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## **International Council for the Exploration of the Sea Conseil International pour l'Exploration de la Mer**

H. C. Andersens Boulevard 44–46  
DK-1553 Copenhagen V  
Denmark  
Telephone (+45) 33 38 67 00  
Telefax (+45) 33 93 42 15  
[www.ices.dk](http://www.ices.dk)  
[info@ices.dk](mailto:info@ices.dk)

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## Executive Summary

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The Study Group on Integration of Economics, Stock Assessment and Fisheries Management (SGIMM) had its first meeting at ICES headquarters in Copenhagen from 14 to 17 June 2011. The group continued the work of the workshop on Introducing Coupled Ecological-Economic Modelling and Risk Assessment into Management Tools (WKIMM, ICES 2010). Ecological-economic modelling in fisheries science is increasingly applied and builds on interdisciplinary expertise from natural and social sciences. A mutual understanding of methodologies and approaches is needed to develop realistic integrated models, including the ecological and economic interactions.

Thus, the idea was to bring together experts from both fields to discuss state-of-the-art approaches in ecological-economic modelling and to increase the exchange between different groups worldwide. The success of last year's workshop was to attract economists for the work within ICES on a scientific basis. To further increase the scope of the group, contact was established with the International Institute of Fisheries Economics and Trade (IIFET) and direct collaboration was agreed on with respect to cooperation on two theme sessions on ecological-economic modelling next year. One theme session will take place at the 6<sup>th</sup> World Fisheries Congress in Edinburgh (7–11 May 2012) and one at the 16<sup>th</sup> biennial conference of IIFET in Dar es Salaam (16–20 July 2012), both convened by members of the SGIMM group.

This year's meeting was again well attended by fisheries economists, but the attendance from fisheries biologists suffered a bit from the ICES advice drafting groups held at the same time as the SGIMM. Nevertheless, presentations and discussions during the meeting helped to include additional bio-economic models, further shape the format of the group, establish plans and formats for scientific reporting among other collaborators through conferences, and resulted in the agreement on a living document to keep track of the status and development of different model approaches to create an inventory of how these approaches were used in different case studies. An approach with a Model Performance and Characteristics Matrix was developed and adopted to distinguish between the scientific use of models and their use in advice. It was also agreed to work by correspondence in 2012 to elaborate on the living document and to carry out a survey on ecological-economic models developed for fisheries purpose. The group will convene again in 2013 to evaluate its work, to write a conclusive report and to decide on the future of the group within ICES. The reason for working by correspondence in 2012 is that several members of the group will meet and attend the World Fisheries Conference 2012 and the IIFET 2012 and here partly continue the SGIMM work among other in cooperation with IIFET.

Within this report, we not only present this year presentations and results, but also include the summary of presentations from last year, to give a more complete picture of available approaches. As previously mentioned, a living document is envisaged including the Model Performance and Characteristics Matrix and summaries, which will be continuously updated and made public. The group discussed various reviewing approaches of bio-economic models in World-wide, North American and European context and to follow up on such approaches. Furthermore, strengthening of the group was discussed by adding an additional co-chair with economic background from outside Europe.

## **1 Opening of the meeting**

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The Study Group on Integration of Economics, Stock Assessment and Fisheries Management (SGIMM) had its first meeting at ICES headquarters, Copenhagen, Denmark from 14 to 17 June 2011. The meeting started with a welcome word from the Chairs and adoption of the agenda.

## **2 Background**

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Fisheries are economic activities that 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 harvested by this fishery. 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, in practical terms we manage the human activity, i.e. the fishery, within the ecosystem not the ecosystem itself. 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 fishery management options on the ecosystem. The 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. Impact assessment on the marine environment and socio-economic cost-benefits of various uses of the marine environment by other sectors compared to fisheries also demands socio-economic and bio-economic management evaluation models in relation to broader marine spatial planning of the multiple claimants to ecosystem services e.g. transport, energy (oil, wind energy, wave energy), recreational use and tourism, etc. Economic impact evaluation provides common platform for evaluating impacts of spatial use by different sectors.

## **3 Overview of existing models and approaches 2011 presentations**

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### **3.1 Intertemporal Choice of Marine Ecosystem Exploitation (Lars Ravn-Jonsen)**

Exploitation of the marine ecosystem brings with it an intertemporal choice: there is a choice of catching the fish today, or restrain from fishing with the option of an increase in the benefit from future harvest. In a marine ecosystem under a common pool management regime the contribution margin from catching the fish belongs to the fisher, while the benefit from the investment of leaving the fish in the sea will be shared in the common pool. The intertemporal choice therefore creates a driver for short sighted use of the ecosystem. The intertemporal balance of exploitation is analyzed by applying capital theory to a size-based ecosystem model. The model reveals a need for intertemporal balance with respect to both fish size and harvest volume. The management therefore is, at an ecosystem level, to set target and regulate not only harvest volume but also size (Ravn-Jonsen, 2011).

### 3.2 F-Cube model for North Sea demersal consume fisheries (Clara Ulrich)

Single-species management is a cause of discarding in mixed fisheries, because individual management objectives may not be consistent with each other and the species are caught simultaneously in relatively unselective fishing operations. As such, the total allowable catch (TAC) of one species may be exhausted before the TAC of another, leading to catches of valuable fish that cannot be landed legally. This important issue is, however, usually not quantified and not accounted for in traditional management advice. A simple approach using traditional catch and effort information was developed, estimating catch potentials for distinct fleets (groups of vessels) and métiers (type of activity), and hence quantifying the risks of over- and underquota utilization for the various stocks. This method, named Fcube (Fleet and Fisheries Forecast, Ulrich *et al.*, 2011), was applied successfully to the international demersal fisheries in the North Sea and shaped into the advice framework. The substantial overquota catches of North Sea cod that will likely occur under the current fisheries regimes are quantified, and it is estimated that the single-species management targets for North Sea cod cannot be achieved unless substantial reductions of TACs of all other stocks and corresponding effort reductions are applied.

This method works with R and using the FLR framework, making it fully compatible with much other fisheries analyses and modelling, including Long-Term Management Strategies Evaluations (MSE), and is therefore a potential tool for addressing future fleet- and fisheries based Long-Term Management Plans as advocated in the 2011 CFP reform proposal.

### 3.3 F-Cube-Econ for North Sea demersal consume fisheries (Ayoe Hoff)

Applying single-species assessment and quotas in multispecies fisheries can lead to overfishing or quota underutilization, because advice can be conflicting when different stocks are caught within the same fishery. During the past decade, increased focus on this issue has resulted in the development of management tools based on fleets, fisheries, and areas, rather than on unit fish stocks. A natural consequence of this has been to consider effort rather than quota management, a final effort decision being based on fleet-harvest potential and fish-stock-preservation considerations. Effort allocation between fleets should not be based on biological considerations alone, but also on the economic behaviour of fishers, because fisheries management has a significant impact on human behaviour as well as on ecosystem development. The FcubeEcon management framework for effort allocation between fleets and fisheries is based on the economic optimization of a fishery's earnings while complying with stock-preservation criteria (Hoff *et al.*, 2010).

FcubeEcon is based on the Fcube model (Ulrich *et al.*, 2011), and takes this approach one step further, as it bases the final effort distribution between fleets and métiers on economic considerations of the harvesting agents. The original Fcube framework does not directly include a choice of effort based on the economic behaviour of fishers. As an approximation to this, Fcube includes a 'value' choice of effort, where the final effort is given by a weighted average of the target species efforts, and where the weights are given by historical landings value shares of the different species. This effort choice is said to illustrate the case where fishers primarily target the most-valuable species. As this value effort will, however, be less than the maximum effort corresponding to the different single-species quotas, any effort between value effort and maximum effort will necessarily contribute to the landings value, so the value effort does not result in the highest landings value. Moreover, although the most valuable species are used to set the effort, this will not necessarily yield the greatest

profit for fishers, because the variable costs depend on effort, catch value, and catch weight.

It should be clear that neither the value choice of effort nor the minimum or maximum choices of effort used by Fcube reflect true economic behaviour, i.e. that fishers are expected to try to maximize their total profit by (i) targeting economically valuable species while trying to comply with the quotas and (ii) keeping their costs of doing so as low as possible. To do this they could also be expected to divide their final effort between fleet metiers optimally, if possible. Such re-allocation of effort can of course only take place if allowed by the fleet structure and management scheme making it possible to re-allocate species quotas between fleet segments (and thus to redefine the relative stability if applied across EU member states). A management system using individual transferable quotas (ITQs) satisfies these conditions just as profit-maximizing behaviour among the fishers entails quota trade and minimization of fishing costs. The literature on ITQs is extensive, starting with the paper of Christy (1973).

The FcubeEcon model has been developed to analyse an ITQ case because it distributes effort between fleet metiers and quotas between fleet segments, while maximizing total fleet profit, given certain constraints, e.g. that the catches of each species should be less than the corresponding TACs or that the catch of a specifically threatened species should be kept below the TAC for that species while the catches of other species are not constrained.

