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Report of the Workshop on Introducing Coupled Ecological-Economic Modelling and Risk Assessment into Management Tools (WKIMM)

16–18 June 2010

Kiel, Germany

International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

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Executive Summary

The workshop held at Kiel University (D), 16–18 June 2010, aimed to review regional examples of state-of-the-art in ecological-economic modelling in fisheries science and to identify ways for further development and integration in relation to scientific fish stock and fisheries advice. It brought together economic and ecological researchers from eight different countries around the world from Europe over North America to Australia presenting theoretical and empirical work and structural issues. There are different approaches in different regions and some structures and processes are case specific. Some functions are transferable between regimes and case studies and thus of general interest.

The type of models to be used and the level of integration will be highly dependent on the objectives to be addressed and the context of the actual use. Within the workshop two major distinctions were made with respect to implementation in relation to the long-term strategic planning and advice and the short-to-medium term management evaluation and advice. The first is dependent on the expected change in the environment on long term temporal and large scale spatial scales including climate cycles and trends on a longer time frame effecting whole ecosystems and generally effecting overall policies and strategic management. The latter relates mainly to short to medium term management decisions, fishing behaviour and impact, and to the short-to-medium-term natural variability in resources and environment on a more local scale within regions, which typically needs to be addressed in scientific advice and predictions with high precision. This is to be used in short term forecasts and management strategy evaluation (MSE) related to especially fish stocks and fisheries taking into consideration effects of seasonal and year-to-year variability and to be spatially disaggregated in more restricted areas. It can for example be addressing effects of severe winters and heat waves affecting stocks and fisheries on a narrow geographical scale taking into consideration short-term variability in availability of fisheries resources, recruitment, etc. Another distinction is the purpose, use and detailing of the models in relation to actual precise assessment and management advice vs. more strategic management evaluation, i.e. the state of the resources and resulting advice for the fishery according to implemented objectives versus the evaluation (and advise) with respect to the strategic overall management objectives.

There exist and were presented models and management evaluation frameworks including coupled ecological and economical models relating to all the above distinctions, some more advanced than others with respect to the state of implementation. None of the models and frameworks has yet been fully implemented into scientific advice when it comes to use of possible coupling between ecology and economy. There are advanced tools available and the scientific basis is present to obtain significant further progress in this work. However, this will need future extensive resources to promote, support and establish the necessary scientific cooperation and platforms for this as well as political will, to use advice from such integrated evaluation.

1 Opening of the meeting

The workshop was opened at 09:30 on 16 June 2010. The Co-Chairs, Jörn Schmidt and Rasmus Nielsen, welcomed the participants to the meeting and provided housekeeping information.

The agenda for the workshop is given in Annex 2.

2 Objective

Fisheries are economic activities, which are dependent on and interact with the ecosystem in which they take place. Changes in the ecosystem are of immediate interest to fisheries if these changes affect the resource, i.e. the fish, shellfish or plants, which is harvested by this fishery. The assessment of the resource is just one prerequisite; another is to predict its potential further development. Therefore ecological models are needed to model the ecosystem, the resource and possible future developments. However, manageable is not the ecosystem but the human activity, i.e. the fishery, within the ecosystem. Fisheries highly impact the ecosystem based on fisheries behaviour resulting from resource availability, management options, and other options. Thus, economic models are needed to assess and to predict the effect of management options for the fishery on the ecosystem. The continuous cyclic feedback of changes in the fishery on the ecosystem and the consequences this will then have on the development of the ecosystem and the feedback to the fishery again, could only be assessed and predicted using integrated ecological-economic models, which incorporate the necessary complexity of both, the ecosystem and the fishery. This system will be even more complex if not only target species of the fisheries are of concern, but also the ecosystem as a whole, i.e. protected habitat, protected species or ecosystem services like water clearance.

3 Overview of existing models and approaches

Below are summaries of the presentations given on day one of the workshop. The presentations could not give an exhaustive overview of all existing approaches, but represent those covering the participants of the workshop. These presentations also include two keynote presentations from Prof. Dr. Trond Bjorndal and Prof. Dr. Anders Skonhoft.

3.1 Managing fleets and fisheries rather than single stocks – Implementing fisheries management evaluation tools capable of comprehending both the biological, economic, sociological and spatial dynamics of the fisheries and ecosystems (J. Rasmus Nielsen)

ICES fisheries are under pressure. Many commercially important fish stocks are declining and so are the number of fishing boats and people employed within the fishing industry. Management and regulation of fisheries become continuously more complicated. Stakeholder confidence in existing assessment and management models is shaken and more efficient management regimes are called for. Existing models in fisheries management advice (FMA) only consider effects of overall fishing on single fish stocks, while not taking broader ecosystem, social and economic impacts of management decisions into account. Mixed fisheries aspects where several fishing fleets fish on several stocks in the same fishery, spatial planning, and long-term management strategy evaluations are also not considered adequately. In response to this situation, management and scientific advice calls for new programmes aiming to develop alternative management evaluation tools and management strategies that have broader, multi-disciplinary and long-term perspectives. This includes social and economic impacts and ecosystem impacts (e.g. by-catch and discard) besides biological consequences on single stocks. Consequently, a new trend has emerged in thinking international fisheries research and FMA by developing conceptual and comprehensive multi-fleet and multi-stock bio-economic simulation tools and management evaluation frameworks (MEF) being spatial and seasonal explicit. A successful implementation of ecosystem, social and economic dynamics and factors on a spatial scale in the advisory process are a major leap towards more holistic and sustainable management within ICES waters and fisheries. Furthermore, MEFs enable higher degree of participatory management evaluation by involving various stakeholders in FMA.

Scientific basis and development: A decade of research

Results from multiple international and national European research projects has been summed up and joined in the paradigm shift approach in thinking and practising FMA (Nielsen and Limborg, 2009). The current advisory system has been evaluated to improve allocation of resources according to use and cost-efficiency (e.g. EU-FP5-EASE-01693-Concerted-Action). Specific EU-policy shortcomings have been studied to devise means for their rectification (e.g. EU-FP5-PKFM-01253-Project). Methods for defining and characterising fleet and fisheries dynamics were developed (e.g. EU-FP5-TECTAC-01291-Project). Technical developments and efficiency increase over time in fishing fleets (e.g. gears and vessel equipment), as well as patterns and developments in fleet and fishermen behaviour were evaluated in several projects (e.g. TECTAC, EU-FP6-CAFÉ-022644). From this knowledge, new programmes focused on developing MEFs able to consider broader bio- and socio-economic effects of alternative management options before potential implementation, and to more directly investigate broader dynamics of the system, i.e. fishing fleet dynamics. This is needed for the development of multi-disciplinary models combining traditional management procedures with subsequent responses by fishing fleets and fish stocks (TECTAC, CAFÉ). The arising inter-disciplinary trend includes also key elements in multi-annual management strategies and making these acceptable to fishermen and optimises their commitment and compliance with regulations (EU-FP6-COMMIT-502289).

Another important aspect is the development of advisory models enabling an ecosystem-based approach to marine management and spatial planning, also addressing dynamics of fleets and fisheries. Socio-economic objectives need to be included by considering biotic, abiotic, and human components of influences on ecosystems and through an integrated approach to fisheries within ecologically meaningful boundaries. Focus is on spatio-temporal closures and more selective fishing gears to minimize negative ecosystem impacts by protecting certain habitats and to reduce unintended by-catch and discard of certain species and sensitive life stages. Spatial explicit management evaluation and advisory tools on fleet basis were developed in EU-FP6-PROTECT-513670 and EU-FP6-EFIMAS-502516.

To facilitate better fisheries management regimes, recent projects (e.g. EFIMAS) use state of the art knowledge to develop actual and holistic operational MEFs and exemplifies the development of the new concept and evaluation tools in FMA and how scientific advice is likely based in foreseeable future (http://efimas.org; see also sections 3.6 and 5.3).

State of the art knowledge base

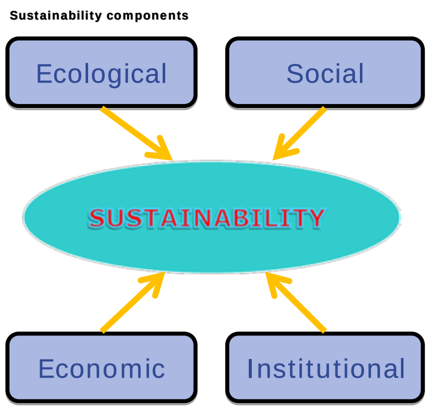
A major challenge is to synthesize the best possible worldwide knowledge to develop relevant MEFs with broad coverage of main current and emerging management problems and issues. Initially, the state-of-the-art knowledge base for different basic and existing fisheries management systems of relevance for ICES including their institutional set-up was synthesized in a book-publication (Motos and Wilson (eds), 2006). This includes generating advice for fleet based, ecosystem based, and participatory management in cooperation with multiple stakeholders. This synthesis was used in a feedback process to develop the MEFs including fishermen and other stakeholder perspectives. Lastly, the book focuses on management scenario modelling and methods and their central role in future FMA. Based on the book conclusions on needs to improve current management and to advice the developed MEFs were made flexible enough to include a broad range of options under alternative systems. This review has been followed up by further reviews of bio-economic models (see section 3.3).

Today, the biological models used in current advice (e.g. ICES (and EU STECF) are mainly single stock assessment models, i.e. relatively simple biological population dynamic models. The above is an example of exploratory, more comprehensive, complex and integrated biological models emerging in ICES through EU Projects. Also, ecosystem models are available such as multi-species biological models, wider ecosystem based biological models besides the mixed fisheries HCR fleet based models when single stock TACs are conflicting, and long term management strategy evaluation using stochastic assessment models. The biological models have been reviewed in the FAO Fisheries Technical Paper 477 (2007): "Models for an ecosystem approach to fisheries". However, only a very few of these are directly implemented in advice, but are for example only used for exploratory purposes in ICES. In EU STECF advice economic models are applied for economic fisheries and fleet advice mainly using output from single species biological models (ICES advice) and are published in the yearly report "Economic Performance of Selected European Fishing Fleets" (Economic Assessment of European Fisheries). Consequently, economic and ecological models are not implemented and not used in an integrated modelling approach in EU STECF and ICES. Such integrated approaches are very sparse worldwide.

Considering different multi-disciplinary types of sustainability

Several directives point at integrated approaches and integration into wider marine management taking also other sectors than the fishing sector into consideration such as the EAFM (EU Ecosystem Based Approach to Fisheries Management) the Bird and Habitat Directive, the Water Framework Directive (WFD) and the Marine Strategy Framework Directive (MSFD). In this context it is necessary to define sustainability in a broader context considering different <u>disciplines</u> and to differentiate l<u>evels</u> of sustainability (e.g. stock / ecosystem). Management objectives and reference points from e.g. international conventions needs to be transformed into o<u>perational management objectives</u> and management strategies which again needs to be transformed into c<u>oncrete management-strategy-reference-points</u> for specific status-indicators with respect to defined sustainability in order to use models for MSE in relation to those. Ideally, the full system of sustainability should be evaluated to "dress" managers to make informed decisions based on a full overview so that they can politically choose between tradeoffs in a framework of different types of sustainability.

Biological Sustainability Criteria used in ICES advice are nearly exclusively on the basis of single species and often on a single stock level. The criteria and reference points were related to stock size (SSB) and single stock fishing mortality (F) under the precautionary approach and are still in the new MSY framework. The criteria in relation to mixed fisheries are the same indictors and sustainability criteria (reference points) as for single species and stocks (which can be conflicting in mixed fisheries) without considering fleet and economic criteria. On the ecosystem level the criteria are vague (even though Ecological Quality Elements and ECOQO's are defined, Reference Points are most often not specifically defined, settled or made operational). However, there is worked intensely done in ICES to define such indicators with the help of several external (e.g. EU) funded research projects.



With respect to economical and sociological sustainability and criteria for this the current management (and associated advice) is in general not build up around fisheries economical and sociological advice. There are no well-defined operational management objectives in force and any well-defined management criteria and indicators set. The advice and management reference points and measures of performance are not well defined - and not implemented. At present the EU STECF mainly evaluates bio-economic consequences of different scenarios for traditional biological based sustainability on single species and single stock level. Some progress in EU STECF (e.g. SGMOS) and ICES (e.g. ICES WGMIXFISH) has been made in relation to exploratory modelling and evaluation but output from here is not fully implemented in advice and management.

