targeting plaice and a Southern small mesh fleet targeting sole is being used initially. Utility functions reflect the management objectives both of the ICES scientific advice framework and of the North Sea Regional Advisory Committee. Models for selection, discarding, misreporting, fleet behaviour and external drivers have been incorporated into the FLR framework.

Control options are based upon

- ICES advice framework: Based upon single species TACs the main objective of which is to ensure that spawning stock biomass (SSB) remains above a threshold at which recruitment may be impaired and that fishing mortality remains below a threshold level that would drive the stock below the biomass threshold. In addition mesh regulations intended to reduce bycatch of plaice in the Southern North Sea sole directed fishery
- Management options and objectives proposed by the North Sea RAC: these are being specified in consultation with the chair of ACFM and form the basis of the scenarios evaluated.

Main sources of Uncertainty and Robustness trials
Robustness trials are being undertaken by considering the level of complaince, levels of discarding and mis-reporting, price and cost scenarious, alternative models for exist/entry, growth, catchability and stock-recruitment. The details are reviewed as: *Level of compliance (*either High, Medium or Low); *Discarding and misreporting (*Based upon the minimum landing size, Based upon Van Keeken estimates for plaice, TAC-based discarding of plaice (likely to be based upon sole TAC), TAC-based misreporting); *Price scenarios (*Constant, Price flexibility, Species-specific price change); *Cost scenarios (*Constant, Fuel price related); *Catchability (*Mesh size, Area closures, Stock changes); *Growth model (*High growth rate, Low growth rate, Increasing

growth rate (inverse of historical trend), Decreasing growth rate (matching historical trend), Density dependent growth); and *Stock-recruit model (*Beverton and Holt with different resilience levels, Beverton and Holt with different carrying capacity levels, Beverton and Holt with temporal changes in carrying capacity).

Various sources of uncertainty have been evaluated on the references points for these two stocks, prior to a full MSE being undertaken. The study considered the biological and economic impacts if moving from a single-species reference point-bases system for plaice and sole to one based on targets that explicitly take account of the multi-stock multi-fleet characteristics of the fisheries (see TEXT BOX 5).

TEXT BOX 5

Can economic and biological management objectives be achieved by the use of MSY-based reference points? A North Sea plaice (Pleuronectes platessa L.) and sole (Solea solea L.) case study

Graham M. Pilling1*, Laurence T. Kell[1], Trevor P. Hutton[1], Peter J. Bromley[1], Alex Tidd[1] and Loes J. Bolle[2]

[1] Cefas, Pakefield Road, Lowestoft, Suffolk, NR33 0HT, UK
[2] Institute for Marine Resources & Ecosystem Studies, PO Box 69, 1970 AB Ijmuiden, The Netherlands.

We examined the biological and economic impact of changing from a single-species limit reference point-based management system to one based upon targets, using the multi-species multi-fleet North Sea flatfish fishery as an example. Robustness of candidate reference points was tested against identified changes in plaice and sole stock productivity and resilience. Biological and social objectives need to be considered as MSY, maximum economic yield and levels needed to maximise employment imply different profit and employment levels, and hence require decisions on the relative importance of fleets and species. In contrast, Ftarget could be achieved with equal effort reductions within both fleets. While changes in stock productivity and resilience affected the effort levels required to maximise employment, MSY Fmax and MEY targets were robust to this uncertainty, but resulting profits and yields did vary widely. Current ICES limit and precautionary biomass and fishing effort reference points were seldom consistent, and although generally robust to biological uncertainty, could result in stock collapse under particular biological scenarios. Adoption of suitable target reference point levels would reduce reliance on these reference points, but requires managers to explicitly define fishery objectives against which targets can be evaluated.

Implementation of models in the FLR

The implementation model has the following characteristics:
*2 species 2 fleets (north and south, combined Dutch-UK fleets with simplified economic model).
*No fleet adaptation. Equilibrium model. YPR/SPR – SRR estimates with BH.
* Catchability estimates. Equilibrium used to define the long-term target.

The following series of steps leads to the completion of the dynamic form of the full-feedback evaluation:

a) Included fleet data into FLEcon

b) Set up FLOMSex.
Assumptions: (1) discarding based on MLS. (2) Sexual dimorphism (3) discard due to over TAC catches. No high-grading. In the current model the landings of OM are the landings as exactly used in the MP, no sampling error
c) Perform a VPA (which has been done using FLXSA)

d) Set the whole single-species TAC at year t+2 (which as been done using FLSTF [one fleet] + FLHCR (setting objectives, e.g. Fpa)

e) Share the TAC by species among the two fleets or amongst the two areas based on relative stability.

f) Determine what is the level of effort BY SPECIES corresponding to this share for each fleet: catches / catchability (fleet, species) and compute the actual level of effort of the fleets corresponding to these mixed-species shares (e.g. The south fleet catch all its share of sole and discard the plaice, the north fleet do the opposite).

1.5.5.1.2 Summary of the Management Procedure

1. Knowledge production model

a. Sampling

Market samples of North Sea plaice as well as sole are taken at Belgian, Danish, Dutch, English and Scottish ports to generate fleet-specific age-length keys (ALKs), fish weights-at-age in the landed catch and weights-at-age in the wild stock. Total official landings are collated by country and then converted into catch numbers using ALKs by fleet. The aggregated data are used annually by the ICES North Sea Demersal Working Group to provide estimates of plaice and sole abundance and fishing mortality by age. Although no quantitative information is available, misreporting is not thought to be large. Large numbers of small plaice caught during the trawling operation are discarded.

The EASE project ((EASE Q5CA-2002-01693)) estimated that the total cost of scientific support to the current fisheries advisory system to be about 1% of the value of landings at first sale, of which the demersal fisheries in the North East Europe are an important part. This implies that the sampling and survey effort for the North Sea demersal stocks is relatively higher than for other stocks, but this is not considered as being too problematic.

Variability of sampling:
Sampling protocols where bootstrapping methods were applied to the market sampling data to estimate sampling precision are reported in by O'Brien *et al*.

(2001) for plaice and these were used here. The same methods were applied for sole (Kraak and Pastoors, 2004). The effect on the assessment of sampling error was also evaluated and compared to sampling error from RV surveys by Kell *et al* (2003a), who in addition characterised the measurement error distributions. Log landed numbers-at-age showed weak positive correlations between adjacent age. The CVs for log weight-at-age were roughly twice as precise as for numbers-at-age. Plaice showed a clearly linear relationship between log sampling variance and log mean numbers-at-age. The relationship was less clearly linear for log weight-at-age. This is to be expected since weight is a power function of numbers. The log variance of weight-at-age showed a negative linear relationship with log mean numbers-at-age. The correlation matrices for catch numbers and mass-at-age and the mean variance relationship were used by Kell *et al.* (2005b) to model measurement error.

Discarding

Discarding of sole is thought to be minor. However catches of undersized or over quota plaice, which are subsequently discarded, are known to be an important source of unaccounted mortality in ICES North Sea plaice population estimates. Estimates of discards are available from the Report of the Study Group on Discards and By-Catch Information (ICES, 2002) by sex for the years 1999-2001. Van Keeken *et al*. (2004) calculated that around 90% of the catches in number were discarded. While Kell and Bromley (2004) analysed ICES discard data and showed that the probability of being discarded depends largely upon size and that due to the lower growth rate of males a greater proportion of males are discarded compared to females. In addition discarding of plaice is also affected by the behaviour of the fleets targeting sole since sole is less abundant than plaice but more valuable and so that plaice catch may be driven by sole effort.

There are therefore alternative but equally plausible hypotheses about discarding processes and how landings data are generated but a lack of knowledge does not allow the correct hypothesis to be identified

> H_1: Plaice discards as estimated by Van Keeken (these are combined sex although discarding is sex specific due to differences in biology and behaviour).
>
> H_2: Plaice below minimum size discarded.
>
> H_3: Plaice fishing mortality driven by sole effort, only landings reported.

Modelling in base case

In the base case, random observation error with a CV of 10% were used for both landings and discards.

Biological data used in the MP

From the working group weights-at-age it can be seen that the growth is linear up to age 15 (the plus group in the assessment) although there have been trends over time. There are strong year class effects. The change in the residual patterns between the early and the rest of the time series is probably due to changes in the way the data have been worked up rather than to any biological phenomenon.

Male and female plaice exhibit sexual dimorphism in growth, maturity and catchability (Figures 14 and 15), which can impact severely on perceptions of the status of the stock, particularly if the discarding of small fish by the fishery is not taken into account in assessments (Kell and Bromley, 2004).

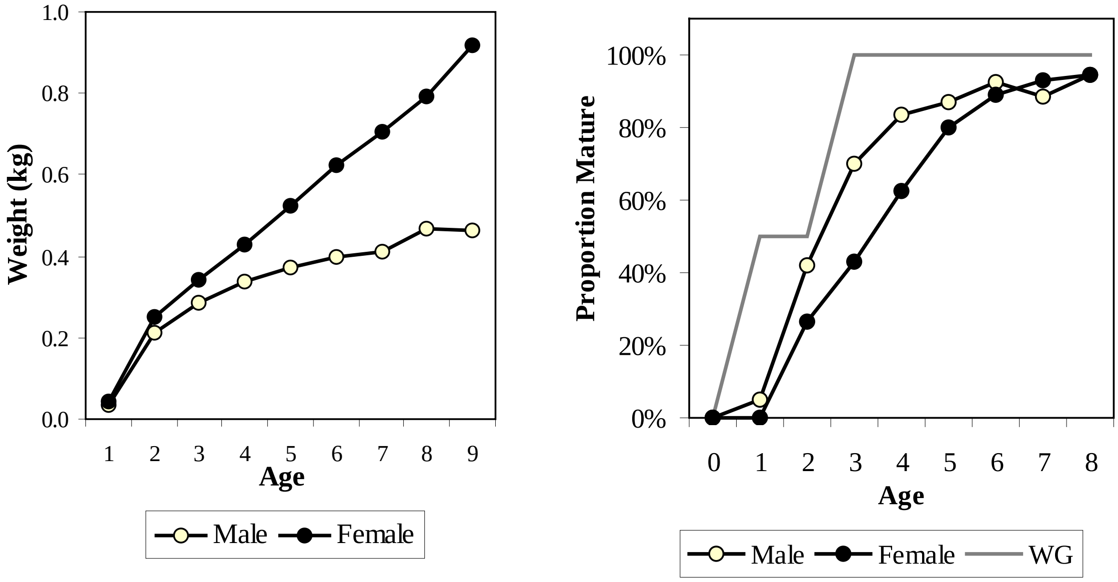


Figure 14. Mean weight- and proportion mature-at-age of male and female North Sea plaice.

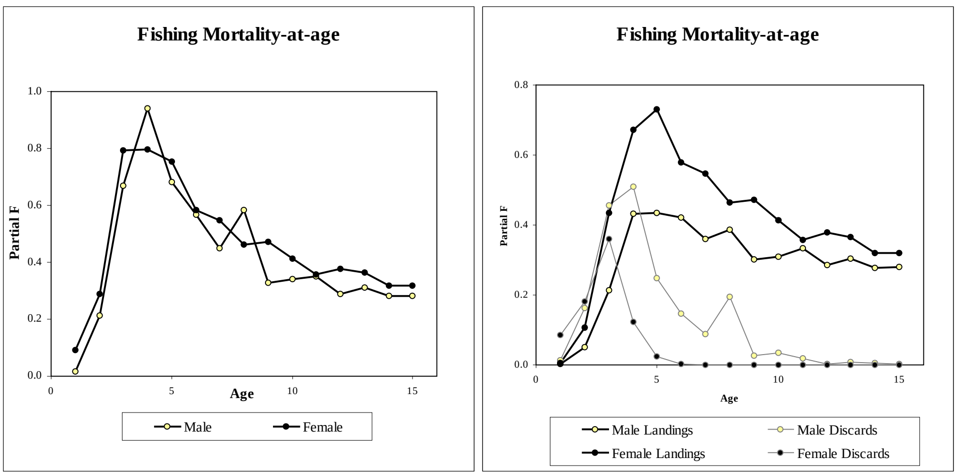


Figure 15. Selectivity-at-age, left panel shows total including discards, right-hand panel show mortality partitioned in to discards and landings.

Kell and Bromley (2004) showed that density dependent sexual maturation may be important at low stock levels in providing resilience to stock collapse. They also showed that productivity of the stock can vary over a time scale of 10-15 years and can have a considerable impact of the estimation of biological reference points.

Although plaice in the North Sea is currently managed as a distinct stock a long history of research into plaice movements and abundance (Bolle *et al*. 2005, Hunter *et al.* 2004a, 2004b leaves the biological integrity of this management division open to question. Kell *et al* (2004) evaluated through simulation, the consequences for the current scientific advice framework of ignoring migratory behaviour of plaice between the North Sea and the Eastern Channel. Results indicate that the effects of stock mixing can generate considerable bias in the perceived state of a stock relative to its true state and that changes in the management applied to one stock may cause changes in the level of bias for neighbouring stocks. However, it was concluded that improved management will not necessarily be achieved by developing increasingly complex spatial and temporal assessment methods but rather by developing simple but robust management strategies that have been evaluated before implementation against plausible hypotheses about the dynamics of the stocks and fisheries to be managed.

b. Assessment

Method and data used, tuning fleets

Plaice and sole are assessed using the single-species stock assessment method XSA (eXtended Survivors Analysis; Shepherd, 1999). XSA is a calibrated variant of virtual population analysis (VPA). The method re-creates a stock's historical population structure from the catch-at-age matrix. Recruitment estimates of the survivors after the last year of data were replaced using calibrated regression estimates of survivors (RCT3; Shepherd, 1997). Catch per unit effort (cpue) data were used to calibrate the assessment model.

Commercial CPUEs and their derivation

Commercial CPUEs are no longer used to calibrate VPA but a comparison of these to RV survey indices would be informative. There are two RV survey indices, the Dutch beam trawl surveys and sole net surveys:

BTS ~ 3rd quarter Dutch beam trawl survey (1985-2000)
SNS ~ 3rd/4th quarter Dutch sole net survey (1982-2000)

Details of these surveys, including fishing stations, gear, etc. are available in the EVARES report (EVARES - FISH/2001/02 - Lot 1) along with a wide range of analyses. Including a bootstrap analysis which allowed the precision of the indices and their influence on the stock assessment to be evaluated (Kell *et al*, 2003a). In 2004, discards were included in the assessment for the first time.

Historical performance of the assessment: prognosis vs. historical assessment

Historically the assessment of sole has been more consistent than the assessment of plaice. Large patterns of over-estimation of SSB in the last year of assessment have been observed (Figure 16). In 2004, the assessment was fully revised and the F and SSB-estimates cannot be compared to previous years.

Figure 16. The trends of SSB and F for Plaice and Sole in the North Sea

Modelling in the base case

Only the BTS survey index was used in the base case, and was simply simulated as being a fraction of the stock in the OM with an observation error with CV 10%.

Method for ICES advice: e.g. Forecast assumptions and inputs, the precautionary approach. What is the basis for reference points?

Management advice for both plaice and sole is provided by the Advisory Committee on Fisheries Management (ACFM) of the International Council for the Exploration of the Sea (ICES), primarily on a single-species basis and based on virtual population analysis (VPA). The objective is to ensure that spawning stock biomass (SSB) and fishing mortality (F) remain above and below threshold values (B_{lim} and F_{lim} respectively). Precautionary reference points (B_{pa} and F_{pa}) are used to take into account uncertainty in assessment and management based upon an arbitrary assumption about stock assessment uncertainty. Within this framework, B_{lim} is the SSB below which either recruitment is impaired or the dynamics are unknown, and B_{pa} is a trigger to ensure that management action is taken before B_{lim} is reached. F_{lim} is the fishing mortality that will drive the stock to B_{lim}, and F_{pa} the precautionary reference point which F should not exceed in order to take into account uncertainty. The reference points are fixed values (rather than an algorithm such as $F_{0.1}$), and they have been derived in a variety of ways under different assumptions about uncertainty.

Modelling in base case
In the base case, ICES advice is implemented with FLSTF class and usual HCR based on the precautionary approach.

c. Economic advice

- *Methods : EIAA, by method as presented by Oostenbrugge (TEXT BOX 3)*
- *Modelling in base case*

The main fleets involved in North Sea Flatfish fisheries are included in the economic advice performed by STECF with the EIAA model, which calculates the global economic consequences of the single-species TACs. This is not modelled in the base case.

2. Management decision model

a. From advice to TAC

Difference between scientific advice and actual TAC: Is there a systematic or random (or at least not modellable) deviation?
Historical variations in the TAC. Is the TAC constraining?
Management is implemented as a stock-specific total allowable catch (TAC) corresponding to a fishing mortality level that will ensure that SSB remains above or recovers to the precautionary biomass level (B_{pa}). The current advice framework assumes near-perfect knowledge of population dynamics, and ICES reference points are fixed, explicitly assuming that no change in productivity occurs.