### **3.4 ATLANTIS in the VECTORS project (Marc Hufnagl)**

Information on the VECTORS project and the ATLANTIS type model, which will be parameterized and used within this project, were provided in a short presentation. VECTORS is a multinational project involving 34 partners and the focus will be on the North Sea, Baltic Sea and Mediterranean. The aim is to understand the main pressures on, and drivers of ecosystem functioning. In an integrated approach, including physics, biology and economy, eventually management advice shall be given and management tools shall be developed. One potential tool is the ATLANTIS model which has successfully been parameterized and used in Australia and e.g. the USA for analyzing and evaluating management strategies. On a VECTORS workshop (May 15th -20th in Copenhagen) several scientists were introduced, by the developer Beth Fulton, into the general structure and processes of the model. Atlantis represents an end-to-end model, is build up by boxes (polygons) and is based on multiple alternative sub-models of varying complexity. Water exchange and fluxes between polygons is predefined externally by a hydrodynamic model. Based on these fluxes the nutrient and species exchange rates are calculated, with the latter being also able to perform active migration between boxes. Energy flow between the boxes and different trophic levels are included via an ecosystem model using an age- and stock-structured formulation, primary production and predator prey matrices. All species can obtain specific age/size structure, habitat preferences, behaviour, growth and mortality rates. Of special interest for SGIMM might be the detailed exploitation model which includes detailed dynamics of fishing fleets. Different levels of complexity can be defined including among others gear selectivity, habitat association, targeting, effort allocation and management. Due to the modular construction alternative assumptions and model implementations for coastal zone management, tourism and pollution are possible. Within VECTORS one focus will be to analyze the effects of installing wind parks in the North Sea. Determining potential impacts, ecosystem and

economy changes will therefore be the main area of use for the ATLANTIS model within VECTORS.

### **3.5 The Atlantis Ecosystem Model: Applications to US West Coast Groundfish Fisheries (Dan Holland)**

We presented an ecosystem that has been used to provide U.S. West Coast fisheries managers with a tool to test the efficiency and robustness of alternative fishery management strategies in an ecosystem framework. In addition to providing insights into how alternative fishery management policies will affect the profitability and sustainability of fisheries, the model illustrates the wider ecosystem impacts of fishery management policies. The Atlantis ecosystem modelling framework is used to represent the spatially explicit food web, oceanography, and fisheries of the California Current. The model domain is the continental shelf running from Central California to the far North of Washington State. We presented two applications done with this model and some general conclusions about use of this model for providing policy advice.

The first application presented was done as part of an Integrated Ecosystem Assessment for the US West Coast's California Current. For this application we explored the potential influence of broad fisheries management options, including status quo management, switching effort from trawl to other gears, and spatial management scenarios. The model was used to provide a forecast of outcomes over 15 years. The model predicted substantial stock rebuilding and increases in fleet catch with fishing mortality constrained to levels occurring in recent years. In previous work we scored these scenarios in terms of metrics related to groundfish abundance and condition and ecosystem health, foci of that ecosystem assessment. Here we reported on an expanded analysis done by coupling Atlantis outputs to IOPAC, a regional input-output model that traces the indirect effects that changes in seafood landings have on the economy. Relative to Status Quo, the other scenarios here involved revenue losses primarily to the bottom trawl fleet. Other fleets, particularly the fixed gear fleets, gained revenue in some scenarios, though spatial closures of Rockfish Conservation Areas reduced revenue to fixed gear fleets. Processor and wholesaler revenue tracked trends in bottom trawl, which accounted for 67% of total landings by value. Economic impacts on the economy roughly equal the revenue of each fishery sector, based on linear multipliers near 1.0 estimated in IOPAC. Thus economic impacts per scenario mirrored the revenue trends and the overall economic impacts (direct, indirect and induced effects) are roughly double the direct effects measure by the ex-vessel revenues from landings. This illustrates the importance of further work to link ecosystem models to dynamic models of fishery or market behaviour that are designed for mid-term forecasting.

We also presented an application of the California Current Atlantis model that evaluated management with individual transferable quotas (ITQ) relative to prior management with bi-monthly cumulative vessel trip limits. Under the individual quota system, which was implemented in 2011, each vessel now has dedicated access to a portion of the quota for groundfish, such as rockfish and flatfish. The modelling work presented investigated the ecological and economic effects of this new management regime. We used the California Current Atlantis model to simulate the abundance of target fish species groups and four overfished rockfish species that are part of the ITQ system but have potentially constraining quotas and are therefore treated as bycatch. We simulated fleet dynamics for the 12 major groundfish fleets, with each fleet choosing fishing locations that maximize net revenue. Net revenue includes landed value of the catch, minus the cost of quota and fixed and variable costs. We explicitly in-



clude an ad-hoc penalty that fishers must pay if they exceed their quota. The main findings are: 1) Even with crude spatial resolution, under the individual quota scenario the simulated fleets show some improved targeting behaviour, avoiding overfished rockfish species and aiding recovery of these stocks. 2) The penalty fishermen expect for exceeding quota has a large effect on fleet behaviour, pointing to the importance of monitoring and enforcement. However the penalty must be set very high to affect behaviour suggesting that the quota price for the overfished species would have to be very high to provide sufficient economic incentive to avoid bycatch.

The complexity and time to run this Atlantis model limits exploratory modelling. A particular problem we ran into was how to model quota prices which are key to behaviour of fishermen with an ITQ system. It was not feasible to model market clearing prices for quota. We developed an IFQ market model based on statistical study in New Zealand by Newell *et al.* (2006) but we had difficulty even getting this running and, to date, have only run models with exogenous quota prices that do not change according to quota availability and fixed penalties for landing catch without quota. We find that Atlantis is a good tool for long run strategic analysis. It is well suited to looking at long run changes that may occur with changes in forage fish and climate. Running models with fishing effort specified simplistically work well, but implementing more complex fleet dynamics and incentives for targeting behaviour has proved difficult. It is probably fair to say that Atlantis is not well suited to providing quantitative predictions from short-run more tactical analysis of specific regulatory changes but is more suited to qualitative advice on longer term strategic management issues. One might be better off modelling the groundfish fishery with a simpler model without species interactions for management strategy evaluations of the ITQ system or other specific management measures.

### **3.6 A Coupled Food Web and Computable General Equilibrium Model for Georges Bank (Eric Thunberg)**

An economic-ecological framework is presented to assess the implementation of ecosystem-based fisheries management (EBFM) in New England. The framework links a computable general equilibrium (CGE) model of a coastal economy to an end-to-end (E2E) model of a marine food web for Georges Bank. The model focuses on the New England region using coastal county economic data for a set of industry sectors and marine ecological data for three top level trophic feeding guilds: planktivores, benthivores, and piscivores. Numerical simulations are undertaken to model the welfare effects of changes in alternative combinations of yields from feeding guilds and alternative manifestations of biological productivity. The economic and distributional effects of these alternative simulations across a range of consumer income levels are estimated. This framework could be used to extend existing methods for assessing the impacts on human communities of fishery rebuilding strategies or for broad scale changes in the marine ecosystem.

### **3.7 Bioeconomic assessment of Northern European Hake Long term Management Plan (Dorleta Garcia, Raul Prellezo)**

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 EFIMAS and COMMIT 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 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.* 2011, 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. Based on the experience in the evaluation of Northern Hake and Anchovy LTMP in Western Waters and the gaps identified in the process in 2010 we started developing a multistock and multifleet simulation model called FLBEIA (FL Bio-Economic Impact Assessment), which among others incorporates fleets' short and long term dynamics. At the moment the model is being tested and applied in several case studies in a preliminary way.

### **3.8 FLBEIA, a bio-economic impact assessment package in R (Raul Prellezo, Dorleta Garcia)**

FLBEIA (FL Bio-Economic Impact Assessment) is an R package (R Development Core Team, 2011) build on top of FLR libraries (Kell *et al.*, 2007). The purpose of the library is to provide a flexible and generic tool to conduct Bio-Economic Impact Assessments of harvest control rule based management strategies under a Management Strategy Evaluation (MSE) framework (Butterworth & Punt, 1999; De la Mare, 1998; Punt & Donovan, 2007). As such it is divided in two main blocks, the operating model (OM), and the management procedure model (MPM). In turn these two blocks are divided in 3 components. The OM is formed by the biological, the fleet and the covariables components and the MPM by the observation, the assessment and the advice components. The model is multistock, multifleet and seasonal and uncertainty is introduced

by means of monte-carlo simulation. The algorithm has been coded in a modular way to ease the checking and the flexibility of the model. The library provides functions that describe the dynamics of the different model components, under certain assumptions, and the user chooses which of the functions are used in each case specific model implementation. Furthermore, if in a specific case study or scenario, for some of the components, the functions provided within FLBEIA do not fulfil the requirements, the user can code the functions that adequately describe the dynamics of those components and use the existing ones for the rest of the components. As the user can construct its own model, selecting existing submodels and constructing new ones, we can define it as a framework more than as a model. The package is still under development but most of its functionalities are already working. The package is being used in several case studies with very different peculiarities, Hake and associated mixed fisheries in Western Watters, Anchovy and associated sequential fisheries in Bay of Biscay, Northeast Atlantic Blueling and associated Mixed Fisheries, Beaked Redfish and Seabream artisanal fisheries. Except the last 2 case studies the rest are multistock and multifleet-multimetier case studies. At the moment there are no functions to model trophic interactions but it is something planned within Anchovy case study. The main limitations of the model are that the stocks must be age structured or aggregated in biomass (length structure is not allowed) and that spatial dimension is not considered explicitly. Spatial characteristics could be modelled assigning stocks and/or fleets/metiers to specific areas.