Integrated approaches

Fishery is a main driver of the marine ecosystem (e.g. North Sea, Baltic Sea, Biscay, Mediterranean, NW Atlantic, etc) and fishery dynamics (multi-fleet) influence directly the ecological (multi-stock) sustainability. Fishery dynamics are very much based on economic considerations, e.g. in relation to levels of fleet capacity, dynamics in relation to revenues and costs, fleet and fisheries specific harvest patterns – e.g. mixed fisheries, behaviour patterns of different fisheries with respect to targeting and effort allocation associated to resource availability and reactions to regulations as well as other economic dynamics of fisheries. In existing ICES management advice fishing mortality, F, is mostly integrated as one overall parameter in stock evaluation not considering fleet specific partial F dynamics (fleets/fisheries/area/season). It is necessary to analyse these at the fishery level and to evaluate their different impacts as integrated activities influenced by biology/ecosystem, economy, sociology and politics (regulations) in order to perform a holistic and integrated evaluation of tradeoffs of different management options in order to forecast potential consequences on a realistic basis.

When developing integrated approaches it is necessary to involve the main drivers influencing the dynamics of the system and to identify units and indicators as well as to establish functional relationships of the dynamics, and estimate parameters for the main drivers and indicators. This is a multi-disciplinary exercise (biology, economy, sociology) that will call for use of integrated evaluation frameworks, tools and models capable of evaluating the integrated drivers and their parameters in multi-disciplinary context. Also, it will be necessary to involve parameters in advice enabling also future cross-sectoral and multi-sectoral evaluation and comparison of impact and benefits of various marine activities and management options. This should be done in relation to spatial planning, broader marine management issues and necessary risk assessment of different activities and options (Marine Strategy Framework Directive). Here the economic parameters seems to be the platform for comparison of impacts - also to enable integration of stakeholder perspectives and their incentives – across sectors such as marine fishery, transport, energy (Oil, Wind-energy, Wave-energy, etc.), recreational use and tourism as well as in relation to environmental organizations protective wishes.

3.2 Current and Potential Rent in Fisheries: two North Sea Case Studies; i) North Sea herring and ii) North Sea demersal fisheries (Trond Bjorndal)

The economic health of marine fisheries worldwide has been in an alarming decline for decades owing to a combination of depleted fish stocks and excessive harvesting effort. One outcome of the stock depletion combined with excessive levels of effort is the dissipation of resource rents, which is estimated at $50 billion worldwide (World Bank, 2008). Thus it is worthwhile to investigate the economic state of the North Sea fisheries.

The paper assesses the possibilities for rent generation in the North Sea herring fishery and the North Sea demersal fisheries (cod, haddock and whiting). A bio-economic model combining fish population dynamics with the economic structure of the fisheries is used to calculate the rent. The model combines biological data with vessel-level economic data for UK pelagic trawlers in case of the herring fishery and three UK demersal fleets, as well as pre-existing parameters from the literature in measuring for potential rent under optimal management conditions. The results are evaluated under various assumptions with regard to price, costs and discount rate. For the herring fishery the current rent was estimated to be negative, assuming relative fixed and variable costs for the herring caught. Thus substantial economic gains could be realized with optimal management of this fishery. However, the argument could be made that the pelagic fleet catches also mackerel, possibly more important in terms of catches and revenues, making the herring fishery a marginal fishery. But even if only the variable costs are used, the current revenues remain low and could be enhanced.

For the analysis it is assumed that a sole owner whose objective is to maximise the present value of net revenues from the fishery manages the resource in question. The net revenue function is given by

$$\Pi(H_t,S_t)$$

where H_t is the harvest and S_t the spawning stock at time t.

The method of Lagrange multipliers can be used to derive equilibrium conditions for an optimum:

$$L = \sum \{\alpha^t \Pi(H_t, S_t) - q_t[S_{t+1} - (S_t - H_t)e^{\delta(S_t)} - G(S_{t-\gamma})]\}$$

where $\alpha = 1/(1 + r)$ and qt = discounted value of the shadow price.

Performing the dynamic optimisation, an implicit expression for the optimal spawning stock S* is derived:

$$e^{\delta(S^*)}\{[\Pi_s+\Pi_H]/\Pi_H\}+\delta'(S^*)[S^*-G(S^*)]+\alpha^{\gamma}G'(S^*)=I+r$$

The term $\Pi_s+\Pi_H]/\Pi_H$ is the marginal stock effect (MSE) in a discrete time nonlinear model.

Let harvest in period t be given by the following Cobb-Douglas production function:

$$H_t = H(K_t, S_t) = aK_t^b S_t^g$$

where Kt is fishing effort in period t.

Bjørndal and Conrad (1987) found that, for North Sea herring, the number of participating vessels may be an appropriate measure of effort, an assumption that will be made in this study.

We assume the cost per unit of effort to be constant. Under this assumption, we can write the cost function as:

$$C(S_t, H_t) = cK_t = c(H_t/aS_t^g)^{1/b}$$

where c is the cost per vessel per fishing season which includes a normal return on capital.

We define industry profit as:

$$\pi_t = pH(S_t, H_t) - cK_t = pH(S_t, H_t) - C(S_t, H_t)$$

where p is unit price of harvest. The industry profit – over and above a normal return on capital - equals the resource rent from the fish stock.

The model is described in more detail in Bjørndal *et al.* (2010). The result for the herring fishery shows that with 5% discount rate the optimal stock size would be 1.325 m tonnes which is slightly higher than the calculated stock at S_{MSY} (1.284 m tonnes). The annual rent would be 93.8 m pound representing 74% of the revenue. This is similar to findings for the Norwegian spring spawning fishery of 69% (Bjørndal 2008).

A similar investigation was made for three demersal fisheries targeting cod, haddock and whiting. The optimal stock sizes are much higher than the current stock sizes, but at a size, which was historically present. The current rent is quite low (aggregated 13.4 m pound) and could be substantially increased (530.5 m pound).

As a conclusion, the rent dissipation in the herring fishery is mainly due to high overcapacity, whereas in the case of the demersal fisheries it is due to stock depletion. The potential rent is very substantial with approx. 50–74% of the revenues.

3.3 On the conflicting management of wild Atlantic salmon and farmed salmon (Anders Skonhoft)

The state of the wild salmon stocks in Norwegian waters is not very good. Stock development is altered by a combination of factors, such as sea temperature, diseases and human activities, both in the spawning rivers as well as through sea farming of salmon. The sea farming outnumbers the wild stocks by far (approximately 500 000 tonnes vs. 2500 tonnes). The wild stocks suffer under escaped farmed salmon, which compete for food and which interbreed with the wild stock and through introduced diseases (e.g. salmon lice). The wild stock is harvested both by commercial and recreational fisheries. The value of the commercial fisheries in the sea is more or less directly related to the meat value, whereas the recreational value is related the willingness to pay for fishing rights. Moreover the economic effects of recreational fisheries in the rivers are of great importance for the local communities.

The interference of the farmed salmon and the wild stocks exhibit ecological as well as economic effects. Thus an integrated ecological and economic study is needed to come to an optimal management of both activities.

The main objective of the currently ongoing project NFR Miljo2015 is to analyze the ecological and economic effects of farmed salmon escapees on the wild salmon stock and the corresponding fisheries as well as to explore sound management strategies for the wild salmon fisheries. To address these overarching objectives, we 1) examine the ecological and economic effects based on a general invasive bio-economic model, 2) explore changes in anglers' demand, 3) explore the economics of genetic interaction between wild and farmed salmon escapees and 4) investigate the economics of selective harvesting (different age classes) and the effects of additional mortality of farming (e.g. introduction of salmon lice).

To address these research questions a bio-economic model was developed taking the specific life cycle into account (salmon die after spawning) as well as the interaction of escaped farmed salmon with the wild stocks introducing stepwise more complexity, i.e. age classes and interbreeding in the biological part and different demand functions in the economic part (with respect to the recreational fisheries).

With the simplest model, the results showed that after the invasion of escaped farmed salmon the total number of salmon in the wild was roughly half escaped farmed salmon and wild salmon. It was assumed that there was no possibility to fish selectively. Thus the results showed an ecological effect, but no economic effect, as the loss in wild salmon catch was substituted by gain in farmed salmon catch. However, the ratio of farmed salmon in the catch of recreational fishermen reduces their willingness to pay by 60 % if half of the catch consisted of farmed salmon and by 84 % if the total catch is farmed salmon.

We developed also an age-structured model of the wild stock without interbreed to investigate the effect of increased natural mortality (e.g. salmon lice). This model consists of 6 different age classes, the recruits, three immature age classes and 2 mature age classes, which can be harvested. Such a model represents a complex dynamic system, which is difficult to optimize, i.e. different fishing mortalities given different goals (minimizing costs or maximizing profits). We used the maximum sustainable yield as a target, but included also harvesting value and stock conservation measures. This kind of optimization was first solved by Reed (1980) with the result that at most two age classes should be targeted. The major difference from the system studied by Reed and others, is that salmon dies after spawning. For this reason, we find that fertility plays a role, but not natural mortality (no biological discounting). However the similarity is that the gain in biomass does play a role. The additional natural mortality induced by, e.g. salmon lice, might lead to a 40 % reduction in survival and thus up to 50 % loss in economic yield. One possible optimal solution could be to harvest already smaller salmon, which implies perfect selectivity, e.g. using variations in migration.

3.4 Review of some bio-economic models developed within the EU Region (Marga Andres)

Survey of existing Bio-economic model

The presentation summarized the bio-economic model review made by Prellezo *et al.* (2009), where the EIAA, TEMAS, MOSES, BEMMFISH, BIRDMOD, MEFISTO, AHF, EMMFID, SRRMCF, COBAS, ECOCORP, ECONMULT and the EFIMAS-FLR models were reviewed. This was a work that follows up upon previous review work under EU STECF and under the EU FP6 EFIMAS Project.

The objective of this survey was to create an operational report that facilitates the selection and use of a model given a predetermined question. This report was focused on giving the reader a reference rather than something that should be read from cover to cover. In that respect, a guide of the key issues which have to be considered in a bioeconomic model was given and models characteristics were summarized in frameworks to facilitate selection of a given model for particular use and for comparison purposes. For more detailed information, a full review following a common template was provided for each model.

Review of models

A main aspect needed to be considered is the objective followed in the development of each model. With respect to this, it is obvious that each model has its own objective. Some models deal with the specific problem of dynamic change in fleet capacity (AHF), the simulation of management strategies (BIRDMOD, EFIMAS-FLR, COBAS, …), economic evaluation of a particular advice (for example EIAA with the ACFM advice), or specify a more concrete problem (for example ECOCORP with the cod recovery plan)or a more general one (SRRMCF which considers the whole Swedish fishing sector, or EMMFID that covers the entire commercial fishery in Denmark).

It should be noted that many of the models were area-specific, i.e., they were developed for a distinctive/specific region. The most obvious examples were those from the Mediterranean (MEFISTO, BEMMFISH, BIRDMOD, MOSES). In fact, only those models based on FLR (including AHF) had case studies in both the Atlantic and Mediterranean (and also outside the EU waters). The reason is that FLR is not a model but a toolbox (framework) to be used for the construction of models and inclusion of already existing assessment and economic models. TEMAS was also meant as a toolbox, but has not been applied to Mediterranean case studies and has only been applied to limited extent generally.

Model orientation is also related to model focus and rationale. Given the management scheme of the Mediterranean, models such as MEFISTO, BEMMFISH, BIRDMOD and MOSES are input (effort) oriented. The Atlantic models are either input oriented (for example COBAS, but also EFIMAS-FLR in specific cases), output (catch) oriented (EIAA, as well as most of the case specific models implemented in FLR) or input and output oriented (AHF, EcoCorP).

Simulation (what if) models are the main approach considered in the models reviewed with the exceptions of MOSES and SRRMCF in which an objective function is optimized (what's best). To highlight the particular example of MOSES, value added is considered as the objective function to be maximized, which is done in order to meet the special characteristics of the Italian remuneration system.