The TAC for both sole and plaice have been fluctuating strongly since 1982. However the year-to-year variation in the TAC stayed within a 10% bound half of the years (see Figure 17).

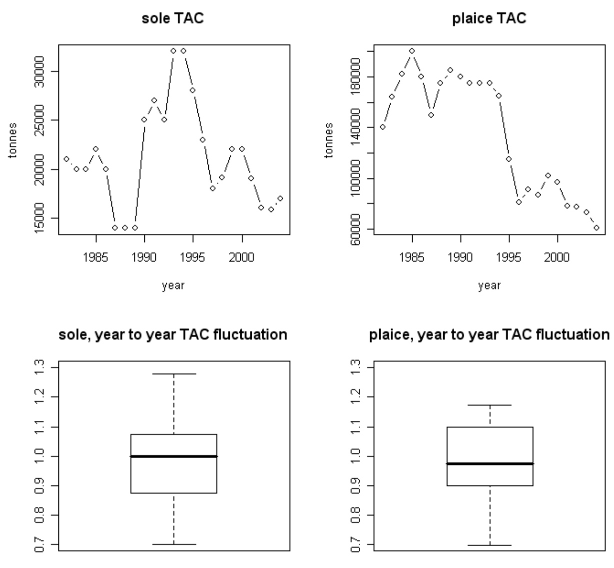


Figure 17. The TAC for both sole and plaice and the year to year variation in the TAC.

Up to the early nineties the landings of sole have exceeded the agreed TAC, while the TAC for plaice was not restrictive, but since 1995 the ratio of WG landings estimates to TAC has been more stable and close to 1, indicating a potentially restrictive TAC (Figure 18).

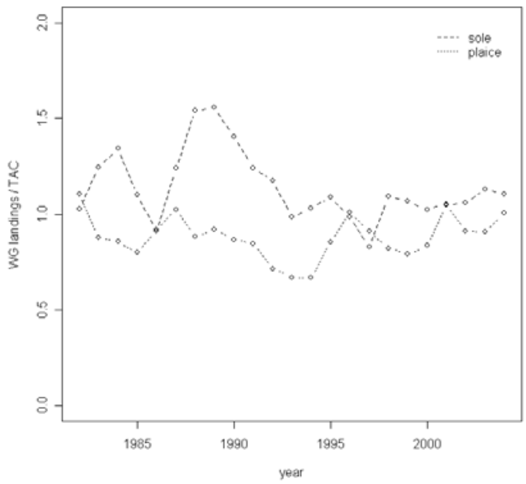


Figure 18. The ratio of WG landings estimates to TAC for Plaice and Sole.

Modelling in base case (e,g, is the TAC set at the ICES level?)
In the base case, no assumption is made about the difference between the scientific advice and the actual TAC, which is subsequently directly corresponding to the harvest control rules.

Other management rules

Recovery plans, time/area regulations, gear restrictions etc?
Plaice and sole are caught in a mixed flatfish beam trawl fishery and landings of sole catches are greater in the south, and those of plaice in the central and northern North Sea. Minimum cod end mesh sizes are 80 mm in the south (the boundary defined by the 55°N line west of 5°E, and by the 56°N line to the east) and 100 mm in the north.

Scientific basis for these?
Based upon distribution and catches.

Modelling in base case?
Limits on inter-annual variation in TACs. Within MATACS, single species harvest control rules were examined. The objective of the simulations was to reduce fishing mortality to the target fishing mortality level. The allowable biological catch (ABC) was derived from a ‘‘short-term projection’’. Numbers-at-age were projected through the year of assessment (for which total catch data are not yet available). Status quo exploitation pattern and mass-at-age were set as the mean of the last 3 years. A projection based on a fixed fishing mortality was then made in the following year, to estimate the ABC. The quota or TAC corresponded to the ABC, except if it differed from the previous year’s TAC by an amount greater than pre-specified limits (the ‘‘TAC bounds’’); i.e.:

If $ABC_{t+1} > TAC_t \times (1+\alpha)$, then
$TAC_{t+1} = TAC_t \times (1+\alpha)$;
Else, if $ABC_{t+1} < TAC_t \times (1-\alpha)$, then
$TAC_{t+1} = TAC_t \times (1-\alpha)$;

Otherwise,

$$TAC_{t+1} = ABC_{t+1}$$

where α is the bound on the annual fluctuation in TAC.

If the target fishing mortality was smaller than the current fishing mortality at the start of the future period, an initial transition period was implemented, where fishing mortality was progressively reduced by 50% each year until the target level was reached. There was no transition period if the target mortality was greater than the current fishing mortality.

The simulated yield in the future was assumed to equate to the TAC set by the management procedure (i.e. no implementation error). Fishing mortality was constrained so that in any year, both the annual increase and absolute level were never more than twice those that had been observed historically. If this constraint were applicable, the TAC would not be taken in that year. In the recent past, yield was as estimated by the ICES Working Groups. The fishery was modelled as a single fishing fleet, with stochastic noise on the selection-at-age.

3. Implementation model

a. Quota share

Relative stability between countries. What is the official sharing rule, what is the actual sharing? Is the relative stability stable?

For North Sea flatfish the assumption of relative stability by country can be assumed to be true (Figure 19). The negotiations and quota sales occurring across member states do not affect widely the share of landings.

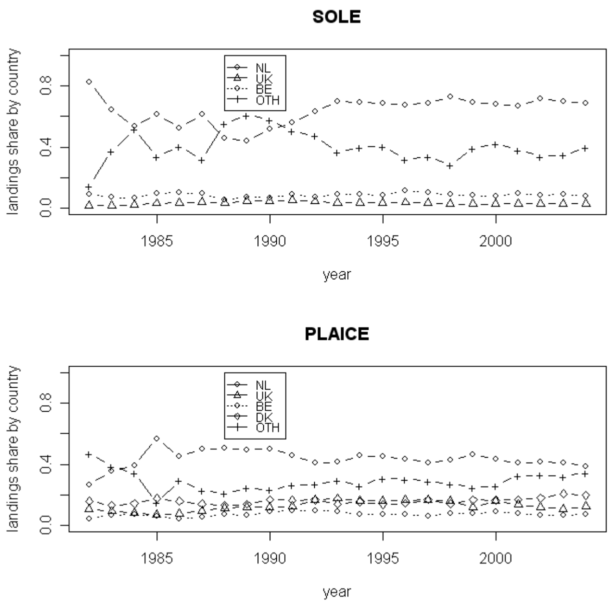


Figure 19. The landings share by country for Sole and Plaice

Quota share from countries to fleets – do we know anything about it? How does the system work in practice – rations, ITQ, others?

Pilling *et al.* (TEXT BOX 5) noted that once appropriate management targets and limits are identified, consideration must be given to distributing the resulting defined effort between the different fleets (in their study, the north and south fleets) in the fishery. One of the basic principals of the Common Fisheries Policy of the European Union is relative stability (Articles 32 to 37 of the EC Treaty; Holden 1994). Relative effort implies that both catch by stock and effort by fleet should be constant, which might be difficult to achieve in practice in mixed fisheries like the North Sea. Pilling *et al*. (submitted) showed that target values of MSP, F_{MSY} or $F_{0.1}$ in the multispecies context imply differing relative levels of effort in the north and south fisheries. The targets shown are therefore unlikely to comply with the requirements of relative stability. To achieve the majority of reference points, reductions in effort are required in both fisheries. However, effort reductions are disproportionately high in the south. This results from the high value of the southern sole catch, and the high proportion of juvenile plaice in the south that are vulnerable to the smaller mesh. As a result, plaice are susceptible to growth overfishing in the south, and discarding of undersized plaice means they do not contribute to revenue.

1.5.5.1.3 Final BBN and Multi-annual Management Plan Evaluation

The Final Bayesian Belief Network for North Sea Flatfish is shown in Figure 20.

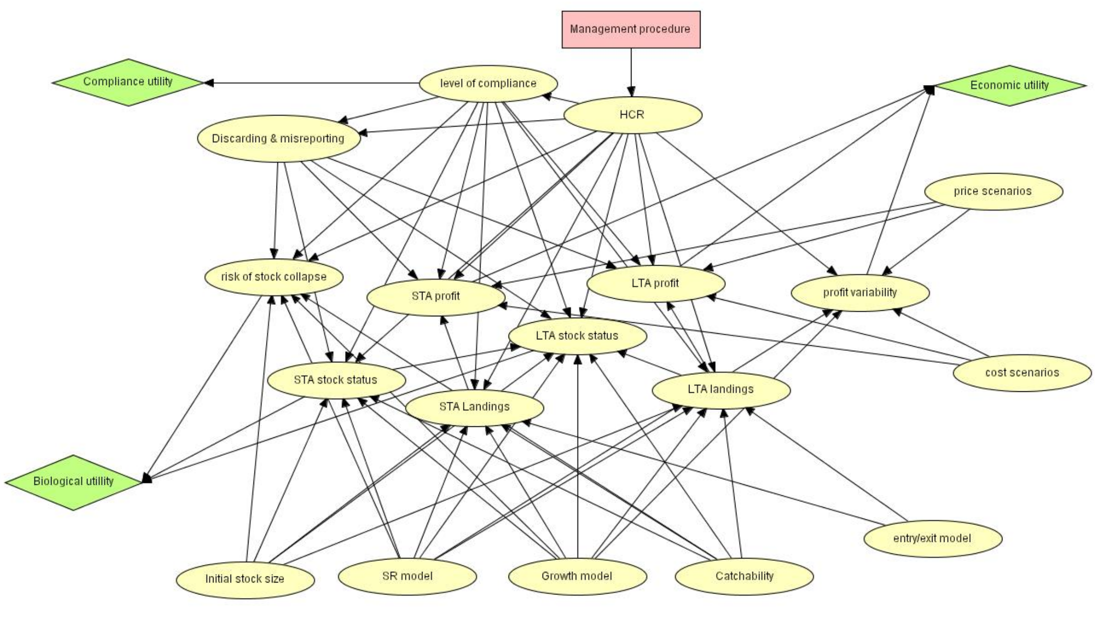


Figure 20. The updated BBN for the North Sea Flatfish case study (STA: Short-term average, LTA: Long-term average).

Alternative management procedures and evaluation of multi-annual plans

The alternative management procedure comprised of three main processes: sampling "raw" data from the underlying population; stock assessment and short-term forecast following standard procedures; and a HCR defining the appropriate management measure given the forecast. Sampling from the true population was mimicked by generating estimates of landings-at-age (sole) and catch-at-age (plaice), similar to the annual assessments for these two stocks. The catches were generated using the selectivity characteristics of the two fleets and a simple lognormal error with a relatively small coefficient of variation (CV=0.1).

The simulation contained a "true" survey that sampled from the populations of the two species using estimated catchability and selectivity patterns in conjunction with their spatial distribution. "Observed" survey catch-at-age by species was generated by applying a lognormal error (CV=0.1) and these series were used for tuning in the stock-assessment process. The stock-assessment process encompassed single-species XSA for plaice and sole, based on catch-at-age and landings-at-age data, respectively. XSA settings and short-term forecasts corresponded to those used in the Working Group. The annual decision process on effort quota was based on the short-term forecast of the SSB remaining after the year to which these would apply. This forecast was compared to the B_{lim} triggers defined in the plan. Implementation error with respect to misreporting or black landings has not been included in the simulation.

The HCR implemented in the model attempted to mimic the NSRAC management plan. The stated objective of the management plan has been formulated with reference to plaice only (documented in 2005 NSRAC meeting notes):

> "*a multi-annual management plan should be adopted for plaice in the North Sea with an initial target of reaching an SSB at the B_{pa} level within 3–5 years with a re-evaluation after 3 years and with the long term aim of exceeding B_{pa}. The plan should be implemented as of the 1st of January 2006. The management plan is aimed at reducing pressure on juvenile plaice and would comprise structural effort reductions accompanied by stability in the TAC for plaice. The multi-annual plan should be accompanied by a monitoring and evaluation scheme, which would also include the monitoring of social and economic impact*."

Therefore nominal fishing effort was reduced by 15% in 2006 compared to 2005 and this level was maintained in the following years. In the stated objective of the plan, an inherent tension exists between reducing effort while maintaining stability in TAC. This posed additional challenges to the implementation of the model.

The Dutch ministry requested an additional maximum annual change in TAC of 15% to be included in the simulations, which represented an extension of the management plan. However, the measures stated in the plan do not refer to TACs but only to decommissioning and days-at-sea limits. Therefore, TACs were not constraining the fishery in the model: the fleets simply exhausted the effort quota and reported whatever catches they generated. A two-tier system where either the TAC or the effort quota could constrain the fishery has not been implemented because the proposed HCR did not specify how the priority between such different measures should have been set. For a review of the results based on research that applied these alternative management procedures see published research (TEXT BOX 6)

Two STECF meetings were held based on Council Regulation (COM 2005 – 714 FINAL) - management plan for fisheries exploiting plaice and sole in the long term.

In 2006 a STECF meeting on the North Sea Flatfish long-term management plans (STECF/SGBRE-05-06) was held. The aim of the meeting was to analyse the robustness of different management strategies to different biological assumptions. A Management Strategy Evaluation (MSE) simulation model coded with support from the COMMIT project was used to carry out the North Sea Flatfish long-term management plan simulations. This work was extended such that in 2007 the following meeting was held: (STECF/SGBRE-07-01) Long-term management plan for sole and plaice.

The results and models presented at the STECF were based on extensive progress made during the COMMIT project. Output from this research has been published (again see TEXT BOX 6).

TEXT BOX 6

Validating management simulation models and implications for communicating results to stakeholders

Pastoors, M. A., Poos, J. J., Kraak, S., and Machiels, M. 2007. Validating management simulation models and implications for communicating results to stakeholders. – ICES Journal of Marine Science, 64: 818-824.

Simulations of management plans generally aim to demonstrate the robustness of these plans to assumptions about population dynamics and fleet dynamics. This type of modelling is characterised by specifying an operating model representing the underlying truth and a management procedure, which mimics the process of acquiring knowledge, formulating management decisions and implementing those decisions. We have applied such a model to an evaluation of a management plan for North Sea flatfish that was proposed by the North Sea Regional Advisory Council in May 2005. We focus on the construction and conditioning of operating models, which are key requirements for this type of simulations. We describe the process of setting up and validating operating models and how that has affected our abilities to communicate the results to the stakeholders. We conclude that there is a tension between the level of detail required by stakeholders and the level of detail we can provide. In communicating the results of simulations, we should make very clear how the operating models depend on our past perceptions of stock dynamics.

1.5.5.2 Northern Hake

1.5.5.2.1 Objectives, Operating Model and Robustness trials

Objectives: Maximisation of the economical and biological profitability.
Strategies:

a) Biological consideration: Hake is under a Recovery Plan. Thus, short term and long term the biomass cannot be allowed to go down under a certain Biomass limit (ICES 2006a/ACFM:01).
b) Socio-economical consideration: Reduce the over-capacity of the fleets and stabilize the variability of the profits.
c) Compliance consideration: Show how much/less fishermen lose when they do accomplish compliance. Use this analysis as a way of try to increase commitment.

Tactics:

a) Yearly variation less than approximately 15% in TAC.
b) Gradual effort reduction (Re-convert part of the fleet targeting Hake to target other species).
c) Show how long term management will lead to reduce variability of the profits (long term stability) and as a consequence maybe commitment can be increased.

Utility functions:
The utility function should be treated as a common item to be developed for all Case Studies. First task to be carried out is to identify what is required and use it as an indicator of these utilities. Table 4 lists the management measures to the evaluated in COMMIT.

Table 4. Scenarios are the Management measures to be deployed along the COMMIT project (all possible ones are included in the EFIMAS project)

Management measure	Knowledge requirements	Relevance for Hake CS	Priority (0:high)
Status quo TAC	-base case operating model	-serves as a reference to gauge the other scenarios	0
Multi-annual TAC restricting	-base case operating model -modelling the link between compliance and TAC variability (see CEMARE, Finnish Institute)	-reduces inter-annual variability in catch and profitability -link with Hake Emergency Plan accepted at the ICES level	0

Outline of Biological, fleet and fishery model. Observation Error model
The base case of Northern Hake has been defined following the assumptions of the assessment working group. Nine age classes, from age 0 to age 8 plus, a single area and yearly time steps for the simulation have been considered. In the biological model a hockey-stick relationship between recruitment and

spawning stock biomass (SSB) is considered with the inflexion point set at SSB_{lim}, over that point of SSB, recruitment will be considered essentially random. The SSB has been calculated using a sex-combined maturity at age that is constant over the years and assuming that the weight of the individuals is a proxy of the fecundity. To calculate the abundance of the older ages the recruitment and the survival equation considering a natural mortality value of 0.2 was used and the fishing mortality of each fleet is proportional to its effort is assumed, being the constant of proportionality equal to the catchability. The link between the biological and fleet model is the fishing mortality.