### **3.9 Baltic Sea, ecological-economic optimization model (Jörn Schmidt)**

The central Baltic Sea fish community is dominated by three species only, i.e. cod, herring and sprat. The fishery mainly consists of single species fisheries. However, fisheries are closely connected, as there are strong ecological inter-connections between the species, i.e. predation by cod and competition between clupeids. Therefore, management measures taken for one species will inevitably affect the other species and its related fisheries.

We developed and applied an age-structured ecological-economic multi-species optimisation model (Voss *et al.* 2011). This model offers the possibility to calculate optimal multi-species F-vectors for different management objectives. As a reference case, the maximum net present value of the combined fisheries is calculated. A weighting scheme in the objective function offers the possibility to calculate the actual costs of side conditions (as deviation from optimum), e.g. maintaining clupeid stocks above a limit biomass, or of maintaining a certain amount of profit in the single fisheries.

### **3.10 Effects of fishing effort allocation on energy efficiency and profitability: Developing an individual-based model for the Danish fisheries (J. Rasmus Nielsen and Francois Bastardie)**

The above presentation to SGIMM covers a combination of modelling approaches published in two recent papers for which the abstracts are given below (Bastardie *et al.*, 2010c,d).

Bastardie, Nielsen, Andersen, Eigaard (2010c). Effects of fishing effort allocation scenarios on energy efficiency and profitability: An individual-based model applied to Danish fisheries.

Global concerns about CO<sub>2</sub> emissions, national CO<sub>2</sub> quotas, and rising fuel prices are incentives for the commercial fishing fleet industry to change their fishing practices and reduce fuel consumption, which constitutes a significant part of fishing costs. Vessel-based fuel consumption, energy efficiency (quantity of fish caught per litre of

fuel used), and profitability are factors that we simulated in developing a spatially explicit individual-based model (IBM) for fishing vessel movements. The observed spatial and seasonal patterns of fishing effort for each fishing activity are evaluated against three alternative effort allocation scenarios for the assumed fishermen's adaptation to these factors: (A) preferring nearby fishing grounds rather than distant grounds with potentially larger catches and higher values, (B) shifting to other fisheries targeting resources located closer to the harbour, and (C) allocating effort towards optimising the expected area-specific profit per trip. The model is informed by data from each Danish fishing vessel >15m after coupling its high resolution spatial and temporal effort data (VMS) with data from logbook landing declarations, sales slips, vessel engine specifications, and fish and fuel prices. The outcomes of scenarios A and B indicate a trade-off between fuel savings and energy efficiency improvements when effort is displaced closer to the harbour compared to reductions in total landing amounts and profit. Scenario C indicates that historic effort allocation has actually been sub-optimal because increased profits from decreased fuel consumption and larger landings could have been obtained by applying a different spatial effort allocation. Based on recent advances in VMS and logbooks data analyses, this paper contributes to improve the modelling of fishing effort allocation, fuel consumption and catch distribution on a much disaggregated level compared to the fleet-based models we developed so far.

Bastardie, Nielsen, Ulrich, Egekvist, Degel (2010d). Detailed mapping of fishing effort and landings by coupling fishing logbooks with satellite-recorded vessel geolocation.

Individual tracking of commercial fishing vessels from vessel monitoring systems (VMS) is now widely available across Europe for scientific purposes. This enables analyses of the spatial and temporal distribution of disaggregated fishing activity as well as high resolution determination of the consequent relative fishing pressure on stocks, provided that an accurate method can link these data with the declaration of catches (logbooks). In the present study, logbook analyses to allocate the fishing activity due to various fisheries (fleet segments) are integrated with processing of raw satellite-recorded data for identifying trips at sea and fishing sequences. Both data sources are linked into one output dataset. A robust method is developed to allocate logbook catches to VMS positions, with focus on potential mismatch. The method is applied to data on the Danish Skagerrak-Kattegat fishing fleets from 2005 to 2008, where 52–56% of the VMS total effort perfectly matched (representing approximately 80% of landings); 14–18% partially matched; and 30% failed to match the logbook data, which was partially related to fleet type, area and year. Comparison of three methods for generating high resolution determination of grid-based fishing effort demonstrated only minor differences, suggesting a mainly equal dispatch of landings between each of the merged fishing positions. Despite possibly poor matching success for this particular region, we demonstrate that the approach can cope with the potentially large sources of error in the data, including the current low accuracy of available VMS pre-processing algorithms and the possible misreporting of areas and catch dates in fishermen's logbook declarations.

### **3.11 Model I: Optimal fishing mortalities trajectories (Jose M. Da-Rocha)**

We characterise optimal fishing mortality trajectory that maximizes the net present value of a fishery's economic indicator. The optimisation problem takes into account: i) the multi-species age-structured population model which is commonly used by Virtual Population Analysis for fish stock assessment; and ii) financial costs and inter-temporal discounting to relate reference points to discounted economic profits

along optimal trajectories. We also provide algorithms that use the parameters estimated in stock assessment to find the steady-state solution of dynamic optimal management problems. We applied these algorithms to:

- 1) Built endogenous optimization bio economic algorithm to recover stocks (Da Rocha *et al.*, 2010), which may be implemented using standard non-linear optimization methods. Because managers cannot force vessels to both fish and invest, the feasible annual reduction in  $F$  is characterized by endogenous constraints set by the state of the resource.
- 2) Compare scenarios, and Harvesting Control Rules, proposed by the biological assessment with the optimal fishing mortality that maximizes the net present value of profits (STECF, 2010). We also applied this approach to show that: EIAA analysis of long-term management plan was biased towards scenarios with  $F > F_{max}$  (Da Rocha and Gutierrez, 2011).

### 3.12 Model II: Endogenous fleet capacity (Jose M. Da-Rocha)

We build a stationary analytically tractable fleet distribution model in which vessels value per unit evolves according to a standard Brownian motion (Da Rocha and Pujolàs, 2011). An analytical solution for the vessels stationary distribution is obtained by using the Kolmogorov forward equation subject to the boundary conditions determined by the optimal exit/entry decision. The model was used to:

- a) Explore the impact of changes in mesh size and area closure regulations on profitability and fleet size through a change in number of days per vessel in the fishery. Constraints on the maximum number of days affect operating profits and vessel entry and delay-exit decisions. Therefore, the distribution of vessels is a function of fishery regulations (scenarios).
- b) Introducing ITQs, trade-offs among the CFP three main objectives (economic, social and environment) are less severe.

## 4 Model Matrices

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The group heavily discussed ways to proceed with the work. It was agreed that a good idea would be a living document in form of a matrix and a summary of each model, collecting existing modelling approaches in a standardized way, to ease the exchange between groups and to simplify an overview. This Model Performance and Characteristics Matrix followed by a Model Summary (Abstract) will then be used to perform an international survey on existing models taking into account previous reviews of bio-economic fisheries models World wide including North American and European reviews. Table 1 is the first suggested approach to collect information about individual model approaches. In 4.1 explanatory notes are given for the rows in the model performance and characteristics model in table 1. In 4.2 the matrices developed during the meeting are presented.

**Table 1. Suggested Model Performance and Characteristics Matrix template to collect information about individual model approaches**

Case Study / Model
Authors / Contact Persons*
Aim: Management addressed, management objectives
Aim: Corresponding advice needed/ addressed
Institutional Set-up: (Bodies involved, needed partners);
Type of Model (biol, econ, soc., long- term, short- term)
Model Dimensions and Model Structure
Usefulness of the Model (Pro, Cons, Problems)
Focus and Trade offs
Data needed
Data available Used in case study/model
Status for application / implementation
Model Platform and Programming Language (free, commercial)
Model output (format)

**References**

#### 4.1 Explanatory text to the rows in the survey table on the models with respect to the collective experience with and collective consensus on the models (mainly to be given by the developers)

- 1) Management addressed and/or relevant management the model can address; aim and management objectives addressed: biological or socio-economic objectives; Recipients: intended / realized management; Type of regulatory framework; Harvest rules addressed; Can the model address impact of technical measures?
- 2) Corresponding Advice (biological and economic) needed: What type of advice: biological/economic/socio-economic (according to objectives, reference points, etc)?; Which indicators are produced for advice? Time frame on short to medium term current advice and/or medium to long term strategic advice; whether and how the model has been used in advice (has it been used in relation to advice and management?); Results coming from the use and implementation of the model; Recipients: intended / realized; Other models use of output from the model?
- 3) Institutional set-up and platforms: This should be split up in relation to partly management/advice as here, but also in relation to who is involved and necessary to involve in developing, informing and implementing the model (see also needed partners below). In both cases it should indicate where and in which context the model was developed and/or used and/or where supposed to be used (should be used). Intended / realized. Has model output been validated or not?
- 4) Needed partners: Involved partners and/or needed partners for partly developing, informing, using and implementing the model (contributions and information from others (man., advice, science), needed partners, platforms, capacity building); Has the model been well scientific documented?
- 5) Type of model: Biological, Economic, Sociological, Bio-Economic, Socio-Economic. Level of integration of biology, economy, sociology of the model should be addressed. What are the links between the components, e.g. how are the economic and biological components linked to provide management advice? Also, to address this it should be informed what level and complexity of the systems the models address and was intended to address (complex or simple type model), time range in form of short to medium term advice/management or/and medium-long term strategic advice/management with respect to type of model; which level or part of the system does the model address (ecosystem/multi-species/single stock, economic system, sociological system); what spatial and temporal resolution does the model operate on; what type of model with respect to e.g. analytical tool/observation model, simulation model (scenario simulation), deterministic or stochastic model, iteration (MCMC) model, other; is the model capable of perform a projection or static scenarios)? Can the model consider uncertainty (and in given case on which parameters)?; Can sensitivity tests be performed (and in given case with which method and on which parameters)?
- 6) Model dimensions and model structure: Which dimensions (e.g. fleets, species, area, season, etc.) are included in the model? What are the main components of the model? Are there separate components for, for instance, the biological and economic procedures?