Another exception to this classification is EMMFID which is both an optimization and a simulation model.

A trade off appears to exist between the generality and the complexity of the models. In general terms, the models which do not have a biological module can handle a large number of fleet segments and stocks (for example EIAA, which handles 60 stock and 50 fleet segments). But those that include this have some limitations in terms of the dimensions they are capable of handling (the BEMMFISH model is a paradigmatic example, a maximum of 4 species and 3 fleets can be conditioned).

There are models whose strength lies in precisely the biological component (FLR based models and BIRDMOD with Aladyn, for example), and with or without feedback between both components. For example AHF and ECONMULT are able to implement two management regimes such as the effort limitation and TACs (whatever is binding) by affecting the biological component. The FLR and AHF models are multi-stock and multi-fleet models having economic operating models as well.

The design and software implementation across the models is quite heterogeneous. GAMS, R and Excel are the most common platforms used. R is supported by the constant development of routines and facilitate the evolution of models and stochastic based models. Furthermore, R is freeware and multi-platform characteristics are also advantageous (AHF, BIRDMORD, FLR EFIMAS are examples of R implementation). On the contrary, Excel is distributed worldwide (in scientific and the non scientific communities) with visual basic programming possibilities (TEMAS or EIAA in its long-run release) or not (EIAA in its base and extended release). GAMS (SRRMCF, EMMFID and COBAS) is also used; however a basic licence and some solvers are needed (also for Excel, Mathematica –ECONMULT- and Fortran –MOSES-). MEFISTO and BEMMFISH can be downloaded as a compiled programme and ECOCORP is based on dynamic systems which require a licence for implementation (VENSIN).

In terms of the quantity of the data input needed, there are extensive differences among the models. Some models are more flexible and can be run with relatively small quantities of data, obviously reducing model performance (see for example TEMAS). Their relationship with the DCR is variable. Some models require all the data input from the DCR (for example EIAA, ECOCORP) whilst others do not. The reasons for the latter are diverse: Some models require data of sectors outside the scope of the DCR like environmental or regional indexes (COBAS for example), a number did not consider the DCR when developing the model (BEMMFISH and BIRDMOD), and others did not consider the DCR due to problems of relating the case study to the segmentation provided by the DCR (FLR-EFIMAS), however, the FLR can be run with DCR data.

The "new" DCR is an improvement, due to the new segmentation provided (especially for fleet based economic data). In any case, many of these models will require a lot of work to be conditioned before using the new data framework.

Conclusions

All together, the models reviewed are very case specific. Given the disparity between fishery systems around the world and variety of questions to be addressed none of the models reviewed can be recommended for general use unless modified. However, depending on the nature of the case study and the question to be addressed, some of the models reviewed could be applicable with some or none modifications. All the models reviewed have good approximations in terms of bioeconomic modelling so they all can serve as inspiration to build modified bioeconomic models upon.

3.5 Evaluation and impact assessments of long term management plans experiences of STECF with coupled biological/economic assessments and models (Ralf Döring)

The Common Fisheries Policy (CFP) of the European Union is under revision and a new basic regulation will come into force 2012. In the last reform long term management plans (LTMP) were introduced as a main instrument in the CFP. It took a while before the first plan was implemented but now more than 10 are in force.

In these plans a revision clause is included giving the EU commission the requirement to perform an evaluation of the outcome of the plan normally every three years. In the overall EU legislation another important clause is relevant for the LTMP: requirement for an impact assessment (IA). Every new LTMP and every revised LTMP has to go through an IA.

The Scientific, Technical and Economic Committee for Fisheries (STECF) of the European Commission conducted some of the IAs and started last year also with the evaluation of plans. So STECF conducted the first evaluations for three flatfish plans (November 2009). In all cases the sub-group dealing with the evaluation or impact assessment included biologists and economists. The experiences from a socio-economic perspective are mixed. In many cases the data was not sufficient to assess the socio-economic consequences very deeply in the IAs. The main problem is the time lag in the data collection with 2008 data available not earlier than 2010. It is then problematic to create a baseline (2010) to assess possible outcomes of changes in the LTMPs. In the first evaluations of LTMPs there was also this problem of the time lag and it was complicated to assess all other influences on the economic performance (like changes in fuel costs).

For the evaluations and IAs there is basically the EIAA-model available to assess the changes in fleet performance while using the data collected under the Data Collection Regulation and proposals for TACs from a biological perspective. Problem of this model is that it original was developed to predict next year's performance from this year's TAC advice and not a more complex situation with TACs and effort limitations.

3.6 The Baltic Cod FLR Management Model (Francois Bastardie and J. Rasmus Nielsen)

A spatially explicit Management Strategy Evaluation (MSE) framework was developed under FLR (Fishery Library in R) for evaluating the performance and robustness of management measures (MMs) (Bastardie *et al.* 2010a). The framework was applied to the international Baltic cod fishery and was used to test the 2008 multi-annual management plan for the eastern cod recovery consisting of various MMs, environmental regimes and fleet adaptation scenarios. The MMs included TAC control compared to direct and indirect effort control, the latter being closed areas and seasons. The environmental scenarios consist of two cod recruitment regimes. The fleet model can respond to management by misreporting level, improvement of catching power, capacity adaptation, and fishing effort re-allocation. The MSE framework was calibrated and implemented using international spatially- and temporally-disaggregated landings and effort data. The main simulation result was that the adaptive-F approach (2007 EU management plan) is robust to errors and most likely will rebuild the stock in the medium term even under low recruitment. The direct reduction of effort (E), in supplement to the TAC control, limits catch under-reporting but the overall effect is impaired by the increase of catching power or spatio-temporal E-reallocation. Spatio-temporal closures also had a positive effect by constraining E-re-allocation to areas with lower catchability. However, this effect was still impaired if seasonal E-reallocation occurred. Over the entire simulation period of 15 years, the fleet based economic evaluation showed variable but always positive fleet profits for all tested effort and quota reductions due to stock recovery for all scenarios simulated.

In another study (Bastardie *et al.*, 2010b) the MSE was used to evaluate the EU 2008 multi-annual plan for Baltic cod stock recovery with respect to the plan combining harvest control rules, that set TACs, with reductions in direct effort (*E*) and fishing mortality (*F*). Performance and robustness of the plan were tested by stochastic simulations under different scenarios of recruitment and sources of uncertainties. Under the different magnitudes of errors investigated, the plan in its current design is likely to reach precautionary targets for the Eastern and the Western Baltic cod stocks by 2015. It is, however, more sensitive to implementation errors (e.g. catch misreporting) than to observation errors (e.g. data collection) when the (i) current settings of the ICES single-stock assessment model are maintained, (ii) intended fishing effort reduction is fully complied with, and (iii) biological parameters are assumed constant. For the Eastern Baltic stock, additional sources of uncertainties from fishery adaptation to the plan are tested using a fleet-based and spatially explicit version of the model, which leads to higher reductions in *F* and no significant change in management robustness. The relative difference between both approaches is mainly due to differences in exploitation patterns in catching the same amount of fish. The effort control is demonstrated to be more efficient when supplemented with a TAC and avoids unintended effects from fishery responses e.g. spatial effort reallocation. Medium-term economic evaluation of fishery performance shows an initial reduction in profit with effort and TAC reductions, but profit is always positive.

See also the example of the evaluation of the Northen hake management plan in FLR (by Dorleta Garcia) in Annex 5, which is one of the suggested case studies for future studies where this represents a data poor case study.

3.7 Bioeconomic modelling tools used at FOI (Ayoe Hoff)

A short presentation of a number of the most important bio-economic models developed in the Division of Fisheries Economics and Management at FOI is given in the presentation. The models include:

The AHF model: Dynamic economic capacity change (investment/disinvestment) given effort and/or harvest control or combinations of these in multi-species fisheries. Has been integrated with age disaggregated stock dynamics under the EFIMAS project.

The FcubEcon model: Assesses economic optimal effort regulation (allocation between fleets) in multi-species multi-fleet fisheries. Based on the Fcube model for mixed fisheries effort advice, and developed under the AFRAME project.

The FISHRENT model: Combining the features of AHF and FcubEcon. Still under development

The BEMCOM model: Assessing economic optimal effort allocation between fleets in a fishing area divided into sub-areas, and thus applicable for assessment of economic effects of Marine Protected Areas. Can run over several years. Developed under the PROTECT project.

The socio-economic models developed at FOI can perform *assessments* of the economic consequences of the fishery, or can include *feedback*, i.e. include effect of the dynamic fishing capacity change resulting from changing earnings in the fishery. A short discussion is given of these two possibilities.

3.8 Ecosystem management and model concepts (Lars Ravn-Jonsen)

The process of creating models can be stylized as:

1) The real world is simplified into a conceptual model

2) The conceptual model is specified and formalized into a mathematical model

3) The mathematical model is calibrated, that is, the parameters in the mathematical model are estimated, and

4) The model is validated, e.g., by testing the calibrated model on data not used for calibration.

Often the first point in the process is over without noticeable discussions. Contrary one should focus on the first point: How to pinpoint models' concepts in the context of ecosystem management models. This is a philosophic task and will be based on theory of Self-organization and emergence.

Formal Abstract

The need for management of the marine ecosystem using a broad perspective has been recommended under a variety of names. This paper uses the term Ecosystem Management, which is seen as a convergence between the ecological idea of an organisational hierarchy and the idea of strategic planning with a planning hierarchy---with the ecosystem being the strategic planning level. Management planning requires, in order to establish a quantifiable means and ends chain, that the goals at the ecosystem level can be linked to operational levels; ecosystem properties must therefore be reducible to lower organisational levels. Emergence caused by constraints at both the component and system levels gives rise to phenomena that can create links between the ecosystem and operational levels. To create these links, the ecosystem's functional elements must be grouped according to their functionality, ignoring any genetic relation. The population structure is below the ecosystem in terms of the planning level, and goals for the community's genetic structure cannot be meaningfully defined without setting strategic goals at the ecosystem level for functional groups.

3.9 The BALMAR Model (Martin Lindegren)

In order to develop an integrated modelling for the Baltic Sea, we performed a brief bio-economic evaluation of the net present value (NPV) of the Eastern Baltic cod fishery, based on a bio-economic model (Röckmann *et al*. 2008) and outputs of stock size (B) and yields (Y) from the BALMAR food-web model (Lindegren *et al*. 2009).

The BALMAR model is a linear multivariate autoregressive model (MAR) based on a theoretical approach for predicting long-term population dynamics (Ives *et al*. 2003). Written in a state-space form, the MAR(1) model we used is given by:

$$\mathbf{X}(t) = \mathbf{BX}(t-1) + \mathbf{CU}(t-y) + \mathbf{E}(t)$$
$$\mathbf{Y}(t) = \mathbf{ZX}(t) + \mathbf{V}(t)$$

where X are spawning stock biomasses (SSB) of cod, sprat and herring in the Baltic Sea at time t and t-1 respectively and B is a 3 x 3 matrix of species interactions. The covariate vector U contains lagged values of mean annual fishing mortalities (F) and a number of selected climate and zooplankton variables known to affect recruitment of cod, sprat and herring respectively.

Röckmann *et al*. (2008) employed a generalized Cobb-Douglas-type cost function with two explanatory variables, assuming that stock size (B) and yield (Y) affect unit variable costs (c) multiplicatively:

$$c_t = \alpha * B_t^{\beta} * Y_t^{y}$$

where, the parameters β and γ represent stock and output elasticities of unit costs, respectively and α a calibration factor. Since unit variable costs are generally assumed to rise with decreasing stock size, both elasticities were set to be negative (i.e., β and γ at -0.2).

NPVs were calculated over a 20-year period maintaining prices fixed at current levels and climate variables fluctuating at mean historical levels throughout the simulated period. Using our coupled ecological - bio-economic model approach, we show that reducing fishing mortaltites (F) would not only be ecologically but economically profitable due to increased landings and reduced fishing costs as the stock and hence the catchability is allowed to increase (Figure 3.9.1). Our findings thus support the need to invest in "natural capital" (i.e. in future stock size) as a long-term management strategy for Baltic cod (Döring and Egelkraut 2008).