For the assessment we use the XSA (eXtended Survivors Analysis) model. This model considers that the data is known without error, as it is done in the Working Group, so for the observation model of the base case we simply aggregate the yearly catch data of the fleets. For the management total allocable catch (TAC) was considered calculated using the Biological References Points (BRP) used by the working group.

In the base case no interaction between the fleet and the economic factors were considered until now. The effort done by the fleet each year was assumed as the effort that allows the fleet to catch the imposed TAC. Fleets used in the model are the 4 commercial and the three surveys used in the traditional ICES Assessment Working Groups.

The next step was to combine fleet dynamics and economics. The main drawback to accomplish this objective is that just a part of the Spanish fleet disaggregated data is available for the only participant of this case study, AZTI. Thus, data for fleet dynamics and economics other than the Basque fleet is estimated/approximated. However, being the objective of this case study to test the Management Framework, estimated data could be equally useful than real one. Also, in this case study special interest is put into the sampling errors in relation to: Catch at age and Abundance Indices. Also attention is paid to the Observation & Process errors, in relation to: Stock and Recruitment relationships, growth and Effort and catchability.

Identify the main sources of uncertainty and Robustness trials.
From the definition of the Bayesian Belief Networks of the Northern Hake Case Study different sources of Uncertainty can be identified:

a) Biological parameters:
   1. Growth Model: two hypothesis can be checked: slow growth (as currently used at the WG) and fast growth (from the preliminary results of the tagging experiences)
   2. Stock and Recruitment relationship: Two options again can be tried: Essentially random and Beverton-Holt: The parameters to be adopted come from the fit to the current assessment stock recruitment data.
      For both stock recruitment models the variability around the inflexion point can be checked (Bayesian Segmented regression) and from that inflexion point a random relationship or a Beverton-Holt relationship can be assumed. Then, in possible simulations, the distribution of the values around the inflexion point can be included in the BBNs. Then,

also estimates of future Biomass are obtained for different values of probabilities distributions.

3. Natural Mortality: in the actual assessment, this is considered as constant for all ages and with a value of 0.2. At this moment, no different information on Natural mortality for different growth models is considered. However, this is something to be taken into account in the future. Thus, this node of the BBN will be kept for the future.
   In relation to robustness trials of this parameter, the other option is to simulate extreme natural mortality (values of 0.4 and even higher). Also, with different natural mortality can be checked until which age the population could reach (different longevities).
4. Initial Population/Biomass: Taken from Assessment (WGHMM) year 1974 is our initial biomass. Just natural mortality, fishing mortality and SR relationship have to be applied and from then the population can be projected.

b) Fleet parameters:

5. Effort and Catchability: different effort scenarios can be simulated for each fleet due to the very different fleet/fisheries exploiting Northern Hake. After the simulation, the result of each scenario can be included in the BBN. Then, for different effort scenarios we get different catch and consequently different Future Biomass.

c) Economic parameters:

These kind of uncertainties and scenarios can be commonly defined thought out all case studies.

6. Prices: Local Landings and Other Landings, in which imports can be included. Then, the two possible scenarios are: 1. prices acceptance (if prices are already determined by other landings: both other species and/or import...) or 2. Price determinant (if prices can be established by the industry). There is a need of identification of relevant variables used to indicate these prices scenarios.
7. Costs: Fuel cost: An increase in the cost of the fuel can be defined in 3 scenarios: stable increase, medium increase and exponential (fast) increase.

Robustness trials:

a) Included uncertainty and checked that the model ran
b) Included a CV higher in the last years and observe how the population changes
c) Use extreme values for parameters to see how the OM reacts
d) Check the above list for possible robustness trials scenarios for Hake

Integrate the economical and biological models:
This work is carried out jointly with the definition of the FLEcon and FLFleet.

Conditioning the operating models and assigning prior probabilities to them:
At the moment the conditioning of the model for the Northern Hake Case Study is based on best available knowledge, which is the XSA of the WG

assessment. Thus, the Operating Model developed can then be used with conditioning tools.

Model assumptions are related to:

1. XSA-based FLBiol
2. No spatial component in fleet or stock dynamics
3. FLXSA as assessment method (as in WG)

1.5.5.2.2 Summary of the Management Procedure

1. Knowledge production model

a. Sampling

Total landings from the Northern stock of hake by statistical area from 1961 to 2004 has been compiled from the Working Group report tables. Discard sampling does not cover all fleets catching hake. Discard rates for several fleets are simply not known. It was thus decided not to include discard estimates into the full time series of catch at age data. Length distribution of catches from 1978 to 2004 is also available in the WG reports. An annual ALK is used based on the sum of numbers at age. Since 2000 French and Spanish (AZTI and IEO) are being combined. For previous years, quarterly ALKs have been applied to quarterly catch composition for Basque VHVO bottom pair trawlers and for the Otter “Baka” trawlers of Ondarroa. For the rest of commercial fleets used in the assessment an annual ALK has been used. Three surveys are used in the assessment model as tuning fleets: FR-RESSGASCS survey in the Bay of Biscay from 1987 to 2002; FR-EVHOE survey in the Bay of Biscay and Celtic Sea from 1997 to 2003 and UK-WCGFS survey in the Celtic Sea from 1988 to 2004.

Modelling in base case

In the base case no sampling error is considered, so no sampling process is simulated. For the historic part, the effort of the fleet is conditioned to produce the catch-at-age matrix used by the working group in the assessment of northern hake. This matrix without error is used in the assessment. The abundance indices used in the assessment is simulated without error. Robustness trials relax this assumption by introducing various levels of noise in the catch data.

b. Assessment

Method and data used, tuning fleets

As in previous years, the model chosen to assess the history of the stock dynamics was XSA. In total seven fleets were used in the assessment, the three surveys mentioned above and the following four commercial fleets: trawling fleets from Vigo and Coruña fishing in Sub-area VII (SP-VIGOTR7 and SP-CORUTR7) and two pair trawling fleets from Ondarroa and Pasajes fishing in Sub-area VIII (SP-PAIRT-ON8 and SP-PAIRT-PA8). The Group did not have confidence in the estimate of age 0 in the landings because of inconsistencies in the data for this age group in recent years. Therefore, age 0 was removed from the catch at age matrix (replaced with 0 landings) and from the commercial fleet data. However, age 0 is still in used in the assessment because indices for age 0 are available from surveys.

Historical performance of the assessment: prognosis vs. historical assessment
Due to the level of uncertainty in the data, concerns over precision and accuracy of age determination, and estimation from the assessment, short and long term projection and yield per recruit analysis, it was not possible to choose among the different perceptions of the stock. Besides, as discard data are not included in the assessment, fishing mortalities on young ages used in the predictions are probably under-estimated. This could lead to over optimistic projections. As a consequence, no management tables are routinely presented by the WG for this stock. It is also not possible to quantify the consequences of a change in F on the state of the stock relative to the precautionary reference points.

Modelling in the base case
In the base case XSA is used as assessment model with the catch-at-age matrix and abundance indices described above. The settings of the model are the same as applied by the working group.

c. Advice

Method for ICES advice: e.g. Forecast assumptions and inputs, the precautionary approach. What is the basis for reference points?
Current precautionary reference points were update in 2003 by ACFM following a revision of both assessment model and input data in recent years. B_{pa} was set equal to the lower observed spawning stock biomass in 2003, around 100,000 t, which corresponds to that observed in 1994. F_{pa} was set equal to the estimated F_{loss} in 2003. To calculate $B_{\lim}$ and $F_{\lim}$ based on B_{pa} and F_{pa}, these two were multiplied by $e^{1.645 \cdot 0.2}$ and $e^{-1.645 \cdot 0.2}$ respectively. Three assessment runs were carried out during WGHMM 2005 for the Northern Hake stock. ACFM accepted the updated assessment for advice purposes. ACFM commented that simulated age composition analysis should be included to acknowledge the uncertainty about ageing and the potential implications for recovery strategies.

Modelling in base case
In the base case the biological reference points described above are used.

d. Economic Advice

Before recently, no formal economic analysis was carried out for management advice on Northern hake. Informal considerations of likely economic impact of management measures play an important role in decision-making, but the lack of detailed economic data, and the multi-species, multi-fleet, multi-flag nature of the fishery has prevented the incorporation of formal economic factors. The Northern hake base case currently links catch and effort dynamics of the various fleets, and initial exploration of the overall effect on the fleets income has been considered. Costs and prices, including the effect of foreign imports is explained in the STECF study group report.

4. Management decision model

a. From advice to TAC

Table 5. Historical variations in the TAC.

Northern Stock Hake	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
TAC(T)	67000	69000	71500	60000	55100	51100	60100	59100	55100	42100	22623	26960	30000	39100	42600
Predicted catch correpon to advice	59000	61500		46000	31000	39000	54000	45000	36000	20000					
% difference	12%	11%	100%	23%	44%	24%	10%	24%	35%	52%	100%	100%	100%	100%	100%

The base case considers that TAC is set every year from 2004 according the rules set out in the Northern hake recovery programme (Table 5). Historically, the TAC fluctuated within a 10% bound in 60% of the recent years, although fluctuations of up to 30% were observed. The TAC has been significantly reduced, as a part of a recovery plan for Northern Hake. However, although restrictive this TAC has only have a limited effect in decreasing the catches, as the landings remained high and above the agreed TAC since 2000 (see Figure 21).

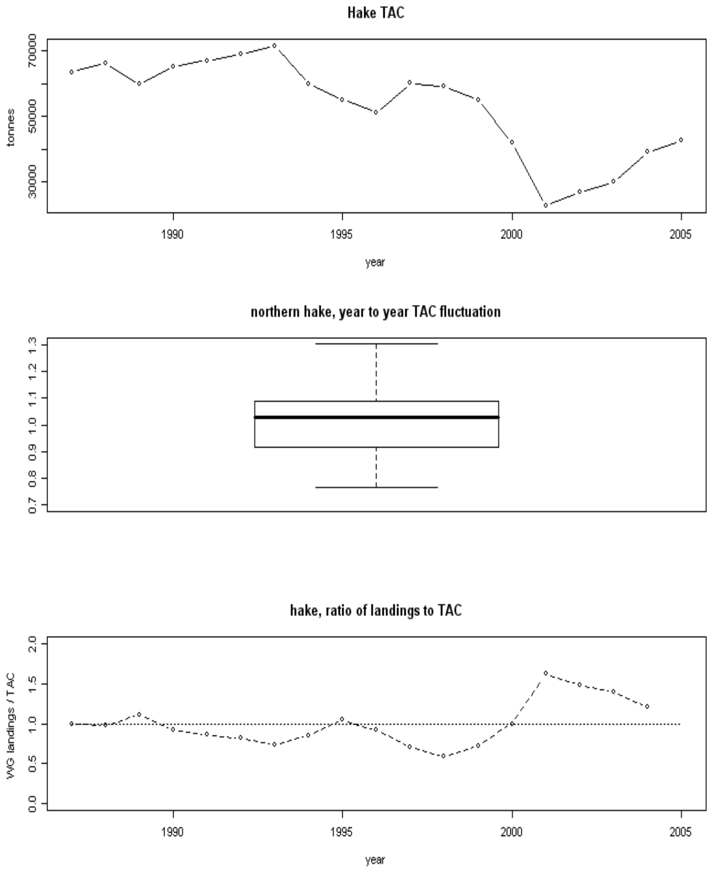


Figure 21. The TAC, year to year TAC fluctuations and the ratio of landings to TAC.

b. Other management rules

Recovery plans, time/area regulations, gear restrictions etc?

Minimum legal sizes for fish caught in Sub areas IV-VI-VII and VIII is set at 27 cm total length (30cm in Division IIIa). From 14th of June 2001, an Emergency Plan was implemented by the Commission for the recovery of the Northern hake stock (Council Regulations N°1162/2001, 2602/2001 and 494/2002).

In addition to a TAC reduction, 2 technical measures were implemented. A 100 mm minimum mesh size has been implemented for otter-trawlers when hake comprises more than 20% of the total amount of marine organisms retained onboard. This measure did not apply to vessels less than 12 m in length and which those return to port within 24 hours of their most recent departure.

Furthermore, two areas have been defined, one in Sub area VII and the other in Sub area VIII, where a 100 mm minimum mesh size is required for all otter-trawlers, whatever the amount of hake caught. Additionally, some fleets from Spain stopped fishing for up to two months in 2001, 2002 and 2003 and one month in 2004.

Scientific basis for these?

There are explicit management objectives for this stock under the EC Reg. No 811/2004 implementing measures for the recovery of the Northern hake stock. It is aims to increase the quantities of mature fish to values equal or greater than 140,000t. This is to be achieved by limiting fishing mortality to 0.25 and by allowing a maximum change in TAC between years of 15%.

Modelling in base case?

In the base case the advice and final TAC is the same and obtained following the recovery plan.

5. Implementation model

a. Quota share

Relative stability between countries. What is the official sharing rule, what is the actual sharing? Is the relative stability stable?

In the base case no complex fleet dynamics are considered so the quota share system is not considered.

b. Implementation and enforcement

Current enforcement depends on the TAC mechanism and the internal allocation rules. Rate of detection of undersized or over-quota catch could be assumed, but no hard data exists for modelling.

1.5.5.2.3 Final BBN and Multi-annual Management Plan Evaluation

The final Bayesian Belief Network for Northern Hake is shown is Figure 22.

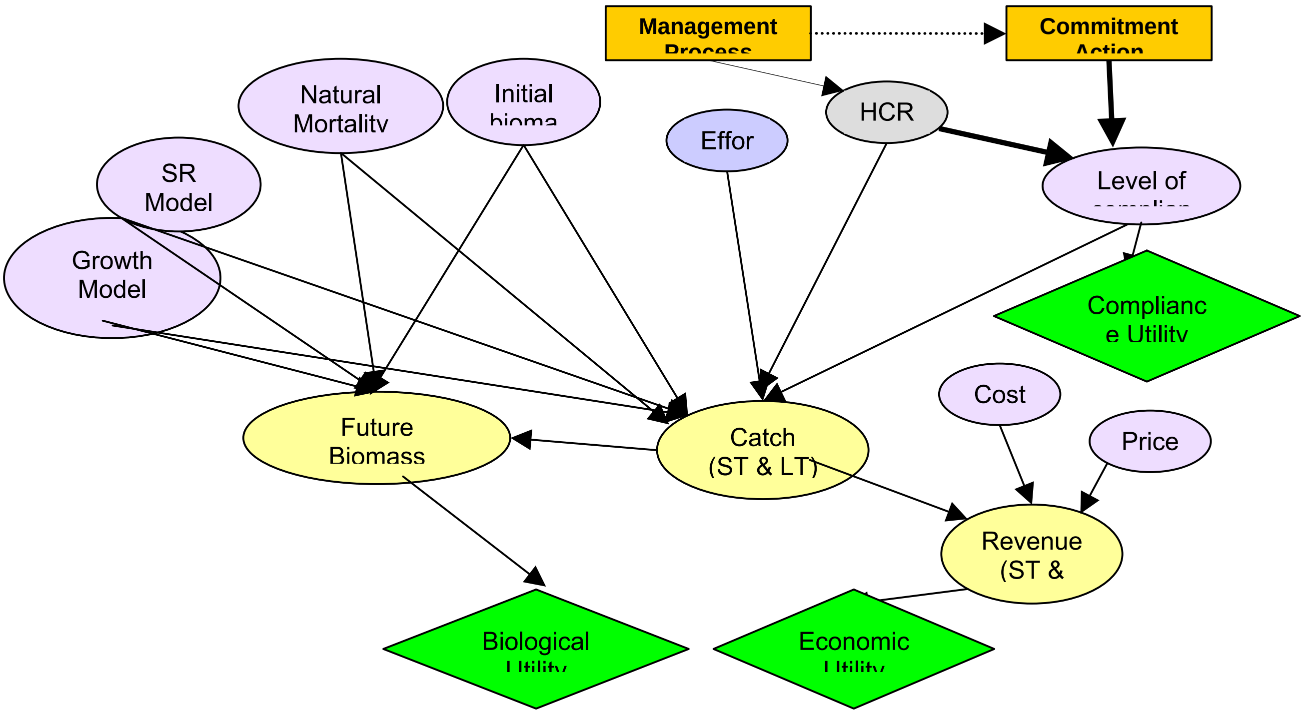


Figure 22. The Bayesian Belief Network for the Northern Hake

Alternative management procedures and evaluation of multi-annual plans

For Northern Hake the alternative management procedures simulated differ in the periodicity of the management action, using a generalization of a HCR of the Northern Hake Recovery Plan EC [2004]. The base case management procedure correspond with the Recovery Plan of Northern, which currently is being set on an annual basis. This Recovery Plan establishes, in future, a multi-annual plan for the recovery of this stock. It establishes some rules to calculate the TAC for year *y* using B_{lim}, F_{pa} and a threshold of 15% in the TAC variation from year to year as limit in the SSB, F and TAC variation respectively. The objective of the plan is to obtain in two subsequent years a mature Northern Hake stock level above B_{pa} (140000 t).