- 7) Usefulness of the model and in which context they are useful and where detected problems (pro, cons, limitations, problems). This is mainly in respect of use and implementation but naturally also addresses the development of the models;
- 8) Focus and Trade offs in what is (and can be) addressed in the models and case studies (main aim of the model and main questions to be answered and main scientific/advisory/management scenarios/options/problems to be addressed;
- 9) What data are accordingly needed; including specification of model variables and parameters – both endogenous and exogenous; Is it necessary to make any estimations or data processing needed before the model can be applied?
- 10) What data are available already; (For Europe in relation to DCF);
- 11) Status for the development, application, implementation and use of the model in the case studies (progress of linking biological and economic operating models or parts in the models). Have the model been used in advice and/or management? In given case how has it been used? If not, why has it not been used? Has it been used in relation to advice and/or management decisions? It is important to obtain information from the model developers on this as well as the progress and problems in this, and why it is so. There is a partly overlap in the contents of this bullet the bullets 1, 2, 3, and especially 6, but this cannot be avoided. Has the model been well documented scientifically? Is the model only developed and used for scientific purposes?

For each of the above bullets the answers could be given according to a scaling of the degree / level (of the models), i.e. low, medium, high.

As such each bullet (row or column) could be used as an axis in a multi-dimensional diagram showing the coverage of all the models according to this scaling.



## 4.2 Individual Model Matrices

### SRRMCF (Swedish Resource Rent Model for the Commercial Fisheries)

Case Study / Model	SRRMCF (Swedish Resource Rent Model for the Commercial Fisheries)
Authors / Contact Persons*	Staffan Waldo*, Staffan.Waldo@ekon.slu.se, Anton Paulrud*, Anton.Paulrud@slu.se
Aim: Management addressed, management objectives	Swedish Fisheries taking place in North Sea, Skagerrak, Kattegat, Baltic22-24, 25-29+32, and 30-31 Fleet and métier based Strategic economic advice, medium term advice (model is short term)
Aim: Corresponding advice needed/ addressed	Economic evaluation of management proposals Multi-fleet Multi-stock
Institutional Set-up: (Bodies involved, needed partners);	Managed by the AgriFood Economics Centre at the Swedish University of Agricultural Sciences (SLU) Data, specification of métiers, etc. in cooperation with Swedish Board of Fisheries and the Institute for Aquatic Resources (SLU) Fleet specific costs derived from EU DCF
Type of Model (biol, econ, soc., long-term, short-term)	Economic optimization allowing fishermen to choose between métiers. Calculation of economic result in current fishery. Deterministic optimisation model Short-term
Model Dimension and Model Structure	
Usefulness of the Model (Pro, Cons, Problems)	Detailed economic model Optimizes over one year using exogenously specified TAC. GAMS optimisation software
Focus and Trade offs	Focus on fleet economics, no dynamic biological module
Data needed	Landings, effort, costs and prices by métier Economic data by fleet segment (by métier if available)
Data available Used in case study/model	Swedish data on landings, effort, costs and prices by métier Economic data by fleet segment based on EU DCF and Swedish Board of Fisheries (e.g. métier)
Status for application / implementation	Used for analysing Swedish ITQ system. The model is currently being updated to data from 2009. Ongoing projects concern fuel subsidies (TACs from BALMAR model) and sprat reduction fisheries in the Baltic (TAC from "skarpills-projektet").
Model Platform and Programming Language (free, commercial)	GAMS (commercial)
Model Output (Format)	

### References

**Western waters, FLMSsim (FLR)**

Case Study / Model	Western waters, FLMSsim (FLR)
Authors / Contact Persons*	Dorleta Garcia*, dgarcia@azti.es, Raul Prellezo*, rprellezo@suk.azti.es
Aim: Management addressed, management objectives	Impact assessment of the LTMP (biological objectives) with respect to: -Enforcement system in relation to TAC -Evaluate the effect of a change from TAC to effort system - Technical changes Short to medium term
Aim: Corresponding advice needed/ addressed	Strategic biological and economic advice Short- to medium-term
Institutional Set-up: (Bodies involved, needed partners);	Internally STECF RACs
Type of Model (biol, econ, soc., long-term, short- term)	Simulation model (Monte-Carlo) Bio-economic, no capital dynamics in the economic part LTMP Short to medium term
Model Dimension and Model Structure	Single Stock and Multifleet. Not multispecies Not explicitly spatial.
Usefulness of the Model (Pro, Cons, Problems)	Pro: -Captures the EU advice system. -Uncertainty is addressed Cons: -Usefulness is limited to advanced R users -Not multispecies -Capital dynamics not included
Focus and Trade offs	Based on management advice and IA. Testing robustness to observation, model and process uncertainty
Data needed	Stock assessment input and outputs (abundance, biological parameters and F). Fleet segmentation, catch at age, price at age, effort, costs (on fleet level) (Economic data is not mandatory but necessary to conduct economic IA)
Data available Used in case study/model	From some stocks there is no availability of assessment (no data or approved assessment). From the economic side data looks sufficient but the segmentation of DCR/DCF can cause problems
Status for application / implementation	Used in several STECF working groups.
Model Platform and Programming Language (free, commercial)	R (free)
Model Output (Format)	FLR objects or R matrices

**References**

- Garcia, D., Prellezo, R., Santurtun, M., and Arregi, L. 2011. Winners and losers of a technical change: A case study of long-term management of the Northern European Hake. *Fisheries Research* 110(1): 98-110.
- Murua, H., Quincoces, I., Garcia, D., and Korta, M. 2010. Is the Northern European hake, *Merluccius merluccius*, management procedure robust to the exclusion of reproductive dynamics? *Fisheries Research*, 104(1-3): 123-135.
- Prellezo, R., and Garcia, D. 2009. Northern Hake Long Term Management Plan Evaluation including fishermen reaction to Management Advice and Enforcement Strategy. ICES CM N: 06.
- Garcia, D., and Prellezo, R. 2009. Fleet reaction to management advice, a key process for success of management plans. ICES/PICES/UNCOVER Symposium.

**Western Waters, FLBEIA (FLR)**

Case Study / Model	Western Waters, FLBEIA (FLR)
Authors / Contact Persons*	Dorleta Garcia*, dgarcia@azti.es, Raul Prellezo*, rprellezo@suk.azti.es
Aim: Management addressed, management objectives	Bio-economic Impact Assessment of Harvest Control Rules and Effort Control Rules
Aim: Corresponding advice needed/ addressed	Strategic and tactic biological and economic advice
Institutional Set-up: (Bodies involved, needed partners);	Internally STECF RACs ICES
Type of Model (biol, econ, soc., long-term, short-term)	Bio-economic model framework Simulation Model (Monte Carlo) Short- to medium- to long-term simulations
Model Dimension and Model Structure	MultiStock, MultiFleet and Seasonal. Allows incorporating covariables outside stocks and fleets. Operating model and management procedure modules. Not explicitly spatial. Modular.
Usefulness of the Model (Pro, Cons, Problems)	Pro: -Flexibility for the users to build their own components (level 3 and 4) Cons: -Usefulness is limited to advanced R
Focus and Trade offs	Based on management advice and IA. Testing robustness to observation, model and process uncertainty Trade offs coming from the application of constraints derived from GES and Marine strategy
Data needed	Stocks assessment inputs and outputs (abundance, biological parameters and F). Fleet segmentation, catch at age, price at age, effort, costs and capital invested by segment (economic data is not mandatory but it is necessary to conduct economic IA). Co-variables and their dynamics.
Data available Used in case study/model	For some stocks assessment inputs/outputs are not available (no data or approved assessment). From the economic side data looks sufficient but the segmentation of DCR/DCF can cause problems.
Status for application / implementation	Some parts are under development (capital dynamics) but the biological, management, and fleet short term behaviour are ready to use. Manual is available
Model Platform and Programming Language (free, commercial)	R (free)
Model Output (Format)	FLR objects