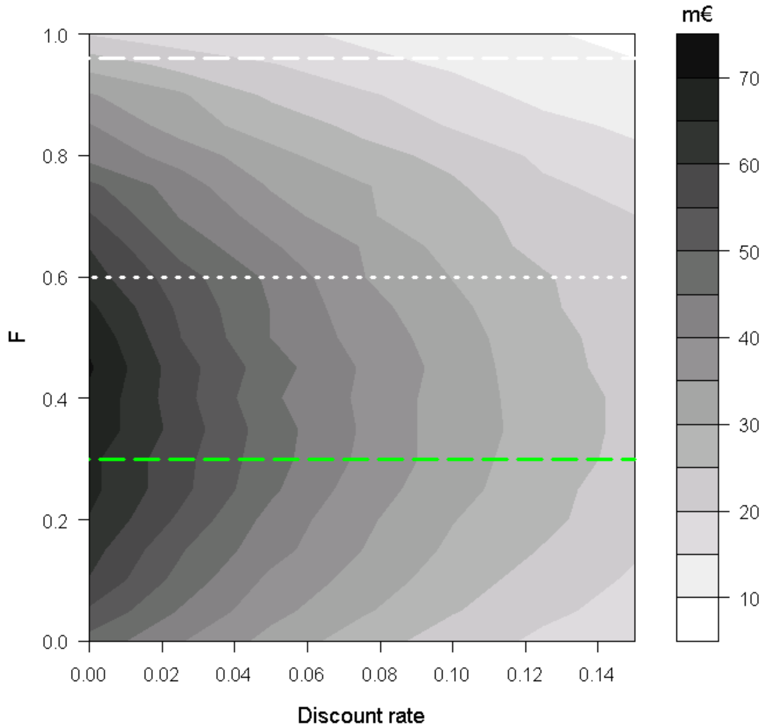


Figure 3.9.1. NPVs (m€) of the Baltic cod fishery are shown over a range of fishermen discount rates (0–15%) and fishing mortalities (F from 0–1). (Fishing mortalities for sprat and herring are maintained at mean historical levels). The horizontal lines denote the previously recommended reference levels, i.e., the precautionary fishing mortality (long-dah), the limiting fishing mortality (dotted), as well as the target fishing mortality (green) defined by the multiannual recovery plan for Eastern Baltic cod.

3.10 Recent work done within the Environmental Economics and Natural Resources Group, Wageningen (Rolf Groeneveld)

Introduction

At the ICES workshop in Kiel, two projects that may be relevant to ICES were presented.

3.10.1 Harvest and investment decisions under annual and multiannual adjustment of fish quota

Diana van Dijk, (Wageningen University), Christopher Costello (University of California, Santa Barbara), David van Dijk (University of Amsterdam), Rolf Groeneveld, (Wageningen University), and Ekko van Ierland (Wageningen University)

Yearly revisions of Total Allowable Catch under EU policies for the management of North Sea fisheries come at high management costs and capital adjustment costs. It is unclear whether current EU fisheries policy strikes the right balance between the need to regularly adjust fish quota to new information on one hand, and the costs of gathering information and adjusting fisheries capital stock on the other hand. To analyze this question we present a model for a single-species fishery, where a profit maximizing decision-maker jointly determines optimal harvest and capital adjustment levels. Two alternative management systems are compared to the case of sole ownership: annual constrained quota adjustment and multiannual quota adjustment. In the case of sole ownership the decision maker optimizes harvest and capital adjustment levels, while under annual constrained quota adjustment change in harvest is constrained by the harvest level of the previous year. Under multiannual quota adjustment capital adjustment is optimized on an annual basis while harvest is fixed for a longer period. We analyze quota adjustment in a stochastic setting, and compare results for the total discounted net benefits that include management costs and fishermen's capital adjustment costs. For the purpose of illustration we apply the model to North Sea plaice. Results of annual constrained quota adjustment show that as the system becomes more rigid the optimal harvest policy changes less between different levels of previous harvest and becomes flatter. The optimal investment policy decreases and becomes flatter as a result of the flattening optimal harvest policy. Results of multiannual quota adjustment show that both optimal policies change very little as the frequency of harvest change decreases. The change in optimal policies, however, decreases together with decreasing frequency of harvest change.

3.10.2 Estimating the relationship between capacity and effort: A case study for the Netherlands

Heleen Bartelings and Erik Buisman (LEI Wageningen UR)

The technical economic efficiency of the Dutch fleet was assessed using both the non parametric DEA analysis and a parametric multi-output production frontier analysis. The DEA analysis showed that the average technical efficiency of the fleet is rather high and time invariant. These results were supported by the multi-output production frontier analysis.

Results showed that on average the technical efficiency was equal to 84% in 2005. This indicates that given to current levels of inputs, which includes both fixed and variable inputs, production could theoretically increase by 16%. A large part of this technical inefficiency could be explained by both the location and length of a trip. On average vessels that fished closer to land, made shorter trips and used more fuel per hp (i.e. trawled faster) had a higher production than other vessels. Investments in gear also paid off, higher investments resulted in higher efficiency.

The multi-output frontier analysis showed that seadays have a close to unity impact on production. A 10% increase in seadays will results in 9.4% increase in production. Other variables like hp and age of the hull have impacts with diminishing returns.

3.11 To Harvest Or Not To Harvest? Towards Ecological-Economic Management of Baltic Salmon (Soile Kulmala)

In the 1997 the now defunct International Baltic Sea Fishery commission launched the Baltic Salmon Action Plan (SAP) that aimed to recover the wild Baltic salmon stocks. The goal was to reach 50% of the estimated smolt production capacity by 2010 while increasing salmon catches. The objectives of the SAP have been achieved only partially and therefore the European commission is developing a multiannual salmon management plan. The underlying preparations included assessment of the ecological and socioeconomic impacts of the forthcoming management plan. ICES provided the ecological impact assessment by using a stochastic simulation model accounting for the life cycle and age-structure of 15 wild salmon stocks. Socioeconomic impacts were evaluated in an international research project by using a bioeconomic simulation model and survey techniques. This talk will focus on the outcomes of the bioeconomic model. The bioeconomic model integrates the ICES biological model with an economic model accounting for commercial salmon fishery from four countries (Finland, Sweden, Denmark, Poland) catching more that 90% of the annual salmon catch. The integrated model was used to evaluate management options defined by DG MARE. During the impact assessment process a new management target was set to attain MSY (75% of the smolt production capacity) by 2015. However, the ecological assessment showed that it would be unlikely to attain the target even with a no-fishing scenario. Economic analysis, on the other hand, showed that no reduce in the fishing effort would be the best management option. And 50% decrease in the effort would decrease the net present value of the profits by 40% without a significant increase in the probability of reaching biological reference point. Salmon fishery is a mixed stock fishery whose management should be based on the weakest stock with the lowest resilience to exploitation. At the same time, the new management plan will most likely aim that both commercial and recreational fishermen are able to use the resource sustainably. It will be interesting to see how the forthcoming plan will deal with these objectives that in the short term seem controversial.

3.12 MEY in Practice: A case-study of the Australia's Northern Prawn Fishery (Soile Kulmala)

The Northern Prawn Fishery (NPF) is the most valuable fishery managed by the Australian Commonwealth Government with a value of landings of 40 million – 100 million Euros per year. Recently, the management target for the fishery has been set to achieve MEY (or relevant proxy) by the year 2014. The bioeconomic model underlying management advice builds on more than 30 years modelling in the fishery. The biological part of the model accounts for three tropical prawn species and their size-structure. Two of the species, Grooved and Brown tiger prawn are the actual target species whereas Endeavor prawns are modelled as a group and they are caught as bycatch. The economic model accounts for variable and fixed costs and size dependent prices. Prices and fuel costs are allowed to change over time, but other cost are assumed to remain constant in real terms. In order to provide the management advice MEY were defined as the equilibrium catch achieved in 2014 that maximise the net present value of the profits over a 50-year period.

3.13 Evaluation of Fishery Management Plans in the United States: Institutional Context, Role of Economics, and Readiness for Ecosystem-Based Fisheries Management (Eric Thunberg)

Development of Fishery Management Plans in the United States takes place within an institutional context characterized by overlapping boundaries, shared jurisdictions, and shared responsibilities. This presentation provides an overview of the Federal statutory context and processes for developing fishery management plans in the United States. The role of economics and economists in the design and evaluation of fishery management plans is emphasized. Readiness for transitioning from single species or single fishery management plans to ecosystem-based fishery management is discussed.

4 Long-term operational models

4.1 Introduction

In order to evaluate the long-term appraisal of ecosystem goods and services (i.e., both in terms of ecological and bio-economic values), a clear definition of the primary scientific and management objectives is necessary; in particular in relation to the consideration and choice of spatio-temporal scales of such modelling activities. It is generally recognised that modelling ecosystem dynamics under external pressures, involving multiple and often synergistic forcing such as commercial fishing, eutrophication and climate change (IPCC 2007), requires an inter-generational time horizon of at least a century (if not longer) and a sufficiently large spatial scale, e.g., large marine ecosystems (LMEs), in order to illustrate potential management problems and trade-offs across national and regional boundaries. However, if the primary objective is to formulate and evaluate ICES long-term management plans for particular fish stocks, a shorter time-span (e.g., 5–10 years) and a smaller spatial scale, defined in relation to the current distributional range of the stock in question, is deemed more appropriate.

Furthermore, it is recognised that as spatio-temporal scales increase, models have to build on properties that can be reliably predicted, for instance by modelling functional characteristics of ecosystems (primary production, secondary production, fish etc) rather than concepts known to be unpredictable over longer time-scales, such as migration and species composition. To that end, models will have to be simple, with few state variables aggregated into suitable entities in order to be tractable on very large spatio-temporal scales. However, since the economic value of marine resources is tightly linked to certain species, it is advisable to the extent possible to include ecosystem specific information in modelling exercises, given that under the chosen spatio-temporal scale these properties can be reliably predicted or assumed fairly constant over the considered period of time. An added value of considering an array of spatio-temporal scales and models with different degrees of complexity is the potential nesting of models developed for ecological and bio-economic evaluations over longer and shorter temporal scales, such that long-term models may be used to inform short-term models in setting sustainable reference levels and ecological- as well as economic targets. Finally, it is recognised that a commitment from ICES to use long-term ecosystem/food-web models is important in implementing and communicating long-term management strategies for stakeholders and the general public.

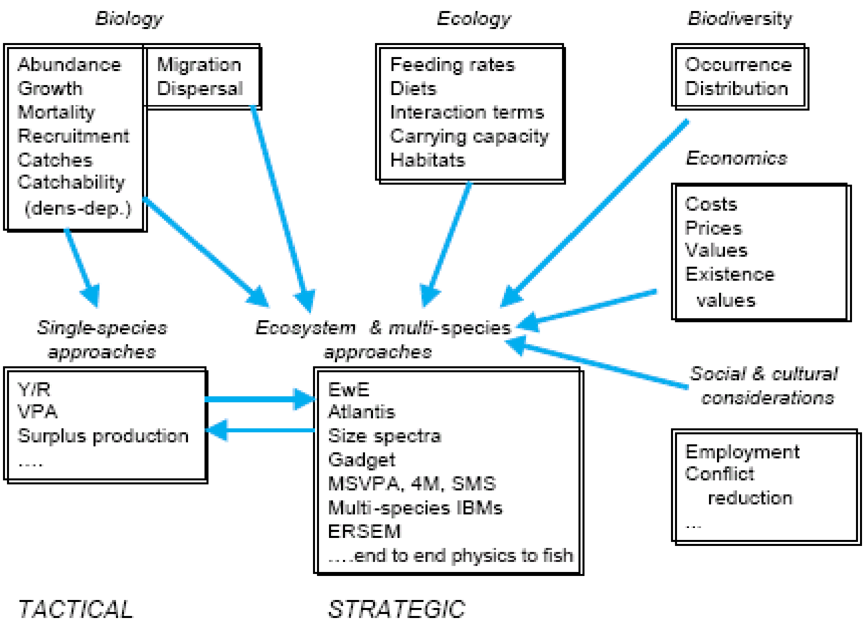


Figure 4.1.1. Information needed for long-term fisheries modelling: from single-species to ecosystem approaches (from Mackinson and Daskalov, 2007).