(1) The HCR to obtain the annual TAC states the following:

- The TAC for 2004 will be the one corresponding to a fishing mortality of 0.25.
- For the 2005 TAC and onwards, if y is the year for which the TAC is calculated:

– The fishing mortality corresponding to the TAC must be smaller than F_{pa} = 0.25.
– The predicted SSB for the end of the year y applying this TAC must be greater than initial SSB in year *y*.

- If the TAC, using the above two rules, results in a TAC such that exceeds or does not reach the TAC of year y − 1 in a 15%. If it does, set it equal to just ±15% of previous year TAC.

- If applying the rules above the predicted SSB for the end of the year y is smaller than B_{lim}, decrease the fishing mortality as much as necessary to obtain an SSB at the end of the year above B_{lim}.

(2) In the case of multiannual management action, if year y is the year in which the management action is carried out to obtain a series of TAC for years y + 1, . . . , y + k, the multiannual HCR works as follows:

- Calculate TACy+1 as it is done with the annual HCR.
- In year y + j with j > 1, project the population using TACy+j−1 to calculate the fishing mortality and set the recruitment equal to the one used to calculate TACy+1. Then apply the annual HCR to the projected population to obtain TACy+j .

The results are presented with a manuscript (see TEXT BOX 7)

In June 2007, a STECF meeting on the Northern hake long-term management plans (STECF/SGBRE-07-03) was held in Lisbon. The aim of the meeting was to analyse the robustness of different management strategies to different biological assumptions. Two algorithms, both integrated in FLR (Kell *et al.* 2007) (TEXT BOX 2), were used to simulate all the agreed scenarios. A simple projection algorithm and the Management Strategy Evaluation (MSE) simulation model coded within COMMIT project were used to carry out the Northern Hake recovery plan simulations.

The simple projection algorithm simulated an age-structured population using a predefined S/R relationship; the survival equation and the Baranov catch equation to project the population forward. The MSE algorithm, besides projecting the population forward, it also modelled the interplay between the biological dynamics of the stocks the dynamics of the fleet, the perception of the stock status via an assessment and a management measure resulting in the HCR that acts on the fishery. The research undertaken in COMMIT was essential to support the work carried out for the necessary simulations, in fact, it was the first time that the MSE approach was used to analyse a management plan for Northern Hake. Although it was recognized that further work is necessary, it was considered a very good starting point to begin introducing the MSE approach in the analysis of management plans. Results and output from this project contributed directly to these meetings (see research output as described in TEXT BOX 7 and TEXT BOX 8). A more recent STECF meeting has used the outputs from the first Hake long-term management plan to predict the impact on economics and social aspects of the fleets (STECF/SGBRE-07-05).

TEXT BOX 7

Testing HCRs for management plans: Application to Northern Hake

Garciá, D., Prellezo, R., Santurtun, MR., and Mosqueira, I.

Assessments made for the Northern Hake proved that this stock was outside safe biological limits from 1992 to 2000, which made the European Commission adopt a management plan for its recovery. In this paper we test the HCR implemented in this recovery plan in a Management Strategy Evaluation Framework, using FLR, which provides a basis for the development and evaluation of methods in fisheries science. We obtain that the HCR, in the current form achieves the goal of the recovery, setting the reference indicators within the sustainable thresholds, even if it is very sensitive to the existing uncertainty and to the assumptions made. Furthermore, a multi-annual HCR has also been tested, obtaining that, in terms of sustainability indicators, setting this rule biennially gives similar results as the annual case, while increasing to a triennial setting increases the risk of these indicators to fall below (or not to reach) the sustainability thresholds. In any of these cases, it has also been obtained that this HCR is just a tool for the recovery and not an adequate management tool for the Northern hake, given that in the mid term, it will create cycles of sustainable and not sustainable exploitation of the stock.

TEXT BOX 8

Evaluation of TAC control – Northern Hake

García, D., Prellezo, R., Santurtun, M., and Mosqueira, I.

The Northern Hake stock in European waters was considered to be outside safe biological limits for almost a decade, from 1992 to 2000. The European Commission adopted a recovery management plan, based on a number of technical measures, to bring the stock status within the pre-established safe biological limits. In this study, the Harvest Control Rules (HCR) contained in this recovery plan are tested within a Management Strategy Evaluation Framework, using the FLR platform. The robustness of the Recovery Plan's HCR is tested for different stock recruitment relationships: segmented regression (with two different break points), Beverton & Holt, and Ricker relationships which partly represent the possible impact of cannibalism on the likelihood of the different S/R models. Also, age-specific mortalities, based on those used for cod in which mortality is denso-dependent, to check the robustness of the management strategy to cannibalism, are used. Despite the sensitivity of the Operational Model to existing uncertainties and to the assumptions implicit in the various stock-recruitment relationships, the HCR in its current formulation should achieve the desired recovery goal, as indicated by the stock status indicators not exceeding sustainability thresholds.

1.5.5.3 Baltic Salmon

1.5.5.3.1 Objectives, Operating Model and Robustness trials

Management objectives

*1) Biological objective (*Sustainability of the stock; Long term average smolt production compared to smolt production capacity i.e. carrying capacity; Risk of stock collapse of weakest stock)

*2) Economical objective (*Sustainability of the fishery; Long term average profitability of the fishing activity; Variability of the profitability_

3) Socio-economic objective (Commitment of stakeholders:

- level of compliance with management regulation
- level of underreporting of efforts, catches and tagging data)

Main sources uncertainty considered

1) Biological uncertainties (- stock-recruit model; - semelparity/iteroparity; - M74 –mortality)

2) Economic uncertainties (- commercial fish price scenarios; - cost scenarios; - river benefits (Net Present Value) scenarios)

3) Fleet / fisherman behaviour uncertainties (- compliance and underreporting - scenarios on response to dioxin problem; - exit/entry model depending on profit or CPUE)

Opertaing model and robustness trials

For Baltic Salmon the robustness trial runs on the operating models were investigated in three phases. Firstly, the equations and functioning of the historical part of the operating model (OM range of years 1992-2007) were tested using the outputs of the WGBAST assessment model as inputs for the OM at the beginning of the time period, the OM runs were then compared with the abundances estimated by the WGBAST assessment model at the end of the period. Secondly to check if OM generates the plausible predictions the projections for years 2008-2037 were explored by running the model with combinations of 17 uncertainty scenarios (Table 6. below).

Finally using the output probability distributions of OM under these different scenarios were tested within the Bayesian Belief Network model.

Table 6. Combinations of uncertainty scenarios for robustness trials.

			base case	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13	Scenario 14	Scenario 15	Scenario 16
Biological	Stock	B&H	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X
	recruit	Ricker		X		X													
	Repeat	semelparity	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
	spawner	iteroparity			X														
	M74	constant	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
		fluctuating					X												
Economic	price	constant	X	X	X	X	X		X		X	X	X			X	X	X	X
		elasticity						X		X				X	X				
	cost	constant	X	X	X	X	X	X			X	X	X	X		X	X	X	X
		increasing							X	X					X				
	river	constant	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X
	benefits	increasing									X								
Fleet behaviour	reporting	current	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
		improved																X	X
	compliance	perfect	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	
		bad															X		X
	Fishermen	profit related	X	X	X	X	X	X	X	X	X	X					X	X	X
	behaviour	catch related											X	X	X	X			
	dioxine	partial ban	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X
		offshore ban										X							

Outline of Biological, fleet and fishery model, Observation Error model

The Baltic salmon operating model was specified and the relevant data was collected and analysed, and the main individual components of the operating model have been conditioned on data using the state of the art Bayesian methodology (ICES 2005). The base case observation error model represents only a part of the data that are collected and analysed in ICES Baltic Salmon and Trout working group assessment. In the base case, it is assumed that only data on recruits are utilized in the harvest control rule, since the management objective involves raising the number of recruits in potential salmon rivers to a half of carrying capacity of those rivers by 2010, and historic trends in recruit estimates have provided the main support for annual changes in management measures.

The base case fleet model has been developed with the help of the Finish fleet data, and the results are incorporated into the bio-economic model. The idea that different fleets respond differently to market conditions and regulations has been seized upon in modelling of fleet dynamics - fleet model consists of three sub-models corresponding to river, coastal and offshore fleets. See P. Levontin - Equations for the Operating Model and Management Procedure in the Baltic Salmon Case Study (downloadable on Commit web-site: http://commit-fish.info)

Model assumptions and conditioning

Model assumptions have been described in P. Levontin - Equations for the Operating Model and Management Procedure in the Baltic Salmon Case Study (downloadable on Commit web-site: http://commit-fish.info).

Conditioning of the OM to the set of sub-models is describes in Figure 23 below.

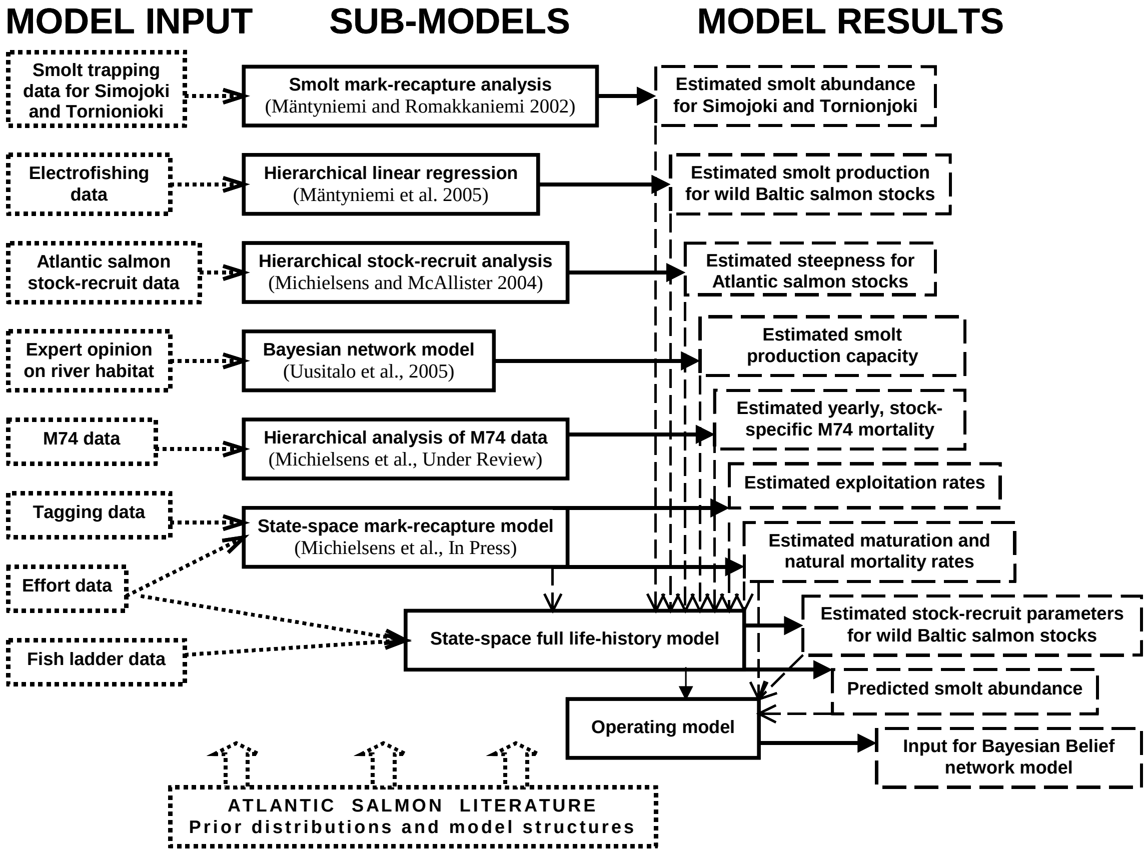


Figure 23 Conditioning of the operating model.

1.5.5.3.2 Summary of the Management Procedure

1. Knowledge production model

a. Sampling

Management decisions have traditionally relied on comparing smolt abundance estimates with smolt production capacity estimates. Smolt abundance estimates are obtained from parr density data. Parr densities are monitored annually in shallow fluvial habitats of the Baltic rivers by electrofishing. Provided that no extraordinary summer flood prevents field work (this happens 1-2 times within a decade), sampling covers all the wild Baltic rivers with an exception of a few rivers (either being too deep for electrofishing or sampled only periodically). Annual average parr density estimates for each river are normally obtained by a simple averaging of the site-specific density estimates.

For 3 rivers, smolt trapping data are available that can be analysed using a mark-recapture model in order to obtain yearly smolt production estimates (Mäntyniemi and Romakkaniemi 2002). For these rivers it is possible to look at the relationship between parr density and corresponding wild smolt production using a linear regression analysis. By using a hierarchical structure based on assumed exchangeability of stock-specific parameters it is possible to predict the smolt abundance for stocks for which only parr density estimates are available, allowing to produce annual smolt production estimates for all stocks within the Baltic Sea area.

Survey variability
Selection of sampling sites has not been random, especially in the largest rivers because of methodical limitations to swiftly flowing (riffles, rapids) and shallow (<1 m), mostly shoreline habitats. The number of sites fished by river vary temporally and among rivers, from a few sites up to about 100 sites/year/river. As one site covers roughly 100-1000 sq. meters of the river surface, all sampling sites within one river commonly cover max. a few per mils of all production areas of the river. Once the network of sampling sites has been established in a river, it has been kept as unchanged as possible over the years. The current assessment methodology tries to account for uncertainty in observation error One major source of uncertainty in the current assessment of Baltic salmon stocks is caused by misreporting of Polish salmon catches as sea trout catches.

Modelling in base case (e.g. not modelled, bootstrap sampling, MonteCarlo?)
Under the base case scenario no parr densities or parr density observations are modelled. Instead only smolt abundances and observed smolt abundances are modelled. For simplicity, observed smolt numbers (R_y) are point estimates sampled from a log-normal distribution with mean predicted by the simulated number of smolts or recruits(N_y). $R_y \sim \mathrm{Lognormal}(N_y + \Delta_{obs}, \sigma_{obs})$, where Δ_{obs} represents bias in observed data. This way it is possible to investigate the importance or value of having unbiased and precise observation.

b. Assessment
Method and data used, tuning fleets
Prior to 2002, the assessment method estimated the annual smolt production and compared this against the smolt production capacity estimates and the trend in smolt production was evaluated. The assessment method evaluates if different catch options reach 50% of the smolt production capacity. Prior to 2002, there have been no major changes in the settings of the assessment method.

Historical performance of the assessment: prognosis vs. historical assessment
Prior to 2002, the historical smolt abundance estimates did not get updated by new smolt abundance estimates in the future and no actual smolt abundance observations exist, so no evaluation can be made of the historical performance of the assessment. By assuming that the current stock assessment provides the underlying biological model, it is however possible to evaluate the performance of this simple assessment procedure.

Modelling in the base case
Assessment is completed by April 1st, based on the data from previous years. Even in a very simple representation of knowledge production that is modelled in the base case, it is important to include the time delay that occurs between observation and assessment, such as it occurs in the current management procedure (ICES 2005). Assessment is the point estimate of the slope of the best-fit line through the last three available data points on smolt abundances.

c. Advice

Method for ICES advice: e.g. Forecast assumptions and inputs, the precautionary approach. What is the basis for reference points?
Scientific advice is completed on April 1st and it corresponds to recommendations made by the ICES working group: If the scientists agree that there is high probability of decline in smolt abundance and re-building targets are jeopardized, they may recommend a decrease in effort. The advice is considered by managers who reach a decision by December. Effort based advice will affect some coastal fisheries (June 1st) and offshore fishery (November 1st and December 31st) for the following year.

Based on the relationship between parr densities and smolt abundance it is possible to predict smolt abundances two years ahead. There is a time lag of two years between the data and the advice. Therefore based on this assessment methodology it is only possible to provide short term predictions for the year for which the advice is given. The status of the different stocks are evaluated in terms of their probability to reach 50% of the smolt production capacity. The 50% level of the smolt production capacities for each river is therefore used as reference points.

The management of Baltic salmon stocks has been based on the Salmon Action Plan (SAP) as established by the former IBSFC (International Baltic Sea Fisheries Commission), which indicated that all wild salmon stocks should reach 50% of the smolt production capacity by 2010 while keeping the catches as high as possible. Based on current assessment methodology (ICES 2006a), these reference points have been estimated probabilistic and account for different types of uncertainties. There is currently no need to re-estimate the smolt production capacity. When the SAP was established in 1997, smolt abundances were low and 50% of the smolt production capacity had been chosen somewhat arbitrarily as a reference point. Given the current information on stock-recruit functions for individual salmon stocks, the original reference point of 50% of the smolt production capacity would need to be revised and replaced by precautionary reference points based on MSY.

Is the forecast accepted by ACFM and STECF?
The forecast do not take into account the impact of different TACs on future smolt abundances

Consistency between the forecast and the assessment
The forecast are entirely consistent with the assessment. In order to evaluate the impact of different TACs on future smolt abundance, the assessment would need to provide estimates of the exploitation of the stocks, requiring an

assessment relying on tagging data, in addition to parr density data and smolt trapping data.