**References**

**Western Waters, FishRent**

Case Study / Model	Western Waters, FishRent
Authors / Contact Persons*	
Aim: Management addressed, management objectives	Determination of Rent
Aim: Corresponding advice needed/ addressed	Strategic economic advice
Institutional Set-up: (Bodies involved, needed partners);	Internally STEC
Type of Model (biol, econ, soc., long-term, short-term)	Long term deterministic simulation and optimization
Model Dimension and Model Structure	
Usefulness of the Model (Pro, Cons, Problems)	Pro: - Excel Cons: -Excel - Biological side simplified (based on biomass, no species interactions) -Deterministic
Focus and Trade offs	Different policies as well as systems of collecting rents
Data needed	Biomass by stock, catches prices and costs (on fleet level)
Data available	From the biological side almost all.
Used in case study/model	From the economic side data looks sufficient but the segmentation of DCR/DCF can cause problems
Status for application / implementation	Final report of the Study on the remuneration of spawning stock biomass <a href="http://ec.europa.eu/fisheries/documentation/studies/remuneration_of_the_spawning_stock_biomass_en.pdf">http://ec.europa.eu/fisheries/documentation/studies/remuneration_of_the_spawning_stock_biomass_en.pdf</a>
Model Platform and Programming Language (free, commercial)	Excel (commercial)
Model Output (Format)	

**References**

**IBM Bio-Economic Framework in R**

Case Study / Model	IBM Bio-Economic Framework in R
Authors / Contact Persons*	Rasmus Nielsen*, rn@aqua.dtu.dk, François Bastardie*, fba@aqua.dtu.dk
Aim: Management addressed, management objectives	Short- and dium term management; fleet based management on effort allocation: cost- and energy efficiency in effort- allocation according to management plans; Biological objectives addressed; Energy efficiency and cost efficiency objectives can be addressed when established;
Aim: Corresponding advice needed/ addressed	Short and medium term, LTMP, multi-fleet and multi-stock based advice on efficient effort allocation: Partial fishing mortalities by fishery/metier given efficiency in effort allocation; Advice aimed towards ICES and EU STECF and National Administrations; Model scientific published and used in scientific research projects but not applied, implemented and used in actual advice yet;
Institutional Set-up: (Bodies involved, needed partners);	
Type of Model (biol, econ, soc., long-term, short- term)	Individual based bio-economic simulation framework in R; Level: Multi-stock and multi-fisheries (Baltic, North Sea); Short term to medium term model; Need detailed information on spatio-temporal disaggregation of the resources
Model Dimension and Model Structure	
Usefulness of the Model (Pro, Cons, Problems)	Complex model; Need some computational power; Biological and economic incentives/logics in fisheries behaviour; IA and MSE of MPs; evaluation of robustness of management options in relation to effort allocation and cost-efficiency;
Focus and Trade offs	MSE and IA of MPs With respect to energy and cost efficiency in the catching sector Advanced R users and modellers
Data needed	Level of data needed: High resolution catch and effort and resource availability data: Catch and effort by stock on individual vessel and fishing trip basis; VMS-information; Trip based log-book information; Specific costs and prices on vessel level; Disaggregated research survey or combined fishery information on disaggregated resource availability (at least on ICES Square)
Data available Used in case study/model	DCF
Status for application / implementation	
Model Platform and Programming Language (free, commercial)	R (free)
Model Output (Format)	

**References**

**Generic Ecosystem model**

Case Study / Model	Generic Ecosystem model
Authors / Contact Persons*	Lars Ravn-Jonsen, lrj@sam.sdu.dk
Aim: Management addressed, management objectives	<ul style="list-style-type: none"> <li>• Bio economic model regarding total harvest of the ecosystem.</li> <li>• Strategic planning model: Strategic goal for harvest with respect to size of fish (trophic level) and mass</li> <li>• Capital theoretic analyses by marginal approach</li> <li>• Diving forces analyse by the capital theory</li> </ul>
Aim: Corresponding advice needed/ addressed	<ul style="list-style-type: none"> <li>• The model can find the first best strategic goal with respect to size and amount of ecosystem harvest.</li> <li>• The model can find the return rate given by ecosystem by investment made by increasing size or decreasing harvest by marginal analyses.</li> <li>• The marginal analyses point to problems to be addressed by regulations of common pool regulation</li> </ul>
Institutional Set-up: (Bodies involved, needed partners);	<p>Used by: Lars Ravn-Jonsen SDU</p> <p>Documented in Ravn-Jonsen (2011)</p> <p>Similarly models used by DTU aqua and Cefas</p> <p>Needed partners: Biologists / Ecologists working with Ecosystem management with a strategic approach.</p>
Type of Model (biol, econ, soc., long-term, short-term)	<p>Type of model: Bioeconomic model with the biological model as a trophic dynamic model with size as functional group, thus a size based mode, and the economic model that allows for flexible fishery with respect to size. The model implementation allows for capital theoretic analyses by a marginal approach.</p> <p>Level and complexity: Ecosystem level modelled by functional groups, long term with time scale of 100-years, no spatial resolution. Economic model target welfare economic and optimizing of capital value at ecosystem level, and regulation at functional group level (size).</p>
Model Dimension and Model Structure	<p>State variable is population density with respect to size. Size and time is modelled continues and the numeric implementation allows for any resolution with respect to size and time step.</p> <p>Fishery is implemented so any selectivity or fleet structure can be applied. In Ravn-Jonsen (2011) there is only one fleet and that fleet is targeting one size.</p>
Usefulness of the Model (Pro, Cons, Problems)	<p>Pros: Quick and simple, suitable for capital theoretic analysis.</p> <p>The biological model is a production model (in the economic sense)</p> <p>Cons; the simplicity will miss aspects, however they can be addressed by other models</p>
Focus and Trade offs	Focus: Strategic planning
Data needed	Parameterize the model for specific systems.
Data available	Generic physiologic functions. Size spectrum analyses
Used in case study/model	
Status for application / implementation	<p>Status: published, Ravn-Jonsen (2011).</p> <p>The model has later been adapted for the North Sea, and a version expanded with life story, and generic cost and price functions is work in progress.</p>
Model Platform and Programming language (free, commercial)	R (free)
Model Output (Format)	

**References**

Ravn-Jensen, L.J. (2011). Intertemporal Choice of Marine Ecosystem Exploitation, *Ecological Economics* 70, pp 1726-1734.



**Atlantis – California Current**

Case Study / Model	Atlantis – California Current
Authors / Contact Persons*	Dan Holland*, Dan.Holland@noaa.gov
Aim: Management addressed, management objectives	Understanding trade-offs between different uses and services of the ecosystem, evaluation of ITQ management vs. prior system; Evaluating implications of shifting use of trawl gear to fixed gear and extending area closures for all gear with bottom contact;
Aim: Corresponding advice needed/ addressed	Integrated ecosystem assessment; Advice for managers on whether to implement ITQ management and what impacts might be; Strategic (medium to long-term) advice on trade-offs in ecosystem uses and services; Understanding future impacts of climate change on system.
Institutional Set-up: (Bodies involved, needed partners);	Partnership between Moore foundation and NOAA primarily with Moore providing some funding and NOAA employees, post-docs and contractors doing work. Provides info the fishery management regional council and other stakeholders.
Type of Model (biol, econ, soc., long-term, short-term)	Ecosystem model with bottom-up and top-down forcing, deterministic, spatial with irregular grid based on bathymetry and latitudinal breaks, dynamic with short time step (days). Focused on long-term strategic advice with outputs addressing a variety of ecosystem services and user groups.
Model Dimension and Model Structure	
Usefulness of the Model (Pro, Cons, Problems)	Atlantis model available now has a reasonably fine spatial scale capable of capturing much of the heterogeneity of species distributions and uses of ecosystem resources though not fine scale enough to capture patchiness of species distributions that fishermen can exploit to target and avoid species and not fine enough scale to evaluate specific installations such as wind farms.
Focus and Trade offs	Focus is on linkages within ecosystem between physical and different biological and human components of system. Trade off is that specific species and fisheries can not be modelled (ecological functional species groups) as realistically and uncertainties not addressed well.
Data needed	Probably will need better data on quota prices. Need better data on fine scale patchiness and short-term spatial dynamics of fish stocks and fishing behaviour, which may be derived from analysis of observer data from the ground fish fishery.
Data available Used in case study/model	Fish tickets (landings prices), logbooks, observer coverage (100% post 2011), cost-earning survey, mandatory economic data collection for harvesters and processors in ITQ fishery, voluntary cost earnings survey for other fishers, data collection and parameterization for Input Output model, ITQ trade data with voluntary price disclosure, trawl surveys, oceanographic models; Atlantis model with full trophic network used.
Status for application / implementation	Model is operational for some applications but the module for modelling fleet dynamics in an ITQ system is not working as intended yet.
Model Platform and Programming Language (free, commercial)	C++ (commercial)
Model Output (Format)	