4.2 Model descriptions

The following section aims to provide a brief overview of ecological and bio-economical models represented within the WKIMM group and beyond, which could be suitable for long-term projections and management advice concerning the multiple needs and aspects of marine ecosystems (Figure 4.1.1). The models cover an array of multi-species, food web and ecosystem-modelling tools of different complexities, ranging from detailed mechanistic models to statistical, mass-balance, size-based and conceptual approaches.

4.2.1 The Atlantis model (Beth Fulton & Soile Kulmala)

Atlantis is an integrated ecosystem modelling framework developed at CSIRO by Dr. Beth Fulton (Fulton *et al.* 2004, 2005, 2007). Atlantis accounts for the biophysical, economic and social aspects of a marine ecosystem and it has near 20 applications (see e.g. Brand *et al*. 2007, Hayes *et al*. 2007, Smith *et al*. 2010). Most of the applications outside Australia are in the US. Atlantis is a modelling framework intended for use in management strategy evaluation (MSE). It therefore couples the end-to-end ecosystem model (which represents the biophysical world and fishing sectors) with monitoring, assessment and management decision models and observes feedbacks between these important steps of an adaptive management cycle. Further, the modular structure of Atlantis allows a user to choose the level of complexity necessary for each application. This can range from a small number of trophic levels with simple interactions and catch equations and no socioeconomic elaboration, to advanced models with sophisticated stock structures, multiple fleets and explicit handling of socioeconomic drivers underlying fleet dynamics. Similarly a wide range of management options is flexible.

At the core of Atlantis is a deterministic biophysical sub-model, coarsely spatially-resolved in three dimensions, which tracks limiting nutrient flows through the main biological groups in the system. The primary ecological processes modelled are consumption, production, waste production, movement and migration, predation, recruitment, habitat dependency, and mortality. Atlantis uses biomass, age- and stock structured formulations. Typically, invertebrates are modelled as biomass whereas vertebrates are considered in more detailed. Representation of the physical environment occurs within the polygonal boxes, matched to the major geographical and bioregional features of the marine system, which is coupled with an oceanographic transport model. Seabed type and features such as canyons are represented in each box, as well as the vertical temperature, salinity, pH and oxygen profiles, advective and diffusive flows, and influence of eddies. The biological components may inhabit the substrate or any vertical layer of the water column or sediments according to environmental preferences.

The human impacts sub-model deals primarily with the dynamics of fishing fleets. The fleet dynamics model can be tailored to each fleet using formulations ranging from simple catch equations to forced effort, or catches, through to a quasi-agent-based approach. In the latter sub-fleets explicitly step through effort allocation decisions based on a memory of past conditions, current economic conditions, distance to fishing grounds, management regulations and social networks. The more complex variants can include for example, quota trading and investment decisions.

To allow for evaluations of adaptive management options, the simulation output from the biophysical and industry sub-models can be fed into an assessment model (either as direct catch reporting of via a submodel that mimics fisheries independent data collection, like trawl surveys). In turn, the outputs of the assessment model (e.g catch recommendations and respective fishing effort levels) can then be fed into a management submodel. The management model is typically a set of decision rules and management actions that respond to the current assessed state of the system. Atlantis includes formulations for fishery management instruments like gear restrictions, quotas, spatial and temporal zoning, size limits, taxes or deemed values.

4.2.2 Stochastic multi-species models (SMS)

SMS (Lewy and Vinther, 2004) is a stock assessment model including such biological interactions estimated from a parameterised size-dependent food selection function. The model is formulated and fitted to observations of total catches, survey CPUE and stomach contents for the North and Baltic Sea. Once the parameters have been estimated, the model can be run in projection mode, using recruitments from stock–recruitment relations and fishery mortality derived from an array of Harvest Control Rules.

SMS is, in contrast to MSVPA (ICES 1996), a stochastic model where the uncertainties on fishery, survey and stomach contents data are included. The parameters are estimated using maximum likelihood (ML) and the confidence limits of the estimated values are calculated by the inverse Hessian matrix or from the posterior distribution from Markov Chain Monte Carlo simulations. The approach contains submodels for stock recruitment, food selection, predation mortality, fishing mortality and survey catchabilities. Further, in contrast to the fully age-structured MSVPA, SMS is a semi age–length structured model where the stomach content observations and the food selection model are length based. This allows for more realistic food selection models and the use of the originally sampled length based stomach data. Catch data models are kept age structured as length-structured data are not available for the cases considered.

In terms of data requirements, input data to SMS are given by quarter of the year and includes catch numbers, mean weight at age, proportion mature and food ratios. Survey CPUE data were used from ICES single species assessment data. Stomach content data, 1977–1994 have previously been compiled for use in the age-based MSVPA and are used by SGMAB (ICES 2005). SMS uses stomach data by size classes, however, and a recompilation of the "raw" stomach data are now available on the standard ICES format. During the recompilation of data, errors were spotted in the old data compilations and some of the methods previously used were rejected. SMS can fit the catch at age, survey CPUE and recruitment submodels reasonably well, but the model has limited ability to predict the stomach contents. When the residuals are plotted against the size of the prey, there seems to be an overweight of positive residuals for the smallest prey of all the prey species. This indicates that more small preys are found in the stomachs than expected from the model.

Currently biological results based on SMS runs are used within age-structured bio-economic models for sprat and cod, developed within the sustainable fisheries group in Kiel. At the moment there is no direct feedback mechanism between the models, but it is envisaged to provide such a feedback in the near future. Technically this will be an interface sending iteratively results from the bio-economic model to SMS and back.

4.2.3 Ecopath with Ecosim (EwE) in the Baltic Sea – the NEST model

Ecopath/Ecosim (Christensen *et al.*, 2005) is a software for building foodweb models (www.ecopath.org), originally proposed by Polovina (1984) and later modified by adding the network analysis (Ulanowicz 1986). Trophic interactions among the functional groups (i) of the ecosystem can be described by a set of linear equations:

$$P_i = Y_i + B_i * M2_i + E_i + P_i * (1\text{-}EE_i)$$

Where P_i is the total production; Y_i is the total catch; B_i is the total biomass; $M2_i$ is the predation mortality; E_i is the net migration; and EE_i is the ecotrophic efficiency of functional group i,(the fraction of production of i that is consumed within the system, exported or harvested). EE_i could be also expressed as:

$$B_i*(P/B)_i * EEi - \sum B_j * (Q/B)_j * DC_{ji} - Y_i - E_i = 0$$

where $(P/B)_i$ is the production/biomass ratio of prey (i); $(Q/B)_j$ is the consumption/biomass ratio of predator (j); DC_{ji} is the fraction of the prey in average diet of predators. The dynamic part, Ecosim, allows temporal analysis and to fit the model to time series.

The current version of the NEST Ecopath/Ecosim model covers the area of the Central Baltic Sea (ICES SD 25–29 excl. GoR) and contains 28 functional groups. The model has been created based on different databases and literature sources. Fish groups are split into multistanza groups to represent the main ontogenetic changes and shifts in diets. Fisheries are represented by 3 fleets fishing on the main fish species (Cod, Sprat and Herring). The mass-balanced model represents the state of the ecosystem in the middle of 1970s and year 1974 has been chosen as a baseline for the temporal Ecosim simulation. To fit and force the Ecosim model, time series of biomasses, fishing mortalities and environmental drivers have been used. Biomasses and fishing mortalities are derived from XSA single species assessment. Calibration time series represent 33 years (1974–2007).

The NEST EwE model is currently being updated to include a bio-economic sub-model capable of evaluating economic scenarios in relation to the commercial fishery on cod, sprat and herring in the Baltic Sea (Tomczak and Hoef, pers. com.).

4.2.4 The Baltic Sea Multivariate Autoregressive Model (BALMAR) (Martin Lindegren)

Multivariate autoregressive models (MAR(1)) provide a statistical framework for modelling food web interactions at multiple trophic levels (Ives *et al*. 2003). A MAR(1) model can be viewed as a linear approximation to a non-linear first-order stochastic process (Ives *et al*. 2003) and in general functions as a set of lagged multiple linear regression equations (one for each species of the food web) solved simultaneously. In its state-space form, the BALMAR model (Lindegren *et al*., 2009) is given by:

$$\mathbf{X}(t) = \mathbf{B}\mathbf{X}(t-1) + \mathbf{C}\mathbf{U}(t-1) + \mathbf{E}(t) \quad (1)$$

$$\mathbf{Y}(t) = \mathbf{Z}\mathbf{X}(t) + \mathbf{V}(t) \quad (2)$$

where **X** are SSB values of cod, sprat and herring derived from multispecies fish stock assessment for the Baltic Sea at time t and t-1 respectively, and **B** is a 3 x 3 matrix of species interactions, an analogue of the "community matrix" used by May (1972) and Pimm (1982). Encompassing the effects of commercial fishing and climate-driven ecosystem dynamics, the covariate vector U contains values of mean annual fishing mortalities (F) and a number of selected climate variables known to affect re-cruitment of cod, sprat and herring respectively. Consequently, **C** is a 3 x 9 matrix whose diagonal elements specify the effect of covariates on each species. The process error **E**(t) is assumed multivariate normal and temporally uncorrelated. Likewise, the observation error of the covariance matrix of the normal random variable V(t) is assumed independent. Regression parameters were found by maximum likelihood estimation using a Kalman filter (Harvey 1989). The Kalman filter is a recursive estimator that sequentially calculates the unobserved values **X**(t) from the previous time step (t-1) using the model formula specified in Eq. 1. Predictions from the "hidden" state are then updated using the observed values, Y(t) of the "true" state (Eq. 2). Model fitting was performed on available time series covering the period 1974–2004.

In order to develop an integrated modelling tool, incorporating both ecological and economical aspects, the BALMAR model has been used to perform a brief bio-economic evaluation of the net present value (NPV) of the Eastern Baltic cod fishery, based on a dynamic coupling with a bio-economic model by Röckmann *et al.* 2008 (see section 3.8 for more details)

4.2.5 Size-based models (Lars Ravn-Jonsen)

An economic production model normally posses two distinct features: i) mass conservation in the allocation between production units, and ii) production as a consequence of allocated resources. The atomic production unit of this marine ecosystem is the individual fish, and production is the somatic growth of the fish. In order to produce, the fish has to consume other fish. The fish is then also a product, a product that can be caught by humans or be internally distributed between production units. Thus, the atomic product of the marine ecosystem is the individual fish, and this product may be internally allocated by a predation interaction, or may be caught by humans as an outlet from the ecosystem. Mass conservation in allocation means that a resource used by a production unit must be supplied either externally or internally. That is, a consumed fish must correspond to an eaten prey. Production as a consequence of allocated resources means that the predator will grow only as a result of the consumed prey. Modelling every single organism in an ecosystem is impossible, so fish must be stratified appropriately.

Based on many years of observation following Sheldon *et al*. (1972) and Sheldon *et al.* (1973), there is an expectation of how the density of fish is distributed with respect to size and of explaining the observation to be a product of the trophic system in the marine ecosystem. Here the function of the individual fish, seen in a trophic context, is closely related to its size. For example, two fish of the same size, but of different species, have much more in common with respect to food preference and predator risk, than, for example, two fish of the same species but of different sizes (Scharf *et al.*, 2000; Jennings *et al.*, 2001). Furthermore, predators in the marine ecosystem are generally considerably larger than their prey, and therefore body size is a rough indicator of trophic level (Borgmann, 1987). In other words, the distribution of individuals with respect to size can be seen as mapping the trophic system. Size is thus a significant variable in the predator--prey interaction, and the fish is in the model stratified accordingly.

The size based model then build on three principles of (i) size as the attribute that determines the predator-prey interaction, (ii) mass balance in the predator-prey allocation, and (iii) mortality and somatic growth as a consequence of the predator-prey allocation.