Economic advice
There is no specific economic advise provided. At the same time the beliefs, intentions, goals and commitments of the Contracting Parties are strongly influenced by economic interests of the national fishing industries.

Modelling in base case
The advice of the working group is modelled using the regression coefficients (A_y) based on three latest available smolt abundance estimates and using the current estimates of recruitment (R_y) in relation to 50% maximum production capacity ($0.5R_0$). Scientists recommendations are based on simple if-then rules, whereby it is assumed that the TAC should not be allowed to fluctuate much from year to year.

If (-0.19 < A_y <- 0.14 and $R_y < 0.5R_0$ and $TAC_y \neq 0$), then $TAC_{y+1} = 0.8TAC_y$.
If (-0.19 < A_y <- 0.14 and $R_y \geq 0.5R_0$ and $TAC_y \neq 0$), then $TAC_{y+1} = 0.9TAC_y$.
If (A_y <- 0.19 or $R_y < 0.25R_0$), then $TAC_{y+1} = 0$.
If (A_y>-0.14 and $R_y \geq 0.5R_0$ and TAC_y < TAC_{MSY}) then $TAC_{y+1} = TAC_y + 0.1TAC_{MSY}$.
If ($R_y \geq 0.8R_0$)
then $TAC_{y+1} = TAC_{MSY}$.
Else, $TAC_{y+1} = TAC_y$.

2. Management decision model
Governments of Baltic Sea States signatories to the Gdansk Convention have committed themselves to promote close cooperation "… with a view to preserving and increasing the living resources of the Baltic Sea and the Belts and obtaining the optimum yield, and, in particular to expanding and coordinating studies towards these ends ..." (Anon., 1999). The former International Baltic Sea Fisheries Commission (IBSFC) was the regional fisheries organization responsible for the rational exploitation of Baltic fishery resources.

d. From Advice to TAC
According to Article IX of the Gdansk Convention, IBSFC prepares and submits recommendations based as far as practicable on the results of the best scientific advice available. Since 1998, ICES scientific advice, considered to be independent, has been delivered to the IBSFC according to a "Memorandum of Understanding between The International Baltic Sea Fisheries Commission and The International Council for the Exploration of the Sea". The contracting Parties largely rely on the ICES scientific advice and

statistical databases for their negotiation arguments and proposal generation and evaluation. For example, Contracting Parties may wish to evaluate a negotiation argument based on some objective considerations, for example, by investigating the correctness of its inference steps, or by examining the validity of its underlying assumptions.

Difference between scientific advice and actual TAC. Is there a systematic or random (or at least not modellable) deviation?
The IBSFC negotiation process is aimed at transforming the scientific advice provided by ICES into agreed management recommendations. The main negotiation issue for the Baltic salmon is setting of the total allowable catch (TAC) and the corresponding technical conservation measures.

Comparing the ICES advice on TACs and the agreed recommendations on TACs for Baltic salmon by IBSFC (Aps *et al.,* 2005) it is possible to conclude (Table 7) that based on the "package deal" consensus, the Commission systematically sets the TACs above the scientific advice which has served mostly as the starting point of the "talking up the quota". IBSFC Contracting Parties as economic value maximisers have been cooperating in creating bigger common value to be allocated to them afterwards: individual identical goals to maximize the value gave rise to a joint goal to set the TAC above the scientific advice.

Table 7. Baltic salmon TACs recommended by ICES, adopted by IBSFC and actual catch as reported by Contracting Parties in 1988-2004; no salmon TACs established for 1974 – 1987; since 1993 figures in number of fish (Aps *et al.,* 2005)

	1988	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**
ICES TAC	< 3000 [1)]	2900 [1)]	1 680 [1)]	-	2 820 - - 3 130	609000	565000	- [2)]	- [2)]
IBSFC TAC	3000 t	3550 t	No TAC	3 780 t	3 980 t	759000 (3795t)	720000	620000	570000
Actual catch	3174 t	4343 t	5 725 t	4 760 t	4 481 t	4 158 t	594396	521894	488631

	1997	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
ICES TAC	- [2)]	- [3)]	410000[4)]	410000[4)]	410000[5)]	410000[5)]	41000[5)]	410000[5)]
IBSFC TAC	520000	520000	510000	540000	520000	510000	510000	495000
Actual catch	421551	396975	344491	396158	323926	323574	313149	312425

1) No TAC for Gulf of Finland
2) Catch as low as possible
3) Offshore and coastal fishery should be closed
4) Offshore and coastal fishery should be closed in the Gulf of Finland
5) 22-31 only

IBSFC created so-called "paper fish" to facilitate consensus among Contracting Parties on national allocations. Baltic herring and sprat "paper fish" provided gains to some Contracting Parties with no loss/gain for other parties because of the allocation schemes (Aps *et al.*, 2005). Consensus based on the "paper fish" gains to fishing industries in transition was sometimes reached at a considerable cost: ICES scientific advice for salmon was systematically exceeded the by the factor of 1.2-1.3 in 1988-2004 while the actual catches were systematically lower than the agreed TAC. As a consequence, the "paper fish" based TAC for salmon was carrying no proper restrictive or regulatory function at all throughout the whole period of regulation.

Historical variations in the TAC. Is the TAC constraining?
As can be seen from Table 5, the TAC has gradually been reduced from about 750 000 salmon in 1993 to about 500 000 salmon in 2004. In recent years, the TAC has not constrained catches at all (Figure 24).

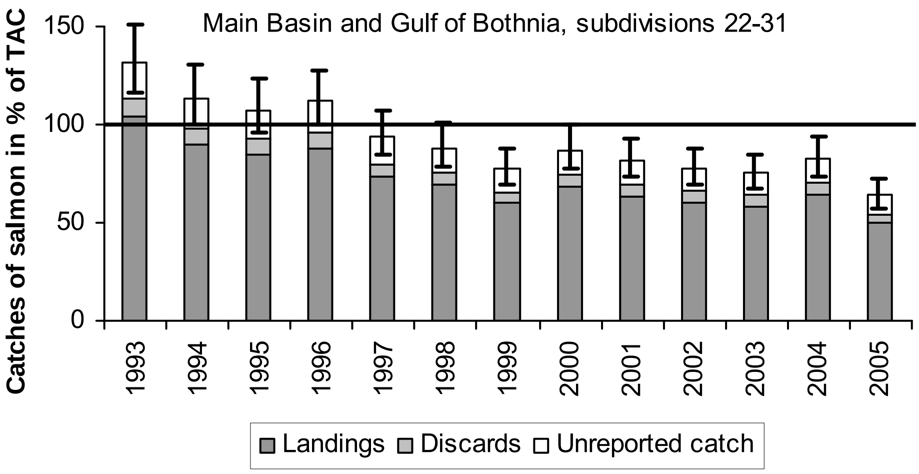


Figure 24. Catches of salmon in percentage of the TAC. Estimates of discards and unreported catches are based on expert opinions (ICES 2006a).

Modelling in base case (e.g. is the TAC set at the ICES level?)
In the base case, it is assumed that managers agree with the advice given by ICES and will set the TAC accordingly. Alternatively, it is possible to model that due to the pressure from industry, the managers agree to less drastic cuts than scientists recommend and increase quotas more readily. In the base case, management is modelled as follows. If in the previous year, catches in coastal and offshore fisheries have not exceeded TAC, and scientific advice does not call for lowering of the catch, managers allow economic factors to shape the fishery in the following year. If TAC was exceeded last year, or TAC advice for the next year is to reduce catch, managers act to reduce effort by the same factor as scientists recommended to reduce TAC. If TAC was exceeded in the last year, but scientist did not recommend reduction in catches, managers insist that effort does not increase. In case fishery that was closed is re-opened an annual increase in effort equal to 10% of effort in 2007 is permitted. If scientists recommend the fishery is closed, no fishing is officially allowed.

A detailed framework (Aps *et al*., 2005) has been proposed to model the negotiation process aiming at balancing of *stakeholder interests* in transforming the scientific advice into agreed management recommendations. Modelling of social influence and the generation of stakeholders joint mental attitudes allow to evaluate the different schemes of management decision. Development of the models is building on the conceptual framework imported from the research on Distributed Artificial Intelligence and Multi-Agent Systems (Jennings 1993; Rahwan *et al.,* 2004).

e. Other management rules

Recovery plans, time/area regulations, gear restrictions etc?

The former IBSFC has implemented a number of measures aimed at sustainable use of the Baltic salmon fishery resources (Aps, 2004), defined by the Baltic Salmon Action Plan (SAP) in 1997. According to this Action Plan, the long-term objectives (to 2010) are:

(1) To prevent the extinction of wild populations, any further decrease in the numbers of naturally produced smolt should not be allowed.
(2) Production of wild salmon should be stimulated gradually, to attain for each salmon river by 2010 a natural production of wild Baltic salmon of at least 50% of the best estimated potential within safe genetic limits, in order to achieve a better balance between wild and reared salmon.
(3) Wild salmon populations should be re-established in potential salmon rivers.
(4) The level of fishing for salmon should be maintained as high as possible, and only restrictions necessary to achieve the first three objectives should be implemented.
(5) Reared smolt and earlier life stage releases should be closely monitored.

Since the TAC for 2007 will only influence smolt abundances in 2011, the original time frame for the Salmon Action Plan has passed. Because IBSFC no longer exist, there has been no decision yet about the continuation or abortion of the SAP.

The management measures besides the TAC-system has delayed the opening of the coastal fishery, which has been applied in both Sweden and Finland. It is assumed that especially older wild salmon migrate earlier to the rivers for spawning than the younger hatchery-reared salmon. Delaying the opening of the coastal fishery would allow more wild salmon to return to the river for spawning. This management measure has been actively used since 1996 (Romakkaniemi *et al.* 2003).

Currently the salmon fishery is undergoing several major changes. The increased fishing period in long lining will increase the exploitation of salmon by long lining, especially from 2008 when drift netting will be totally banned. The previous rule of a maximum number of hooks per vessel is no longer in effect after adopting the new EC Council regulation.

When the new and lower EU content limit for dioxin (including dioxin like PCBs) was introduced in November 2006, it became impossible to sell salmon above approximately 2 kg in Denmark. The 2 kg weight limit is also very close to the minimum landing size of 60 cm.

An extensive review of the fisheries management cost for Baltic salmon has been done by Shivarov *et al.* (2005): (http://www.honeybee.helsinki.fi/mmtal/abs/DP10.pdf). The study concluded that the management costs, including large-scale stocking programmes, clearly exceed the value of catch in monetary terms during the past few years and engage substantial human resources. In addition, the authors conclude the management efforts may actually contribute to the deterioration of the salmon stocks through the significant financial transfers by the government, providing false incentives to fishermen. From an economic point of view it would be reasonable to stop subsidising the salmon fisheries by discontinuing the large scare stocking of hatchery-reared salmon.

Modelling in base case

Even though IBSFC no longer exists, it is assumed that future management objectives follow the SAP. Therefore 50% of the smolt production capacity is still used as a management objective within the model.

3. Implementation model

Quota share

Relative stability between countries.

The TAC for salmon in the Main Basin and Gulf of Bothnia is allocated to countries as indicated in Table 8.

Table 8. The allocation of TAC by country for salmon.

	Percentage of TAC (%)
Denmark	20
Estonia	2
Finland	25
Germany	2
Latvia	13
Lithuania	2
Poland	6
Russia	2
Sweden	27

This allocation key has remained the same over the years. Between countries bilateral negations are possible enabling the exchange in shares of the TAC for one stock against shares from another stock.

Quota share from countries to fleets – do we know anything about it? How does the system work in practice – rations, ITQ, others?

Because of the geographical distribution of the salmon i.e. most spawning grounds are located in the rivers of the North within Finland and Sweden while the feeding grounds are located in the South in the Baltic Main Basin, different countries will have different fishing fleets. Finland and Sweden dominate the coastal fisheries by trapnets or other gear since the salmon pass by their coastal areas when migrating to the spawning areas. Denmark and Poland mainly concentrate on the offshore fisheries by longlines and driftnets. Finland only redistributes the Quota between mainland Finland and the Åland Island. Sweden redistributes the quota between the North and the South of the country with the south predominately concentrating on the offshore fishery and the north on the coastal fishery. Denmark redistributes the quota over the fishing season and Poland redistributes it over the fleet, which is predominantly an offshore fishing fleet.

Modelling in base case (Fixed average shares by fleet? Or another option?)
The first step is to distribute TAC advice that comes from management model among the relevant fleets and fisheries. Here, we distribute TAC according the proportion of catch in the fishery among units and fisheries that existed in 2003.

$TAC_{u,y,ctn} = (Catch_{u,ctn,2003}/Total3_{2003})*TAC_y$,

where Total3 means the total of three fishery for which TAC will be relevant in the future – coastal trapnet, gillnet and offshore longline.

f. Implementation and enforcement

What do we know about enforcement and compliance?
In recent years, the landings have been below the TAC. There exist however a significant amount of unreported catches. In addition it is assumed that a significant amount of the sea trout landed by Polish fishermen are in actual effect salmon (ICES 2006a). Because landings have been below the TAC, there have not been any major problems with enforcement.

Modelling in base case?
Because the TAC has not been reached during the last few years, the model assumes that economic realities (e.g. decreased salmon prices because of the large amount of aquaculture salmon, decreased catches in the coastal fishery because of seals entering the nets and removing a large part of the catches, increased fuel prices, etc) are partly directing the fishing behaviour. In order to be able to model the behaviour of fishermen and their compliance with the TAC, we calculate both the effort corresponding to a TAC or management defined effort (E^{man}) and the effort obtained from an economic exit/entry model assuming profit maximization among fishermen (E^{econ}). We specify the following rules:

If ($E^{econ} < E^{man}$), then
$E_{y+1} = E^{econ}_{y+1.}$

If (E^{econ} = > E^{man}), then
we calculate the value that corresponds to a partial non-compliance such as catching 10% more salmon than recommended by management ($E_{1.1}$) and we set the effort to be:
$E_{y+1} = \min(E^{econ}_{y+1}, E_{1.1})$.

In order to obtain E^{econ}, an economic exit/entry model is used to predict future efforts based on last years profits. Within this model it is assumed that the harvest rate by the river fishery remains constant whereby the actual catches will increase as the salmon abundance in the river increases. Because the driftnet fishery will be banned by EU regulation starting in 2008, the coastal driftnet and offshore driftnet fisheries will be assumed to disappear. The fishing effort by the offshore longline and coastal trapnet/gillnet fisheries are modeled according to exit/entry rules. If the fishery was profitable last year, then more effort will be allocated next year. Hence the effort suggested by the market conditions is given by the following equation:

$\mathrm{E}^{\pi}{}_{y+1,f} = \mathrm{E}_{y,f} + \xi_l \mathrm{I}_{\pi} \mathrm{E}_{y,f}$ whereby ξ_f is the elasticity of fishing effort which determines how easy it is to enter or exit the fishery and I_{π} is an indicator which value depend on whether the fishery will make a profit or not,

$$\mathrm{I}_{\pi} = \begin{cases} 1 & \pi > 0 \\ 0 \quad \text{if, respectively,} & \pi = 0 \\ -1 & \pi < 0 \end{cases}.$$

The annual profits for a particular fishery ($\pi_{\mathrm{f,y}}$) are calculated using the following equations:

$\pi_{\mathrm{f,y}} = \varphi_{\mathrm{f}} \mathrm{C}_{\mathrm{y,f}} - \gamma_{\mathrm{f}} E_{\mathrm{y,f}}$ whereby φ_f is the price per 1000 salmon caught by a particular fishery, $\mathrm{C}_{\mathrm{y,f}}$ is the yearly catch by a particular fishery and γ_f is the cost per unit effort for a particular fishery.

The management defined effort (E^{man}) will depend on the compliance of the fishermen to the management regulations. A compliance factor $c \in [0,1]$ is used in order to model how closely management recommendations are followed by fisherman, c = 1 indicates perfect compliance, c = 0 indicates that only economic factors influence fishing effort. In the base case, the value of 80% is assumed for compliance. Thus the actual effort for the following year is given by:

$\mathrm{E}_{y+1,f,u} = c * \min(\mathrm{E}^{\pi}{}_{y+1,f,u}, \mathrm{E}^{m}{}_{y+1,f,u}) + (1-c) * \mathrm{E}^{\pi}{}_{y+1,f,u}$.

1.5.5.3.3 Final BBN and Multi-annual Management Plan Evaluation

The Bayesian Belief Network for the synthesis is shown is Figure 25.