**References**

**Coupled Food Web and CGE – Georges Bank**

Case Study / Model	Coupled food web and Computable General Equilibrium Model of Georges Bank
Authors / Contact Persons*	Eric Thunberg*, Eric.Thunberg@noaa.gov
Aim: Management addressed, management objectives	Understanding the economic implications of changes in ecosystem states.
Aim: Corresponding advice needed/ addressed	Integrated ecosystem assessment, Strategic long-term advice on trade-offs in ecosystem uses and services, Understanding future impacts of climate change on system
Institutional Set-up: (Bodies involved, needed partners);	Partnership between NOAA Fisheries and the Marine Policy Center of the Woods Hole Oceanographic Institute
Type of Model (biol, econ, soc., long-term, short-term)	Donor controlled food web model based on Steele <i>et al.</i> (2007) of the Georges Banks food web. Computable general equilibrium model of the New England regional economy. Models are run separately by first estimating fishery production through simulation of ecosystem states. The economic value of the resulting changes in fishery production are estimated by solving for market clearing prices using the CGE model.
Model Dimension and Model Structure	Computable general equilibrium models belong to a class of regional economic models. CGE models are an abstraction of a regional economy through estimation of a system of supply and demand equations. The impact of a changes in fishery production is derived by solving the CGE model for market clearing prices. Since the model uses a system of supply and demand equations that resulting economic impacts measure the changes in consumer and producer surplus.
Usefulness of the Model (Pro, Cons, Problems)	CGE models are complex and require data that may not be readily available. The major advantage to CGE is the ability to model economic adjustments. This means that some consideration needs to be given to whether a policy change would have a substantial long term impact on a regional economy before investing the time and effort into developing a CGE model. It is likely that CGE models will be most useful in addressing fundamental changes in ecosystem states and not as useful in examining small to modest near term changes in fishery management policy.  CGE models are based largely on market transactions. This means that embedded externalities will be reflected in the model. Similarly, non-market values for ecosystem services will not be reflected in the model.
Focus and Trade offs	Focus is on linkages between ecosystem states and regional economies. Both food web and CGE models, by necessity are an abstraction of the natural and economic systems. As such they may not be well suited to evaluate management concerns on a species-specific or at a fishing fleet level. Best use may be to inform long term questions such as the implications of climate change.
Data needed	CGE models require data on purchases and sales between industrial

	sectors of an economy. In most countries these data are derived from National income accounts. If a model is to be developed on a finer regional scale then primary data collection may be required.
Data available Used in case study/model	Data to construct the CGE model of the New England economy were purchased through Minnesota IMPLAN group. These data include an accounting matrix of purchases and sales between over 500 sectors. These data were aggregated into fewer sectors to make the model more tractable.
Status for application / implementation	Model is operational for some applications but is still under development. Emphasis is to be placed on refining the model to include fishing sectors by gears and to include a broader set of human uses of the marine ecosystem such as recreational fishing, tourism, etc.
Model Platform and Programming Language (free, commercial)	
Model Output (Format)	

### References

Steele, J.H., Collie, J.S., Bisagni, J.J., Gifford, D.J., Fogarty, M.J., Link, J.S., Sullivan, B.K., Sieracki, M.E., Beet, A.R., Mountain, D.G., Durbin, E.G., Palka, D., Stockhausen, W.T., 2007. Balancing end-to-end budgets of the Georges Bank ecosystem. *Progress in Oceanography* 74, 423-448.

### Related Literature

Seung, Chang K. 2006. A Review of Regional Economic Models for Fisheries Management in the U.S. *Marine Resource Economics*. 21:101-124.

Pan, H. P. Failler, and C. Floros. 2007. A Regional Computable General Equilibrium Model for Fisheries. CEMARE Research Paper No. 163. Portsmouth, UK.

**North Sea demersal fishery, Fcube, FcubeEcon**

Case Study / Model	North Sea demersal fishery, Fcube, FcubeEcon
Authors / Contact Persons*	Ayoe Hoff*, ah@foi.dk, Clara Ulrich*, clu@aqua.dtu.dk
Aim: Management addressed, management objectives	Fleet and metier based management, based on traditional single species TACs. Can also be translated into effort quota, as effort is one input Short to medium term, strategic economic advice
Aim: Corresponding advice needed/ addressed	Biological/economic short-term advice. Economic medium term strategic advice (reallocation of fishing rights between metiers and fleets, also across borders).
Institutional Set-up: (Bodies involved, needed partners);	Could/should be used as alternative to single species TAC advice in mixed fisheries. (request from the EU and ICES, resulting in SGMIXMAN and WGMIXFISH)
Type of Model (biol, econ, soc., long-term, short-term)	Short-term biological and bio-economic model based on fleets and targeted stocks. Fcube is a FLR simulation model, while FcubeEcon is applied as an optimisation in Excel using Fcube as a deterministic model; Quite simple setup; multi-stock, multi-fleet, based on ICES single stock assessment Fcube estimates catch potentials for distinct fleets and metiers based on traditional catch and effort information, thus estimating the potentials for single species TAC under- or over-shoots. Fcube proposes short-term fleet based management advice based on <i>biological</i> considerations. FcubeEcon: An economic module build into Fcube, using the same approach, but basing the final fleet bases management advice on <i>economic</i> considerations of the optimal economic behaviour of the fleets (profit maximisation). FcubeEcon can base it's advice on various constraints, e.g. compliance with single species TACs.
Model Dimension and Model Structure	No limitations on number of fleets and stocks. Effort and catch by fleet can be shared across several metiers.
Usefulness of the Model (Pro, Cons, Problems)	Fcube/FcubeEcon are simple models; it is easy to understand the basics of the models and they are easy to use, they build on standard stocks and fleets data, and they need standard computational power. The results are valuable guidelines on fleet and metier based management Fcube/FcubeEcon are short-term management advice, only giving advice for one year, given the proposed single species TACs in this year. However, the FLR structure of Fcube makes it simple to include this within a long-term Management Strategies Evaluation framework. FcubeEcon proposes reallocation of effort between metiers and fleets, which may not be possible in the short run.
Focus and Trade offs	Fleet and metier based multi-stock management, as opposed to single species management.
Data needed	Fleet data, including historical effort and landings by metier of the included species. Stock data for the included species, including historical age classes (preferably for 3 years), fishing and natural mortalities. Can also be potentially adapted to stocks without analytical assessment. Economic data for the included fleet segments: cost disaggregated down to effort specific and landings specific. Prices obtained for the included stocks. Single species TAC advice in the assessment year of the included stocks.
Data available Used in case	For the NS case study: Necessary fleet data. Stock data for cod, haddock, plaice Pollock, sole, whiting. Nephrops biological data included under

study/model	few simplification hypotheses. Economic data for 12 of the 19 included fleet segments.
Status for application / implementation	The model has been applied to the North Sea Demersal fishery, the Greek Aegean Sea (eastern Mediterranean) coastal and demersal fishery, and the Spanish fishery in the Western area. The model has been documented in a number of reports and publications (see references below).
Model Platform and Programming Language (free, commercial)	R (free)
Model Output (Format)	Fcube : FLStocks and FLFleets objects in FLR. FcubeEcon : FcubeEcon : Excel table.

### References

- Hamon, K., Ulrich, C., Hoff, A., and Kell, L. T., 2007. Evaluation of management strategies for the mixed North Sea roundfish fisheries with the FLR framework. In Oxley, L. and Kulasiri, D. (eds) MODSIM 2007 International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, December 2007, pp. 2813-2819.  
[http://mssanz.org.au/modsim07/papers/51\\_s26/EvaluationOfmanagements26\\_Hamon\\_.pdf](http://mssanz.org.au/modsim07/papers/51_s26/EvaluationOfmanagements26_Hamon_.pdf)
- Hoff, A., Frost, H., Ulrich, C., Damalas, D., Maravelias, C. D., Goti, L., and Santurtún, M. 2010. Economic effort management in multispecies fisheries: the FcubeEcon model. – ICES Journal of Marine Science, 67: 1802–1810
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- Maravelias, C., Damalas, D., Ulrich, C., Katsanevakis, S., and Hoff, A., 2011. Investigating demersal mixed-fisheries management with the Fcube method in the Aegean Sea (eastern Mediterranean). Fisheries Management and Ecology, in press
- Ulrich, C., Reeves, S.A., Vermard, Y., Holmes, S., and Vanhee W., 2011. Reconciling single-species TACs in the North Sea demersal fisheries using the Fcube mixed-fisheries advice framework. ICES Journal of Marine Science, 68: 1535–1547

**Baltic Sea, ecological-economic optimization model**

Case Study / Model	Baltic Sea, ecological-economic optimization model
Authors / Contact Persons*	Martin Quaas*, quaas@economics.uni-kiel.de, Rudi Voss, voss@economics.uni-kiel.de, Jörn Schmidt, jschmidt@economics.uni-kiel.de
Aim: Management addressed, management objectives	Optimal net revenue under consideration of species interactions, age structure and environmental sensitive stock-recruit relationships
Aim: Corresponding advice needed/ addressed	Strategic medium to long term advice for total harvest of single species, multi-age classes; gives variable F for transition period until steady state, avoids negative revenues
Institutional Set-up: (Bodies involved, needed partners);	Used in academic context; builds on standard assessment from ICES with respect to age structure of the species under consideration and for input data; uses functional relationships from stochastic multispecies model (SMS) developed by DTU-Aqua
Type of Model (biol, econ, soc., long-term, short-term)	Ecological-economic optimization model Medium to long-term
Model Dimensions and Model Structure	Considers whole fisheries and stocks; at the moment the model covers eastern Baltic cod, Baltic sprat and Central Baltic herring
Usefulness of the Model (Pro, Cons, Problems)	The model consists of functional relationships and a limited number of input parameter and is thus easy to understand and to apply. The model does not resolve fleets or métiers and assumes optimal effort allocation and constant costs and price over time
Focus and Trade offs	The model shows the effect of species interactions on the optimal harvest of a given species, e.g. optimal sprat harvest under different cod management scenarios.
Data needed	Stock assessment data, costs, prices and stock-recruit relationships. The latter can also be dependent on temperature or salinity or other environmental variables.
Data available Used in case study/model	For the Baltic case study all necessary data is available; improvement can be made with respect to environmental sensitive S/R-relationships and functional relationships of species interactions
Status for application / implementation	The model is currently in use for different studies on Baltic fisheries, partly published
Model Platform and Programming Language (free, commercial)	Matlab (commercial) with KNITRO solver (commercial)
Model output (Format)	Matlab vectors and matrices, raw txt data