Organisms are in the model stratified according to body mass m, referred to as size. The models' state variable is concerned with the number of fish in the sea at a given size. The state variable $N(t,m)$ gives the density of fish of size m at time t and is referred to as the spectrum. Density with respect to weight signifies that, in order to know the number of fish in an interval of size, for example, between m_1 and m_2, the density must be integrated: $\int_{m1}^{m2} N \, \mathrm{d}m$. conservation of mass in every predation event is secured by arranging the predator--prey interaction in a two-dimensional interaction density $\Phi(m_p,m_r)$, given the density of the interaction between prey with mass m_p and predator with mass m_r. μN, the density of mortality of prey can then be found as $\int_0^\infty \Phi(m_p,m_r)dm_r$. EN, the density of consumed mass by predators will be $\int_0^\infty m_p \Phi(m_p,m_r)\mathrm{d}m_p$. If the mass of predation victims and the consumption of predators are integrated over prey and predators, respectively, the two-dimensional interaction density produces the mass balance of the system as

$$\int_0^\infty m_p \int_0^\infty \Phi(m_p,m_r)dm_r dm_p \equiv \int_0^\infty \int_0^\infty m_p \Phi(m_p,m_r)dm_p dm_r \qquad (1)$$

On the left-hand side, the biomass of all consumed prey is indicated and on the right-hand side, the biomass of all predators' consumption is indicated. This mass balance identity (1), where the mortality and consumption are calculated on their respective sides, serves as a foundation for the model. It has two concepts: the individuals described by their respective mass as a continuum, and the two-dimensional predator-prey interaction density describing the allocation caused by predation. As the principle of mass conservation is an identity, and therefore can be summarised to system level without any accumulation of errors, the mass balance principle is a strong concept for modelling.

Consumption leads to somatic growth g of the predator. Because a fish's attribute in this model is its size, a fish is a point in the m-dimension. When a fish grows, and therefore increases in size, its equivalent point moves up the m-dimension with speed g. The total effect of all fish with somatic growth is a flux—a number of particles passing a given point—of gN. In the model, growth is a consequence of consumed prey g=$g(E)$.

Fishery is included in the model, with vN representing mortality due to fishing. The same principle of conservation of mass applies to this interaction: What is caught has to equal what leaves the ecosystem.

From the predator-prey interaction and fishing interaction, growth and mortality are derived, and this leads to the dynamic of the spectrum. As growth leads to a flux gN of particles in the spectrum, the dynamic can be described with a flow equation, known as the Kendrick--von Foerster equation:

$$\frac{\partial N}{\partial t} = -\frac{\partial gN}{\partial m} - \mu N - vN$$

The above description covers the most simple size based model, the model of Benoit and Rochet (2004). The model of Andersen and Beyer (2006) operates with life story as an extra functional dimension. This adds an extra dimension to the distributions of individuals; in this case, the asymptotic maximum size in a von Bertalanffy growth equation. Size-based models with named species are also constructed (under publication). It is also possible to make the model with discrete size classes with number of fish in the classes. If the SMS model incorporates growth as a function of consumed prey, the model will be a sizes-based model with discrete size classes and spices.

As the model have the features of an economic production model, the size-based model will give shadow prices that reflects the production in the system. The model therefore has the potential for supplying realistic opportunity costs of the fishery. The size spectrum is, as it is seen to be the product of some fundamental characters of the trophic system, anticipated to be a very stable feature of the marine ecosystem. This principle is therefore suitably for long-term prediction. The incorporation of economics with size-based models is still limited; however, Ravn-Jonsen (2010) finds the size-based model suitable for capital theoretic analyses.

5 Short-term modelling

In summary the topic short-term operational models include some of the currently used models within the advice and evaluation frameworks, including the STECF. Most economic models used in advice today are made on top of the standard stock assessment models, which use the output from these. However, only few models such as those developed in FLR provide today realistic tools and models for integrating multi-stock and multi-fleet bio-economic management evaluation on integrated basis and at a stock age disaggregated level. Such models are necessary to be implemented for evaluation e.g. mixed fisheries aspects and interactions taking into account also biological interactions. This category of models will be the basis for the development of management plans both on the short and medium term as well as long-term management strategy plans for stocks and fisheries taking into consideration ecosystem effects and physical impacts as well. The full integration of economic and ecological models is necessary as the feedback of ecological changes and fisheries impact on management and those feedback mechanisms are currently not included in advice. The depth of detail will be dependent on the specific objective of the model, but at the moment most of the models investigating management effects on the fishery use too simple ecological sub models if any. The workshop has pointed at groups of models and evaluation tools as well as specific case studies where the above should be implemented.

5.1 Aspects necessary to be addressed in relation to short term strategies, tactics, and operational models

General model specifications and set-up

It will be necessary to clearly define short term according to management plans and make it consistent with management plans e.g. in relation to implications for choice of full feed-back model or not. Integrated (coupled) models with a full feed-back component (Biological Operating Model and Fleet Operating Model) on the assessment will be necessary when working on the 3–5 year scale, e.g. to evaluate effects of discarding behaviour. In general, it will also be necessary to define a common terminology.

Economic models are based on behavioural assumptions (e.g. profit maximization). It will be necessary to use behavioural models of catch and F-patterns by fleet or metier to evaluate different restrictions, objection functions and harvest strategies by linking stock models with fisheries, fleet or economic models. This includes cost functions, multi-product cost functions, price functions, demand functions and more economic functions describing fisheries behaviour and dynamics. It will also involve good perception and prediction models, i.e. fisheries behaviour models, with respect to fishermen's choice of effort allocation in time and space with given gear. In relation to build and feed the behavioural models with data, it will be necessary to consider the use of simulation and optimization models (or even individual based models (IBM) on the vessel scale). Here it will be necessary to include e.g. expected net revenue (maximize) and to consider conditional constraints (kWd, TAC, ITQ, etc.).

In relation to economic models the following considerations were put forward at the workshop:

a) Use CPUE by fleet – allocate effort (based on expected revenue);
b) Match economic production functions with ecological catch estimation models. Data then need to be more complex;
c) Enable sensitivity analysis of economic modelling outcomes in relation to biological uncertainty (with regard to different types of errors/uncertainty, eg. observation error, process error, model error, implementation error (management uncertainty)). Sensitivity analyses and risk assessment have to be a part of this.

With respect to model dimensions (dependent on data availability) different types of models need to be considered. It will be necessary to consider age disaggregated models (e.g. VPA) instead of simple surplus production or size-based models in relation to the present ICES advice and models used in the assessment.

The disaggregation levels should ideally also be related to spatio-temporal disaggregated models to take into account the timescales matching the seasonal behaviour of fish and fisheries and the spatial scales within stock and fishery and between stocks and fishery. In relation to fisheries disaggregation the levels of vessel, metier, and fleet should be addressed.

To consider other uses of the ecosystem and to integrate different sectors which have short term implications, one should apply value functions which put values on different types of ecosystem services, employment, etc. and which can be used to describe tradeoffs in relation to marine management advice. This includes information on and description of environmental goods and services as well as issues of marine spatial planning.

Data needs to support short-term models and possible functional relationships:

It is important to consider what data on which aggregation level is needed and can be used and the availability and access of this data in relation to the purposes (e.g. with respect to EU law). This includes the consideration of metier-based databases from logbooks merged with sales slips and vessel register data (EU DCF) as well as VMS satellite data, electronic logbooks, fully documented fishery data through video monitoring, etc. This also includes data from fishery dependent international surveys for resource availability, fishery gear selectivity data and fleet-based economic data (e.g., cost dynamics and structure) as well as information from interviews of selected fishers (e.g., cost dynamics). At the workshop a row of considerations were made:

- EU DCF data and formats should be made available and used
- Fleet dynamics
- Cost dynamics (Based on observer information, interviews, accounting data; based on samples from the total fleet (both variable and fixed costs); databases uses this information; US has statistical / regression models / map programming type of models to calculate this up to fleet).
- Allocation of variable costs: (Can be associated to the activity (metier) and the unit of effort; maybe there is not much difference in variable costs per unit of effort of a vessel disregarding which activity it participates in; in relation to data it will be necessary to test hypotheses in relation to this; use of averages or make statistical regression models; variable costs per day at sea).
- Allocation of fixed costs: (Associated to the actual fishing capacity. Allocating fixed costs according to effort per activity or catch fraction (value share). Price dynamics (Should include price market analysis).

5.2 Spatial models

One special objective for short-term operational models will be how to deal with spatial aspects. Spatial aspects are and will be even more important in marine management, as besides fisheries many other usages have to be coordinated and managed within the marine environment, e.g. transportation, energy production, drilling, conservation. Besides these more general aspects, also issues directly related to fisheries can be better tackled with spatial explicit models. This includes effort allocation of fleet segments and the feedback on the stock, e.g. through implementation of marine protected areas, as well as the estimation of better production (harvest) functions.

5.3 Example of platform for future fisheries management evaluation and advice: Enabling virtual fisheries management and advice before implementation

The EFIMAS project, and sister projects developed and integrated a set of new and existing software tools and simulation models, generating a more robust Management Strategy Evaluation (MSE) framework that allows testing plausible hypotheses about dynamics of fish stocks, fisheries and fleets. (See Nielsen and Limborg, 2009). The MEF contributes to a conceptual change and paradigm shift in generating advice and management with entire fleets and fisheries as the central units. Here the basic management instrument is the input, i.e. the capacity of fishing fleets in form of number, size and efficiency of the vessels, and their fleet and fisheries based effort (activity). This differs from the traditional output based ICES approach providing advice on single fish stock catch limits from rather uncertain terminal year stock assessments and under strong assumptions on future total stock fishing mortality (F), without much consideration on factors creating and controlling F and partial Fs by fleet. The developed frameworks allow simulating and evaluating, respectively, the biological, social and economical consequences of a range of proposed management options and objectives within different management regimes.

Managing fisheries in a virtual environment provides more reliable scientific advice to stakeholders: In the same way that a pilot might fly in a simulator before flying for real, the simulation tools evaluates the robustness of alternative strategies and virtual regimes to give more holistic FMA in broader context before implementation. This provides managers and stakeholders a better idea of the consequence of a given strategy or intervention before opting for a particular management approach.

Developing a management evaluation framework

In particularly EFIMAS has: (i) Used and developed computer based models that can run stochastic simulations incorporating data from selected EU fisheries and stocks considering fleet interactions, (ii) and through scenario evaluations compared the performance a range of current and emerging EU management options under alternative management systems and objectives (Figure 5.1).

Figure 5.2 shows a conceptual box flow diagram of the overall simulation module. The input data are generated by a descriptive model (operating model), which is assumed to represent the "true/real" system. The input data are then processed by a traditional or an alternative fish stock or fisheries assessment model or economic fishery model (knowledge production model), which is used to generate FMA.

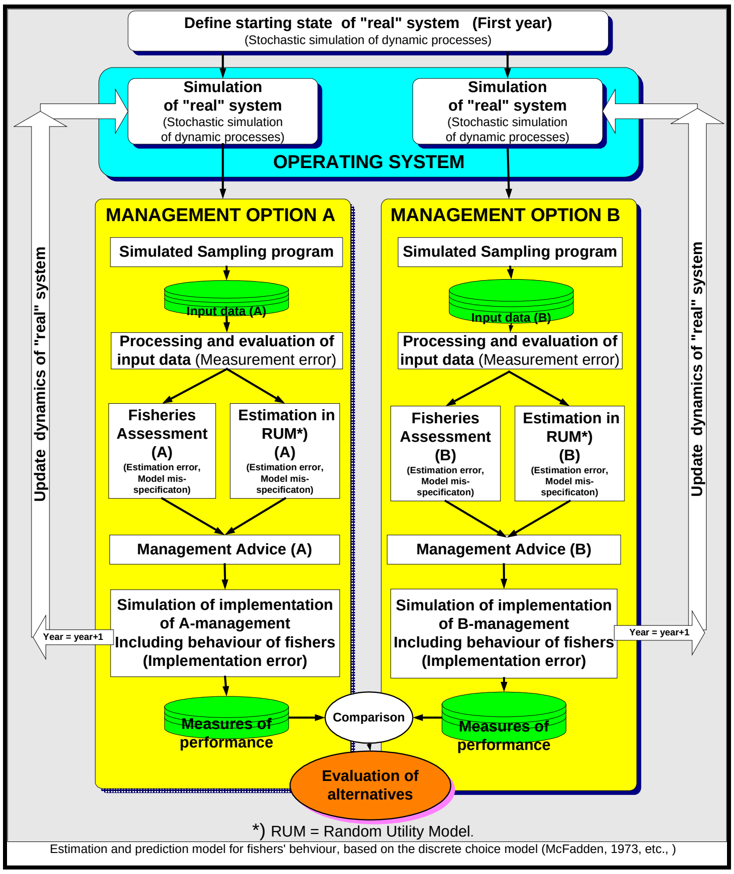


Figure 5.1 Diagramatic example of MEF phases evaluating and comparing two (A & B) alternative management options.