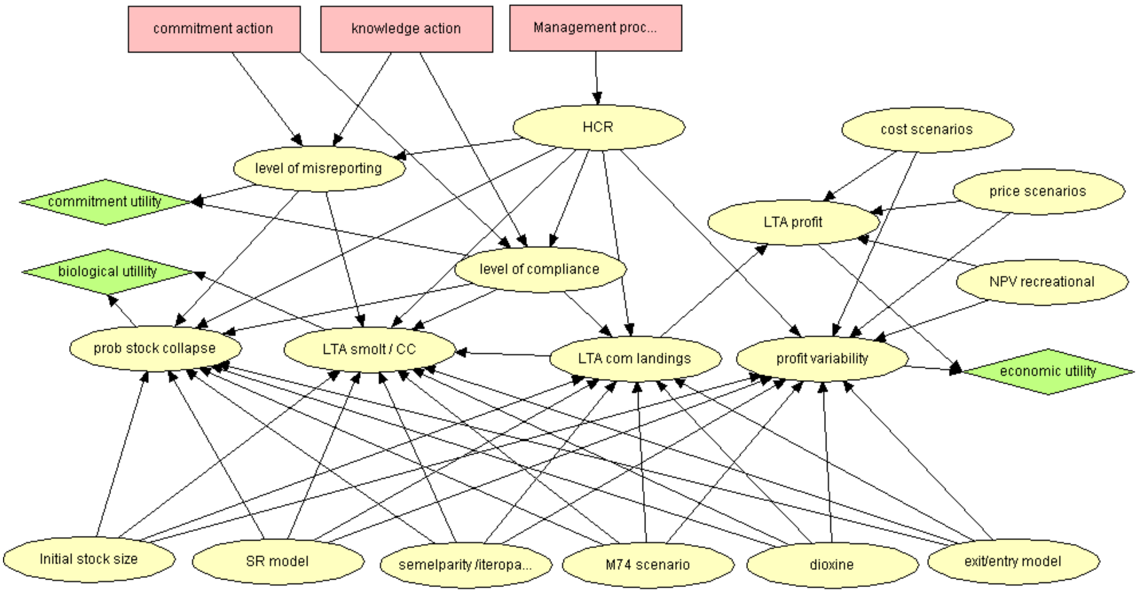


Figure 25. A Bayesian Belief Network diagram for the Baltic Salmon to explore the uncertainties and system behaviour under the different management procedures.

Bayesian Belief network for commitment

The Bayesian Belief Network that incorporate commitment is shown in Figure 26. This allows the group to consider the socio-economic analysis of fishermen's commitment by:

- Analysis of social capital in different rivers
- In depth interviews and questionnaires
- Detailed socio-economic Bayesian network

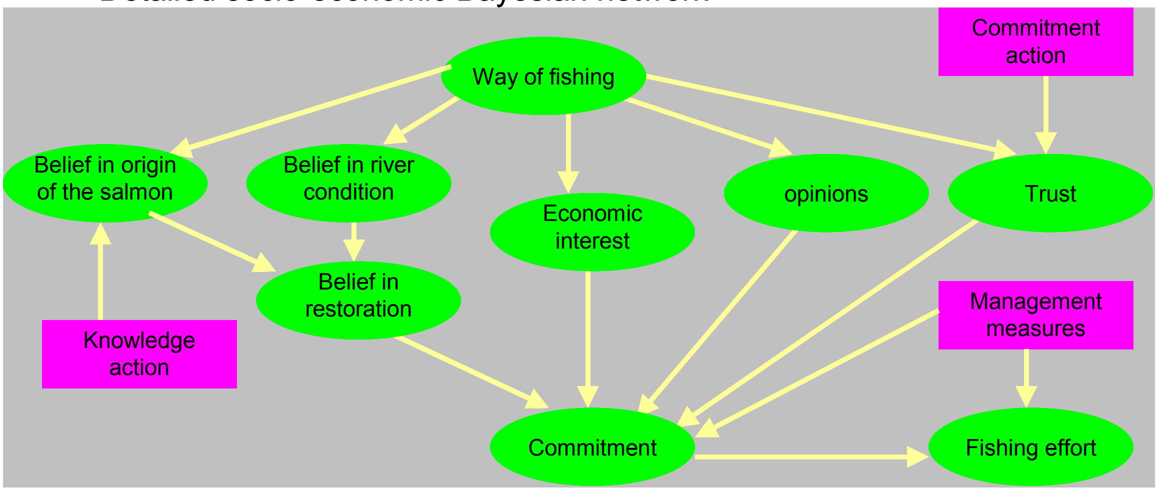


Figure 26. A simplified Bayesian Belief Network diagram describing the main factors behind the commitment of the salmon fishermen (P. Haapasaari *et al.*, 2005).

The issue of commitment is dealt with explicitly in the study by Haapasaari *et al.* (2007) (see TEXT BOX 9) in the case study: Baltic Salmon.

TEXT BOX 9

Management measures and fishers' commitment towards sustainable exploitation: a case study of Atlantic salmon fisheries in the Baltic Sea

Haapasaari, P., Michielsens, C. G. J., Karjalainen, T. P., Reinikainen, K., and Kuikka, S. 2007. Management measures and fishers' commitment towards sustainable exploitation: a case study of Atlantic salmon fisheries in the Baltic Sea. – ICES Journal of Marine Science, 64: 825–833.

Fisheries management aimed at sustainable exploitation may indirectly affect fish populations by influencing human behaviour. We propose a methodology that includes stakeholders' opinions, perceptions, and resulting behaviour within assessment models designed to evaluate the impact of different management measures on the stocks. Based on interviews and a questionnaire, we use a Bayesian Belief Network (BBN) to examine which factors determine fishers' commitment to sustainable fisheries goals, what impact commitment has on exploitation rate, and what measures can be taken to improve commitment. In addition to exploring alternative management measures, the analysis evaluates knowledge actions (providing information to fishers) and commitment actions (intended to increase trust, consensus, and cooperation). The method is applied in a Baltic Sea case study where commitment is important for successful recovery of Atlantic salmon (*Salmo salar*) stocks. The results indicate that the more fishers rely on fishing as their source of income, the less is their commitment and the smaller is the impact of changes in commitment on subsequent catches. The results suggest that commitment can be improved by selecting management measures favoured by fishers, and by combining them with commitment and knowledge actions.

The same is true for the study by Kulmala *et al.* (in prep.)(TEXT BOX 10) which applies game theoretic methodology. The model is executed by using FLR framework (Fisheries Library for R) that is an open-source framework that promotes both the transparency of modelling and the co-operation of fisheries biologists and fisheries economists.

The model is used to run different scenarios for catch and effort options and the model outcome results present both the status of the stocks and the economic performance of the fishing fleet.

TEXT BOX 10

Manuscript on applying game theory to find the negotiation parties and expected gains from better commitment (Baltic Salmon Case study)

Soile Kulmala*, Polina Levontin**, Marko Lindroos***, Catherine Michielsens*, Tapani Pakarinen* and Sakari Kuikka****

*Finnish Game and Fisheries Research Institute, Helsinki
** Imperial College, London
***University of Helsinki, Department of Economics and Management
****University of Helsinki, Department of Biological and Environmental Sciences

The paper puts forward a model currently used in the Baltic salmon stocks assessment. The model accounts for full life-history of 15 naturally reproducing and 4 hatchery-reared salmon stocks. Designed to give economically and biologically sound management recommendations, the model accounts four countries whose fleets target salmon with different types of gear in a different time of year. It is calibrated by using the latest stock assessment results and salmon price and fishing costs data from the four countries. The model is executed by using FLR framework (Fisheries Library for R) that is an open-source framework that promotes both the transparency of modelling and the co-operation of fisheries biologists and fisheries economists. The model is used to run different scenarios for catch and effort options and the model outcome results both the status of the stocks and the economic performance of the fishing fleet. Further, the analysis includes a game theoretical study of the allocation of the net benefits from the fishery between the four countries.

Alternative management procedures and evaluation of multi-annual plans

Twelve different management scenarios are evaluated and assessed. We evaluated both model-free and model-based HCR and compare their performance under a range of scenarios. These scenarios are construed using various elements that are relevant to the management of Baltic salmon: the opening time of the coastal fishery, the releases of reared fish, the assessment based on smolt or spawner data, the different HCR, the multi-annual rules for setting TAC levels, and the economic conditions for fishing. In order to judge the robustness of management strategies, all of the management regimes choices were applied to stocks in the same initial, overfished conditions.

<u>Harvest control rules</u>
In this section, harvest control rules that are evaluated as part of management strategies are described.

HCR 1. Smolt trend and smolt observation, possible fishery closure (model based)

One such rule is based on assessment of trend in smolt abundance and also on the current estimates of recruitment (R_y) in relation to 50% maximum production capacity (R_0). The manager would consider both pieces of observation and recommend an action according to the decision table below (Table 9).

Table 9. HCR based on smolt trend and smolt observations

Trend \ Recruitment	Less than 25% of the CC	Between 25% and 50% of the CC	Between 50% and 80% of the CC	Above 80% of the CC
Severe decline	Zero catch	Zero catch	Zero catch	TAC at MSY
Moderate decline	Zero catch	Reduce TAC By 20%	Reduce TAC By 10%	TAC at MSY
Positive or only slightly negative trend	Zero catch	Same TAC as Last year	Increase TAC by 10% up to TAC at MSY	TAC at MSY

Translated into the set of if-then rules, the management strategy described in the table above is equivalent to:

If (-0.19 < A_y <- 0.14 and $R_y < 0.5R_0$ and $TAC_y \neq 0$), then

$TAC_{y+1} = 0.8TAC_y$.

If (-0.19 < A_y <- 0.14 and $R_y \geq 0.5R_0$ and $TAC_y \neq 0$), then $TAC_{y+1} = 0.9TAC_y$.

If (A_y <- 0.19 or $R_y < 0.25R_0$), then $TAC_{y+1} = 0$.

If (A_y>-0.14 and $R_y \geq 0.5R_0$ and $TAC_y < TAC_{MSY}$) then $TAC_{y+1} = TAC_y + 0.1TAC_{MSY}$.

If ($R_y \geq 0.8R_0$)

then $TAC_{y+1} = TAC_{MSY}$.

Else, $TAC_{y+1} = TAC_y$.

In this and in other harvest control rules described, the maximum catch allowed under the management strategy is denoted by TAC_{MSY} – it is not necessarily a reference point rigorously calculated, but rather a soft management target – for example, as it is referred to in the commitments to sustainable fisheries articulated in the World Summit for Sustainable Development in 2002.

HCR 2. Constant TAC (model-free)

The simplest example of a harvest control rule is to keep either TAC or total effort constant at some level, for instance:

$$TAC_y = TAC_{MSY}$$

HCR 3. TAC based directly on observations (model-free)

Another simple harvest control rules is to allow TAC to fluctuate with some index of abundance, based on fishery independent data, such as estimates/observations of spawner escapement or spawner biomass or even recruitment projections. For example,

$$TAC_{y+1} = TAC_y \frac{S_y}{S_{y-1}} .$$

HCR 4. TAC as a step-linear function of some index (model – based)

Another way to set a harvest control rule is to make it a function of some index, for example a proportion of virgin recruitment as depicted in 0. This is a kind of HCR that is entirely defined by management reference points and thus could be expected to be susceptible to biases in the estimates of those reference points, as well as the particulars of the model used to estimate where the stock is relative to the reference point (Cooke 1999).

In an example of such a harvest control rule depicted in Figure 27 no catches are allowed, if assessed recruitment is below 20% of the estimated carrying capacity in the index stock unit; TAC depends linearly on the estimated, from observations, proportion of the carrying capacity, if those estimates fall between 20 and 75%; and maximum catch is allowed, if it is found that the recruitment exceeds 75% of the carrying capacity.

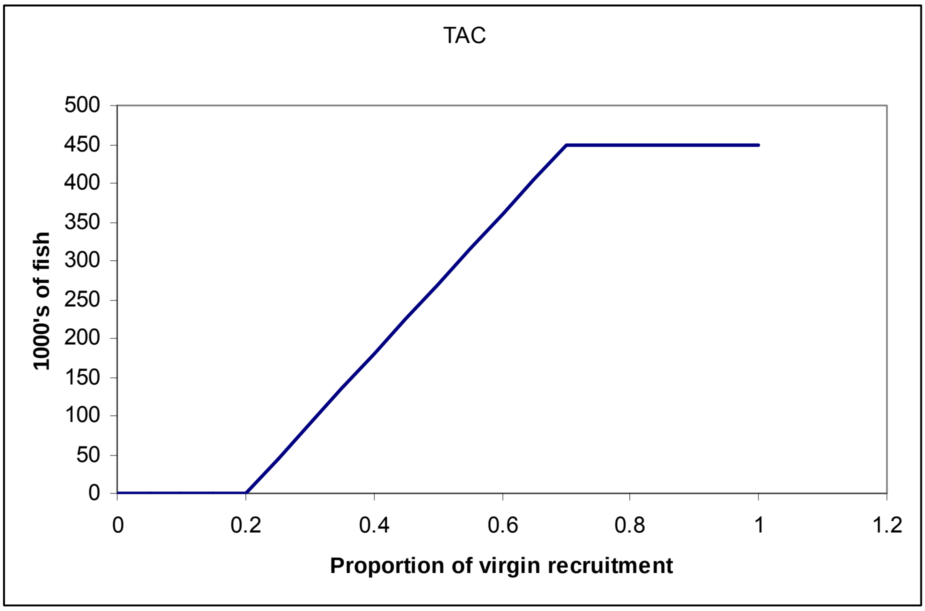


Figure 27. An example of a harvest control rule

HCR 5. Multi-annual harvest control rules

One of the desirable qualities of a management procedure, from the industry's point of view, is stability. Multi-annual management strategies, where advice is stabilized over years, are, therefore, of interest (Geromont *et al.* 1999). Such advice can have a generic form:

$$TAC_{y+1} = TAC'''_{y+1}(1-\beta) + \beta TAC_y .$$

In the equation above, TAC for the future year is a linear combination of the TAC set by some harvest control rule, TAC'''_{y+1}, and the TAC from the previous year. If beta parameter equals to zero, then TAC from last year has no influence on the TAC for the next year. If beta is equal to 1, then TAC is kept constant at the level of the initial setting.

Evaluation of management strategies

We first explore various management options directly in terms of monitored statistics, without the subjectivity of the utility functions. Table 10 describes the twelve management options simulated and explains the reason for selecting each particular set of management strategy attributes. The stock is assumed to be at the level of overfishing as existed in 1992.

The economic conditions corresponding to both 1992 and to 2007 are simulated and compared. In 1992, the market demand for salmon was higher, and both coastal and longline fisheries were more active, however, the fishery has declined since, and the economic prognosis is for much lower efforts starting 2007.

Other than for modelling these two scenarios for market conditions, we disregard the issue whether the economic conditions would force fishermen to catch more or less fish; to test various management strategies, whenever a TAC based harvest control rule is used, it is assumed that all of the TAC is caught, subject to maximum effort limits.

Table 10. Management options simulated with the operating model

Management options	
Description	*Operating Model Settings*
Name in BBN: 1_Base Management strategy: Longline catches are controlled through a HCR based on smolt trend and recruitment in the weakest unit relative to CC. Longline fishery faces closure if recruitment falls too low. Effort is also restricted by setting a maximum allowed value. The coastal fishery is assumed to fish at the level of 1992 undisturbed. No releases.	• Maximum TAC for longline is 150 (thousands fish) • No change in coast open. date. • Effort for coastal trapnet is constant • Economic scenario: 1992 • HCR is smolt trend, with closures, HCR 1. • Maximum effort longline is 50 (in 100,000 geardays) • No releases of reared fish
Name in BBN: 2_HighCatch Management strategy: Allow high catches in both offshore and coastal fisheries. No assessment. Effort control. Coastal fishery is opened a week earlier. Release reared smolts to maintain higher catches.	• Effort in longline fishery constant at 30 (in 100,000 geardays) • Open coastal fishery 1 week early • Effort in the coastal constant, but reflecting longer fishing season • Economic scenario: 1992 • Releases
Name in BBN: 3_Adapt Management strategy: Both coastal and offshore fisheries are strictly regulated. TAC is set based on spawner data. Effort in coastal fishery is controlled to prevent a large gap in catches between the coastal and offshore fisheries. No releases.	• TAC for longline capped at 150. • No change in coast open. date. • Effort in trapnet fishery is reduced by 25% if catches exceed twice the TAC set for longline • Economic scenario: 1992 • HCR is based on spawner ass., HCR 3. • Maximum effort longline is 50
Name in BBN: 4_OpenEarly Evaluate: Change in the opening date of the coastal fishery Compare: Same as 1_Base, except for the opening date.	• Open coastal fishery 1 week early • Effort coast reflects longer fishing season
Name in BBN: 5_LowCTN Evaluate: Change in economic conditions Compare: Same as 1_Base, except market conditions are as in 2007, i.e. lower desired effort in the coastal fishery	• Economic scenario: 2007
Name in BBN: 6_Releases Evaluate: The effect of releasing reared smolts. Compare: Same as 5_LowCTN, except releases are made every year in the same numbers as in recent years.	• Releases
Name in BBN: 7_NoAsses. Management strategy: No assessment. Fix TAC for longline at 100, 000 fish, and make sure the effort does not exceed 20 (in 100,000	• TAC for longline is fixed at 100,000 fish, HCR 2. • Open coastal fishery 1 week early • Effort coast is constant, but 25% higher because of the longer

geardays). Relax the coastal fishery regulations by opening it up a week earlier and release reared smolts to support catches.	fishing season • Economic scenario: 2007 • Maximum effort in longline is 20 (in 100,000 geardays) • Releases
Name in BBN: 8_NoReleases Evaluate: The effect of releasing reared smolts under a different management system. Compare: Same as 7_NoAsses, but without reared smolts.	• No releases
Name in BBN: 9_MultiAnnual. Management strategy: Multi-annual HCR, (TAC for next year depends on TAC for the last year to add stability to management.) Enable high coastal catches by opening the season two weeks earlier.	• TAC for longline is capped at 150,000 fish • Multi-annual HCR rule for setting TAC using spawner data, HCR 5. • Initial TAC is 30,000 fish. • Open fishery two weeks earlier. • Effort coast is constant reflecting longer fishing season • Economic scenario: 2007 • Maximum effort longline is 20 (in 100,000 geardays) • Releases
Name in BBN: 10_Effort2007 Management strategy: Keep effort constant.	• Effort constant in both fisheries as in 2007 • Releases
Name in BBN: 11_Compliance Evaluate: Low compliance Compare: Same as 8_NoReleases, but low compliance.	• Overfishing by 20% of TAC • Effort non-compliance 50%
Name in BBN: 12_HCR Management strategy: Explore an alternative HCR based on annual smolt counts, explore the importance of capping TAC at some particular level. Compare: 5_LowCTN, which has the same effort in the coastal fishery, but manages longline fishery differently.	• No releases • Maximum longline effort is 60 (in 100,000 geardays) • TAC is capped at 200,000 fish • HCR is based linearly on annual smolt observations in the weakest unit as proportion of the estimated carrying capacity, HCR 4.