**References**

Voss R, Hinrichsen H-H, Quaas MF, Schmidt JO and Tahvonen O (2011) Temperature change and Baltic sprat: from observations to ecological-economic modelling. *ICES Journal of Marine Science*. 68(6): 1244-1256

**IBM Framework in R: Individual vessel based multi-stock and multi-fleet bio-economic and energy efficiency fishery management evaluation model**

Case Study / Model	IBM Framework in R: Individual vessel based multi-stock and multi-fleet bio-economic and energy efficiency fishery management evaluation model (using coupled Logbook and VMS Data and high resolution research survey data for fish abundance)
Authors / Contact Persons*	Francois Bastardie and J. Rasmus Nielsen, DTU Aqua
Aim: Management addressed, management objectives	Short- and medium term multi-stock and multi-fleet fisheries based management; bio-economic and energy related (climate impact) fleet based management on effort allocation: cost-benefit and energy efficiency in effort- allocation according to management plans. Biological objectives addressed: energy efficiency, climate impact, and cost-benefit efficiency objectives can be addressed when the model is implemented; Targeted management bodies: EU and National Governments.
Aim: Corresponding advice needed/ addressed	Short and medium term advice among other in relation to MSE for LTMPs; multi-fleet and multi-stock based advice on cost-benefit and energy efficient effort allocation: partial fishing mortalities by fishery/metier given efficiency in effort allocation. Advice aimed towards ICES and EU STECF and National Administrations. Model scientifically published and used in scientific research projects but not applied, implemented and used in actual advice yet;
Institutional Set-up: (Bodies involved, needed partners);	Development, establishment and publication of the model (scientific documentation): university and fisheries research institutes (DTU Aqua and research partners); Model published in scientific journals; Intended implementation into advice: ICES and EU STECF and National administrations;
Type of Model (biol, econ, soc., long-term, short- term)	Individual based bio-economic simulation framework in R. Level: Multi-stock and multi-fisheries (Baltic, North Sea) fleet based model; Complex and data demanding model; Short term to medium term model; Using detailed information on spatio-temporal disaggregated level with coupling of Logbook and VMS data and high resolution research survey abundance estimates of the resources; Fisheries behavioural model;
Model Dimensions and Model Structure	Biological and Fleet Based Technical Interaction and Economic Operating Models. Operating with individual vessels belonging to fleets and fisheries (e.g. DCF metiers). Biological OM on species and stock level covering several stocks (in e.g. mixed fisheries) with high resolution spatio-temporal abundance and resource availability information from research surveys. Length and age based model.
Usefulness of the Model (Pro, Cons, Problems)	Complex and data demanding bio-economic model; Need some computer power; Biological and economic incentives / logics (and behavioural models) for fisheries behaviour. IA and MSE of MPs. Evaluation of robustness of management options in relation to effort allocation and cost-efficiency and energy efficiency. Need highly disaggregated and high quality fisheries and resource availability data. Can simulate all fishery realistic and as such useful in ICES and EU STECF advice.
Focus and Trade offs	Scientific establishment of complex individual based models for the fishery; MSE and IA of MPs in relation to fisheries advice (ICES, EU STECF); Evaluation of energy and cost efficiency in the catching sector; Need very detailed data and advanced R users and modellers to be operated.

Data needed	EU DCF Data; Detailed trip based information by vessel from logbooks, sales slips-, VMS data as well as yearly vessel register data on catch/landing, effort, landing value and prices. Need furthermore yearly and metier disaggregated vessel/metier information on costs. Biological ICES stock assessment data and dis-aggregated research survey data of resource availability at least on ICES statistical square level.
Data available Used in case study/model	All the above data has been available except cost dynamics over the year and by fishery which is averaged from yearly costs as well as proper resource abundance model information using research survey information resource availability
Status for application / implementation	Model developed and tested; Model published in international peer reviewed scientific journals; Model not implemented in advice; Model need further information on cost dynamics and from advanced model describing resource availability on high dis-aggregated spatio-temporal level;
Model Platform and Programming Language (free, commercial)	IBM model developed in R with associated analysis of VMS and Logbook data in R (Freeware)
Model output (format)	Partial fishing mortality by stock, effort, value of catch and profit by vessel and trip (which can be summed up to e.g. metier and quarter/year). Furthermore, energy use and energy efficiency measures (e.g. value or amount of catch per unit of energy (fuel). Furthermore, behavioural estimates of effort allocation and effort re-allocation given economy and regulations.

## References

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## 5 Outlook and Future Challenges

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In 2012 the group will only work via correspondence to expand the investigative approach presented in 4 and to further develop a survey on models. The reason for working by correspondence in 2012 is that several members of the group will meet and attend the IIFET 2012 and here partly continue the SGIMM work in cooperation with IIFET. The results will be discussed in the meeting in 2013 and possibly published on a dedicated website to start an online repository including the matrices, literature and presentations on these models. Finally, strengthening of the group was discussed by adding an additional co-chair with economic background from outside Europe.

## 6 References

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## Annex 1: List of participants

Name	Address	Phone/Fax	Email
Jörn Schmidt (Co-Chair)	Sustainable Fisheries, Department of Economics, University Kiel, Wilhelm- Seelig-Platz 1, 24118 Kiel, Germany	++49 431 880 5632 ++49 431 880 3150	jschmidt@economics.uni-kiel.de
J. Rasmus Nielsen (Co-Chair)	DTU-Aqua, National Institute of Aquatic Resources, Technical University of Denmark, Charlottenlund Slot, Jægersborg Allé 1, 2920 Charlottenlund, Denmark		rn@aqua.dtu.dk
Eric Thunberg	NOAA, Northeast Fisheries Science Center , Social Sciences Branch, , 166 Water St., 02543 Woods Hole, USA		Eric.Thunberg@noaa.gov
Jose M. Da-Rocha (by correspondence)	Universidade de Vigo Departamento de Fundamentos del Análisis Económico Facultad de Ciencias Económicas y Empresariales Campus As Lagoas-Marcosende 36310 Vigo, Spain		jmrocha@uvigo.es
Ralf Döring	Institut für Seefischerei, Johann Heinrich von Thünen-Institut, Bundesforschungsinstitut für Ländliche Räume, Wald und Fischerei, Palmaille 9, 22767 Hamburg, Germany		ralf.doering@vti.bund.de
Hans Frost (part- time)	Institute of Food and Resource Economics/Fisheries Economics and Management Division, Rolighedsvej 25, 1958 Frederiksberg C, Denmark		hf@foi.dk
Dorleta Garcia	AZTI Tecnalia, E-48395 Sukarrieta (Bizkaia), Spain		dgarcia@azti.es
Ayoe Hoff	Institute of Food and Resource Economics/Fisheries Economics and Management Division, Rolighedsvej 25, 1958 Frederiksberg C, Denmark		ah@foi.dk

Dan Holland	NOAA, Northwest Fisheries Science Center 2725 Montlake Blvd. East Seattle, WA 98112-2097, USA	Dan.Holland@noaa.gov
Marc Hufnagl	DTU-Aqua, National Institute of Aquatic Resources, Technical University of Denmark, Charlottenlund Slot, Jægersborg Allé 1, 2920 Charlottenlund, Denmark	mhuf@aqua.dtu.dk
Paul Marchal (part-time)	IFREMER, Channel and North Sea Fisheries Department, 150 Quai Gambetta, BP 699, 62321 Boulogne s/mer, France	paul.marchal@ifremer.fr
Raul Prellezo	AZTI Tecnalia, E-48395 Sukarrieta (Bizkaia), Spain	rprellezo@suk.azti.es
Lars Ravn-Jonsen	Department of Environmental and Business Economics, Niels Bohrs Vej 9, 6700 Esbjerg, Denmark	lrj@sam.sdu.dk
Clara Ulrich (part-time)	DTU-Aqua, National Institute of Aquatic Resources, Technical University of Denmark, Charlottenlund Slot, Jægersborg Allé 1, 2920 Charlottenlund, Denmark	clu@aqua.dtu.dk
Staffan Waldo	Institute for economy, Agricultural and Food Economics, Box 7013, 750 07 Uppsala, Sweden	Staffan.Waldo@ekon.slu.se
Yvonne Walther	Swedish University of Agricultural Sciences Institute of Marine Research, Utövägen 5, SE-37137 Karlskrona	yvonne.walther@slu.se

## Annex 2: Agenda

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### Tuesday, 14.06

- 14:00 Welcome and Housekeeping
- 14:15 General introduction to the Study Group, outline of the meeting, adopting the Agenda (Rasmus Nielsen/Jörn Schmidt)
- 15:45 Health Break
- 16:00 FishRent (Hans Frost)
- 17:00 The Intertemporal Choice of Marine Ecosystem Exploitation (Lars-Ravn-Jonsen)
- 18:00 End of day 1