By simulating the effect that the resulting management actions would have on the "true/real" system it is possible to generate a range of performance measures, covering the resource as well as the fishery. These measures enable comparison of a range of options under alternative systems and objectives under consideration of uncertainties in all of the processes.

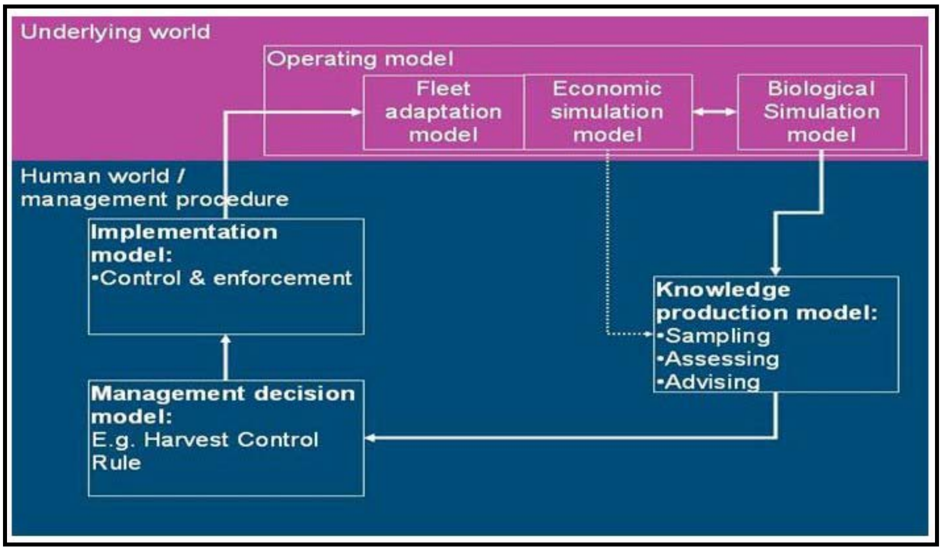


Figure 5.2 The Conceptual Evaluation Framework: Operating Models and Management Procedures.

The developed MEFs can evaluate fleet and mixed fisheries interactions and fisheries behaviour (Box 1). They evaluate uncertainties in stock and fisheries dynamics, data collection, assessment, modelling, as well as the advisory, management and implementation processes. Being capable of evaluating the relative performance of multiple alternative options the MEFs possess strong capacity in performing sensitivity and risk analyses of consequences.

Box 1. Modelling fishermen and fleet behaviour

It is necessary to simulate and establish models on how fishermen and fleets and the advisory systems will react to different management measures, i.e. to establish fisheries behaviour models and advisory process models in the MEFs. Fisheries behaviour can be divided into (i) "strategic or structural behaviour" and (ii) "tactic or trip related behaviour". The first accounts for the investment in new vessels and withdrawal from the industry (e.g. decommission), thus reflecting long-term trends, while the latter accounts for short term decisions by the single vessels for fishing operations (Figure 5.3).

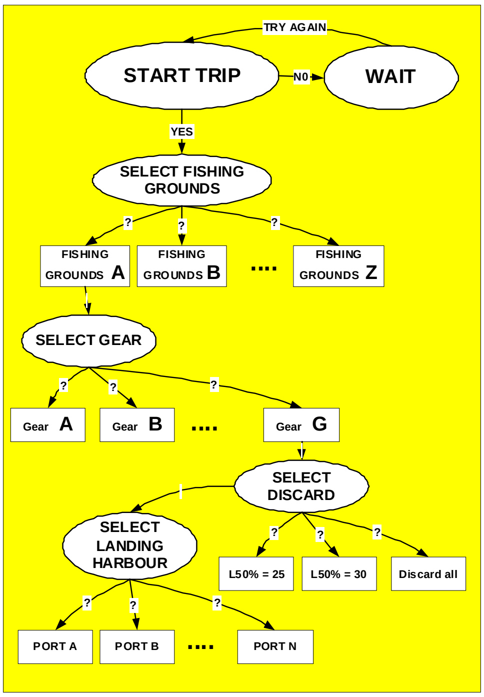
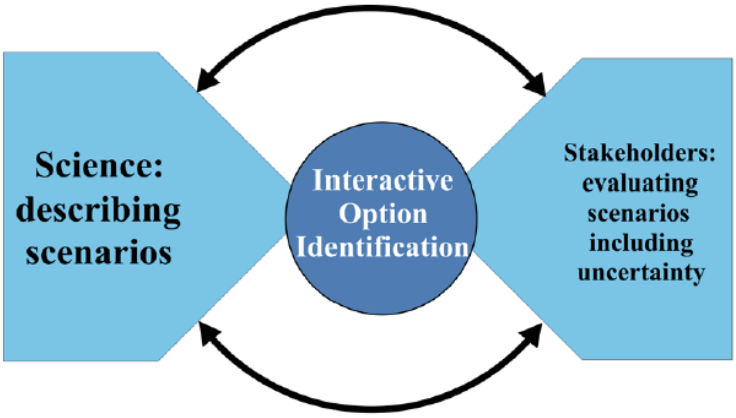


Figure 5.3. Decision tree for fishing trip related fisherman and fleet behaviour.

Evaluation of the framework performance and output including stakeholder participation



Participatory Modelling: Science Promoting Transparency

Process evaluation, stakeholder participation and feed-back mechanism in management advice

The overall evaluation comprises process evaluation (PE) and technical evaluation (TE). PE focuses on participatory management. Here participatory and iterative scenario-based MEF modelling is used to obtain input and cyclic feed-back from multiple (regional) stakeholders for different options, and to test the general utility of the operational MEF during (i) development, (ii) case study applications, (iii) evaluation of case specific results, and (iv) overall efficiency to capture changes in the fisheries systems and the applicability in other stocks/fisheries (general utility).

Fisheries management and advice change rapidly toward a more responsive and efficient system. Increasing stakeholder participation in decision-making is central and brings about changes in the role of science. The developed MEFs inform an exploratory and adaptive decision-making process enabling science-based policy even when uncertainty is high. Participatory modelling do not substitute for using science to set limits, but can focus on crafting strategies and force stakeholders to clarify their objectives and explicitly address the tradeoffs implied by various strategies. MEFs facilitate collaboration across disciplines, ensures that models and software are easily validated, and widely available. The main MEF is open software source (R, http://www.R-project.org) promoting transparency and allowing technology transfer and development internationally and across disciplines. The software aims at user-friendliness when experts are to implement it in cooperation with stakeholders. As such, the suite of projects has helped to restore the somewhat shaken trust of stakeholders by incorporating a wider range of variables to illuminate the decision-making process and make it more accessible to them.

Technical evaluation

TE includes build in facilities, capabilities and utilities to evaluate uncertainty, errors, sensitivity, robustness, predictive power and limitations in use through rigorous tests of validity of assumptions and hypotheses on processes and states of the resource and fisheries systems. Further, TE includes MEF utility in terms of technical requirements for set-up and use.

Results and dissemination as examples

The MEFs have been continuously tested in several cases covering important EU fisheries, areas, and a broad variety of existing and worldwide emerging and innovative management options and systems to illustrate the capacity of the MEFs. This covers regulation by traditional TAC (Total Allowable Catch) including possible catch misreporting, multi-annual TACs, direct effort control and decision rules systems, indirect effort control through spatial and temporal closures, rights-based approaches (e.g. individual transferable quotas) and participatory governance, as well as the use of different stock assessment models or models for economic dynamics.

The use with respect to biological advice and exploratory evaluation covers many ICES stock assessment and mixed fisheries working groups (www.ices.dk), EU STECF working groups (https://stecf.jrc.ec.europa.eu/home), EU RACs (Regional Advisory Councils), NAFO Scientific Council working groups (www.nafo.int), ICCAT (www.iccat.int) and IWC (www.iwcoffice.org) working groups, and dissemination through many scientific peer reviewed papers, conferences, user courses, and workshops.

Future perspectives

Future perspectives is to fully integrate the MEF in standard ICES and EU (STECF) management advice procedures and implement participatory and scenario based modelling in proper institutional context with advice from the established multi-disciplinary scientific networks of excellence and research platforms. Also, the aim is to develop and design the flexible MEFs further towards new processes and approaches including ecosystem based management advice considering biological interactions to comply with anthropogenic effects on the entire ecosystem and climate-induced effects. As such, the MEF(s) can be used to define new status and management indicators and precautionary limits according to induced changes when evaluating management scenarios. Such integrated modelling will be the new generation of management advice and bring it to the next level. However, in order to accomplish this it will be necessary to integrate further ecological and economical modelling and methods as well as to obtain platforms to do this scientifically as well as to continue the procedure of integrating this into scientific management advice.

6 Outlook and Future Challenges

The type of models to be used and the level of integration will be highly dependent on the objectives to be addressed and the context of the actual use. Within the workshop two major distinctions were made with respect to implementation in relation to the long-term strategic planning and advice and the short-to-medium term management evaluation and advice. The first is dependent on the expected change in the environment on the long term and the large scale trends which include climate cycles and trends on a longer time frame effecting whole ecosystems in/ between more extensive world regions and general effects of overall policies and strategic management. The latter relates mainly to short to medium term management decisions, fishing behaviour and impact, and to the short-to-medium-term natural variability in resources and environment on a more local scale within regions which typically needs to be addressed in scientific advice and predictions with high precision. Consequently, the latter relates more to short-term variability both in ecology and fishery and the immediate effects of management and the reactions to this. This is to be used in short term forecasts and management strategy evaluation (MSE) related to especially fish stocks and fisheries taking into consideration effects of seasonal and year-to-year variability and to be spatially disaggregated in more restricted areas. It can for example be addressing effects of severe winters and heat waves affecting stocks and fisheries on a narrow geographical scale taking into consideration short term variability in availability of fisheries resources, recruitment, etc. Another distinction is the purpose, use and detailing of the models in relation to actual precise assessment and management advice vs. more strategic management evaluation, i.e. the state of the resources and resulting advice for the fishery according to implemented objectives versus the evaluation (and advise) with respect to the strategic overall management objectives.

There exists and were presented models and management evaluation frameworks including coupled ecological and economical models relating to all the above distinctions, some more advanced than others with respect to state of implementation. None of the models and frameworks have yet been fully implemented into scientific advice when it comes to use of possible coupling between ecology and economy. There exists advanced tools and the scientific basis to obtain make significant further progress in this work, however, this will need future extensive resources to promote, support and establish the necessary scientific cooperation and platforms for this as well as political will, resources and platforms to do this and use advice from such integrated evaluation.

The group first of all suggests a follow up workshop next year where more specific issues, models, and case studies should be focussed upon as examples. This includes fleshing out specific case studies with application of economical models where the ecological and economical modelling can be done in actual integrated approaches as examples. These case studies should cover both data rich and data poor case studies and address emerging marine management problems. The group discussed several case studies, which could be relevant and illustrative examples. The case studies discussed are listed in Annex 5.

The group would like to invite to an open discussion with ACOM and SCICOM on how to proceed based on the draft report. This could among other be done by meeting in a smaller group first, perhaps at the ICES ASC in Nantes and prepare for a discussion in a larger forum such as e.g. the ACOM/ SCICOM meetings, and finally write the conclusions into the final report.

In summary, to scientifically develop integrated ecological and economical modelling and to implement this over time in scientific advice, some main issues needs to be considered and solved. To do this:

- it needs assembly and cooperation of multi-disciplinary scientific expertise (biologists, economists);
- it needs integration of analytical and modelling expertise and adequate knowledge and experience with necessary software and its use;
- it needs platforms to organize and support that experts with the above skills are brought together in order to make this integrated scientific development and start on implementing this into advice.