Various project outputs were produced reflecting the extensive effort expended on the Baltic case study, that is reviews of the biology, uncertainty evaluation via Bayesian methodology (TEXT BOX 11), and the study by Levontin *et al.* that consider various uncertainties in the system dynamics by applying Bayesian Belief Networks (TEXT BOX 12). In terms of policy a key outcome is the contribution the project has made to the assessment of Baltic Salmon stocks within the ICES working group (see TEXT BOX 13).

TEXT BOX 11

Combining multiple Bayesian data analyses in a sequential framework for quantitative fisheries stock assessment

Catherine G.J. Michielsens, Murdoch K. McAllister, Sakari Kuikka, Samu Mäntyniemi, Atso Romakkaniemi, Tapani Pakarinen, Lars Karlsson and Laura Uusitalo

This paper presents a sequential Bayesian framework for quantitative fisheries stock assessment, relying on a wide range of fisheries dependent and independent data and information. The presented methodology combines information from multiple Bayesian data analyses through the incorporation of the joint posterior probability density functions (pdfs) in subsequent analyses, either as informative prior pdfs or as additional likelihood contributions. The paper presents different practical strategies to minimise any loss of information between analyses. Using this methodology, the final stock assessment model used for the provision of the management advice can be kept relatively simple, despite the dependence on a large variety of data and other information. The methodology is illustrated for the assessment of the mixed-stock fishery for four wild Atlantic salmon (*Salmo salar*) stocks in the northern Baltic Sea. The incorporation of different data and information results in a considerable update of previously available smolt abundance and smolt production capacity estimates by substantially reducing the associated uncertainty. The methodology also allows, for the first time, to estimate stock-recruit functions for the different salmon stocks.

TEXT BOX 12

A BBNs and synthesis of Baltic salmon case

Levontin, P.,* Michielsens, C.,** Kulmala, S.,** Pakarinen, T.,** Romakkaniemi, A.,** and Kuikka, S.***

*Imperial College, London, UK.
**Finnish Game and Fisheries Research Institute, Helsinki, Finland.
***University of Helsinki, Finland.

The purpose of constructing an operating model and performing evaluations with different management options is to explore the relationships between uncertainties in the modelled system and the ability to control the system in a satisfactory manner. The complexity of analysis arises not only through the many combinations of parameter and structural uncertainties, options for economic and environmental scenarios, and the management choices modelled, but also from existence of diverse perspectives of what would be a satisfactory outcome of management. There are essentially two types of questions that we are interested in: one set of questions belongs to the field of natural science - these questions concern dynamics of interactions between the resource and its exploitation; the other type of questions belongs to the field of social science or management - these questions are about the satisfaction of stakeholders with the state and the management of the system. One methodology for approaching both types of questions is the Bayesian Belief Networks.

TEXT BOX 13

A TAC decision – the end result of a struggle

Päivi Haapasaari: Faculty of Education, P.O. BOX 2000, FIN-90014 University of Oulu, Finland.

Decision making of total allowable catches (TAC) in the EU has been blamed for endangering fish stocks and for leading to economically inefficient consequences. Decisions are taken by politically elected ministers of the member states based on initiative from the European Commission. The initiative for its part is based on scientific advice prepared by the ICES, and the Common Fisheries Policy, the main aim of which is to prevent over-utilization of fish resources. The negotiation targets of the ministers should be adjusted within the frames of sustainability defined in the scientific process, but often ministers end up in compromises that have been described uncontrollable for both the Commission and the member governments. The aim of this study was to analyze the context of the TAC decisions, concentrating especially on the issue of setting TAC for Baltic salmon stocks for the year 2008. Qualitative material was collected mainly through focused key-person interviews and participant observation, and the approach of analyzing was hermeneutic. Applying Bourdieu's concepts and theory, a picture of the context of the TAC decisions as a social playing field was sketched. In this field the teams of politics, administration, science, nature conservation and fishing industry are vying for getting their voice through in the final decision. The relations between and within these participating groups and the dynamics leading to the end result were examined. Identifying the critical points can potentially lead to developing measures or methodologies that help decision makers commit to the scientific advice and make more sound decisions. This might diminish the influence of variables leading to unsustainable or uncontrollable consequences.

The methodology developed in COMMIT has also been directly applied to the current advice of ICES. Baltic salmon as it is the only ICES stock, for which the Bayesian approach gives the methodological background. Both the operational aims of the management, as well as the state of the stocks is given in probabilities, and thereafter it is the role of the managers to conclude, what the uncertainties mean from the management point of view. This is especially now true when the long-term aim of the management is to reach MSY by year 2015, the advice gives the probability to reach this aim by alternative management actions. In the case of Baltic salmon this goal may not be enough due to the fact, that all stocks cannot reach their MSY by the same management decisions due to their different productivity rates (e.g. differences in river water quality). Current advice takes this into account by providing stock and area specific advice, as developed in the COMMIT project.

In the case of Baltic salmon, there is very strong evidence that the current offshore fishery has been successful only due to the fact, that the restrictive management actions have improved the productivity of wild stock so much, that the CPUE of the off shore fishery has stayed on profitable level.

1.5.6 Synthesis: Generic Bayesian Belief Network

The application of the Bayesian Belief Networks (BBNs) has not only been case study specific. One is able to apply the knowledge gained across the case studies in order to obtain as output a generic. A comparison across the case studies has been completed in order to synthesize knowledge and improve the understanding. The current general BBN is obtained through the interaction between the different case studies and as a result of the development of the individual BBNs. It synthesises the increased understanding obtained in the individual case studies and in turn, has further influenced the development of the individual BBNs. The stocks and fisheries within the different case studies differ significantly but the main characteristics of the net (main objectives, management objectives, utility functions, sources of uncertainty, model structure and ways of populating the model) are similar across the different case studies.

The main objective of the Bayesian Belief Networks (BBN) is to examine which management procedures are most robust to different types of uncertainty (among which commitment/ compliance uncertainty) and result in the best overall utility (biological, economical and social (commitment)). In practise the BBN networks achieve this goal by summarising the results from different settings or runs of the simulation evaluation framework, used to evaluate the different management procedures. The management procedures are evaluated in terms of the chance that they will achieve the desired management objectives (see Table 11). The chance of achieving the objectives is not only dependent on the management procedures but also on the model uncertainties and how robust the different management procedures are to the different types of uncertainty (Table 11).

Table 11. Bayesian Belief Networks allow testing different management procedures in terms of their ability to achieve the various management objectives given the various types of uncertainty

	Management objectives	Uncertainties
Biological	Sustainability of the stock e.g. - optimum status of the stock (long term average) - low risk of stock collapse	e.g. - stock-recruit model uncertainty - growth model uncertainty - uncertainty on natural mortality
Economic	Sustainability of the fishery e.g. - high profitability of the fishing activity (long term average) - low variability of the profitability	e.g. - future price uncertainty - future cost uncertainty (e.g. fuel)
Socio-economic	Commitment of stakeholders e.g. - high level of compliance - low level of misreporting	e.g. - compliance, misreporting, discarding - impact of price and CPUE - exit/entry model uncertainty

Even though each case study has given their own interpretation to 1) what are the management objectives, 2) how to monitor the extent in which these objectives have been met and 3) what are the most important uncertainties to consider, a general structure for the belief network has been set up, irrespective of the case study (Figure 28). Rather than concentrating on causal links between model parameters, the BBN model in the COMMIT project is used to synthesise results from different runs of the simulation evaluation model.

The number of actual causal links is kept low since the focus is on long-term management objectives while causal links often relate to the relationships between model parameters at certain points in time. Monitored over several years, the causal relationships between monitored variables invariably decreases or disappears completely. Only these model output values which are monitored are of particular interest. For example, nodes such as fishing effort are not included in the BBN model structure in cases where fishing effort is a function of the harvest control rule and the fleet adaptation model and will differ over the years. In each case however, there exist different scenarios on how the fishing effort will change over time, then a separate node for fishing effort can be included in the BBN model, representing different settings of the operating model.

Fishing effort can still be monitored from the operating model in cases where it is seen as in indicator for the fishing capacity. This allows one to evaluate the effect of different management procedures on overcapacity (and can be monitored as one of the factors determining the economic utility). Whether or not to include fishing effort in the BBN therefore depends on the interpretation given to the model node on fishing effort.

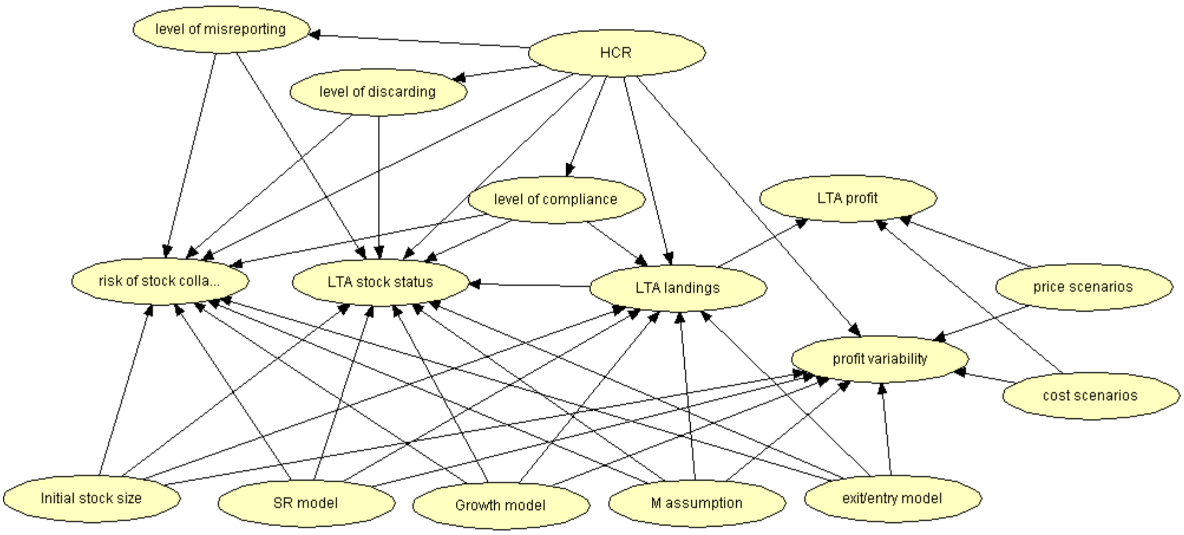


Figure 28: General structure for the BBN across case studies.

The different types of uncertainties considered within the belief network model can be viewed as the different settings of the simulation evaluation framework. In Figure 29, the main model outputs have been circled in red while the nodes circled in green indicate the different settings of the simulation evaluation framework. Populating the BBN model is an automated process whereby all the different results for each simulation run are saved together with the settings of that particular simulation and read directly into the Hugin software. Once the user specifies the links (arrows) between the different model inputs, the Hugin software fills in the conditional probability tables.

The different management procedures are combinations of sets of knowledge production and management decision models. These management procedures are evaluated in terms of their overall biological, economical and commitment utilities. By using individual utility functions it is possible to evaluate if the ranking of preferred management procedures changes when evaluating them in terms of the different types of utilities. The individual utility functions weight the different indictors influencing the utility. For example, the biological utility of a particular management procedure can be a function which weights the long-term average status of the stock and the risk of stock collapse.

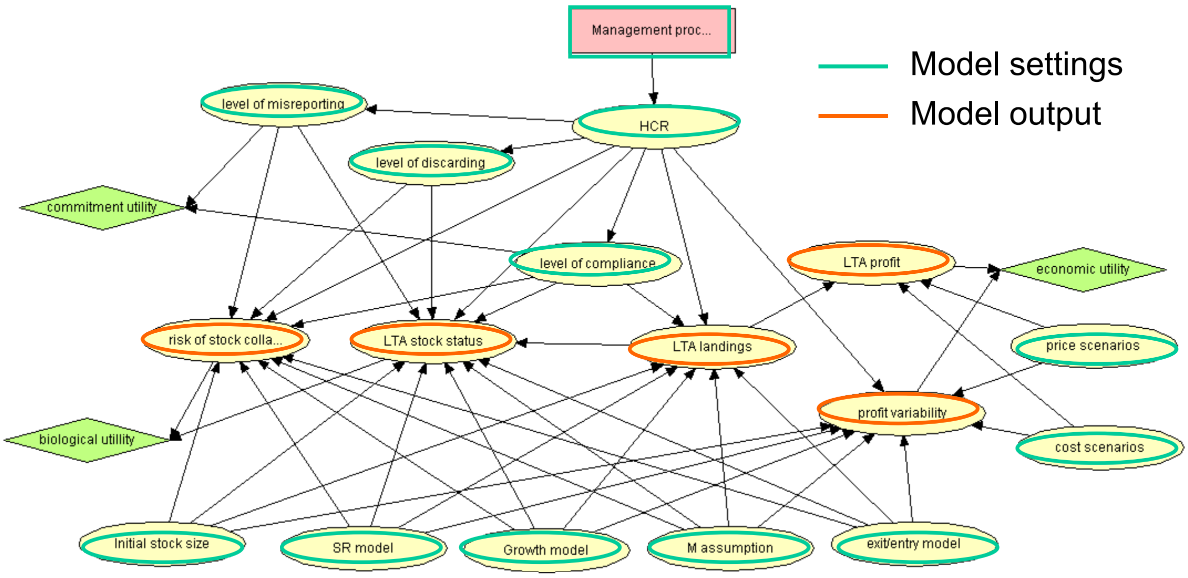


Figure 29: General structure for the BBN used to evaluate different management procedures in terms of their ability to reach the greatest biological, economic and commitment/compliance utility. Model variables circled in red consist of the variables monitored when running the simulation evaluation model under different simulation or model settings (circled in green).

Once the BBN network has been populated it can be used to evaluate the utilities of the different management procedures. In addition it can be used to evaluate the value-of-information and the value-of-control. The value-of-information indicates how much should be paid for better information. This depends for example on how much decisions could change if new information is obtained and how well the new decision can be implemented. The value-of-control indicates how much should be paid for better control (management) of the system. How much the expected state of the system could be improved, if the precision of the control would be improved.

Figure 30 illustrates how the value-of-information and value-of-control can be incorporated and examined within the BBN. In case additional data or information is available which reduces the uncertainty in the choice between different models, or different scenarios, this will have an impact on the Harvest Control Rule (HCR) which can be chosen to be less restrictive on the predicted profitability of the fleet. Using the BBN it is possible to examine, which uncertainties matter most and on which further analyses should focus.

Therefore the BBN not only serve to synthesise the final results from the simulation evaluation model but are also are used as a dynamic tool to guide its development. For this purpose, the BBN should be used as soon as the robustness trials with the operating models have been done. By examining the results of the robustness trials within the BBN, not only can the validity of the operating models be examined, but also the validity of the BBN model structure and monitored model parameters can be established. In addition to the value-of-information, further analysis on the value-of-control can be done. Management procedures are much less useful when there are also external political decision influencing the eventual HCR, thereby loosing control over the system.