### Wednesday, 15.06

- 09:00 F-Cube model for North Sea demersal consume fisheries (Clara Ulrich)
- 09:45 F-Cube-Econ for North Sea demersal consume fisheries (Ayoe Hoff)
- 10:45 Health Break
- 11:00 General Discussion
- 12:45 Lunch Break
- 13:45 ATLANTIS presentation (Marc Hufnagl)
- 14:45 Linking ecology, economics, and fleet dynamics to evaluate alternative management strategies for US West Coast fisheries: An Atlantis Model of the California Current (Dan Holland)
- 15:45 Health Break
- 16:00 CGE/food web model for Georges Bank case study (Eric Thunberg)
- 17:00 General Discussion
- 18:00 End of day 2

### Thursday, 16.06

- 09:00 FLBEIA, a bio-economic impact assessment package in R (Raul Prellezo, Dorleta Garcia)
- 09:45 Bioeconomic assessment of Northern European Hake Long term Management Plan (Dorleta Garcia, Raul Prellezo)
- 10:30 Health Break
- 10:45 General Discussion about a matrix approach and a living document
- 12:00 Lunch Break
- 13:00 Presentation about Council Workshop on socio-economic considerations within ICES (Poul Degnbol)
- 14:00 General discussion about a matrix approach and a living document

- 15:00 IBM Model for evaluating cost-efficiency of effort allocation in relation to energy use (J. Rasmus Nielsen/Francois Bastardie)
- 16:00 Health Break
- 16:15 Work on case study matrices
- 18:00 End of day 3

**Friday, 17.06**

- 09:00 Baltic Sea, ecological-economic optimization model (Jörn Schmidt)
- 09:30 Work on case study matrices
- 11:00 Final conclusion
- 12:00 End of meeting

### Annex 3: SGIMM draft resolution for the next meeting

The **Study Group on Integration of Economics, Stock Assessment and Fisheries Management** (SGIMM), chaired by Jörn Schmidt, Germany, J. Rasmus Nielsen, Denmark and Eric Thunberg\*, USA, will work by correspondence in 2012 to:

- a) Evaluate further the world wide state-of-the-art in integrating economic (modelling), stock assessment and fisheries management plans relevant for ICES; In this context develop further the suggested Model Performance and Characteristics Matrices and Model Summaries reviewing each of the relevant models both in scientific, advisory and management context;
- 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 and scientific evaluation of fisheries and stocks;
- 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 as well as expertise needed 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 scientific evaluation and advice on integrated fish stock and fisheries management; Hereunder develop further the cooperation with IFET on this.

SGIMM will report by 15 August 2012 (via SSGRSP and SSGSUE) 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 and review of their development level, characteristics and performance. However, the possibilities to coordinate the expertise of economists, sociologists, and ecologists to develop and evaluate 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	<p>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:</p> <ul style="list-style-type: none"> <li>the economic and sociological incentives of fishermen and industry</li> <li>the bio-economic interaction between different fisheries and both biological and economical consequences of different management scenarios</li> <li>and transaction costs of different policies</li> </ul> <p>coupled with the existing sound biological knowledge within ICES.</p> <p>Further scientific overview and evaluation of performance, characteristics and scientific and advisory implementation of the models is necessary in order to advice on implementation.</p> <p>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</p>

	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 and further develop the models and their integration scientifically 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, SCICOM members, 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	None
Linkages to Advisory Committees	The incorporation of economy in fisheries advice should be of basic interest to ACOM and the general scientific overview and further development of interest to SCICOM
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.
Linkages to other Organisations	Contact and agreement on scientific collaboration has been established with the International Institute of Fisheries Economics and Trade (IIFET). Direct collaboration was agreed on with respect to cooperation on two theme sessions on ecological-economic modelling next year. One theme session will take place at the 6th World Fisheries Congress in Edinburgh (7–11 May 2012) and one at the 16th biennial conference of IIFET in Dar es Salaam (16–20 July 2012), both convened by members of the SGIMM group.



## **Annex 4: Overview of existing models and approaches 2010 presentations**

Below are summaries of the presentations given on day one of the Workshop „Introducing coupled ecological-economic modelling and risk assessment into management tools” (WKIMM), 16.06–18.06.2010 in Kiel. The summaries are given here to archive the different approaches presented in the context of ecological-economic modelling in fisheries. Still not exhaustive, the collection will be expanded in the upcoming years and corresponding model matrices will be collected in a living document, which will be made public at some point in time. These presentations also include two keynote presentations from Prof. Dr. Trond Bjørndal and Prof. Dr. Anders Skonhøft.

### **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 section 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).

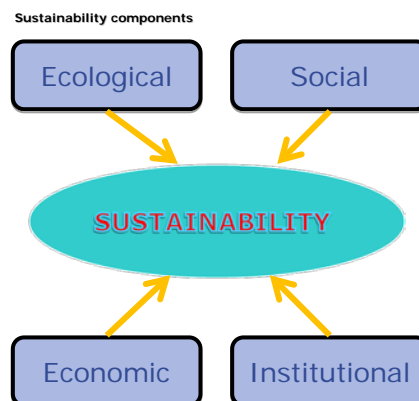
Today, the biological models used in current advice (e.g. ICES (and EU STECF) are mainly single stock assessment models, i.e. relatively simple biological population dynamic models. The above is an example of exploratory, more comprehensive, complex and integrated biological models emerging in ICES through 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 disciplines and to differentiate levels of sustainability (e.g. stock / ecosystem). Management objectives and reference points from e.g. international conventions needs to be transformed into operational management objectives and management strategies which again needs to be transformed into concrete management-strategy-reference-points 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 trade offs 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 indicators 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, behavior 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 trade offs 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.

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

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:

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

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

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

$$e^{\delta(S^*)} \{ [\Pi_S + \Pi_H] / \Pi_H \} + \delta'(S^*) [S^* - G(S^*)] + \alpha' G'(S^*) = 1 + r$$

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:

$$H_t = H(K_t, S_t) = a K_t^b S_t^c$$

where  $K_t$  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.

### **On the conflicting management of wild Atlantic salmon and farmed salmon (Anders Skonhøft)**

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 Miljø2015 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.

## **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, BIRDMOD, 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-). ME-FISTO and BEMMFISH can be downloaded as a compiled programme and ECO-CORP 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.

### **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.

### **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.

### **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.

### **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.

### 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:

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

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

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:

$$c_t = \alpha * B_t^\beta * Y_t^\gamma$$

where, the parameters  $\beta$  and  $\gamma$  represent stock and output elasticities of unit costs, respectively and  $\alpha$  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.,  $\beta$  and  $\gamma$  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 mortalities (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 (Fig. 1). Our findings thus support the need to in-

vest in “natural capital” (i.e. in future stock size) as a long-term management strategy for Baltic cod (Döring and Egelkraut 2008).

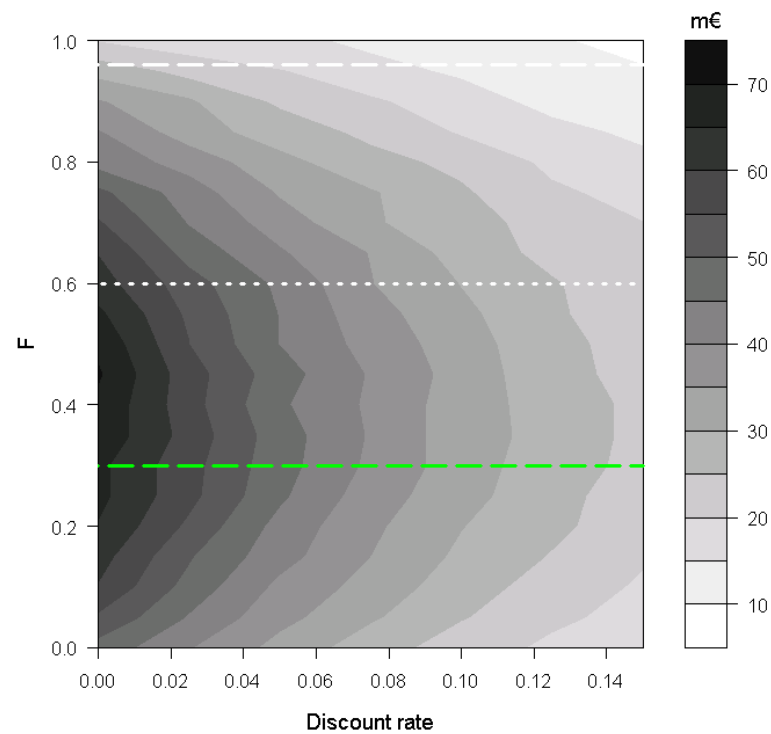


Figure 1. NPVs (m€) of the Baltic cod fishery are shown over a range of fishermen discount rates (0–15%) and fishing mortalities ( $F$  from 0–1). (Fishing mortalities for sprat and herring are maintained at mean historical levels). The horizontal lines denote the previously recommended reference levels,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

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

### **Introduction**

At the ICES workshop in Kiel I presented two projects that may be relevant for ICES.

### **Harvest and investment decisions under annual and multiannual adjustment of fish quota**

**By 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 analyse 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.

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

**By 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 result in 9.4% increase in production. Other variables like hp and age of the hull have impacts with diminishing returns.

### **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 than 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.

### **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.

**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.