The platforms to do this exist (models and evaluation frameworks), however, in order to make them fit for general use they need to be further explored on case specific basis as well as to be further developed. The latter especially with respect to inclusion of additional economic models for certain economic dynamics and to explore necessity of simulation and optimization capabilities of the models with respect to economic modelling.

Summary of the WKIMM Subgroup topic discussion on how to continue work

The group found ICES a suitable platform for development of coupled biological-economical modelling. The reasons mentioned is that no other fora can match what ICES can provide by terms of continuum, scope of science and experts available. There should however be cross cutting activities with others.

A well-established feedback loop with ACOM and SCICOM is needed. The group should report to both ACOM and SCICOM. Initially, there is a need for a discussion with ACOM what the wishes are from the advice side in the case of including economical modelling in current or future advice processes.

The incentive is primary scientific according to the group but should have a clear connection to advisory needs.

The Workshop brings together different groups of scientists from ICES and governmental institutions and Academia from Universities. It also joins different disciplines in terms of biology and economy. There may be cultural differences in wishes and needs, although not considered a problem, there should be an awareness that differences may exist and an open discussion should provide a clear focus to avoid misunderstandings.

To keep momentum in the workshop the incentives of participation is important. There are virtually no funds to be granted for participation and it based on the participants own will and resources to participate. Hence the quality of science is vital. There should be possibilities to publish peer-reviewed papers from the results. The meetings should be of high profile with good keynote speakers and not to forget nice social events to bring people together. The first meeting was a very good example how it can be done with facilities provided by the University of Kiel including a small sponsoring providing lunch and coffee for all participants, which kept the spirits high during the meeting.

Parallel approaches are to give focal points to biological economical science in a future ICES Theme Session for the Annual Science Conference and in a longer term consider to have an ICES symposia on the subject if it fits the development.

There are also possibilities to form new consortia for project applications and similar initiatives. As this will be a time consuming part of a workshop this may be formed as intersessional work. In the initial phase travel and networking funds is the most valuable asset.

Added value that became quite clear during the discussions of the workshop was that the governmental institutional sampling schemes could provide valuable data for little or perhaps no extra cost to the scientist.

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Annex 2: Agenda

Wednesday 16.06.

09:30 Welcome and Housekeeping

10:00 Jörn Schmidt, CAU (D): General introduction to the workshop and background for its establishment

10:20 Rasmus Nielsen, DTU-Aqua (DK): Ecological-economic modelling in fisheries science – perspectives, EU developments, questions and implementation - examples from recent EU Projects

10:45 Coffee Break

11:00 Keynote – Trond Bjorndal, CEMARE (UK): "Current and Potential Rent in Fisheries: two North Sea Case Studies; i) North Sea herring and ii) North Sea demersal fisheries"

12:00 Lunch

13:00 Short Welcome by the Speaker of the Cluster of Excellence "Future Ocean" Martin Visbek

13:10 Keynote Anders Skonhoft, SNF (N): "On the conflicting management of wild Atlantic salmon and farmed salmon"

14:10 Marga Andres, AZTI (E): Review of bio-economic models in the EU

14:30 Ralf Döring, vTI (D): Evaluation and impact assessments of long term management plans experiences of STECF with coupled biological/economic assessments and models

14:50 Francois Bastardie, DTU Aqua (DK): The Baltic Cod FLR Management Model

15:10 Coffee break

15:30 Ayoe Hoff, FOI (DK): Bioeconomic modelling tools used at FOI

15:50 Lars Ravn-Jonson, SDU (DK): Ecosystem management and model concepts

16:10 Martin Lindegren, DTU Aqua (DK): The BALMAR Model

16:30 Rolf Groeneveld, WUR (NL): Recent work done within the Environmental Economics and Natural Resources Group, Wageningen

16:50 Soile Kulmala, CSIRO (Austalia): The Baltic Salmon case study; Australia Northern Prawn Fishery

17:10 Eric Thunberg *et al.*, NOAA (USA): Evaluation of Fishery Management Plans in the United States

17:30 Some closing remarks for the next day

18:00 End of day 1

Thursday 17.06.

09:00 Start of Session 1 (2 hours discussion of selected issues and answering specific questions in writing in sub-groups, and 2 hours for presentation (in power point form) and discussion of results from the subgroups under session 1 in plenary)

13:00 Lunch

14:00 Session 2 (“open space” discussion on issues emerged from session 1)

16:00 Coffee break

16:20 Summary of Session 2

18:30 End of day 2

Friday 18.06.

09:00 Final discussion and summary of conclusions in subgroups and plenary from session 1 and 2, including: conclusions and recommendations on how to progress from here (near future work), what issues should be focussed upon, what necessary networks to be expanded / established, necessary expertise and institutions to be involved, etc., as well as a discussion covering potentials of: future follow up workshops, establishment of a relevant working group, linking to other working groups and international research projects / networks.

13:00 End of Workshop

Annex 3: Preliminary draft resolution

The below is a preliminary suggestion for recommendations from WKIMM to be discussed by ACOM and SCICOM during the 2010 ICES ASC before a final version is produced.

A **Study Group** or a **Workshop on integration of economics, stock assessment and fisheries management** (SGIMM or WKIMM), chaired by Jörn Schmidt, Germany, and Rasmus Nielsen, Denmark, will meet in VENUE, June 2011 [4 days] to:

a) Evaluate further the world wide state-of-the-art in integrating economic (modelling), stock assessment and fisheries management plans relevant for ICES;
b) Develop further existing integrated frameworks, models and methods on case specific basis for integrated bio-economic modelling of fisheries, and test and discuss their general utility with respect to general implementation in ICES fisheries;
c) Discuss and identify functions for economic dynamics (parameters) needed to be integrated into the models and frameworks;
d) Identify further the data and information required for integrated bio-economic modelling of fisheries and application of socio-economic evaluation methods on short and long term basis;
e) Identify platforms and multi-disciplinary fora (fisheries biology (ecology), economy, sociology) to develop, link and use ecological-economic modelling tools to be used in integrated fish stock and fisheries management.

WGXXX will report by 5 August 2011 (via SSGRSP) for the attention of SCICOM and ACOM.

Supporting Information

Priority	There is an increasing demand for coupled ecological and economical models in advice giving bodies. However, the possibilities to coordinate the expertise of economists, sociologists, and ecologists to develop further bio-economic models and management evaluation frameworks is not fully used yet. The goal will be to further couple economic and sociological expertise directly with the ecological understanding within ICES to enhance the quality of fisheries assessment and the value of the advice.
Scientific justification	The incorporation of bio-economics in fisheries assessment might lead to a better result and an enhanced communication with fisheries industry, fishermen, managers and other stakeholders as the advice could be made on the basis of a deepened understanding of: the economic and sociological incentives of fishermen and industry the bio-economic interaction between different fisheries and both biological and economical consequences of different management scenarios and transaction costs of different policies coupled with the existing sound biological knowledge within ICES. The workshop will directly feed goals 3 and 5 of the ICES action plan: "Evaluate options for sustainable marine-related industries, particularly fishing and mariculture" and "Enhance collaboration with organisations, scientific programmes, and stakeholders (including the fishing industry) that are relevant to the ICES goals".
Relation to Strategic Plan	The possibility to incorporate economics and socio-economics directly into the scientific advice would enhance the acceptance of the advice on stakeholder level and to "*…deliver the advice that decision makers need…*" (goal 3 of the strategic plan).

Resource requirements	No specific resource requirements beyond the need for members to prepare for and participate in the meeting.
Participants	Interested scientists, economic modellers, ecological modellers, ACOM members, Assessment group members, stock assessment experts (as well as selected stakeholder observers, e.g. RACs and managers).
Secretariat facilities	SharePoint site, secretariat support for reporting.
Financial	Travel cost support
Linkages to advisory committees	The incorporation of economy in fisheries advice should be of basic interest to ACOM.
Linkages to other committees or groups	Assessment groups (ACOM). Scientific methods to enable Integrated Marine Management across sectors and implementing an Ecosystem Based Approach to Fisheries Management has significant scientific focus and is relevant for ICES SCICOM and several ICES groups hereunder.

Annex 4: Recommendations

The main recommendation from WKIMM is to discuss results and further proceedings with ACOM and SCICOM. Any further recommendations with respect to links to other groups and with respect to the terms of references and specific case studies to be used in further work will be result of this discussion.

Annex 5: Case studies suggested at WKIMM to focus on in the coming workshop or study group

Data rich cases

North Sea Cod Man. Plan:

Single species models (XSA, SMS, ICA, SURBA, Stochastic Model, etc)

Multi-species models (SMS, MSVPA, 4M)

Ecosystem models (size based, ecopath/ecosim, in the long term ATLANTIS)

Econ fleet dynamic models (FLR/AHF, Price and demand models, F-CUBE)

Socio-economic/welfare/Man. Syst/governance models (yes)

Baltic Cod Man. Plan:

Discard Ban in the Baltic Sea

Single species models (XSA, SMS, ICA, SURBA, Stochastic Model, etc)

Multi-species models (SMS, MSVPA, 4M)

Ecosystem models (BALMAR, ECOPATH/ECOSIM, and others)

Econ fleet dynamic models (FLR-FBA/RN, FLR-AHF)

Socio-economic/welfare/Man. Syst/governance models (No)

Data poor

Bay of Biscay Northern hake management plan (see also elaboration on this below)

Important economic non-assessed species

Qualitative economic model

Other

Australian South-Eastern Case Study

Gulf of Maine Atlantic Herring – Tuna –Whale Case study (Ecosystem components modelled, Non-market values involved here, recreational values, non-market uses)

General

Not in the first place addressing: Rent maximization across sectors, Rent seeking, Governance, Game Theory and Bayesian Believe Game analyses, etc.

A5-1 Example of the Bioeconomic assessment of Northern European Hake Long term Management Plan (Dorleta Garcia)

Northern stock of European Hake is under Recovery Plan at present, however in 2007 it was foreseen that the objective of the plan was going to be fulfilled by 2008, so in that year a bio-economic impact assessment of possible Long Term Management Plans (LTMP) for this stock was carried out by the STECF. The assessment was divided in two parts, one focused on biological aspects (SEC 2007b) and the other one on economic ones (SEC 2007a).

The biological impact assessment was conducted using a stochastic simulation model developed under COMMIT and EFIMAS EU projects. The model was built using FLR libraries (Kell *et al*. 2007) and followed a Management Strategy Evaluation (MSE) approach (Butterworth 2007, Kell *et al*. 2006, Punt and Donovan 2007). It was a single stock and a single fleet model and it assumed that the fleet caught exactly the settled TAC every year. This TAC was obtained every year according to a predefined Harvest Control Rule (HCR). Different HCR were tested against different assumptions about stock-recruitment dynamics, individual growth patterns and discards.

The economic impact assessment model was carried out afterwards on top of on the biological simulations using the EIAA model (SEC 2004). The EIAA took the medians of the stock biomass and the landings obtained in the biological simulation and calculated fleet based economic indicators using a Cobb-Douglass production model. Furthermore, after 10 years of projection it assumed that the system had already reached stability. Thus, the biological and economic impact assessments of the LTMP were not fully consistent. Besides that the economic assessment did not incorporate all the complexity considered in the biological impact assessment, age structure, stochastic, variability in the long term…

Thereafter, the simulation model used in the biological impact assessment was further developed in order to be able to conduct integrated bio-economic impact assessments. The exploitation was divided by fleet segments and instead of assuming that the fleets caught exactly their quota share it could be assumed that they maximize their revenue, so the overall TAC could be exceeded or not reached depending on economic incentives (Garcia *et al*. 2009, Garcia and Prellezo 2009). These advances represent a small but significant step towards a realistic integrated bio-economic model but much work is still needed. The fleets that exploit Northern Hake are mixed-species fisheries so a realistic bio-economic model should include the most important species harvested by these fleets. Besides from an economic perspective and within a multiannual management framework it is relevant to consider the investment/disinvestment dynamics of the fleet, a large reduction in fishing opportunities in the short term could reduce the fleet capacity in such a way that in the long run it will not be enough capacity to harvest the long term gains. Thus, in the short term the intention is to develop a multi-species and multi-stock bio-economic simulation model which includes short term (tactic) and long term (strategic) fleet dynamics.

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