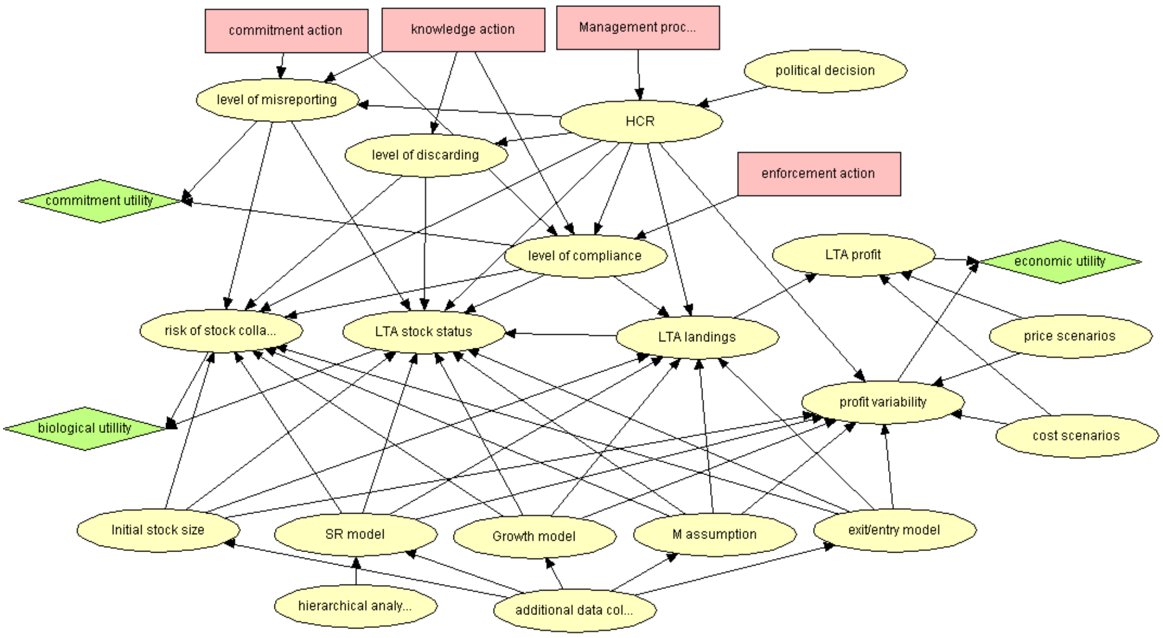


Figure 30 Example of the general BBN structure used to evaluate the value-of-information and the value-of-control and direct further analyses.

When using the BBN, a special focus has been placed on commitment. There are two different ways commitment is dealt with. Either the commitment is modelled in terms of the level compliance, misreporting and discarding. The main idea is to evaluate what level of compliance and reporting would be needed in order for the management procedures to work and which management procedures are robust to high levels of non-compliance and misreporting. In addition it can be explored what the economic benefits of compliance are in terms of the costs need to achieve compliance. Or a separate BBN can be developed which explores the factors that influence stakeholders commitment and how these factors can be influenced to increase stakeholders commitment. This commitment BBN was only developed for the Baltic salmon case study. Even though the actual causal relationships are transferable to the other case studies, it examined if the factors influencing commitment and the network structure are applicable to other case studies and what lessons can be learned from them when thinking about stakeholder commitment.

1.6 Impacts on Sectors and Research Community

The research within COMMIT resulted in the initial development of multi-annual management plans under both the CFP, cost of control measures and benefits of alternative management plans including the potential economic impacts of such plans. The importance of the methodology developed by COMMIT for providing advice has been recognised. For example ICES stock assessment working groups have used and applying the FLR (Fisheries Library in R) framework for providing advice.

A New Scientific Advisory Framework
Traditional fisheries advice requires identification of a 'best assessment' which means rejecting all other alternatives, even though some may be almost as plausible. Schnute and Richards (2001) further highlighted a problem for advice based on stock assessment, where an elegant model can become alluring to the analyst who invented it. After a while, the model's output starts to appear as if it gives a reasonable picture of the real world. "Like the mythical sculptor Pygmalion, the creator can fall in love with his creation and become blind to other realities." An alternative, as pioneered in Europe by COMMIT, is Management Strategy Evaluation (MSE) which allows the testing of models and management strategies and often reveal surprising limitations of longstanding fisheries advice and therefore act as a healthy antidote to the Pygmalion effect (Schnute *et al*. 2007). Under the MSE approach the objective is no longer to come up with "the answer" but to evaluate the consequences of a strategy to alternative assumptions about stock dynamics, i.e. its robustness. This allows alternative strategies to be proposed and evaluated for a range of management objectives of relevance to stakeholders and trade-offs between them.

Scientific Tools
Schnute *et al* pointed out that it would greatly advance fisheries science and hence management if the worldwide community of fishery scientists agreed to the design of a comprehensive testing system. However, no one person or institution can act alone to develop all the required standards. It will have to be a collective effort that spans organizations and disciplines before it will be recognized as adequate. Results will need to be replicated at different times and places and potentially, the tests need to be replicated easily by anyone who thinks the existing standards might contain errors. COMMIT addressed these challenges by collaborating with other European projects on the development of FLR (www.flr-project.org), an open source development effort to build a framework for the evaluation of fisheries management strategies designed to facilitate collaboration within and across (biological, ecological, statistical, mathematical, economic, and social) disciplines. And in particular to ensure that new modelling methods and software are more easily validated and evaluated, as well as becoming widely available once developed.

Collaboration within Europe 6th and 7th Framework Programmes
A variety of FP6 and FP7 projects have built on this framework and applied it to a large range of cases studies and extended it to incorporate bio-economic (e.g. EFIMAS), mixed fisheries advice (AFRAME) and an improved understanding of biological processes (UNCOVER). FLR has also been used to incorporate a range of tools for fishery independent management strategies (FISBOAT), data poor stock (POORFISH), collection and use of data in real time (CEDAR) and the cost of enforcement (COBECOS). The project PRONE is now using the work of COMMIT to provide quantitative evaluation of risk and to help to develop a comprehensive framework for the risk management in collaboration with stakeholders. While the new FP7 project JAKFISH will be using the FLR framework in participatory modelling to allow the methodology of COMMIT to better address the stakeholders needs and facilitate discussions in real-world negotiation contexts.

The FLR framework has already been used in a variety of projects. Some of the development has been in conjunction with the European projects FEMS and EFIMAS where FLR has been used to run management evaluations. There is increasing interest in FLR being used for running standard stock assessments. For example, in March 2006, FLR was used to assist in assessing stock for the ICES WKHAD working group. Several journal articles regarding the evaluation of management strategies and predicting the effects of environmental variation have used the FLR framework (Kell *et al*. 2005a, Kell *et al* .2005b). The latest applications of FLR were presented at the ICES Symposium on Fisheries Management Strategies in Galway, 2006. Details can be found at: http://www.ices06sfms.com/index.shtml.

<u>Case Studies</u>
North Sea Flatfish
The results of the North Sea Flatfish case study have found application through the use of the model components in various stakeholder fora. These model components describe the dynamics of the exploitation of the North Sea plaice and sole stocks. The evaluation of several proposals for management strategies from EU management bodies (STECF) and the North Sea RAC have been performed using this knowledge. The evaluation of the implementation error with respect to the harvest control rules in the management strategies has been explicitly taken into account by modelling the discarding behaviour of the major fishing fleets. The models developed for the COMMIT framework indicated that strong fishing effort reductions would improve the sustainability of the two flatfish species. The current TAC system with quota for the individual species is less effective because of its potential for over-quota discarding. Future studies may evaluate the impacts of other management strategies, including a wide range of management measures, including technical measures.

In the technical annex of the COMMIT project it was stated that the project would integrate interactions between biological and economic, including models of non-compliance, resulting in more ‘realistic’ impacts of management plans being estimated. In the course of the project this approach has been successfully implemented in different cases (Baltic salmon, North Sea flat fish, Northern Hake). Because of the delay in the EFIMAS project, a large part of the resource has been used for the implementation of the (economic part of the) models. The economics included the definition and implementation of cost functions, price data and price functions and indicators of economic performance. In the NS case study special attention was given to the effects of effort reductions on catchability through optimisation behaviour of fishermen. The newly developed bio-economic model for the flat fish fishery in the North Sea had a direct impact on the management process, through the STECF meetings and advice on the flat fish management plan in 2006 and 2007. The confrontation of the results from the COMMIT/EFIMAS model with the traditionally used EIAA model showed the uncertainty in the economic outcomes of the models. Initially this added uncertainty to the model outcomes, but using the methodology developed in COMMIT, this will lead to more robust management options in the mid- and long-term. (see for example the paper on the flatfish case)

Baltic Salmon
In the case of Baltic salmon, the modelling was carried out mainly by applying Bayesian models. Especially the use of hierarchical S/R models was an important novelty application to such cases, where the stock has been on a low level in the history, and there is still a need to evaluate, what would be the future catch potential of the stock. In a case exploitation level has been high and biomasses low, the obtained S/R information cannot be informative in showing what could be the future catch potential and/or stock recovery. The hierarchical model took into account the expert knowledge related to the different rivers, as well as all the S/R information available from the Baltic and Atlantic areas.

Similar techniques would be very important to apply in current situation, where MSY or FMSY must be estimated to achieve the agreed objectives of Johannesburg agreement. Even though such estimates may be uncertain and not really predictable, it is still the duty of the scientists to try to estimate them, or at least to show how they could be learned by management actions over the time period available.

The Baltic salmon case study also applied an explicit way of modelling implementation uncertainty and commitment to alternative management approaches. This was based on a three step procedure: first an expert interview to understand the mechanisms, then a mail questionnaire to a large number of stakeholders, and finally a new interview of key persons, based on previous results. In these interviews, the likely future response of the stakeholder groups was estimated also for those management actions, which have never been applied and cannot be studied by usual empirical methods. All impacts were estimated by probabilities, i.e. the management "power" and the quality of knowledge were described by probabilities.

Similar techniques are important to apply to other fisheries as well, because the implementation uncertainty, and the ways to manage them, must be taken into account when evaluating required degree of management actions. In a case we want to have a high probability to achieve the management aims, the high implementation uncertainty may lead to even more restrictive management actions than would be required in a case of low implementation uncertainty.

In addition, the Baltic salmon case developed a Bayesian run-reconstruction model (state spaced model) to describe the dynamic of the stocks in time and in space. This takes into account the uncertainty in stock estimated, and the area specific management actions, like closure of coastal fisheries along the spawning migration. Similar, are specific migration models may be needed for stocks which have long migrations with variable degree of exploitation and variable contributions to SSB. Especially the estimation of high catchability on some areas may be important to make correct management conclusions. In terms of policy a key outcome is the contribution the project has made to the assessment of Baltic Salmon stocks within the ICES working group.

Northern Hake

For Northern Hake, the recovery plan was tested within a Management Strategy Evaluation framework. The uncertainties in the biological factors (that is: the recruitment dynamics; growth, assumptions and natural mortality, cannibalism) was evaluated. However, the proposed multi-annual management plans and Harvest Control Rule (HCR) were found to be robust to alternative hypotheses as to these uncertainty associated in these biological factors. In term so impacts on the sectors this was presented at a meeting in June 2007, that is a STECF meeting on the Northern hake long-term management plans (STECF/SGBRE-07-03) that was held in Lisbon. Two algorithms, both integrated in FLR (Kell *et al.* 2007), were used to simulate all the agreed scenarios. A simple projection algorithm and the Management Strategy Evaluation (MSE) simulation model coded within COMMIT project were used to carry out the Northern Hake recovery plan simulations. A more recent STECF meeting has used the outputs from the first Hake long-term management plan to predict the impact on economics and social aspects of the fleets (STECF/SGBRE-07-05).

Initiatives by EU advice bodies incorporating COMMIT input:

ICES

The Working on Fisheries Systems (see ICES 2006b) has noted that the work of COMMIT and the development of the FLR framework is a major step forward in developing a shared language that can be used among scientists and then can make a significant contribution to clarifying communications across the science boundary with and among stakeholders. For example FLR is now being routinely used by ICES to undertake stock assessment (e.g. WNGSSK, HAWG, WGNSDS, WGHMM, WGBAST) leaving more time to evaluate management plans and address a variety of management and scientific problems (e.g. SGRAMA, SGMAS, Request on NEA mackerel, WKEFA, WGFS). Strategic groups such as the ICES Methods Working Group used it to provide a better basis for method development. The ICES WG on Fishery Systems noted that “*the development of FLR is a major step forward in developing a shared language that can be used among scientists, initially,* *and then can make a significant contribution to clarifying communications across the science boundary with and among stakeholders. In doing so it is anticipating ….fisheries-based advice*”.

This project has in the end extended the boundaries of method development in the area of management strategy evaluation not only in terms of high academic standards and publication in leading scientific journals but also in terms of policy implications, that is implementation of results from STECF meetings on the assessment of long term (multi-annual) management plans of important and economically important EU fisheries commercially exploited and environmentally sensitive fish stocks (sole, plaice, Northern hake and the Baltic Salmon).

STECF

The full and extensive evaluation of multi-annual management plans have been conducted for the European Commission via STECF for the COMMIT case studies (i.e. North Sea Flatfish and Northern Hake) including economic analysis’s, but also for other case studies showing the generic applicability of the tools built by COMMIT. For example the evaluation of multi-annual management plans for stocks not already subject to long-term plans, these plans are intended to provide stability for the industry and FLR was used to evaluate the long-term consequences to sustainability. Following this work the STECF concluded that the FLR framework is ready for future and should be used to evaluate management plans on a case specific basis.

International

The work of COMMIT, particular the FLR framework is being picked up internationally and workshops have been held in Canada and the USA (in Florida in December 2007). Within Australasian research bodies there is also an interest in the progress made.

The Future

There is a clear demand from stakeholders to be more involved in the decision-making process including a demand for increased transparency and understanding, both of the knowledge base of advice and of the criteria entering the management decision processes (http://www.nsrac.org): Therefore the FP7 project. JAKFISH will work with stakeholders to apply the scientific framework of COMMIT and allow management plans to be developed in collaboration with stakeholders. Most fisheries management advice provided by ICES is on a "*single species*" basis. However, an objective of the Common Fisheries Policy is *to minimise the impact of fishing activities on marine eco-systems* and to progressively implement an *eco-system-based approach to fisheries management* (EAFM) therefore the FP7 project IMMAGE will extend FLR to develop management regimes that are robust to ecosystem change, Management strategy evaluation will be used to develop indicator-based management systems using a simulation model to describe alternative hypotheses about ecosystem dynamics.

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2. Dissemination and use

2.1 Exploitable knowledge and its use

For the COMMIT project there are no results that can be defined as exploitable results; that is: *defined as knowledge having a potential for industrial or commercial application in research activities or for developing, creating or marketing a product or process or for creating or providing a service.*

2.2 Dissemination of knowledge

Overview table

Planned/actual Dates	Type	Type of audience	Countries addressed	Size of audience	Partner responsible /involved
9th-11th July 2007	Conference	Researcher	Various EU	50-100	LEI, AZTI
18th-22nd June 2007	Meeting	Government, research and industry officials	Various EU	±20	CEFAS, AZTI, DIFRES, FGFRI, LEI
4th-8th June 2007	Meeting	Government, research and industry officials	Various EU	±10	AZTI
11th-20th April 2007	Meeting	Government, research and industry officials	Various EU	±8	FGFRI
20th-23rd March 2007	Meeting	Government, research and industry officials	Various EU	±10	IMARES, LEI
26th-29th September 2006	Meeting	Government, research and industry officials	Various EU	±10	IMARES, LEI, FRS
19th-23rd September 2006	Conference	Researcher	Various EU	±250	CEFAS, AZTI, DIFRES, FGFRI, FRS, IPIMAR, IMARES
27th-30th June 2006	Conference	Researcher	Various EU plus USA and Australian	±300	CEFAS, AZTI, DIFRES, FGFRI, FRS, IPIMAR, IMARES, EMI
15th-17th June 2006	Conference	Researcher	Various EU and international countries	±300	CEFAS
20th-24th September 2005	Conference	Researcher	Various EU	±250	CEFAS, AZTI, DIFRES, FGFRI, FRS, IPIMAR, IMARES
14th-17th June 2005	Conference	Researcher	Various EU	±100	FGFRI
21st-23rd March 2005	Conference	Researcher	Various EU	50-100	CEMARE, LEI
9th-11th February 2005	Conference	Researcher	Various EU	±50	FGFRI, EMI

2.3 Publishable results

The publishable results are available in a series of peer-reviewed (in most cases) scientific papers. The sectors that will be interested in these results include the fishing industry and their representative organisations and the government bodies responsible for fisheries management. As mentioned, these papers have been published in various journals and as such are publicly available. Collaboration is sort with other marine science institutes who have an interest in the methodology and they can access these published results in the journals. The intellectual property rights are published and copyright exist on each article. The contact details of the first author are published in the journal, which is protocol.

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